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WARATAH, GREY MOUNTAIN NO. 1 & NO. 2 DAMS
Reservoir level reduction risk reassessment

ENTURA-CC492
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1. Summary

1.1 Scope of this study

Entura has been engaged by TasWater to undertake investigate the effects of dewatering three dams:

- Grey Mountain No. 1 Dam
- Grey Mountain No. 2 Dam; and
- Waratah Dam

All three dams currently plot above the ANCOLD limit of tolerability and are candidates for decommissioning. As an interim measure TasWater are considering the possibility of dewatering all three dams by utilising the scour outlets as a risk mitigation measure.

Entura has been engaged to:

- Develop outlet rating curves for each of the dams
- Develop daily time series of inflows into the reservoir either by scaling a nearby stream gauge or from the sustainable yields project (ie Grey Mountain 1 & 2) as necessary and then routing it through the reservoirs to understand the ability of the outlets to keep the reservoirs effectively dewatered.
- Routing of flood inflows through the reservoirs from a representative starting level based on the results of the yield modelling.
- Review of the critical failure modes to reassess the probabilities of failure of each structure in a dewatered state.
- Update the risk assessment for each of the dams including the changes in flood partitioning and consequences of operating the reservoirs at a lower level.

1.2 Hydrological dewatering simulations

Long-term hydrological simulations have been run for Waratah Dam, and Grey Mountain 1 and 2 Dams to determine whether their existing outlets are suitable for dewatering the dams. The simulations passed historical inflow time series through each storage based on their storage volume, spillway and dewatering outlet discharge ratings. The water level response of each dam has been presented as duration curves and a table of peak levels for given annual exceedance probabilities.

The duration curves give an indication of the likelihood that draining each dam using the scour outlets will be effective.

Table 1.1: Summary of storage duration modelling

Dam	% Time at min reservoir level	% Time below Full Supply Level	Maximum Level Reached (Relative to FSL)	Duration of simulated data
Waratah Dam	25%	80%	+ 0.76 m	55 years

1.3 Potential Risk Reduction

1.3.1 Waratah Dam

The risk position of Waratah Dam has been reassessed based on updated hydrologic assumptions resulting in a substantial increase to the current risk position of the dam. Additionally the impacts of attempting to reduce the operating level in the dam by permanently opening the scour valve have been assessed.

The impact of the updated hydrology on the current risk position is:

- Societal risk has substantially increased in comparison with the previous assessment and is still well above the ANCOLD limit of tolerability for existing dams (ANCOLD 2003).
- Individual life safety risk has substantially increased from 2.6×10^{-4} to 1.6×10^{-3} in comparison with the previous assessment and is well above the threshold of 10^{-4}, recommended as a minimum acceptable individual life safety risk by ANCOLD (ANCOLD 2003).
- Financial and economic risk has substantially increased from $161K/annum to $949K/annum.

By permanently opening the scour valve, the following risk outcomes would be achieved:

- Societal risk will be reduced slightly; however the dam will still plot well above the ANCOLD limit of tolerability for existing dams (ANCOLD 2003).
- Individual life safety risk will be reduced from 1.6×10^{-3} to 8.3×10^{-4}, however this is still in excess of the threshold of 10^{-4}, recommended as a minimum acceptable individual life safety risk by ANCOLD (ANCOLD, 2003).
- Financial and economic risk would be reduced from $949K/annum to $517K/annum.

It is strongly recommended that Waratah Dam be either upgraded to reduce the risk of failure or decommissioned as soon as reasonably practicable. As an immediate risk reduction activity, the bottom outlet should also be opened.

2. Waratah Dam

2.1 Dam Details

Waratah Dam is a 6m high clay core rockfill embankment and has a crest length of 87.4 m. It retains a storage of 800 ML at full supply level (FSL), has a timber overflow weir discharging into unlined channel and an outlet through the bottom of the embankment which is DN450mm cast iron with a valve housed at the downstream toe. A summary of the key dam information is included below (Ng, 2013):

Table 2.1: Dam Details – Waratah Dam

	GENERAL	
DAM	Waratah Dam	
LOCATION	1 km southeast of Waratah (60 km southwest of Burnie)	
SYSTEM	Waratah System	
CATCHMENT (RIVER)	Waratah River	
YEAR OF CONSTRUCTION	Unknown (dam repaired in 1975/76 following overtopping failure)	
DAM CONSEQUENCE CATEGORY	Sunny Day Failure	**Significant**
	Flood Failure	**Significant**
DAM ID NUMBER	4806	
COORDINATES	E 378 212 m, N 5 409 783 m	
	EMBANKMENT	
TYPE	Clay core rockfill	
CREST LEVEL	R.L. 608.8 m	
CREST LENGTH	87.4 m	
CREST WIDTH	8 m	
HEIGHT	6 m	
UPSTREAM SLOPE	1V : 2H	
DOWNSTREAM SLOPE	1V : 2H	
	RESERVOIR	
FULL SUPPLY LEVEL (FSL)	Spillway crest level	
CAPACITY AT FSL	800 ML	
SURFACE AREA AT FSL	47.65 ha (0.48 km^2)	
CATCHMENT AREA	9.97 km^2	
ON-STREAM / OFF-STREAM	On-stream	

SPILLWAY	
TYPE	Timber overflow weir discharging into unlined channel
SPILLWAY CREST LEVEL	R.L. 608 m
SPILLWAY CREST WIDTH	5.1 m
CURRENT DESIGN FLOOD	Assumed DCF
DAM CREST FLOOD (DCF)	≈1:50AEP (updated during this assessment from ≈ 1:2 200 AEP – 5.3 m^3/s due to update of likely critical flood durations – refer to section 2.2.1 for discussion)
OUTLET WORKS	
OUTLET	DN450 cast iron outlet pipe and valve

2.2 Flood Loading Review

2.2.1 Hydrology Review

The first flood hydrology review was completed by Byeveld and Smyth (2010) using the Tasmanian Regional Method and made the conservative assumption that the inflows equalled outflows. This was updated during the portfolio risk assessment (Hoang & Ng, 2013) where the Probably Maximum Flood (PMF) critical storm duration was assumed to be approximately 2 hours based on the expected time of concentration for the inflow flood. This inflow flood was routed through the reservoir for the PMF and more frequent events by scaling down the peak of the flood but not changing the duration, to approximately estimate reservoir level versus AEP curve used in the risk assessment. When reassessing the flood hydrology for this study it was found that the assumption that the inflow and outflow flood duration was only approximately 2 hours was non-conservative and the critical outflow duration for the more frequent events was much longer.

As a result, the current operation scenario has been re-run for Waratah Dam where the dewatering outlet is assumed closed at all times and inflows are discharged over the spillway crest only. This study considers much longer durations for the more frequent events and this is considered to be a more robust estimate, although not a full flood hydrology review. Hence, this results in a higher current risk position than previously reported in the portfolio risk assessment. Also a result of the updated hydrology the dam crest flood (DCF) likelihood has been increased from ≈ 1:2,200 AEP to ≈1:50AEP.

The following assumptions and methodology has been used:

- Historical inflow datasets are on a daily time step and have been sourced from the 55 year record of rainfall runoff model data developed for yield analysis of Waratah River (Pokhrel, 2015).
- The model uses dam storage volume and spillway ratings as defined in the Operations and Maintenance manual for Waratah Dam (Ng, 2013).
- The model uses an outlet rating curve derived during this risk review. The assumptions and discharge curve are included in Appendix A.1.
- The simulation is continuous and run on an hourly time-step starting at the beginning of the inflows time series (1960 for Waratah Dam) and finishing in 2009.

- The modelled starting position for the dam was found to be insensitive to the outcome with the dam drawing down during initial low flow sequences.
- No allowance has been made for evaporation from the dam surface or other losses such as seepage.
- Dam level frequency results (peak levels for given AEP) should be treated as indicative only as the continuous simulation uses daily time series input data that has been generated for other purposes (e.g. yield analysis or climate change impact assessment).

Storage duration and flood frequency outputs from the review are included in Appendix A.2.

2.2.2 Partitioning

The hydrologic loading has been reviewed as per Section 2.2.1 considering the discharge from the outlet conduit. A discharge curve for the outlet conduit had to be developed and this is included in Appendix A.2. Due to the increase in the current hydrology the estimated pool of record has been reassessed as dam crest level (RL 608.8m).

Table 2.2: Flood loading partitioning

Storage level (RL m)	AEP of the storage level	Partition	Probability of partition	Normal loading or flood loading?	Description
603.0	1.0E+00				Maximum storage level that is exceeded at least once every year
		1	3.75E-01	Normal	
604.6	6.2E-01				Level of negligible hydraulic gradient
		2	3.95E-01	Normal	
608	2.3E-01				Full Supply Level
		3	1.94E-02	Normal	
608.3	2.1E-01				
		4	5.60E-02	Normal	
608.5	1.5E-01				
		5	1.34E-01	Normal	
608.7	2.0E-02				
		6	1.48E-02	Normal	
608.8	5.2E-03				Pool of record, Dam Crest Level
		7	5.01E-03	Flood	
609	2.0E-04				Dam crest level + 200mm

		8	1.57E-04	Flood	
609.2	4.3E-05				Dam crest level + 400mm
		9	4.26E-05	Flood	

2.3 Likelihood Reassessment

The key failure modes that drive the risk position of Waratah Dam are summarised below in **Error! Reference source not found.**. Only the failure modes identified in the portfolio risk assessment (Hoang & Ng 2013) which have numerical impact on the risk position of the dam were recalculated.

As discussed in Section 2.2.1 the current risk position of Waratah Dam was revised as it was determined that the previous hydrological assumptions were non-conservative due to the assumed critical duration of the Dam Crest Flood. Thus the current risk position has increased compared to that reported by Hoang and Ng (2013). Additionally the pool of record was reassessed as approximately dam crest level (RL 608.8 m), with the increase in the flood hydrology the previously assumed pool of record of RL 608.3 m, occurred too frequently to be considered credible.

The dominant failure modes that drive the risk position for Waratah Dam are piping failure modes initiated by zones of poor compaction within the core/foundation interface and piping along the outlet conduit as well as erosion of the spillway channel. For the piping failure modes, under low reservoir level the hydraulic gradient is reduced to a level where it is considered that the conditional probability of initiation of piping along a defect is minimal. As a result the annual probability of failure has been reduced under normal operating conditions in comparison to the reassessed current probability of failure.

There is also some benefit under flood loading to the risk position, compared with the reassessed current risk position, due to the reduced likelihood of reaching higher storage levels due to dewatering of the reservoir.

A summary of the key probabilities of failure is included below in Table 2.3.

Table 2.3: Key Failure Modes – Waratah Dam

Loading condition	Failure mode	Original Annual P_f (Hoang & Ng 2013)	Reassessed Current Annual P_f	Reassessed Lowered Reservoir Annual P_f
Normal	Piping through a poorly compacted or high permeability layer on the core-foundation contact (FM05)	**2.4×10^{-2}**	**2.3×10^{-2}**	**1.5×10^{-2}**
	Piping through a poorly compacted or high permeability zone around a conduit through the embankment (FM06)	**2.4×10^{-2}**	**2.3×10^{-2}**	**1.5×10^{-2}**
	Erosion of spillway channel (FM03)	**0**	**2.5×10^{-1}**	**1.6×10^{-1}**
Flood	Erosion of spillway channel (FM03)	**5.4×10^{-3}**	**1.7×10^{-2}**	**4.3×10^{-3}**
	Flood Overtopping (FM01)	**4.3×10^{-5}**	**1.2×10^{-3}**	**3.3×10^{-4}**
	Spillway Blockage due to debris (FM02)	**5.2×10^{-5}**	**1.5×10^{-3}**	**4.3×10^{-4}**
	Piping through a poorly compacted or high permeability layer on the core-foundation contact (FM05)	**3.0×10^{-4}**	**4.0×10^{-4}**	**1.0×10^{-4}**
	Piping through a poorly compacted or high permeability zone around a conduit through the embankment (FM06)	**3.0×10^{-4}**	**4.0×10^{-4}**	**1.0×10^{-4}**
	TOTAL	**5.4×10^{-2}**	**3.2×10^{-1}**	**1.9×10^{-1}**

2.4 Consequence Reassessment

2.4.1 Loss of life

The potential loss of life for Waratah Dam is considered to be driven by itinerants travelling on both William Street and Smith Street downstream of the dam. Potential loss of life and exposure was calculated for Sunny Day and Flood conditions during the portfolio risk assessment (Hoang & Ng 2013). This exposure factor is applied to the annual probability of failure attributed by each failure mode such that the likelihood of failure resulting in loss of life (*f*) is calculated. The resultant cumulative *f* is therefore less than the total annual probability of failure of the dam. Additionally it was assumed that below FSL that PLL would be 0 due to insufficient volume of water.

This approach was adopted, however for the partition less than FSL it was assumed that the PLL would be 0. The partitioning of the PLL is included below in Table 2.4.

Table 2.4: Probable loss of life partitioning

Storage level (RL m)	Representative Storage Volume (ML)	Partition	Probable Loss of Life	Exposure (Business Hours)	Exposure (After Hours)
603.0					
	181	1	0	0.06	0.10
608.0					
	871.5	2	1	0.08	0.18
608.3					
	999	3	1	0.08	0.18
608.5					
	1114	4	1	0.08	0.18
608.7					
	1200	5	1	0.08	0.18
608.8					
	1295	6	1	0.08	0.18
609.0					
	1426	7	1	0.08	0.18
609.2					
	1491	8	1	0.08	0.18

2.4.2 Financial Consequences

Financial consequences were adopted directly from the portfolio risk assessment (Hoang & Ng, 2013).

Table 2.5: Waratah Dam – estimated economic and financial costs of dam failure

Scenario	Total economic and financial costs
Sunny Day Failure	$3.0 M
Flood (no Failure)	$0.1 M
Flood Failure	$3.0 M

2.5 Risk Reduction

The reassessed current risk position and potential risk reduction for dewatering Waratah Dam is presented below in Table 2.6 and Figure 2.1. There is a risk benefit to attempting to dewater Waratah Dam, however the dam will still well exceed the limit of tolerability for both individual risk (>10^{-4}) and societal risk.

Table 2.6: Financial and individual life safety risk reduction

	Financial Risk ($/annum)	Individual Life Safety Risk
Previous Assessment (Hoang & Ng, 2013)	$161,000	2.6×10^{-4}
Current Risk Position	$949,000	1.6×10^{-3}
Dewatered Risk Position	$517,000	8.3×10^{-4}

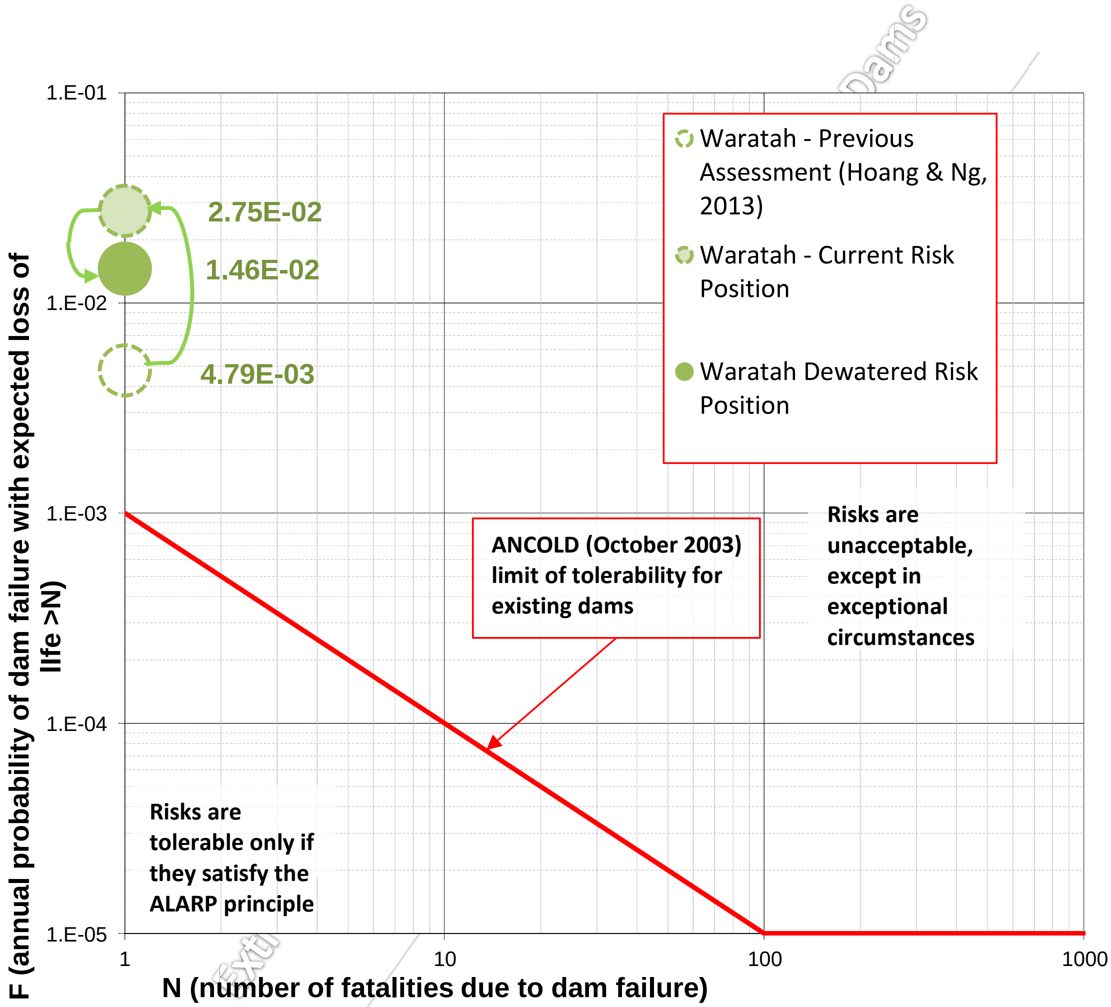

Figure 2.1: Societal risk reduction

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3. References

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Appendices

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A Waratah Dam

A.1 Outlet Conduit Discharge Curve

A.2 Hydrology Review

A.1 Outline Conduit Discharge Curve

CALCULATION SHEET

Project No.: P511806

File No.: E306068

Project: Waratah Dam Risk Reassessment

Calculation Description: Discharge Rating Curve

Prepared: Nick Glover 23 / 01 / 17 Checked: Mike Wallis 24 / 01 / 17 Page 1 of 1

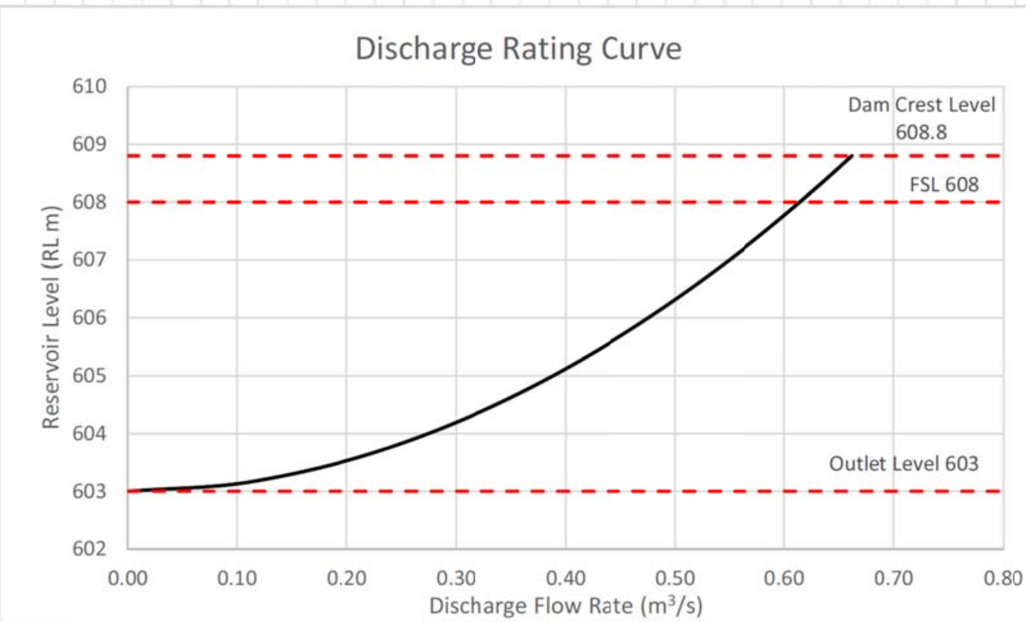
Dam Details - obtained from Operation & Maintenance Manual (Ng, 2013):

- Full Supply Level = 606.3 m (Hoang, 2017)
- Dam Crest Level = 607.5 m (Hoang, 2017)
- Dam is 6 m high
- 6 m high embankment 1:2 slopes 8 m wide crest = 32m wide at foundation minimum

- 1 x 400mm diameter cast iron outlet pipe
- Intake Level Unknown
- 400mm control valve located at downstream end of outlet pipe valve type unknown

Assumptions:

- Laminar Flow
- Assume 40m conduit
- Assume outlet level at RL 603 m (to match storage curve in O&M Manual (Ng, 2013))
- Roughness [mm] (cast iron pipe) = 1.5 mm (assuming pitting and slime build up within pipe)
- Inlet loss assume no trash rack - round pipe inlet, K = 0.22
- Exit loss assume gate valve at full open with round pipe exit K = 1.1



References:

- Ng, S. (July, 2013), *Waratah Dam Operations and Maintenance Manual,* Entura for Cradle Mountain Water, Revision 0, 23 July 2013
- Hoang, T. (January, 2017), *Waratah Dam - Comprehensive Surveillance Report 2016,* Entura for TasWater, 12 January 2017

A.2 Hydrology Review

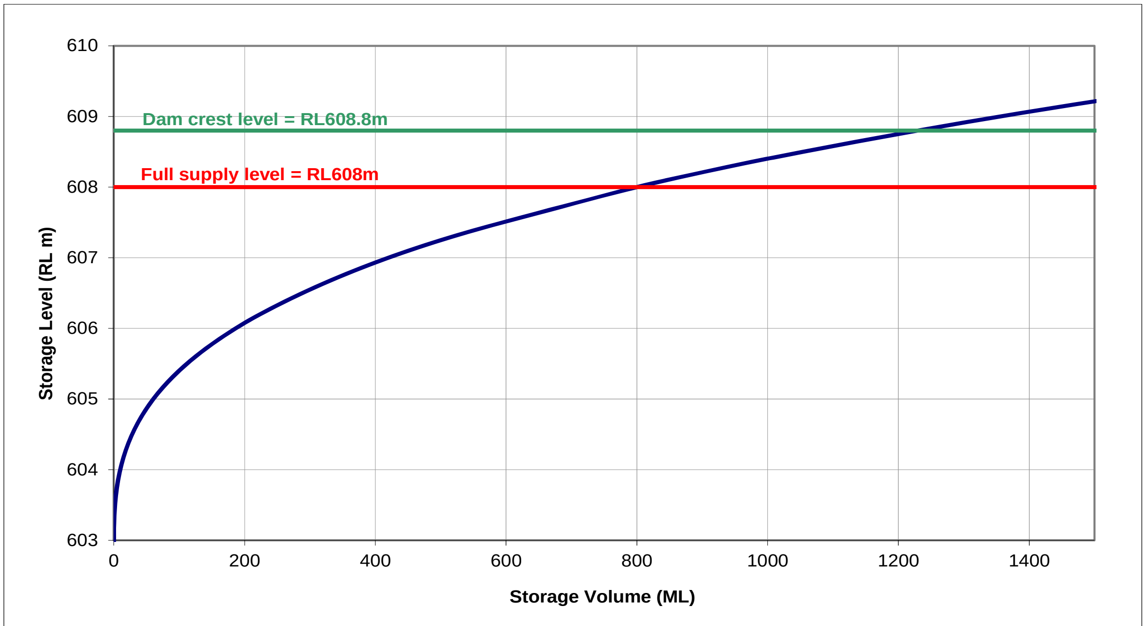


Figure A.1: Waratah Dam Storage Capacity Curve

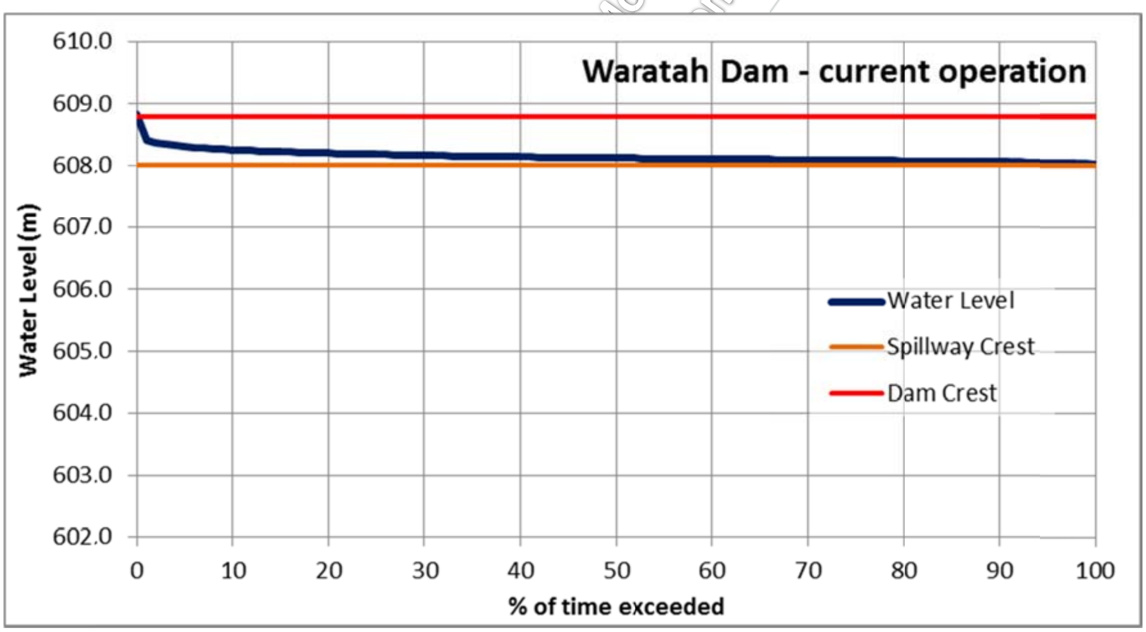


Figure A.2: Waratah Dam – current operation storage duration curve (updated to reflect revised hydrology)

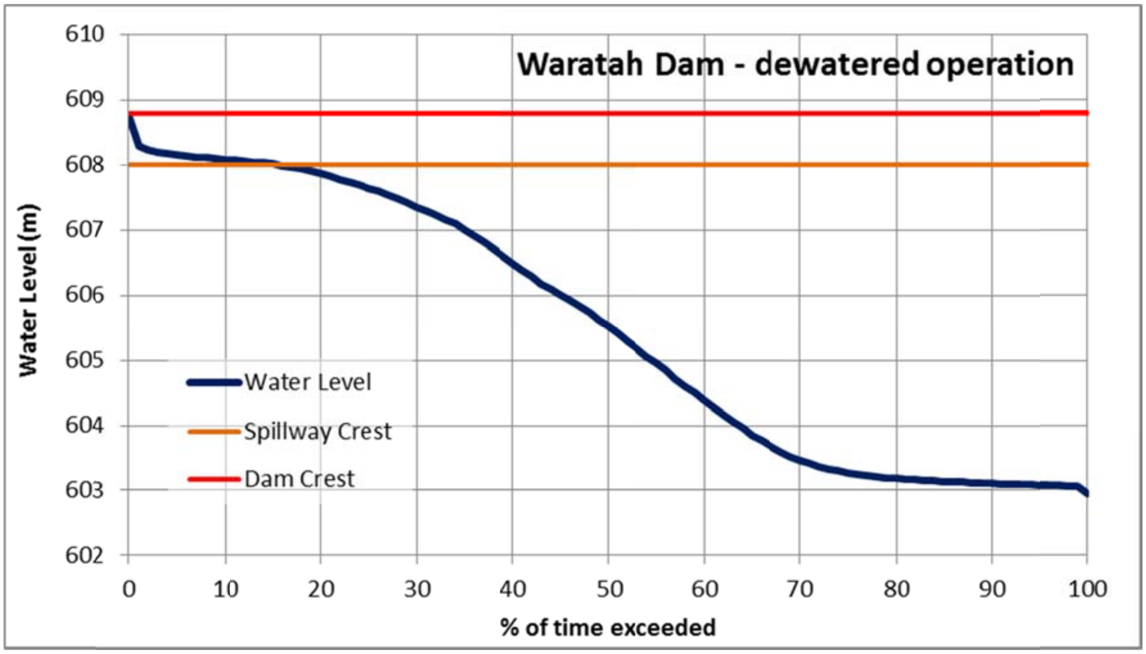


Figure A.3: Waratah Dam – dewatered operation storage duration curve

Table A.1: Waratah Dam - Update Flood Frequency Data

Flood AEP (1:Y, years)	**Flood AEP**	**Storage level – current operation (RL m)**	**Storage level – dewatered operation (RL m)**
1	**1.0E+00**	**608.00**	**603.00**
5	**2.0E-01**	**608.54**	**608.47**
10	**1.0E-01**	**608.61**	**608.55**
50	**2.0E-02**	**608.80**	**608.70**
100	**1.0E-02**	**608.90**	**608.76**
1,000	1.0E-03	608.95	608.90
10,000	1.0E-04	609.04	609.04
100,000	1.0E-05	609.47	609.47
10,000,000	1.0E-07	610.32	610.32

Note: Values bolded in the table above have been reviewed considering the discharge from the scour outlet. For AEP greater than 1:100 the impact of the discharge outlet is negligible, these values in excess of 1:100AEP have been adopted from Hoang & Ng (2013).