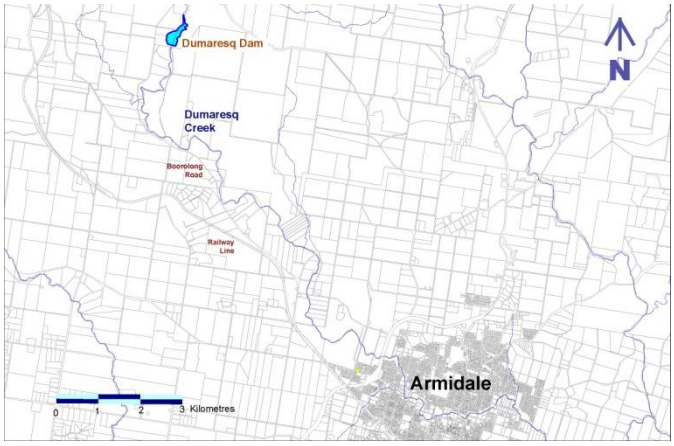
Dumaresq Dam Safety

Background

Armidale Dumaresq Council situated in the Northern Tablelands owns and is responsible for three prescribed dams. These are Dumaresq, Puddledock and Malpas Dams. The oldest of the three Dumaresq Dam, a concrete gravity dam, was constructed in 1896. It was followed in 1928 by Puddledock Dam a concrete arch with concrete gravity abutments. Finally in 1968 Malpas Dam, 31m high earth and rockfill embankment dam located on the Gara River north east of Armidale, replaced Dumaresq and Puddledock Dams as the main water supply for Armidale. Since then Dumaresq Dam, situated some 10 kilometres northwest of Armidale on Dumaresq Creek, has become an important recreational area and is no longer required as a source of raw water for Armidale.



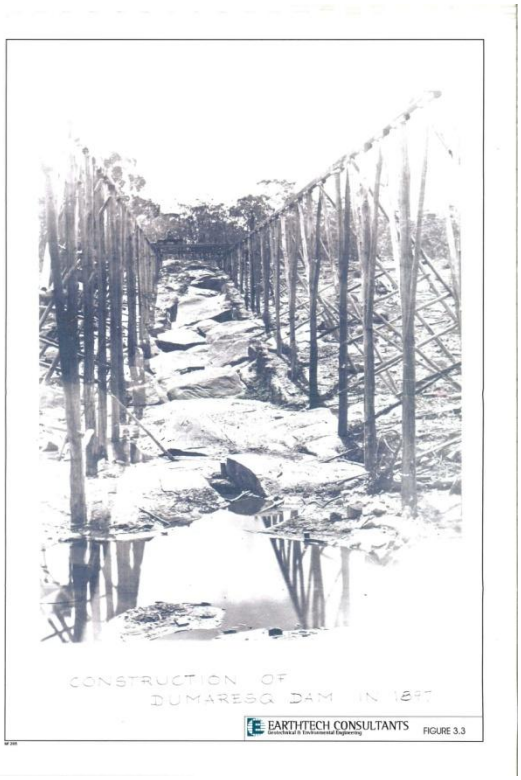
Description

As stated, Dumaresq Dam is a straight concrete gravity dam with a maximum height of 11.9 metres. The length of the crest is 189 metres and width of the crest is 0.8 metres. The right abutment is a 49 metres long homogeneous earthfill embankment with a clay puddle core cutoff down to rock foundation. The embankment is protected by a concrete wing wall whilst on the left the abutment abuts against the natural ground surface.

The spillway slot in the central area of the dam was formed by the construction of 0.75 metre high concrete wall on either side and is at an elevation of 1074.00 m AHD. Any flood with a height above 1074.75 m AHD will utilise the whole of the length of the crest as a spillway. At this stage the freeboard available, i.e. up to the earthfill embankment crest, is 0.55 metres. The capacity of the spillway is 114 m^3/sec at dam crest level and 300 m^3/sec at embankment crest level. After flowing over the spillway the kinetic energy of the water is dissipated on the downstream natural rock structure. The embankment crest level, crucial when considering the possibility of the dam failing by over topping, is 1075.30 m AHD.

The dam wall was constructed using "cyclopean" construction or "pluming" whereby large granite boulders are embedded in the concrete to reduce the amount of concrete used and probably to increase the shear capability across horizontal construction joints.

The catchment area of the dam is 21 km^2 of mainly bush area. The reservoir has a theoretical storage capacity of 440 Ml. This has been reduced to 380 Ml by siltation. The area of the reservoir is approximately 12 hectares.



Previous Studies and Reports

Surveillance and Status Reports

In addition to the detailed reports listed below it is a requirement of the DSC that Council undertakes a surveillance report on the dam every five years. NSW government departments also undertook a number of audit inspections during this period to determine the status of the dam. Reports produced include the following:

Report	Produced by:
Surveillance Report 1985	Department of Public Works
Surveillance Report 1991	Department of Public Works
Surveillance Report 1997	NSW Department of Land and Water Conservation (DLWC)
Audit Inspection 2000	
Surveillance Report 2003	Ministry of Energy and Utilities
Audit Inspection 2004	Department of Energy, Utilities and Sustainability
Dam Safety Inspection Report 2004	Dam Safety Unit NSW Office of Water
Dam Safety Inspection Report 2009	Dam Safety Unit NSW Office of Water
Surveillance Report 2010	GHD

Flood Study Report

In August 1994 the Hydrology Group of NSW Public Works produced a Flood Study of Armidale's three dams as part of a Dam Surveillance exercise by Public Works. The group estimated that the probable maximum flood (PMF) for Dumaresq Dam would result in a peak outflow of around 1150 m^3/sec, corresponding to a peak water level above the spillway invert level of 2.5 metres. This is above the embankment crest level. The "0.5 PMF" peak outflow was estimated at 570 m^3/sec with a water level above the spillway of about 1.8 metres.

The techniques used to prepare this estimate followed the methodology given in the Institution of Engineers, Australia "Australian Rainfall and Runoff, A Guide to Flood Estimation, 1987" (ARR 1987). A caveat in the report states that these flood estimates should be taken as preliminary and that the "true" flood estimates could be much greater (or lower)!

Dambreak Study

In March 2000 NSW Public Works produced a dambreak study to determine the problems that could occur downstream should the dam fail. This information was then used to apply a hazard rating to the dam. The study investigated the following scenarios:

- Sunny day dambreak
- Imminent failure flood (IFF) with and without a dambreak

- Probable maximum flood with and without a dambreak

The IFF dambreak was assumed to have occurred when the water level in the reservoir reaches the top of the earthfill embankment on the western abutment.

At the time hazard ratings were determined to fall into one of the following levels:

- High
- Significant
- Low

Two types of dam failure were recognized for the purpose of determining the hazard rating:

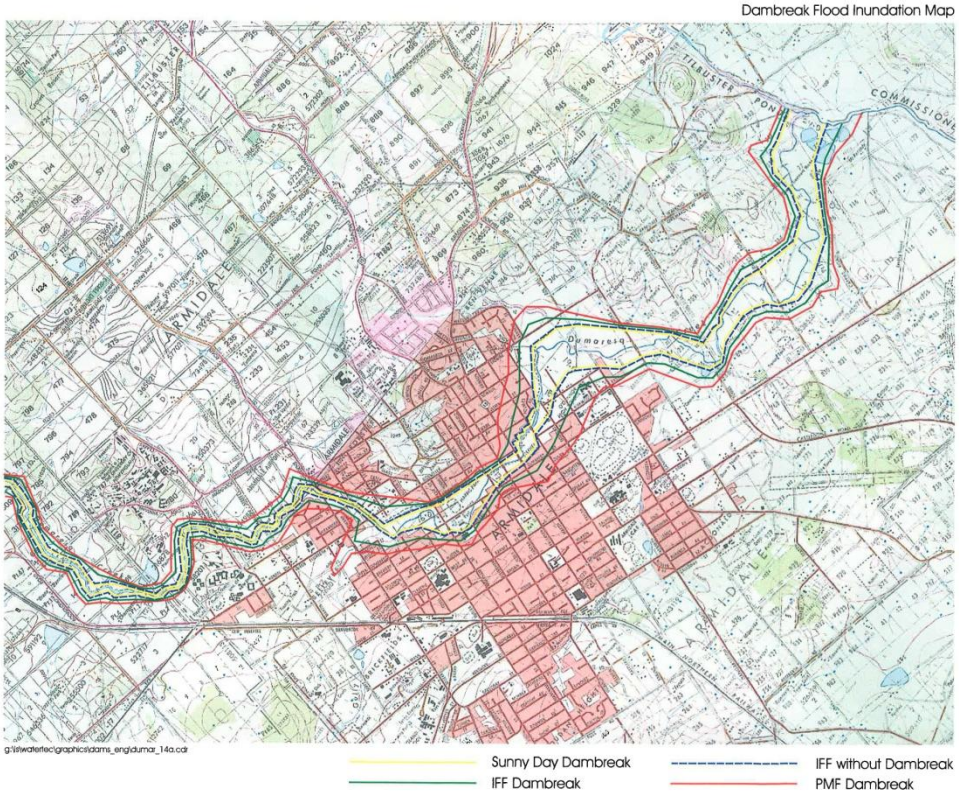
- Failures that occur without any attendant natural flooding and
- Failures that occur in association with a natural flood,

giving rise to two types of hazard rating namely:

- "Sunny Day" hazard rating (SDHR)
- Incremental Flood Hazard Category (IFHC)

The PMF outflow was estimated at 1430 m^3/sec and the study looked at breach development times of 5 and 10 minutes in accordance with ANCOLD guidelines. Downstream flooding was determined by the use of a MIKE11 hydraulic mode.

FIGURE 14a
Dambreak Flood Inundation Map



The report came to the conclusion that Dumaresq Dam was a high hazard dam for both the sunny day dambreak and PMF dambreak cases.

Portfolio Risk Assessment

In 2001/2002 the Snowy Mountain Engineering Corporation prepared a Portfolio Risk Assessment for the Department of Land and Water Conservation on 21 NSW local water utility dams with known deficiencies. Dumaresq Dam was one of those dams.

Applying ANCOLD risk guidelines to data provided by previous analyses of the dam led them to make two recommendations:

1. Immediate: Prepare a Dam Safety Emergency Plan and install a flood monitoring system. See the section on Risk Mitigation Measures below.
   Consider the relocation of houses that are too close to the dam to permit a flood warning system.
2. Within 5 Years: Upgrade dam by installing anchors and providing protection to abutments. The cost at that time was estimated at $4.5 million.

Report on Stability Assessment

Towards the end of 2001 Armidale Dumaresq Council appointed EarthTech Consultants to undertake a detailed analysis of the stability of Dumaresq Dam. The scope of the analysis included:

1. Review all available information on the dam's design, construction and performance from Council's records.
2. Field Investigation to include:
   - Geological mapping of rock foundation downstream of the dam wall.
   - Diamond core drilling of two holes through the concrete gravity section of the embankment and into the foundation rock.
   - Near-surface concrete core samples of large diameter (⌀100 - 120 mm)for use in obtaining insitu compressive stress of concrete.
   - Laboratory testing of core samples to determine the characteristics of the concrete including its compressive strength.
3. Confirm that the dam is stable under loads that may be applied during its lifetime so that it will not rupture, overturn or slide.

EarthTech's report concluded that although the dam had stood for over 100 years without any serious problems, applying the criteria in the ANCOLD guidelines that no tension should be allowed in the concrete, then the dam wall is unstable under reservoir full conditions. Obviously the theoretical instability increases as the water level in the reservoir rises.

They also looked at earthquake loading but following a pseudo static analysis determined that that the extreme load case resultant was within the concrete surface of the dam and the sliding factor was greater than 1, indicating that it was not the critical load case.

The consultant suggested that the following remedial measures be considered:

a. lowering the height of the dam wall by 2.5 metres,
b. maintain the dam as is and install either post tensioned or passive anchors or
c. some combination of the above.

Upgrade Report

In 2007 Armidale Dumaresq Council appointed GHD to undertake the investigation of physical condition and options for the upgrading of Dumaresq Dam to acceptable flood capacity. Their report was provided in three section; a geotechnical investigation, a dambreak study and the main report on stability options,

Geotechnical Report

A geotechnical investigation of the dam wall undertaken by GHD Geotechnics. The work was to include two boreholes down through the dam wall into the rock of the foundation. Unfortunately, due to the fact that the drilling contractor could only use a small drilling rig on the confined space of the top of the wall, the second borehole was abandoned before it could hit the foundation rock. The report was presented in February 2008. The report calculated that the adjusted characteristic compressive strength of the concrete was 15 Mpa whilst the adjusted characteristic tensile strength was 3.1 Mpa. It did note that these results were only preliminary and that further geotechnical investigations would be necessary prior to detailed design.

Dam Break Study and Flood Inundation Map

This was an update of the 2000 Public Works Dambreak Study. The hydrological modelling was carried out using the XP-RAFTS software to determine flood peaks within the dam catchment area and also in the downstream catchment.

The analysis showed that the 100 year Average Return Interval (ARI) event produced a peak discharge of 114 m^3/sec, corresponding to a water level 1074.74 metres AHD. Given that the dam crest level is 1074.75 metres AHD this event was adopted as the dam crest flood (DCF). For the PMF the peak inflow was calculated at 1047 m^3/sec.

The dambreak breach was estimated, using parameters recommended by ANCOLD, namely a catastrophic failure of a 50 metre length of the dam wall down to two thirds the height of the dam.

Downstream flooding areas were determined using a MIKE 11 model. The results showed that for a sunny day failure the persons at risk (PAR) totalled 44.

For a PMF the PAR without a dambreak was 2550 whilst with a dambreak this increased to 2670, i.e. an incremental PAR due to the dambreak of 120.

Report on Stability Analysis and Options

GHD's report titled "Investigation of Physical Condition and Upgrading Options" was presented to Council in July 2009. GHD were tasked with:

- geotechnical evaluation (see above),
- updating the hydrological and hydraulic assessment of flooding,
- revisit the previous dambreak analysis (see above),
- identifying the engineering options for upgrading the dam,
- assessing the value of the dam taking into account its heritage and recreational roles and
- undertaking a preliminary environmental assessment.

The re-evaluation of the flooding utilised the BOM report "The Estimation of the Probable Maximum Precipitation in Australia: Generalised Short Duration Method" (GSDM), June 2003. Using the XP-RAFTS software it was determined that the maximum peak water level in the dam resulted from the 2.5-hour PMPDF storm event. For this storm event, the peak water level is 1076.3 metres AHD and the peak inflow is 1047 m3/sec.

Analysis of the concrete strength parameters was predetermined by ANCOLD guidelines that do not allow for tensile strength in the concrete when determining a dam's stability. However, if this condition prevails the stability analysis shows that the dam falls over when full. Not only does this not happen but during it's 100+ year lifetime there must have been many occasions when the water level was well above the spillway crest. Using this information the consultants determined that the tensile strength of the concrete was 130 kpa. Circular logic at its best.

In the report GHD concluded that the dam did not meet acceptable safety conditions either during flooding events or during a maximum design earthquake. They then investigated what would be necessary in order to achieve an acceptable outcome.

In their report GHD considered eight options. These were presented to Armidale Dumaresq Council and the Department of Water and Energy (DWE). Following this four options were selected for further investigation.

8.	Non structural upgrading. Essentially a risk assessment of the existing dam to show that the risks inherent in leaving it as is are manageable.	$ 800,000
3.	Installation of post-tensioned anchors.	$ 5,000,000
2.	Reducing the height of the dam.	$ 1,900,000
1	Decommissioning the dam.	$ 1,800,000

A fully detailed report was then presented to Armidale Dumaresq Council.

Consideration of Options by Council

At a meeting of Armidale Dumaresq Council held in April 2009 Council was told that Option 8 was not viable as the time for the dambreak flood wave to travel to the edge of the City was too short. They therefore approved Option 3, installation of post-tensioned anchors, providing that money was available from higher levels of government to offset the cost. Should additional money not be available then Option 2, reducing the height of the dam, would be preferred.

Loss of Life Assessment

Upon receiving the report on the upgrading of Dumaresq Dam from GHD, the DSC asked Armidale Dumaresq Council to commission a Loss of Life (LoL) assessment. This was undertaken by GHD in 2010 in accordance with 'A Procedure for Estimating Loss of Life Caused by Dam Failure' (Graham, 1999). The previous GHD dam break study was used to define the inundation zone in the event of dam failure.

The consultant calculated that the best assessment, i.e. a weighted combination of day and night PAR, of loss of life to be 1.66 persons for the PMF with dam break scenario, and 1.01 persons for the 100 Year ARI with dam break event. The worst case loss of life assessment, i.e. failure during day time during the week is 2.13 persons for the PMF with dam break scenario, and 1.39 for the 100 Year ARI with dam break.

This means that the Flood Consequence Category in accordance with Table 1 of DSC3A is High B. The design flood that should be adopted for the proposed dam safety upgrade then becomes the 1:1,000,000 Annual Exceedance Probability (AEP) event. This is one step up from the previously accepted FCC of High C for which the design flood is the 1:100,000 AEP event.

Risk Mitigation Measures

Since the provision of a portfolio risk assessment prepared by the Snowy Mountain Engineering Corporation In 2001/2002 (see above) Armidale Dumaresq Council has focussed on having an operational Dam Safety and Emergency plan (DSEP) and a robust early warning system.

Dam Safety and Emergency Plan

The Dumaresq Dam DSEP was first produced in 2004 by the NSW Department of Public Works. It was updated in 2009 to include revised requirements for the DSC and again in 2013 to reflect the fact that the Department of Public Works are no longer prepared to be involved in offering advice on dam performance during an emergency.

The DESP contains the following alert levels for the dam:

- Protection Alert: 1074.30 m AHD 300mm over the spillway
- White Alert: 1074.50 m AHD 500mm over the spillway
- Amber Alert : 1074.70 m AHD 700mm over the spillway
- Red Alert: 1075.50 m AHD 1200mm over the spillway

For an alert level above the Protection Alert the operator or the manger should contact the SES. It should be noted that up to the amber alert level the overflow is contained within the spillway slot and the red alert is only 100mm below the level of the right abutment crest.

Early Warning System

The Dumaresq Creek catchment contains a number of stations that provide an early warning of flooding or dam failure. This includes water level recorders on the dam wall, downstream flow recorder and an automatic rain gauge. To improve security the readings from the main warning stations are two completely separate systems. One, maintained by Elpro Pty. Ltd., reports through Armidale Dumaresq Council's SCADA system the other operated and maintained by the New South Wales Office of Water (NOW) reports through their telemetry system and can be accessed via the NOW web site.

Seepage Measurement

As required by ANCOLD guidelines Dumaresq Dam is inspected three times a week by ADC operational personnel, who have all completed the DSC's three day dam inspection accreditation course. As part of that inspection they measure the seepage through the dam wall. This varies between 0.5 to 1.5 l/min, with the main determinant of the amount of seepage being the ambient temperature, i.e. flow increases during cold winters returning to the lower baseline during the summer.

Follow up Activities

Following the submission of the LoL assessment, Armidale Dumaresq Council received a number of letters from the DSC asking for an upgraded concept design to be prepared and submitted to the DSC for approval following a peer review. However, a number of issues transpired that caused Council's engineers to conclude that revisiting the concept design in the GHD Report might prove to be advantageous.

- Approaches to higher levels of government for additional funds for the selected option did not produce any results.

- The rational for discarding Option 8, that the flood wave travel time to Armidale was of the order of 10 minutes, was shown to be incorrect. In fact it takes approximate, one hour for it to reach the outskirts of the city.
- It was felt that there could be other options for upgrading the dam apart from the four presented to Council that might accomplish the objectives set by the DSC at less cost.
- It became apparent that there was considerable support within the community for the retention of Dumaresq Dam and reservoir in its current condition and the recreational aspects of the area are highly prized.

Accordingly in August 2012 Council placed an open tender on Tenderlink for a consultant to undertake the investigation, preliminary design, detail design and preparation of tender documents for the upgrading of Dumaresq Dam.

Initial Consultant Tender Process

Tenders were received from five consultants. Following a rigorous tender assessment process it was decided that the most favourable submission was the one from NSW Public Works. A report was prepared that recommended to Council that their tender be accepted for the work for a total cost of $223,000. This report was presented to a Council meeting on the 5th November 2012 and the recommendation was approved. The following day a rescission motion was submitted from two of the Councillors who had been present at the meeting.

As one of the concerns expressed by the dissenting Councillors was that they did not have sufficient information on the upgrading project a workshop was arranged at which information expanding and clarifying the contents of the tender acceptance report was presented. The workshop was attended by representatives from Public Works and the DSC's executive engineer, Steve Knight. The former emphasised their extensive knowledge of this type of problems and their experience in working with local councils and the DSC. The latter explained that the upgrading of the dam was a matter of public safety and that Armidale Dumaresq Council as the owner had a statutory responsibility to ensure that the dam met the current standards as set out in the legislation.

Non-withstanding the presentation from the external attendees, at their next meeting Councillors approved the rescission motion. This meant that Public Work's tender could not be accepted and that Council would have to retender the project.

Retender Process

The principal concerns of Councillors regarding the initial tender were;

- They felt that the hydrological/hydraulic phase of the project was under emphasized. It was their expectation that revisiting the dambreak flooding would show that it posed only manageable risks to the

population of Armidale, undercutting the DSC rationale for upgrading the dam.

- They also were concerned that if at any stage the physical upgrading of the dam is shown not to be necessary then the consultant should not be recompensed for the loss of the remainder of the contract.
- They wanted to ensure that all sections of the community, especially those who have expressed alarm over the possibility of losing the dam, should be consulted throughout the process.
- That each phase of the project should be subject to a peer review.

The tender documents were rewritten to emphasise these points and posted on Tenderlink in January 2012. As previously five tenders were received, although Public Works declined to tender. The selection panel decided that the proposal from Arup was most advantageous to Armidale. A report was presented to Council on the 25th February 2013 recommending the award of the contract to Arup for the sum of $229,571. This recommendation was accepted.

Upgrading Contract Phase 1

On award of the contract Arup commenced work on the first phase of the project, a review of the hydrological and hydraulic analyses undertaken previously to ensure that any the conclusions reached wee still valid or could be questioned.

Their initial review and analysis turned up a number of areas were the consultant was of the opinion that further investigation was warranted. The main aspects to be looked at were:

1. The reservoir flood routing was only undertaken for a 1:100 year ARI and a PMF. Looking at a range of floods between these two would give a better indication of the conditions that would have to be dealt with during the design process.
2. The breach outflow hydrographs used within the 2009 dambreak study appear to overestimate the volume of water, and the peak flow, released from the dam.
3. The Manning's "n" values, a measure of the condition of the floodplain, included in the Mike 11 model appear to be high.
4. Probable Loss of Life calculations are threshold based and sensitive to flood warning time assumptions.

The consultant was given permission to expend additional money on further investigation and analyses to resolve the issues raised.

The consultant has now submitted a final report to Armidale Dumaresq Council and the DSC. It has yet been subject to a peer review. The main conclusions of the report are:

1. The dambreak assessment identifies that the probable LoL estimate in the PMF event is 1.8 persons. The resultant FCC is 'High C', with a design flood for any upgrade works being a 1:100,000 AEP flood.
2. The routing results show that for the 1:100,000 AEP the water level will be 0.53m above the embankment crest.
3. The analysis assumes that the entire 189m crest length of the concrete section would spill the water during an extreme flood event. This implies that the concrete section of the dam will need to be upgraded so that it is safe for the increased reservoir loading.

Discussion

Over the past twenty years Armidale Dumaresq Council has expended considerable time and energy on the investigation and analysis of the condition of Dumaresq Dam. It should be noted that over this period ADC's other two dams, Puddledock and Malpas Dams have received a similar amount of attention for the same reasons. Malpas Dam fortunately was built so be expanded, so with a freeboard of 8.56 metres it is an extremely safe dam. Puddledock Dam is similar to Dumaresq Dam in that it has stood successfully for almost 50 years yet does not meet current safety standards.

All of the studies prepared by the various consultants tend to reach the same conclusion. Under a dam crest flood or a probable maximum flood failure there will be extensive flooding within Armidale with a possible loss of life of between 1 and 2 persons. This puts the dam in a flood consequence category of High C leading to it having to be designed for a 1:100,000 year average return interval event. For this flood not only will some way have to be found to prevent the scouring of the right abutment, but the whole length of the dam wall will have to be strengthened. The preferred method of doing this is by installing post tensioned anchors.

However, there are a few problems in implementing the preferred remedial measures expeditiously:

1. The amount of money required for the upgrading is significant for a city the size of Armidale, especially as the asset in question no longer fulfils a water supply role.
2. ANCOLD guidelines state that no tension is to be allowed in the concrete. However, as Dumaresq Dam has stood up for over 100 years with no overt sign of distress it is obvious that it is being held up by the tension in the concrete. In addition a research paper undertaken for ICOLD, the European Commission on Large Dams on the sliding safety of gravity dams (Giovanni Ruggeri, 2004)stated that for the dams included in the study the concrete and the concrete/rock interface exhibited significant tensile strength.
3. Obviously preventing overtopping of the embankemt is essential as there are numerous examples of dams failing because of this However.

It is possible that the strengthening of the dam wall would not be necessary as it could be good for another 100 years.

4. The dam is most likely to fail during a significant flooding event. At this time it is highly likely that Armidale will be experiencing serious flooding problems even without a dambreak. Given the distance from the dam to the outskirts of Armidale it is difficult to make the case to Council and the general public that the expenditure is justified by the reduction in risk to the general population.
5. Opposition from certain sections of the public to any action that will reduce or impair the amenity of the Dumaresq Dam recreational area.