NSW Public Works

Proposed Reconstructed Oaky River Dam

Dambreak Study

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Cover photo: Failed Oaky River Dam wall, 29/8/2023 (K. Chan, NSW Public Works)

Executive Summary

Armidale Regional Council (Council) has engaged NSW Public Works (NSWPW) to undertake a reconstruction design for the failed Oaky River Dam. As part of validating the design's compliance, a Dambreak Study is required to determine the Sunny Day and Flood Consequence Categories (SDCC and FCC) for the proposed reconstructed dam. The study was undertaken in full compliance with the guidelines as set by Dams Safety NSW (DSNSW).

The objectives of this Dambreak Study were to determine the proposed dam's Acceptable Earthquake and Flood Capacities (AEC and AFC) via the SDCC and FCC in preparation for the dam's subsequent detailed design and Risk Report.

This study was undertaken in three (3) phases:

1. Hydrologic Modelling – to produce flood inflow data as inputs into the floodplain modelling;
2. Hydraulic Modelling – to analyse the flooding characteristics along the floodplain inclusive of flood inundation mapping; and
3. Dam Failure Consequence Assessment – to analyse the modelled flood impacts (Population At Risk (PAR) analysis, preliminary qualitative desktop environmental impact search, etc.).

The computer flood hydrologic modelling was carried out by WRM Water + Environment with a constructed URBS model while the computer flood hydraulic modelling was carried out by NSWPW with a constructed 2D MIKE+ model. The modelling reach stretched from the dam wall down to the confluence of Oaky and Chandler Rivers. As part of the hydraulic modelling process, a dam flood routing exercise was also carried out to determine the proposed dam's peak floodwater levels for various typical extreme design flood events. Such results were used to form the dam reconstruction concept design. The routing model was also used to produce the dambreak outflow hydrographs which were fed into the MIKE+ model. The analysis encompassed the simulation of seven (7) distinct flood events pertaining to the proposed dam:

1. Sunny Day Dambreak event (SDDB);
2. 1% AEP design flood event (1%);
3. 1% Dambreak event (1%DB);
4. 1 in 10,000 AEP design flood event (10K);.
5. 10K Dambreak event (10KDB);
6. Probable Maximum Flood event (PMF); and
7. PMF Dambreak event (PMFDB).

The dambreak modelling, assessment and determination of the SDCC and FCC were carried out following the latest methodologies from DSNSW and ANCOLD. Flood inundation maps were plotted to assist with the assessment and determination processes. However, the flood dambreak modelling is considered incomplete as ANCOLD's Base Safety Condition (BSC) criteria was not met within the current analysis domain. This is attributed by the tall river valley acting as a massive open channel that efficiently conveys extreme floodwater volumes downstream. Such efficient conveyance system highlights the absence of flat and wide floodplains above the riverbanks in which river floodwater forces and levels are unable to laterally spread and attenuate.

The latest aerial imagery from Six Maps was examined to identified PAR locations. Within the current analysis domain, no such locations were identified due to Oaky River's deep gorge

characteristics downstream of the dam such that human habitation is unlikely and not conveniently supported. With no PAR locations identified, a Potential Loss of Life (PLL) assessment was hence not carried out.

It is imperative that if within Council's control, the dam's downstream PAR (especially non-itinerants) be discouraged to grow within the modelled Dambreak Affected Zones and Incremental Dambreak Zones. This will ensure that the proposed dam's Consequence Categories will not escalate in the future to attract a more stringent DSMS regime, as stipulated by the Regulation and the ANCOLD guidelines, which will involve more of Council's efforts and funding.

Based on the preliminary environmental impact search results, the proposed dam's SDCC and FCC were both determined to be **SIGNIFICANT**. Such requires the reconstruction design of the proposed dam to safely cater for Operating Basis Earthquake (OBE) and Safety Evaluation Earthquake (SEE) of the 1 in 500 AEP and 1 in 1,000 AEP earthquake events respectively; and an AFC of the 1 in 10,000 AEP flood event.

The escalation of the SDCC and FCC from **LOW** (pre 2013 dam failure) to **SIGNIFICANT** is mainly attributed to the recent discovery of the potential presence of environmentally sensitive items downstream of the dam. It is noted that a formal Dambreak and Consequence Study has never been carried out. The current SDCC and FCC status of **SIGNIFICANT**, albeit 'tentative', is considered reasonable (and should not be lowered) given the proposed dam's role in the Armidale 30-year Integrated Water Cycle Management (IWCM) Strategy. To clear the 'tentative' status, extending the current 'incomplete' flood dambreak modelling may be required but would be a significant exercise and the necessity of this should be determined based on future emerging project information, e.g., with the eventual EIS assessment outcomes.

It is noted that the proposed dam wall's stability analysis for potential failure events such as sliding and overturning under the influence of the determined OBE, SEE or AFC event loadings is not part of this study. In terms of the proposed dam's spillway capacity, the design accommodates a minimum freeboard of 0.39 m above the peak dam 1 in 10,000 AEP floodwater level to the proposed Abutment Crest Level (ACL).

In examining potential climate change impacts, the year 2090 SSP5 – 8.5 AFC event was recommended by WRM to be modelled and the peak dam floodwater level increase by 0.80 m compared to current climate conditions. The dam's design was not modified as it was considered 'climate-change-adaptable' since a minimum freeboard of 0.59 m to the top of the dam wall's abutment blocks (above the ACL) would be available. It is NSWPW's recommendation that the subsequent SBA assessment stability analysis of the proposed dam wall complies with the ANCOLD (2013) stability criteria assessed with the climate changed AFC event loading condition. An Environmental Impact Statement (EIS) is required to be undertaken as part of the reconstruction design of Oaky River Dam but has yet to commence. Once underway, the established Streamlined Secretary's Environmental Assessment Requirements (SEARs) may include additional climate change design criteria developed by the consulted stakeholders.

During the eventual undertaking of the EIS, it is further recommended to:

- Examine the necessity of extending the current flood dambreak modelling reach with the opinions of the involved environmental scientists, hydrologists and other relevant stakeholders.
- If the above were to be enacted with additional downstream environmental impacts revealed, redetermining the proposed dam's SDCC and FCC would then be warranted.

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Abbreviations and Notations

ACL	Abutment Crest Level
AEP	Annual Exceedance Probability
AFC	Acceptable Flood Capacity
AHD	Australian Height Datum
ANCOLD	Australian National Committee on Large Dams
ARR2019	Australian Rainfall and Runoff 2019 Edition
AS	Australian Standard
AVM	Average Variability Method
BoM	The Bureau of Meteorology
BSC	Base Safety Condition
Council	Armidale Regional Council
DB	Dambreak
DBAZ	Dambreak Affected Zone
DCF	Dam Crest Flood
DCL	Dam Crest Level
DEM	Digital Elevation Model
DSC	NSW Dams Safety Committee (replaced by DSNSW)
DSEP	Dam Safety Emergency Plan (now known as EP)
DSMS	Dam Safety Management System
DSMSD	DSMS Document
DSNSW	Dams Safety NSW
DV	Flood Depth times Flood Velocity ratio
EF	Exposure Factor
EIS	Environmental Impact Statement
EP	Emergency Plan
FCC	Flood Consequence Category
FSL	Full Supply Level
GSAM	Generalised Southeast Australia Method
GSDM	Generalised Short Duration Method
GTSMR	Generalised Tropical Storm Method Revised

IDBZ	Incremental Dambreak Zone
NSWPW	NSW Public Works
O&M	Operations and Maintenance
OBE	Operating Basis Earthquake
PAR	Population At Risk
PAREX	Exposed Population At Risk
PLL	Potential Loss of Life
PMF	Probable Maximum Flood
PMFDB	Probable Maximum Flood Dambreak Event
PMP	Probable Maximum Precipitation
PMPDF	Probable Maximum Precipitation Design Flood (replaced by the PMPF in ARR2019)
PMPF	Probable Maximum Precipitation Flood
RBA	Risk Based Approach
RCEM	Reclamation Consequence Estimating Methodology
RFFE model	Regional Flood Frequency Estimation Model (replaced the Rational Method where applicable)
SBA	Standards Based Approach
SEE	Safety Evaluation Earthquake
SES	State Emergency Service
SDCC	Sunny Day Consequence Category
SDDB	Sunny Day Dambreak Event
TF	Time of Day Factor
WT	Warning Time

1. Introduction

1.1 General

Armidale Regional Council (Council) has engaged NSW Public Works (NSWPW) to undertake a reconstruction design for the failed Oaky River Dam. As part of validating the design's compliance, a Dambreak Study is required to determine the Sunny Day and Flood Consequence Categories (SDCC and FCC) of the proposed reconstructed dam to satisfy the dam's Dam Safety Management System (DSMS), mandated by the *Dams Safety Regulation 2019*. This study has been carried out in accordance with current guidelines as set by Dams Safety NSW (DSNSW) and ANCOLD.

A total of seven (7) extreme flood events were modelled for the dam and its downstream floodplain to satisfy DSNSW's requirements:

1. Sunny Day Dambreak (SDDB) event;
2. 1% AEP Design Flood (1%) event;
3. 1% Dambreak (1%DB) event;
4. 1 in 10,000 AEP design flood (10K) event;
5. 10K Dambreak (10KDB) event;
6. Probable Maximum Flood (PMF) event; and
7. PMF Dambreak (PMFDB) event.

The main objectives of this study was to:

- Quantitatively assess the Potential Loss of Life (PLL) estimates for the above extreme flood events.
- Determine the proposed reconstructed dam's SDCC and FCC.
- With the above, deduce the dam's Operating Basis Earthquake (OBE), Safety Evaluation Earthquake (SEE) and Acceptable Flood Capacity (AFC) requirements.
- Prepare input data for the dam's subsequent detailed design and Risk Report calculations.

This study was undertaken in three (3) phases:

1. Hydrologic Modelling – to produce flood inflow data as inputs into the floodplain modelling;
2. Hydraulic Modelling – to analyse the flooding characteristics along the floodplain inclusive of flood inundation mapping; and
3. Dam Failure Consequence Assessment – to analyse the modelled flood impacts (PAR analysis, preliminary qualitative desktop environmental impact search, etc.).

1.2 Background Information

Oaky River Dam was (pre-failure) / is currently a ‘declared’ water retaining structure under the *Dams Safety Act 2015* even though its SDCC and FCC were both previously determined to be **LOW**. It is the only sizeable prescribed / declared dam that has failed in recent NSW history. Armidale Regional Council (Council) engaged NSW Public Works (NSWPW) to undertake a reconstruction design for the dam.

Oaky River Dam was constructed between 1951 and 1956 by the then New England County Council (later Country Energy and then Essential Energy) as part of the Oaky River Hydro-Electric Scheme. The scheme served to provide power to its constituent areas in the Armidale region.

The dam is located approximately 50 km east of Armidale and is accessible by a reasonably conditioned road, with the last 10 km being gravel. With a gross storage capacity at Full Supply Level (FSL) of approximately 2.78 GL (top of the existing closed radial gates) and a catchment area of 203 km², the dam wall contained waters in Oaky River which were then diverted through a tunnel and steel pipe to a surface power station located approximately 1 km downstream of the dam on the right bank of the river.

The as built dam comprised a concrete gravity gated overfall section flanked by concrete faced rockfill abutments. The concrete section had a crest length of 43 m and a maximum height of 11 m. The rockfill abutments had a maximum height of 18 m, crest lengths 40 m (left) 50 m (right), crest width 10 m and side slopes of 1V:1.3H both upstream and downstream.

Floodwaters were controlled by four 8.5 m wide by 6.7 m high steel radial gates which provided a 0.90 m freeboard to the crest of the rockfill abutments. The gates were numbered 1 to 4, no.4 being closest to the dam’s right bank. Gates 1 and 4 could only be operated manually while gates 2 and 3 could be operated automatically or manually.

Water was drawn through a 0.90 m diameter steel pipe for discharge to the power station. There were four 1.20 m diameter scour pipes.

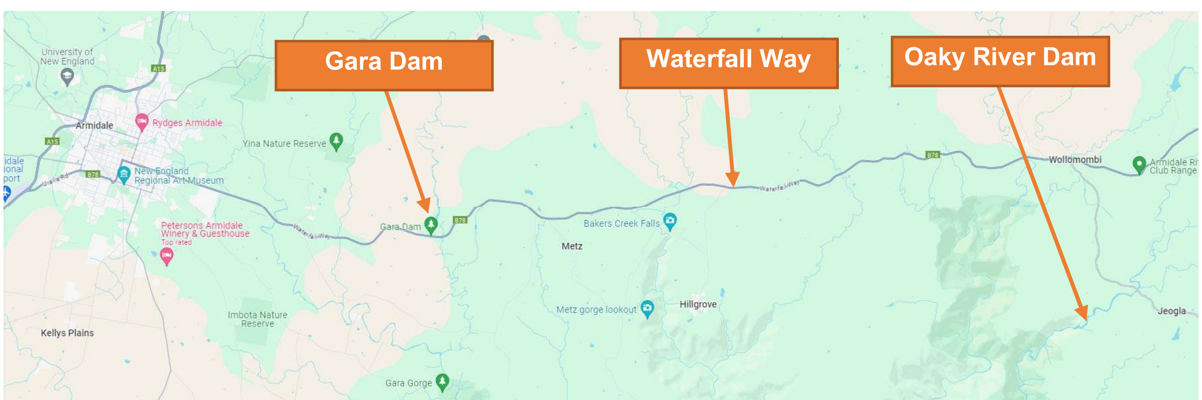

Figure 1-1 Oaky River Dam Locality Plan

Following an extreme flood event on Friday 22nd February 2013, water overtopped the dam crest leading to total collapse of the right embankment and one span of the nearby intake tower access bridge. The dam’s left embankment was also severely damaged. As a consequence of the collapse of the right embankment, the power to the gates was cut, rendering them inoperable. The dam was not repaired by Essential Energy.

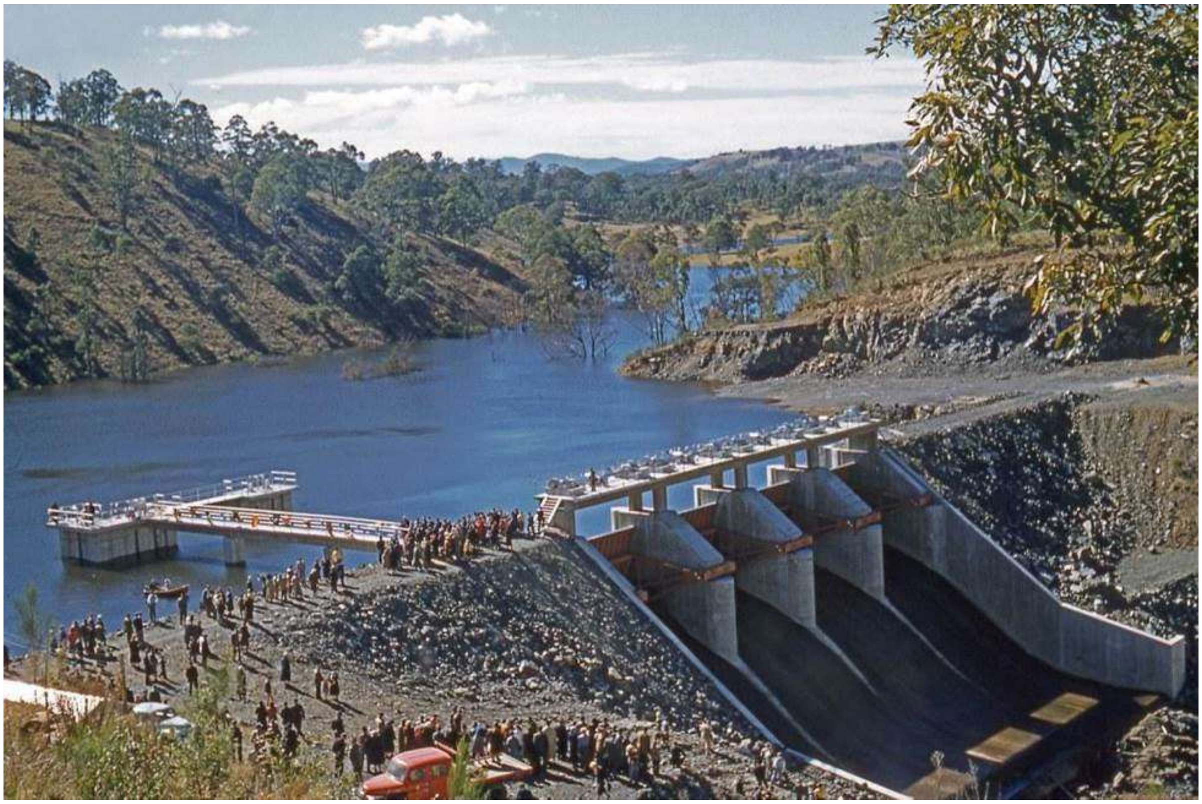

Figure 1-2 Oaky River Dam Opening 1956

Figure 1-3 Oaky River Dam Post-Failure

To accommodate Armidale's aspirational growth water usage demand as part of their 30-year Integrated Water Cycle Management (IWCM) Strategy, Council in 2022 decided to purchase and reconstruct Oaky River Dam as an 'immediate' water planning solution compared to augmenting Malpas Dam. A new pipeline will be constructed to feed the Oaky River Dam storage waters to the Armidale Water Treatment Plant. Refer to NSWPW's May 2024 'Consolidated Options and Scenario Analysis' report for details of the demand and yield modelling outcomes.

In April 2024, NSWPW carried out a concept design for the reconstruction of the dam wall, intake and outlet system. For the new concrete gravity wall, which will completely span from abutment to abutment, the design entails a new mass concrete buttress cross-section encasing / keying into the existing central concrete ogee spillway structure, with the existing defunct radial gates and crest footbridge removed. Below figure presents the 3D model of the dam wall's design.

Refer to NSWPW's 'Oaky River Reconstruction Concept Design' report for further information.

Table 1-1 summarises the general characteristics of the proposed reconstructed dam.

Table 1-1 Dam Data Sheet as of NSWPW's April 2024 Concept Design

Name	Oaky River Dam
Ownership	Armidale Regional Council
Designed	NSW Public Works (2024-25)
Year of Completion	Yet to be constructed
River / Creek	Oaky River
Purpose	Potable water supply
Dam Wall Type	Concrete gravity structure
Max. Height	Approx. 19 m to FSL at max. section
Total Crest Length	Approx. 208 m
Crest Width	Approx. 2.62 m ogee top
Base Width	Approx. 17 m at max. section
Full Supply Level (FSL)	874.50 mAHD (same as top elevation of current defunct radial gates)
Capacity	2.78 GL @ FSL
Dam Crest Level (DCL)	@ FSL
Spillway Trigger Level	@ FSL
Spillway Type	130 m long ogee crest with stepped downstream face
Abutment Crest Level (ACL)	878.65 mAHD RHS ~42 m long; LHS ~26 m long
Dam Catchment Area	203 km^2
Intake and Outlet Works	▪ Two Chambers Intake Structure and Pump Station – Fifteen 1.76 m × 2 m intake ports from 875.50 to 866 mAHD for draw off to water supply pump station; Three intake ports for future hydro power generation system. All ports will be fitted with trashracks and fine screens.

	▪ Booster pump station Outlet Penstock – DN750 with DN800 guard valve (butterfly). ▪ Dewatering Outlet Penstock – DN500 with DN500 guard valve (butterfly) reducing to DN300. ▪ Environmental Release Outlet – DN150 with DN150 control valve (plunger) from downstream of the DN500 butterfly valve.
Sunny Day Consequence Category	SDCC = LOW*
Acceptable Earthquake Capacity	Operating Basis Earthquake (OBE) = 1 in 500 AEP* Safety Evaluation Earthquake (SEE) = 1 in 1,000 AEP*
Flood Consequence Category	FCC = LOW*
Acceptable Flood Capacity	AFC = 1 in 1,000 AEP*

* Expired. Revised with the results of this study (see Section 3).

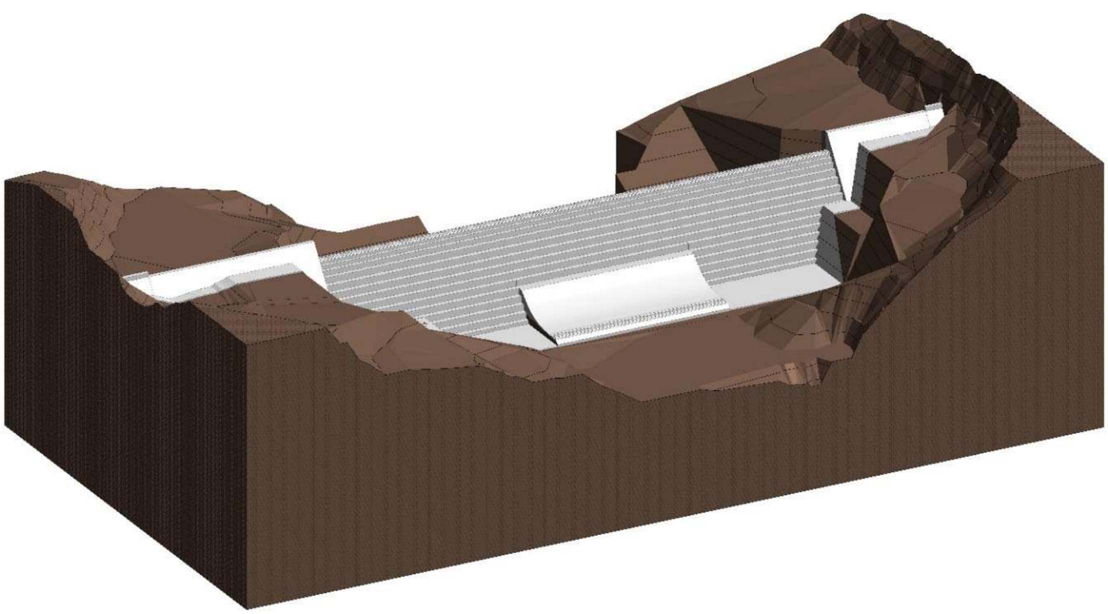

Figure 1-4 Concept Design of the Oaky River Dam Wall Reconstruction

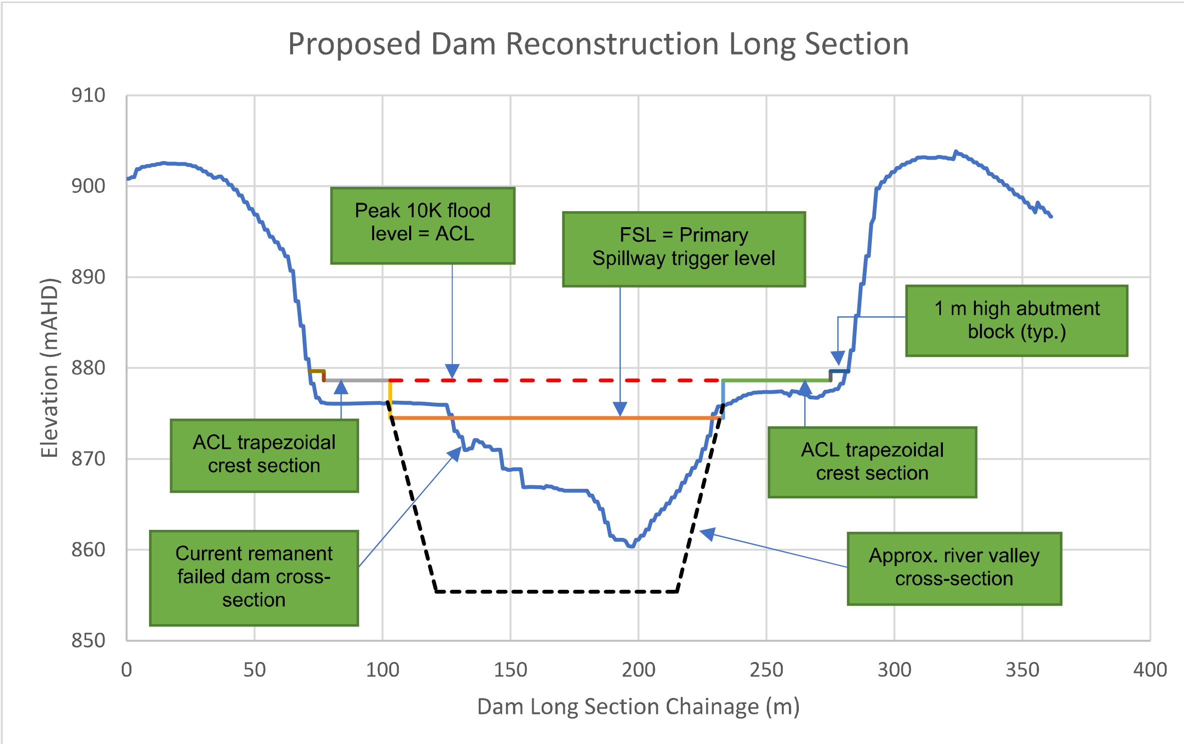

Figure 1-5 Proposed Dam Reconstruction Long-Section (facing downstream)

1.3 Requirements of Dams Safety NSW (DSNSW)

For declared dams, basins and other related water retaining structures in NSW, except for flood levee systems, DSNSW requires a number of mandatory dam safety documents to be available / exercised by the dam owner in accordance with the Dams Safety Act 2015 and the Dams Safety Regulation 2019. “Declared” dams generally refers to structures that:

- Were “prescribed” prior to the repeal of the Dams Safety Act 1978; or
- Retain / detain waters over 15 m high; or
- Cause a major or catastrophic level of severity of damage or loss in the event of credible structural failures; or
- endanger the life of a person (the conditional probability of a 10% chance of the loss of one (1) life, or worst) in the event of credible dam failures.

Some of the mandatory safety operation documents include:

- Dam Safety Management System Document (DSMSD).
- Emergency Plan (EP) (to be reviewed annually and updated every 5 years under normal conditions / circumstances).
- Operation and Maintenance (O&M) Plan (to be updated annually but 5 yearly for dams with their critical Consequence Categories lower than **HIGH C**).
- Dambreak and PLL Study (also known as the *assessment of consequence categories* – generally to be reassessed every 15 years under unchanged conditions / normal circumstances).

- Comprehensive Safety Review (generally to be reassessed every 15 years under unchanged conditions / normal circumstances).
- Risk Report (5 yearly intermediate review of the Safety Review).
- Annual Dams Safety Standards (ADSS) Report.
- 5 yearly external Surveillance Inspection Report.
- Intermediate external inspection report.

Similar to the advice from ANCOLD, DSNSW recommends the abovementioned documents to be prepared in consideration of not just the structure alone, but also the evolving downstream environment. The main objectives of these investigations / documents are to assist the dam owner to understand and manage the tolerability of identified credible dam failure risks. It is expected of the owner to manage the safety and residual / emerging risks of their water retaining structure(s) through a dedicated Dam Safety Management System (DSMS), which is required by DSNSW to be documented in a DSMS Document (DSMSD).

According to the Regulation, an external peer review performed by a “competent person” of the Consequence Categories (i.e., a Dambreak and PLL Study) would be required for structures with their critical Consequence Category assessed to be **HIGH C** or higher. For further technical dam safety information and requirements, the dam owner is encouraged to consult the Regulation, DSNSW guidelines or dam engineering consultants to ensure that their structures are appropriately investigated, designed, constructed, operated and maintained.

2. Computer Flood Modelling

2.1 Preparation of Flood Modelling Input Data

2.1.1 Storage-Height Relationship

Oaky River Dam's storage-height curve was developed based on ELVIS LiDAR data (2018, 2 m grid) and boat probing of a number of dam storage valley cross-sections below an instantaneous breached storage elevation of 862.42 mAHD (31st August 2023 by NSWPW).

The boat probing estimated the dam storage invert to be at approximately 855.40 mAHD. With the survey valley cross-sections post-processed with 12D and Leica Infinity, the volume retained by the breached dam wall at 862.42 mAHD was estimated to be approximately 39,500 m^3. Refer to **Appendix A** for details of the estimation methodology. As this elevation was deemed to be below the optimal water draw-off elevation range, in terms of suspected water quality concerns and physical constraints of the eventual intake structure, it was considered acceptable to assume a linear storage-height relationship from the invert to this elevation, for the general purposes of this study.

It was observed that the ELVIS LiDAR was only reasonably accurate from 863 mAHD upwards due to the scan picking up the instantaneous water surface elevations at the time of the LiDAR flyover. As a result, the storage volumes between 862.42 mAHD and 863 mAHD were extrapolated from the assumed linear storage-height relationship as explained above. The ELVIS LiDAR generated volume data from 863 mAHD to 893 mAHD was subsequently 'stitched' on top.

'Truthing' of the 2018 ELVIS LiDAR was attempted with the localised dam wall drone LiDAR captured as part of NSWPW's August 2023 survey expedition. In summary, it was found that the 2018 ELVIS LiDAR offered elevations on average 0.267 m *higher* than then localised drone LiDAR data. This means dam storage volumes determined with ELVIS LiDAR are likely to be conservative if compared to 'truthing' the storage elevations by generally subtracting 0.267 m (i.e., gaining volumes by 'dropping' the grid). As such, the decision was made to not adjust the elevations of the storage-height curve generated with the ELVIS LiDAR due to accuracy uncertainties of this simple localised truthing exercise.

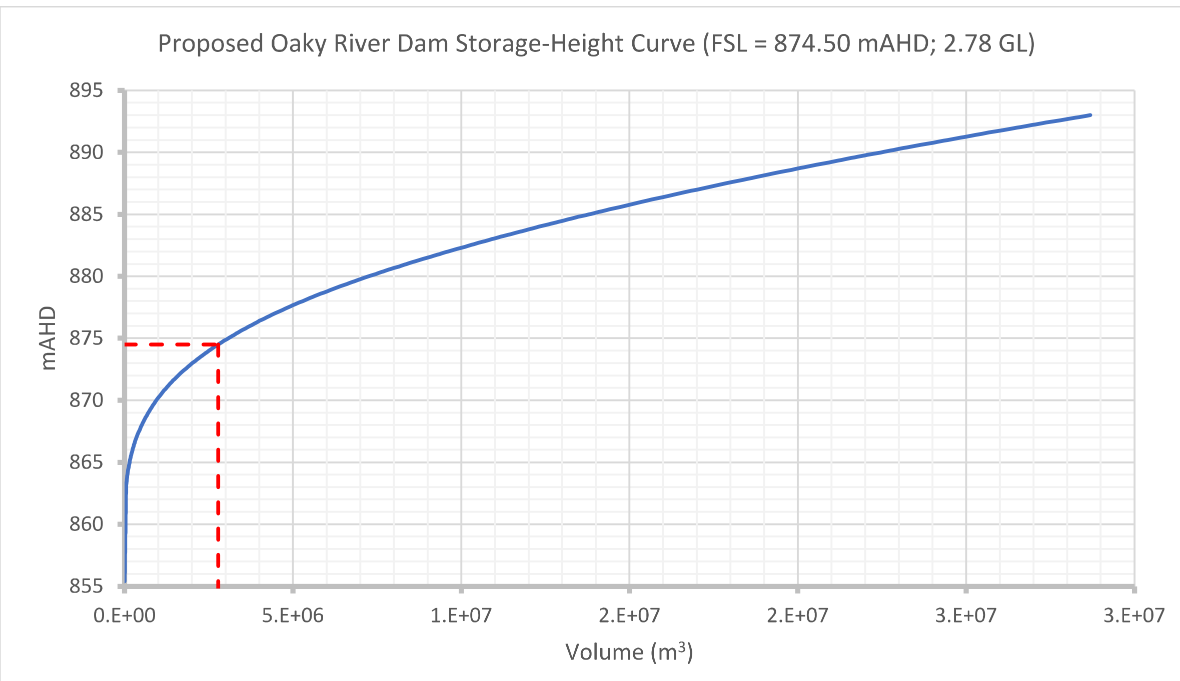

Figure 2-1 Oaky River Dam Storage-Height Curve

2.1.2 Spillway Rating, Initial Dam Flood Routing and Concept Design

The spillway rating was developed in two phases; an initial phase for the purpose of determining the critical-duration-representative AFC event during the hydrologic modelling for the concept design; and a final phase to develop a more accurate rating for the flood dambreak outflow modelling following the concept design. NSWPW's subconsultant WRM Water + Environment was engaged to carry out the dam's flood hydrology study and initial dam flood routing exercise.

The following is a summary of the modelling steps undertaken to arrive at the concept design spillway configuration, which was prior to the undertaking of this dambreak study:

- The proposed spillway trigger level, i.e., the Full Supply Level (FSL), was set at 874.50 mAHD which is the dam's previous pre-failure FSL at the top elevation of the current defunct radial gates, as requested by Council. This was also set as the initial dam storage water level condition for the subsequent dam routing exercise as suggested by ARR2019.
- A 'convenient' uncontrolled overfall spillway length of 130 m was estimated based on the current valley cross-section shape along the current dam long-sectional centreline as revealed by the available ELVIS LiDAR data.
- WRM then proceeded with the AFC dam flood routing exercise with an URBS model assuming:
  - a static weir co-efficient of C = 2, i.e., representing the dam's spillway ogee crested structure, for the entire 130 m overfall spillway length. This was referred to as the 'primary spillway section' in the routing. This co-efficient used by the URBS model through the broad crested weir equation formed the initial spillway rating relationship.
  - the flood releases to be fully contained within the 130 m overfall spillway length during the flood event's entire duration, i.e., no flood overtopping at the Abutment Crest Level (ACL).
  - the AFC to be the 1 in 10,000 AEP flood event based on the expectation that the FCC would be determined to be **SIGNIFICANT**.
- This yielded the dam's critical-duration-representative event for the AFC in which its routed peak floodwater level of 878.65 mAHD was set as the ACL, i.e., the 130 m long overfall spillway section fully contains the AFC event.
- The abutment crest portions, both sides beyond the primary spillway, were designed as trapezoidal cross-sections (vertical upstream face; 1V:0.7H downstream face) for simple construction since weir overflow efficiency is not essential for flood events less frequent (more severe) than the AFC event. This was referred to as the 'secondary spillway sections' in the routing.
- Arbitrary 1 m high 'abutment blocks' (above the ACL) were allowed for at both dam wall abutments to neatly contain some extreme flood overtopping exceeding the AFC event.

The above results were adopted as the base physical dimensions for the dam reconstruction concept design.

Refer to the following subsection for further reporting of the hydrologic modelling.

After the initial dam flood routing exercise assisting with the determination of the conceptual primary spillway length and the ACL, the spillway rating was subsequently more accurately revised for the flood dambreak outflow modelling, i.e., one of the many tasks of this study.

Three (3) spillway rating curves were developed to fully serve the final dam flood routing exercise:

- Primary spillway – The rating of the designated ogee section was estimated with the broad crested weir equation with head-varying C coefficients in accordance with the internationally recognised 'Design of Small Dams' publication. The subsequent 2D floodplain modelling from downstream of the dam wall confirmed that the primary spillway would not be drowned out at the peak of the AFC event.
- Secondary spillway (ACL overtopping) – The rating for flood overtopping of the trapezoidal abutment crest sections was estimated with the broad crested weir equation with head-varying C coefficients in accordance with empirical values for trapezoid-shape weirs published in the internationally recognised textbook 'Brater and King'.
- Tertiary spillway (informal overflow) – The dam storage's immediate right rim, along the current unpaved access road alignment, would commence 'flood breakout' to the west when the dam's floodwater elevation exceeds 879.28 mAHD. This is generally referred to as the 'right saddle' and the breakout floodwaters would drain southwest and eventually merge back into Oaky River some 850 m downstream of the dam wall. The rating of the saddle was modelled by WRM on HEC-RAS with the conveyance cross-sections extracted from ELVIS LiDAR data. Below figure shows the proximity of the right saddle.

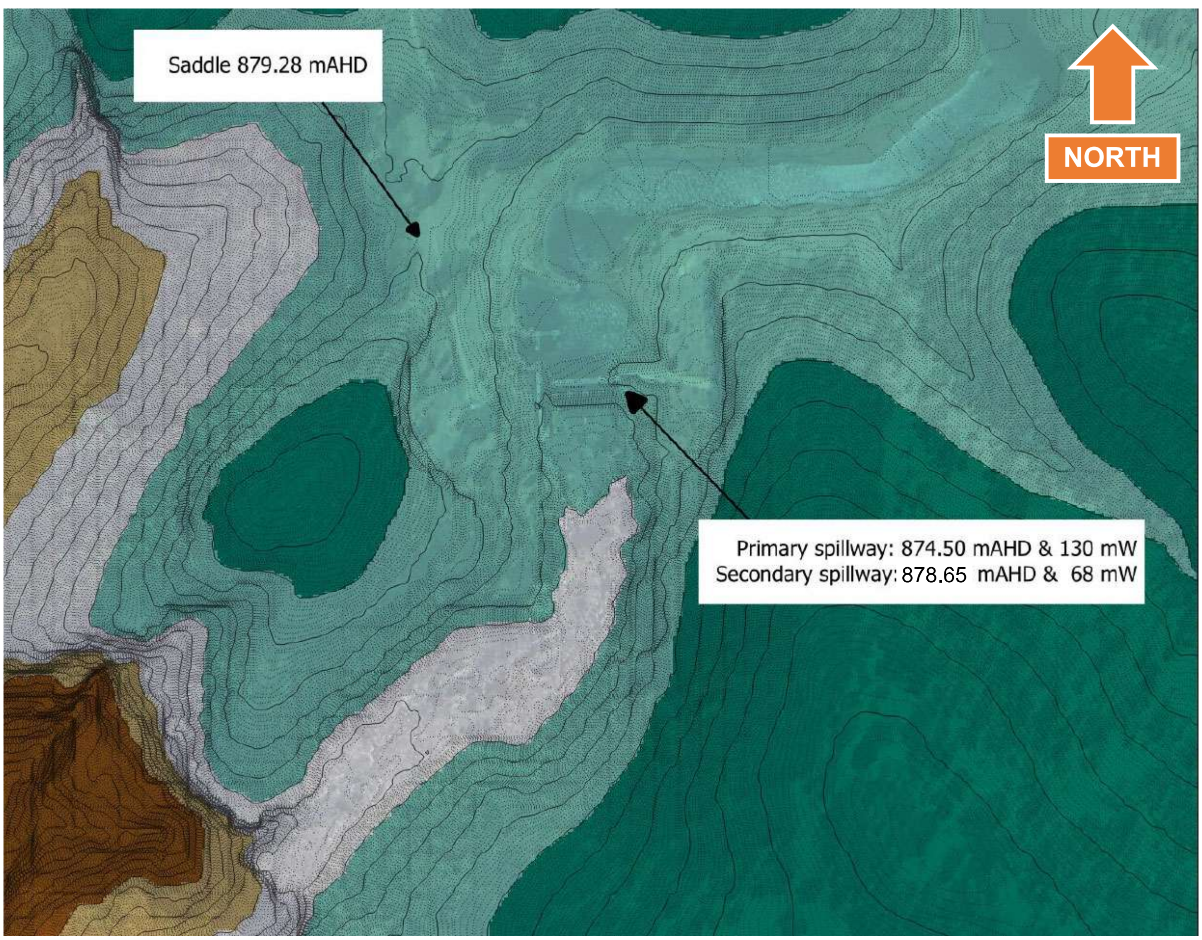

Figure 2-2 Location of the Right Saddle in reference with Dam Wall (after WRM, 2024)

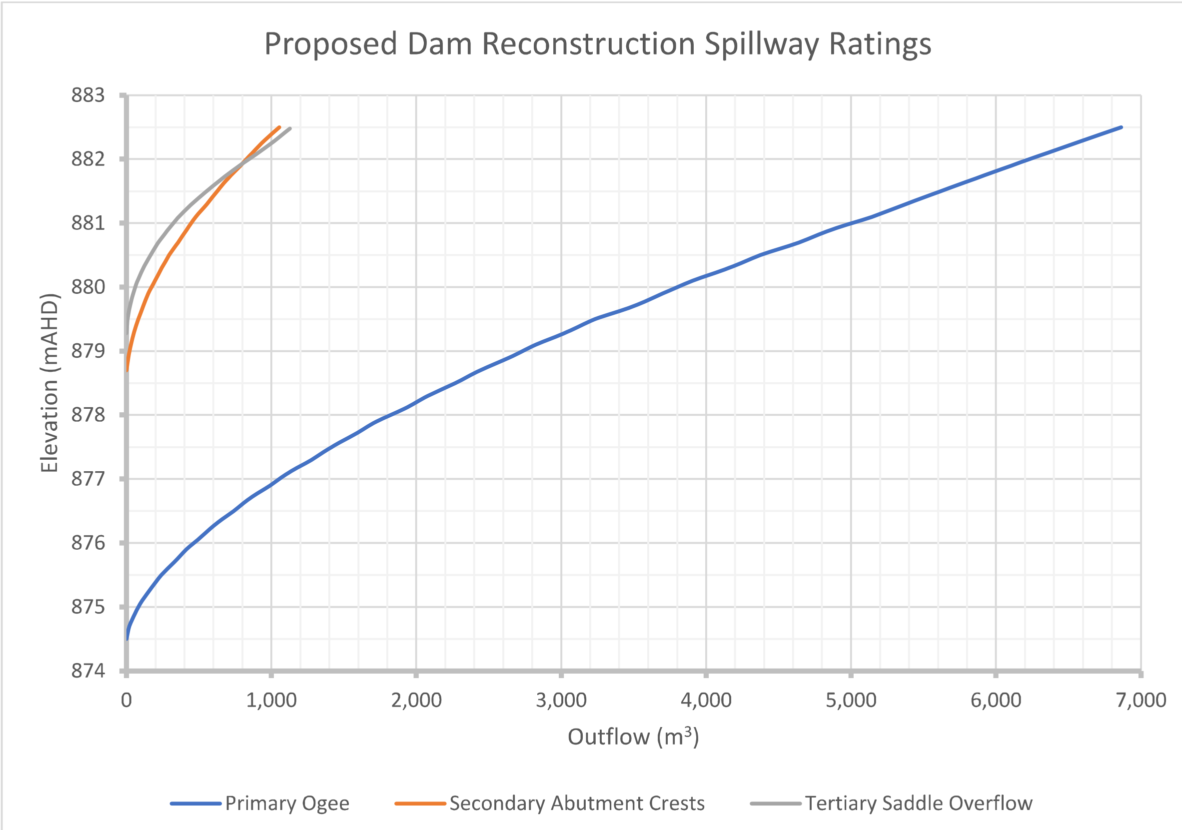

Figure 2-3 Proposed Spillway Ratings

2.2 Hydrologic Modelling

2.2.1 Description of Model

An URBS hydrological model was constructed by WRM to accomplish the flood hydrology modelling for the dam and the downstream concurrent flooding catchments. The modelling was accomplished in accordance with ARR2019 and the latest BoM guidelines. Refer to **Appendix B** for WRM's full modelling report.

The modelling captured the Oaky River Dam catchment as well as the downstream concurrent flooding catchments down to Oaky River's confluence with Chandler River. As no historic streamflow gauges or rainfall stations are available within the Oaky River Dam catchment, calibration of the URBS model was not possible. Hence the modelling parameters and discharges were verified against results from the Regional Flood Frequency Estimate (RFFE) model and 'rapid' empirical PMPF / PMF comparison methods by Watt et al. (2018).

As briefly reported in Subsection 2.1.2, WRM carried out the initial dam flood routing process with the constructed URBS model. Most of the standard extreme flooding AEPs were examined to produce stage and discharge Flood Frequency Curves (FFC) for the proposed dam. The determination procedure of the critical-duration-representative flood events for each AEP is described following.

- For all three events, the critical storm duration is the duration derived from the nearest event above mean dam water level for the ensemble of 10 temporal patterns for that duration.
- For the 1 in 100 and 10,000 AEP events, the representative design storm is the storm which produced a peak dam water level (and peak dam outflow) that is closest to (but above) the median dam water level for the critical duration.
- For the PMF, the representative design storm is the storm which produced the highest peak dam water level and highest peak dam outflow.

Figure 2-4 Representative Flood Events Determination Procedure (after WRM, 2024)

Refer to WRM's results for the initial routing results and FFCs. Refer to the following subsection for a summary of the final dam flood routing results.

With the dam's critical-duration-representative flood events determined, the downstream concurrent flooding inflow hydrographs were produced corresponding to the respective representative events for logical modelling consistency. All inflow hydrographs were used as inputs into the subsequent 2D flood hydrodynamic modelling which examined the 1% AEP (1%) flood, 1 in 10,000 AEP (10K) flood and the PMF events.

2.3 Hydraulic Modelling

2.3.1 Final Dam Flood Routing

With the more accurately revised spillway rating curves as described in Subsection 2.1.2, NSWPW performed the final dam routing with a MIKE11 model as it is capable of also producing dambreak outflow hydrographs. The proposed dam's storage-height curve, spillway rating curves and the dam flood inflow hydrographs corresponding to the critical-duration-representative events were the input data into the construction of this final routing model. The follow table summarises the final dam flood routing results.

Table 2-1 Final Dam Flood Routing Results Summary

AEP	Peak Dam Floodwater Level (mAHD)	Freeboard to ACL (m)	Overtopping Status (m)*
1%	876.13	2.52	---
1 in 1,000	877.18	1.47	---
1 in 10,000	878.26	0.39	---
1 in 100,000	879.68	Overtopping	0.03
1 in 1 million	880.65	Overtopping	1.00
1 in 5 million (PMPF)	881.15	Overtopping	1.50
1 in 9 million (PMF)	881.32	Overtopping	1.67

* Top of abutment blocks @ 879.65 mAHD

It is noted that the above peak dam floodwater levels are different to WRM's initial routing results. NSWPW's 1% AEP result was higher than WRM's due to a lower weir C co-efficient efficiency at low heads (i.e., not yet reached an efficiency of C = 2). From the 1 in 1,000 AEP flood and upwards, i.e., higher heads, NSWPW's results were lower than WRM's since C ≥ 2 efficiency was achieved.

In accommodating for some conservatism and modelling uncertainties, WRM's initial 1 in 10,000 AEP flood routing peak of 878.65 mAHD was retained as the proposed ACL in the reconstruction concept design.

2.3.2 Dambreak Outflow Modelling

Dambreak modelling of the proposed dam characteristics was accomplished with the constructed MIKE11 model as described above.

Due to the difficult and uncertain nature in estimating the full breach shape of concrete gravity dam walls, ANCOLD (2012) was sought to assist with the breach shape and time estimation. According to ANCOLD (2012), *it is suggested that at least 30% of the monoliths are removed within either an instantaneous or relatively short period of time*. However, a complete dam wall removal type breach was adopted to more appropriately represent the consequences of typical concrete gravity dam wall overturning failures as this failure mode (generally considered more catastrophic than sliding failures) will be examined in the dam's upcoming stability analysis.

The Breach Formation Time (T_F), which has been defined in various ways by different academics, however, its most recognised definition is the duration from the first instance of breaching of the dam to when the breach is fully formed, was set at 5 mins for all examined dambreak events. In consideration of model numerical stability due to the sudden release of extreme flood flow volumes, 5 mins was notionally adopted to adequately represent an instant failure / removal of the dam wall.

Several well-known published dam breach prediction papers (e.g. Wahl 1998 & 2004, Pierce 2010) describe empirical relationships between various dam characteristics and dam breach parameters (overtopping and non-overtopping scenarios) for earthen / rockfill embankment and concrete dams. Some of the empirical equations discussed include the Von Thun and Gillette Method, Froehlich Method, Costa Method, Hagen Method, USBR Method, etc. Of note, both Costa and Hagen's Methods were explicitly indicated to contain recorded concrete dam wall failure data. These two (2) methods included expressions to estimate the peak dambreak (DB) outflow value.

The resultant dambreak outflow hydrographs formed part of the inputs required for the subsequent 2D floodplain modelling. The following table summarises the adopted dam breach parameters for the examined dambreak events.

Table 2-2 Adopted Breach Parameters for the Proposed Reconstructed Oaky River Dam

Parameter	SDDB	1%DB	10KDB	PMFDB
Breach Times				
Storage Initial Condition	At FSL			
Time of Breach (T_B)	Immediate at T = 0	At peak floodwater elevation		
Breach Formation Time (T_F)	Assumed 5 mins commencing at T_B			
Breach Dimensions *(Linearly fully developed within T_F)*				
Completed Breach Shape	Complete dam wall removal; completed breach shape as per river valley cross-section dash line as depicted in Figure 1-5			
Estimated Empirical Peak Dambreak Outflow Range*	6,153 – 6,603 m^3/s	7,448 – 7,865 m^3/s	9,318 – 9,659 m^3/s	12,351 – 12,506 m^3/s
Modelled Peak Dambreak Outflow#	9,589 m^3/s	10,771 m^3/s	12,660 m^3/s	18,025 m^3/s

* Estimated with empirical equations from Costa and Hagen.

MIKE11 dambreak routing results. Calibration of the model by prolonging the T_F to obtain a peak within the empirical range was not attempted as a T_F > 5 mins is not considered in line with ANCOLD 2012's suggestion of "removed within either an instantaneous or relatively short period of time".

2.3.3 2D Flood Hydrodynamic Modelling

The floodplain hydrodynamic model was setup using the advanced hydraulic software MIKE+ 2024. The analysis encompassed the simulation of seven (7) distinct flood events pertaining to the proposed dam:

1. Sunny Day Dambreak event (SDDB);
2. 1% AEP design flood event (1%);
3. 1% Dambreak event (1%DB);
4. 1 in 10,000 AEP design flood event (10K);.
5. 10K Dambreak event (10KDB);
6. Probable Maximum Flood event (PMF); and
7. PMF Dambreak event (PMFDB).

At this stage, the modelling of three (3) flood related dambreak events is considered adequate enough to provide some resolution in highlighting the crucial gradient changes of the 'AEP vs consequences' relationship for subsequent risk assessments.

2.3.3.1 Topographic Data

Accurate topographic data is fundamental for understanding floodplain characteristics. For this study, Digital Elevation Model (DEM) data was obtained from a reliable government source, the ELVIS Elevation and Depth website (https://elevation.fsdf.org.au/). This cloud-based platform facilitates easy access to Australian elevation and bathymetry data within specific areas of interest.

This investigation focused on the Oaky River Dam downstream catchment area, for which the most suitable DEM dataset was provided by NSW Spatial Services. The characteristics of this dataset are as follows:

- LiDAR capture – conducted between May 2015 and September 2015.
- Vertical accuracy ± 0.30 m at 95% confidence interval.
- Horizontal accuracy ± 0.80 m at 95% confidence interval.
- Resolution 2.00 m grid.

This dataset's robust characteristics ensure its suitability for the flood modelling analysis, offering reliable elevation data crucial for assessing flooding consequences.

2.3.3.2 2D Model

The DEM obtained from ELVIS was processed to create a 5 m grid covering the entire floodplain downstream of the Oaky River dam wall. ESRI ArcGIS' bilinear sampling technique was applied for resampling to ensure accuracy and consistency in representation.

The model domain was extended downstream to encompass a total length of approximately 20 km along the Oaky River, extending from the dam to the confluence with Chandler River. Additionally, an extra 6 km of Chandler River upstream from the confluence was incorporated into the model to accommodate the hydrodynamics of the adopted downstream modelling boundary conditions (refer to Subsection 2.3.3.5).

A 5 m grid size was chosen to balance computational efficiency with the need to preserve natural floodplain characteristics. This grid resolution enables the representation of intricate terrain features while maintaining reasonable model run times, particularly crucial for accommodating the significant dambreak flow rates anticipated in the analysis. This DEM formed the modelling base in MIKE+'s MIKE21 component. The computational domain of the 2D model encompassed a total of 4,305,630 grid points. This included the integration of eight (8) catchment concurrent flooding inflow points along the river onto the MIKE21 model, sourced from the hydrology study as described in Subsection 2.2.1.

2.3.3.3 1D Model

To ensure accurate representation of inflow boundaries in the 2D model, a 1D model was configured. This setup served a dual purpose: firstly, to incorporate model inflow boundaries into the 2D model, and secondly, to efficiently distribute exceptionally large flows from both dambreak and catchment inflows originating from the extreme flood events onto the finely gridded 2D modelling base.

Cross-sections derived from the DEM were extracted to delineate model boundary interfaces and incorporated in the 1D model domain. This approach not only enhanced the accuracy of the model representation but also minimised boundary instability, thus improving the overall reliability and accuracy of the hydraulic simulations.

2.3.3.4 Manning's 'n' Categorisation

Given the extensive dambreak modelling and the relatively consistent, undisturbed nature of the catchment and floodplain, a uniform Manning's 'n' roughness coefficient of 0.067 was applied. This choice accommodates the large flows while ensuring practical efficiency in computation. The standardised approach maintains model robustness and comparability across scenarios, facilitating interpretation processes.

2.3.3.5 Downstream Boundary Conditions

The 2D model uses a free outflow boundary condition that facilitates the natural flow of water out of the computational domain, mimicking real-world conditions where water exits without obstruction. This boundary condition is implemented using a 'weak' approach, where the values of primitive variables, such as water level and velocities, in a virtual 'ghost cell' adjacent to the boundary are determined based on the values of the nearest interior cell within the model domain. To ensure a smooth transition, a simple Neumann condition is applied at the boundary, specifying that the gradient (or slope) of the water level and velocities remains zero. This boundary was placed at the confluence of Chandler and Styx Rivers, approximately 8 km downstream of the confluence of Oaky and Chandler Rivers, to avoid potential boundary modelling instabilities disturbing the results at the Oaky-Chandler confluence which is the current dambreak consequence analysis extent.

To supplement the hydrodynamics of this applied boundary condition, preliminarily estimated 'static' inflows from the Chandler River catchment were inserted into the short 6 km stretch of Chandler River, allowed for in the 2D model domain, to 'fill up' the 8 km of Chandler River from confluence to confluence. This 'fill up' is to ensure that some expected 'flood impact cushioning' is allowed for such that the modelled incremental flood conditions (i.e., dambreak incremental flood depths and dambreak flow velocities vs natural flood flow velocities) would be realistic enough to not result in unreasonable differences. Refer to **Appendix C** for WRM's adopted procedure in estimating the supplementary flows into the downstream boundary. It is noted that this estimation is considered rough compared to using Chandler River flood inflow hydrographs produced via formal hydrological modelling. It was observed that adopting this current rough estimation is more accurate (reasonably less conservative) than not inserting any flows at all as the floodwater volume contribution from the Chandler River catchment is significant (see Subsection 2.3.3.10). The necessity to formally model this is discussed in Subsection 3.3.

WRM's work on this matter excluded joint occurrence probability assessments with flood occurrences on the Oaky River catchment. As such, the following occurrence combinations were assumed for the MIKE+ modelling:

- Oaky River 1% AEP flood coinciding with Chandler River 'half' 1% AEP flood.
- Oaky River 10K flood coinciding with Chandler River 1% AEP flood.
- Oaky River PMF coinciding with Chandler River 10K flood.

2.3.3.6 Base Safety Condition (BSC)

According to ANCOLD (2000), where a flood capacity stage is reached such that the dambreak "incremental effects" are insignificant, it is referred to as the Base Safety Condition (BSC). The BSC is met if the downstream incremental depth of flooding is less than 300 mm, in accordance with ANCOLD (2000 and 2003b). Some authorities (e.g., FERC in the United States) consider that if the incremental flood effects downstream of the dam are less than 600 mm, it would be acceptable. However, this criterion has been set more conservatively by ANCOLD at 300 mm incremental flood depth. Examination of the BSC is for the purpose of establishing an appropriate finite floodplain extent for the dam's downstream dambreak flood consequence assessment.

Note that the BSC is irrelevant for properties *only* inundated by “dambreak events”, i.e., incrementally dambreak flooded. However, such properties will still be subject to consequence assessment, irrespective of flood depth severities, due to their “incrementally flooded” status, i.e., would not be affected if no dambreak. This consideration is in-line with the guidance provided in ANCOLD (2012).

Application of the BSC in a dambreak study is in-line with the guidance provided in DSNSW’s Declared dams consequence category assessment and determination methodology in the NSW Government Gazette Number 113, 18th March 2022, Part 2: Clause 4b.

The following subsections explain the use of the BSC concept for consequence assessments.

2.3.3.7 Dambreak Affected Zone

For the technical analyses required in a dambreak study, the flood consequences identified to be situated within the Dambreak Affected Zone are considered. The determination of the Dambreak Affected Zone is based on the BSC concept, i.e., any flood inundation areas where the BSC *is not met*. Additionally, the consequences identified to be “incrementally flooded” are also to be considered. Refer to the following subsection for further explanation.

According to ANCOLD (2003b), the Dambreak Affected Zone is defined as “*that zone of flooding where the changes in the characteristics of flooding, such as depth and velocity, due to dambreak are such that there is potential for incremental loss of life or significant incremental damage to property or the environment. The zone can be taken to end where the increase in flood level due to dambreak is 300 mm, provided no significant incremental consequences would be expected beyond that point”*.

Note that the BSC and Dambreak Affected Zone concepts are irrelevant for the Sunny Day Dambreak (SDDB) event as it does not involve any preceding natural flooding, i.e. incremental flood effects do not apply.

2.3.3.8 BSC Inundation Mapping Representations

To clearly delineate the defined “Dambreak Affected Zone” for each examined dambreak event, the relevant areas have been coloured “blue” in the plotted BSC inundation maps. Therefore, the BSC would be met, for incrementally flooded areas, once beyond the blue inundation areas.

Areas beyond the blue areas which are characterised with incremental flood depth less than 300 mm (labelled as “Base Safety Condition Zone”) are coloured “orange”.

Areas beyond the blue and orange areas were modelled to be incrementally dambreak flooded (i.e., additionally flood-affected by the flood dambreak event, irrespective of flood depth) and are coloured “red” (labelled as “Incremental Dambreak Zone”). Therefore, the blue and orange areas combined form the maximum flood inundation extent of the “natural flooding” event only.

In conclusion, only the flood-affected sites identified to be situated within the blue and red inundation areas contribute to the dambreak consequence assessment.

2.3.3.9 Results

The main output of the modelling are the plotted flood inundation maps, displayed in **Appendix D**. The maps were plotted with the application of the BSC.

2.3.3.10 Conclusion

In a Standards Based Approach (SBA) modelling assessment perspective, the current computer flood modelling results prove to be incomplete as the BSC was not met for all modelled flood events (irrelevant for the SDDB event) at the model's downstream boundary, i.e., the confluence of Oaky and Chandler Rivers. The modelled dambreak incremental flood depths near the rivers' confluence are as follow:

- 1%DB = 5.22 m;
- 10KDB = 4.31 m; and
- PMFDB = 4.11 m (> 5 m without the Chandler River inflow contribution into the downstream boundary condition as discussed in Subsection 2.3.3.5).

Due to Oaky River's deep gorge characteristics downstream of the dam, easily observable from Six Maps, the tall river valley acts as a massive open channel that efficiently conveys extreme floodwater volumes downstream and beyond the confluence of Oaky and Chandler Rivers. Such efficient conveyance system highlights the absence of flat and wide floodplains above the riverbanks in which river floodwater forces and levels are unable to laterally spread and attenuate. This explains why the modelled Dambreak Affected Zones are long, seemingly without end.

It is noted that the Oaky River flood modelling reach is currently some 20 km from the dam to the confluence, which is considered lengthy in a 'single model' 2D environment. The need for modelling beyond this point was not originally anticipated due to the potential requirement of extra substantial modelling including flood hydrology for the entire Chandler River, Falls Station Creek and Styx River catchments and 2D hydraulic modelling down to the confluence of Chandler and Macleay Rivers (further additional 25+ km from the Oaky-Chandler Rivers confluence).

3. Consequence and Capacity Assessments

3.1 Downstream Population At Risk (PAR)

Due to Oaky River's deep gorge characteristics downstream of the dam, as explained in Subsection 2.3.3.10, no Population At Risk (PAR) locations were identified from the dam down to the confluence of Oaky and Chandler Rivers, as evident from the examination of Six Maps' aerial imagery. It is noted that the Warm Corner Trail terminates close to the north of this confluence. This potential 'itinerant PAR location' is considered to be of low dambreak flood impact significance as the majority of the trail is not situated on an obvious floodplain of Oaky River.

Beyond this confluence at some 14 km upstream of the confluence of Chandler and Macleay Rivers, the Halls Peak / Chandler River Camping Trail emerges parallel to the immediate left floodplain of Chandler River. It is noted that this itinerant PAR location is currently a long distance beyond the current flood modelling termination point, i.e., the confluence of Oaky and Chandler Rivers.

With no PAR locations identified, a Potential Loss of Life (PLL) assessment was hence not carried out. It is imperative that if within Council's control, the dam's downstream PAR (especially non-itinerants) be discouraged to grow within the modelled Dambreak Affected Zones and Incremental Dambreak Zones. This will ensure that the proposed dam's Consequence Categories would not escalate in the future to attract a more stringent DSMS regime, as stipulated by the Regulation and the ANCOLD guidelines, which would involve more of Council's efforts and funding.

3.2 Downstream Environmentally Sensitive Locations

It is noted that an Environmental Impact Statement (EIS) is required to be undertaken as part of the reconstruction design of Oaky River Dam. As the EIS has yet to commence, a preliminary qualitative desktop environmental impact search was carried out for the purposes of this Dambreak Study. The search domain was limited to the current flood modelling extent, i.e., from the dam to the confluence of Oaky and Chandler Rivers.

In terms of ecosystems, the search identified the potential likely dambreak flood impacts of a number of rainforest Plant Community Types (PCT), in which none are NSW or Commonwealth listed as critically endangered.

In terms of endangered ecological communities, a number of Commonwealth 'Matter of National Environmental Significance' (MNES) threatened species were recorded and listed under the *Environmental Protection and Biodiversity Act 1999* as critically endangered. Over 60 threaten woodland species are listed threaten species that may occur within the search domain. In terms of NSW threaten species, searches in the vicinity of the Armidale plateau listed 120 species as potentially occurring within the study domain. Parts of the study area have been mapped to contain some biodiversity values. It is additionally noted that Gondwana Rainforest ecosystems are likely to occur within the search domain. Such rainforest are also listed as MNES with addition tag of World Heritage Properties and National Heritage Places. A detailed ground study will be required to determine the presence and potential degree of dambreak flood impact of these ecological communities.

In terms of heritage and recreation significance, the search yielded no immediate obvious locations that would be inundated by dambreak floodwaters. However, the study domain is protected by a State Heritage Curtilage – Gondwana Rainforests of Australia. According to the modelled relatively narrow inundation corridor along Oaky River, the dambreak flood impacts may not reach major / catastrophic severity levels.

Refer to **Appendix E** for the preliminary desktop investigation report.

3.3 Discussion on the Current Flood Modelling Extent

Regarding the examination of dambreak flood consequences of 'public safety risks', i.e., PAR and PLL assessments, extending the current computer flood modelling domain to say, the confluence of Chandler and Macleay Rivers would unlikely enhance the assessment accuracy. This has been deduced from the observation of available aerial imagery whereby the deep gorge nature of the river is evident from the dam down to the confluence of Chandler and Macleay Rivers and beyond, in which human habitation is unlikely and not conveniently supported. Such outcome was expected given the knowledge acquired from the 2013 dam failure news and reporting.

Regarding the examination of dam flood consequences of 'environmental damage risks', the necessity of extending the current computer flood modelling domain to enhance the assessment accuracy is currently unknown. It is suggested to use the eventual EIS assessment outcomes, analysed in the context of a dambreak consequence assessment, to determine the sensitivity of the damage severities. If the damage severities within the current modelling domain were assessed to be on the periphery of 'a step change in damage class', extending the flood modelling further downstream may prove to be more indicative for the environmental consequence assessment. For example, if the damage severity within the current modelling domain were to be found on the boarder of medium to major damage class, then extending the model would appear to be warranted to ensure that a 'class jump' (more impacts revealed) or 'class stay' (no additional impacts revealed) would be captured. Such is important as it will have an impact towards the proposed dam's Consequence Categories.

It is reiterated that, as per explained in Subsection 2.3.3.10, extending the flood modelling would be a significant undertaking as the additional flood hydrologic modelling would encompass at least another three (3) major river catchments, in which joint occurrence probability assessments with flood occurrences on the Oaky River catchment would additionally be required. If this were to be deemed warranted, then it is anticipated that the BSC could be met somewhere along the Chandler River prior to its confluence with Macleay River.

3.4 Current Severity of Damage and Losses of Proposed Dam Arrangement

DSNSW's PLL Consequence Category Matrix (Table 1 of DSNSW (2022)) requires two (2) variables to arrive at the Consequence Category:

- Severity of Damage and Losses; and
- Incremental PLL – however, PAR and PLL assessed to be zero as discussed in Subsection 3.1.

Tables 3A, 3B and 3C of DSNSW (2022) were completed for the SDDB and the PMFDB events, for the proposed reconstructed dam, and the highest Severity of Damage and Loss category was assessed to be <u>major</u> for both events, based on the preliminary environmental impact search results as report in **Appendix E**. Refer to **Appendix F** for the completed tables. It is suggested that this exercise be revisited in parallel with the undertaking of the eventual EIS of the dam's reconstruction design.

Table 1

Potential Loss of Life (PLL)	Severity of Damage and Loss			
	Minor	**Medium**	**Major**	**Catastrophic**
Less than 0.1	Very Low	Low	Significant	High C
0.1 to less than 1	Significant	Significant	High C	High B
1 to less than 5		High C	High B	High A
5 to less than 50		High A (where PLL is 5 or above and less than 10, can be reduced to High B)	High A	Extreme
50 or more			Extreme	Extreme

Clarified in ANCOLD (2012) to be the critical <u>incremental</u> <u>PLL</u> estimate

Figure 3-1 Table 1 of DSNSW (2022)

3.5 Sunny Day Consequence Category (SDCC)

With a PLL value of zero and the severity level assessed to be major, in accordance with Table 1 of DSNSW (2022), the proposed dam's SDCC was assessed to be **SIGNIFICANT**.

3.6 Acceptable Earthquake Capacities

With an SDCC of **SIGNIFICANT**, in accordance with ANCOLD (2019), the dam is required to cater for Operating Basis Earthquake (OBE) and Safety Evaluation Earthquake (SEE) events of <u>1 in 500 AEP</u> and <u>1 in 1,000 AEP</u> respectively.

3.7 Flood Consequence Category (FCC)

With a critical incremental PLL value of zero and the severity level assessed to be major, in accordance with Table 1 of DSNSW (2022), the dam's FCC was assessed to be **SIGNIFICANT**, i.e., unchanged as per assumed in Subsection 2.1.2.

3.8 Acceptable Flood Capacity (AFC)

With an FCC of **SIGNIFICANT**, in accordance with ANCOLD (2000), the dam is required to cater for (safely pass) flood events up to the <u>1 in 10,000 AEP</u> flood (10K) event with the dam's initial condition at the FSL.

3.9 Commentary on Design Adequacy

It is noted that the proposed dam wall's stability analysis for potential failure events such as sliding and overturning under the influence of the determined OBE, SEE or AFC event loadings is not part of this study.

For contemporary concrete dam wall designs, it is generally preferred for the AFC event to be neatly and fully accommodated within the designated spillway overfall section of the dam wall, i.e., the Abutment Crest Level (ACL) higher than the peak AFC floodwater elevation to prevent overtopping floodwaters eroding the dam abutment slopes. The design accommodated for this as a minimum freeboard of 0.39 m above the peak dam 1 in 10,000 AEP floodwater level is available, as well as a ‘zero’ freeboard at the top of the abutment blocks for the peak dam 1 in 100,000 AEP floodwater level (refer to Table 2-1).

3.10 Inspections and Monitoring Frequencies

As the SDCC was found to be **SIGNIFICANT**, the dam’s *Routine Inspections* (to be carried out by Council), when reconstructed, are to be performed on twice-weekly basis according to ANCOLD (2003a). In addition, dam safety monitoring data should be collected, record and analysed at the frequencies as suggested in Table 5.3 of ANCOLD (2003a). As the critical Consequence Category was found to be **SIGNIFICANT**, the dam’s *Intermediate Inspections* (to be carried out by an independent dam engineering specialist, e.g., NSWPW) are to be performed on an annual basis according to ANCOLD (2003a).

3.11 Climate Change Considerations

It is noted that there are currently no clear guidance and requirements for the consideration of climate change within dams investigation and designs. The Dams Safety Regulation 2019 does not currently explicitly mandate climate change considerations while the ANCOLD 2022 Guidelines currently only suggest practitioners to “keep abreast of relevant developments”.

Climate change modelling guidance is currently clearly available from ARR2019 and publications by Department of Climate Change, Energy, the Environment and Water (DCCEEW). However, no clear guidance / criteria is currently available as to how best to ‘address / cater’ for the future changed hydrology and hydraulics in a dams investigation and design context. Once the EIS is underway for the Oaky River Dam reconstruction design, the established Streamlined Secretary’s Environmental Assessment Requirements (SEARs) may include climate change design criteria developed by the consulted stakeholders.

At present in the absence of any clear investigation and design guidance from DSNSW, academics, stakeholders and Council, NSWPW have adopted a simple ‘minimum criteria’ whereby, the proposed dam wall shall remain stable under the climate changed AFC event loading condition. WRM was subsequently engaged to model the climate changed 1 in 10,000 AEP dam flood inflow hydrograph for NSWPW’s incorporation into the dam’s reconstruction detailed design.

It was recommended by WRM to follow the DCCEEW (2023) guidance to model the proposed dam’s AFC event for the year 2090 adhering with the business-as-usual growth trajectory which fits closest to Shared Socioeconomical Pathway (SSP) 5 – 8.5. With WRM’s modelled critical climate changed 1 in 10,000 AEP dam flood inflow hydrograph, NSWPW routed this through the current MIKE11 dam flood routing model and resulted in a peak floodwater level of 879.06 mAHD, i.e., a minimum freeboard of 0.59 m to the top of the abutment blocks would be available (0.41 m peak overtopping of the ACL). As the currently proposed dam wall’s abutment blocks would theoretically fully contain the climate changed AFC event (i.e., no floodwater overtopping in contact with the dam abutment slopes), the current spillway concept design arrangement was not modified and considered climate-change-adaptable.

It is recommended that the subsequent SBA assessment stability analysis of the proposed dam wall be assessed with the climate changed AFC event loading condition, complying with the ANCOLD (2013) stability criteria. Refer to **Appendix B** for further information of the adopted climate change modelling procedure.

4. Conclusion

At the request of Council following on from the concept design, NSWPW has carried out a Dambreak Study for the proposed reconstructed Oaky River Dam with the objective of determining the SDCC, FCC and design capacity requirements in preparation for the dam's upcoming detailed design and Risk Report. This study was undertaken in three (3) phases:

1. Hydrologic Modelling;
2. Hydraulic Modelling; and
3. Dam Failure Consequence Assessment, i.e., PAR analysis, preliminary qualitative desktop environmental impact search and determination of proposed dam's Consequence Categories.

The computer flood hydrologic modelling was carried out by WRM Water + Environment with a constructed URBS model while the computer flood hydraulic modelling was carried out by NSWPW with a constructed 2D MIKE+ model. The modelling reach stretched from the dam wall down to the confluence of Oaky and Chandler Rivers. The analysis encompassed the simulation of seven (7) distinct flood events pertaining to the proposed dam:

1. SDDB;
2. 1% AEP;
3. 1%DB;
4. 10K;.
5. 10KDB;
6. PMF; and
7. PMFDB.

The dambreak modelling, assessment and determination of the SDCC and FCC were carried out following the latest methodologies from DSNSW and ANCOLD. Flood inundation maps were plotted to assist with the assessment and determination processes. As evident from the inundation maps, no PAR locations were identified and hence a PLL assessment was not carried out. Such outcome was expected given the knowledge acquired from the 2013 dam failure news and reporting.

It is imperative that if within Council's control, the dam's downstream PAR (especially non-itinerants) be discouraged to grow within the modelled Dambreak Affected Zones and Incremental Dambreak Zones. This will ensure that the proposed dam's Consequence Categories will not escalate in the future to attract a more stringent DSMS regime, as stipulated by the Regulation and the ANCOLD guidelines, which will involve more of Council's efforts and funding.

Based on the preliminary environmental impact search results, the proposed dam's SDCC and FCC were both determined to be **SIGNIFICANT**. Such requires the reconstruction design of the proposed dam to safely cater for OBE and SEE of the 1 in 500 AEP and 1 in 1,000 AEP earthquake events respectively; and an AFC of the 1 in 10,000 AEP flood event. The escalation of the SDCC and FCC from **LOW** (pre 2013 dam failure) to **SIGNIFICANT** is mainly attributed to the recent discovery of the potential presence of environmentally sensitive items downstream of the dam. It is noted that a formal Dambreak and Consequence Study has never been carried out. The current SDCC and FCC status of **SIGNIFICANT**, albeit 'tentative' (yet to be endorsed by DSNSW and the provision for additional flood modelling), is considered reasonable (and should not be lowered) given the proposed dam's role in the Armidale 30-year IWCM Strategy. It is reiterated that the current flood dambreak modelling is considered incomplete as the BSC was not met. However, extending the model would be a significant exercise and the necessity of this should be determined based on future emerging project information, e.g., with the eventual EIS assessment outcomes.

It is noted that the proposed dam wall's stability analysis for potential failure events such as sliding and overturning under the influence of the determined OBE, SEE or AFC event loadings is not part of this study. In terms of the proposed dam's spillway capacity, the concept design accommodates a minimum freeboard of 0.39 m (i.e., the ACL) above the peak dam 1 in 10,000 AEP floodwater level.

In examining potential climate change impacts, the year 2090 SSP5 – 8.5 AFC event was recommended by WRM to be modelled and the peak dam floodwater level increased by 0.80 m compared to current climate conditions. The dam's design was not modified as a minimum freeboard of 0.59 m to the top of the abutment blocks would be available. It is NSWPW's recommendation that the subsequent SBA assessment stability analysis of the proposed dam wall complies with the ANCOLD (2013) stability criteria assessed with the climate changed AFC event loading condition. An EIS is required to be undertaken as part of the reconstruction design of Oaky River Dam but has yet to commence. Once underway, the established SEARs may include additional climate change design criteria developed by the consulted stakeholders.

During the eventual undertaking of the dam's reconstruction EIS, it is further recommended to:

- Examine the necessity of extending the current flood dambreak modelling reach with the opinions of the involved environmental scientists, hydrologists and other relevant stakeholders.
- If the above were to be enacted with additional downstream environmental impacts revealed, redetermining the proposed dam's SDCC and FCC would then be warranted.

5. References

Reference	Full Description
ANCOLD (2000)	ANCOLD (Australian National Committee on Large Dams) (2000) – *Guidelines on Selection of Acceptable Flood Capacity for Dams*, March 2000
ANCOLD (2003a)	ANCOLD (Australian National Committee on Large Dams) (2003) – *Guidelines on Dam Safety Management*, August 2003
ANCOLD (2003b)	ANCOLD (Australian National Committee on Large Dams) (2003) – *Guidelines on Risk Assessment*, October 2003
ANCOLD (2012)	ANCOLD (Australian National Committee on Large Dams) (2012) – *Guidelines on the Consequence Categories for Dams*, October 2012
ANCOLD (2013)	ANCOLD (Australian National Committee on Large Dams) (2013) – *Guidelines on Design Criteria for Concrete Gravity Dams*, February 2013
ANCOLD (2019)	ANCOLD (Australian National Committee on Large Dams) (2019) – *Guidelines for Design of Dams and Appurtenant Structures for Earthquake*, July 2019
ANCOLD (2022)	ANCOLD (Australian National Committee on Large Dams) (2022) – *Guidelines on Risk Assessment*, July 2022
Ball et all (2019)	Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (2019) – "*Australian Rainfall and Runoff: A Guide to Flood Estimation*" Commonwealth of Australia (Geoscience Australia)
DSC2D (2010)	NSW Dams Safety Committee, DSC2D "Demonstration of Safety for Dams", June 2010
DSC3A (2015)	NSW Dams Safety Committee, DSC3A "Consequence Categories for Dams", June 2010 (Updated November 2015)
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