Prepared for
Hunter Water Corporation
ABN: 46 228 513 446

Grahamstown Dam

Risk Assessment Summary Report

Grahamstown Dam

Risk Assessment Summary Report

Client: Hunter Water Corporation

ABN: 46 228 513 446

Prepared by

AECOM Australia Pty Ltd
Gadigal Country, Level 21, 420 George Street, Sydney NSW 2000, PO Box Q410, QVB Post Office NSW 1230, Australia
T +61 1800 868 654 www.aecom.com
ABN 20 093 846 925

27-Jun-2024

Job No.: 60680791

AECOM in Australia and New Zealand is certified to ISO9001, ISO14001 and ISO45001.

Quality Information

Document	Grahamstown Dam
Ref	60680791
Date	27-Jun-2024
Originator	Mary Diab
Checker/s	Boe Donaldson
Verifier/s	Lorreta Agnew

Revision History

Rev	Revision Date	Details	Approved	
			Name/Position	Signature
A	22-Apr-2024	Draft	Boe Donaldson	
0	27-Jun-2024	Final	Lorreta Agnew Project Manager	

Table of Contents

1.0 Introduction

A dam is a water-holding structure with one or more embankments built across a creek, river or natural depression to contain the water in an area. Water builds up behind the dam's embankments when it rains or when water is pumped into the dam from a river. This build-up of water creates an artificial body of water (referred to as a reservoir), as shown in Figure 1. Around the world, the key purpose of dams is to capture, store and manage water for drinking, irrigation, electricity generation, and in some cases to minimise the impact of floods or to store by-products of industry and mining.

Dams can be built from a combination of earthfill (such as clay), rockfill, concrete, or quarried stone and need to be strong and robust enough to hold back the force of the water in the dam that pushes against them. As dams hold millions of litres of water working against gravity and are subject to many seasonal or cyclical events, there is always a risk of failure over time.

A dam failure is when the dam "breaks" in a manner that leads to an uncontrolled release of water. There are several ways a dam can fail, these include flood events, internal erosion (also referred to as 'piping'), earthquakes, landslides, foundation failure, equipment failure (such as the outlet or control gates), structural failure and rapid drawdown of the dam. The main components of a dam are shown in Figure 1 and are referred to in this summary report and in the main report.

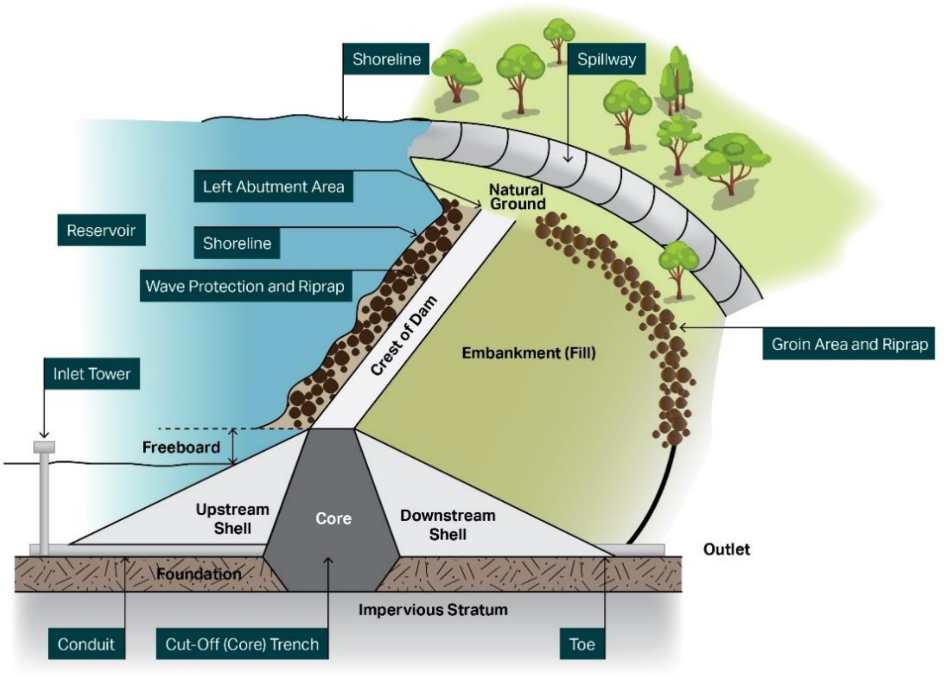

Figure 1 Main components of a typical dam

In New South Wales the state government, through Dams Safety NSW, is responsible for the management of dam safety through the *Dams Safety Act 2015* (amended 2023) and the Dams Safety Regulation 2019 (amended 2023). Once a dam is 'declared' under the Act, Dams Safety NSW directs dam owners to assess the safety of dams through risk-based audits and inspections. The Act requires dam owners to also undertake certain inspections and reviews annually, five yearly and every 15-years. More information on this is available at www.damsafety.nsw.gov.au.

As a responsible dam owner, Hunter Water Corporation (Hunter Water) completes periodic reporting on safety, risk, and maintenance to the independent regulator (Dams Safety NSW) to ensure the dams they own continue to operate safely.

AECOM Australia Pty Ltd (AECOM) was engaged by Hunter Water to carry out a risk assessment for Grahamstown Dam. This was the first time that a holistic and quantitative risk assessment has been conducted under the new guidelines with the assessment being finalised in mid-2024. Dam engineers and safety specialists worked closely with key staff at Hunter Water to identify the key risks associated with Grahamstown Dam and the factors that contribute to these risks. The objective of the risk assessment was to determine the safety of the dam (i.e. the potential for a dam failure) following the risk-based approach recommended by the Australian National Committee on Large Dams (ANCOLD) (2022) Guidelines on Risk Assessment. The Act requires that a risk assessment considers the likelihood of an event occurring and the consequences in terms of potential loss of life.

This report presents a summary of the Grahamstown Dam risk assessment. It outlines how the risk assessment was conducted, the risks which were identified and the recommendations to Hunter Water. Hunter Water will consider the recommendations of the assessment and decide what actions to take.

The risk assessment report and its outcomes undergo an independent review by an ‘Expert Panel’. The reviewer’s role is to complete a technical and quality review of the risk assessment report, including commentary on the adopted approaches (methods), parameters and assessment criteria; discussion of results from engineering assessments; and suggested recommendations. Once matters raised by the Expert Panel are addressed to the satisfaction of the Panel the risk assessment report is finalised and sent to Dams Safety NSW.

2.0 Grahamstown Dam

Grahamstown Dam is located approximately 20 kilometres north of Newcastle and is the Lower Hunter’s largest drinking water supply dam. Located near Raymond Terrace and Medowie, Grahamstown Dam is owned and operated by Hunter Water.

The dam is classified as an off-river storage facility, meaning it stores untreated water that is primarily pumped from the Williams River at Seaham Weir into the northern end of Grahamstown Dam. Grahamstown Dam provides an average of 40% of water to the Lower Hunter region annually and up to 75% of Hunter Water’s peak daily supply requirements.

The dam has the following components:

- Main and Saddle embankments comprising a central clay core flanked by sandfill shoulders
- The Subsidiary embankment comprising a central bentonite slurry wall flanked by sandfill shoulders
- Irrawang embankment comprising a clay core with filters and earthfill shoulders
- Grahamstown (Irrawang) Spillway, which passes water from the dam when the level exceeds Full Supply Level (FSL), during a flood event
- George Schroder Pump Station, which conveys water from the dam to the Grahamstown Water Treatment Plant (Tomago) for treatment and supply to Hunter Water’s customers
- The Campvale Pump Station, which takes water from the Campvale Swamp, pumping it into the dam.

Most of the water that enters the dam is pumped from the Williams River where Seaham Weir separates the downstream tidal estuarine salt water from the upstream fresh water. Water is then transferred via the Balickera Pump Station and Balickera Canal into the dam, as shown in Figure 2. Figure 3 shows images of the main embankment and George Schroder pumping station.

The dam has a surface area of approximately 28 square kilometres and stores some water captured from its own small catchment area. The dam surface comprises approximately 56% of the catchment area with the remainder of the catchment consisting mainly of forested lands, small farms, and minor developments to the north of the dam.

Grahamstown Dam has undergone regular improvement studies and upgrades aimed at increasing capacity and safety. In 2005, major works were undertaken on the dam to increase storage capacity in line with population growth in the Lower Hunter. Figure 4 shows the various studies and upgrades undertaken at Grahamstown Dam.

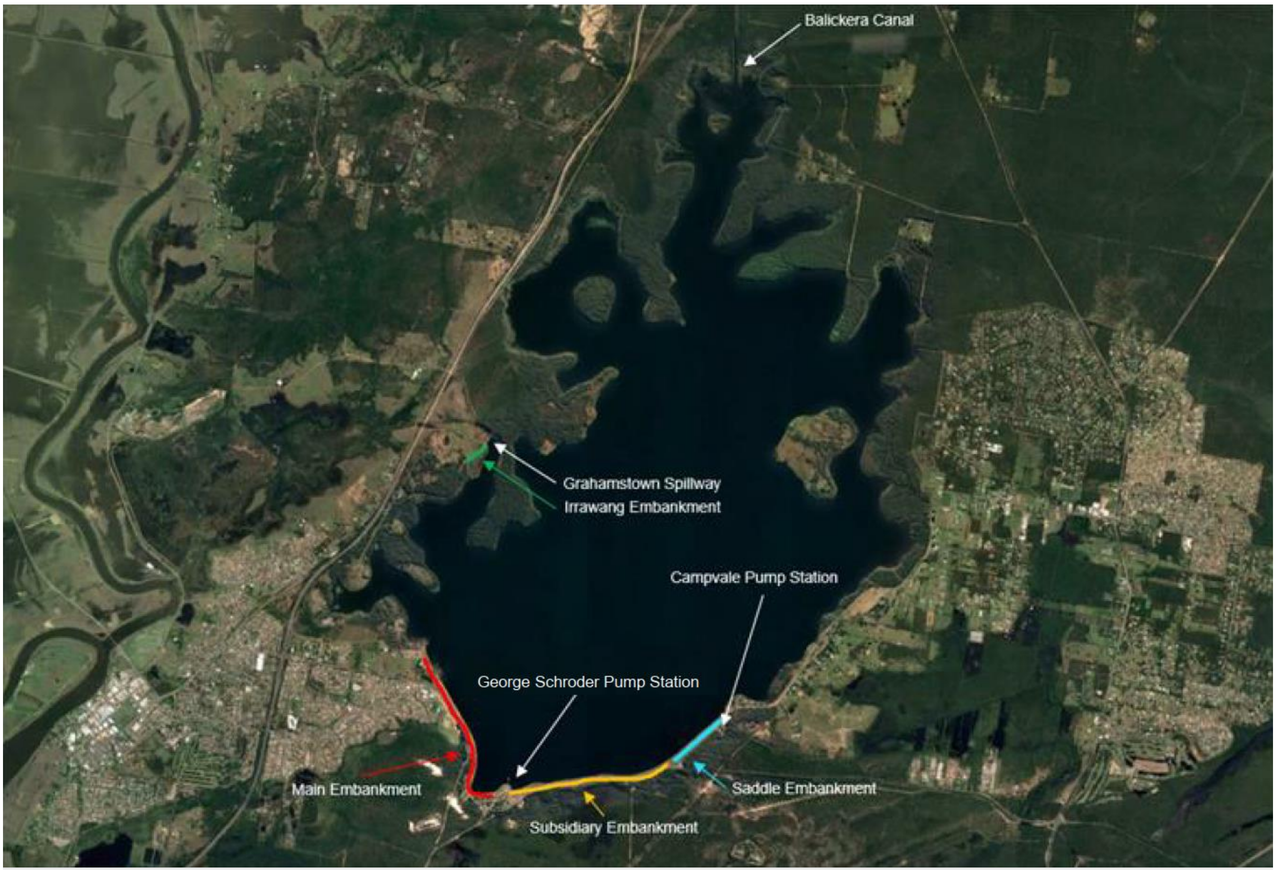

Figure 2 Main components of Grahamstown Dam

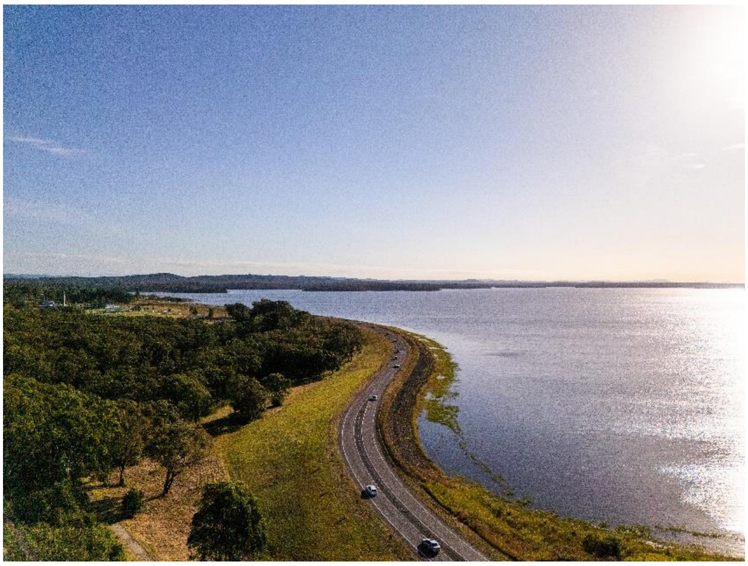

Figure 3 Photographs of George Schroder Pump Station (left) and Main Embankment (right)

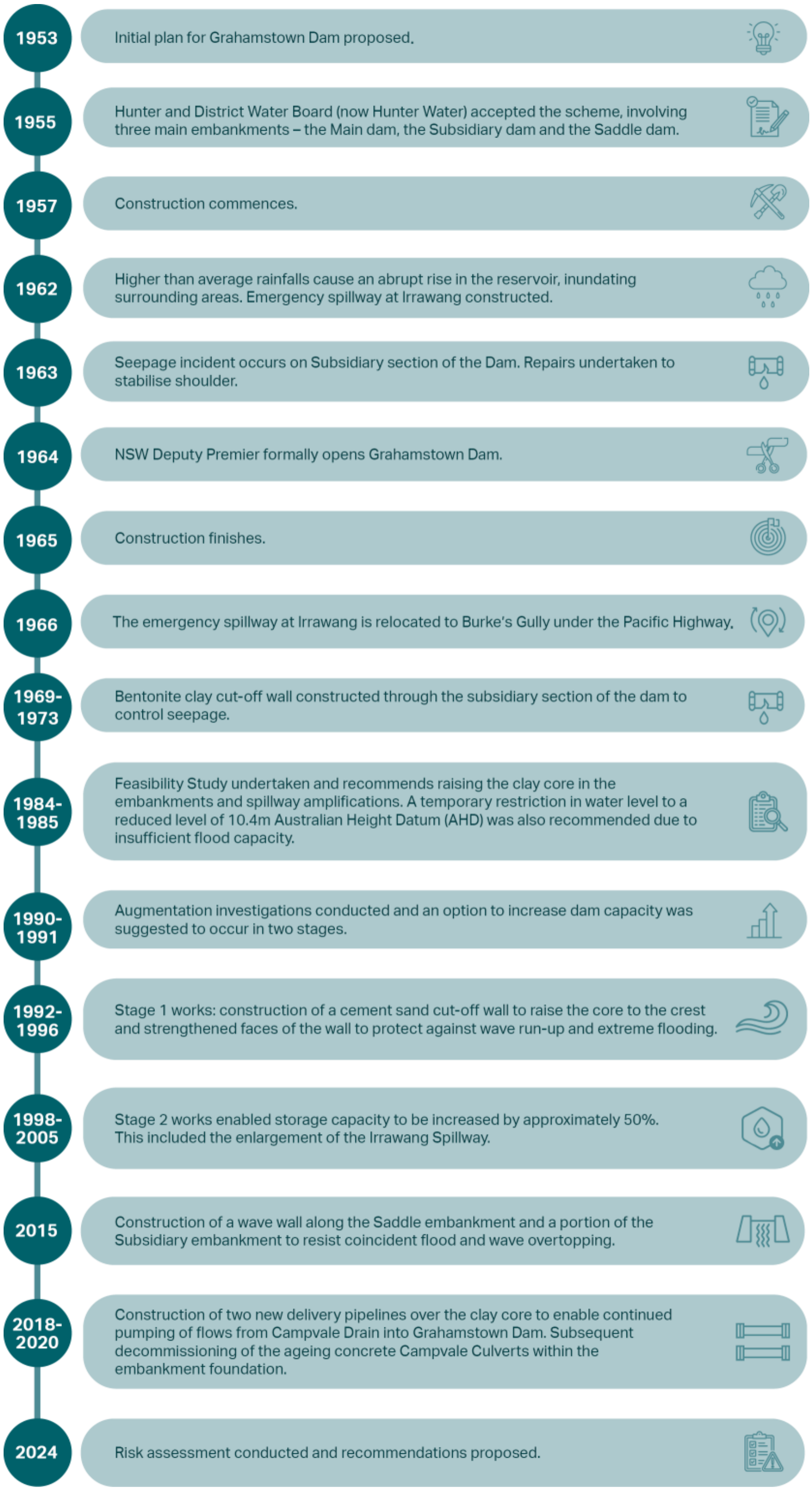

Figure 4 Timeline of Grahamstown Dam and completed works

3.0 About the risk assessment

3.1 What is a risk assessment?

Dam risk assessments generally consider two aspects, the likelihood (probability) of an event occurring and the consequence (what would happen) if that event were to occur. The risk assessment considers all the possible hazard scenarios that could result in an uncontrolled release of water from the dam, threatening the safety of people located nearby. This is known as the societal risk.

The risk assessment for Grahamstown Dam was undertaken in conjunction with geotechnical investigations, engineering assessments and a Dam Safety Review (DSR) to help inform ‘failure modes’ – or the different ways that the dam could feasibly fail. The main risk assessment report references where these investigations and studies have been used to inform the risk assessment.

A range of possible failure modes were examined to determine how the dam could behave when subjected to a range of scenarios. Those failure modes identified as being credible for Grahamstown Dam were investigated more closely and formed the basis of the risk assessment.

The risk assessment was carried out in response to the Dam Safety Regulation which states that an owner must assess the societal and individual risk using the risk management framework outlined in the Regulation. This risk assessment was undertaken by following the recommended procedures outlined in the ANCOLD (2022) Guidelines and complies with the Dams Safety NSW Societal and Individual risk rating methodology. The probabilities for each potential failure mode were estimated in workshops and assigned for each dam component where credible failure modes were identified. Business risks were not identified or assessed as part of the risk assessment.

3.2 Risk factor probability

Two key scenarios that had the highest probability of failure were identified for Grahamstown Dam:

Earthquake: was determined as the main hazard that could cause failure of the dam. Under an earthquake (or seismic) scenario the sandy shoulders and foundations of the dam embankments may become unstable through a phenomenon known as ‘liquefaction’. Liquefaction is a process that can occur when wet, sandy sediments behave like quicksand due to the shaking motion of an earthquake. This process could destabilise the sandy shoulders of the dam embankments; and in the worst-case scenario, lead to the erosion and failure of the dam embankment, releasing the water to downstream areas.

Piping: is the term given by dam engineers to describe internal erosion. Internal erosion or “piping” is caused by a combination of defects (or unfavourable features) that may be present in the embankment or foundation along with seepage which may then initiate the erosion process. The erosion process involves removal of material from the dam effectively forming a tunnel through the embankment, until a breach occurs, releasing the water to downstream areas.

A summary of the estimated annual probabilities of failure for each of the identified credible and significant failure modes for Grahamstown Dam is presented in Table 1.

Table 1 Approximate annual probabilities of failure for identified failure modes

Failure Mode Number	Failure mode ID	Failure Mode Description	Approximate annual probability of failure
Main Dam			
1	GRA-F1	Piping through embankment occurs in the main dam during normal operations or a flood.	1 in 22,000,000
2	GRA-F2	Piping through foundation occurs in the main dam during normal operations or a flood.	1 in 11,500,000
3	GRA-F3	Piping through embankment into foundation occurs in the main dam during normal operations or a flood.	1 in 77,500,000
4	GRA-F4	Piping around left abutment occurs in the main dam during normal operations or a flood.	1 in 168,500,000
5	GRA-F5	Piping due to earthquake cracking occurs in the main dam.	1 in 205,000,000
6	GRA-F6	Liquefaction leading to loss of freeboard occurs as a result of an earthquake affecting the main dam.	1 in 3,500
Saddle Dam			
7	GRA-F7	Piping through embankment occurs in the saddle dam during normal operations or a flood.	1 in 22,500,000
8	GRA-F8	Piping through foundation occurs in the saddle dam during normal operations or a flood.	1 in 44,000,000
9	GRA-F9	Piping through embankment into foundation occurs during normal operations or a flood.	1 in 3,950,000
10	GRA-F10	Piping adjacent to Campvale Conduit occurs in the saddle dam during normal operations or a flood.	1 in 2,850,000
11	GRA-F11	Piping due to earthquake cracking occurs in the saddle dam.	1 in 5,950,000
12	GRA-F12	Liquefaction leading to loss of freeboard occurs as a result of an earthquake affecting the saddle dam.	1 in 55,000
Subsidiary Dam			
13	GRA-F13	Piping through embankment occurs in the subsidiary dam during normal operations or a flood.	1 in 500,000
14	GRA-F14	Piping through foundation occurs in the subsidiary dam during normal operations or a flood.	1 in 1,060,000
15	GRA-F16	Liquefaction leading to loss of freeboard occurs as a result of an earthquake affecting the subsidiary dam.	1 in 47,500
Irrawang Spillway & Embankment			
16	GRA-F17	Piping through embankment occurs in the Irrawang embankment during normal operations or a flood.	1 in 17,000

The approximate annual probability of failure means the likelihood of the failure occurring per year. That means, if an event occurs one year, the probability of it occurring the subsequent year is not reduced as it is an annual probability of the event occurring.

Understanding the above risks means that Hunter Water can continue to be proactive in planning and delivering safety upgrades for Grahamstown Dam and enhance emergency response plan's 'disaster readiness' for all foreseeable hazards that may compromise the safety of the dam.

3.3 Potential consequences of failures

The NSW regulatory framework and ANCOLD (2022) Guidelines consider the consequences of a potential dam failure and provide tolerable thresholds for risks to people (societal risk). From Table 1 the most likely failure mode is an earthquake causing liquefaction of the main embankment and leading to 'loss of freeboard', where the embankment loses its structure and water overtops the embankment (failure mode 6, GRA-F6). Figure 5 shows the respective contribution that failure mode 6 (GRA-F6) makes to the societal risk for Grahamstown Dam along with Table 1.

The annual probability of the event occurring (shown on the vertical axis in Figure 5) considers the timing of the failure, conditions at the time of the failure and the ability for advanced warning to people at risk downstream of the failure. The numbers plotted along the horizontal axis in Figure 5 represent the possible life loss consequence and have been presented to show how identified failure modes contribute to the societal risk. Estimation of potential life loss consequences is based on multiple scenarios taking into consideration the failure location, inundated area, the water level of the dam, and a range of other factors. This is a theoretical assessment based on a published methodology in the Dams Safety Act.

Figure 5 shows that failure mode 6 (GRA-F6) contributes the most to the calculated societal risk. The total societal risk position for the dam is above the Dams Safety NSW safety threshold for existing dams and the ANCOLD 2022 societal risk guideline thresholds.

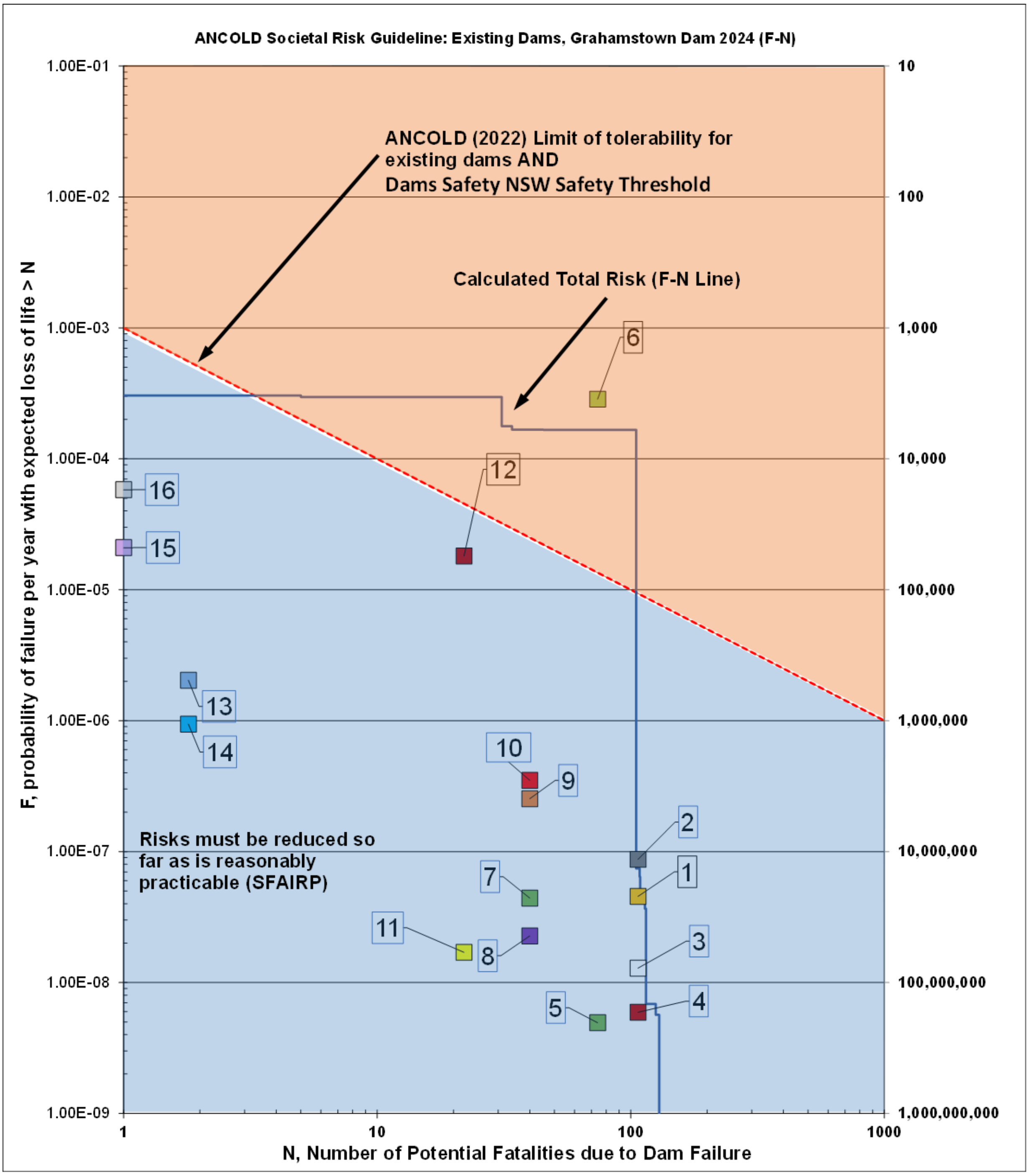

Figure 5 Societal Risk (F-N) Line including F, N pairs representative of the calculated risk (annual probability of failure) and potential fatalities associated with identified failure modes

The blue line in Figure 5 shows the cumulative risk for all of the failure modes. The red line in Figure 5 shows the safety threshold. Risks above this threshold are considered unacceptable and require risk reduction measures to be implemented to reduce the probability of failure and/or consequences to the downstream community. However, all risks (even those below the threshold) must be reduced so far as is reasonably practicable (SFAIRP).

3.4 Risk assessment findings

The latest dam safety studies have shown that Grahamstown Dam operates within the Dams Safety NSW safety threshold under normal and flood conditions. However, following the methodology outlined by Dams Safety NSW, the risk assessment has identified that the dam exceeds the safety threshold in earthquake events.

The risk assessment has identified that the greatest risk to society (accounting for approximately 98% of the total societal risk) to the dam is possible failure of the Main embankment due to earthquake forces, which could cause the embankments of the dam to become unstable and move due to liquefaction. The next largest contributor to the societal risk included failure of the Saddle embankment due to liquefaction in an earthquake.

The risks associated with earthquakes have existed since the construction of Grahamstown Dam in the 1960s and is not a result of poor maintenance by Hunter Water or due to inadequate design at the time of the scheme’s conception. The risk has recently been understood in greater detail as advances in geotechnical engineering, scientific monitoring, and advanced computer modelling have provided better analytical methods to identify and understand how the sandfill shoulders and sandy foundations of the embankments could potentially behave under earthquake forces. Figure 6 shows images of geotechnical works which were undertaken at the embankments to help inform the risk assessment.

Figure 6 Images showing geotechnical works on Grahamstown Dam

The chance of an earthquake causing liquefaction that leads to the failure of the Main embankment has been assessed as being approximately a one in 3,500 year event or a 0.03% chance of occurring in a single year. Whilst larger earthquakes mostly contribute to the risk of liquefication, small earthquakes or tremors could also lead to liquefication as the looser soils in the dam could destabilise under these events, this has been accounted in the above number which is estimated based on current knowledge relating to seismic activity in the Newcastle region. Newcastle's 1989 Magnitude 5.6 (on the Richter scale) earthquake did not trigger liquefaction at the dam. Available evidence indicates that the earthquake's impact was limited at Grahamstown due to a range of reasons such as the epicentre being far enough away from the dam, or the duration of the earthquake not being long enough to trigger liquefaction (which requires enough cycles to generate excess water pressure in the soil during the event).

The risk assessment findings present an opportunity for Hunter Water to manage the risk to an acceptable level. Hunter Water is working with experienced dam engineers and specialists to explore options to reduce the risks to an acceptable level. Hunter Water and its emergency services partners (including the NSW State Emergency Services (SES)) have a Dam Safety Emergency Plan in place to respond to incidents, including earthquake. If an earthquake occurs, this plan will be activated to trigger an appropriate response, depending on the intensity of the earthquake and/or observable damage to the dam.

4.0 Risk assessment recommendations

Although Grahamstown Dam is operating satisfactorily during day-to-day operations, as a responsible dam owner Hunter Water is committed to making sure that the dam remains safe and secure into the future under a range of possible different operating scenarios including in the event of a flood and/or earthquake.

A number of recommendations were made to Hunter Water based on outcomes of the risk assessment, which relate to further investigations that should be conducted to reduce uncertainty of the risks associated with a large earthquake event.

Engineering assessments, analytical methods, standards and guidelines have changed a lot since the construction of Grahamstown Dam and are continually improving with advances in science, monitoring and modelling. These changes contribute to an improved understanding of the dam and conditions which it may experience throughout its operation. As such, it is not unexpected that actions are needed to ensure Grahamstown Dam continues to operate safely under all conditions and scenarios for many decades to come. The recommendations provided in the risk assessment aim to refine the societal risk position of Grahamstown Dam and to address identified uncertainties associated with the current assessment. They also aim to address gaps in available data or new analytical methods or databases that may be available. Hunter Water will present risk mitigation measures (upgrades) for the dam based on the below recommendations.

Key recommendations from the risk assessment include:

- Investigations to better understand the impact of earthquakes on the liquefaction potential for Grahamstown Dam, the behaviour of the embankment, and impact to the dam structure.
- Commence engineering and technical designs for embankment upgrades that aim to reduce inherent risks associated with failure modes.
- Undertake modelling to assess the effectiveness of warning times in the event of a dam failure.
- As an interim step, reduce the water level of the dam to reduce risks associated with an earthquake.

The above investigations will enable Hunter Water to manage and mitigate risks in accordance with principles required by the Dams Safety NSW regulations.

5.0 Next steps

Hunter Water is committed to addressing the risks identified in the dam risk assessment report to ensure people and property remain safe, and this important water resource remains secure for the Hunter region. Hunter Water will consider the recommendations and determine appropriate mitigation measures to increase the safety of Grahamstown Dam. Hunter Water will be engaging with the community on proposed options for reducing risks at the dam and will continue to update the community as this work progresses.

A Dam Safety Emergency Plan (DSEP) is required under the Act and is already in place. The DSEP is a document that sets in motion procedures and actions to be executed by emergency agencies to minimise the potential for loss of life in the rare event of an earthquake related failure of the dam. The plan includes the potential evacuation of low-lying areas in the event of a significant earthquake. Currently, if a significant earthquake were to occur, Hunter Water and its emergency services partners will follow this plan.