Paradise Dam Upgrade Options Assessment

Independent Design, Cost and Risk Review

Building Queensland

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Document prepared by:

Aurecon Australasia Pty Ltd

ABN 54 005 139 873

Ground Floor, 25 King Street
Bowen Hills QLD 4006

Locked Bag 331
Brisbane QLD 4001
Australia

T +61 7 3173 8000
F +61 7 3173 8001
E brisbane@aurecongroup.com
W aurecongroup.com

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Author signature		Approver signature	
Name	MP Jonker RPEQ 18049	Name	J Bowman
Title	ANZ Dams Lead	Title	Associate Infrastructure Advisory

Executive summary

Purpose of this Report

This Report presents an independent review for Building Queensland, of the engineering design, cost estimations and risk assessments of selected options to improve the safety of Paradise Dam in the long-term, as developed by SunWater and its consultants. After floods caused erosion damage downstream of the dam in 2013, SunWater determined that during certain flood events (like the 2013 flood event), there would be an unacceptable risk of dam failure when assessed against the ANCOLD risk criteria, due to deficiencies within the dam wall and its foundations. The Queensland Government has tasked Building Queensland with assessing and reporting by February 2020, on options to ensure long-term risk reduction of Paradise Dam and thereby the water security for the region.

Building Queensland has been working with SunWater and key stakeholders to define the requirements for a Detailed Business Case for the Paradise Dam Improvement Project (PDIP). Aurecon was engaged by Building Queensland to provide an independent Design-Cost-Risk review of the proposed options and worked as part of a broader project team, led by Building Queensland, who was contributing to the development of an Options Assessment Review for the Detailed Business Case of the PDIP.

The broad scope of the review presented in this Report, was to provide comments on the selected options regarding retaining the original Full Supply Level (FSL), a permanently lowering of the FSL and full decommissioning.

The following long-term options have been identified by Building Queensland for the Options Assessment:

- **Option 1:** Full upgrade with the primary spillway at the original FSL
- **Option 1a:** Full upgrade with the primary spillway at the original FSL and rebuilding Monoliths R-W
- **Option 1b:** Full upgrade and reinstating the original FSL with a gated solution
- **Option 2:** Full upgrade with the primary spillway crest level 5 m below the original FSL
- **Option 3:** Full upgrade with the primary spillway crest level 10 m below the original FSL
- **Option 3a:** Full upgrade with the primary spillway crest level 10 m below the original FSL plus the development of alternative water supply options
- **Option 4:** Full upgrade with the primary spillway crest level 5-10 m below the original FSL
- **Option 5:** Full decommissioning

Options 1, 3 and 5 were brought forward from SunWater's Preliminary Business Case and the other options added during the Options Assessment.

Effects of Essential Works on long-term options

At the time of preparing this Report, SunWater and GHD have been developing the design of early works (the Essential Works) that would be implemented prior to the long-term options, which were the subject of this Report. The Essential Works would involve lowering the primary spillway crest by 5 m. The Essential Works were excluded by Building Queensland from Aurecon's brief for the review of the long-term options as presented in this Report.

The design of the long-term options assumed a base condition of the dam prior to the Essential Works (except for Option 1b). Upon completion of the Essential Works, the implementation of the long-term options would require additional work, which have not yet been considered in the Options Assessment from a technical design perspective or from a cost offset perspective. **It must thus be noted that the Essential Works might have a significant impact on the long-term works option assessment and selection process and therefore the selection of the preferred option to take forward.**

Current condition of the dam

Availability of the design and construction records

The available design and construction records include the Detailed Design Report, the technical specification, the Final Design Report and updated design drawings. The Detailed Design Report contains information on the preconstruction compressive and tensile strength testing of the concrete, and updates regarding changes to the excavation and design during the initial stages of construction. The Final Design Report covers further design changes made during the construction of the dam. Neither report covers lift joint shear strength testing undertaken during construction to verify the design assumptions, as is normal practice with roller compacted concrete (RCC) dam construction. The Final Design Report contains the following statement: *"A separate report will be issued that contains records including construction processes used, foundation surface mapping, instrumentation data, inspection reports and photographic records. This separate report is called the Construction Report."* **It is understood that the Construction Report was never compiled** after completion of the project, even though records of quality assurance testing and control undertaken during construction are available. **The Construction Report would have been invaluable to understanding the construction practices and the placed RCC properties.**

Condition of RCC lift joints

Core drilling investigations of the RCC lift joints have identified extensive unbonded lift joints in the dam. Based on limited investigation results, it is not possible to conclude whether each lift joint is unbonded only over part of the joint area, or whether the entire joint area is unbonded in some lift joints. The latter situation is much worse. Given the uncertainty about the persistence of unbonded lift joints, combined with the limited area of joint treatment near the upstream face, **it is considered appropriate to assume that, for the options assessment (prefeasibility stage), all the lift joints should be considered unbonded**. Further investigations using horizontal and vertical core drilling would be required to improve the understanding of the extent of the unbonded lift joints.

Based on the visual inspection and the photos taken of cores from the dam, several cores include honeycombing at the bottom of the lift. The reason has not been reported but honeycombing in RCC is typically the result of poor workability of the RCC mix, compaction methods, environmental conditions, or a combination of these. **The honeycombing would affect the lift joint shear strength.**

Shear strength of RCC lift joints

The shear strength of the lift joints is the most critical hardened property for RCC gravity dams affecting the sliding stability within the dam wall, more important than the shear strength of the mass concrete within the lift layers. In the case of Paradise Dam, the lift joint shear strength is also one of issues of most uncertainty. The importance of understanding the condition of the lift joints has been recognised by SunWater and the lift joints have been extensively investigated since 2014.

It is not clear whether the original design assumptions regarding lift joint shear strengths, made in lieu of testing, was further investigated and confirmed through testing at the time of construction, which should have been done. **The original design assumptions now appear non-conservative.**

The proposed average residual shear strength parameters of ϕ = 37-39.3° and c = 0 for up to 600 kPa normal stress, is considered appropriate for use in the options assessment, given limited available data. More certainty is required for the feasibility study and detailed design, given that some test results indicated shear strengths of less than ϕ = 30°. **Additional core sampling and testing should be undertaken to increase confidence in the test results.** The further testing should consider the effect of low cementitious RCC on the accuracy of the shear testing when one sample is used for multiples tests, as well as the effect of the honeycomb concrete where present against a lift joints.

Density of RCC

As the stability of the dam is dependent on the weight of the concrete, the impact of using the lower bound and mean densities should be considered. **Using the lower bound density and lower bound shear strength, combines two uncertainties and could result in overly conservative results.** It would be reasonable to assume that the average density in any two-dimensional cross section is equal to the average density of the test values.

Foundation geological model and geotechnical parameters

The procedure for developing the latest geological and geotechnical model of the site followed a logical sequence consistent with the procedure recommended by ANCOLD.

The knowledge and understanding of the foundations have increased during studies and investigations undertaken since the Safety Review. The knowledge has been sufficiently expanded to understand the potential for erosion in the primary and secondary spillway, and the potential for sliding failure in the foundations. Despite the investigations and modelling completed to date, there are several uncertainties about the foundation (e.g. zones of fractured and faulted rock) regarding:

- the difference in the original foundation design and the actual excavation depths
- the complexity of the geology and the rock mass, being a combination of structurally disturbed blocks and zones enveloped in a very complicated series of faults and breccia zones – it is possible that other unidentified fault systems are also present
- the modelling of kinematic systems – such systems should be considered using a three-dimensional model to account for defect orientations
- how deep-seated sliding in the foundation has been modelled considering hydraulic uplift and the defect orientations
- the reliable and competence of the foundation rock for an anchor design – it is understood that in situ testing of anchors are planned and this Report endorses such testing

A three-dimensional model was being developed by SunWater at the time of finalising this Report and some or all the above issues might be addressed by assessing the model. SunWater should complete the current geotechnical and geological assessment of the foundations of the dam, including the development of the 3D geological model. Further targeted investigations might be required to complete the geological model for the feasibility study and the detailed design of the selected option.

Review of SunWater's dam safety modelling process

The SunWater document *Dam Safety Improvement Decision Criteria – Guidelines, DS20, Revision: 1 (HB #2339310), Last Revision Date: May 2018* (SunWater 2018) was reviewed and the process found to be consistent with contemporary practices recommended by ANCOLD, ICOLD and DRNME.

Review of the options' designs

Option 1, 1a and 1b – retaining the FSL

Option 1 does not achieve the desired risk position by meeting the ANCOLD life safety risk criteria.

As noted in the Draft Report, this does not necessarily mean that the concept of retaining the FSL should be abandoned and Option 1 should instead be considered an incomplete option to retain the original FSL and meeting the ANCOLD risk criteria. SunWater has since the completion of the Draft Report, provided two additional options (labelled Options 1a and 1b) to upgrade the dam while retaining the original FSL. Although these two options have not been developed and costed to an equivalent standard as Options 1, 2 and 3 and not reviewed to the same level for this Report (no design, cost or risk documentation provided), they are useful for gaining an appreciation of what might be possible for retaining the original storage capacity.

Option 1a is the same as Option 1 but also include rebuilding the secondary spillway monoliths R to W. This is feasible but would add significant cost to Option 1. Option 1b is a full upgrade and returning the original FSL with a gated solution, assuming the 5 m lowering during the Essential Works has been completed. Option 1b has been dismissed by SunWater considering the risks and costs associated with mechanical operated gates. There are benefits and drawbacks associates with mechanically operated gates. Alternatives gate arrangements, such as fuse gates, have not yet been assessed.

The scope of the Option 1 works for the proposed risk reduction measures addresses the dam safety deficiencies in terms of the potential failure modes that dominate the current risk position of the dam.

The outstanding issues of uncertainty include:

- protection of the left abutment downstream toe against overtopping flows
- based on the geology, erosion downstream of the extended apron – additional protection might be required
- based on the CFD modelling, the secondary spillway return channel would still be overtopped (as currently) and it could lead to undermining and failure of right abutment apron and foundation
- the stability of the monoliths on the bend in the secondary spillway where the dam axis is curved and the transverse joints flare open
- the effectiveness of the anchors during operation under the applied loads, due to the spacing of the anchors and the strength of the rock to provide sufficient anchor resistance – further investigations are required to confirm the rock strength, for example prototype testing of an anchor

The execution of the proposed Option 1 works, including the installation of the anchors, is considered viable.

Suitable alternatives to retaining the FSL include the use of a downstream RCC buttress and a combination of anchoring and buttressing. It is understood that buttressing had been considered early in the options assessment (first TRP workshop) and dismissed due to the large volume of concrete required for the buttress and associated costs (in the same order as a new dam), as well as concerns about finding adequate foundations for the buttress downstream of the primary spillway. This alternative has not been documented in the available records. It is also not clear whether a combined buttress and anchor option has been considered.

Option 2, 3 and 4 – lowering the FSL

The comments in this Report apply to the 5 m, 10 m and optimal level between 5 and 10 m lowering of the spillway crest.

The scope of works for the proposed risk reduction measures addresses the dam safety deficiencies in terms of the potential failure modes that dominate the current risk position of the dam. The outstanding issues of uncertainty include:

- as for Option 1, based on the geology, erosion downstream of the extended apron – additional protection might be required
- as for Option 1, the stability of the monoliths on the bend in the secondary spillway where the dam axis is curved and the transverse joints flare open
- as for Option 1, the effectiveness of the anchors during operation under the applied loads (although less risk compared to Option 1) – further investigations are required to confirm the rock strength, for example prototype testing of an anchor

Options 2, 3 and 4, based on the scope of works, would achieve risk positions below the ANCOLD life safety limit of tolerability.

Option 5 – full decommissioning

This design of the decommissioning option has not been developed to the same level as Options 1, 2 and 3. It seems unlikely that this option would go ahead, so the level of design at this stage is acceptable.

The scope of works would address the dam safety deficiencies by eliminating the risks. According to the Preliminary Business Case, the decommissioning would involve a complete removal and a return to the pre-dam site. This seems over the top, as the objective should be to remove the works to the extent where there was no residual safety and environmental risk if no ongoing maintenance was carried out on the site. The key project risk would be the extent of the remediation required and the treatment of potential anoxic sediment in the bottom of the reservoir.

The decommissioning is viable from a dams engineering perspective. The impact on the economy of loss of the storage is beyond the scope of this Report but has been assessed separately by others.

Review of the options' cost estimations

Cost estimates for Options 1, 3 and 5 have been developed during the Preliminary Business Case in 2018. The estimates are very detailed given the level of design and lack details about the assumptions and construction methodologies they have been based on.

New estimates have been developed in 2019 after the further development of Options 1 and 3. The estimates are more detailed, although the level of design is still at concept design stage and further investigations are required to inform the design.

A cost estimate for Option 2 was developed in 2020 based on the 2018 estimate for Option 3 by adjusting only the quantities, even though the design assumptions for Option 2 (e.g. shear strength) are now different to what was assumed for Option 3 in 2018.

The only cost estimate for Option 5 was done in 2018.

Pursuant to the above, the diverse levels of cost estimates are problematic. It would be advisable to complete further development of preliminary designs and cost estimates for the options using the new starting point (base case) (the primary spillway level at the completion of the Essential Works), to ensure consistency in the comparison of the costs in the options assessment.

The cost estimates completed to date should only be used as an indicator of the comparative costs (i.e. for ranking the options); however, it should not be viewed as indicative of the expected project cost. The cost estimate is only as reliable as the level of engineering design. Further investigations and any subsequent changes in the concept design after the 2018 cost estimate might affect the comparative costs.

Review of risk assessments and the options' risk positions

Option 1 would reduce the risk to the level of the limit of tolerability, but the mitigation measures are **inadequate** to reduce the risks to below the Limit of Tolerability. As this option is essentially an incomplete solution, additional work is required to lower the risk to achieve a tolerable risk position below the limit line and to achieve the ALARP risk position. Option 1 has been modified in Options 1a and 1b, but the residual risk positions have not been demonstrated yet.

The mitigation measures included in Option 2 (5 m lowering of FSL) are adequate to reduce the risks to below the Limit of Tolerability and **this might be adequate to achieve the ALARP position**. As Option 2 results in a risk position less than an order below the line, it is expected than further work might be required to achieve the ALARP position, such as Option 4 (5-10 m lowering of FSL). However, this might not be the case and Option 2 could represent the ALARP position. Further investigations of risk reduction options are required to confirm this issue, but Options 2 and 3 could be considered "bookends" to find the optimal risk position.

The mitigation measures included in Options 3 (10 m lowering of FSL) would result in a risk position close to two orders below the limit line. It is expected that the cost of further major risk reduction works might not be justified, and **this is possibly the ALARP risk position**. Only small cost items could be added to reduce the risk further.

The mitigation measures included in Option 5 (full decommissioning) are adequate to reduce the risks to below the Limit of Tolerability.

Comments regarding SunWater's portfolio risk management

It is understood that SunWater has other dams with risk profiles still above the ANCOLD limit of tolerability. From a portfolio risk management perspective, SunWater may want to consider first lowering the risks at all the other dams to the level of the limit of tolerability, before undertaking further improvement works (with associated high costs) to achieve the ALARP position at any of the dams, including Paradise Dam. Although further work could be justified at a single dam based on an ALARP assessment, large expenses might be required for only small risk reductions to achieve the ALARP position at a single dam. Such expenses would achieve better value from an organisational risk exposure perspective, by funding risk reduction works at dams that have higher risk positions, especially if above the ANCOLD limit of tolerability

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1 Introduction

1.1 Purpose of this Report

This Report[1] presents an independent review for Building Queensland, of the engineering design, cost estimations and risk assessments of selected options to improve the safety of Paradise Dam, as developed by SunWater and its consultants. The review is to inform the broader Options Assessment process for the Building Queensland led Detailed Business Case of the Paradise Dam Improvement Project (PDIP).

This Report is an update of the Draft Reports[2] issued in January 2020 and February 2020 respectively, and took onboard comments provided by SunWater / GHD and the Project Working Group, as well as updating of some project details that changed during the review process.

After floods caused erosion damage downstream of the dam in 2013, SunWater carried out a 20-year Dam Safety Review (SunWater 2014 & 2016a)[3] and Comprehensive Risk Assessment (SunWater 2016b), which determined that during certain flood events (like the 2013 flood event), there would be an unacceptable risk of dam failure when assessed against ANCOLD[4] risk criteria. As part of the PDIP, SunWater has undertaken further options assessments and developed a Preliminary Business Case in 2018 (SunWater 2018b), of long-term works to reduce the risks that have been identified.

The Queensland Government has tasked Building Queensland with assessing and reporting by February 2020, on options to ensure long-term risk reduction of Paradise Dam and thereby the water security for the region. Building Queensland has been working with SunWater and key stakeholders to define the requirements for a Detailed Business Case for the PDIP.

Aurecon was engaged by Building Queensland to provide an independent Design-Cost-Risk review of the proposed options and worked as part of a broader project team, led by Building Queensland, who was contributing to the development of an Options Assessment Review Report.

Parallel to the above-mentioned process, SunWater progressed accelerated works that included lowering of the storage level ahead of the 2019/20 wet season so that the immediate Essential Works, which would lower the full supply level by 5 m, could commence in early 2020. These Essential Works were not in the scope of the present review presented in this Report; however, as the works would affect the long-term options, some comments have been provided regarding the effect of Essential Works on the long-term options assessment.

1.2 Scope of work

1.2.1 Brief description of layout of Paradise Dam

A brief description of Paradise Dam is provided below to provide context to the subsequent review comments presented in this Report. More detailed descriptions are provided in the Dam Safety Review Report (SunWater 2016a) and other reports prepared in recent years for the PDIP (see Appendix A).

Paradise Dam is located roughly 20 km north-west of Biggenden and 80 km south-west of Bundaberg on the Burnett River in Queensland. The 45 km long narrow reservoir has a surface area of 3,000 ha and a storage volume of 300,000 ML.

[1] This current version of the Design, Cost, Risk review report by Aurecon (12 February 2020)
[2] Previous draft versions of the Design, Cost, Risk review report by Aurecon, Rev 0 issued 16 January 2020 and Rev 1 issued 3 February 2020
[3] Details of the project references are listed in Appendix A
[4] Australian National Committee on Large Dams

The dam was constructed by the Burnett Dam Alliance, consisting of Burnett Water Pty Ltd (the owner of the dam at the time of construction), McMahon Holdings, Walter Construction Group[5] (construction contractors), and Hydro Tasmania and SMEC Australia (engineering consultants). At the time of construction of the dam, the shares in Burnett Water Pty Ltd were held by the State of Queensland.

The general arrangement of Paradise Dam is shown in Figure 1.

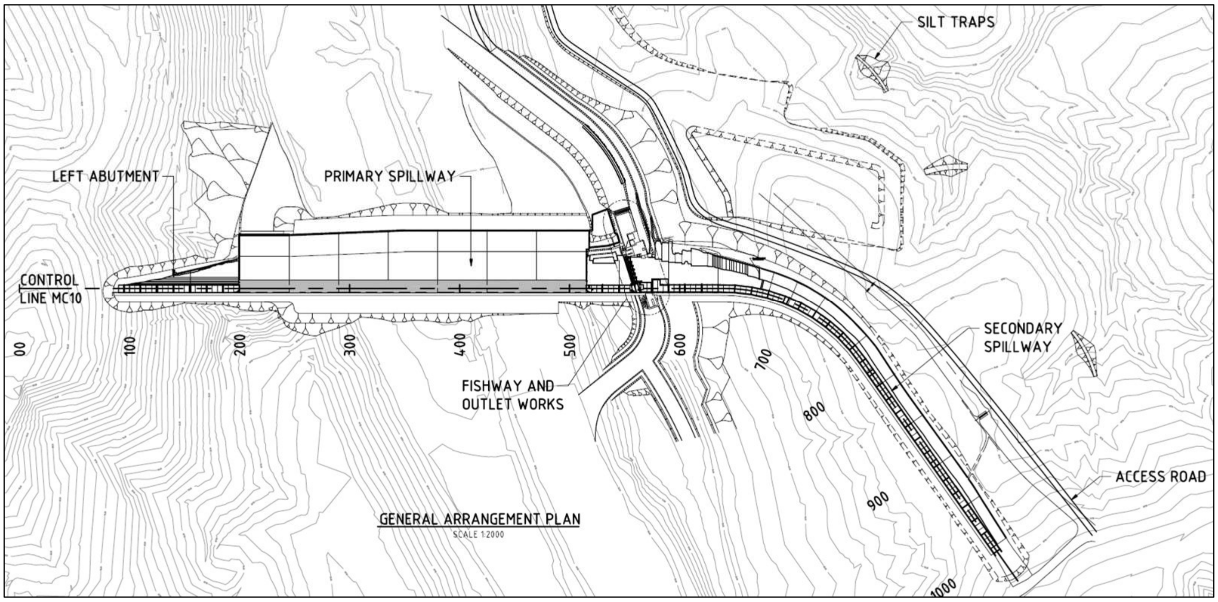

Figure 1 General arrangement of Paradise Dam (extract from drawing BDA-D-C-008)

Paradise Dam is a concrete gravity structure that was constructed primarily using roller compacted concrete (RCC) as construction material. The dam wall comprises three zones, i.e. (1) the primary spillway, which spans the Burnett River, is 315 m long and up to 38 m high above the lowest foundation level, (2) the secondary spillway, which is situated on the right abutment, is 485 m long and up to 48 m high, and (3) the left abutment closing wall is 120 m long and up to 53 m high. The sections of the dam are labelled as monoliths according to the transverse cracks induced in the RCC. Three monoliths (labelled A, B and C) form the left abutment, seven monoliths (labelled D, E, F, G, H, J and K) form the primary spillway (each being 45 m wide), and twelve monoliths (labelled L to W) form the secondary spillway.

A 20 m long apron extends along the base of the primary spillway and was intended to protect the toe of the spillway against erosion and to allow energy dissipation of the spillway discharge. Beyond the apron, the outflow from the dam discharges onto exposed rock and the river bed.

The outlet works comprise a free-standing tower and a conduit through the dam on the right-hand side of the primary spillway.

1.2.2 Brief history of Paradise Dam

Construction of the dam commenced in 2003 and it was completed in December 2005.

Following completion of the dam, the shares in Burnett Water Pty Ltd were transferred by the State to SunWater, who became responsible for the management of the dam.

Due to the drought conditions, the dam filled for the first time only in March 2010 when wet commissioning occurred.

[5] The Walter Construction Group went into receivership halfway through construction (it is not known who took on their responsibilities in the Alliance after this event)

Three major flood events occurred at Paradise Dam in late 2010 and early 2011. The peak of the largest flood was 6 m over the primary spillway at EL 73.56 m AHD (FSL is at EL 67.6 m AHD). Only limited damage was caused to the dam.

The flood of record (1 in 200 Annual Exceedance Probability (AEP) event) occurred in late January 2013 and overtopped the primary spillway by 8.65 m at its peak. Substantial damage occurred during this event, mainly the primary spillway apron and downstream rock that was scoured.

Paradise Dam was originally designed to safely pass flood events up to the Probable Maximum Precipitation design flood (PMPDF) of 1 in 30,000 AEP with a peak discharge of 93,400 m³/s and a corresponding peak reservoir level of 20.1 m above the primary spillway crest. The design basis for passing floods was that the primary spillway would operate first, followed by the secondary spillway at the 1 in 1,000 AEP event (~22,000 m³/s) and finally the left abutment at the 1 in 10,000 AEP event (~50,000 m³/s).

The latest hydrology study (HARC 2019) indicates that the secondary spillway would operate at the 1 in 800 AEP flood event (~22,200 m³/s outflow) (based on the reservoir level initially at FSL) to the 1 in 1,100 AEP flood event (~23,750 m³/s outflow) (based on joint probability). It also indicates that the left abutment would overtop at the 1 in 10,700 AEP flood event (~49,800 m³/s total outflow) (based on the reservoir level initially at FSL) to the 1 in 11,600 AEP flood event (~50,700 m³/s total outflow) (based on joint probability). The Probable Maximum Flood (PMF) outflow was estimated to be 119,000 m³/s with a peak reservoir level of EL 90.1 m AHD, i.e. 7.1 m above the left abutment and 22.5 m above the primary spillway crest.

1.2.3 Background to the present review

Several investigations and studies have been undertaken since 2013 in the lead up to the present Options Assessment and Detailed Business Case, as listed in Appendix A. Selected key events are briefly described below, given their importance in the history of understanding the current condition of the dam and the basis for the dam improvement options.

SunWater conducts Routine Inspections, Intermediate Inspections, five-yearly Comprehensive Surveillance Reviews and 20-yearly Dam Safety Reviews as part of its overall dam safety management practices. After the 2013 flood repairs were undertaken, the 20-year Dam Safety Review (SunWater 2014 & 2016a) and Comprehensive Risk Assessment (2016b) of Paradise Dam was brought forward to commence in 2014 and it highlighted several potential risks. During these studies, SunWater determined that further investigations and potential remedial works were required to address the risks that had been identified. The primary dam safety risks initially identified related to:

- limited or inadequate erosion protection downstream of the primary and secondary spillway
- increased risks related to geological defects and weaknesses through the foundation and rock below and downstream of the dam (particularly considering the limited geological modelling and geotechnical testing and data available from the original design and construction)

Based on the outcome of the Dam Safety Review in 2014 and review of the Comprehensive Risk Assessment in 2015, additional studies required to determine the appropriate program of works to address these risks led to the establishment of the PDIP. The PDIP involved, amongst others:

- Stage 1 review and implementation of non-structural measures for improved emergency response and planning, including enhanced early warning systems and modelling, improved planning and collaborating with disaster management agencies, more effective messaging, communication and education (completed by January 2015) – this reduced the consequences and thereby the risk of a dam failure
- Stage 2 works to strengthen the base of the primary spillway at monoliths D and K where rock was exposed at each end of the spillway (completed between May 2015 and August 2017) – this reduced the likelihood and thereby the risk of a dam failure
- Combined Stage 3 and 4 further long-term works on the secondary spillway and primary spillway, to be implemented over the period from 2020 to 2025 – these major works would reduce the likelihood and thus the risk, to below the ANCOLD limit of tolerability

During Stage 2, SunWater conducted further technical investigations to review and update the Dam Safety Review (SunWater 2016a), as well as to review and update the Comprehensive Risk Assessment

(SunWater 2016b). The outcome revised and increased the risk position of Paradise Dam, thereby requiring a change in the scope of Stages 3 and 4.

The combined Stage 3 and 4 (long-term works) component of the PDIP commenced in 2017 with concept designs, options assessment and the development of the Preliminary Business Case (PBC) (SunWater 2018b) completed by SunWater by mid-2018. The objective was to implement the final improvement works necessary to reduce the dam risks to an acceptable level in accordance with the ANCOLD, Queensland State and other national and international dam safety guidelines and standards.

Following completion of the Preliminary Business Case (PBC) in June 2018, two options were shortlisted. SunWater engaged GHD consultants to develop the concept designs for improvements works that retain the dam at its current primary spillway level and storage capacity (labelled Option 2 in the PBC), and an option with a reduced primary spillway level (being 10 m lower than the existing level) and reduced storage capacity with corresponding reduced improvement works considering the lower flood loading for this option (labelled Option 3 in the PBC).

While SunWater (with GHD) conducted further detailed analysis and preparation of the design of the shortlisted long-term works options, potential higher risks to the safety of the dam were identified based on a review of historical information on the dam and foundations. These risks were related to the condition of the RCC lift joints and sliding stability within the dam, which had not been identified earlier due to the dam being assumed as constructed according to the design assumptions and specifications. Given the increased dam safety risk and concerns, the only practical way to assess whether the construction of the RCC by the Burnett Dam Alliance was satisfactory, was to carry out concrete and geotechnical investigations and testing. SunWater subsequently engaged SMEC consultants to undertake the investigation and testing of the RCC at specific locations within the dam wall, as well as drilling through other areas of the dam for the geotechnical investigation and testing of the foundations. This work was carried out from February to August 2019 (SMEC 2019). RCC drill cores and lift joint samples were obtained from vertical and horizontal holes cored from the spillway and abutment, with laboratory testing undertaken from August to September 2019. SMEC also reviewed core samples taken by SunWater in 2015 during the Comprehensive Risk Assessment.

Following the above-mentioned investigations, GHD revised its stability assessment of the RCC strength during August and September 2019 (GHD 2019o). Because of this work, SunWater has determined that:

- the stability of the dam is considered adequate when the dam is full
- during certain flood events, there is an unacceptable risk of dam failure when assessed against ANCOLD risk criteria; this risk arises because of the assessed condition of the RCC joints (as the major failure mechanism)

Building Queensland led the PDIP Detailed Business Case. This included an options assessment process to review the preferred scope for the long-term works component of the PDIP based on a selection of options identified in the Preliminary Business Case, which included the following options <u>and the subject of review in this Report</u>:

- **Full upgrade and retaining the original Full Supply Level**[6] – (or returning the primary spillway post Essential Works back to the original full storage capacity) with associated improvement works, or
- **Full upgrade and permanently lowering the Full Supply Level** – the spillway to be permanently lowered beneath the existing crest level (with corresponding improvement works, as well as considering alternative options for any reduced water supply options), considering 5 m, 10 m, or an optimised level in between, or
- **Full decommissioning**

Given the increased risk determined in 2019, compared to the 2016 Comprehensive Risk Assessment, to appropriately ensure the safety of downstream communities, SunWater took immediate action, including:

- reducing the storage level of the dam to 42%
- reviewing emergency management procedures with Councils and agencies, including warnings and triggers in Sunwater's Emergency Action Plan

[6] The Full Supply Level (FSL) is the level in the storage representing 100% capacity, which in an uncontrolled spillway, is the crest of the spillway, or the lowest spillway level if multiple levels are present.

- immediately commencing planning and design of the Essential Works (lowering the primary spillway) to allow construction to commence at the end of the upcoming wet season
- engaging an RCC expert (Tatro Hinds Advanced Concrete Engineering) to undertake a review of the SunWater Technical Review Panel findings (Tatro Hinds 2019)

1.2.4 Methodology

The broad scope of the review presented in this Report, was to provide comments on the selected options listed above, i.e. retaining the original Full Supply Level (FSL), permanently lowering the FSL and the full decommissioning.

It should be noted that the designs, cost estimates and risk assessments of the options were originally developed during the Preliminary Business Case (PBC). The options involving retaining the original FSL and a permanent 10 m lowering of the FSL were further developed after the PBC. Refined cost estimates were also developed for these two options. The design of an option involving a permanent 5 m lowering of the FSL was developed in parallel with the present review, but the cost estimate was based on the PBC schedules. The full decommissioning option was not further developed after the PBC. The design and risk review considered the original designs of the selected options prepared for the PBC and where applicable, the further development of those options.

This review involved the following activities:

- Commenting on SunWater's dam safety modelling process
- Reviewing background information about the dam, its history and recent investigations and studies, including a site inspection to gain a firsthand understanding of the site conditions
- Providing advice on the current understanding of the present condition of Paradise Dam based on available information
- Commenting on the design of the options in relation to validity of the dam safety assessments, assumed design factors, the basis for design, design methodology and the scoping of options
- Commenting on the costs estimations and risk assessments, including the basis and methodology for costs, cost assumptions and risk / contingency allowances
- Interface with Natural Capital Economics (engaged by Building Queensland), who carried out the Options Assessment process, by sharing the outcomes of this design-cost-risk review

SunWater provided information on the dam and the various studies in electronic form via a data room. The information covered several publications from the Detailed Design Report (BDA 2004) through to publications released to the public in November 2019, and publications released in January 2020 covering further studies completed in parallel with the present review. The information was screened against criteria necessary for the present review to identify any gaps in the information. The screening summary is enclosed in Appendix A.

The review focussed only on the failure modes where there were multiple options to reduce the risk, i.e. failure modes related to limited or inadequate protection downstream of the primary and secondary spillways, related to geological defects and weaknesses through the foundation and rock below and downstream of the dam, and related to low shear strength at the lift joints within the dam body. Other works, such as those related to the outlet works, are common to all the options and have not been reviewed, as they would not affect the option selection.

1.2.5 Limitations of the review and Report

It must be noted that the present review involved only a cursory review of past work undertaken on Paradise Dam, such as the original design, the flood damage repairs, the dam safety review, the comprehensive risk assessment, the further investigations and the options designs. The present review relied only on available information in reports prepared by others, and did not include any modelling, analyses or computations to verify the work by others.

Besides the fact that the project timeframe did not permit an in-depth review of the large body of work completed especially since 2014, all those studies have already been subject to technical peer review by industry experts over the course of many years. For the present review, the focus was largely on understanding the soundness of the processes and logic followed in the SunWater options studies with respect to interpretation of available information, and a cursory review to assess the validity and adequacy of the models, parameters and assumptions made regarding the geology and RCC dam wall, the methodologies and procedures used, and the design criteria adopted. Nonetheless, the Reviewers[7] have provided comments of a technical review nature where they deemed it appropriate.

By providing the review comments in this Report, the Reviewers do not warrant the accuracy of the previous work (including but not limited to reviews, studies, designs, cost estimates and risk assessments) prepared by others. The Reviewers do not accept responsibility or liability in any form whatsoever, for the design, the cost estimates, the risk assessments or any other work prepared by others.

The dam improvement works are required to address existing deficiencies in the dam regardless of the cause. This review is not a forensic assessment to determine the root cause of the deficiencies and it does not seek to assign blame to any individual, organisation or entity involved with Paradise Dam.

The Essential Works (i.e. the 5 m lowering of the primary spillway, to be completed prior to implementing the long-term works) were excluded by Building Queensland from Aurecon's brief for the long-term options review presented in this Report. At the start of the review process, the amount of lowering during the Essential Works were still being investigated and the 5 m lowering was confirmed only after completion of the Draft Report. The design of the long-term options assumed a base condition of the dam prior to the Essential Works (except for Option 1b, one of three options added after completion of the Draft Report). It must be noted that the Essential Works might have a significant impact on the long-term works option selection process and therefore the feasibility of the preferred option. (See further comments provided in Section 4.2.3)

This review was undertaken while the options were still being developed by GHD and several reports and documentation that have been reviewed, were only at a draft stage at the completion of the review process. Further testing was also in progress. GHD developed the design of the 5 m lowering of the FSL in parallel with this review and its outcome was provided while the Draft Report was being completed. It is acknowledged that the review had to meet predetermined deadlines; however, the adopted process of undertaking the review concurrently with the options development might result in inconsistencies between the comments in this Report and the final version of reviewed deliverables, while some finalised deliverables might contain content not considered in this review.

1.2.6 The Reviewers

The review presented in this Report was undertaken by the following persons (hereafter "the Reviewers"):

Marius Jonker – Dam engineering (design and risk assessment)

Marius was the lead reviewer and responsible for the review of the design of the options and the risk assessments.

Marius is Aurecon's National Dams Lead for Australia and New Zealand. With 30 years of experience in dam engineering and related fields, Marius is very familiar with all aspects of dam projects, from planning and feasibility studies through design of new, upgraded and modified dams, construction phase services and decommissioning studies. He is also well-versed in dam safety projects including dam safety portfolio management, full safety reviews, individual dam and portfolio risk assessments, safety inspections, monitoring, surveillance, operation, maintenance and dam safety emergency planning based on Australian National Committee on Large Dams (ANCOLD), international guidelines and State-based dam safety regulations.

Marius's experience spans projects in Australia, New Zealand, Malaysia, Philippines, India, Peru, South Africa, Zimbabwe, Botswana and Swaziland. With a civil master's degree in water engineering and hydraulic structures, Marius publishes and presents papers for national and international forums on dams engineering and has lectured on several dams engineering topics at workshops and seminars. He currently serves on the ANCOLD Guidelines Steering Committee and is chairing two committees developing new guidelines on

[7] The authors of this Report as described in Section 1.2.6

outlet works and arch dams respectively. He previously served on the committee that developed the current *Guidelines on Design Criteria for Concrete Gravity Dams*.

Edward "Ted" Warren – Concrete and RCC construction in dams and hydropower projects

Ted was responsible for provided expert advice on the RCC materials and construction issues, in particular, the RCC material strengths. He reviewed the information regarding the concrete construction and condition.

Edward has worked on several large civil Infrastructure, dams and water resource projects in more than 15 countries and 6 continents worldwide during his 35-year career and has an excellent technical knowledge of heavy Civil Engineering/ construction. He has worked on numerous projects both in the public and private sectors including but not limited to, The U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, Jordan Valley Authority, THPC, EVN, EEPCO, DHPI, various water resource and hydropower governing authorities throughout the world and more recently- China Three Gorges Corporation. He has worked worldwide on more than 30 RCC dam projects with large contractor joint ventures, engineers, clients, hydropower developers, consultants in the western world and extensively in developing countries, including; India, Chile, Honduras Jordan, China, Myanmar, Vietnam, Laos, Zambia, Ethiopia, DR Congo, Iran and Nepal. He has a thorough understanding of various construction philosophies, particularly in the development and applications of roller compacted concrete (RCC) dams. He has an excellent understanding in the procurement process of resources for the execution of construction projects from conception, design and implementation to final project completion. He has excellent negotiating and collaboration skills, quality control, health, safety and environmental plans, Team Leadership, client relations, Value Engineering, scheduling and cost estimating skills. He has extensive contractor experience and also worked as an Expert Advisor for civil designers, contractors, and directly represented various Client/Developers, construction management consultants for RCC dams and hydropower projects worldwide ranging in value from less than USD $100 million to USD $8 billion.

Alan Rae Consulting – Cost estimator

Alan was responsible for the review of the cost estimates of the options in the PBC in 2018, and the subsequent further design development and cost estimates in 2019 and 2020.

Alan commenced his career in 1958 and from 1965 to 1977 he was the Chief Estimator for Leighton Contractors. Alan commenced his consultancy practice in 1978. He has been involved in several major infrastructure projects in Australia and overseas. His clients include major contractors and design consultants. Recent cost plans he had prepared include

- AROWS Dam, Adelaide River, NT (2019)
- Eurobodalla Southern Storage, NSW (2018)
- Nicholson River Decommissioning, East Gippsland Water Corporation (2017)
- Greenvale Dam Rehabilitation, Thiess $40mill
- Other major infrastructure projects
  - Eastlink for Thiess/Holland Joint Venture - Value $2.5 billion
  - Peninsula Link - Linking Melbourne Authority and Thiess - Value $0.75 billion
  - Padma River Bridge - Bangladesh, AECOM - Value $3 billion
  - Upgrade M1 Freeway, VicRoads/ AECOM - Value >$1 billion
  - Upgrade M80 Freeway, VicRoads - Value >$1 billion
  - East- West Link Stage 2 - Value $3.5 billion
  - North East Link Study - Value >$5 billion
  - Rail Freight Study Melbourne - Brisbane - Value $10 billion
  - Hastings Port Study, GHD, AECOM, VicRoads - Value >$1 billion
  - Port of Botany Stage 1, AECOM - Value $0.3 billion
  - Geelong Bypass Project - 4 Stages, Princes Highway to Colac, VicRoads $<1 billion
  - Barwon River Bridge - VicRoads $40 million
  - Bulla Bypass Options - VicRoads <$1 billion
  - Several Road/Rail Grade Separations, Melbourne, VicRoads >$0.1 billion ea

Alan was awarded the Order of Australia Medal 2013 for Services to Community and Rotary International.

1.3 Structure of the Report

The review has been presented as follows in this Report:

Section 2 Comments on the current condition of the dam

Section 3 Comments on SunWater’s dam safety modelling process

Section 4 Comments on design of options

Section 5 Comments on cost estimates

Section 6 Comments on risk assessments

2 Comments on the current condition of the dam

2.1 Introduction

To provide comments on the engineering design, cost estimation and risk assessment of options to improve the safety of Paradise Dam, it was necessary to first understand the current condition of the dam, including:

- the geological and geotechnical model and analysis, specifically in relation to the primary and the secondary spillway erosion, and the dam wall foundation stability
- the dam wall materials and construction
- the dam wall design

This section presents comments on the understanding of the current condition of Paradise Dam, based on a desktop study of available records and observations made during a site visit. As all the upgrade options are based on the same existing conditions, a significant portion of reviewing the upgrade options was spend on understanding the existing physical conditions and the performance of the dam and its foundations.

2.2 Records for review

Historical information on the original design and construction and the flood repairs, has been obtained from the records listed under “Historical information” and “Current condition and risk position” in the data screening schedule shown in Appendix A.

The available records contain the Detailed Design Report (BDA 2004) and the Final Design Report (BDA 2005) (the dam was constructed from 2003-2005). The Detailed Design Report (BDA 2004) contains information on the preconstruction compressive and tensile strength testing of the concrete, and updates regarding changes to the excavation and design during the initial stages of construction. The Final Design Report (BDA 2005) covers further design changes made during the construction of the dam. Neither report covers lift joint shear strength testing undertaken during construction to verify the design assumptions, as is normal practice with RCC dam construction.

The Final Design Report (BDA 2005) contains the following text: *“The Final Design Report does not provide all details of the actual construction of the works. A separate report will be issued that contains records including construction processes used, foundation surface mapping, instrumentation data, inspection reports and photographic records. This separate report is called the Construction Report.”*

It is understood that the Construction Report was never compiled after completion of the project, even though records of quality assurance testing and control undertaken during construction are available (according to comment by SunWater on the Draft Report). The Construction Report would have been invaluable to understanding the construction practices and placed RCC properties.

2.3 Site familiarisation visit

Marius Jonker (Aurecon) represented the review team during a site visit on 3 December 2019. He was guided through the site by Craig Hillier (Design Manager, SunWater). Jim Binney (Natural Capital Economics) attended part of the site visit.

The visit included viewing the dam wall from the crest of the secondary spillway and from the primary spillway apron. The outlet works were viewed from the dam crest and close-up at the downstream side.

The rock outcrop and eroded areas downstream of the primary spillway apron were viewed from close-up.

Some concrete cores stored in the shed on site was also inspected. Concrete and rock cores from the SMEC 2019 drilling was neatly stored in sealed boxes (the records, logs and photos are included in the SMEC (2019) report). Only cores in open boxes were inspected, so as not to disturb or accidentally damage the cores through handling.

2.4 Comments regarding current potential failure modes

The potential failure modes are described in:

- Paradise Dam, Dam Safety Review, Revised Report (SunWater 2016a)
- Paradise Dam, Comprehensive Risk Assessment, Revised Report (SunWater 2016b)
- Paradise Dam Spillway Improvement – Preliminary Design, Update of Comprehensive Risk Assessment (GHD 2019a)

Based on the review of the above records, the following comments are made regarding the current potential failure modes:

a) Table 3.1 in GHD (2019a) provides the most recent assessment of the potential failure modes. This table was reviewed, and it is considered a thorough assessment of the potential failure modes. Adequate reasons have been provided and sound engineering judgement applied to include or exclude failure modes in the risk assessment. This table of potential failure modes is considered adequate for further options assessments.

b) Table 3.1 in GHD (2019a) is more comprehensive than the potential failure modes provided in the 2016 reports. This raises the question whether all the failure modes have been properly assessed in the engineering and geological analyses of the dam and its foundations, during the Safety Review and during the initial stages of the PDIP.

2.5 Comments regarding material properties

2.5.1 Dam wall material properties

Based on the review of the records listed in Section 2.2, the following comments are made regarding the dam wall material properties:

a) Comments regarding the lift joint condition

   i) The shear strength of the lift joints is the most critical hardened property for RCC gravity dams affecting the sliding stability within the dam wall. The condition of the lift joints is thus of equal importance.

   ii) The importance of understanding the condition of the lift joints has been recognised by SunWater and the lift joints have been extensively investigated since 2014.

   The records describing the RCC core drilling investigations carried out in 2006, 2014, 2015 and 2019, indicate extensive unbonded lift joints in the locations that have been investigated. The inclined and vertical holes indicated over 80% unbonded lift joints and the horizontal holes indicate over 50% unbonded lift joints, where the holes intersected the joints. Based on limited investigation results, it is not possible to conclude whether 50-80% of each lift joint is unbonded, or whether the entire joint area of 50-80% lifts is unbonded. The latter situation is much worse.

   Given the above-mentioned uncertainty about the persistence of unbonded lift joints, combined with the limited area of joint treatment near the upstream face, **the Reviewers agree that it is appropriate to assume that, for the options assessment (prefeasibility stage), all the lift joints should be considered unbonded**. Further core drilling investigations using horizontal coring and vertical coring through double or triple barrel coring, would be required to improve the understanding of the extent of the unbonded lift joints. Such investigations could be deferred until the detailed design stage.

iii) It is acknowledged that the drilling techniques and handling of the cores might have negatively affected the lift joints, resulting in an overestimation of the extent of unbonded lift joints. However, with low strength and poorly compacted RCC, it is difficult to get satisfactory results from coring. On other coring campaigns with high cementitious mixes, the Reviewers have seen far better results in every aspect even with poor drilling operations. The latest coring, video documentations and extraction operations of the 150 mm cores appeared to have been done by a highly skilled crew. The real problems appear to lie within the RCC itself and the manner in which the dam was constructed.

iv) Based on the visual inspection and the photos taken of other cores from the dam, several cores include honeycombing at the bottom of the lift. Although undesirable, it has been observed in other lean, low cementitious mix RCC dams. The reason for the segregation has not been reported, but it is typically the result of poor workability, compaction methods, environmental conditions, or a combination of these.

Sufficient workability is required to achieve compaction or consolidation of the mixture through the entire lift. Workability is most affected by the fines content, water content and quality of the flyash. In the case of Paradise Dam, the flyash was removed from the mix (and thereby also a portion of the fines), but it is not clear whether it had been replaced by other fines. Being a lean mix, the mix was also relatively dry. It thus appears that the honeycombing in some places, might be due to poor workability of the RCC mixture due to insufficient fines and paste to fill all voids during placement and compaction.

The above situation might have been exacerbated using a heavy 18 tonne roller. More passes of a lighter 10 tonne roller have been found to be generally more effective at other RCC dams.

Environmental conditions during construction could have contributed to drying of concrete surface prior to placement of the next lift, causing poor bonding between the lift joints.

Regardless of the cause of the unbonded lift joints, it seems conclusive that the lift joints are unbonded due to construction practices and not conditions experienced since construction.

v) The spatial extent of the unbonded lift joints (i.e. over the length and height of the dam wall), is not shown in the records. The records imply that the unbonded lift joints are spread over the dam and not clustered in one zone of the dam. The spatial extent of the unbonded lift joints should be confirmed during investigations scheduled for the detailed design, to inform the type and extent of the strengthening works.

b) Lift joint shear strength

i) As mentioned, the shear strength of the lift joints is the most critical hardened property for RCC gravity dams affecting the sliding stability within the dam wall, more important than the shear strength of the mass concrete within the lift layers. In the case of Paradise Dam, the lift joint shear strength is also one of issues of most uncertainty.

ii) The original design of Paradise Dam assumed that all the lift joints would be bonded and adopted the sum of cohesion and sliding friction resistance. It has been demonstrated in the Dam Safety Review (SunWater 2016a) and subsequent investigations, that this is not the as-constructed condition.

iii) The importance of understanding of the lift joint shear strength has been recognised by SunWater and it has been extensively investigated since 2014. As the lift joints in Paradise Dam are considered unbonded, the shear resistance should include only the sliding friction resistance between the lift surfaces. The investigations have appropriately focussed on estimating a representative friction angle only.

iv) The original design assumptions regarding lift joint shear strengths, made in lieu of testing, are considered reasonable. However, based on the records, it is not clear whether the lift joint shear strength was further investigated and confirmed through testing at the time of construction, which should have been done. The original assumptions now appear non-conservative.

v) The shear strengths adopted in the Dam Safety Review (SunWater 2016) are reasonable “typical” shear strength values when referring to a data base of test results (e.g. EPRI 1992) in lieu of field assessments. However, it did not consider the actual condition of the concrete cores at the lift joint locations, i.e. it is on the low side for peak shear strength for bonded lift joints, and on the high side for sliding friction strength of unbonded lift joints. The residual shear strength is around typical mean value.

vi) Statistical methods require input of several test samples that are representative of the entire dam. The current analysis does not include a sufficiently large sample size and it is also a combination of vertical, inclined and horizontal cores. The Reviewers question the reliability of using statistical methods given the relatively small sample size and uncertainty about the quality of the shear testing.

vii) The effect of honeycombing in the upper layer (top of lift joint) has not been considered in detail. Although some samples presented boney concrete above the lift joint, only sample RCC-S 2.3-3.3 included honeycomb concrete. Given the lack of paste (matrix) holding the course aggregate in place, the concrete above the lift joint could crush and might reduce the lift joint shear strength. However, this is not always the case and it depends on the degree of honeycombing. It was noted that the tests on samples with honeycombing on the joint, produced lower residual strengths, some less than 30°.

viii) The proposed average residual shear strength of ϕ = 37-39.3° and c = 0 for up to 600 kPa normal stress, is considered appropriate for use in the options assessment, given limited available data. However, more certainty is required for the feasibility study and detailed design. Additional sampling and testing should be undertaken to increase confidence in the test results. The locations should be selected to represent entire dam, not just locations easy to access, and include lift joint conditions with and without honeycombing.

ix) The Reviewers concur, in general, with the findings reported by Tatro Hinds (2019), as well as the comments made in the TRP Report No. 3 (TRP 2019b) regarding the shear testing issues. The Reviewers have the following additional comments.

  - The Reviewers consider that the use of low cementitious RCC could have a significant effect on the accuracy of the shear testing where one sample has been used to estimate the peak strength, sliding strength as well as residual strength. It is possible that the residual shear strengths have been underestimated due to the method of re-using the samples.
  - The Reviewers agree that performing testing on RCC cylinders less than 150 mm dia. is not recommended and would go on to say that coring and testing of 100 mm cores is not going to reveal anything of use for the RCC testing, other than for geological exploration. If any geological exploration requires drilling through an RCC mass, then it would be recommended to have a look at the cores, but any further laboratory testing would not be of much benefit other than simple densities and visual inspections.

- Mr Ted Warren commented that based on everything he had reviewed the findings of this evaluation campaign is not surprising and very similar to findings of RCC dams adopting a similar low cementitious approach. Many have performed quite well under extreme loading conditions but are much lower dams.

c) Density of RCC

i) The density of the RCC mass concrete is a key factor in the stabilizing dead weight load of the dam body and it also affects the shear resistance on the lift joints (provides the normal load that is multiplied with the shear friction). However, it appears this parameter has not been investigated in depth, as was done for the shear strength.

ii) Given the lack of entrained air and lower water content, RCC mixtures typically result in slightly higher densities than conventional air-entrained mass concrete. However, with lean RCC mixes there is also a concern about low densities.

iii) The density of 23.9 kN/m³ used in the dam stability analyses for the Dam Safety Review (SunWater 2016a), represents the lower bound of the densities determined during construction and the 2019 investigations. According to BDA (2005), the lowest density of the RCC based on construction records was 24.4 kN/m³. The 2019 investigation determined the densities to range from 24.0 to 25.4 kN/m³ based on 8 results. GHD (2019n) adopted an even lower density of 23.5 kN/m³.

As the stability of the dam is dependent on the weight of the concrete, the impact of using the lower bound and mean densities should be considered. Using the lower bound density and lower bound shear strength, combines two uncertainties and could result in overly conservative results. It would be reasonable to assume that the average density in any 2D cross section is equal to the average density of the test values. It is unrealistic to assume that all the concrete in a specific section has a density equal to the lower bound test value.

iv) As a general remark, the range of densities determined during construction could indicate either consistent low densities during construction or a high coefficient of variation in the quality control at the RCC batch plant. Cylinder densities of fresh RCC taken in the field during construction, would have been valuable in this case.

d) Compressive strength of RCC

i) It is not clear what the actual compressive strength of the concrete is. The Dam Safety Review adopted a 1-year compressive strength of 14 MPa based on preconstruction trial RCC mixes. This seems reasonable.

e) Tensile strength of RCC

i) The Dam Safety Review adopted a tensile strength of 260 kPa where no bedding mix was used, based on preconstruction trial RCC mixes. Considering the unbonded condition of the lift joints, it should be assumed that the dam has zero tensile strength.

2.5.2 Foundation properties and geologic model

Based on the review of the records listed in Section 2.2, the following comments are made regarding the foundation properties and the geologic model:

a) The foundation conditions, information and investigations have been described and discussed in depth in the records reviewed for this Report. To avoid repetition, that information and a description of the site geology and geotechnical conditions are not repeated here.

b) The procedure for developing the latest geological and geotechnical model of the site followed a logical sequence, as recommended by ANCOLD (draft practice note on geotechnical site investigations). This generally included:

- Desktop study of all available information since the investigations for the original design
- Developing a preliminary geological model
- Undertaking a gap analysis
- Expanding the information and model with mapping and non-intrusive investigations
- Scoping a targeted site investigation and testing program to fill remaining gaps
- Refining the geological and geotechnical model (data presented in *Leapfrog* software)

c) The knowledge and understanding of the foundations have increased during studies and investigations undertaken since the Safety Review. The knowledge has been sufficiently expanded to understand the potential for erosion in the primary and secondary spillway, and the potential for sliding failure in the foundations. Although not required for the Options Assessment, further investigations would be required for the feasibility study and the detailed design of the selected option. SunWater may decide whether to undertake such investigations for the Options Assessment or defer it to the detailed design stage.

d) Despite the investigations and modelling completed to date, there are several uncertainties about the foundation (e.g. zones of fractured and faulted rock). These uncertainties are briefly mentioned below.

i) There is a degree of uncertainty about the difference in the original foundation design and the actual excavation depths. There is only limited information in this regard in the Detailed Design Report. The Final Design Report states that the excavation for the secondary spillway was terminated at a higher level but recognised that the foundation is also erodible under overtopping flow conditions. No further information has been provided but presumable would have been included in the Construction Report, which has apparently not been prepared.

It is understood that GHD used the as-constructed excavation cross sections to create the foundation surface of the dam (GHD comment on the Draft Report).

ii) The site has complex geology and the rock mass is a combination of structurally disturbed blocks and zones enveloped in a very complicated series of faults and breccia zones. Although the principal structural elements of the rock mass have been identified as the Paradise and Apron Faults together with related secondary shears and faults, it is possible that other fault systems are also present. It would be beneficial to refine the current geological model and domains. It is understood that further assessment of the site geology and the development of a detailed 3D model is ongoing, but these have not been completed in time for this Report.

iii) The modelling of kinematic systems is not fully understood. Such systems should be considered using a 3D model to account for defect orientations.

There is still uncertainty about the geotechnical parameters that should be used in the stability analyses. It is unclear how the latest SMEC (2019) data (investigation, testing and modelling) has been incorporated in the stability analyses.

SunWater advised in a comment on the Draft Report, that the geotechnical model is currently being updated to incorporate the findings from the 2019 investigations. Following this update, they will review the kinematically feasible failure modes, rock strength parameters, stability analysis and scour assessment.

iv) It is unclear how deep-seated sliding in the foundation has been modelled considering hydraulic uplift and the defect orientations. The uplift should be applied on all sliding and release surfaces within the foundation in a 3D model, assuming no uplift reduction. When applied on a wedge in the foundation, especially on the inclined abutments, the uplift would be higher than assuming a horizontal base of the dam in a 2D model.

v) Given the complexities and uncertainty about the geological model, there is uncertainty about how reliable an anchor design would be. It is understood that in situ testing of anchors are planned. The Reviewers endorse this testing, as it would provide clarity of whether anchoring would be successful and reduce a key uncertainty in the current options assessment.

e) The erodibility of the rock downstream of the spillways has been adequately assessed by an international erosion expert (Dr Erik Bollaert, Aqua Vision 2016). Although further investigations and analyses could be carried out to better understand the location and shape of the erosion holes, it is already clear that further erosion would occur and that the aprons at the primary and secondary spillway should be extended to sufficiently cover currently exposed rock.

f) The studies and investigations of the foundations have been peer reviewed. This is important given the complexity of the geology and a degree of subjectivity in interpreting the geological information.

2.6 Comments regarding load inputs

2.6.1 Hydrologic load input

Based on the review of the records listed in Section 2.2, the following comments are made regarding the hydrologic input:

a) The hydrologic input has been reported in the report "Paradise Dam Failure Impact Assessment, Hydrology, Dambreak Modelling and Life Loss Assessment Report", Version 1, June 2019, prepared by HARC (HARC 2019).

b) The above-mentioned report represents the latest practices and methods for hydrology studies.

2.6.2 Seismic load input

Based on the review of the records listed in Section 2.2, the following comments are made regarding the seismic input:

a) The seismic input has been reported in the report "Paradise Dam Seismic Hazard Assessment", February 2019, prepared by the Seismic Research Centre (SRC) (SRC 2019).

b) The above-mentioned report represents the latest practices probabilistic seismic hazard assessment studies.

2.7 Comments regarding Dam Safety Review and the Comprehensive Risk Assessment

Based on the review of the records listed in Section 2.2, the following comments are made regarding the Dam Safety Review and the Comprehensive Risk Assessment:

a) The scope of the Dam Safety Review is consistent with the Queensland and ANCOLD dam safety guidelines.

b) The design basis and criteria of the Dam Safety Review is consistent with the Queensland and ANCOLD dam safety and other guidelines.

c) Some material properties of the dam wall and foundations are now outdated given the further investigations completed since the Dam Safety Review. The hydrology and seismology studies have also since been updated. The 2016 reports would require some updating to reflect the current knowledge of the dam and foundations, as well as the mentioned studies.

d) The analyses methods are consistent with the ANCOLD guidelines and relevant international practices, regardless of the input values.

e) The loads and load combinations are consistent with the ANCOLD Guidelines on Design Criteria for Concrete Gravity Dams (ANCOLD 2013). It would however be beneficial to review the uplift loads.

   i) The uplift could be relieved in the dam wall due to face drains, but no uplift reduction would occur at the foundation contact zone, as there are no foundation drains. 100% uplift should be used to assess sliding within the foundations.

   ii) According to the design drawings, the face drains do not extend to the base of the dam wall. There is a zone between the foundation and the face drain outlet where 100% uplift would apply if there were a leak in the membrane.

   iii) The uplift might be reduced at the face drains under conditions experienced to date. However, it is uncertain whether the drain capacity would be sufficient at high reservoir levels, as the leakage could exceed the drain capacity. It might be non-conservative to adopt less than 100% uplift for flood load conditions. (This is in line with the principle that piezometer readings (reflecting the effectiveness of foundation drains and uplift) under FSL conditions cannot be extrapolated with confidence above the highest reservoir level for flood conditions.)

   iv) The piezometer near the heel might be affected by localised conditions such as the grout curtain and be in a sealed zone in the foundation. The uplift might be higher elsewhere and the uplift might have been underestimated. Additional piezometers are required for confirm the uplift profile at the base of the dam and in the foundations.

f) The risk assessment has been undertaken in accordance with the latest practices, methods and guidelines, including the ANCOLD Guidelines on Risk Assessment (ANCOLD 2003). Although the risk assessment is based on uncertainty in the engineering analysis, and has uncertainty in itself, it can be concluded with a high level of confidence, that the life safety risk position is currently above the limit of tolerability criteria.

2.8 Additional comments

a) This comment provides some background about the use of RCC in dam construction in Australia and worldwide, and compares the approach taken at Paradise Dam with practices at the time.

RCC can be considered as both a construction material and a construction method. It has been used in road construction since the 1920s and in an early form in dams during the 1960s and 1970s. The first use of RCC as used today, was in 1975 at Tarbela Dam in Pakistan. Since completion of the first major RCC dam, Willow Creek Dam in 1982 in the USA, the development of RCC and its use in dams have progressed rapidly. In most cases today, it is the preferred material and method due to rapid construction and less expensive materials. There are presently over 750 RCC dams in operation worldwide.

RCC mixes are classified according to cementitious content (cement plus pozzolan), as follows:

- low paste mix (<100 kg/m³)
- medium paste mix (100-150 kg/m³)
- high paste mix (>150 kg/m³)

Most earlier RCC dams were constructed using low to medium paste mixes due to cost savings in the concrete materials, despite the need for an upstream membrane. Most modern RCC dams are constructed using a high paste mix. The increased material cost is offset against a more optimised design than in the past due to the use of modern design and construction tools, the use of lower grade aggregates, and achieving water tightness in the dam body thus eliminating the need for an upstream membrane.

The decision to construct Paradise Dam using RCC is considered in line with the practices at the time, considering that RCC technology was well developed and the significant cost savings compared to a conventional concrete gravity dam.

Several RCC dams have been constructed in Australia since the 1980s before Paradise Dam was constructed, including (from "*The International Journal of Hydropower and Dam, 2019 World Atlas & Industry Guide*"):

- Copperfield Dam (40 m high gravity dam in Qld, completed in 1984, medium paste mix) (second major RCC dam internationally after Willow Creek Dam)
- New Victoria Dam (52 m high gravity dam in WA, completed in 1991, medium paste mix)
- Lower Molonglo Storage (32 m high gravity dam in ACT, completed in 1994, high paste mix)
- Loyalty Road Basin (30 m high gravity dam in NSW, completed in 1995, low paste mix)
- Cadiangullong Dam (43 m high gravity dam in NSW, completed in 1997, high paste mix)

Since the completion of Paradise Dam in 2005, other major RCC dams have been constructed in Australia, including:

- Meander Dam (50 m high gravity dam in Tas, completed in 2007, low paste mix),
- North Para Dam (33 m high gravity dam in SA, completed in 2007, high paste mix)
- Wyaralong Dam (48 m high gravity dam in Qld, completed in 2011, high paste mix)
- Enlarged Cotter Dam (80 m high gravity dam in ACT, completed in 2013, high paste mix)

All these dams are understood to have performed satisfactory to date. Meander Dam is notably like Paradise Dam and has a cementitious content of 70 kg/m³ with no pozzolan, and an upstream membrane for water tightness.

b) The major difference between RCC and conventional concrete gravity dams, is the higher number of lift joints in RCC dams and thus the higher potential for occurrence of a weak lift joint and resulting sliding failure mechanism. RCC dams have however performed well despite this weakness, likely due to the awareness of the importance of the lift joints during the design and construction. RCC dams are also relatively young (the major RCC dams are all younger than 40 years old) compared to conventional concrete dams and have been constructed using modern construction plant and equipment. Based on performance to date, RCC dams are performing similar to conventional concrete dams with the most likely failure mode being sliding in the foundation, especially when combined with overtopping erosion.

c) The current cross section of Paradise Dam presents a relatively steep downstream slope of 0.64(H):1(V). Modern concrete gravity dams typically have slopes of 0.7(H):1(V) to 0.8(H):1(V). A flatter slope is often used in RCC dams due to concerns about the lift joint quality and shear resistance, and that the outer "skin" (facing systems) is usually excluded when evaluating the stability and stresses. In the case of Paradise Dam, it seems a steeper slope was adopted due to having a membrane on the upstream face, which would eliminate (or significantly reduce) uplift pressures within the body of the dam. The membrane however does not affect the uplift within the foundation and the steeper slope would be detrimental to sliding stability at and in the foundations.

d) In low cementitious RCC gravity dams, an inclined upstream face is often used, i.e. having a cross section symmetrical to the dam axis. This increases the sliding plane lengths and adds dead weight to the structure. In the case of Paradise Dam, a vertical face has been adopted in to allow for a membrane and precast panels to be used.

e) It appears that the combination of lean RCC (and associated lift joints issues), a membrane of the upstream face and a steep downstream slope, all contribute to the lack of adequate stability in the dam.

3 Comments on SunWater's dam safety modelling process

3.1 Introduction

This section presents comments on SunWater's dam safety modelling process.

SunWater's multi-criteria for assessing the options include (1) dam safety, (2) costs, (3) delivery risks, (4) customers and stakeholders, (5) environment and (6) asset management. The performance of an option in achieving the regulatory requirements for dam safety is a key factor in determining the viability of that option.

The purpose of this review was to undertake an independent review of Sunwater's dam safety modelling process and outputs. The review examined the inputs to the modelling process and any assumptions made about the values of the inputs. The review of the output examined how the outputs were developed, interpreted and reported. These aspects were assessed against contemporary practices recommended by ANCOLD, ICOLD and DRNME.

3.2 Records for review

This review was based on the following SunWater document:

> **Dam Safety Improvement Decision Criteria – Guidelines**, DS20, Revision: 1 (HB #2339310), Last Revision Date: May 2018 (SunWater 2018)

It must be noted that there was some uncertainty early on in this project, about which document represented SunWater's current dam safety modelling process. The above-mentioned document supersedes the following documents that also refer to SunWater's dam safety modelling process:

- Preliminary Business Case, Paradise Dam – Facility Strategy and Options Analysis Project, Project N-WBXB-04-06-10-AD, File No 17-004547/001, prepared by SunWater, June 2018
- Dam Safety Upgrade Decision Criteria Options Paper, Final Draft 5 Report, August 2010, contained in Appendix A of the Paradise Dam Comprehensive Risk Assessment, Revised Report, Final Report, Project N-WBXB-04-06-10-CG, File No 14-004361/003, prepared by SunWater, June 2016

3.3 Comments regarding dam safety process

Based on the review of SunWater (2018), the following comments are made regarding SunWater's dam safety modelling and decision criteria.

a) The 41-page document was reviewed, and the process found to be generally in line with contemporary practices recommended by ANCOLD, ICOLD and DRNME.

b) The only portion of the process that could be reviewed, is the flow diagram for Steps 3 to 7 (see extract below from the flow diagram in Appendix B of the SunWater (2018)). The questions under Steps 5, 6 and 7 can all be answered at the same time using the outcomes of a risk assessment which is used to answer the question for Step 3. Steps 5, 6 and 7 should follow Step 3, before moving to Step 4. If a feasible failure part can be initiated under Normal loading conditions, and a change to the operating conditions could reduce the risk, it should be implemented regardless of whether it is considered sustainable.

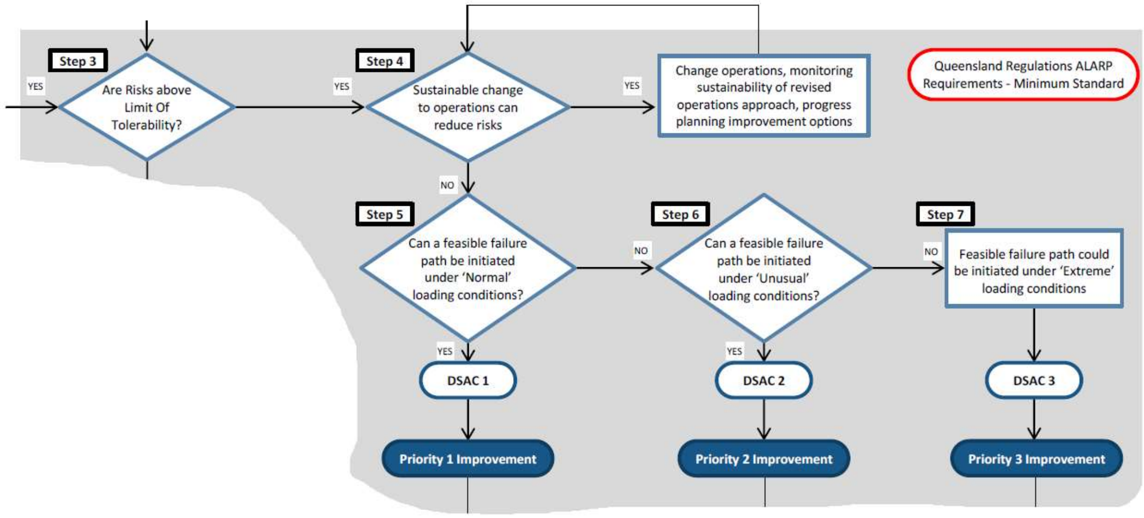

Figure 2 Extract from Dam Safety Improvement Decision Criteria (2018 flowchart)

4 Comments on design of options

4.1 Introduction

This section presents comments on the design of the dam improvement options after consideration of:

- whether the design assumptions (basis for design), design criteria and methodologies for the respective options are in accordance with contemporary dam design practices recommended by ANCOLD and other international organizations such as ICOLD, USACE, USBR and FERC
- whether the design and scope of works effectively addresses the dam safety deficiencies (i.e. a fatal flaw assessment)
- whether there are any suitable alternative approaches to the designs

It must be noted that this is only a cursory review, recognising that an in-depth technical review has already been conducted by an independent technical review panel (TRP) engaged by SunWater. The Reviewers for this Report have reviewed the supplied records and formed their own opinion about the options, as reported in Sections 4.4 to 4.6. The comments below should be read in conjunction with the supplied records. The approach was to keep the comments brief and not repeat information already provided in the supplied records.

4.2 Summary of options

4.2.1 Options reviewed

The following options have been identified for inclusion in the Detailed Business Case:

- **Option 1:** Full upgrade with the primary spillway at the original FSL
- **Option 1a:** Full upgrade with the primary spillway at the original FSL and rebuilding Monoliths R-W
- **Option 1b:** Full upgrade and reinstating the original FSL with a gated solution *
- **Option 2:** Full upgrade with the primary spillway crest level 5 m below the original FSL
- **Option 3:** Full upgrade with the primary spillway crest level 10 m below the original FSL
- **Option 3a:** Full upgrade with the primary spillway crest level 10 m below the original FSL plus the development of alternative supply options
- **Option 4:** Full upgrade with the primary spillway crest level 5-10 m below the original FSL
- **Option 5:** Full decommissioning

* Assumed a base case of the primary spillway already been lowered by 5 m during the Essential Works.

Options 1, 3 and 5 were brought forward from the Preliminary Business Case and the other options added during the Options Assessment for the Detailed Business Case.

Note that the numbering of the options has changes since the Preliminary Business Case and the Draft Report, in accordance with advice from Building Queensland.

This review focussed on Options 1, Options 2, 3 and 4 collectively, and Option 5. The scope of work at the dam for Option 3a is the same as for Option 3. Options 1a and 1b have been added after completion of the Draft Report[8], which commented that Option 1 should not be abandoned (as previously suggested) and instead the scope be expanded to lower the risk to below the ANCOLD limit of tolerability. (See further comments in this regard in Section 4.2.2)

[8] Previous draft versions of the Design, Cost, Risk review report by Aurecon, Rev 0 issued 16 January 2020 and Rev 1 issued 3 February 2020

The intention was that the scope of work, concept designs and cost estimates developed to date for Options 1/1a and 3 could be used as “bookends” to define the same for Option 4, assuming a base case of the dam in its current configuration (i.e. no Essential Works implemented). However, this might **not** be the case once the Essential Works have been completed, as outlined in Section 4.2.3.

4.2.2 Additional options (not reviewed)

Following the Project Working Group meeting on 29 January 2020, SunWater provided additional commentary by email on 30 January 2020, on Option 1 to retain the original FSL. This was done because Option 1, which was a further development of a concept identified in the SunWater’s PBC, does not reach a risk position below the ANCOLD Limit of Tolerability (ANCOLD 2003).

As noted by the Reviewers for the Draft Report, this does not necessarily mean that the concept of retaining the FSL should be abandoned and Option 1 should instead be considered an incomplete option to retain the original FSL and meeting the ANCOLD risk criteria. Additional work could be added to the scope to lower the risk, as has subsequently been shown for Options 1a and 1b. Additional improvement measures could be undertaken to reduce the risk further. SunWater has since the completion of the Draft Report, provided two additional options (labelled Options 1a and 1b) to upgrade the dam while retaining the original FSL. Although these have not been developed and costed to an equivalent standard as Options 1, 2 and 3 and not reviewed to the same level for this Report (no design, cost or risk documentation provided), they are useful for gaining an appreciation of what might be possible for retaining the original storage capacity. The additional options are:

- **Option 1a:** As for Option 1 plus rebuilding secondary spillway Monoliths R to W. GHD’s preliminary design report determined that 73% of the residual contributing risk for Option 1 is overturning / sliding of the secondary spillway monoliths. This is primarily due the likelihood of a high-level, low angle fault / feature in the foundation. Removal of this material by demolition and reconstructing Monoliths R to W should mitigate this residual risk and therefore improve the risk position for Option 1. (The residual risk has not yet been demonstrated in a risk assessment.)
- **Option 1b:** Full upgrade and returning the original FSL with a gated solution (assuming the 5 m lowering during the Essential Works has been completed). This is based on a concept developed by GHD in April 2019 as a potential means of returning the FSL if a 10 m lowering was undertaken in the Essential Works.

4.2.3 Effects of Essential Works on long-term options

As mentioned before, at the time of preparing this Report, SunWater and GHD have been developing the design of the Essential Works that would be implemented prior to the long-term options. These works would involve lowering the primary spillway crest by 5 - 10 m and confirmed as 5 m after completion of the Draft Report. **This would have a significant effect on the long-term Options Assessment**.

Upon completion of the Essential Works, **Option 1 would require additional work to raise the primary spillway crest** back up to the current FSL (these works have not yet been considered in the Options Assessment) or gates be provided (e.g. Option 1b). Depending on the lowering for the Essential Works, **Option 2** might require additional work to **lower the primary spillway crest further to the long-term level**, while **Option 3** might require additional work **to raise the primary spillway crest back to the long-term level**. These works have **not yet been considered in the current Options Assessment** from a technical design perspective or from a cost offset perspective.

Aurecon was also asked to comment on SunWater’s claim that there is only one opportunity to lower the level of the primary spillway due to dam stability issues. The Reviewers consider that there is no apparent technical impediment to undertaking additional lowering works beyond what is currently announced for the Essential Works (5 m lowering and assuming no anchoring), particularly given extensive further works are still required to strengthen the primary spillway after the Essential Works are completed. It would however have a cost effect. This claim should not influence the assessment of long term options for Paradise Dam.

4.3 Records for review

Information on the design of the long-term options has been obtained from the records listed under "Phase 3: Dam Engineering Review of Design of 5 Options" in the data screening schedule shown in Appendix A.

4.4 Comments regarding design of Option 1 retaining FSL

SunWater has provided a summary of works required for Options 1, 1a and 1b, as shown in Table 1.

Table 1 Summary of options to retain the FSL (provided by SunWater, January 2020)

Option		Storage Capacity	Key upgrades	Risk Improvement
1	Full Upgrade – Maintaining FSL	300,000ML	■ Post tension anchoring: – Primary Spillway: 98 No. 91 Strand PT anchors – Secondary Spillway: Mono L-R 24 No. 82 strand PT anchors; Mono S-W 10 No. 55 strand anchors – Left Abutment: 10 No. 73 Strand PT anchors ■ 60 m long stilling basin ■ New gravity training walls ■ Secondary spillway side channel and gravity wall ■ Outlet works modifications ■ Left abutment and basalt pimple erosion protection	Just above ANCOLD Limit of Tolerability, as currently assessed for proposed improvement scope. Alternate improvements outlined as Options 2A & 2B
1a	Full Upgrade – Maintaining FSL (Option 1 + Rebuild Monoliths R-W)	300,000ML	Same as Option 1 plus: ■ Temporary coffer dam upstream of secondary spillway ■ Demolition of Monoliths R-W ■ Removal of 5-8m of poor foundation material ■ Rebuild Monoliths R-W	Not assessed, but may anticipate being like Option 3C, as very preliminary view only
1b	Full Upgrade – Maintaining FSL – Gated Solution	300,000ML	**Stage 1:** Demolition of top 10 m primary spillway crest to provide short term risk improvement. **Stage 2:** ■ Construct 55 m long stilling basin ■ New gravity training walls ■ Post tension anchoring: – Primary Spillway: 84 No. 91 Strand PT anchors – Secondary Spillway: Mono L-S 57 No. 55 strand PT anchors; Mono R-W 73 No. 27 strand anchors ■ Re-construct ogee crest to primary spillway incorporating gallery for maintenance of post tensioned anchors ■ Installation of 5 m high x 15 m wide Hydraulic Flap Gates ■ Raise Secondary Spillway by 5 m ■ Secondary Spillway channel capping ■ Outlet works modifications ■ Left abutment and basalt pimple erosion protection	Not assessed, but anticipated being like Option 3C, though noting SunWater has reservations and risk concerns regarding gated options

Based on the review of the records listed in Section 4.3, the following comments are made regarding Option 1 only.

a) For Option 1, as presented, it was assumed that the dam would be in its current configuration when this work is commenced. As discussed in Section 4.2.3, it is acknowledged that the primary spillway might have already been lowered by 5 m during the Essential Works and the new configuration would affect the execution of the long-term solution. The actual scope for Option 1 would thus be different to what has been assumed in the long-term options assessment.

b) The scope of the Option 1 works for the proposed risk reduction measures addresses the dam safety deficiencies in terms of the potential failure modes that dominate the current risk position of the dam.

   The outstanding issues are:

   - Protection of the left abutment downstream toe against overtopping flows at flood levels above the left abutment crest. Although the likelihood of the PMPDF peak reservoir level is low, there is a high conditional probability of erosion and failure of the left abutment. The remaining uncertainty is whether the works are adequate to lower the risk to below the limit of tolerability.
   - Based on the geology, erosion downstream of extended apron might still be possible; additional protection might be required.
   - Based on the CFD modelling, the secondary spillway return channel would still be overtopped (as currently) and it could lead to undermining and failure of right abutment apron and foundation.
   - In general, even though a gravity dam must be stable in any 2-dimensional section, in a 3-dimensional evaluation of the dam and foundations, the lack of capacity could be redistributed to the adjacent sections where the dam has a sufficient margin of safety. In the case of Paradise Dam, the stability of the monoliths on the bend in the secondary spillway require special attention. In this area the dam axis is curved and with the transverse joints perpendicular to the axis, the joints flare open, i.e. there would be no transfer of sliding resistance to adjoining monoliths.

c) The execution of the proposed Option 1 works, including the installation of the anchors, is considered viable. Access to the primary spillway crest would be difficult but possible.

d) Option 1 relies on anchors to achieve sliding stability. Traditional calculation methods have resulted in generally conservative results. Although appropriate for preliminary analyses for options studies, for the detailed design, the analysis could be significantly improved by making use of modern, comprehensive numerical analyses in conjunction with 3D models of the rock mass structure, realistic rock and rock mass properties, and the results of prototype anchor tests in the rock mass concerned.

   In the case of Paradise Dam, there is uncertainty about the effectiveness of the anchors during operation under the applied loads, due to the spacing of the anchors and the strength of the rock to provide sufficient anchor resistance. Further investigations are required to confirm the rock strength, for example installing a prototype anchor and testing it to determine its failure load.

e) Basis of design:

   i) The design assumptions are reasonable, but further work is required to better understand the concrete and foundation parameters, as discussed in Section 2.

   ii) The design and acceptance criteria are in accordance with the latest ANCOLD and international practices.

   iii) The methodologies used in the design are in accordance with the latest ANCOLD and international practices.

f) Option 1, based on the scope of works, does not achieve the desired risk position below the ANCOLD life safety limit of tolerability. Option 1 therefore does not present a complete solution. This does not necessarily mean that the concept of retaining the FSL should be abandoned.

Additional work could be added to the scope to lower the risk, as has subsequently been shown for Options 1a and 1b. See also Section 6.6.

g) Suitable alternatives to retaining the FSL include the use of a downstream RCC buttress to increase the cross section and protect the downstream rock at both the primary and secondary spillways, and a combination of anchoring and buttressing.

It is understood that buttressing had been considered early in the options assessment (first TRP workshop) and dismissed due to the large volume of concrete required for the buttress and associated costs (in the same order as a new dam), as well as concerns about finding adequate foundations for the buttress downstream of the primary spillway. This alternative has not been adequately documented in the available records. It is also not clear whether a combined buttress and anchor option has been considered.

There are many examples of dams that have used RCC mass and/or CVC mass with subsequent tension anchors for stability long after construction, as is proposed in Option 2. Some recent examples in the USA are:

- **USACE Bluestone Dam 2000-2020** (still ongoing with improvements mostly from scouring and movement)
- **USBR Pueblo Dam 2000 (Arkansas River)** RCC backfill of scouring, movement in the downstream direction, RCC buttressing of lower portion of dam and tension anchors drilled through the RCC mass, spillway improvements
- **Loch Raven Dam, Baltimore MD 2001-2002** RCC buttress of existing dam and tension anchors
- **Westly Seale (**Corpus Christi TX) 2001-2002, Mass concrete buttressing with tension anchors

h) Suitable alternatives for the spillway apron protection include an extension of the buttress (if adopted) over the eroded areas (or areas susceptible to erosion) or changing the hydraulic operation from a stepped spillway with an apron, to a smooth spillway with a roller bucket or flip bucket. Changing the spillway hydraulics would require detailed modelling to ensure the current conditions are not exacerbated.

4.5 Comments regarding design of Options 2, 3 and 4 for lowering the FSL

SunWater has provided a summary of works required for Options 3A and 3C, as shown in Table 2.

Table 2 Summary of options with lowering the FSL (provided by SunWater, January 2020)

Option		Storage Capacity	Key upgrades	Risk Improvement
2	Full upgrade - Partial Spillway reduction by 5 m	184,000ML	▪ Primary spillway lowering by 5 m ▪ Raising of the Secondary Spillway by 5 m ▪ Post tension anchoring: – Primary Spillway: 84 No. 91 Strand PT anchors – Secondary Spillway: Mono L-S 57 No. 55 strand PT anchors; Mono R-W 73 No. 27 strand anchors ▪ 55 m long stilling basin ▪ Capping of the Secondary Spillway channel ▪ New gravity training Walls ▪ Lowering of intake tower and fishway ▪ Remediation of reservoir rim ▪ Outlet works modifications ▪ Left abutment and basalt pimple erosion protection	Within half an order of magnitude below ANCOLD Limit of Tolerability

Option		Storage Capacity	Key upgrades	Risk Improvement
3	Full upgrade - Partial Spillway reduction by 10 m	114,000ML	▪ Primary Spillway lowering by 10 m ▪ Post tension anchoring: – Primary Spillway: 35 No. 91 Strand PT anchors – Secondary Spillway: Mono L-R 30 No. 82 strand PT anchors; Mono S-W 10 No. 24 strand anchors ▪ 50 m long stilling basin ▪ New gravity training walls ▪ Lowering of intake tower and fishway ▪ Remediation of reservoir rim ▪ Outlet works modifications ▪ Left abutment and basalt pimple erosion protection	2 orders of magnitude below ANCOLD Limit of Tolerability

The comments below apply to the 5 m, 10 m and optimal level between 5 and 10 m lowering of the spillway crest. The comments are largely based on the design of the 10 m lowering, which was provided at the start of the review process, with judgement used as how it would apply to the other two scenarios. The design of the 5 m lowering was provided only on 15 January 2020. No design has been prepared for the optimal 5-10 m lowering, but the comments would equally apply to any level between 5 and 10 m.

Based on the review of the records listed in Section 4.3, the following comments are made.

a) For Options 2 and 3, as presented, it was assumed that the dam would be in its current configuration when this work is commenced. As discussed in Section 4.2.3, it is acknowledged that the primary spillway might have already been lowered by 5 m during the Essential Works and the new configuration would affect the execution of the long-term solution. The actual scope for Options 2, 3 and 4 would thus be different to what has been assumed in the long-term options assessment.

b) The scope of works for the proposed risk reduction measures addresses the dam safety deficiencies in terms of the potential failure modes that dominate the current risk position of the dam.

   The outstanding issues are:

   - As for Option 1, based on the geology, erosion downstream of extended apron might still be possible; additional protection might be required.
   - As for Option 1, the stability of the monoliths on the bend in the secondary spillway require special attention. In this area, the dam axis is curved and with the transverse joints perpendicular to the axis, the joints flare open, i.e. there is no transfer of sliding resistance to adjoining monoliths.

c) The execution of the proposed Option 2 and 3 works, including the installation of the anchors, is considered viable. There is, however, uncertainty about the effectiveness of the anchors during operation under the applied loads (although less risk compared to Option 1), due to the close spacing of the anchors and the strength of the rock to provide sufficient anchor resistance. Further investigations are required to confirm the rock strength, for example installing a prototype anchor and testing it to determine its failure load.

   As for Option 1, access to the primary spillway crest would be difficult for the demolition work, but possible. The demolition is also viable but might take considerable time. The risk to construction and the safety of the dam would have to be managed, but the measures could be resolved in the detailed design stage.

d) Basis of design:

   i) The design assumptions are reasonable, but further work is required to better understand the concrete and foundation parameters, as discussed in Section 2.

ii) The design and acceptance criteria are in accordance with the latest ANCOLD and international practices.

iii) The methodologies used in the design are in accordance with the latest ANCOLD and international practices.

e) Options 2 and 3, based on the scope of works, would achieve risk positions below the ANCOLD life safety limit of tolerability. See also Section 6.6.

f) A suitable alternative to lowering the spillway crest level while maintaining the lowered crest level flood capacity include the use of spillway gates (e.g. Option 1b), fuse gates, or a fuse plug embankment at a suitable location.

The benefit of mechanical gates is that they could be used to pre-release stored water to provide flood storage space in the case of predicted high inflows, to regulate the outflows to maximise the capture and storage of floodwater, and to ensure the dam remains in a safe operating range. Once fully opened, they provide the full flood capacity of the lowered spillway sill level. The disadvantages are that the gates rely on human intervention for flood operation, they require regular maintenance and testing, and they add a risk due to potential for failure to operate on demand during a flood event, which could cause the dam to overtop and cause damage or even failure of the dam.

Fuse plug embankments provide the benefit of storing water during normal operating conditions, but also providing discharge capacity during flood events. The disadvantages are that they require regular maintenance and they could operate (breach) prematurely, causing a dambreak flood event that could put people at risk. Based on the topography around the dam, there does not appear to be a suitable location for a fuse plug embankment.

An alternative to mechanically operated gates is fuse gates, e.g. Hydroplus. The main benefit of this type of gate is that it does not require human intervention to operate (it relies purely on the equilibrium of static forces). This type of gate could be installed on the flat top of the lowered primary spillway and provide for a labyrinth crest that could discharge more flow than a straight crest before a gate is tipped. Once all the gates have tipped, the lowered spillway crest would remain, i.e. the same proposed shape and flood capacity as with no gates. The disadvantage is that they require maintenance, but much less frequent than mechanical gates, and they would need to be replaced once they have initiated.

4.6 Comments regarding design of Option 5 full decommissioning

SunWater has provided a summary of works required for Option 5, as shown in Table 3.

Table 3 Summary of full decommissioning option (provided by SunWater, January 2020)

Option	Storage Capacity	Key upgrades	Risk Improvement
5 Full Decommissioning	0 ML	■ Dewatering of the reservoir ■ Removal of the dam structure, outlet works and associated facilities ■ Removal/treatment of sediments which have accumulated in the reservoir ■ Rehabilitation and revegetation of the reservoir area	Dam failure risk eliminated

This option has not been developed to the same level as Options 1, 2 and 3. Based on the review of the records listed in Section 4.3 and the details prepared for the Preliminary Business Case, the following comments are made.

a) The scope of works would address dam safety deficiencies by eliminating the risks. It is however not clear to what extent the works would be decommissioned, and if there would be residual risk due to remaining works. According to the PBC, the decommissioning would involve a complete removal and a return to the pre-dam site. This seems over the top, as the objective should be to remove the works to the extent where there was no residual safety and environmental risk if no ongoing maintenance was carried out on the site. Some works, such as concrete works below natural ground level, could be left in place and buried. The key project risk would be the extent of the remediation required and the treatment of potential anoxic sediment in the bottom of the reservoir.

b) The decommissioning is viable from a dams engineering perspective. The impact on the economy of loss of the storage is beyond the scope of this Report but has been assessed separately by others.

c) The design of the decommissioning has not yet been undertaken. It seems unlikely that this option would go ahead, so the level of design at this stage is acceptable.

5 Comments on cost estimates

5.1 Introduction

This section presents comments on the cost estimates of Options 1, 2, 3 and 5.

The review was carried out by a specialist sub-consultant, Alan Rae Consulting. Alan has over 50 years of experience in the cost estimation of major infrastructure projects.

The cost estimations were benchmarked against recent cost estimates for the following dams:

- Eurobodalla Southern Storage (new dam for Eurobodalla Shire Council in NSW) in 2016/17
- Adelaide River Off-stream Water Storage (AROWS) (new dam in the Northern Territory) in 2019
- Decommissioning of Nicholson River Dam (East Gippsland Water in Victoria) in 2017

5.2 Records for review

Information on the cost estimations of the long-term options has been obtained from the records listed under "Phase 4: Cost Review" in the data screening schedule shown in Appendix A.

The cost estimates have been developed in various stages of the options development. Estimates for Options 1, 3 and 5 based on the preliminary designs prepared by GHD for the Preliminary Business Case, are shown in the following report:

- Paradise Dam Facility Strategy & Options Analysis, Reference 1560-01 Rev D, prepared by Project Support for GHD, February 2018 (Project Support 2018)

SunWater and GHD have since further developed the designs of Options 1 and 3 in more detail for the Detailed Business Case. The following cost estimates have been prepared for the further developed options:

- Paradise Dam Spillway Improvement Option 2[9], Estimate Report (draft), prepared by WT Partnership for GHD, August 2019 (WTP 2019a)
- Paradise Dam Spillway Improvement Option 3, Estimate Report (draft), prepared by WT Partnership for GHD, August 2019 (WTP 2019b)

The cost estimate for Option 2, the 5 m lowering of the FSL, is provided in the following recently supplied report:

- Paradise Dam Spillway Improvement Project Concept Design for Option 9[10] - 5 m Lowering, GHD, January 2020 (GHD 2020)

5.3 Comments regarding the cost estimations

5.3.1 Level of cost estimations

a) The level of costs estimates for each of the options has been reviewed.

b) Cost estimates for the preliminary designs of Options 1, 3 and 5 have been developed during the Preliminary Business Case as presented in the report by Project Support (2018). The estimates are very detailed given the level of design which they have been based on. The 2018 estimates

[9] Relabelled as Option 1 in this Report (as advised by Building Queensland)
[10] GHD's Option 9 was labelled Option 3C in the Draft Report and is Option 2 in this Report (as advised by Building Queensland)

lack details about the assumptions and construction methodologies they have been based on, but the details are commensurate with the level of design at the time.

New estimates have been developed after the further development of the options, as presented in WTP (2019a and 2019b). The estimates are more detailed, although the level of design is still at concept design stage and further investigations are required to inform the design. The level of cost estimates by WTP (2019) is much more detailed and provides more information on the assumed construction methodologies.

c) The only cost estimate for Option 5 is provided in Project Support (2018).

d) The recent cost estimate for Option 2 (GHD's Option 9) was based on the Project Support (2018) work for Option 3 by adjusting only the quantities, even though the design assumptions for Option 2 (e.g. shear strength) are now different to what was assumed for Option 3 in 2018.

e) Pursuant to the above, the diverse levels of cost estimates are problematic.

    i) **The Project Support (2018) estimates should only be used as an indicator of the comparative costs (i.e. for ranking the options); however, it should not be viewed as indicative of the expected project cost.** The question is whether the further investigations and any subsequent changes in the concept design after the 2018 cost estimate would affect the comparative costs.

    ii) More confidence could be placed on the WTP (2019a & b) estimates, given the further developed concept design and details about the cost estimates provided in their report. **However, it would be advisable not to rely too much on these estimates for budget planning purposes just because of the level of detail in the cost estimates. The cost estimate is only as reliable as the engineering design which it is based on.** More detailed engineering design is required to have confidence in the estimates as indicative of the project costs.

f) It would be advisable to review and update the cost estimates for all the options still under consideration, to ensure consistency in the comparison of the costs in the options assessment.

5.3.2 Proposed works methods and assumptions

a) The Project Support (2018) cost estimates provided limited information regarding assumptions made in determining the costs. WTP (2019a & b) provided more information in this regard.

b) The assumptions provided in WTP (2019a & b) are typical for this type of work; however, the assumptions and methodologies could vary between contractors and the WT assumptions might not be valid for the selected contractor. Early contractor involvement is required to gain more certainty about assumptions and their impact on the costs.

c) Given the level of engineering design at this stage, it is not practical to assess the sensitivity of the costs to variances in the assumptions, which should be advised by an experienced contractor.

5.3.3 Quantities and certainty about estimates

a) Given the available information and type of documents and files, it was not possible to review the quantities.

b) Given the demolition, concrete works and anchoring, there is a high degree of certainty in the quantity estimates. The main uncertainty would be related to concrete placed on sound or eroded rock where there are inaccuracies in the survey of the current surface.

5.3.4 Direct costs unit rates

a) The unit rates were reviewed against typical industry benchmarks and lower and upper limits defined with median values. This is presented in Appendix B.

b) The unit rates compare well with other industry benchmarked projects.

5.3.5 Indirect costs assumptions and indices

a) The indirect cost assumptions were reviewed along with the levels of contingency allowed in the costs.

b) The Project Support (2018) cost estimates provided no information on assumptions for indirect costs.

c) The WTP (2019a & b) assumptions are typical of the type of infrastructure involved.

d) The Reviewers consider that site overheads would be in the order of 25% (including supervision, miscellaneous plant and equipment, site accommodation, site services, small tools, testing of minor materials, site buildings, preparation of as-built information, establishment and demobilisation of the site and insurances). This is based on an estimate that the site would have a work force of about 200 accommodated on site or nearby town.

5.3.6 Level of contingencies

a) The level of contingencies is considered reasonable.

b) The Project Support (2018) cost estimates include an item of 10% for Unmeasured Work and later an item of 40% for Contingency; the former allowance is unnecessary given the latter.

5.3.7 General comments

a) The sensitivity to varying assumptions and rates is best analysed in a Monte Carlo simulation of the cost estimates using the lower and upper values of quantities, rates and mark ups.

b) It should be noted that escalation has not yet been applied to the Project Solutions (2018) estimates and it would be in the order of 3-4% per year.

c) It should also be noted that a contractor’s margin has not been included but would be 10-12%. This amount would include head office costs to operate the site.

d) It appears that there are some missing items in the Project Solutions (2018) estimates:

- All projects would have unforeseen costs arising from environmental issues on the site. These are unpredicted, so an allowance should be included.
- In Option 1, Material Extraction and Testing Facilities were not included as included in all other options.
- An item for a 24-month maintenance period should be included for all options.
- The concrete batching plant would be installed in the same location as the previous contract; it is considered that there would be potential savings in the re-establishment of the plant.

6 Comments on risk assessments

6.1 Introduction and risk criteria

This section presents the following:

- Assessment of the present risk and the risk reduction achieved with each option
- Review of the risks accounted for in the dam in its present state in terms of current and known failure modes.
- For each option, review of the mitigation measures included in the design, and the impact the risks mitigation measures have had on the risk profile, design scope and cost for the option.
- Review of the robustness of the risk identification, assessment and mitigation process and provide expert commentary on these.

The review has been assessed against the criteria presented in the ANCOLD Guidelines on Risk Assessment (2003).

The Reviewers did not participate in any risk workshops.

6.2 Records for review

Information on the risk assessment of the long-term options has been obtained from the records listed under "Phase 5: Risk Review" in the data screening schedule shown in Appendix A.

6.3 Comments regarding risk profile and failure modes of dam in present state

a) The potential failure modes and risk assessment as presented in the records listed in Section 6.2, were reviewed. The GHD (2019a, 2019b, 2019c, 2020) reports are considered a reasonable reflection of the current risks of the dam in its present state.

b) It must be noted that the risk analysis of concrete dams involves a degree of subjective failure probabilities, i.e. if different groups undertook the risk assessments, there could be some differences in the event trees and conditional probabilities depending of the views of the participants in the workshops.

6.4 Comments regarding impact of mitigation measures on risk profile

a) Comments on the mitigation measures are included in the design of Options 1, 2, 3 and 5, are included in Section 4.

b) Option 1 would reduce the risk to the level of the limit of tolerability, but not entirely below the limit line. The mitigation measures are thus **inadequate** to reduce the risks to below the Limit of Tolerability. As this option is essentially an incomplete solution, additional work is required to lower the risk to achieve a tolerable risk position below the limit line and to achieve the ALARP risk position. Option 1 has been modified in Options 1a and 1b, but the residual risk positions have not been demonstrated yet.

c) The mitigation measures included in Options 3 (10 m lowering of FSL) would result in a risk position close to two orders below the limit line. It is expected that the cost of further major risk reduction works might not be justified, and **this is likely the ALARP risk position**. Only small cost items could be added to reduce the risk further.

d) The mitigation measures included in Option 2 (5 m lowering of FSL) are adequate to reduce the risks to below the Limit of Tolerability and **this might be adequate to achieve the ALARP position**. As Option 2 results in a risk position less than an order below the line, it is expected than further work might be required to achieve the ALARP position, such as Option 4 (5-10 m lowering of FSL). However, this might not be the case and Option 2 could represent the ALARP position. Further investigations of risk reduction options are required to confirm this issue, but Options 2 and 3 could be considered “bookends” to find the optimal risk position.

e) The mitigation measures included in Option 5 (full decommissioning) are adequate to reduce the risks to below the Limit of Tolerability.

f) See also further comments in Section 6.6.

g) The latest FN-plots (GHD 2020) for the options are shown below.

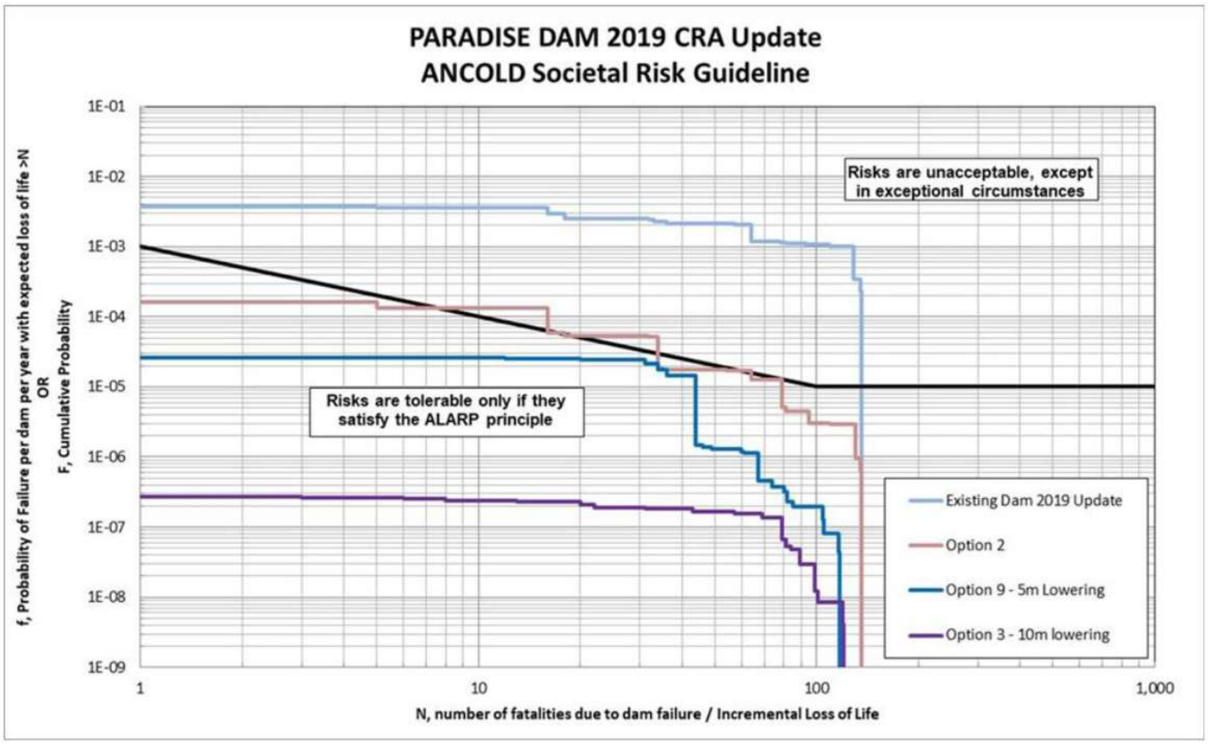

Figure 3 FN-plot for upgrade options (from GHD 2020)

Note, in Figure 3, Option 1 is labelled as Option 2, and Option 2 is labelled as Option 9.

6.5 Comments regarding risk assessment and mitigation process

a) The process for the risk identification, assessment and mitigation process as presented by SunWater (2016b) and GHD (2019a, 2019i, 2019p, 2020), is in accordance with ANCOLD guidelines and considered robust.

6.6 Comments regarding SunWater’s portfolio risk management

a) It is understood that SunWater has other dams with risk profiles still above the ANCOLD limit of tolerability. From a portfolio risk management perspective, SunWater may want to consider first lowering the risks at all the other dams to the level of the limit of tolerability, before undertaking further improvement works (with associated high costs) to achieve the ALARP position at any of the dams, including Paradise Dam. Although further work could be justified at a single dam based on an ALARP assessment, large expenses might be required for only small risk reductions to achieve the ALARP position at a single dam. Such expenses would achieve better value from an organisational risk exposure perspective, by funding risk reduction works at dams that have higher risk positions, especially if above the ANCOLD limit of tolerability.

7 Summary of findings

Table 4 below presents a summary of the key findings of this review that require further investigations to conclusively complete the options assessment.

Table 4 Key findings affecting the completion of the options assessment

Key findings	Commentary regarding findings
1. Despite the investigations and modelling completed to date, there are several uncertainties about the foundations regarding the geological structures, kinematic systems, deep-seated sliding, as well as the reliability and the effectiveness of the rock for anchoring due to the spacing of the anchors and the strength of the rock to provide sufficient anchor resistance.	**To address the uncertainties, it is suggested to:** ▪ **complete the current geotechnical and geological assessment of the foundations of the dam, including the development of a 3D geological model, and** ▪ **undertake prototype anchoring trials to confirm foundation capacity regarding the options that include anchors.** It should be noted that, although the 3D model might address the uncertainties, it is expected that further targeted investigations might be required to complete the geological model for the feasibility study and the detailed design of the selected option. This aspect should be reviewed after completion and interpretation of the 3D geological model.
2. It can be assumed that, for the options assessment, all the lift joints are treated as unbonded. The original design assumptions regarding lift joint shear strength now appear non-conservative and it is not clear whether the original design assumptions were further investigated and confirmed through testing at the time of construction, which should have been done.	**To address the uncertainties, it is suggested to undertake further core sampling and testing of the RCC (noting that this would need to be done at the same time as the essential works in the primary spillway).** Horizontal and vertical core drilling would improve the understanding of the extent of the unbonded lift joints and provide additional samples for testing to confirm the lift joint shear strength. The holes should be located to supplement the previous investigations to achieve a representative spread of sample points across the entire length and height of the dam. It would be beneficial to inspect any existing open drill holes in the RCC from previous investigations. From the core drilling investigations, select additional samples for testing to increase confidence in the test results. Further testing should consider the effect of low cementitious RCC on the accuracy of the shear testing when one sample is used for multiples tests, as well as the effect of the honeycomb concrete where present against a lift joints.
3. The design of the long-term options assumed a base condition of the dam prior to the Essential Works (except for Option 1b). The Essential Works might have a significant impact on the long-term works options assessment and selection process and therefore the selection of the preferred option to take forward.	**To address the uncertainties, it is suggested to complete further development of preliminary designs and cost estimates for the options using the new starting point (base case) (the primary spillway level at the completion of the Essential Works).**

Other findings of the review are summarised below.

a) A Construction Report was never compiled, even though records of quality assurance testing and control undertaken during construction are available. The Construction Report would have been invaluable to understanding the construction practices and the existing placed RCC properties. It is suggested that SunWater consider the following:

- Assess the availability of information to compile a Construction Report.
- Compile a Construction Report using the available site records and the records of quality assurance testing and control undertaken during construction, including liaison with the original designers and constructors.
- Expand the report to include any subsequent upgrade and remedial works.

b) The effect of using the lower bound and mean densities combined with lower bound shear strength, combines two uncertainties and could result in overly conservative results. It is suggested that the core drilling investigations include additional samples for density testing.

c) Option 1 is feasible and would reduce the risk to the limit of tolerability, but the mitigation measures are inadequate to reduce the risks to below the Limit of Tolerability, even assuming the foundations are adequate for the anchoring. To retain the existing FSL, additional work, such as Options 1a and 1b, should be considered to lower the risk further. Further assessments might include:

- Confirming the risk position of Option 1a.
- Reviewing the protection of the left abutment downstream toe against overtopping flows.
- Based on the further geological modelling, reviewing the erosion potential downstream of the extended apron – additional protection might be required.
- Based on the CFD modelling, reviewing the secondary spillway return channel hydraulics and erosion potential.
- Reviewing the stability of the monoliths on the bend in the secondary spillway.
- Assessing the effectiveness of the anchors during operation under the applied loads, as discussed under Finding 1 in Table 4.

d) Options 2, 3 (including 3a) and 4 are feasible and based on the level of lowering, might achieve the ALARP risk position. The mitigation measures included in Option 2 are adequate to reduce the risks to below the Limit of Tolerability and this might be adequate to achieve the ALARP position. As the risk position less than an order below the line, it is expected than further work would likely be required to achieve the ALARP position.

   The mitigation measures included in Options 3 and 3a would result in a risk position close to two orders below the limit line and this might be the ALARP risk position. Only small cost items could be added to reduce the risk further.

   Further assessments might include:

- Confirming the extent of lowering (5 to 10 m) that would achieve the ALARP risk position.
- Based on the further geological modelling, reviewing the erosion potential downstream of the extended apron – additional protection might be required.
- Reviewing the stability of the monoliths on the bend in the secondary spillway.
- Assessing the effectiveness of the anchors during operation under the applied loads, as discussed under Finding 1 in Table 4.

e) Option 5 is feasible and would achieve the ALARP risk position.

f) The cost estimates should only be used as an indicator of the comparative costs (i.e. for ranking the options); however, it should not be viewed as indicative of the expected project cost.

8 References

Project related reference are listed in Appendix A

ANCOLD (2003), ANCOLD Guidelines on Risk Assessment, Australian National Committee on Large Dams

ANCOLD (2013), ANCOLD Guidelines on Design Criteria for Concrete Gravity Dams, Australian National Committee on Large Dams

EPRI (1992), Uplift Pressures, Shear Strengths, and Tensile Strengths for Stability Analysis of Concrete Gravity Dams, Prepared by Stone & Webster Engineering Corporation, Denver, Colorado, for the Electric Power Research Institute, Report No. EPRI TR-100345, Volume 1, August 1992

Herweynen et al (2004), Burnett RCC dam design - an innovative approach to site specific conditions, Herweynen, R., Griggs, T., Schrader, E. and Starr, D., Proceedings of ANCOLD Conference 2004, Melbourne

Herweynen & Griggs (2006), Burnett RCC dam - an innovative approach to floods, Herweynen, R. and Griggs T., Entura, ICOLD 22nd Congress on Large Dams, Q. 84 - R. 18, pp. 279-297

Herweynen & Griggs (2012), Unique Challenges Influencing the Design and Construction of Three Recent Australian RCC Dams, Herweynen, R. and Griggs, T., Entura, Proceedings of the ICOLD International Symposium on Dams for a Changing World, Kyoto, 2012

Lopez et al (2005), RCC construction and quality control for Burnett Dam, Lopez, J., Griggs, T., Montalvo, R., Herweynen, R. and Schrader, E., Proceedings of ANCOLD Conference 2005, Perth

Appendix A
Data screening

Legend for assessing quality of information:

(green)	Latest version, still valid, can be used
(amber)	Not the latest version, parts still valid, use with caution knowing what has been superseded
(red)	Superseded, no longer valid, disregard

ID	Category	Document name	By	Date	Reference	Status and comments	Historical information				Current condition and risk position				Phase 2 Dam Safety Modelling Review	Phase 3: Dam Engineering Review of Design of 5 Options																		Phase 4 Cost Review	Phase 5 Risk Review		Expert Input	
							Original design	Original construction	Flood repairs design	Flood repairs construction	Comprehensive Inspection Report	Intermediate Inspection Report	Dams Safety Review Report	Comprehensive Risk Assessment	Review of SunWater's Dam Safety Modelling process	Seismic hazard assessment	Hydrology study	Failure impact assessment	Geological and geotechnical	Scour investigation & modelling	Concrete materials investigations	Spillway hydraulic modelling	Outlet works	Dam wall stability assessments	Reinforced concrete structures	Survey	Risk and Safety in Design	**Option 1:** Full upgrade without lowering the spillway	**Option 2:** Permanent lowering of spillway crest level by 5 m	**Option 3:** Permanent lowering of spillway crest level by 10 m	**Option 4:** Permanent lowering of spillway crest level by 5 - 10 m	**Option 5:** Full Decommissioning	SunWater independent peer review	Cost estimations	Comprehensive Risk Assessment	Comprehensive Risk Assessment (updated for Options Assessment)	For Alan Rae	For Ted Warren
1	**Preliminary Business Case**																																					
2		**Preliminary Business Case, Paradise Dam - Facility Strategy and Options Analysis Project (Final)**	SunWater	Jun-18	SunWater (2018b)	Caution, superseded strength parameters used																					●										●	●
3		App A: PBC Supporting Technical and Environmental Review				Not included here, but see ID 8																																
4		App B: Risk Register																									○											
5		App C: Sun Water Enterprise Wide Risk Criteria																																				
6		App D: Procurement Strategy Advantages and Disadvantages																																				
7		App E: DBC Delivery Schedule																																				
8		**Paradise Dam Facility Strategy & Options Analysis, Preliminary Business Case - Supporting Technical and Environmental Review (Final)**	GHD	Mar-18	GHD (2018a)	Caution; some information have been superseded	●	●	●		●																	●		●		●		●			●	●
9		App A: SunWater Drawings of Primary and Secondary Spillway Upgrade Works																																				
10		App B: Concept Sketches																																				
11		App C: Drawings of Left Abutment Shotcrete Protection Works																																				
12		App D: Marked-up Sketches of Outlet Works Remediation and Modification																																				
13		App E: Report on Review of Capital Cost Estimate	Project Support	Feb-18		See also ID 336-352																												○				
14		App F: Report on Review of Alternative Water Supply Strategies																																				
15		**Pardise Dam Comprehensive Risk Assessment, Revised Report 2016 (Final)**	SunWater	Jun-16	SunWater (2016b)	Caution, parts superseded								●	●		●	●	●			●		●								●	●		●			●
16		App A: SunWater's Approach to Dam Safety Upgrades	SunWater	Aug-10		Superseded									○																							
17		App B: Upgrade Conceptual Designs and Dam Drawings	GHD			Superseded																																
18		App C: Inundation Plots				Superseded												○																				
19		App D: Event trees				Superseded																																
20		App E: PLL Calculations				Superseded												○																				
21		App F: F-N Plots				Superseded																																
22		App G: Spillway Capacity				Superseded																																
23		App H: Upgrade Cost Estimates				Superseded																																
24		App I: ALARP Calculations				Superseded																																
25		App J: 2014 Comprehensive Dam Safety Inspection Recommendations	SunWater	Jul-05	SunWater (2014a)	OK to use, still valid					○																											●
26		App K: Peer Review Comments	Bell et al	Dec-15		Note of peer review comments																											○					●
27		App L: Paths to Failure				Superseded																																
28		App M: Environmental Risk Assessment				Superseded																																
29		App N: Severity of Damages and Losses Matrix				Superseded												○																				
30		App O: Notes from Action Plan to Close out Phase 3 works, Paradise Dam CRA Workshops 27 - 28-8-2015 & 26-9-2014 & Paradise Dam CRA update notes 6 & 7 Nov 2014				Superseded																																

ID	Category	Document name	By	Date	Reference	Status and comments	Historical information				Current condition and risk position				Phase 2 Dam Safety Modelling Review	Phase 3: Dam Engineering Review of Design of 5 Options																		Phase 4 Cost Review	Phase 5 Risk Review		Expert Input	
							Original design	Original construction	Flood repairs design	Flood repairs construction	Comprehensive Inspection Report	Intermediate Inspection Report	Dams Safety Review Report	Comprehensive Risk Assessment	Review of SunWater's Dam Safety Modelling process	Seismic hazard assessment	Hydrology study	Failure impact assessment	Geological and geotechnical	Scour investigation & modelling	Concrete materials investigations	Spillway hydraulic modelling	Outlet works	Dam wall stability assessments	Reinforced concrete structures	Survey	Risk and Safety in Design	**Option 1:** Full upgrade without lowering the spillway	**Option 2:** Permanent lowering of spillway crest level by 5 m	**Option 3:** Permanent lowering of spillway crest level by 10 m	**Option 4:** Permanent lowering of spillway crest level by 5 - 10 m	**Option 5:** Full Decommissioning	SunWater independent peer review	Cost estimations	Comprehensive Risk Assessment	Comprehensive Risk Assessment (updated for Options Assessment)	For Alan Rae	For Ted Warren
31		App P: Paradise Dam Decommissioning Report – Revision B	Project Support	Jun-13		Superseded																																
32		App Q: Summary of Stability Analysis Results	AECOM	Apr-16		Same as ID 61 but different date																		○														●
33		**Paradise Dam Failure Impact Assessment, Hydrology, Dambreak and Consequence Assessment Report (Draft B)**	HARC	Dec-17		Superseded											●	●																				
34		**Paradise Dam (Burnett) Mini Hydro Operation Manual (Rev B)**	Tyco Tamar	Jul-14	Tyco Tamar (2014)	OK to use, still valid																	●															
35		**Paradise Dam - Dam Safety Review (Final)**	SunWater	Oct-14	SunWater (2014b)	Superseded																																
36		App A: PATHS TO FAILURE	Not included			Superseded																																
37		App B: DAM BREAK ANALYSIS - INUNDATION PLANS (2004 STUDY)	Not included			Superseded																																
38		App C: SEISMOLOGY REPORT	Not included			Superseded																																
39		App D: BURNETT RIVER DAM 2004 FLOOD HYDROLOGY REPORT	Not included			Superseded																																
40		App E: PLOTS OF INSTRUMENTATION DATA	Not included			Superseded																																
41		App F: POST FLOOD OF RECORD COMPREHENSIVE DAM SAFETY INSPECTION, OCTOBER 2013	Not included			Superseded																																
42		App G: REPORT ON GEOTECHNICAL INVESTIGATIONS PARADISE DAM 2013-2014	Not included			Superseded																																
43		App H: STABILITY ANALYSIS REVIEW REPORT	Not included			Superseded																																
44		App I: DAM SAFETY STRUCTURAL ASSESSMENTS REPORT AND PEER REVIEW REPORT	Not included			Superseded																																
45		App J: OPERATION AND MAINTENANCE REVIEW – IRRIGATION VALVES AND ENVIRONMENTAL OUTLET GATES – DAM SAFETY ISSUES	Not included			Superseded																																
46		App K: REPORT ON TESTING UNDERTAKEN ON 11 MAR 2010 ON THE ENVIRONMENTAL RELEASE GATE	Not included			Superseded																																
47		App L: DRAWINGS	Not included			Superseded																																
48		**Paradise Dam, Review of Geological Data, Geological Model Development and Scoping of Investigations (Final)**	GHD	Jun-18	GHD (2018b)	OK to use, still valid													●																			●
49		**Paradise Dam Geological Model 20180608.lfview**	GHD	Jun-18	GHD (2018b)	Leapfrog file, need software to open													●																			●
50		**Paradise Dam Leapfrog Model Transmittal and Explanatory Notes (memorandum)**	GHD	Jun-18	GHD (2018b)	OK to use, still valid													●																			●
51		**Paradise dam HD.wmv**	GHD	Jun-18	GHD (2018b)	OK to use, still valid													●																			●
52		**Paradise Dam, Hydraulic Modelling Review and CFD Model Development (Final)**	GHD	Jun-18	GHD (2018c)	OK to use, still valid																●						●		●								●
53		**Paradise Dam_ALARP Calculations_updated.XLSX**		Unknown		OK to use, still valid								●																					●			
54		**Summary FN.xlsx**		Unknown		OK to use, still valid								●																					●			
55		**Paradise Dam - Dam Safety Review - Revised Report 2016 (Final)**	SunWater	Apr-16	SunWater (2016a)	OK to use, still valid	●		●		●		●	●		●	●	●	●	●	●	●	●	●	●								●		●			●
56		App A: PATHS TO FAILURE	SunWater											○																								
57		App B: DAM BREAK ANALYSIS - INUNDATION PLANS	GHD	Sep-14	GHD (2014)													○																				
58		App C: SEISMOLOGY REPORT	SRC	Mar-14		Superseded										○																						
59		App D: PLOTS OF INSTRUMENTATION DATA	SunWater																																			

ID	Category	Document name	By	Date	Reference	Status and comments	Historical information				Current condition and risk position				Phase 2 Dam Safety Modelling Review	Phase 3: Dam Engineering Review of Design of 5 Options																		Phase 4 Cost Review	Phase 5 Risk Review		Expert Input	
							Original design	Original construction	Flood repairs design	Flood repairs construction	Comprehensive Inspection Report	Intermediate Inspection Report	Dams Safety Review Report	Comprehensive Risk Assessment	Review of SunWater's Dam Safety Modelling process	Seismic hazard assessment	Hydrology study	Failure impact assessment	Geological and geotechnical	Scour investigation & modelling	Concrete materials investigations	Spillway hydraulic modelling	Outlet works	Dam wall stability assessments	Reinforced concrete structures	Survey	Risk and Safety in Design	**Option 1:** Full upgrade without lowering the spillway	**Option 2:** Permanent lowering of spillway crest level by 5 m	**Option 3:** Permanent lowering of spillway crest level by 10 m	**Option 4:** Permanent lowering of spillway crest level by 5 - 10 m	**Option 5:** Full Decommissioning	SunWater independent peer review	Cost estimations	Comprehensive Risk Assessment	Comprehensive Risk Assessment (updated for Options Assessment)	For Alan Rae	For Ted Warren
60		App E: POST FLOOD OF RECORD COMPREHENSIVE DAM SAFETY INSPECTION, OCTOBER 2013	SunWater	Oct-13	SunWater (2013)				○		○																											
61		App F: STABILITY ASSESSMENT FOR PARADISE DAM- TECHNICAL MEMORANDUM BY AECOM, APRIL 2016	AECOM	Apr-16	AECOM (2016)	Same as ID 32 but different date																		○														
62		App G: DAM SAFETY STRUCTURAL ASSESSMENT REPORTS	Hatch	Jan-14	Hatch (2014)																			○	○								○					
63		App H: OPERATION AND MAINTENANCE REVIEW – IRRIGATION VALVES AND ENVIRONMENTAL OUTLET GATES – DAM SAFETY ISSUES	SunWater	Oct-14																			○															
64		App I: MANLY HYDRAULICS LABORATORY REPORTS	Public Works	Feb-16	Public Works (2016)																	○																
65		App J: AQUAVISION ENGINEERING SCOUR MODEL REPORT	AquaVision	Jan-16	AquaVision (2016)															○																		
66		App K: REPORT ON TESTING UNDERTAKEN ON 11 MAR 2010 ON THE ENVIRONMENTAL RELEASE GATE	Entura	Mar-10	Entura (2010)																		○															
67		App L: DRAWINGS	SunWater																																			
68	**Detailed Business Case**																																					
69	01 Engineering\01 Drawings	**Paradise Dam Option 2 Drawings (Draft)**	GHD	Jul-19		Replaced																						●										
70		**Paradise Dam Option 3 Drawings (Draft)**	GHD	Jul-19		Replaced																								●								
71	01 Engineering\02 Reports	**Paradise Dam Seismic Hazard Assessment (Final)**	SRC	Feb-19	SRC (2019)	Latest										●																						●
72		**Paradise Dam, Outlet Conduit Capacity Assessment Under Earthquake Loading (Draft)**	Super-structures	Mar-19		Superseded																	●		●													
73		**Dam stability analyses (Final) (memorandum)**	GHD	Dec-18		Superseded																		●				●		●								
74		**Dam stability analyses (Revision 1) (Final) (memorandum)**	GHD	Sep-19		Superseded																		●				●		●								
75		**Review of AECOM PLAXIS Model and Option 2 Assessment (Draft) (memorandum)**	GHD	Feb-19	GHD (2019b)																			●				●										●
76		**Summary of Option 3 Assessment (Draft) (memorandum)**	GHD	Apr-19	GHD (2019c)																			●						●								●
77		**Review of RCC shear strengths (Final) (memorandum)**	GHD	Sep-19		Superseded															●																	
78		**Intake Tower Seismic Assessment (Draft) (memorandum)**	GHD	May-19	GHD (2019d)																				●													●
79		**Paradise Dam Spillway Improvement - Interim Lowering Detailed Design Report (Draft)**	GHD	Jul-19	GHD (2019i)	Reflecting 5 m lowering																							●									●
80		**Paradise Dam Spillway Improvement - Preliminary Design, CFD Modelling of Option 2 Spillway Arrangement (Draft)**	GHD	May-19		Superseded																●						●										
81		**Paradise Dam Spillway Improvement - Preliminary Design, CFD Modelling of Option 3 Spillway Arrangement (Draft)**	GHD	May-19		Superseded																●								●								
82		**Paradise Dam Spillway Improvement Project, Preliminary Design Report (Draft)**	GHD	Jul-19	GHD (2019j)	Latest								●							●	●			●			●		●					●		●	●
83		App B - FMA review	GHD	Jul-19										○																					○		○	○
84		App C - Comments on Specific Failure Modes from Initial CRA Review												○																					○		○	○
85		App D - Photographs of 2014 horizontal core holes																			○																○	○
86		App E - 2015 RCC Shear Strength Laboratory Test Certificates																			○																○	○
87		App F - Comparison Of RAAX Imagery And Core Photographs																			○																○	○
88		App G - Paradise Dam Option 2 Drawings (draft).pdf	GHD	Jul-19		Same as ID 69																						○									○	○
89		App H - Paradise Dam Spillway Improvement - Preliminary Design, CFD Modelling of Option 2 Spillway Arrangement (Draft)	GHD	May-19		Same as ID 80																○						○									○	○
90		App I - Paradise Dam, Outlet Conduit Capacity Assessment Under Earthquake Loading (Draft)	Super-structures	Mar-19	Superstructures (2019)	Same as ID 72																			○												○	○

ID	Category	Document name	By	Date	Reference	Status and comments	Historical information				Current condition and risk position				Phase 2 Dam Safety Modelling Review	Phase 3: Dam Engineering Review of Design of 5 Options																		Phase 4 Cost Review	Phase 5 Risk Review		Expert Input	
							Original design	Original construction	Flood repairs design	Flood repairs construction	Comprehensive Inspection Report	Intermediate Inspection Report	Dams Safety Review Report	Comprehensive Risk Assessment	Review of SunWater's Dam Safety Modelling process	Seismic hazard assessment	Hydrology study	Failure impact assessment	Geological and geotechnical	Scour investigation & modelling	Concrete materials investigations	Spillway hydraulic modelling	Outlet works	Dam wall stability assessments	Reinforced concrete structures	Survey	Risk and Safety in Design	**Option 1:** Full upgrade without lowering the spillway	**Option 2:** Permanent lowering of spillway crest level by 5 m	**Option 3:** Permanent lowering of spillway crest level by 10 m	**Option 4:** Permanent lowering of spillway crest level by 5 - 10 m	**Option 5:** Full Decommissioning	SunWater independent peer review	Cost estimations	Comprehensive Risk Assessment	Comprehensive Risk Assessment (updated for Options Assessment)	For Alan Rae	For Ted Warren
91		App J - Paradise Dam Option 3 Drawings (Draft)	GHD	Jul-19		Same as ID 70																							○							○	○
92		App K - Paradise Dam Spillway Improvement - Preliminary Design, CFD Modelling of Option 3 Spillway Arrangement (Draft)	GHD	May-19		Same as ID 81																○							○							○	○
93		App L - Summary of Constructability Review	Not included																																		
94		App M - Report on Cost Estimate	Not included																																		
95	01 Engineering\03 Models	**41-32235-DM-SPILLWAY STRUCTURE_OPTION_3 - DRAFT 20190722.nwd**																																			
96		**41-32235-DM-SPILLWAY STRUCTURE_OPTION_2 - DRAFT 20190722.nwd**																																			
97	02 Risk Assessment	**Paradise Dam - Risk Assessment Update for Option 2 and 3 with PLAXIS results (Draft) (memorandum)**	GHD	May-19	GHD (2019e)	Latest																						●		●						●		●
98		**HSE040 Safety in Design Risk Assessment**	GHD	Nov-18	GHD (2018d)																						●											
99		**Paradise Dam Spillway Improvement - Preliminary Design, Update of Comprehensive Risk Assessment (Draft)**	GHD	Jan-19	GHD (2019a)	Replaces ID 15								●																					●			●
100		App B – Stability Analysis Results from SunWater (2016b)				From ID 61 in ID 55																																
101		App C – Extract from SunWater (2016a) on Event Tree Logic	Not included																																		
102		**Paradise Dam Traffic Light Assessment (Draft)**	GHD	Oct-19	GHD (2019m)																																
103		**Paradise Dam Failure Impact Assessment, Hydrology, Dambreak Modelling and Life Loss Assessment Report (Final) (Version 1)**	HARC	Jun-19	HARC (2019)	Latest											●	●																				
104	03 Geotech\01 2019 Investigation	**Paradise Dam Improvement Project, DRAFT Geotechnical Investigation Factual Report**	SMEC	Aug-19	SMEC (2019)	After ID 117													●		●																	●
105		App A - SMEC explanatory notes of abbreviations and terms																																			
106		App B - Drawings																																			
107		App C - Borehole Logs																																			
108		App D - Horizontal Concrete Core Logs																																			
109		App E - Laboratory Certificates	GHD	Aug-19																																	
110		App F - Borehole Imaging Results (Televiewer)																																			
111		App G - Water Pressure Test Results (Packers)																																			
112		App H - Downhole Gamma-Gamma Results																																			
113		App I - Geological Mapping Data																																			
114		App J - RCC Digital Data																																			
115		App K - Core Photos Digital Data																																			
116		App L - Geophysical Report																																			
117	03 Geotech\02 Geotechnical Model Report May 2019	**Paradise Dam Spillway Improvement Project, Paradise Dam Geotechnical Model Report (Final)**	GHD	May-19	GHD (2019f)	Note, not updated with ID 104													●																			●
118	03 Geotech\03 BDA 2005-2006 drilling	**Preliminary Report - RCC Coring at Paradise Dam.pdf**	BDA	2005-06	BDA (2006)	RCC investigation															●																	●
		Several Excel and PowerPoint files on concrete core drilling	BDA	2005-06																	●																	
119	04 Survey	**Paradise Dam - Survey - Tif - 20 Feb 2019**	NorthGroup	Feb-19	NorthGroup (2019a)																					●												
120		**Paraidse Dam - Survey Contour Plan and Aerial Photo - 20 Feb 2019.pdf**	NorthGroup	Feb-19	NorthGroup (2019b)																					●												
121		**103642-1902#005rev0 (ECW conversion)**	NorthGroup	Feb-19	NorthGroup (2019c)																																
122	**Existing Dam Drawings**						●	●	●	●																												●
123		226891 - FLOATING BARRIER GENERAL ARRANGEMENT.pdf	BDA	2004-05			○	○																														
124		227625 - GENERAL ARRANGEMENT.pdf	BDA	2004-05			○	○																														
125		242292-A - RECTIFICATION WORKS - SITE PLAN.pdf	BDA	2004-05			○	○																														
126		242293-A - RECTIFICATION WORKS - OUTLET WORKS - SITE PLAN.pdf	BDA	2004-05			○	○																														
127		243025-A - LOCALITY PLAN.pdf	BDA	2004-05			○	○																														
128		245862-0 - MECHANICAL AND HYDRAULIC DRAWING REGISTER.pdf	BDA	2004-05			○	○																														

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129	Folder	ABUTMENTS AND SPILLWAY	BDA	2004-05			○	○																														
130	Folder	CONSTRUCTION FACILITIES	BDA	2004-05			○	○																														
131	Folder	DAM IMPROVEMENT PROJECT STAGE 2 (2017)	GHD	2017					○	○																												
132	Folder	ELECTRICAL SERVICES	BDA	2004-05			○	○																														
133	Folder	ENVIRONMENTAL MANAGEMENT	BDA	2004-05			○	○																														
134	Folder	FISHWAY	BDA	2004-05			○	○																														
135	Folder	FISHWAY VALVE ROOM	BDA	2004-05			○	○																														
136	Folder	FLOOD REPAIR 2013	SunWater	2013					○	○																												
137	Folder	FOUNDATIONS	BDA	2004-05			○	○																														
138	Folder	GENERAL	BDA	2004-05			○	○																														
139	Folder	INSTRUMENTATION	BDA	2004-05			○	○																														
140	Folder	INVESTIGATIONS	BDA	2004-05			○	○																														
141	Folder	MINI HYDRO	BDA	2004-05			○	○																														
142	Folder	OUTLET WORKS	BDA	2004-05			○	○																														
143	**BDA Design Report**																																					
144	01 Detail Design Report	**Report in several Word files and PDFs**	BDA	Jul-04	BDA (2004)		●	●																														●
145		PRODUCTION-#545980-v1-Burnett_River_Dam_Detail_Design_Report_July_2004_-_Table_of_Contents.DOC	BDA	Jul-04	BDA (2004)	TOC	○	○																														
146		PRODUCTION-#545985-v1-Burnett_River_Dam_Detail_Design_Report_July_2004_-_Executive_Summary.DOC	BDA	Jul-04	BDA (2004)	Executive Summary	○	○																														
147		PRODUCTION-#545986-v1-Burnett River Dam Detail Design Report July 2004 - Section 1 Introduction.DOC	BDA	Jul-04	BDA (2004)	Section 1	○	○																														
148		PRODUCTION-#545988-v1-Burnett River Dam Detail Design Report July 2004 - Section 2 Geology and Geotechnical Design.DOC	BDA	Jul-04	BDA (2004)	Section 2	○	○																														
149		PRODUCTION-#545990-v1-Burnett River Dam Detail Design Report July 2004 - Section 3 Hydrology.DOC	BDA	Jul-04	BDA (2004)	Section 3	○	○																														
150		PRODUCTION-#545991-v1-Burnett River Dam Detail Design Report July 2004 - Section 4 Hydraulic Design.DOC	BDA	Jul-04	BDA (2004)	Section 4	○	○																														
151		PRODUCTION-#545997-v1-Burnett River Dam Detail Design Report July 2004 - Section 5 Dam.DOC	BDA	Jul-04	BDA (2004)	Section 5	○	○																														
152		PRODUCTION-#545999-v1-Burnett River Dam Detail Design Report July 2004 - Section 6 RCC Design.DOC	BDA	Jul-04	BDA (2004)	Section 6	○	○																														
153		PRODUCTION-#546000-v1-Burnett River Dam Detail Design Report July 2004 - Section 7 Outlet Works.DOC	BDA	Jul-04	BDA (2004)	Section 7	○	○																														
154		PRODUCTION-#546001-v1-Burnett River Dam Detail Design Report July 2004 - Section 8 Mechanical Works.DOC	BDA	Jul-04	BDA (2004)	Section 8	○	○																														
155		PRODUCTION-#546003-v1-Burnett River Dam Detail Design Report July 2004 - Section 9 Electrical Works.DOC	BDA	Jul-04	BDA (2004)	Section 9	○	○																														
156		PRODUCTION-#546004-v1-Burnett River Dam Detail Design Report July 2004 - Section 10 Fishway.DOC	BDA	Jul-04	BDA (2004)	Section 10	○	○																														
157		PRODUCTION-#546005-v1-Burnett River Dam Detail Design Report July 2004 - Section 11 Infrastructure.DOC	BDA	Jul-04	BDA (2004)	Section 11	○	○																														
158		PRODUCTION-#546006-v1-Burnett River Dam Detail Design Report July 2004 - Section 12 Recreational Facilities.DOC	BDA	Jul-04	BDA (2004)	Section 12	○	○																														
160		PRODUCTION-#800217-v1-Burnett River Dam Detail Design Report July 2004 - Appendix A Hydrology and Sediment Load Studies.PDF	BDA	Jul-04	BDA (2004)	App A	○	○																														

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178		PRODUCTION-#829348-v1-Burnett River Dam Detail Design Report July 2004 - Appendix B Hydraulic Dambreak Model for Emergency Action Plan and Hazard Category Reassessme.PDF	BDA	Jul-04	BDA (2004)	App B	○	○																														
162		PRODUCTION-#800410-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report.PDF	BDA	Jul-04	BDA (2004)	App C	○	○																														
161		PRODUCTION-#800258-v1-Burnett River Dam Detail Design Report July 2004 - Appendix D Hydraulic Model Study Report for the Dam_ Outlet Works and Fishway.PDF	BDA	Jul-04	BDA (2004)	App D	○	○																														
170		PRODUCTION-#800421-v1-Burnett River Dam Detail Design Report July 2004 - Appendix E RCC Material Investigation and Testing Report.PDF	BDA	Jul-04	BDA (2004)	App E	○	○																														
171		PRODUCTION-#800448-v1-Burnett River Dam Detail Design Report July 2004 - Appendix F Environmental and Regulatory Approvals.PDF	BDA	Jul-04	BDA (2004)	App F	○	○																														
172		PRODUCTION-#800449-v1-Burnett River Dam Detail Design Report July 2004 - Appendix G Emergency Action Plan.PDF	BDA	Jul-04	BDA (2004)	App G	○	○																														
176		PRODUCTION-#800669-v1-Burnett River Dam Detail Design Report July 2004 - Appendix H RCC Cavitation and Erosion Resistance (Publications).PDF	BDA	Jul-04	BDA (2004)	App H	○	○																														
177		PRODUCTION-#800773-v1-Burnett River Dam Detail Design Report July 2004 - Appendix I CARPI Membrane (Product Research).PDF	BDA	Jul-04	BDA (2004)	App I	○	○																														
159		PRODUCTION-#796455-v1-Burnett River Dam Detail Design Report July 2004 - Appendix K Results of Dam Stability Analysis.PDF	BDA	Jul-04	BDA (2004)	App K	○	○																														
168		PRODUCTION-#800417-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix A MRD Borehole Logs_ Test Pit Logs_ Seismic.PDF	BDA	Jul-04	BDA (2004)	App C - App A	○	○																														
169		PRODUCTION-#800419-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix B Golder Borehole Logs_ Test Pit Logs (Fina.PDF	BDA	Jul-04	BDA (2004)	App C - App B	○	○																														
163		PRODUCTION-#800411-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix C Contact Mapping.PDF	BDA	Jul-04	BDA (2004)	App C - App C	○	○																														
164		PRODUCTION-#800412-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix D Foundation Strength Parameters – Primary .pdf	BDA	Jul-04	BDA (2004)	App C - App D	○	○																														
165		PRODUCTION-#800413-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix E Laboratory Tests (Preliminary Design).PDF	BDA	Jul-04	BDA (2004)	App C - App E	○	○																														
166		PRODUCTION-#800414-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix F Foundation Strength Parameters – Secondar.pdf	BDA	Jul-04	BDA (2004)	App C - App F	○	○																														
167		PRODUCTION-#800415-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix G Laboratory Tests (Final Design).PDF	BDA	Jul-04	BDA (2004)	App C - App G	○	○																														
173		PRODUCTION-#800629-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix H Procedures for Foundation Inspection Mapp.PDF	BDA	Jul-04	BDA (2004)	App C - App H	○	○																														

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174		PRODUCTION-#800630-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix I Excavation Stability.PDF	BDA	Jul-04	BDA (2004)	App C - App I	○	○																															
175		PRODUCTION-#800631-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix J Seepage and Piping Control.PDF	BDA	Jul-04	BDA (2004)	App C - App J	○	○																															
179		PRODUCTION-#829354-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix K Infrastructure.PDF	BDA	Jul-04	BDA (2004)	App C - App K	○	○																															
180		PRODUCTION-#829356-v1-Burnett River Dam Detail Design Report July 2004 - Appendix C Geotechnical Design Report - Appendix L Important Information about your Geotechn.PDF	BDA	Jul-04	BDA (2004)	App C - App L	○	○																															
181	02 Final Design Report	**Burnett River Dam - Final Design Report (Final)**	BDA	Nov-05	BDA (2005)	Full report and appendices	●	●																															●
182	03 RCC Specification	**Roller Compacted Concrete Specification**			BDA (2003)		●	●																															●
183	04 Ernie S Construction Advice						●	●																															●
184		60kg Mix Thermal Results 20040527.pdf					○	○																															
185		Aggregate Gradation- 20040211.pdf					○	○																															
186		Aggregate Graduation and Handling July- August 20040730.pdf					○	○																															
187		Aggregate Production Rate 20040527.pdf					○	○																															
188		Aggregate Quantity 20050614.pdf					○	○																															
189		Aggregate source rock 20040421.pdf					○	○																															
190		Aggregate source rock 20040422.pdf					○	○																															
191		ANCOLD paper20050917.pdf					○	○																															
192		Bedding - Even More Comment 20040923.pdf					○	○																															
193		Bedding Fillet at Panels20040924.pdf					○	○																															
194		Bedding Issues 20040802.pdf					○	○																															
195		Bedding Issues Supplement 20040802.pdf					○	○																															
196		Bedding Mix Supplemental Clarfications & Recommendations 20040923.pdf					○	○																															
197		Blend Sand- RCC Aggregate 20031202.pdf					○	○																															
198		Blend Sand- RCC Aggregate 20031204.pdf					○	○																															
199		Brief Comments and Reminders for Jose Lopez - Schrader Visit 20040519.pdf					○	○																															
200		Burnett- Conveyor- Read and Save for future Reference 20031126.pdf					○	○																															
201		Carpi Membrane At Monolith Joints 20040924.pdf					○	○																															
202		Cement and Ash Comparison to Thiss Mix Results 20040125.pdf					○	○																															
203		Cement Storage and Silos 20040805.pdf					○	○																															
204		Chemical Grout Contacts 20050816.pdf					○	○																															
205		Cofferdam- acess- Diversion 20040928.pdf					○	○																															
206		Cofferdam Comments for RCC Dams 20040121.pdf					○	○																															
207		Cold Joint Treatment & Criteria 20040802.pdf					○	○																															
208		Comment Earnie Schrader RCC Schedule 20040109.pdf					○	○																															
209		Contacts 20040211.pdf					○	○																															
210		Conveyor Covers 20040929.pdf					○	○																															
211		Conveyor Issues 20040109-11.pdf					○	○																															
212		Conveyor- Mixer Hopper & Sampling 20040112.pdf					○	○																															
213		Conveyor- MJ60m space vs 45m space 20040109.pdf					○	○																															

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214		Conveyor Modification - Chute to Upstream Area 20041208.pdf					○	○																														
215		Corral Des Palmas- Saluda- Burnett -Schrader 20040108.pdf					○	○																														
216		Dam Site Laboratory- Unsuitability of Plastic Cylinder Moulds 20040522.pdf					○	○																														
217		Denismeter Calibration Program 20040524.pdf					○	○																														
218		Density Test Requirements & Clarification 20040125.pdf					○	○																														
219		Dental Concrete 20040802.pdf					○	○																														
220		Detailed Placement Schedule with Cement & Panrl Use 20040723.pdf					○	○																														
221		Detailed Placement Schedule with Cement & Panrl Use 20040730.pdf					○	○																														
222		Due dlligence 20050819.pdf					○	○																														
223		Earnie - Cores 20050817.pdf					○	○																														
224		Earnie Question- File Nos 20031201.pdf					○	○																														
225		Earnie Schrader - Due Diligence Visit 20050705.pdf					○	○																														
226		Earnie Schrader - Read Me 20040926.pdf					○	○																														
227		Example of Poor Pozzolan Performance with Lean RCC & Basalt 20040121.pdf					○	○																														
228		Foundation Seeps at Dentaland RCC 20040804.pdf					○	○																														
229		GERCC - Schrader Comments 20040809.pdf					○	○																														
230		GERCC Final Comments 20040811.pdf					○	○																														
231		Goodnight in Aggregate 20040108.pdf					○	○																														
232		Goodnight Material for RCC 20040107.pdf					○	○																														
233		Goodnight Material for RCC 20040108.pdf					○	○																														
234		Goodnight Material 20040105.pdf					○	○																														
235		Grout and Pimple Treatment 20040925.pdf					○	○																														
236		Jack Post Shape 20040115.pdf					○	○																														
237		Jose's Nuc Gauge Calibration Program 20040524.pdf					○	○																														
238		Lab Test Priorites 20040526.pdf					○	○																														
239		Left Abutment Memo Joint 20050816.pdf					○	○																														
240		Lift Joint Cleaning 20041210.pdf					○	○																														
241		Low Density - Spillway 20050514.pdf					○	○																														
242		Material Property & Thermal Update 20040118.pdf					○	○																														
243		Material Property and Thermal Update 20040425.pdf					○	○																														
244		Mechanical Equipment Burnett Dam 20040127.pdf					○	○																														
245		Memo 35 Revision 20040406.pdf					○	○																														
246		Memo from EArnie - excel files 20040429.pdf					○	○																														
247		Miscellaneous Comments- Production- Membrane Punctures- Strain Gauges 20041118.pdf					○	○																														
248		Miscellaneous Comments Wet Weather RCC 20041119.pdf					○	○																														
249		Mixing -Placing Performance Test Procedure for Roller Compacted Concrete.pdf					○	○																														
250		Monolith Joint Former 20040410.pdf					○	○																														
251		Monolith Joint Former 20040924.pdf					○	○																														
252		More Comments Concerning Goodnight Bed for RCC 20040122.pdf					○	○																														
253		More Files from Earnie- Property Mixes 20040527.pdf					○	○																														
254		More on GERCC 20040810.pdf					○	○																														
255		Mujib RCC Report 20031126.pdf					○	○																														
256		Mujib RCC Report 20031130.pdf					○	○																														
257		News from Colombia 20040422.pdf					○	○																														

ID	Category	Document name	By	Date	Reference	Status and comments	Historical information				Current condition and risk position				Phase 2 Dam Safety Modelling Review	Phase 3: Dam Engineering Review of Design of 5 Options																		Phase 4 Cost Review	Phase 5 Risk Review		Expert Input	
							Original design	Original construction	Flood repairs design	Flood repairs construction	Comprehensive Inspection Report	Intermediate Inspection Report	Dams Safety Review Report	Comprehensive Risk Assessment	Review of SunWater's Dam Safety Modelling process	Seismic hazard assessment	Hydrology study	Failure impact assessment	Geological and geotechnical	Scour investigation & modelling	Concrete materials investigations	Spillway hydraulic modelling	Outlet works	Dam wall stability assessments	Reinforced concrete structures	Survey	Risk and Safety in Design	**Option 1:** Full upgrade without lowering the spillway	**Option 2:** Permanent lowering of spillway crest level by 5 m	**Option 3:** Permanent lowering of spillway crest level by 10 m	**Option 4:** Permanent lowering of spillway crest level by 5 - 10 m	**Option 5:** Full Decommissioning	SunWater independent peer review	Cost estimations	Comprehensive Risk Assessment	Comprehensive Risk Assessment (updated for Options Assessment)	For Alan Rae	For Ted Warren
258		Non- Linear FEM Stress Anlysis 20040925.pdf					O	O																														
259		Nuclear GAuge Geiger Counter 20040428.pdf					O	O																														
260		Nuclear Gauge Mtg 20031130.pdf					O	O																														
261		Nuclear Gauge20031205.pdf					O	O																														
262		Please Confirm Memo 70 Received 20050512.pdf					O	O																														
263		Plinth - Excavation and RCC Start20031104.pdf					O	O																														
264		Plinth- Schrader Comment 20031205.pdf					O	O																														
265		Positrack Dozer 20040127.pdf					O	O																														
266		Potential Change of Cement - July -August 20040730.pdf					O	O																														
267		Potential GERCC-20040801.pdf					O	O																														
268		Potential Jobsite Personnel 20040125.pdf					O	O																														
269		Questions Regarding the 150kg-m3 RCC mix 20050404.pdf					O	O																														
270		Rapid RCC Placement Method for Left Abutment 20041015.pdf					O	O																														
271		RCC Aggregate and Mix Verification Tests 20040330.pdf					O	O																														
272		RCC Cores 20050815.pdf					O	O																														
273		RCC Dam Issues 20050324.pdf					O	O																														
274		RCC Dam- Right Abutment & Apron 20050329.pdf					O	O																														
275		RCC Dam- Thermal 20050324.pdf					O	O																														
276		RCC Density- Testing - Achieving Density - Gauge 20040807.pdf					O	O																														
277		RCC Density Verification In - Situ 20040818.pdf					O	O																														
278		RCC Haul Trucks 20040113.pdf					O	O																														
279		RCC Lift Surface Cleaning 20041209.pdf					O	O																														
280		RCC Materia Properties 20040112l.pdf					O	O																														
281		RCC Mix Design QA20031125.pdf					O	O																														
282		RCC Mix Trial Program & Trial placement 20040522.pdf					O	O																														
283		RCC Mix Water 20040310.pdf					O	O																														
284		RCC Moisture 20040925.pdf					O	O																														
285		Rcc Quality Control 20040211.pdf					O	O																														
286		RCC Quality Control Testing- Additional Comment 20050324.pdf					O	O																														
287		RCC Related Tests & Frequency 20040804.pdf					O	O																														
288		RCC Time of Compaction- Again20050323.pdf					O	O																														
289		RCC to Abutment Contact 20041209.pdf					O	O																														
290		RCC Trial Report 20040806.pdf					O	O																														
291		Read This One - Memos 79-80-80B-82 & 83 Electronic 20050326.pdf					O	O																														
292		Re-evaluation of Downstream Face Conventional Step Methodology 20040423.pdf					O	O																														
293		Rolled Down Edge- Upstream to Downstream 20040925.pdf					O	O																														
294		Roller Compacted Concrete 20030627.pdf					O	O																														
295		Rotec-Schrader Comments 20031126.pdf					O	O																														
296		S&J trip to Saluda & Monterery 20031204.pdf					O	O																														
297		Saluda 20040211.pdf					O	O																														
298		Schedule & Thermal Comments - Memo 39.pdf					O	O																														
299		Schedule & Thermal Comments from Earnie 20040525.pdf					O	O																														
300		Set Time - To Compaction 20041219.pdf					O	O																														
301		Specification- Aggregate Gradation 20040125.pdf					O	O																														
302		Specification- Permability Testing 20040125.pdf					O	O																														
303		Spillway Crest Top-OUt 75. doc 20041209.pdf					O	O																														
304		Stockpile Management 20040927.pdf					O	O																														

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305		Strain Gauge Instrumentation 20040930.pdf					○	○																														
306		Strata Gauge 20031213.pdf					○	○																														
307		Summary of Lab Test Program Results to Date 20040527.pdf					○	○																														
308		Thermal Couples 20040123.pdf					○	○																														
309		Thermal Properties - Anlysis and Detailed Schedule 20040527.pdf					○	○																														
310		Thermal Update-for ES Schedule as of May 2004 20040524.pdf					○	○																														
311		Time Allowed to Compact RCC 20040805.pdf					○	○																														
312		Top of Conduit to RCC Contact 20040924.pdf					○	○																														
313		Trial Mix Program using Actual Aggregate 20040327.pdf					○	○																														
314		Trial Mix Program using Actual Aggregate 20040331.pdf					○	○																														
315		Trial Mix Program using Actual Aggregate 20040401.pdf					○	○																														
316		Trial Program from Jose Lopez 20040507.pdf					○	○																														
317		Unformed Downstream FAce of RCC 20040804.pdf					○	○																														
318		Update Earnie- Visit to Saluda 20031222.pdf					○	○																														
319		Updated Table of Material Properties 20040529.pdf					○	○																														
320		Updated Thermal Write-Up Summary 20040529.pdf					○	○																														
321		Upstream Face and Options & Trial Placement Monollith Joint 20040802.pdf					○	○																														
322		Use New Aggregate in Current RCC 20040804.pdf					○	○																														
323		Visit - Brisbane Jan 2004 - 20031211.pdf					○	○																														
324		Visit to Brisbane Jan 2004 - 20031209.pdf					○	○																														
325		Visit to Corral Des Palmas - Steve Johnson20031209.pdf					○	○																														
326		Visit to Corral Des Palmas & Saluda 20031204.pdf					○	○																														
327		Visit to Corral Des Palmas & Saluda 20031211.pdf					○	○																														
328	**TRP Workshops**																																					
329	TRP Workshop#1																																					
330		**SAM_1288.MP4**		May-19	GHD (2019g)																												●					●
331		**Paradise Dam TRP Workshop 20190529 v3 PowerPoint**	GHD	May-19	GHD (2019h)																												●					●
332	TRP Workshop#2					See ID 362																																
333		**Paradise Dam TRP Workshop 2.ppt**	GHD	Aug-19	GHD (2019k)																												●					●
334		**Paradise Dam - TRP Workshop No 2 - 20190827-28 (for TRP)**	GHD	Aug-19	GHD (2019l)																												●					●
335	TRP Workshop#3																																					
336		**Paradise Dam Safety Improvement Project - Technical Review Panel Report No 3**	TRP	Dec-19	TRP (2019b)																												●					●
337	**Cost estimates**																																					
338		**Paradise Dam Facility Strategy & Options Analysis, Basis of Estimate Report**	Project Support	Feb-18	Project Support (2018)																													●			●	
339		Submission Schedule Opt 2 - V06.pdf																																○			○	
340		Submission Schedule Opt 2 - V06.xlsx																																○			○	
341		Submission Schedule Opt 3A - V07.pdf																																○			○	
342		Submission Schedule Opt 3A - V07.xlsx																																○			○	
343		Submission Schedule Opt 3B - V06.pdf																																○			○	
344		Submission Schedule Opt 3B - V06.xlsx																																○			○	
345		Submission Schedule Opt 4 - V06.pdf																																○			○	
346		Submission Schedule Opt 6 - V04.pdf																																○			○	
347		Submission Schedule Opt 6 - V04.xlsx																																○			○	
348		Submission Schedule Opt 7A - V05.pdf																																○			○	
349		Submission Schedule Opt 7A - V05.xlsx																																○			○	

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350		Submission Schedule Opt 7B - V05.pdf																																○			○	
351		Submission Schedule Opt 7B - V05.xlsx																																○			○	
352		Paradise Dam Option 3A V07 Cash Flow.pdf																																○			○	
353		Paradise Dam Option 7A V05 Cash Flow.pdf																																○			○	
354		Paradise Dam Option 7B V05 Cash Flow.pdf																																○			○	
355		**Paradise Dam Spillway Improvement Option 2, Estimate Report (Draft)**	WT Partnership	Aug-19	WTP (2019a)																													○			○	
356		**Paradise Dam Spillway Improvement Option 3, Estimate Report (Draft)**	WT Partnership	Aug-19	WTP (2019b)																													○			○	
357	**Publicly released documents**																																					
358		**Paradise Dam Safety Improvement Project, Overview Report (Final)**	SunWater	Nov-19	SunWater (2019)	Latest summary																						●	●	●	●	●						●
359		**Paradise Dam, Shear Strength Evaluation Comments (Final)**	Tatro Hinds	Nov-19	Tatro Hinds (2019)	RCC review																		●														●
360		**Dam stability assessment (Revision 1) (Final)**	GHD	Nov-19	GHD (2019n)	Replaces ID 73 & 74																		●				●		●								●
361		**RCC Shear Strength Review (Final)**	GHD	Nov-19	GHD (2019o)	Replaces ID 77																		●														●
362		**Paradise Dam Safety Improvement Project, Technical Review Panel Report No 2**	TRP	Sep-19	TRP (2019a)														●	●	●			●												●		●
363	**SunWater Dam Safety Modelling**																																					
364		**Dam Safety Decision Criteria Options Paper**	SunWater	Aug-10		Superseded									●																							
365		**Dam Safety Improvement Decision Criteria Guidelines (Final)**	SunWater	May-18	SunWater (2018a)	Use for Phase 2									●																							
366	**Updated Reports**																																					
367		**Summary of risk assessment outcomes for the existing dam and 5 m and 10 m Essential Works Lowering (Final)**	GHD	Dec-19	GHD (2019p)																															●		
368		**Paradise Dam Spillway Improvement Project, Concept Design for Option 9 - 5 m lowering (Draft)**	GHD	Jan-20	GHD (2020)																								●							●		
369		App A - Stability analyses																											○									
370		App B - Cost estimate																											○					●				
371		App C - Sketches																											○									

Appendix B
Cost tables with industry benchmarking and lower and upper limits

Note, these cost tables are only for use in the options assessment with the view of ranking the options based on comparative costs. **These are not indicative project cost estimates** and should not be viewed or used for budget planning or funding.

As mentioned in the Report, the cost estimates must be updated to be on the same basis for comparison.

PARADISE DAM

COST ESTIMATE FOR OPTIONS COMPARISON ONLY - NOTE THIS IS NOT A PROJECT COST ESTIMATE

OPTION 1: FULL UPGRADE AND RETAIN ORIGINAL FSL

SUMMARY

A	**Direct Cost**
A1	Project Establishments and Controls (excludes Item A1.1 Overheads @ 25% of CV)
A2	Temporary Access
A3	Primary Spillway Stilling Basin & Strengthening
A4	Training Walls
A5	Secondary Spillway Side Channel
A6	Post-Tensioned Anchors
A7	Left Abutment Shotcrete Protection
A8	Bassalt Outcrop
A9	Primary Spillway Training Wall Strengthening
A10	Outlet Works Modification
A11	Unmeasured Scope @ 10% of above
A1.1	Overheads @ 25% of above
CV	**Construction Value**
B	**Owner's Cost**
BE	**Base Estimate**
C	Contingency & Project Risk
E	Escalation - Nil Applied
TFP	**Total for Project**

Item	Description	Unit	Quantity	Unit rate	Amount		Variation +	Variation -
A	**DIRECT COSTS**							
A1	**Project Establishment and Controls**							
~~A1.1~~	~~Overheads (@ 25 % of CV)~~	Item	Moved to end to eliminate circular calculation			Causes circular calculation if this item and unmeasured scope are included within CV		
A1.2	Construction Camp operation	Month	46.0	412,874.19	18,992,213	44 months according to Tabe 6	20%	20%
A1.3	FIFO/BIBO	Month	46.0	115,308.69	5,304,200	44 months according to Tabe 6	10%	5%
A1.8	Dilapidation Survey for assessment of public roads to site	Item	1.0	20,000.00	20,000		10%	10%
A1.9	Provision for contribution to public road rehabilitation	Item	1.0	440,000.00	440,000		10%	10%
A1.10	Provision of As-Built Information	Item	1.0	75,000.00	75,000		0%	20%
A1.11	Provision of O&M Manual modification	Item	1.0	50,000.00	50,000		0%	20%
A1.12	Establisment of on-site concrete batch plant	Item	1.0	2,541,333.47	2,541,333		0%	20%
A2	**Temporary Access**							
A2.1	Establish Stockpile Area (Strip & stockpile topsoil for re-use)	m²	300,000.0	2.00	600,000		10%	10%
A2.2	Prepare Haul Road from stockpile area to stream bed and crossing to the left of hand of abutment	m	1,500.0	115.71	173,565		10%	10%
A2.3	Haul road maintenance & dust suppression	Item	1.0	5,598,217.66	5,598,218		15%	15%
A2.4	Borrow material from downstream borrow area to construct working platform between access ramp to RL 67.6 at Mono Block D & M	m³	360,000.0	21.59	7,772,400		0%	10%
A2.5	Removal of all ramps back to borrow areas	m³	360,000.0	17.95	6,462,000		10%	10%
A2.6	Reinstate Stockpile Area	m²	300,000.0	3.78	1,134,000		10%	10%
A3	**Primary Spillway Stilling Basin & Strengthening (Drawing 246523)**							
A3.2	Scabble and prepair concrete surface	m²	7,940.0	137.99	1,095,641		10%	10%
A3.3	Excavation and removal of fill material	m³	3,000.0	42.82	128,460		0%	20%

A3.4	Clean-down of rock foundation for stilling basin extension	m²	6,930.0	16.63	115,246		10%	10%
A3.5	Supply and Install concrete N20 - fill voids under new apron slab	m³	10,320.0	403.10	4,159,992		10%	10%
A3.6	Locate existing reinforcing in apron slab constructed in 2013 (per slab)	No.	21.0	3,449.77	72,445		0%	25%
A3.7	Supply and Install Dia 36 Macalloy 1030 Bar 11m long	No.	3,816.0	3,302.58	12,602,645		0%	30%
A3.8	Fabricate, supply and install anchor head plates for spilling basin anchors	No.	3,816.0	969.00	3,697,704		20%	20%
A3.9	Supply and Install Reinforcement - apron slab	tonne	1,130.0	3,003.43	3,393,876		10%	20%
A3.10	Supply and Install N32 Concrete - above existing apron slab	m³	5,510.0	444.99	2,451,895		10%	20%
A3.11	Supply and Install N32 Concrete - new downstream apron slab	m³	6,000.0	432.71	2,596,260		20%	0%
A3.12	Supply and Install Reinforcement - disipator blocks and end sill	tonne	400.0	3,003.44	1,201,376		10%	10%
A3.13	Supply and Install N32 Concrete - disipator blocks and end sill	m³	5,000.0	676.03	3,380,150		10%	10%
A3.14	Temporary access for construction of Macalloy anchors	Item	1.0	57,496.23	57,496		10%	10%
A3.15	Supply and Install N32 Concrete for replacement of Spillway Wall	m³	1,472.0	673.47	991,348		10%	10%
A3.16	Excavation of material from geological feature	m³	750.0	92.36	69,270		10%	10%
A3.17	Clean-down of foundation within geological feature	m²	275.0	16.63	4,573		10%	10%
A2.17	Supply and place dental concrete in geological feature	m³	750.0	409.99	307,493		10%	10%
A4	**Training Walls**							
A4.1	Earthworks (PS added item)	m³	4,000.0	40.67	162,680		5%	20%
A4.2	Spillway training walls to both abutments	m³	22,020.0	540.90	11,910,618		20%	10%
A4.5	Supply and install reinforcement - gravity wall skin	tonne	2,100.0	3,003.43	6,307,203		10%	10%
A5	**Secondary Spillway Side Channel**							
A5.1	Scabble and prepare concrete surface	m²	3,500.0	137.99	482,965		10%	10%
A5.2	Excavation and removal of fill material	m³	57,000.0	34.67	1,976,190		0%	15%
A5.3	Excavation and removal of fill material (Rock)	m³	38,200.0	93.71	3,579,722		0%	15%
A5.4	Clean-down of rock foundation for stilling basin extension	m²	16,500.0	16.63	274,395		10%	10%
A5.5	Supply and Install blinding concrete N20 (not on drawings)	m³	4,125.0	360.96	1,488,960		10%	10%
A5.6	Supply and Install Dia 50 Macalloy 1030 Bar 12m long (Unable to locate on drawings)	No.	563.0	5,277.76	2,971,379		0%	30%
A5.7	Supply and Install N28 Anchor Bar (Double corrosion protection)	No.	3,520.0	2,158.94	7,599,469		0%	20%
A5.8	Supply and Install Reinforcement (Apron)	tonne	1,520.0	3,003.43	4,565,214		10%	10%
A5.9	Supply and Install N32 Concrete (Apron)	m³	15,170.0	426.12	6,464,240		20%	10%
A5.10	Supply and Install N20 Concrete (Concrete Gravity Wall)	m³	30,600.0	444.79	13,610,574		10%	10%
A5.11	Supply and Install Reinforcement (Gravity Wall Skin)	tonne	845.0	3,003.43	2,537,898		10%	10%
A5.12	Supply and installation of Waterstop (Copper 300mm x 1.6mm)	m	1,550.0	66.25	102,688		10%	10%
A5.13	Temporary access for construction of Macalloy anchors	Item	1.0	57,496.23	57,496		15%	15%
A5.14	Demolition of existing apron and sill (New Item)	m³	1,500.0	226.31	339,465		0%	20%
A6	**Post-Tensioning Anchoring**							
A6.1	*Primary Spillway*							
A6.1.1	Demolish reinforced concrete for spreader beam in primary spillway crest	m³	3,938.0	316.43	1,246,101		0%	20%
A6.1.2	Anchors (incl supply, core, waterproof grouting, installation, grouting & stressing) - 87 x 15.2mm strand anchor x 130m long	No.	56.0	384,309.39	21,521,326		10%	15%

A6.1.3	Reinforced concrete for spreader beam incl 200kg/m3 reinforcement	m³	2,363.0	1,078.35	2,548,141	10%	10%
A6.1.4	Stainless steel cover plates (300 kg/cover)	No.	56.0	5,272.61	295,266	10%	10%
A6.2	*Secondary Spillway*				-	0%	0%
A6.2.1	Demolish reinforced concrete/RCC for spreader beam in secondary spillway crest	m³	8,438.0	309.90	2,614,936	0%	20%
A6.2.2	Anchors (incl supply, core, waterproof grouting, installation, grouting & stressing) 59 x 15.2mm strand anchor x 100m long	No.	50.0	376,170.44	18,808,522	10%	10%
6.2.3	Reinforced concrete for spreader beam incl 200kg/m3 reinforcement	m³	3,375.0	1,078.81	3,640,984	10%	10%
A6.2.4	Reinforced concrete for crest reinstatement incl 100kg/m3 reinforcement	m³	5,063.0	879.58	4,453,314	10%	10%
A6.2.5	Stainless steel cover plates (300 kg/cover)	No.	50.0	5,272.91	263,646	10%	10%
A6.3	*Left Abutment*				-	0%	0%
A6.3.1	Demolish reinforced concrete/RCC for spreader beam in secondary spillway crest	m³	1,950.0	328.70	640,965	10%	20%
A6.3.2	Anchors (incl supply, core, waterproof grouting, installation, grouting & stressing) 59 x 15.2mm strand anchor x 100m long	No.	8.0	588,985.28	4,711,882	0%	25%
A6.3.3	Reinforced concrete for spreader beam incl 200kg/m3 reinforcement	m³	900.0	1,374.16	1,236,744	5%	15%
A6.3.4	Reinforced concrete for crest reinstatement incl 100kg/m3 reinforcement	m³	1,050.0	1,004.07	1,054,274	10%	10%
A6.3.5	Stainless steel cover plates (300 kg/cover)	No.	8.0	5,287.40	42,299	10%	10%
A7	**Left Abutment Erosion Potection (Drawing 41-29277-C015-0 to C018-0)**						
A7.1	Demolish concrete access stairs	m³	40.0	272.92	10,917	20%	10%
A7.2	Scabble and prepair concrete surface	m²	170.0	137.99	23,458	10%	20%
A7.3	Excavation and removal of cut material	m³	1,000.0	60.04	60,040	10%	20%
A7.4	Supply and Install N28 Anchor Bar (Double corrosion protection) 11m long	No.	104.0	3,433.32	357,065	10%	10%
A75	Supply and Install N28 Anchor Bar (Double corrosion protection) 5m long	No.	208.0	1,756.46	365,344	10%	10%
A7.6	Supply and Install Reinforcement - mesh	m²	700.0	58.76	41,132	10%	20%
A7.7	Supply and Install N32 Concrete - shotcrete 325mm thick	m³	250.0	604.17	151,043	10%	10%
A7.8	Supply and Install N20 Concrete - infill concrete	m³	100.0	530.52	53,052	10%	10%
A8	**Basalt Outcrop - (Drawing 245186-A)**						
A8.1	Scabble and prepare concrete surface	m²	550.0	137.99	75,895	10%	10%
A8.2	Supply and Install N20 x 3m Galvanised Anchor Bars	No.	130.0	1,278.48	166,202	10%	50%
A8.3	Supply and Install Reinforcement	tonne	19.0	3,814.42	72,474	0%	25%
A8.4	Supply and Install N32 Concrete	m³	743.0	603.36	448,296	0%	20%
A9	**Primary Spillway Training Wall Strengthening**						
A9.1	Scabble and prepare concrete surface	m²	352.0	137.99	48,572	0%	10%
A9.2	Excavation of rock or RCC	m³	50.0	1,125.20	56,260	10%	10%
A9.3	Supply and Install Shear Connectors (N12 U-bars)	No.	400.0	1,419.81	567,924	0%	25%
A9.4	Supply and Install Reinforcement	tonne	10.0	3,814.42	38,144	0%	25%
A9.5	Supply and Install N32 Concrete	m³	106.0	698.21	74,010	0%	25%
A9.6	Full height access to downstream face of dam at each abutment	LS	1.0	114,992.46	114,992	0%	10%
A10	**Outlet Works Modification**						
A10.1	Intake tower strengthening - Gr 316 stainless steel beams and base plates	tonne	2.7	29,024.95	78,367	10%	10%

A10.2	Coarse screen strengthening - Beam reinforcement	tonne	1.3	31,887.59	40,178		10%	10%
A10.3	Fine screen strengthening				-		10%	10%
A10.3.1	Beam reinforcement	tonne	4.9	14,712.08	71,354		10%	10%
A10.3.2	Screen modifications	tonne	0.5	84,472.92	44,771		10%	10%
A10.4	Outlet shutters - Shutter reinforcements	tonne	2.2	18,405.23	40,307		10%	10%
A10.5	Crossover bulkhead - reinforcements	tonne	0.2	87,527.59	16,630		10%	10%
A10.6	Irrigation bulkhead - reinforcements	tonne	0.2	87,527.60	16,630		10%	10%
A10.7	Regulating and guard gates - modifications and reinforcement	tonne	1.8	28,251.32	49,440		10%	10%
A10.8	Guard gate isolation system - option 3						0%	0%
A10.9	Guard gate isolation system - option 2						0%	0%
A10.10	Guard gate isolation system - option 1						0%	0%
A10.10.1	Steel retrieval box	tonne	47.0	9,085.38	427,013		0%	20%
A10.10.2	Bracing frames	tonne	14.0	9,454.65	132,365		0%	20%
A10.10.3	Steel bonnet and cover	tonne	4.0	17,834.07	71,336		0%	20%
A10.10.4	Knife gate and actuating cylinders (5.5m wide x 0.8m long) 40m head	Item	1.0	254,018.35	254,018		10%	10%
A10.10.5	Watertight bulkhead door (1.8 x 1m, 40m pressure rating)	Item	1.0	22,768.51	22,769		10%	10%
A10.10.6	Anchors and bolts not quantified	Item	1.0	2,299.85	2,300		10%	10%
A10.11	Guard and Regulator Gate Actuator Guards				-		10%	10%
A10.11.1	DN 2200 x 25 thk x 7.5m long pipes	tonne	20.4	16,272.71	331,150		0%	20%
A10.11.2	DN 2200 flange PN 16	No.	2.0	10,088.43	20,177		0%	20%
A10.11.3	Support columns	tonne	0.4	16,076.98	6,431		10%	20%
A10.11.4	Anchors M30 x 500mm gr 8.8 galvanized with HIT RE 500 adhesive	No.	32.0	120.17	3,845		10%	10%
A10.12	LLOW valve room strengthening				-		0%	0%
A10.12.1	Reinforced concrete for walls	m³	112.3	5,360.34	601,966		0%	25%
A10.12.2	Reinforced concrete for floor	m³	33.7	1,370.26	46,178		10%	10%
A10.13	LLOW control room steel floor - additional beams 2 x 200PFC x 5.5m	tonne	0.3	19,304.91	4,826		10%	10%
A10.14	Outlet works conduit roof slab strengthening - grouted anchor bars (2.5m long 26mm dia VSL-CT stress bar with anchor plate)	No.	60.0	1,374.12	82,447		10%	10%
A10.15	Unmeasured scope 30% x OWM CV	Item	30%	2,364,498.78	709,350	The reported value of $708,547 is inconsistent with subtotal of measured scope.	0%	50%
	Subtotal 1 (sum A1 to A10)							
A11	Unmeasured scope - (mark-up on Subtotal 1)	Item	10%			Should be mark-up on sum of A1 to A10, not included sum of A1 to A10	0%	50%
	Subtotal 2 (= Subtotal 1 + A1.1)							
A1.1	Overheads - (mark-up on Subtotal 2)	Item	25%			35% according to Report. Should be mark-up on sum of A1 to A11, not included sum of A1 to A11	0%	20%
CV	**CONSTRUCTION VALUE**					Overestimated due to incorrect method of mark-ups		
B	**OWNER'S COSTS**							
B1	Project Management	Item	3%				10%	10%
B2	Concept Design	Item	3%				10%	10%
B3	Detail Design / Engineering Certification during construction	Item	5%				10%	10%
B4	EIS	Item						
B5	Principals Insurance	Item	1%				0%	100%
B6	Portable long service levee and WHS fee	Item	0.475%				0%	100%
B7	Stakeholder Community Management	Item	1%				0%	100%
B8	De-Commissioning and Handover Costs	Item	3%				0%	100%
B9	Fisheries/EPA Monitoring	Item	1%				0%	100%
B10	Land Costs / Accommodation Works - placeholder	Item						

B11	Construction Management	Item	10%				0%	50%
	Total Owner's Cost					Overestimated due to incorrect method of mark-ups		
BE	**BASE ESTIMATE**					Overestimated due to incorrect method of mark-ups		
C	**CONTINGENCY**							
C1	Project Contingency (mark-up on BE)	Item	40%				0%	50%
	Total Contingency					Overestimated due to incorrect method of mark-ups		
D	**ESCALATION**							
D1	Escalation - Nil Applied	Item	1.0					
	Total Escalation							
	TOTAL FOR PROJECT					Overestimated due to incorrect method of mark-ups		

PARADISE DAM

COST ESTIMATE FOR OPTIONS COMPARISON ONLY - NOTE THIS IS NOT A PROJECT COST ESTIMATE

OPTION 2: FULL UPGRADE AND LOWER SPILLWAY CREST BY 5 m

Drawing References

Fixed crest lowered by 5m to EL 62.6

Stilling Basin Length of 55 m

Anchorage Specification:

Primary Spillway - 91 x 15.2mm strand anchor x 130m long @ 3.75 m spacings

Secondary Spillway Monos L to Q - 55 x 15.2mm strand anchor x 90m long @ 3.75 m spacings

Secondary Spillway Monos R to W - 27 x 15.2mm strand anchor x 75m long @ 3.75 m spacings

SUMMARY

A	**DIRECT COSTS**
A1	Project Establishment and Controls (excluding Overheads)
A2	Temporary Access
A3	Demolition
A4	Primary Spillway Crest
A5	Primary Spillway Stilling Basin
A6	Training Walls
A7	Post-tensioned Anchors
A7a	Secondary Spillway Apron Slab Overlay
A8	Left Abutment Erosion Protection
A9	Basalt Outcrop
A10	Primary Spillway Training Wall Strengthening
A11	Outlet Works
A12	Fishway Works
A13	Outlet Works Modifications
A14	Remediation of Dam Water Storage Area
A15	Raising of Secondary Spillway Crest
A16	Unmeasured Scope @ 10% of above
A1.1	Overheads @ 25% of above
CV	**Construction Value**
B	**Owner's Cost**
BE	**Base Estimate**
C	Contingency & Project Risk
E	Escalation - Nil Applied
TFP	**Total for Project**

Item	Description	Unit	Quantity	Unit rate	Amount		Variation +	Variation -
A	**DIRECT COSTS**							
A1	**Project Establishment and Controls**							
~~A1.1~~	~~Overheads (@ 25 % of CV)~~	Item	Moved to end to eliminate circular calculation			Causes circular calculation if this item and unmeasured scope are included within CV		
A1.2	Construction Camp operation	Month	40.0	371,006.00	14,840,240	Seems high compared to Option 3A (10 m lowering)	20%	20%
A1.3	FIFO/BIBO	Month	40.0	139,181.00	5,567,240	Seems high compared to Option 3A (10 m lowering)	10%	5%
A1.8	Dilapidation Survey for assessment of public roads to site	Item	1.0	20,000.00	20,000		10%	10%
A1.9	Provision for contribution to public road rehabilitation	Item	1.0	440,000.00	440,000		10%	10%
A1.10	Provision of As-Built Information	Item	1.0	75,000.00	75,000		0%	20%
A1.11	Provision of O&M Manual modification	Item	1.0	50,000.00	50,000		0%	20%
A1.12	Establisment of on-site concrete batch plant	Item	1.0	2,270,704.00	2,270,704		0%	50%

A2	**Temporary Access**						
A2.1	Establish Stockpile Area (Strip & stockpile topsoil for re-use)	m²	300,000.0	2.00	600,000	10%	10%
A2.2	Prepare Haul Road from stockpile area to stream bed and crossing to the left of hand of abutment	m	1,500.0	116.00	174,000	10%	10%
A2.3	Haul road maintenance & dust suppression	tem	1.0	4,953,878.00	4,953,878	10%	10%
A2.4	Borrow material from downstream borrow area to construct working platform between access ramp to RL 67.6 at Mono Block D & M	m³	360,000.0	22.00	7,920,000	0%	10%
A2.7	Removal of all ramps back to borrow areas	m³	360,000.0	18.00	6,480,000	10%	10%
A2.8	Reinstate Stockpile Area	m²	300,000.0	3.80	1,140,000	10%	10%
A3	**Demolition**						
A3.1	Demolish Ogee Crest by sawing & breakers (includes cost of buying saw & blades)	m³	3,906.0	417.00	1,628,802	0%	20%
A3.2	Demolish Mono Block D to K	m³	27,594.0	117.00	3,228,498	0%	20%
A3.3	Demolish RCC for spreader beam	m³	2,362.5	69.00	163,013	0%	20%
A4	**Primary Spillway Crest**						
A4.1	Supply and install N28 x 5m long double corrosion protection grouted bars for new spillway crest at 3m centres	No.	954.0	1,575.00	1,502,550	0%	25%
A4.2	Reinforcement to new ogee crest (80kg/m3)	tonne	730.8	3,278.00	2,395,562	10%	10%
A4.3	Concrete to new ogee crest plus spreader beam	m³	9,135.0	507.00	4,631,445	5%	10%
A4.4	Supply and install N28 x 5m long double corrosion protection grouted bars for reinforced facing of abutment at 3m centres	No.	23.0	1,625.00	37,375	0%	25%
A4.5	Supply and place reinforced concrete facing against abutments where profile of principal spillway ogee removed	m³	100.0	738.00	73,800	10%	10%
A5	**Primary Spillway Stilling Basin (Drawing 246523)**						
A5.1	Scabble and prepare concrete surface	m²	7,940.0	138.00	1,095,720	10%	10%
A5.2	Excavation and removal of fill material	m³	3,000.0	43.00	129,000	0%	20%
A5.3	Supply and Install concrete N20 - fill voids under new apron slab	m³	18,060.0	403.00	7,278,180	10%	10%
A5.4	Locate existing reinforcing in apron slab constructed in 2013 (per slab)	No.	21.0	3,458.00	72,618	10%	10%
A5.5	Supply and Install Dia 50 Macalloy 1030 Bar 11m long	No.	5,247.0	3,310.00	17,367,570	0%	25%
A5.6	Fabricate, supply and install anchor head plate for spilling basin anchors	No.	5,247.0	971.00	5,094,837	0%	30%
A5.7	Supply and Install Reinforcement - apron slab	tonne	1,553.8	3,010.00	4,676,938	20%	20%
A5.8	Supply and Install N32 Concrete - above existing apron slab	m³	5,510.0	446.00	2,457,460	10%	10%
A5.9	Supply and Install N32 Concrete - new downstream apron slab	m³	10,500.0	427.00	4,483,500	20%	0%
A5.10	Supply and Install Reinforcement - disipator blocks and end sill	tonne	330.0	3,011.00	993,630	20%	0%
A5.11	Supply and Install N32 Concrete - disipator blocks and end sill	m³	6,875.0	623.00	4,283,125	10%	10%
A5.12	Temporary access for construction of Macalloy anchors	Item	1.0	57,632.00	57,632	10%	10%
A5.13	Supply and Install N32 Concrete for replacement of Spillway Wall	m³	2,024.0	625.00	1,265,000	10%	10%
A6	**Training Walls**						
A6.1	Earthworks	m³	5,500.0	41.00	225,500	5%	20%

A6.2	Spillway Training Walls to EL 61.0	m²	30,277.5	542.00	16,410,405	20%	10%
A6.3	Supply and Install Reinforcement - 100kg/m3	tonne	2,887.5	3,011.00	8,694,263	10%	10%
A7	**Post-Tensioned Anchoring**						
A7.1.1	Anchors (incl supply, core, waterproof 91 x 15.2mm strand anchor x 130m long @ 3.75 m spacings with Primary Spillway	No.	84.0	414,050.00	34,780,200	10%	15%
A7.1.2	Anchors (incl supply, core, waterproof 55 x 15.2mm strand anchor x 90m long @ 3.75 m spacings Secondary Spillway Monos L to Q	No.	57.0	346,500.00	19,750,500	10%	15%
A7.1.3	Anchors (incl supply, core, waterproof 27 x 15.2mm strand anchor x 75m long @ 3.75 m spacings Secondary Spillway Monos R to W	No.	73.0	212,625.00	15,521,625	10%	15%
A7.1.4	Reinforced concrete for spreader beam incl 200kg/m3 reinforcement primary spillway crest	m³	2,363.0	1,086.00	2,566,218	10%	10%
A7.1.5	Reinfored concrete distribution block (200kg/m3 reinforcement)	No.	214.0	19,117.00	4,091,038	10%	10%
A7.1.6	Stainless steel cover plates (300 kg/cover)	No.	214.0	5,717.00	1,223,438	10%	10%
A7a	**Secondary Spillway Apron Slab Overlay**						
A7a.1	Scabble and prepare concrete surface	m²	5,850.0	138.00	807,300	10%	10%
A7a.2	Supply and Install Dia 36 Macalloy 1030 Bar 11m long	No.	1,113.0	3,310.00	3,684,030	0%	30%
A7a.3	Fabricate, supply and install anchor head plate for spilling basin anchors	No.	1,113.0	971.00	1,080,723	10%	10%
A7a.4	Supply and Install Reinforcement - overlay slab	tonne	706.2	3,010.00	2,125,662	10%	10%
A7a.5	Supply and Install N32 Concrete - above existing apron slab	m³	7,062.0	446.00	3,149,652	10%	10%
A8	**Left Abutment Erosion Protection (Drawing 41-29277-C015-0 to C018-0)**						
A8.1	Demolish concrete access stairs	m³	40.0	274.00	10,960	20%	10%
A8.2	Scabble and prepair concrete surface	m²	170.0	138.00	23,460	10%	20%
A8.3	Excavation and removal of cut material	m³	1,000.0	60.00	60,000	10%	20%
A8.4	Supply and Install N28 Anchor Bar (Double corrosion protection) 10m long	No.	104.0	3,441.00	357,864	10%	10%
A8.5	Supply and Install N28 Anchor Bar (Double corrosion protection) 5m long	No.	208.0	1,761.00	366,288	10%	10%
A8.6	Supply and Install Reinforcement - mesh	m²	700.0	59.00	41,300	10%	20%
A8.7	Supply and Install N32 Concrete - shotcrete 325mm thick	m³	250.0	613.00	153,250	10%	10%
A8.8	Supply and Install N20 Concrete - infill concrete	m³	100.0	532.00	53,200	10%	10%
A9	**Basalt Outcrop - (Drawing 245186-A)**						
A9.1	Scabble and prepare concrete surface	m²	550.0	138.00	75,900	10%	10%
A9.2	Supply and Install N20 x 6m Galvanised Anchor Bars	No.	130.0	1,648.00	214,240	0%	50%
A9.3	Supply and Install Reinforcement	tonne	19.0	3,823.00	72,637	0%	25%
A9.4	Supply and Install N32 Concrete	m³	743.0	611.00	453,973	0%	20%
A10	**Primary Spillway Training Wall Strengthening**						
A10.1	Scabble and prepare concrete surface	m²	352.0	138.00	48,576	0%	10%
A10.2	Excavation of rock or RCC	m³	50.0	1,128.00	56,400	10%	10%
A10.3	Supply and Install Shear Connectors (N12 U-bars)	No.	400.0	1,423.00	569,200	0%	25%
A10.4	Supply and Install Reinforcement	tonne	10.0	3,823.00	38,230	0%	25%
A10.5	Supply and Install N32 Concrete	m³	106.0	710.00	75,260	0%	20%
A10.6	Full height access to downstream face of dam at each abutment	LS	1.0	115,264.00	115,264	0%	10%

A11	**Outlet Works**						
A11.1	Remove environmental outlet course screen and retain for reuse	Item	1.0	37,228.95	37,229	10%	10%
A11.2	Remove environmental outlet sill down to RL 53.5	m³	72.9	234.62	17,104	10%	10%
A11.3	Install 2.5m long N24 dowel bars 1.5m into existing concrete for connection of new sill	No.	56.0	13,319.57	745,896	0%	50%
A11.4	Construct new environmental outlet sill to RL 55.0 and screen support	m³	27.0	6,812.49	183,937	0%	50%
A12	**Fishway Works**						
A12.1	Modifications to upstream fishway for crest raising	LS	1.0	1,000,000.00	1,000,000	10%	10%
A12.2	Fishway attraction chamber concrete demolition including handrailing and grating	m³	31.0	11,404.82	353,549	10%	10%
A12.3	Dia. 1290 steel pipe demolition	m	11.0	9,324.11	102,565	10%	10%
A12.4	New structural steel including bolts	kg	1,350.0	9.22	12,447	10%	10%
A12.5	New grating and stair tread area	m²	15.0	521.63	7,824	10%	10%
A12.6	Installing Grating and Stair	Item	1.0	7,284.40	7,284	10%	10%
A12.7	New handrailing	m	22.0	191.05	4,203	10%	10%
A12.8	M20 Hilti Hit V-R chemical anchors	Item	8.0	46.89	375	10%	10%
A12.9	Salvage existing level sensors, downstream single and quad leaf gates including gate frames. Reinstall on new fishway including connection to existing hydraulic system.	Item	1.0	62,222.13	62,222	10%	10%
A12.10	Removal of existing level sensors, downstream single and quad leaf gates including gate frames	Item	1.0	16,333.30	16,333	10%	10%
A12.11	Re-installation of existing level sensors, downstream single and quad leaf gates including gate frames	Item	1.0	45,888.83	45,889	10%	10%
A12.12	Fabricate stainless steel fish attraction chamber	kg	15,400.0	10.79	166,166	10%	10%
A12.13	Transport to site of fish chamber	Item	1.0	2,822.26	2,822	10%	10%
A12.14	Installation of fish chamber, complete including connection to fish channel and Dia. 1290 pipe	Item	1.0	152,144.00	152,144	10%	10%
A12.15	Chemical anchors complete, including adhesive	No.	12.0	46.89	563	10%	10%
A12.16	Supply and transport to site of Dia. 1290 spool piece, including gasket and fasteners	Item	1.0	8,572.26	8,572	10%	10%
A12.17	Installation of Dia. 1290 spool piece, including gasket and fasteners	Item	1.0	72,546.60	72,547	10%	10%
A12.18	Removal of existing fish channel on dam face for re-use at lower level	Item	1.0	84,085.20	84,085	10%	10%
A12.19	Re-installation of existing fish channel on dam face and connection to fish chamber	Item	1.0	124,697.80	124,698	10%	10%
A13	**Outlet Works Modification**						
A13.1	Intake tower strengthening - Gr 316 stainless steel beams and base plates	tonne	2.7	34,729.00	93,768	10%	10%
A13.2	Coarse screen strengthening - Beam reinforcement	tonne	1.3	39,601.00	51,481	10%	10%
A13.3	Fine screen strengthening					10%	10%
A13.3.1	Beam reinforcement	tonne	4.9	16,731.00	81,982	10%	10%
A13.3.2	Screen modifications	tonne	0.5	120,991.00	60,496	10%	10%
A13.4	Outlet shutters - Shutter reinforcements	tonne	2.2	18,449.00	40,588	10%	10%
A13.5	Crossover bulkhead - reinforcements	tonne	0.2	87,734.00	17,547	10%	10%
A13.6	Irrigation bulkhead - reinforcements	tonne	0.2	87,734.00	17,547	10%	10%
A13.7	Regulating and guard gates - modifications and reinforcement	tonne	1.8	28,318.00	50,972	10%	10%
A13.8	Guard gate isolation system - option 1					0%	0%
A13.8.1	Steel retrieval box	tonne	47.0	9,827.00	461,869	0%	20%
A13.8.2	Bracing frames	tonne	14.0	10,197.00	142,758	0%	20%

A13.8.3	Steel bonnet and cover	tonne	4.0	17,876.00	71,504		0%	20%
A13.8.4	Knife gate and actuating cylinders (5.5m wide x 0.8m long) 40m head	Item	1.0	254,618.00	254,618		10%	10%
A13.8.5	Watertight bulkhead door (1.8 x 1m, 40m pressure rating)	Item	1.0	22,822.00	22,822		10%	10%
A13.8.6	Anchors and bolts not quantified	Item	1.0	2,305.00	2,305		10%	10%
A13.9	Guard and Regulator Gate Actuator Guards						0%	0%
A13.9.1	DN 2200 x 25 thk x 7.5m long pipes	tonne	20.4	16,311.00	332,744		0%	20%
A13.9.2	DN 2200 flange PN 16	No.	2.0	10,112.00	20,224		0%	20%
A13.9.3	Support columns	tonne	0.4	16,835.00	6,734		10%	20%
A13.9.4	Anchors M30 x 500mm gr 8.8 galvanized with HIT RE 500 adhesive	No.	32.0	120.00	3,840		10%	10%
A13.10	LLOW valve room strengthening						0%	0%
A13.10.1	Reinforced concrete for walls	m³	112.3	5,304.00	595,639		0%	20%
A13.10.2	Reinforced concrete for floor	m³	33.7	1,305.00	43,979		10%	10%
A13.11	LLOW control room steel floor - additional beams 2 x 200PFC x 5.5m	tonne	0.3	19,351.00	5,805		10%	10%
A13.12	Outlet works conduit roof slab strengthening - grouted anchor bars (2.5m long 26mm dia VSL-CT stress bar with anchor plate)	No	60.0	1,377.00	82,620		10%	10%
	Sub Total							
A13.13	Unmeasured scope 30% x OWM CV	Item	30%		738,553		0%	50%
A14	**Remediation of Dam Water Storage Area**							
A14.1	Non-remnant Area - Ameliorate dam storage area by tilling soil back into ground insitu using agricultural plant and adding fertiliser and then seed	ha	547.0	12,305.00	6,730,835		0%	50%
A14.2	Remnant Area - by adding fertiliser and then seed (561ha)						0%	0%
A14.2.1	Flat terrain	ha	80.0	3,942.00	315,360		10%	10%
A14.2.2	Hilly terrain	ha	80.0	5,304.00	424,320		0%	15%
A14.2.3	Conservation area	ha	52.5	5,887.00	309,068		10%	10%
A14.3	Riparian stabilisation - Jute matting & tube stock	ha	8.0	107,527.00	860,216		10%	10%
A14.4	Maintenance	month	12.0	112,560.00	1,350,720		20%	0%
A14.5	Fencing - 4 Strand plain wire & 1200 wide gates @ 1km crs	km	171.0	40,495.00	6,924,645		0%	50%
A15	**Raising & Extension of Secondary Spillway Crest**							
A15.1	Demolition of parapet walls	m³	1,314.0	336.00	441,504		0%	10%
A15.2	N32 concrete crest raising	m³	16,800.0	700.00	11,760,000		0%	10%
A15.3	Crest raising reinforcing (35 kg/m3)	tonne	588.0	3,011.00	1,770,468		0%	10%
A15.4	Reconstruction of existing parapet walls	m³	1,314.0	800.00	1,051,200		0%	10%
A15.5	Crest dowels, N24 x 3m long	No	480.0	1,575.00	756,000		0%	10%
A15.6	Extension monoliths reinforced concrete	m³	6,970.0	700.00	4,879,000		10%	20%
A15.7	Extension concrete parapet walls	m³	233.0	800.00	186,400		10%	20%
	Subtotal 1 (sum A1 to A15)							
A16	Unmeasured scope - (mark-up on Subtotal 1)	Item	10%			Should be mark-up on sum of A1 to A15, not included sum of A1 to A15	0%	50%
	Subtotal 2 (= Subtotal 1 + A1.1)							
A1.1	Overheads - (mark-up on Subtotal 2)	Item	25%			35% according to Report Should be mark-up on sum of A1 to A15, not included sum of A1 to A15		
CV	**CONSTRUCTION VALUE**					Overestimated due to incorrect method of mark-ups	0%	20%

B	**OWNER'S COST**				
B1	Project Management	Item	3%		
B2	Concept Design	Item	3%		
B3	Detail Design / Engineering Certification during construction	Item	5%		
B4	EIS	Item			
B5	Principals Insurance	Item	1%		
B6	Portable long service levee and WHS fee	Item	0.475%		
B7	Stakeholder Community Management	Item	1%		
B8	De-Commissioning and Handover Costs	Item	3%		
B9	Fisheries/EPA Monitoring	Item	1%		
B10	Land Costs / Accommodation Works - placeholder	Item			
B11	Construction Management	Item	10%		
	Total Owner's Cost				
BE	**BASE ESTIMATE**				
C	**CONTINGENCY**				
C1	Project Contingency (mark-up on BE)	Item	40%		
	Total Contingency				
D	**ESCALATION**				
D1	Escalation - Nil Applied	Item	1.0		
	Total Escalation				
	TOTAL FOR PROJECT				

	10%	10%
	10%	10%
	10%	10%
	0%	100%
	0%	100%
	0%	100%
	0%	100%
	0%	100%
	0%	50%
Overestimated due to incorrect method of mark-ups		
Overestimated due to incorrect method of mark-ups		
Overestimated due to incorrect method of mark-ups		
Overestimated due to incorrect method of mark-ups		

PARADISE DAM

COST ESTIMATE FOR OPTIONS COMPARISON ONLY - NOTE THIS IS NOT A PROJECT COST ESTIMATE

OPTION 3: FULL UPGRADE AND LOWER SPILLWAY CREST BY 10 m, WITH ABUTMENT WORKS AND SADDLE DAM

Drawing References

Drawing Nos: 4131160 - SK061ur, to SK064ur & SK075ur

SUMMARY

A	**DIRECT COSTS**
A1	Project Establishments and Controls
A2	Material Extraction & Testing Facilities
A3	Temporary Access
A4	Diversion/Coffer Dam
A5	Primary Spillway Crest
A6	Environmental Gate
A7	Primary Spillway Stilling Basin
A8	Training Walls
A9	Left Abutment
A10	Left Abutment Erosion Protection
A11	Right Abutment (Blocks L-Q)
A12	Right Abutment (Blocks R-W, X & Y)
A13	Bassalt Outcrop
A14	Primary Spillway Training Wall Strengthening
A15	Outlet Works
A16	Fishway Works
A17	Outlet Works Modification
A18	Remediation Works
A19	Unmeasured Scope @ 10% of above
A1.1	Overheads @ 25% of above
CV	**Construction Value**
B	**Owner's Cost**
BE	**Base Estimate**
C	Contingency & Project Risk
E	Escalation - Nil Applied
TFP	**Total for Project**

Item	Description	Unit	Quantity	Unit rate	Amount		Variation +	Variation -
A	**DIRECT COSTS**							
A1	**Project Establishment and Controls**							
~~A1.1~~	~~Overheads (@ 25 % of CV)~~	Item	Moved to end to eliminate circular calculation			Causes circular calculation if this item and unmeasured scope are included within CV		
A1.2	Construction Camp operation	Month	39.0	742,746.00	28,967,094	40 months according to Tabe 6	20%	20%
A1.3	FIFO/BIBO	Month	39.0	122,376.00	4,772,664	40 months according to Tabe 6	10%	5%
A1.4	Dilapidation Survey for assessment of public roads to site	Item	1.0	20,000.00	20,000		10%	10%
A1.5	Provision for contribution to public road rehabilitation	Item	1.0	440,000.00	440,000		10%	10%
A1.6	Provision of As-Built Information	Item	1.0	75,000.00	75,000		0%	20%
A1.7	Provision of O&M Manual modification	Item	1.0	50,000.00	50,000		0%	20%
A1.8	Establishment of on-site concrete batch plant	Item	1.0	2,477,362.00	2,477,362		0%	50%
A2	**Material Extraction & Testing Facilities**							
A2.1	Establish & rehabilitate quarry borrow pit (90,000m3)	Item	1.0	409,024.00	409,024		10%	10%

A2.2	Establish & rehabilitate clay borrow pit (25,000m3)	Item	1.0	137,892.00	137,892	10%	10%
A2.3	Establish & rehabilitate sand borrow pit (9,000m3)	Item	1.0	57,741.00	57,741	10%	10%
A24	Testing Facilities for Earthworks & Concrete	Item	1.0	4,447,750.00	4,447,750	0%	15%
A3	**Temporary Access Ramp to Ogee Crest**						
A3.1	Establish Stockpile Area (Strip & stockpile topsoil for re-use)	m²	300,000.0	2.00	600,000	10%	10%
A3.2	Prepare Haul Road from stockpile area to stream bed and crossing to the left of hand of abutment	m	1,500.0	113.00	169,500	10%	10%
A3.3	Haul road maintenance & dust suppression	Item	1.0	4,671,852.00	4,671,852	10%	10%
A3.4	Borrow material from downstream borrow area to construct working platform between access ramp to RL 67.6 at Mono Block D & M	m³	360,000.0	21.00	7,560,000	0%	10%
A3.5	Removal of all ramps back to borrow areas	m³	360,000.0	18.00	6,480,000	10%	10%
A3.6	Reinstate Stockpile Area	m²	300,000.0	3.70	1,110,000	10%	10%
A4	**Diversion / Coffer Dam**						
A4.1	Cofferdam - Zone 1 Clay core (10km haul distance)	m³	4,096.0	93.00	380,928	0%	20%
A4.2	Cofferdam - Zone 2A Fine filter (5km haul distance)	m³	862.0	195.00	168,090	0%	20%
A4.3	Cofferdam - Zone 3A Rock fill/select fill (2km haul distance)	m³	16,599.0	83.00	1,377,717	0%	20%
A4.4	Dewater construction area (GHD Allowance)	LS	1.0	250,000.00	250,000	20%	20%
A5	**Primary Spillway Crest**						
A5.1	Demolish conventional concrete from ogee crest	m³	3,906.0	394.00	1,538,964	10%	20%
A5.2	Demolish RCC down to required profile	m³	56,889.0	77.00	4,380,453	10%	10%
A5.3	Supply and install N28 x 5m long double corrosion protection grouted bars for reinforced facing of at abutment at 3m centres	No.	954.0	1,539.00	1,468,206	0%	25%
A5.4	Reinforcement to new ogee crest (80kg/m3)	tonne	756.0	3,202.00	2,420,712	10%	10%
A5.5	Concrete to new ogee crest	m³	9,135.0	495.00	4,521,825	5%	10%
A5.6	Supply and place reinforced concrete facing against abutments where profile of principal spillway ogee removed	m³	193.0	718.00	138,574	10%	10%
A5.7	Supply and place concrete to spreader beam 1.5m deep	m³	2,363.0	478.00	1,129,514	10%	10%
A5.8	Reinforcement to spreader beam (200kg/m3)	tonne	474.0	3,202.00	1,517,748	0%	10%
A5.9	Anchors (incl supply, core, waterproof 86 x 15.2mm strand anchor x 130m long	No.	91.0	362,545.00	32,991,595	10%	10%
A5.10	Stainless steel cover plates (300 kg/cover)	No.	91.0	5,164.00	469,924	10%	10%
A5.11	Supply and place reinforced concrete for replacement of spillway walls (100 kg/m3)	tonne	276.0	3,202.00	883,752	0%	10%
A5.12	Supply and place N32 concrete for replacement of spillway wall (Shotcrete)	m³	2,760.0	496.00	1,368,960	10%	10%
A6	**Environmental Gate**						
A6.1	Demolish RCC for environmental gate	m³	2,904.0	40.00	116,160	15%	0%
A6.2	Supply and install N28 x 5m long double corrosion protection grouted bars for side wall lining of gate slot at 3m centres	No.	59.0	1,374.00	81,066	10%	10%
A6.3	Supply and install N28 x 5m long double corrosion protection grouted bars for lining of gate slot at 3m centres (CHECK QTY)	No.	36.0	1,732.00	62,352	10%	10%
A6.4	Supply and place reinforced concrete for gate slot base lining and support (150kg/m3)	m³	384.0	1,140.00	437,760	10%	10%
A6.5	Supply and place reinforced concrete for gate slot wall lining (150kg/m3)	m³	484.0	1,148.00	555,632	20%	0%
A6.6	Supply and installation of control equipment including hydraulic pump and generator (Incl backup)	PS	1.0	500,000.00	500,000	20%	20%

A7	**Primary Spillway Stilling Basin**						
A7.1	Scabble and prepair concrete surface	m²	7,940.0	135.00	1,071,900	10%	10%
A7.2	Excavation and removal of fill material	m³	3,000.0	42.00	126,000	0%	20%
A7.3	Clean-down of rock foundation for stilling basin extension	m²	6,930.0	16.00	110,880	10%	10%
A7.4	Supply and Install concrete N20 - fill voids under new apron slab	m³	28,380.0	393.00	11,153,340	10%	10%
A7.5	Locate existing reinforcing in apron slab constructed in 2013 (per slab)	No.	21.0	3,378.00	70,938	0%	25%
A7.6	Supply and Install Dia 36 Macalloy 1030 Bar 11m long	No.	7,155.0	3,234.00	23,139,270	0%	30%
A7.7	Fabricate, supply and install anchor head plates for spilling basin anchors	No.	7,155.0	949.00	6,790,095	20%	20%
A7.8	Supply and Install Reinforcement - apron slab	tonne	2,119.0	2,941.00	6,231,979	10%	10%
A7.9	Supply and Install N32 Concrete - above existing apron slab	m³	5,510.0	436.00	2,402,360	20%	0%
A7.10	Supply and Install N32 Concrete - new downstream apron slab	m³	16,500.0	412.00	6,798,000	20%	0%
A7.11	Supply and Install Reinforcement - disipator blocks and end sill	tonne	450.0	2,941.00	1,323,450	10%	10%
A7.12	Supply and Install N32 Concrete - disipator blocks and end sill	m³	9,375.0	537.00	5,034,375	10%	10%
A7.13	Temporary access for construction of Macalloy anchors	Item	1.0	56,304.00	56,304	10%	10%
A8	**Training Walls**						
A8.1	Earthworks (PS added item)	m³	4,000.0	40.00	160,000	5%	20%
A8.2	Spillway training walls to both abutments	m³	41,288.0	530.00	21,882,640	20%	10%
A8.3	Supply and install reinforcement - gravity wall skin	tonne	4,129.0	2,941.00	12,143,389	10%	10%
A9	**Left Abutment**						
A9.1	Demolish fittings (handrail)	m	240.0	267.00	64,080	0%	20%
A9.2	Supply and place concrete to 1m raise	m³	840.0	445.00	373,800	10%	10%
A9.3	Reinforcement skin to 1m raise (N28-200 EW-EF)	tonne	106.0	2,941.00	311,746	10%	10%
A9.4	Supply and place concrete to parapet wall	m³	52.0	2,507.00	130,364	10%	10%
A9.5	Reinforcement to parapet wall (100kg/m3)	tonne	6.0	2,941.00	17,646	10%	10%
A9.6	Pedestrial hand rail	m	240.0	265.00	63,600	10%	10%
A10	**Left Abutment Erosion Potection (Drawing 41-29277-C015-0 to C018-0)**						
A10.1	Demolish concrete access stairs	m³	40.0	270.00	10,800	20%	10%
A10.2	Scabble and prepair concrete surface	m²	170.0	135.00	22,950	10%	20%
A10.3	Excavation and removal of cut material	m³	1,000.0	59.00	59,000	10%	20%
A10.4	Supply and Install N28 Anchor Bar (Double corrosion protection) 11m long	No.	104.0	3,362.00	349,648	10%	10%
A10.5	Supply and Install N28 Anchor Bar (Double corrosion protection) 5m long	No.	208.0	1,720.00	357,760	10%	10%
A10.6	Supply and Install Reinforcement - mesh	m²	700.0	58.00	40,600	10%	20%
A10.7	Supply and Install N32 Concrete - shotcrete 325mm thick	m³	250.0	592.00	148,000	10%	10%
A10.8	Supply and Install N20 Concrete - infill concrete	m³	100.0	520.00	52,000	10%	10%
A11	**Right Abutment (Blocks L-Q)**						
A11.1	Demolish parapet walls and slab	m³	1,257.0	303.00	380,871	10%	10%
A11.2	Supply and place concrete to spreader beam	m³	1,575.0	753.00	1,185,975	10%	10%
A11.3	Reinforcement to spreader beam (200kg/m3)	tonne	315.0	2,941.00	926,415	10%	10%
A11.4	Supply and place concrete to abutment raise (5.25m)	m³	6,143.0	477.00	2,930,211	10%	10%
A11.5	Reinforcement skin to abutment raise (N28-200 EW-EF)	tonne	234.0	2,941.00	688,194	10%	10%
A11.6	Supply and place concrete to parapet wall	m³	158.0	2,507.00	396,106	10%	10%

A11.7	Reinforcement to parapet wall (100kg/m3)	tonne	16.0	2,941.00	47,056		10%	10%
A11.8	Handrail to parapet	m	420.0	169.00	70,980		10%	10%
A11.9	Anchors (incl supply, core, waterproof 64 x 15.2mm strand anchor x 100m long	No.	19.0	431,367.00	8,195,973		10%	15%
A11.10	Stainless steel cover plates (300 kg/cover)	No.	19.0	5,168.00	98,192		10%	10%
A12	**Right Abutment (Blocks R-W, X & Y)**							
A12.1	Demolish RCC and fittings	m³	12,000.0	158.00	1,896,000		0%	25%
A12.2	Excavate foundations (Rippable)	m³	85,000.0	47.00	3,995,000		0%	25%
A12.3	Grouting - drill and grout 30m deep @ 3m c/c	m	3,750.0	75.00	281,250		0%	10%
A12.4	Supply and place concrete to grout cap	m³	338.0	1,097.00	370,786		0%	20%
A12.5	RCC gravity wall - concrete (medium paste, 180kg/m3 cementitous	m³	80,000.0	322.00	25,760,000		10%	10%
A12.6	Reinforcement to capping beam (200kg/m3)	tonne	154.0	2,941.00	452,914		10%	10%
A12.7	Supply and place concrete to capping beam	m³	767.0	461.00	353,587		10%	10%
A12.8	Supply and place concrete to parapet wall	m³	275.0	2,507.00	689,425		10%	10%
A12.9	Reinforcement to parapet wall (100kg/m3)	tonne	28.0	2,941.00	82,348		10%	10%
A12.10	Handrail to parapet	m	730.0	169.00	123,370		10%	10%
A12.11	Zone 1 - backfill grout cap	m³	15,000.0	93.00	1,395,000		10%	10%
A13	**Basalt Outcrop - (Drawing 245186-A)**							
A13.1	Scabble and prepare concrete surface	m²	550.0	135.00	74,250		10%	10%
A13.2	Supply and Install N20 x 3m Galvanised Anchor Bars	No.	130.0	1,252.00	162,760		0%	50%
A13.3	Supply and Install Reinforcement	tonne	19.0	3,735.00	70,965		0%	25%
A13.4	Supply and Install N32 Concrete	m³	743.0	591.00	439,113		0%	20%
A14	**Primary Spillway Training Wall Strengthening**							
A14.1	Scabble and prepare concrete surface	m²	352.0	135.00	47,520		0%	10%
A14.2	Excavation of rock or RCC	m³	50.0	1,102.00	55,100		10%	10%
A14.3	Supply and Install Shear Connectors (N12 U-bars)	No.	400.0	1,390.00	556,000		0%	25%
A14.4	Supply and Install Reinforcement	tonne	10.0	3,735.00	37,350		0%	25%
A14.5	Supply and Install N32 Concrete	m³	106.0	684.00	72,504		0%	20%
A14.6	Full height access to downstream face of dam at each abutment	LS	1.0	112,607.00	112,607		0%	10%
A15	**Outlet Works**							
A15.1	Remove environmental outlet course screen and retain for reuse	item	1.0	36,305.00	36,305		10%	10%
A15.2	Remove environmental outlet sill down to RL 48.5	m³	129.0	229.00	29,541		10%	10%
A15.3	Install 2.5m long N24 dowel bars 1.5m into existing concrete for connection of new sill	No.	56.0	12,989.00	727,384		0%	50%
A15.4	Construct new environmental outlet sill to RL 50.0 and screen support	m³	27.0	6,643.00	179,361		0%	50%
A16	**Fishway Works**							
A16.1	Demolish downstream fishway chamber	m³	25.0	496.00	12,400		10%	10%
A16.2	Construct new downstrean fishway chamber	m³	25.0	4,346.00	108,650		0%	10%
A12.3	Connect to existing pipework	Item	1.0	22,521.00	22,521		10%	10%
A17	**Outlet Works Modification**							
A17.1	Intake tower strengthening - Gr 316 stainless steel beams and base plates	tonne	2.7	28,423.00	76,742		10%	10%
A17.2	Coarse screen strengthening - Beam reinforcement	tonne	1.3	31,226.00	39,345		10%	10%
A17.3	Fine screen strengthening						10%	10%
A17.3.1	Beam reinforcement	tonne	4.9	14,407.00	69,874		10%	10%

A17.3.2	Screen modifications	tonne	0.5	82,722.00	43,843		10%	10%
A17.4	Outlet shutters - Shutter reinforcements	tonne	2.2	18,023.00	39,470		10%	10%
A17.5	Crossover bulkhead - reinforcements	tonne	0.2	85,712.00	16,285		10%	10%
A17.6	Irrigation bulkhead - reinforcements	tonne	0.2	85,713.00	16,285		10%	10%
A17.7	Regulating and guard gates - modifications and reinforcement	tonne	1.8	27,665.00	48,414		10%	10%
A17.10	Guard gate isolation system - option 1				-		0%	0%
A17.10.1	Steel retrieval box	tonne	47.0	8,897.00	418,159		0%	20%
A17.10.2	Bracing frames	tonne	14.0	9,259.00	129,626		0%	20%
A17.10.3	Steel bonnet and cover	tonne	4.0	17,464.00	69,856		0%	20%
A17.10.4	Knife gate and actuating cylinders (5.5m wide x 0.8m long) 40m head	No.	1.0	248,750.00	248,750		10%	10%
A17.10.5	Watertight bulkhead door (1.8 x 1m, 40m pressure rating)	Item	1.0	22,296.00	22,296		10%	10%
A17.10.6	Anchors and bolts not quantified	Item	1.0	2,252.00	2,252		10%	10%
A17.11	Guard and Regulator Gate Actuator Guards				-		0%	0%
A17.11.1	DN 2200 x 25 thk x 7.5m long pipes	tonne	20.4	15,935.00	324,277		0%	20%
A17.11.2	DN 2200 flange PN 16	No.	2.0	9,879.00	19,758		0%	20%
A17.11.3	Support columns	tonne	0.4	15,744.00	6,298		10%	20%
A17.11.4	Anchors M30 x 500mm gr 8.8 galvanized with HIT RE 500 adhesive	No.	32.0	118.00	3,776		10%	10%
A17.12	LLOW valve room strengthening				-		0%	0%
A17.12.1	Reinforced concrete for walls	m³	112.3	5,182.00	581,939		0%	20%
A17.12.2	Reinforced concrete for floor	m³	33.7	1,275.00	42,968		10%	10%
A17.13	LLOW control room steel floor - additional beams 2 x 200PFC x 5.5m	tonne	0.3	18,905.00	4,726		10%	10%
A17.14	Outlet works conduit roof slab strengthening - grouted anchor bars (2.5m long 26mm dia VSL-CT stress bar with anchor plate)	No.	60.0	1,346.00	80,760		10%	10%
	Sub Total							
A17.15	Unmeasured scope 30% x OWM CV	Item	30%		691,710		0%	50%
A18	**Remediation of Dam Water Storage Area**							
A18.1	Non-remnant Area - Ameloirate dam storage area by tilling soil back into ground insitu using agricultural plant and adding fertiliser and then seed	ha	1,094.0	12,115.00	13,253,810		0%	50%
A18.2	Remnant Area - by adding fertiliser and then seed (442 ha)						0%	0%
A18.2.1	Flat terrain < 3%	ha	160.0	4,026.00	644,160		10%	10%
A18.2.2	Hilly terrain 3 to 30%	ha	160.0	1,177.00	188,320		0%	15%
A18.2.3	Conservation area 25% of remnant area	ha	105.0	1,281.00	134,505		10%	10%
A18.2.4	Riparian stabilisation - Jute matting & tube stock	ha	16.0	105,049.00	1,680,784		10%	10%
A18.3	Maintenance	month	24.0	51,183.00	1,228,392		20%	0%
A18.4	Fencing - 4 Strand plain wire & 1200 wide gates @ 1km crs	km	342.1	39,562.00	13,532,182		0%	50%
	Subtotal 1 (sum A1 to A18)							
A19	Unmeasured scope - (mark-up on Subtotal 1)	Item	10%			Should be mark-up on sum of A1 to A19, not included sum of A1 to A19	0%	50%
	Subtotal 2 (= Subtotal 1 + A1.1)							
A1.1	Overheads - (mark-up on Subtotal 2)	Item	25%			35% according to Report Should be mark-up on sum of A1 to A19, not included sum of A1 to A19	0%	20%
CV	**CONSTRUCTION VALUE**					Overestimated due to incorrect method of mark-ups		

B	**OWNER'S COST**							
B1	Project Management	Item	3%				10%	10%
B2	Concept Design	Item	3%				10%	10%
B3	Detail Design / Engineering Certification during construction	Item	5%				10%	10%
B4	EIS	Item						
B5	Principals Insurance	Item	1%				0%	100%
B6	Portable long service levee and WHS fee	Item	0.475%				0%	100%
B7	Stakeholder Community Management	Item	1%				0%	100%
B8	De-Commissioning and Handover Costs	Item	3%				0%	100%
B9	Fisheries/EPA Monitoring	Item	1%				0%	100%
B10	Land Costs / Accommodation Works - placeholder	Item						
B11	Construction Management	Item	10%				0%	50%
	Total Owner's Cost					Overestimated due to incorrect method of mark-ups		
BE	**BASE ESTIMATE**					Overestimated due to incorrect method of mark-ups		
C	**CONTINGENCY**							
C1	Project Contingency (mark-up on BE)	Item	40%				0%	50%
	Total Contingency					Overestimated due to incorrect method of mark-ups		
D	**ESCALATION**							
D1	Escalation - Nil Applied	Item	1.0					
	Total Escalation							
	TOTAL FOR PROJECT					Overestimated due to incorrect method of mark-ups		

PARADISE DAM
COST ESTIMATE FOR OPTIONS COMPARISON ONLY - NOTE THIS IS NOT A PROJECT COST ESTIMATE
OPTION 5: FULL DECOMMISSIONING (WORKING FROM DAM STRUCTURE)

Drawing References
Burnett River Dam Alliance As Cons

SUMMARY

A	**DIRECT COSTS**
A1	Project Establishment and Controls
A2	Decomissioning
A3	Remediation
A4	Unmeasured Scope @ 10% of above
A1.1	Overheads @ 25% of above
CV	**Construction Value (CV)**
B	**Owner's Cost (OC)**
BE	**Base Estimate (CV + OC)**
C	Contingency & Project Risk
E	Escalation - Nil Applied
TFP	**Total For Project**

Item	Description	Unit	Quantity	Unit rate	Amount		Variation +	Variation -
A	**DIRECT COSTS**							
A1	**Project Establishment and Controls**							
~~A1.1~~	~~Overheads (@ 25 % of CV)~~	Item	Moved to end to eliminate circular calculation			Causes circular calculation if this item and unmeasured scope are included within CV		
A1.2	Construction Camp operation	Month	21.0	754,639.20	15,847,423	39 months according to Tabe 6	20%	20%
A1.3	FIFO/BIBO	Month	21.0	71,572.20	1,503,016	39 months according to Tabe 6	10%	5%
A1.8	Dilapidation Survey for assessment of public roads to site	Item	1.0	20,000.00	20,000		10%	10%
A1.9	Provision for contribution to public road rehabilitation	Item	1.0	440,000.00	440,000		10%	10%
A1.10	Provision of As-Built Information	Item	1.0	75,000.00	75,000		0%	20%
A1.11	Provision of O&M Manual modification	Item	1.0		-			
A2	**DECOMMISSIONING**							
A2.1	Establish Stockpile Area (Strip & stockpile topsoil for re-use)	m²	200,000.0	1.94	388,000		10%	10%
A2.2	Prepare Haul Road from stockpile area to stream bed and crossing to the left of hand of abutment	m	1,500.0	112.45	168,675		10%	10%
A2.3	Haul road maintenance & dust suppression	Item	1.0	2,470,834.00	2,470,834		15%	15%
A2.4	Borrow material from downstream to construct access ramp to RL 67.6 to Mono Block D & M - Excluded				-			
A2.5	Demolish Left Abutment & Wing Wall	m³	30,067.0	82.06	2,467,298		15%	15%
A2.6	Construct Siphon to dewater below RL 42.00 - Allowance if required	Item	1.0	100,000.00	100,000		20%	20%
A2.7	Demolish Mono Block D to K - Chainage 200 to 515 (Spillway)	m³	259,706.0	80.71	20,960,871		15%	15%
A2.8	Remove Mech & Elec from Intake Tower & Fishway & Outlet Works	Item	1.0	1,190,858.00	1,190,858		20%	20%
A2.9	Demolish Intake Tower	m³	1,550.0	300.75	466,163		0%	25%
A2.10	Demolish Fishway & Outlet Works	m³	5,500.0	300.75	1,654,125		0%	25%
A2.11	Demolish Right Abutment & Wing Wall - After Mono Block K	m³	110,756.0	73.36	8,125,060		10%	15%
A2.12	Demolish up and down stream abutment aprons & upstands	m³	6,000.0	214.53	1,287,180		5%	20%

A2.13	Demolish other concrete structures (provisional quantity)	m³	5,000.0	214.56	1,072,800		5%	20%
A2.14	Removal of all ramps back to borrow areas - Excluded				-			
A2.15	Reinstate Stockpile Area	m²	200,000.0	3.71	742,000		10%	25%
A3	**Re-mediation of Dam Storage Area**							
A3.1	Excavate and removal of acumulated silty material within 7000m upstream of dam wall	m³	4,851,000	15.00	72,765,000		0%	20%
A3.2	Treatment of anoxic material (30%)	m³	1,455,300	1.77	2,575,881		10%	20%
A3.3	Non-remnant Area - Ameloirate dam storage area by tilling soil back into ground insitu using agricultural plant and adding fertiliser and then seed	ha	1,652.0	11,929.34	19,707,270		0%	25%
A3.4	Remnant Area - by adding fertiliser and then seed (668ha)							
A3.4.1	Flat terrain	ha	242.0	3,821.65	924,839		10%	10%
A3.4.2	Hilly terrain	ha	242.0	5,141.63	1,244,274		10%	10%
A3.4.3	Conservation area	ha	161.0	5,707.34	918,882		10%	10%
A3.5	Riparian stabilisation - Jute matting & tube stock	ha	24.0	104,243.40	2,501,842		20%	20%
A3.6	Maintenance	month	24.0	109,122.60	2,618,942		10%	10%
A3.7	Fencing - 4 Strand plain wire & 1200 wide gates @ 1km crs	km	342.1	39,258.41	13,430,302		0%	50%
	Subtotal 1 (sum A1 to A3)							
A4	Unmeasured scope - (mark-up on Subtotal 1)	Item	10%			Should be mark-up on sum of A1 to A3, not included sum of A1 to A3	10%	10%
	Subtotal 2 (= Subtotal 1 + A1.1)							
A1.1	Overheads - (mark-up on Subtotal 2)	Item	25%			35% according to Report Should be mark-up on sum of A1 to A3, not included sum of A1 to A3	0%	20%
CV	**CONSTRUCTION VALUE**					Overestimated due to incorrect method of mark-ups		
B	**OWNER'S COST**							
B1	Project Management	Item	3%				10%	10%
B2	Concept Design	Item	3%				10%	10%
B3	Detail Design / Engineering Certification during construction	Item	5%				10%	10%
B4	EIS	Item	1.00			$4M according to Table 4		
B5	Principals Insurance	Item	1%				0%	100%
B6	Portable long service levee and WHS fee	Item	0.475%				0%	100%
B7	Stakeholder Community Management	Item	1%				0%	100%
B8	De-Commissioning and Handover Costs	Item	3%				0%	100%
B9	Fisheries/EPA Monitoring	Item	1%				0%	100%
B10	Land Costs / Accommodation Works - placeholder	Item						
B11	Construction Management	Item	10%				0%	50%
	Total Owner's Cost					Overestimated due to incorrect method of mark-ups		
BE	**BASE ESTIMATE**					Overestimated due to incorrect method of mark-ups		
C	**CONTINGENCY**							
C1	Project Contingency (mark-up on BE)	Item	40%				0%	50%
	Total Contingency					Overestimated due to incorrect method of mark-ups		
D	**ESCALATION**							
D1	Escalation - Nil Applied	Item	1.0					
	Total Escalation							
	TOTAL FOR PROJECT					Overestimated due to incorrect method of mark-ups		

Document prepared by

Aurecon Australasia Pty Ltd
ABN 54 005 139 873
Ground Floor, 25 King Street
Bowen Hills QLD 4006
Locked Bag 331
Brisbane QLD 4001
Australia

T +61 7 3173 8000
F +61 7 3173 8001
E brisbane@aurecongroup.com
W aurecongroup.com

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