Public Works
NSW Water Solutions

Dams & Civil

PARADISE DAM

FLOOD EVENT OF JANUARY TO MARCH 2013

REVIEW OF DAM SAFETY MANAGEMENT ACTIONS

REPORT FOR THE OFFICE OF WATER REGULATION

Queensland Government

DEPARTMENT OF ENERGY AND WATER SUPPLY

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Foreword

Paradise Dam was completed in 2005. It is a 52m high roller compacted concrete (RCC) gravity dam on the Burnett River some 80km south-west of Bundaberg, Queensland. A large flood occurred at the dam during the 2010/2011 wet season when much of Queensland experienced record, or near record, flood conditions. However, a far larger flood occurred during the January to March period of 2013.

The purpose of this independent review is to examine the dam safety management actions taken prior to, during and after the January to March 2013 flood event at Paradise Dam and to determine what lessons can be drawn from the experience, especially with regard to any need to improve dam safety procedures.

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Acronyms

AADT	Annual Average Daily Traffic
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ANCOLD	Australian National Committee on Large Dams
CBD	Central Business District
CEO	Chief Executive Officer
DDMG	District Disaster Management Group
DERM	Department of Environment and Resource Management
DEWS	Department of Energy and Water Supply
DG	Director General
EAP	Emergency Action Plan
EEC	Emergency Event Coordinator
F-N	Chart on which societal risks are compared with tolerable risk criteria
LDMG	Local Disaster Management Group
NRM	Natural Resources and Mines
PAR	Population at Risk
P1	Phase 1 remedial works
P2	Phase 2 remedial works
P3	Phase 3 remedial works
SDMG	State Disaster Management Group
SITREP	Situation report
SOP	Standing Operating Procedure
SW	SunWater Ltd

Executive Summary

On 12 June 2013, the Queensland Department of Water and Energy (DEWS) advised that it had accepted the *Paradise Dam Review – Consultancy Proposal (P13033)* dated May 2013. The purpose of the review is to examine the dam safety management actions taken prior to, during and after the January to March 2013 flood event at Paradise Dam and to determine what lessons can be drawn from the experience, especially with regard to any need to improve dam safety procedures. The Terms of Reference for the review are at **Appendix A**.

The review was to commence on 24 June 2013 and to be completed by Friday 19 July 2013. Meaningful work did not commence until Monday 1 July 2013 because the first documents from the dam owner arrived on Friday 28 June 2013.

A site inspection was made on 2 July 2013. A draft report was sent to DEWS on 5 August 2013. Comments of DEWS and SunWater were received from DEWS on 13 August 2013. This final report is provided to DEWS on a confidential basis.

Paradise Dam was completed in 2005. It is a 52m high roller compacted concrete (RCC) gravity dam on the Burnett River some 80km south-west of Bundaberg, Queensland.

At 33,000km^2 the very large catchment area produces large flood flows at the dam. A large flood occurred at the dam during the 2010/2011 wet season when much of Queensland experienced record, or near record, flood conditions. However, at Paradise Dam, a far larger flood occurred during the January to March period of 2013. It is these flood events, particularly that of 2013, which are the main focus of this review. The trigger for the review was significant damage and scour which occurred in the dam's energy dissipation zone during the 2013 flood.

The dam owner, SunWater, co-operated fully with the review. All told, SunWater made available 311 files to assist the review. All of these files have been examined to find material of relevance to the review.

Based on our review the following advice is provided in answer to the Terms of Reference.

First Term of Reference

Was there any damage to the dam from previous flood events that had not been rectified by the January-March 2013 flood event. If there was such unrectified damage, may it have worsened the damage from the January-March 2013 flood event, or adversely affected SunWater's ability to respond to the flood event, both during it and immediately afterwards? Are any changes to SunWater's practices/procedures desirable?

Advice

1. ***There was damage from previous flood events that had not been rectified prior to the January-March 2013 flood event;***

2. ***The unrectified damages in the preceding point had no significant effect on the damages which occurred during the January to March 2013 flood event.***

3. ***The unrectified damages had no effect on SunWater's ability to respond to the January to March 2013 flood event.***

4. ***SunWater's documented procedures for dam safety are sound and in accordance with accepted industry practice, with the development permit conditions for the dam, with the regulator's guidelines (NRM 2002) and otherwise with ANCOLD guidelines, in particular with the guidelines on dam safety management (ANCOLD 2003).***

5. ***It is desirable that the SunWater standards, notably DS13, be amended to better cover the spillways of dams including the energy dissipation zone. SOP 19 would benefit from inclusion of training on case studies of gravity dam failures and their causes and consequences, and on case studies of damages to gravity dam energy dissipators and of rock scour.***

6. ***It is desirable that SunWater review its procedures for assessing the potential for rock scour at its dams, particularly those dams with high specific power discharges (peak power per metre length of spillway crest). If not already applied, the recognized methodologies for estimating rock scour should become part of the assessment procedure for those dams with high specific power discharges.***

7. ***It is desirable that the potential for further rock scour at Paradise Dam is estimated carefully before the coming wet season and the work is reviewed by an independent peer reviewer recognized for knowledge of and experience in rock scour estimation methodologies. The peer reviewer should be involved from the outset so as to comment on the analysis scenarios and approach. The outcome of the work should include a "best estimate" result. As a minimum the work should cover a range of flood magnitudes and two configurations:***
   - ***The configuration of the rock surface downstream of the dissipator as it will exist on completion of Phase 2 remedial works; and***
   - ***The situation where the dissipator apron has been subsequently destroyed and removed by floodwaters.***

8. ***It is desirable that the stability analysis of critical dam monoliths is refined before the coming wet season and the work is reviewed by two independent peer reviewers, one recognized for knowledge of and experience in gravity dam stability analysis and one a recognized specialist in rock mechanics (unless a suitable person highly skilled in both fields can be found). The peer reviewers should be involved from the outset so as to comment on the analysis scenarios and approach. The outcome of the work should include "best estimate" results as well as results of traditional standards-based analyses. At this stage it appears the analyses should give consideration to:***
   - ***The selection of analysis methodology and safety criteria for gravity dam stability;***
   - ***The outcomes of the rock scour analyses under the preceding point;***
   - ***The latest knowledge of foundation geology;***
   - ***A further review of the stabilizing forces provided by tailwater;***
   - ***Any proposed reliance on passive anchors, including the consideration that the load capacity cannot be monitored in the long term.***

9. ***It is desirable that the risk assessments be updated when results from the preceding two work items are available. Consideration should be given to these aspects of the risk analyses:***
   - ***The results should be "best estimate";***
   - ***In addition to the failure pathway in the interim design report there should be a parallel failure pathway involving destruction of the dissipator apron by abrasion and the energy of the overflow;***
   - ***An event tree branch for the probability of sliding, given deep scour to the dam toe, should be included;***
   - ***The results from the scour and stability analyses should inform the probability of deep scour and the probability of sliding***
   - ***The reasoning underlying the selection of the risk analysis values needs to be fully documented.***

10. ***It is desirable that the results of the updated risk assessment inform SunWater's level of preparedness for the coming wet season and level of surveillance at the dam in the event of a flood. A precautionary approach should be taken having regard to these facts:***
    - ***The analyses have wide uncertainty;***
    - ***It is not reasonably practicable to know exactly what is happening in the energy dissipation zone during a flood event; and***
    - ***Public safety would potentially be at risk.***

11. ***The reservations of SunWater's independent peer reviewers regarding the value of analyses before the coming wet season, as proposed in our preceding advices, need to be fully heard and carefully considered. Resolution of those reservations lies outside the scope of this review.***

Second Term of Reference

Consider the adequacy of SunWater's response immediately prior, during, and immediately after, the January-March 2013 flood event, and opportunities for improvements in practices/procedures. In making this assessment, the contractor should cover:

- *Communications between SunWater, the Local Disaster Management Groups, and emergency response groups more generally.*
- *Given the circumstances (especially the prevailing weather conditions), assess the time taken, and methodologies used, to assess the damage, and commence emergency repairs.*

Advice

1. ***SunWater responded adequately prior to, during and immediately after the flood event. A precautionary approach was taken by activating the EAP for a potential sunny day failure event after the flood had subsided and until the emergency repairs had reduced risks to target levels.***

2. ***The available evidence indicates that SunWater maintained an excellent level of communication with the disaster management groups in the Bundaberg area. SunWater dam safety engineers provided authoritative information on the safety status of the dam and the disaster management groups relied on that information.***

3. ***Given the circumstances it faced, SunWater commenced the emergency repairs within a reasonable time. The methods for initiating releases, gaining access and determining the damage were reasonable given the time pressures.***

4. ***The application of risk assessment to assess the damages in a workshop of experienced professional people was a sound approach to the estimation of dam safety risks.***

5. ***An opportunity for improvement of practices/procedures for any future events exists in the risk assessment process with regard to:***
    - ***Documentation of the risk assessment, particularly as regards the description of failure mechanisms and the reasoning which underlies probability values;***
    - ***Assigning "best estimate" risk values. If SunWater sees reasons to take a precautionary approach, that should be done after the "best estimate" risk assessment results are available;***
    - ***Use of event trees primarily, but also fault trees if appropriate, to fully define failure mechanisms; and***

- ***Bolstering engineering judgment by science and world experience of dam performance to the maximum practicable extent.***

6. ***Given what is now known about the performance of the dam in floods, there would appear to be an opportunity of improving SOP 42, and possibly other guidance documents, with respect to:***
    - ***Ensuring that a dam safety engineer makes a site inspection as a matter of urgency after a report of damage which is potentially a dam safety incident as defined by the regulator;***
    - ***Specifying that "time to notify" under DS 2 of the development permit conditions runs from the date of the engineer's inspection provided the damage is confirmed as a "dam safety incident"; and***
    - ***Specifying who is responsible for initiating notification of the regulator and seeing that it is made within the required time of seven days.***

7. ***There is an opportunity to improve procedures by SunWater training its personnel to enter sufficient words in the "Message" field of Communication Records to enable others to comprehend the subject of the communication.***

Third Term of Reference

Consider, given all the circumstances e.g. incomplete knowledge of the repairs commencement, the appropriateness of the emergency repairs, the length of time to complete them, and whether this period could have reasonably been reduced. Could the risk mitigation measures in place, which were to minimise the consequences of dam failure, (while the emergency repairs were completed), been improved? Could SunWater's practices/procedures be changed to potentially produce better outcomes in similar, future events?

Advice

1. ***Given the circumstances it faced, it was not reasonably practicable for SunWater to reduce the time required for completion of the emergency repairs.***

2. ***The emergency repairs were an appropriate means of progressively reducing risk.***

3. ***The activation of the EAP for a sunny day failure scenario was a reasonable, though precautionary, means of risk mitigation and it was not reasonably practicable to improve the mitigation measures within the time available without detriment to other critical activities.***

4. ***The EAP should be revised to allow for the risks which are now known to exist at Paradise Dam. In particular, response plans should be devised for possible future damage scenarios.***

Fourth Term of Reference

Are changes to the dam's Emergency Action Plan, or other documentation and procedures, desirable? (Noting that significant changes will be required, in any event, to comply with new legislative requirements).

Advice

1. ***The EAP covers all of the content required by the dam safety regulator's guidelines, though not always as fully as is desirable.***

2. ***If the advice under the first Term of Reference is followed, it is desirable that the EAP is revised to take account of the findings of the analyses proposed under that TOR.***
3. ***It is desirable that SunWater work together with the disaster management groups in an effort to make the EAP more user friendly and to maximise the effectiveness of evacuation.***
4. ***It is desirable that the EAP be revised to better deal with redundant systems for emergency management.***
5. ***It is desirable that the EAP be revised to provide better information on assets and resources which may be required for emergency management.***
6. ***It is desirable that the EAP be reviewed to remove any content that is not applicable to Paradise Dam.***
7. ***It is desirable that there be a list of acronyms and their meaning immediately after the table of contents.***
8. ***It is desirable that the EAP be revised to make clear statements about the need for continuous attendance of surveillance personnel at the dam.***
9. ***It is desirable that the EAP be revised to make clear statements about the urgency for inspections by a dam safety engineer.***
10. ***It is desirable that the EAP be revised to give better guidance on the reporting by personnel at the site of changed conditions at the dam.***
11. ***It is desirable that consideration be given to revision of the EAP to give guidance on the impact of releases from the dam on downstream access and residents.***
12. ***It is desirable that the EAP be revised to provide more useful information on available access modes and routes to the dam.***
13. ***It is desirable that the EAP be revised to provide a more accurate definition of incremental flood effects.***
14. ***It is desirable that consideration be given to the value of 2D inundation modelling and to the preparation of more accurate mapping on which to plot inundation extent.***
15. ***It is desirable that the EAP be revised to remove any inappropriate or outdated references.***

Fifth Term of Reference

Other matters the contractor considers relevant, following prior written approval by the Director-General of the Department of Energy and Water Supply.

Advice

1. ***It is desirable that the feasibility of improvements at the dam, and to other infrastructure, be investigated as part of the Phase 3 work. These are improvements which may assist dam safety management generally and which may reduce the time***

required for any future remediation in particular. Some key matters to be examined are:

- ***Increasing the flow capacity of culverts on the normal southern access road to the dam to reduce the likelihood of wash-outs;***
- ***Improvements to the right bank access at the dam that would avoid destruction of the access in every large flood;***
- ***Improvements that could provide early access to the left bank at the dam for a) inspecting personnel and b) heavy equipment needed for remediation work;***
- ***Subject to the outcome of the preceding point, provision of safe access down the left bank to the left end of the dissipator apron;***
- ***Measures to prevent ingress of gravel or other debris to the environmental flow gate chamber;***
- ***Measures to safeguard the hydraulic rams that are designed to open the environmental flow gates;***
- ***Measures to better protect the electric power system used to operate release facilities and to reduce the time required for repair in the event power is lost in floods; and***
- ***Improvements which would allow a greater release discharge without disrupting any potential future remediation work in the energy dissipation zone.***

Overall SunWater has a world class dam safety management system and it maintains an excellent level of communication with disaster management groups.

Hopefully the advice arising from this review will make an impressive dam safety management system even better.

There is a need to better understand the dam safety risks of Paradise Dam before the coming wet season.

1 Introduction

1.1 The Review

On 12 June 2013 the Queensland Department of Water and Energy (DEWS) advised that it had accepted the *Paradise Dam Review – Consultancy Proposal (P13033)* dated May 2013.

The essential purpose of the review is to independently examine the dam safety management actions taken prior to, during and after the January to March 2013 flood event at Paradise Dam and to determine what lessons can be drawn from the experience, especially with regard to any need to improve dam safety procedures.

At the time of execution of the contract, the only document available was Allen (2013).

The Terms of Reference for the review are at **Appendix A.**

This final report is provided to DEWS on a confidential basis.

1.2 The Timing

The review was to commence on 24 June 2013 and to be completed by Friday 19 July 2013. Meaningful work did not commence until Monday 1 July 2013 because the first tranche of documents from the dam owner only arrived late on Friday 28 June 2013. A day was lost through the site inspection and discussions in Brisbane requiring three days instead of two. Another day was lost on renaming files to enable navigation. Half a day was lost on a progress report which was not originally scheduled. And the volume of documents was far greater than envisaged. The result was that the draft report was not provided to DEWS until Monday 5 August 2013. Comments of DEWS and SunWater were provided by DEWS on Tuesday 13 August 2013.

1.3 The Dam

Paradise Dam was completed in 2005. It is a 52m high roller compacted concrete (RCC) gravity dam on the Burnett River some 80km south-west of Bundaberg, Queensland. At 33,000km^2, the very large catchment area produces large flood flows at the dam.

A large flood occurred at the dam during the 2010/2011 wet season when much of Queensland experienced record, or near record, flood conditions. However, at Paradise Dam, a far larger flood occurred during the January to March period of 2013.

It is these flood events, particularly that of 2013, which are the main focus of this review. The trigger for the review was significant damage and scour which occurred in the dam's energy dissipation zone during the 2013 flood.

1.4 The Parties

Dam Owner

SunWater Ltd is the dam owner subsequent to its purchase of the original owner Burnett Water Pty Ltd.

Dam Operator

SunWater operates the dam.

Dam Safety Regulator

The dam safety regulator is the Chief Executive of the Queensland Department of Energy and Water Supply. In this review references are simply to "the regulator". Statutes conferring regulatory powers are:

1. The *Water Act 2000*;
2. The *Water Supply (Safety and Reliability) Act 2008*; and
3. The *Sustainable Planning Act 2009*.

The regulator commissioned the review and is the recipient of this report.

Emergency Response Agencies

Emergency response is managed under a hierarchy of disaster management groups:

- Local Disaster Management Groups (LDMG);
- District Disaster Management Groups (DDMG); and
- The State Disaster Management Group (SDMG).

Subsidiary agencies undertake evacuations and care for people.

1.5 The Documents

SunWater has an impressive documentation system for dam safety management. In our observation, the design of the system, the range of documents which are preserved and their ease of retrieval rank with world best practice.

The documents provided for this review are identified at **Appendix B**. That list is derived from one provided by Allens Linklaters, lawyers retained by SunWater.

The numbers of documents given below were taken from two CDs and one USB disk sent from Allens Linklaters. For reasons which are not important to the review the number of files below may not match the number at **Appendix B**.

Documents received from SunWater are summarized as follows:

- Tranche 1 of documents received on 28 June 2013 contained 67 documents. Most were short briefing notes, e-mails, letters, charts, programs or progress reports of a few pages. There was a design report of over 100 pages relating to Phase 1 and Phase 2 remedial works.
- Tranche 2 received on the same day contained 156 files. Some 80 of these files were photographs. There were 4 files containing 339 drawings of the dam. The remaining files included inspection reports, flood event reports, standards and guides, procedure documents and more correspondence ranging from a few pages to some 500 pages.
- Tranche 3 received on 10 July 2013 contained 87 files. These were primarily e-mail communications between SunWater and the disaster management groups during the sunny day failure emergency event following the end of the January to March flood event but there were some communications from the flood event itself.

All told, SunWater made available 311 files. One file, QS02 December 2012, was sent separately by e-mail.

Documents received from DEWS were:

- Draft Emergency Action Plan (EAP) guidelines (DEWS 2013); and
- Development permit conditions related to the safety of Paradise Dam (Queensland Dam Safety Regulator 2007).

Given the time available, the documents were consulted only as necessary for the purposes of the review. It was not reasonably practicable to fully read and study all documents. Every file was opened and scanned in a search for content of significant relevance to the Terms of Reference. It is possible that some content of significant relevance has been missed but we believe that is unlikely.

1.6 The Regulator’s Requirements

Those of the regulator’s requirements which are relevant have been studied for the purposes of the review; in particular the guidelines on dam safety management and the Paradise Dam development permit conditions relating to dam safety.

In this review no consideration has been given to the adequacy of the regulator’s requirements because such work is beyond the Terms of Reference.

1.7 The Focus of the Review

In addressing the Terms of Reference there has been a particular focus on dam safety risks in the coming wet season. The Phase 3 activities planned by SunWater include a peer reviewed dam safety review. It can reasonably be expected that the safety review will adequately address longer term risks.

Within the time available it has not been reasonably practicable to make a comprehensive review of SunWater's dam safety procedures and practices. Such a review would be a large task requiring months to complete. In our observation, SunWater's procedures and practices relating to dam safety are of a high standard. Our focus has been on the standards and procedures which are directly relevant to SunWater actions immediately prior to, during and since the January to March 2013 flood event.

1.8 Acknowledgement

SunWater provided full co-operation with this review and made available a sufficient range of relevant documents.

2 Consequences Should the Dam Fail

2.1 The River Downstream of the Dam

Downstream of the dam the Burnett River flows in a north easterly direction until it enters the sea. Some distance upstream of the mouth the river flows through the provincial city of Bundaberg. That city has been affected by floods experienced over the past century, including the flood of January to March 2013. The direct distance from the dam to Bundaberg CBD is around 70km and from the dam to the river mouth about 83km. Since the river has very pronounced meanders the river distances are much greater. Upstream from Bundaberg there are persons at risk from any potential dam failure in the areas of Burnett, Kolan, Isis and Biggendon nearest the dam. Public safety is at risk should the dam fail.

2.2 Failure Impact Assessment

The Queensland regulator requires that failure impact assessments be undertaken for some dams. Paradise Dam has been classified as a *referable dam* and it is therefore subject to any dam safety requirements advised by the dam safety regulator. The dam has been assessed to be a Category 2 dam – that is the *population at risk (PAR)* in the event of dam failure exceeds 100 persons.

2.3 ANCOLD Consequence Category

The consequence classification system in terms of the guidelines of the Australian National Committee on Large Dams (ANCOLD 2012) has relevance to determination of the safety of the dam. For example, the adequacy of the dam's stability is influenced by the ANCOLD classification.

3 Dam Safety Management Procedures

3.1 Requirements of the Dam Safety Regulator

Published guidance

The regulator has published guidelines which inform dam owners and operators of the normal expectations for dam safety management. The guidelines of most relevance for this review are the dam safety management guidelines (NRM 2002).

The guidelines cover the total safety management system, much of which is not of significant relevance for this review.

Sub-section 3.1 deals with development permits, which may contain enforceable conditions relating to dam safety. Sub-section 3.3 outlines the regulator's powers relating to emergency action. Sub-section 4.3 makes it clear that for the classification of dams an owner is only obliged to estimate the *population at risk (PAR)* in a potential dam failure but that it is highly desirable to make a comprehensive assessment of potential failure consequences. Sub-section 7.3 indicates when safety reviews should be undertaken. Section 8 deals with incidents and failures, and Section 9 deals with emergency action planning - both of these topics are directly relevant to this review. There are provisions for the reporting of both incidents and emergency events. Appendix 5 is relevant to the extent that it sets out expectations for special inspection reports.

A second guidance document to be mentioned, though not particularly relevant to this review, is that dealing with failure impact assessments of dams (DERM 2010). The purpose of a failure impact assessment is to determine whether a proposed or existing dam is a *referable dam*. If a dam is *referable,* it is subject to any dam safety requirements of the regulator.

As noted earlier, Paradise Dam has been classified as a Category 2 *referable dam*.

Specific requirements

<u>Development permit dam safety conditions</u>

The conditions DEWS (2007) were provided by DEWS and have been studied as part of this review.

<u>Dam safety conditions imposed by statutory notice</u>

Our understanding is that no statutory notices have been issued in connection with Paradise Dam.

<u>Dam safety requirements in correspondence</u>

Summaries of requirements issued after the January to March 2013 flood will be found in the section on *Dam Safety Management Actions*.

3.2 SunWater Procedures

Documented Procedures

SunWater has a suite of standards or guides, applicable to all its dams. SunWater personnel are to follow these guides in performing dam safety management activities.

Then there are other documents, prepared pursuant to the standards, which are specific to Paradise Dam and which guide actions in certain circumstances. The one most relevant to this review is the Emergency Action Plan (EAP - SunWater October 2011, updated March 2013).

Informal Procedures and Practices

The undocumented procedures relevant to this review include procedures for assessment of potential rock scour at spillways and procedures for undertaking dam safety risk assessments.

Relevance of Disaster Management Group Procedures

Any such procedures have been regarded as outside the scope of this review.

4 Discussions and Site Inspection

4.1 Overview

On 1 July 2013, Len McDonald of NSW Public Works travelled to the SunWater offices in Brisbane and met with SunWater personnel on that morning for a briefing on the flood events and the consequent dam safety management actions. The personnel who took part for part or all of the discussion period were:

- [redacted]
- [redacted]
- [redacted]
- [redacted].

In the afternoon Messrs [redacted] and McDonald travelled to Bundaberg by car.

On 2 July 2013, [redacted] and Len McDonald drove to Paradise Dam and met with [redacted], [redacted] for the dam. After discussions in the site office, the party made an inspection of the dam.

The weather was fine with a stiff south-west breeze. There was no flow over the dam spillway and no significant flows through the outlet systems. The reservoir level appeared to be a couple of metres below full supply level (FSL).

The inspection commenced around 0930h and finished around 1240h.

4.2 Observations

Because the flood damage has been well documented, only a few photos from the inspection are included at **Appendix C** of this report. These either show progress of remedial work on the day or features of special significance for this review.

The inspection commenced on the crest at the right side of the spillway. There was a good overview here of the downstream side of the dam where concrete was being poured for the Phase 2 remedial work at the left end of the spillway. The extent of rock scour during the January to March 2013 flood event was evident. Damage to the valve house area could also be appreciated. **Photo 1** is an overview of the remedial works area.

The party then entered the inlet tower where the switchboard was observed. Submergence of the switchboard by the flood had caused a power loss of major duration. The difficulty in getting the outlet system ready for release without power was explained.

The left end of the spillway dissipator apron was then inspected. Concrete was being poured in the large scour hole immediately downstream of the apron. The damaged area of the apron had already been reinstated in conventional concrete. Geologic features were observed which it could reasonably be inferred had contributed to the deep scour in this area. **Photo 2** shows one such feature.

At the base of the left abutment slope a block of the dissipator end sill could be observed as in **Photo 3**. Many such blocks litter the downstream area, some hundreds of metres downstream. All of those observed had been abraded by rock and gravel drawn into the dissipator in the earlier 2010/2011 flood event. The abrasion had been sufficient to expose the reinforcing steel as is evident in the photo.

Work to pour concrete steps which would protect the roughly 13m high steep face of the deep scour hole at the left end of the spillway apron was in progress. **Photo 4** shows preparations for the pouring of concrete.

At the right end of the dissipator apron, there had been another significant scour hole of up to 6m depth but generally around 3.5m deep. This scour had undercut the apron for a couple of metres. In **Photo 5** it can be seen that this hole had been filled with concrete.

Examination of the remaining original RCC sections of the dissipator apron did not reveal any serious abrasion from the January to March 2013 flood. **Photo 6** shows the typical condition of the surface of the apron. This result is in contrast to the experience of the 2010/2011 flood when quite marked abrasion occurred on and adjacent to the end sill.

About 150m downstream of the apron an inspection was made of another end sill block. **Photo 7** shows this block. Though weighing some seven tonnes this block had been carried 150m from its original location. The abrasion by rock and gravel in the 2010/2011 flood is clearly seen. As observed with other blocks the reinforcing steel had failed in tension indicating that the high velocity water jet from the spillway had imposed loads in excess of the end sill's structural capacity. The classic "necking in" of reinforcement bars typical of a tensile failure is clearly evident in **Photo 8**.

In this same vicinity a sample area of the exposed rock was examined. This inspection revealed a considerable variability in the rock conditions. In some places, as in **Photo 9**, the rock jointing was tight and the rock would be more resistant to scour. In other places the rock was very closely fractured with loose joints as can be seen in **Photo 10** and it would be less resistant to scour.

Nearby there was a slab of RCC from the dissipator apron. This slab had been rounded by abrasion in the turbulent flow of the flood. Significantly the impression of the reinforcing steel was visible, as seen in **Photo 11**. This is evidence of separation of the RCC along the plane of the steel under pounding of the overflow jet rather than failure by abrasion.

An inspection was then made of the valve house and hydro station where flooding had caused a great deal of difficulty.

Finally, the damaged hydraulic ram that was designed to lift the environmental flow gate was inspected. The ram is now stored above flood level on the right bank of the river. The damage to the ram has been well recorded by SunWater.

5 The Flood Event

5.1 Overview

Eastern Australia has experienced a wet phase since late 2010. The 2010/2011 summer saw many rainfall and flood records broken. The Burnett River experienced high flows in that period. Unlike many other areas, the Burnett experienced a much larger flood in January 2013 from the residual effects of tropical cyclone Oswald. **Figure 1** is a long term hydrograph of the Paradise Dam headwater level from late 2010 to the end of April 2013, taken from document SWA.502.001.2339. The red line is the FSL of the Paradise Dam reservoir 67.60m AHD.

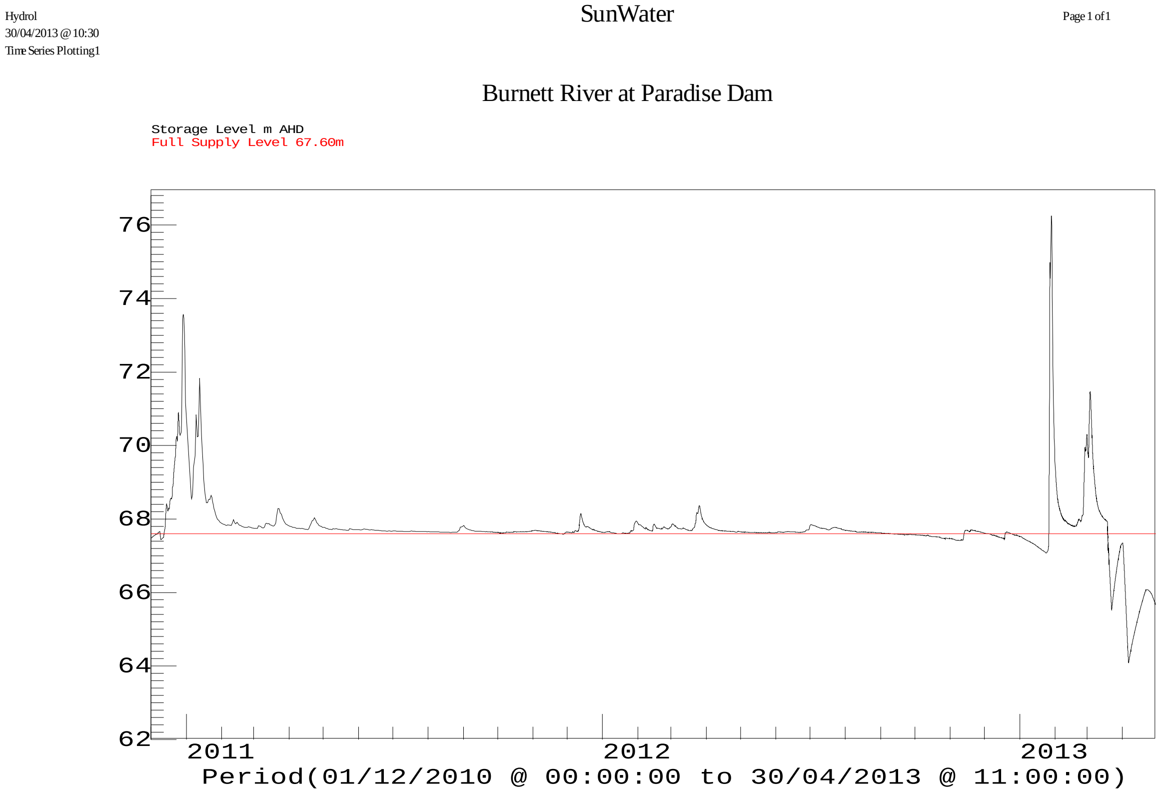

Figure 1 – Hydrograph of Paradise Dam Headwater Level

5.2 The 2010/2011 Flood Event

It will be seen from **Figure 1** that the difference between headwater level and crest level reached about 6.0m on 29 December 2010 at 0400h. The actual peak was recorded as 5.96m. There was a later peak of around 4.2m on 12 January 2011 at 2000h.

There was no significant scour of rock downstream from the dissipator apron in the 2010/2011 flood event and the end sill of the dissipator, though abraded by gravel to expose the steel, remained intact. However, there was a wide range of damages including lost access, scour on both river banks, rock dumped on roads and outlet works, loss of electric power, damaged handrails and so on.

This event is recorded in the flood event report (Sunwater 29 November 2011). Note that the citation date is the event end date, not the date the report was issued. The 29 November 2011 was the first date that the spillway ceased to discharge, but only for a short time. The first significant cessation of spill was in September 2012.

5.3 The Aftermath of the 2010/2011 Flood Event

After the 2010/2011 flood event, the main interest for this review is the damage which occurred during the event, the action taken to remediate the damage and whether any of this mattered during or after the January to March 2013 flood event. In this regard, the key actions were:

1. March 2011 – five yearly comprehensive inspection report was issued. The inspection took place from 8 to 12 November 2010; that is, before the 2010/2011 flood event. There was no significant scour downstream of the dissipator apron. Trees were growing in the river channel. There was no damage to the dissipator. The main issue with the spillway was the need to clean blocked drain holes.
2. 24 to 25 May 2011 – annual inspection was undertaken. Dam was spilling. Dissipator submerged except for the far left end. Extensive flood damage. Outlet system and mini-hydro are not operable. Scour was observed on lower left bank. Reinforcement was exposed on the visible end sill sections.
3. 3 to 4 May 2012 - annual inspection was undertaken. Dam was spilling. Damage was much as reported in May 2011. Dissipator was submerged except far left end. Extensive flood damage was observed. Outlet system and mini-hydro are not operable. Scour was observed on lower left bank. Reinforcement was exposed on the visible end sill sections.
4. 31 August 2012 – a letter from SunWater to DEWS provided a status report on the whole of the dam portfolio. Included was a very informative report dated July 2012 on the flood damage repairs which had been made, progress toward completion of other repairs and difficulties being experienced, particularly with the outlet system. Urgency is understood by SunWater.
5. 18 September 2012 – a site inspection was undertaken by an engineer and geologist, both of SunWater, as recorded at Appendix A of the 2010/2011 damage inspection and civil works rectification report (SunWater June 2013).
6. 2 November 2012 – the dissipator apron was inspected following dewatering. The documents provided for this review do not include a separate report of this inspection so far as we can see. The only description of the inspection that we have found is that in 2010/2011 damage inspection and civil works rectification report (SunWater June 2013).

5.4 The January to March 2013 Flood Event

The reservoir level peaked at around 8.65m above crest level on 28 January 2013 at around 1900h. There was a second flood peak of around 3.86m on 3 March 2013 at around 2100h. Between these events the reservoir inflow and discharge over the spillway prevented detailed inspection and assessment of damage caused by the first flood peak.

Figure 2, being document SWA.502.001.3202 provided for this review, shows the discharge under peak flow conditions at 1826h on 28 January 2013. The turbulence of the flow gives a graphic impression of the very large energy dissipation which is occurring.

Figure 2 – Turbulent Flow at the Left End of the Spillway

The flood event is fully documented in the flood event report of SunWater (19 March 2013). Again the citation date is that of the end of the flood event.

There was a wide range of damages including lost access, scour on both river banks, rock dumped on roads and outlet works, loss of electric power, damaged handrails and so on. Much of that damage became progressively evident from late January to early February. However, the continuing spillway discharge prevented inspection of the energy dissipation zone.

When it became possible to inspect the dissipation area on 8 February 2013, it was evident from the flow pattern and protruding reinforcing bars that significant damage had occurred. An engineering inspection of 21 February 2013 confirmed extensive damage to the energy dissipator. On 11 March 2013, a more informative inspection was possible and the damage was better defined. Substantial scouring of rock was found downstream of the dissipator apron, the dissipator end sill had been destroyed, some sections of the dissipator apron had been destroyed and there was substantial damage to the outlet system.

In view of the damages in the spillway dissipator zone, SunWater continued with a sunny day emergency event after the end of the flood event on 19 March 2013.

The actions taken post-flood are set out more fully in the *Dam Safety Management Actions* section.

The damages to the dam are well documented in the damages report of SunWater (March 2013) prepared for DEWS.

5.5 The Aftermath of the January to March 2013 Flood Event

The aftermath of the January to March 2013 flood event is the main subject of this review and is well covered elsewhere in this report.

6 Lessons from the Flood Experiences

In this section, only those lessons directly relevant to dam safety are discussed.

6.1 During the 2010/2011 Flood

For the purposes of this review, it is not necessary to consider lessons from the experience during the 2010/2011 flood.

6.2 After the 2010/2011 Flood

Some main lessons to be drawn from the 2010/2011 flood aftermath are:

1. The spillway can continue to flow for very long periods – since December 2010 the spillway flowed continuously until September 2012 apart from three days in November 2011 and two days in January 2012. That is a period of 21 months with virtually continuous flow. Extended flow periods prevent detailed inspection of the energy dissipation zone and it is not reasonably practicable to undertake remedial works while the spillway has any significant discharge.

2. Rock and gravel are drawn into the dissipator – the end sill and the left training wall were rounded by abrasion to an extent that exposed the reinforcing steel. That damage was only of cosmetic significance in the short term but would cause problems of steel corrosion in the long term. There was some localised damage which was indicative of more serious abrasion as seen in **Figure 3** (taken from the 2010/2011 damage inspection and civil works rectification report, SunWater June 2013).

Figure 3 – Abrasion through Dissipator Apron

Abrasion by rock and gravel has the potential to destroy a dissipator slab. CBDB (2002) describes the case of Marimbondo Dam in Brazil. In that case release of up to 6,356m^3/s through the left hand spillway gates caused a recirculation flow which drew rock and gravel into the hydraulic jump dissipator. The dissipator apron was extensively abraded, in some places through to the foundation rock. Over significant areas up to 500mm of conventional concrete had been removed. **Figure 4** is an overview in which reinforcing steel can be seen rolled up by the flood in front of block N.

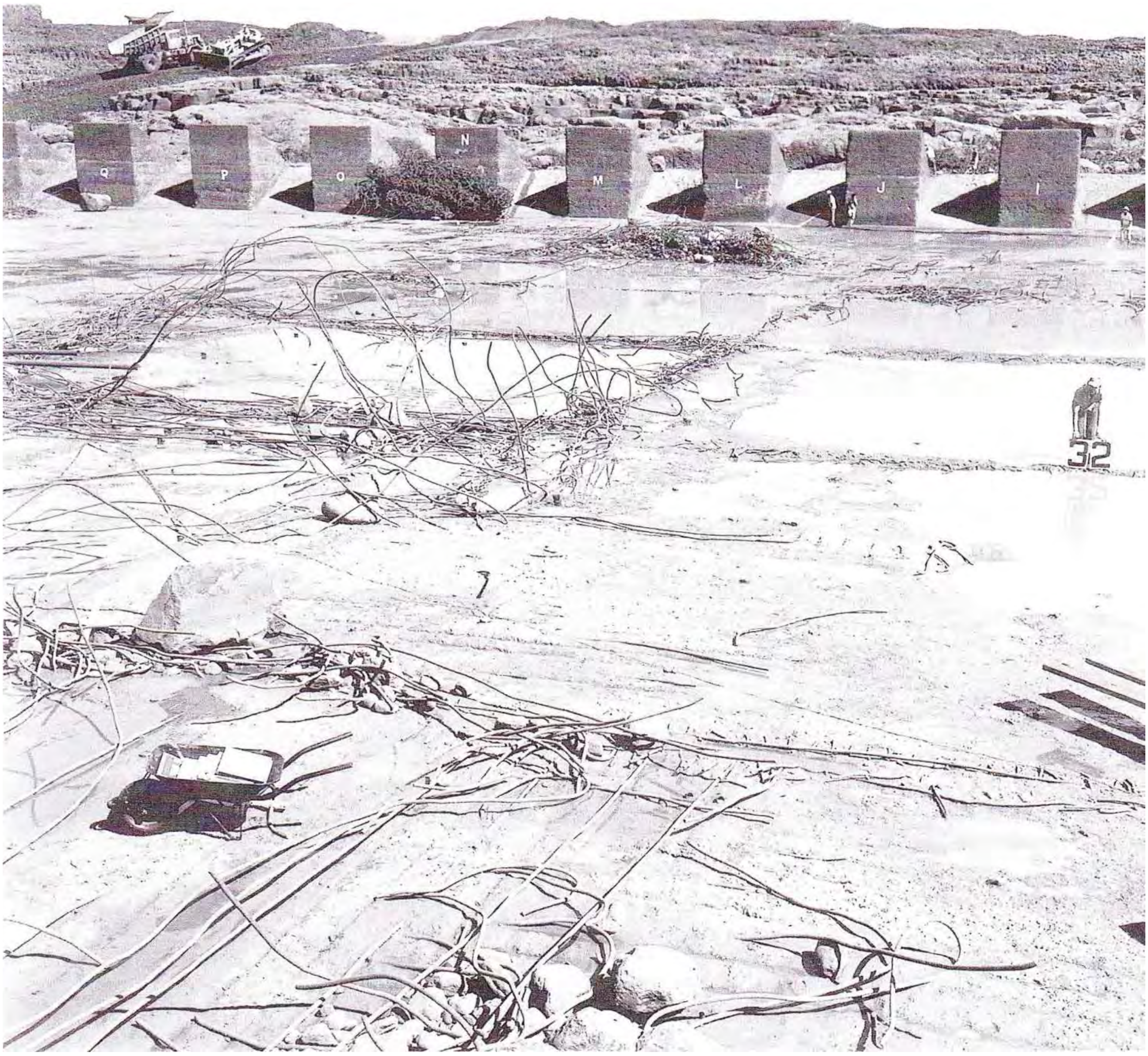

Figure 4 – Abrasion Damage to Marimbondo Dam Dissipator

Figure 5 below is a closer view of the steel rolled up by the flood.

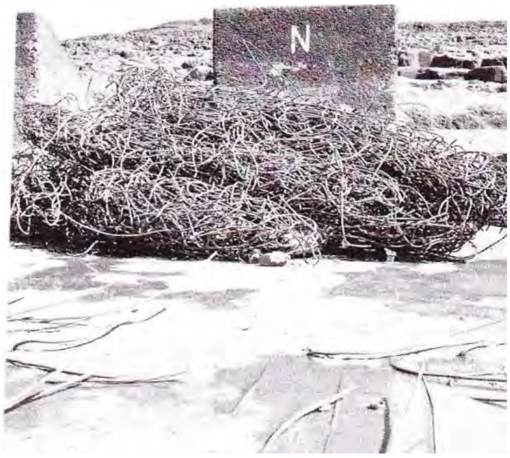

Figure 5 – Steel Torn out of the Dissipator Slab at Marimbondo Dam

Serious damage to the concrete aprons of stilling basins has occurred on a number of dams. Regan et al. (1979) report the abrasion damage which occurred at Libby Dam and Dworshak Dam, both US Army Corps of Engineer structures. At Libby Dam, the whole stilling basin floor was abraded, in places to a depth of 3m right through the concrete and into the foundation rock. At Dworshak Dam, 1,530m^3 of concrete was lost to abrasion with scour going right through the concrete and into the rock to a total depth of up to 3.3m.

The Marimbondo, Libby and Dworshak examples are cited only to demonstrate that abrasion has the potential to destroy a dissipator slab. At Paradise Dam, there does not appear to have been any significant abrasion of the dissipator slab during the January to March 2013 flood. This may have been due to the failure of the end sill. When the end sill is reconstructed there is a question of whether abrasion could return in a future flood. The available store of loose rock and gravel does not seem to have been seriously depleted yet and could be replenished by scour or removal from high on the river bank in a larger future flood in any case. **Figure 6**, taken after the 2013 flood event and document SWA.502.001.2891 provided for this review, indicates that a substantial store of rock and gravel is still available in the near vicinity of the dissipator.

3. Observed behaviour of dissipation flows – a hydraulics specialist, [redacted], was engaged by SunWater to advise on the spillway performance during the 2010/2011 flood event. His report is [redacted] (2012). The first issue to be noted from his advice is that the spillway flow is not two dimensional as would normally be expected in a long uncontrolled spillway. This is mainly attributed to the rise in the elevation of the dissipator apron toward the left end of the spillway. [redacted] believes that the recirculation pattern which has been set up is accentuated by the scour which occurred on the lower left abutment in the 2010/2011 flood event and that this recirculation is a mechanism for feeding rock and gravel back into the dissipator apron. Eric recommended that measures be taken to interrupt the recirculation flow. No such measures have yet been implemented. This relates to the potential abrasion problem mentioned under our preceding point.

Figure 6 – Rock and Gravel in the Near Vicinity of the Dissipator

The second point from [redacted] advice is that the dissipator is acting more like a roller bucket than a hydraulic jump dissipator as was intended. This raises questions in our minds which would require specialist advice. There has been reliance by SunWater on high tailwater levels both in terms of cushioning the energy of the spillway flow and of the beneficial effects on dam stability. [redacted] of GHD alluded to the first of these issues in sentence 1, paragraph 1, sub-section 7.5 of his review of the comprehensive risk assessment ([redacted] 2009). As regards stability, in a true hydraulic jump spillway the river tailwater level would not be fully available to stabilize the dam. In the actual dissipation flows, whilst the tailwater is virtually against the overflow jet, there would be pressure fluctuations which may mean it is unwise to rely on the full tailwater depth as a stabilizing force. SunWater engineers are aware of these issues. Our aim is to emphasize the uncertainty of the tailwater effects.

4. Damages occur to site access roads, electric power and release facilities – the 2010/2011 flood submerged switch boards, destroyed site access roads and damaged flow release facilities. With the present configuration of these facilities such damage is virtually inevitable in any large flood.

6.3 During the January to March 2013 Flood

Two key lessons were:

1. The access to the site can be interrupted by flood damage – it is understood that the access road at two culverts washed out during the heavy rainfall which occurred. Whether for that or other reasons, access to the dam was lost before noon on 26 January 2013 before the dam had started to spill. The damage at the culvert locations may have hindered efforts to attend the dam and apparently delayed efforts to make emergency repairs. Entries in the flood event report confirm there was no access to the dam site from a time a little before noon on 26 January, on all of 27 January and on 28 January prior to about 1330h. There is no reliable access on the northern side of the river (the left bank).

2. It is not reasonably practicable to know what damages are occurring in the energy dissipation zone during the flood event – flood flows are highly turbulent in the energy dissipation zone and the water is turbid from high suspended solids content. As a result it is not reasonably practicable to know what is happening to the dissipator and to the rock immediately downstream. That remains the case for a long period during the recession of the flood.

6.4 After the January to March 2013 Flood

Some key lessons to be drawn are:

1. Lessons as from the aftermath of the 2010/2011 flood - the lessons learned from inspection after the 2010/2011 flood were all observed again in the 2013 flood except that there is no evidence of significant damages to the dissipator apron from abrasion by rock and gravel.

2. The rock in the energy dissipation zone is susceptible to deep scour – inspection after the flood revealed major rock scour. There are some points to be made about rock scour in the energy dissipation zones of dams. Firstly, experience shows that major rock scour in a large flood is not necessarily the end of the scour process. The classic demonstration of this reality is the case of Kariba Dam on the Zimbabwe/Zambia border (Bollaert 2005). In that case scour continued from successive floods over decades, eventually leading to a scour hole over 80m deep. **Figure 7** from CBDB (2002) shows the progression. Conditions at Paradise Dam are quite different but the possibility of further scour cannot be ruled out on the evidence available at this stage. Secondly, experience of scour at large dams is highly variable for reasons which are not immediately obvious. Because of large flows in its rivers, Brazil offers instructive lessons on rock scour at dams (CBDB 2002). Foz do Areia and Salto Santiago dams on the Iguacu River and Machadinho and Ita Dams on the Uruaguy River are all within the one geologic province of more or less horizontal basalt flows. All four dams have experienced large floods with comparable peak discharges in the order of 10,000m^3/s to 19,000m^3/s and comparable energy dissipation heads in the range of 90m to 130m. Yet Ita and Machadinho Dams experienced major rock scour with up to 200,000m^3 of fresh rock being removed whilst the experience at Salto Santiago and Foz do Areia Dams was negligible rock scour. When these dams are examined in more detail it becomes clear that engineering judgment is a poor guide to the likelihood of rock scour and that account needs to be taken of detail metrics of unit power, stress relief factors, rock joint spacing, orientation and cementation among other factors. This reality points to the need to apply rock scour estimation methodologies such as those developed by Annandale and separately by Bollaert as an aid to judgment.

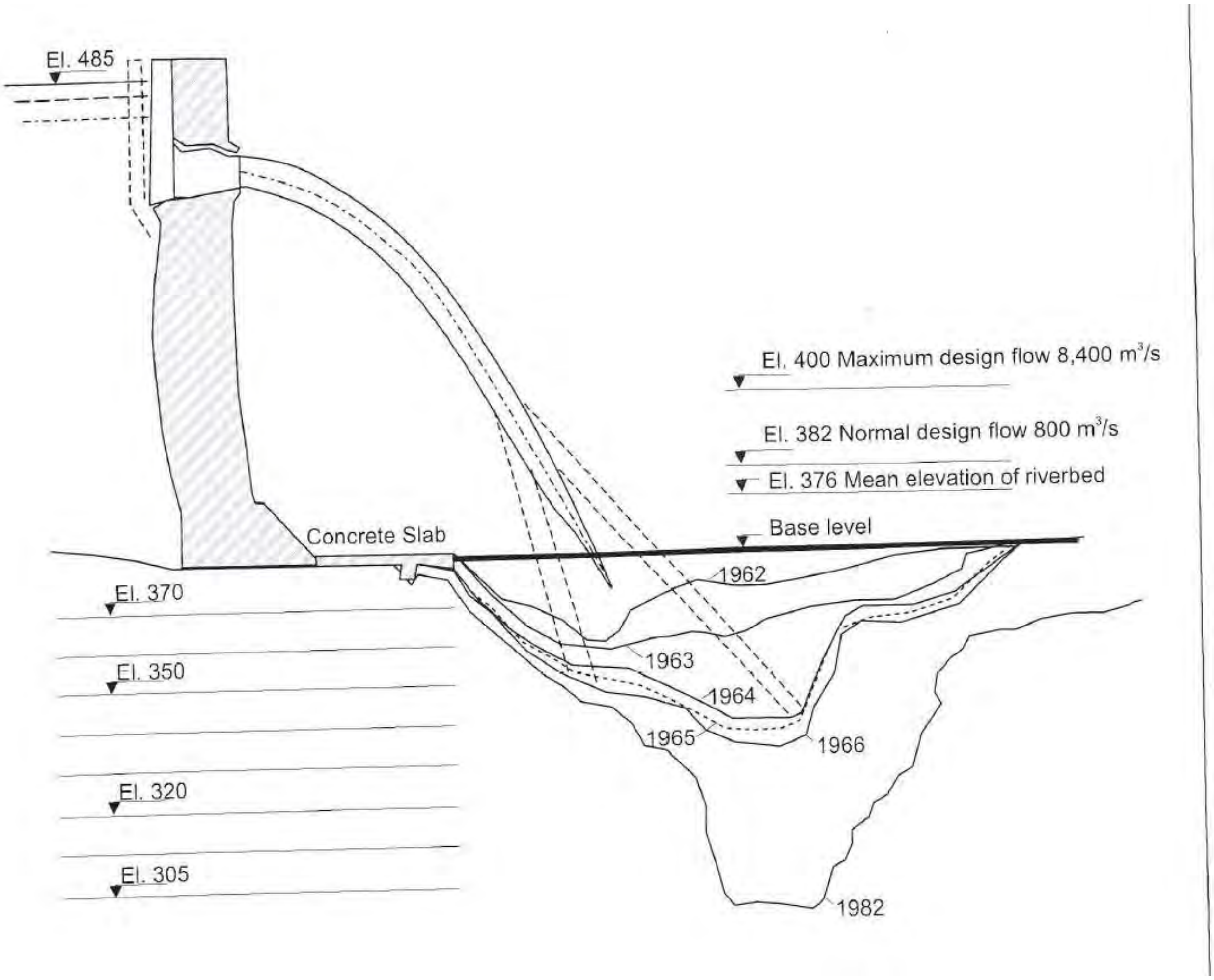

Figure 7 – Progression of Scour at Kariba Dam

3. <u>The dissipator apron can be seriously damaged, if not destroyed, by high energy flows</u> – there was relatively minor damage to the RCC apron during the 2010/2011 flood event. According to [redacted] (2012) this damage was due to abrasion by rock and gravel rather than to cavitation. On the evidence observed by us that conclusion is correct. In the 2013 flood the damage to the apron was on a much greater scale but was not due to abrasion. This time the evidence points to separation of the RCC layers at the plane of the reinforcing steel and destruction of the RCC above that level by pounding from the high energy discharge jet. **Figure 8**, taken from the interim design report (SunWater 7 June 2013), is strong evidence for that mechanism, as is **Photo 11** of **Appendix C.**

Figure 8 – Damage to Dissipator Slab from 2013 Flood

A point of significance in **Figure 8** is that there is a hole in the RCC below the plane of the reinforcement. The question is whether a future flood could destroy the dissipator slab. The damaged section shown in **Figure 8** has been replaced by anchored conventional concrete from Ch. 209 to Ch. 260. Another damaged section has likewise been replaced between Ch. 302 and Ch. 335. The "Ch." refers to chainage measured parallel to the dam axis. The replaced sections of apron would be substantially more robust than the original RCC apron. The available evidence shows that:

- The apron has been damaged by rock and gravel in the 2011 flood. The Marimbondo Dam case shows that even conventional concrete slabs can be virtually destroyed by rock and gravel abrasion;
- In the 2013 flood the RCC apron has been seriously damaged by the energy of the discharge jet without any evidence of significant abrasion;
- The flow pattern in the energy dissipation zone is complex ([redacted] 2012) and reliance on tailwater to protect the slab seems to be attended by considerable uncertainty.

Our conclusion is that destruction of the apron slab in a future flood, whilst it may be unlikely, cannot be ruled out with confidence at this stage. There could be two mechanisms combining to destroy the dissipator. The experiences at Marimbondo, Libby and Dworshak Dams, outlined earlier, suggest that abrasion alone could possibly destroy the dissipator. The pounding energy of the overflow would assist the destruction of the apron. The lesson is that the risks of such a failure pathway need to be examined in detail.

7 Dam Safety Management Actions

7.1 The Timeline

The latest bar chart program made available to us gives the start and end date of all activities involved in the emergency repairs following the January to March 2013 flood event.

For the purpose of this review, a sufficient picture of actions taken can be constructed from inspection reports, briefing notes, e-mails, letters, flood event reports, sitreps, photos, bar chart programs and progress reports. In the summary that follows there are key events, actions and a précis of the key documents.

The following timeline does not include communication between SunWater and the disaster management groups. Communication with disaster management groups is dealt with in a later section of this report.

1. **26 January 2013** – the operator left the dam at around 1100h with the reservoir below spillway crest level and minimal inflow into the reservoir.
2. **26 January 2013** – access to the dam was cut before noon.
3. **26 January 2013** – the dam began to spill at around 1530h.
4. **27 January 2013** – efforts throughout the day to find a means of access to the dam failed.
5. **28 January 2013** – at 1313h the operator advised he was on site and will inspect the dam.
6. **28 January 2013** – first flood peak of 8.65m above spillway crest at about 1900h.
7. **8 February 2013** – e-mail site to head office advising of damage to the end sill and reinforcing bars protruding through the flow.
8. **12 February 2013** – an engineer attended the dam and observed damage to the extent possible with spillway overflow (letter of 12 August 2013 from SunWater CEO to Director of Dam Safety, DEWS – a later document that is not listed at Appendix B).
9. **13 February 2013** – the engineer made a report of the damage observed on the preceding day.
10. **21 February 2013** – flood damage inspection report by dam safety engineers. Scour holes in the RCC apron. Some parts of the end sill have been washed away. Most of dissipator not visible due to spill.
11. **21 February 2013** – inspection photo shows that anchor bars are protruding out of the spillway flow.
12. **27 February 2013** – briefing note SW internal: Request approval to go to 24/7 surveillance when flow over crest exceeds 200mm. Significant damage to end sill on left side of dissipator. Anchor bars protruding and flow channels on left side of dissipator apron.
13. **28 February 2013** – risk assessment made, no action option dismissed.
14. **March 2013** (date unknown) – draft flood damage report for 2013 flood issued.
15. **1 March 2013** - briefing note SW internal: Request approval to go to 24/7 surveillance when flow over crest exceeds 1.67m, the annual exceedance probability (AEP) 1 in 2 flood. Risk assessment supports such action.
16. **1 March 2013** – 24/7 surveillance commenced, stopped on 7 March 2013.
17. **1 March 2013** – letter memo CEO of SW to DG of DEWS: Extensive damage to dissipator, 24/7 surveillance while spilling, early identification of further damage, routine under EAP.
18. **3 March 2013** – second flood peak of 3.86m above spillway crest.
19. **7 March 2013** – evidence of more extensive damage to end sill.
20. **8 March 2013** – workshop of SW people on possible repairs.
21. **11 and 12 March 2013** – further inspection of damage was made.
22. **13 March 2013** – meeting SW people following site inspection. Is it a notifiable incident (Level 3 EAP)? Not yet but when overflow exceeds AEP of 1 in 1. Open environmental gate despite risks. Stability is being done.
23. **14 March 2013** – briefing note SW internal: Recommend EAP Level 3 and 24/7 surveillance if surcharge exceeds 1.09m. Site visit on 11 March by geologist, engineers. Meeting 13 March to consider observations. Still cannot confirm rock scour extent due to overflow. There are problems in opening the environmental flow gate but plan to proceed anyway. No access

to left side of site. No access to outlet house. No power. Risk values presented. Photo of 13 March 2013 shows the upper level of the apron has gone and flow suggests the whole apron may be gone in places.

24. **14 March 2013** – work commenced to make environmental flow gate operational.
25. **15 March 2013** – DEWS briefed by SW.
26. **15 March 2013** – letter SW to DEWS: Refers to today's meeting of SW/DEWS officers. Outlines flood peaks. Site visit 11 March by geologist, engineers. Outlines damage as best known given overflow. Further flood could cause scour, stability issues. AEP 1 in 2 has risk 1 in 2000. AEP 1 in 1 will trigger AEP. Environmental gate under repair. Will reduce below FSL. LDMGs warned. Building cofferdam, then open environmental gate.
27. **17 March 2013** – 200 tonne crane set up at 1230h to lift environmental flow gate.
28. **18 March 2013** – the environmental release gates were made functional thus allowing drawdown of the reservoir.
29. **18 March 2013** – release from environmental flow gate commenced late tonight.
30. **19 March 2013** – headwater fell below spillway crest level.
31. **19 March 2013** – e-mail SW to DG of DEWS: Sending January to March 2013 flood damage report.
32. **19 March 2013** – e-mail SW to DG of DEWS: Send appendices January to March 2013 flood damage report.
33. **19 March 2013** – e-mail SW to DG of DEWS: Send appendices January to March 2013 flood damage report.
34. **21 March 2013** – work on right bank access commenced.
35. **22 March 2013** – environmental flow gate closed this afternoon. Materials for culvert arrived today.
36. **27 March 2013** – fish are being relocated, culvert and cofferdam under construction.
37. **28 March 2013** – the site downstream of the dissipator is flooded.
38. **2 April 2013** – briefing note CEO of SW to DEWS: Recounts dam history and 2013 flood history. Outlines damage to the dissipator. End sill has gone and the apron floor is damaged. Risk assessment workshops on 1 March and 8 March. Emergency repairs commenced on 14 March. The environmental flow gate has been operated. Access has been established. A bund has been built to protect the area downstream of the dissipator. The rock scour holes have been dewatered. The design of repair work continues. A three phase program has been planned. P1 is due for completion in July and P2 in November.
39. **7 April 2013** – access to the site established.
40. **11 April 2013** – e-mail to DG of DEWS: Minister's office requests DEWS to arrange report on damage to be provided by SW.
41. **12 April 2013** – e-mail DEWS to SW: Record of meeting DEWS/SW of 12 April 2013. DEWS expects multiple work teams working 24/7. Can P1 July end date be advanced? P2 plan outlined. Stability results provided. P3 concept advised. The 18 barrell culvert limited to 54 m^3/s.
42. **12 April 2013** – site dewatered.
43. **12 April 2013** – e-mail SW internal: Informing CEO of DEWS/SW meeting.
44. **17 April 2013** – e-mail DG of DEWS to CEO of SW: DEWS asks SW to provide report by 24 April.
45. **17 April 2013** – e-mail CEO of SW to staff: SW staff to arrange report.
46. **18 April 2013** – removal of damaged RCC apron completed.
47. **19 April 2013** – access culvert completed, cofferdam completed.
48. **19 April 2013** – e-mail DEWS to CEO of SW: DEWS sending letter to SW requesting a program for remedial work.
49. **19 April 2013** – letter DG of DEWS to CEO of SW: refers to extensive discussions SW/DEWS. Program due 19 April now promised 24 April. Request meeting. Program to consider a) will repairs fix the structural problem? b) what steps being made to progressively reduce the risk? c) assurance of urgency – if not 24/7 make a cogent case.
50. **20 April 2013** – commence environmental flow gate release up to 230m^3/s.
51. **21 April 2013** – foundation preparation deep scour completed.

52. **23 April 2013** – e-mail SW to DG of DEWS: Sends letter of CEO of SW.
53. **23 April 2013** – letter CEO of SW to DG of DEWS: refers to DG's letter of 19 April 2013. Highest urgency assured. Addressing dam safety risks, WH&S, effectiveness of repairs. Outlines damage to dissipator zone. Risks as F-N chart attached. Risks are above the limit of tolerability. Outlines repairs P1A, P1B, P1C and P2 and corresponding risk reductions. Outlines P1, P2 and P3 plans. WH&S risks outline. RiskPro report attached. Outlines works needed to enable 24/7 repairs. Analysis shows 3 days saving at best. Concrete batch plant set up on site. For P2 incentives for early completion to be considered. Repairs need to be of sufficient quality for possible long-term service. Some compromises made on normal quality standards to reduce time for completion. This letter a precursor to that of CEO of SW to DG of DEWS of 8 May 2013 – very similar layout.
54. **24 April 2013** – e-mail SW to DG of DEWS et al.: SW CEO providing briefing note to DEWS and Ministers.
55. **26 April 2013** – weekly report date.
56. **28 April 2013** – anchor bars for the apron are being installed.
57. **30 April 2013** – concrete pours (5) for deep scour hole completed.
58. **2 May 2013** – installation of apron anchor bars completed.
59. **3 May 2013** – weekly progress report date.
60. **3 May 2013** – e-mail SW to DG of DEWS: sending letter from CEO of SW to DEWS.
61. **3 May 2013** – letter CEO of SW to DG of DEWS: responds to DG's letter of 26 April 2013 (not available to these reviewers): inspection of 2010/2011 flood damage was not possible before September 2012 due to almost constant spilling. Gives reasons why the 2010/2011 flood damage had no bearing on the 2013 flood damages.
62. **3 May 2013** - e-mail SW to DEWS: Send progress report. Submit proposed risk sundial
63. **7 May 2013** – e-mail SW to DEWS: SW sending remedial work program to DEWS. Program is evolving and will change.
64. **7 May 2013** – letter DEWS to CEO of SW: deduced from other correspondence. Letter not provided for this review.
65. **8 May 2013** – e-mail CEO of SW to DG of DEWS; Sending letter from CEO of SW to DG of DEWS.
66. **8 May 2013** – letter CEO of SW to DG of DEWS: refers to DEWS letter of 7 May 2013 (not seen by these reviewers). Highest urgency assured. Addressing dam safety risks, WH&S, effectiveness of repairs. Outlines damage to dissipator zone. Risks attached. Cannot fully document the risks as requested because that would divert people from remedial works. Outlines repairs P1A, P1B, P1C and P2 and corresponding risk reductions. Outlines P1, P2 and P3 plans. Bar program is attached. P1B has slipped 2 days because of concrete supply from Childers. Concrete batch plant set up on site. Anchoring, capping of deep scour may roll into P2. Difficult to explain risks easily as requested – proposed sundial chart attached. Also F-N charts attached. WH&S risks outlined. RiskPro report of 23 April attached. Outlines works needed to enable 24/7 repairs. Analysis shows 3 days saving at best. For P2 incentives for early completion to be considered. Repairs need to be of sufficient quality for possible long-term service. Some compromises made on normal quality standards to reduce time for completion. A risk assessment of outlet system as requested cannot be provided because that would divert people from remedial work.
67. **8 May 2013** – e-mail SW to DEWS: SW sending progress report for week ending 3 May 2013 to DEWS.
68. **8 May 2013** – e-mail DEWS to CEO of SW: Sending letter from DG of DEWS to CEO of SW.
69. **8 May 2013** – letter DG of DEWS to CEO of SW: Thanks for letter, report of today. P1 works acceptable subject to a) send risk workshop notes by 15 May b) send risk assessments for P1 and P2 by 7 June. Allen to be kept fully informed. His nominee to attend SW/LDMG briefing session. Send update on progress and P2 planning by 22 May. Refers to meeting of 24 April. Chair of SDMG has been briefed.
70. **10 May 2013** – concrete for apron repair completed.
71. **10 May 2013** – weekly progress report date.

72. **14 May 2013** – e-mail SW to DEWS: Sending progress report. Two extra concrete lifts to get good foundation. Site visit planned for LDMGs, regulator. Refer briefing of DEWS yesterday on SW risk assessment.
73. **14 My 2013** – site visit for disaster management groups and regulator.
74. **15 May 2013** – environmental release gate closed.
75. **15 May 2013** – e-mail SW to DG of DEWS: Sending 10 documents on risk assessment as requested by DG on 8 May 2013.
76. **15 May 2013** – letter CEO of SW to DG of DEWS: Responding to DG letter 8 May. Enclose 10 documents on risk assessment workshops, notes, F-N plots and the like.
77. **17 May 2013** – weekly progress report date.
78. **22 May 2013** - e-mail SW to DEWS: Send progress report, program. Delay 2 days from original, expect to recover if fine. Liaison with LDMGs, DDMG now included.
79. **22 May 2013** – e-mail SW to DG of DEWS: Sending CEO of SW letter.
80. **22 May 2013** – letter CEO of SW to DG of DEWS: Responding to DG letter of 8 May. P1 works due to finish 17 June 2013, 2 days behind original program. P1 drawings sent to DEWS on 16 May. Expect P2 drawings week starting 27 May. P2 drawings went to contractor on 17 May. Contractor will be on site 28 May. P2 due to finish 2 November 2013. Incentives for early completion under discussion with contractor. Defining P3 scope of works has commenced.
81. **24 May 2013** – weekly report date.
82. **24 May 2013** – Bundaberg LDMG, regulator site inspection.
83. **31 May 2013** – weekly report date.
84. **31 May 2013** – e-mail DEWS to CEO of SW: Request confirmation P1 completion, details of P2 works, planning for P3.
85. **29 May 2013** - e-mail SW to DEWS: Sending progress report.
86. **June 2013** (date unknown) – 2010/2011 flood damage inspection and works rectification report issued.
87. **4 June 2013** – shotcreting of vertical face commenced.
88. **4 June 2013** – e-mail SW to DEWS: Send progress report, P1 program.
89. **7 June 2013** – weekly progress report date.
90. **7 June 2013** – interim design report provided to regulator.
91. **11 June 2013** – P1 emergency repairs completed, 4 days ahead of original schedule.
92. **11 June 2013** – P2 contractor commenced work.
93. **11 June 2013** – environmental release gate opened discharging 35m^3/s.
94. **11 June 2013** – shotcreting of vertical face completed.
95. **12 June 2013** – sunny day failure activation of EAP stood down.
96. **12 June 2013** – e-mail SW to DEWS: Send progress report. EAP now stood down. Any change to review TOR?
97. **14 June 2013** – weekly progress report date.
98. **17 June 2013** – P2 contractor took possession of site.
99. **19 June 2013** – e-mail SW to DEWS: Send progress report, program, P1 complete.
100. **20 June 2013** - e-mail SW to DEWS: Sending two letters, P2 program, P3 program. Response to DG request of 31 May 2013.
101. **20 June 2013** – letter CEO of SW to DG of DEWS: Responding to DEWS letter of 31 May. P1 is completed. Risk target met 11 June, 4 days ahead of original program. Outlines changes that reduced time – capping deep scour rolled into P2, reduced shotcrete length. Construction report available early August. Interim design report provided 7 June. Contractor started work on site 11 June. Site handed to contractor 17 June. P2 program attached. P1 start risk 1 in 333, end risk 1 in 4,444. P2 end risk 1 in 40,000. Negotiating incentive to finish early. Initial P3 program attached. P3 activities outlined. Portfolio F-N chart given, note Burdekin Falls highest risk, upgrade due 2035.
102. **21 June 2013** – weekly report date.
103. **21 June 2013** – flood damage inspection report 2010/2011 flood provided to regulator.
104. **26 June 2013** - e-mail SW to DEWS: Send progress report, program.

8 Compliance with Procedures

So far as can be seen, SunWater has complied with regulatory procedures and with its own dam safety procedures to the extent that was reasonably practicable.

Two issues of note are:

- No attendance at dam site by SunWater operations personnel from around 1100h on 26 January to about 1300h on 28 January 2013. The EAP requires that when headwater is above the flood of record and rising fast the dam is to be inspected every 4 hours. The inspection frequency rises until at the AEP of 1 in 10,000 flood the inspection is to be continuous. The subject lack of attendance was strictly a breach of the EAP requirement but it was something which was beyond the control of SunWater. Given what is now known of the damages which can occur in the energy dissipation zone, there is a clear need to maintain a continuous surveillance of the dam at floods of much greater frequency than AEP of 1 in 10,000. The EAP needs to be revised to require continuous surveillance in flood conditions where damage to the dissipator or deep scour could occur. The understanding of the flood conditions which could produce such damages may change as risk assessment is refined. At this stage it would be prudent to take a precautionary approach. SunWater would need to work out how continuous attendance could be arranged; and
- The lapse of time from report of damage to energy dissipator on 8 February to engineer inspection of 21 February 2013. According to the letter of the CEO of SunWater of 12 August 2013 engineers did attend the site during this period. It is accepted that the spillway was flowing and it was not possible to clearly see the nature of the damage which had occurred. The point is though that, in terms of the time of seven days specified for reporting of incidents to the dam safety regulator as set out in DS 2 of the development permit conditions, time has apparently run from 21 February 2013. Otherwise there had been a breach of SunWater procedure, which requires compliance with the development permit conditions. No SunWater procedure was found stipulating how soon an engineer inspection is to be made following a report of damage. Nor was any definition found for the starting event from which time runs in terms of the seven day notification period. Given that the clear aim of development permit condition DS 2 is that the regulator will be promptly advised of an incident, why did not time run from the operator's report of 8 February or from the engineer's report of 13 February? There may be good answers to these questions but they are not found in the documented procedures so far as we can see. This whole area appears in need of some better definition.

9 Interaction with the Disaster Management Groups

9.1 Communications

The EAP flood event report for the January to March 2013 contains some 30 e-mail chains, comprising probably 100 to 150 messages. Most messages were internal to SunWater. A proportion of messages were to disaster management groups of the Bundaberg area.

The primary messages involving disaster management groups ran from 0731h on 27 January to 1711h on 15 March 2013. That is, from the day before the first flood peak to twelve days after the second flood peak.

Tranche 3 of documents provided by SunWater comprised 87 files mainly related to the sunny day activation of the EAP but did contain a proportion of documents relating to the flood event phase. These communications ran from 25 January 2013 to 12 June 2013.

In the Tranche 3 list there were 5 PDFs of communication record for these dates:

- 15 March 2013;
- 18 March 2013;
- 22 March 2013;
- 28 March 2013; and
- 2 April 2013.

These were presumably intended as a sample of communication records. Times and persons called were all recorded. It was generally not possible to know what the call was about but there are indications most calls were to downstream residents to let them know about releases from the environmental flow gate.

Also in the Tranche 3 list there were 3 Excel files of messages sent for these dates:

- 5 April 2013;
- 19 April 2013; and
- 4 June 2013.

This was a good record which showed that the same simple message had been sent to many people. All three messages were about releases from the environmental flow gate.

Finally the Tranche 3 list had 82 e-mail files. Some were e-mail chains so there were probably in excess of 200 messages. Also there was something in the order of 200 attachments. These were mainly situation reports – known as *sitreps* - but there were some weekly progress reports, media releases and many photographs. Virtually all of the Tranche 3 e-mails were between SunWater and the disaster management groups.

The Tranche 3 documents provide evidence of a really excellent level of communication between SunWater and the disaster management groups. Twice daily *sitreps* were provided to the disaster management groups every day, a fact confirmed within the groups' own internal communications. It is difficult to conceive of a better level of communication. The evidence from the e-mails is that there are excellent relationships between SunWater and the disaster management groups. All the relevant messages indicate that the disaster management groups felt that they were adequately informed and that the SunWater inputs were helpful to the discharge of their responsibilities.

9.2 Feedback from the Disaster Management Groups

On the morning of Tuesday 9 July 2013 an e-mail request was sent to:

1. Chairperson and District Disaster Coordinator, District Disaster Management Group (Bundaberg DDMG);
2. Disaster Management Support Officer, Bundaberg DDMG
3. Chair Bundaberg Local Disaster Management Group (LDMG)
4. Disaster Management Coordinator Bundaberg LDMG
5. Chair North Burnett LDMG
6. Disaster Management Coordinator North Burnett LDMG

A reminder was sent on the morning of Wednesday 17 July 2013.

Later that day a very helpful response was received from the Disaster Management Support Officer, Bundaberg Disaster District.

The request and the response are at **Appendix D.**

10 Consideration In Support of the Advice Under the Terms of Reference

In this section of the report, reference is made to each numbered point under Advice in the next section of this report.

10.1 First Term of Reference

1. Were there unrectified damages?

The rectification works planned but not completed prior to the January to March 2013 flood are listed in **Table 1**, which was taken from the interim design report (SunWater 7 June 2013).

Table 1 – 2010/2011 Flood Damages Planned for Rectification

Section	Description	Observation	Rectification Work
3.7	Right Bank Downstream of Primary Spillway	Hole formed by removal of rock below shotcrete may lead to instability of shotcrete face	Backfill hole with reinforced concrete anchored with grouted anchor bars
3.8	Downstream Face of Primary Spillway	Drains below walkway are flowing. Stability of structure depends on pressure relief provided by drains	Clean horizontal foundation drains to full depth.
		Concrete removed may expose reinforcing bars and lead to corrosion	Damaged concrete and holes deeper than 20 mm should be filled with a suitable concrete repair material
3.9.1	Primary Spillway Dissipator Apron Underdrains	Collector drain pipe caps and protector plates have been removed	Inspect 14 collector drain pipes and provide protection plate on drains
3.9.2	Primary Spillway Energy Dissipator Apron	Apron slab underdrains blocked. Drains needed to reduce uplift pressure	Clean 190 apron underdrains to full depth
		Exposed reinforcement in the dissipator apron may lead to spalling of the concrete	Reinstate reinforcing bars and backfill holes with Grade 32 MPa concrete
3.9.3	Primary Spillway End Sill	Exposed reinforcement in the end sill may lead to spalling of the concrete	Where reinforcing bars are exposed and cover reduced encase end sill with 175 mm thick concrete
3.9.5	Primary Spillway Apron and End Sill Abrasion	Rock downstream of the dissipator apron is causing abrasion of the concrete apron slab and end sill	Remove rock less than 1.0 m diameter for a distance of 100 m downstream of end sill

Section	Description	Observation	Rectification Work
3.10	Primary Spillway Left Bank Training Wall	Reinforcing bars exposed on top and end corners of wall may lead to spalling of concrete	Remove concrete around exposed reinforcing bars and reinstate wall to original profile

For reasons which are not entirely clear the list in **Table 1** is shorter than that given in the 2010/11 flood damage inspection and civil works rectification report (SunWater June 2013). The significant omission from **Table 1** with relevance to the first Term of Reference is rectification of the scour area on the lower left abutment just downstream of the left training wall. That work is described at sub-section 3.11 of the 2010/11 flood damage inspection and civil works rectification report. There were also mechanical and electrical rectification works related to the flow release system which had not been fully completed prior to the January to March 2013 flood.

2. Did unrectified damages worsen damage from the 2013 flood?

Using the section numbers in **Table 1** as references, these works are briefly discussed as follows:

- 3.7 – a moderate depth scour of up to 6m but more generally around 3.5m deep developed at this location (right end of spillway apron) during the 2013 flood and undercut the dissipator apron. The planned work arising from the 2010/2011 flood was small scale at the base of the shotcrete and largely on the right side of the scour which developed. Had the work been completed before the 2013 flood, the repair would have been outflanked by new scour from the 2013 flood and it would not have prevented the majority of the scour which occurred during that flood;

- 3.8 – the drain holes did not contribute to the damages which occurred during the 2013 flood. The holes in the concrete face did not contribute to any significant damage in the 2013 flood;

- 3.9.1 – there is no evidence that lack of drain caps and protector plates caused any damage during the 2013 flood;

- 3.9.2 – there is no evidence of such blockage of drains having caused any damages during the 2013 flood. The exposed reinforcement causing spalling is a potential long-term problem and it did not contribute to any damages during the 2013 flood;

- 3.9.3 - The exposed reinforcement causing spalling is a potential long-term problem and it did not contribute to any damages during the 2013 flood;

- 3.9.5 – Abrasion by rock and gravel has the potential to cause serious damage but there is no evidence of any significant abrasion damage as the result of the 2013 flood;

- 3.10 - The exposed reinforcement causing spalling is a potential long-term problem and it did not contribute to any damages during the 2013 flood;

  Scour at base of left abutment – This scour was essentially to the left of a line projected downstream from the left training wall. Had the repairs outlined in the 2010/11 flood damage inspection and civil works rectification report (SunWater June 2013) been completed prior to the 2013 flood event, they would not have prevented to any significant extent the damages which occurred in the 2013 flood event. [redacted] (2012) saw this left bank scour as a factor that would accentuate the potential for recirculation flow to draw rock and gravel into the dissipator to cause serious damage. However, there is no evidence of any significant abrasion damage from the 2013 flood. This lack of abrasion damage may have been due to failure of the end sill in the 2013 flood.

- Functionality of flow release facilities – whether or not the release facilities had been fully rectified is an irrelevant consideration because they would have been damaged again by the 2013 flood in any event.

3. Did unrectified damages hinder SunWater's ability to respond to the 2013 flood?

None of the damages listed under the preceding point had any effect on SunWater's ability to respond to the flood event. The factors which hindered the response were access problems, continued flow over the spillway and damage to release facilities, all of which were going to happen whether or not the damages listed under Point 1 had been rectified.

4. Are any changes to SunWater's practices or procedures desirable – overview

SunWater provided a suite of 17 standards which have been reviewed by us. The main 16 standards are:

- DS00 – *Dam Safety Management Program – Definition of Roles, Responsibilities and Titles,* February 2013;
- DS01 – *Dam Safety Management Program Overview,* February 2013;
- DS02 – *Dam Safety Management Structure,* February 2013;
- DS03 – *Dam Safety – Operation and Maintenance Manuals for Referable Dams,* February 2013;
- DS04 – *Dam Safety – Operating Procedures (SOPs) for Referable Dams,* February 2013;
- DS04 P1 – *Flood Operations Centre – Standing Operating Procedure – Status, Resourcing and Workflows,* March 2013;
- DS05 – *Dam Safety – Emergency Action Plans (EAPs) for Referable Dams,* February 2013;
- DS06 – *Data Books for Referable Dams,* February 2013;
- DS08 – *Dam Safety – Failure Impact Assessments (FIAs),*February 2013;
- DS09 – *Dam Safety – Acceptable Flood Capacity and Comprehensive Risk Assessments for Referable Dams,* February 2013;
- DS10 – *Dam Safety – Annual Inspections for Referable Dams,* March 2013;
- DS11 – *Dam Safety – Five (5) Yearly Comprehensive Inspections for Referable Dams,* March 2013;
- DS12 – *Dam Safety – Training Programs and Accreditation,* January 2011;
- DS13 – *Dam Safety – Dam Inspection Techniques,* January 2011 **(due for review in January 2012)**;
- DS14 – *Dam Safety – Documentation Control and Review,* March 2013;
- DS15 – *Dam Safety – Instrumentation Monitoring Program,* January 2011 **(due for review in January 2012)**.

These standards apply to all referable dams owned by SunWater. They are as good a suite of standards as we have observed anywhere. If any standards are overdue for review that situation should be rectified as soon as reasonably practicable.

An additional guide applicable to the total SunWater portfolio is:

- *Dam Safety Upgrade Decision Criteria Options Paper,* August 2010.

This document was quickly scanned but is not directly relevant to the Terms of Reference for this review. The document was not studied in detail. It is a complex document and a proper review would require more time than is available within the scope of the present assignment.

The following procedures specific to Paradise Dam have been reviewed:

- The Emergency Action Plan;
- The Standing Operating Procedures; and
- The Detailed Operations and Maintenance Manual.

These documents all accord with recognized good practice, with development permit conditions and with regulator and ANCOLD guidelines, so far as we can see. It is not known whether the documents have been reviewed before 1 June each year as required by the development permit conditions because an advice to the regulator of "no amendment needed" could have been issued. It would be useful if any such notices were prominently recorded at the front of the documents.

5. Are any changes to SunWater's practices or procedures desirable? – first issue

The SunWater standards, notably DS13, would benefit from the inclusion of a section on spillways including the energy dissipation zone. Methods for monitoring changes in rock scour should be included. Cavitation damage and abrasion damage could be more fully described. Clues to distinguishing cavitation damage from abrasion damage could be given. Guidance on looking for evidence of overtopping of spillway walls might be included. Tree growth in spillway approach channels should be covered. Inspection of underdrain condition should be included. At present there are only three brief references to spillways in the DS13 standard. It is desirable that spillways be more fully covered in the dam safety standards.

The SOP 19 on personnel training could also be improved by including study of case studies of gravity dam failures, their causes and consequences. As a result, operations personnel should know that gravity dams fail with little or no warning and with high severity flooding. They should also know that the main causes are undetected foundation flaws and flood loading, and that no gravity dam has failed as the result of earthquake loading. Then case studies of damage to energy dissipators and of rock scour would provide useful knowledge. As a result, operations personnel should know how to distinguish abrasion damage from cavitation damage and they should be aware that floods can scour large volumes of fresh rock.

6. Are any changes to SunWater's practices or procedures desirable? – second issue

Sub-section 7.5 of the comprehensive risk assessment (SunWater 2009) concluded that failure by foundation scour resulting from flood overflow was *impossible* at Paradise Dam due to the high tailwater level. That conclusion apparently took account of some external advice. Whether or not that advice was correctly interpreted and applied we do not know. In any event the conclusion must surely now be in question. These considerations point to a need for SunWater to review its procedures for estimating rock scour, especially at dams with high specific power discharge (peak power per metre length of spillway). A key question would be whether recognized methodologies, such as those developed by Annandale and separately by Bollaert, should be applied. It is desirable that SunWater carefully review its procedures for estimation of rock scour.

7. Are any changes to SunWater's practices or procedures desirable? – third issue

A preamble giving some background to this and the following suite of analyses is required before the analyses themselves are discussed. These three analyses are informed by these considerations:

- Though unlikely, a flood of similar or greater magnitude to the January to March 2013 flood could plausibly occur in the coming wet season;
- On the evidence available to us, destruction of the dissipator apron slab by a combination of particle abrasion and discharge energy in a large flood cannot be ruled out;
- In that event deep scour would likely occur close to the dam toe and stability of the dam could be compromised;
- It is not reasonably practicable to know exactly what is happening to the rock foundation in the energy dissipation zone during a large flood;
- Experience shows that gravity dams generally fail rapidly with little or no warning;
- A dam failure would endanger public safety.

Considerable uncertainty surrounds these points. The uncertainties are such that engineering judgment could prove to be a poor guide to performance.

In considering this situation we believe that a good case can be made to try and reduce the uncertainty to the extent that can be achieved in the time available before the coming wet season. In effect we are suggesting that some analysis activities be brought forward from the Phase 3 safety review. That safety review will not be completed until after the coming wet season. If our proposal is accepted, the analyses may need further refinement as better knowledge, for example of the site geology, becomes available during the safety review. But that is not a compelling argument against undertaking analyses now on the best information currently available.

That brings us to the first of the analyses.

It is desirable that rock scour be estimated by or for SunWater for:

- A range of flood conditions; and
- Two scenarios, one with the dissipator apron remaining intact with exposed rock configuration as at the end of Phase 2 work and the other with the dissipator apron fully destroyed

The estimation methodologies we have in mind are such as those developed by Annandale or those developed by Bollaert. The analyses should be peer reviewed by a person recognised for their knowledge and experience of rock scour estimation. The peer reviewer should be involved from the outset so as to comment on the scenarios to be analysed and the approach to be taken. The analysis outcomes should include some which are as nearly as practicable “best estimate”.

8. Are any changes to SunWater’s practices or procedures desirable? – fourth issue

The preamble to the preceding analyses informs these analyses also.

SunWater has undertaken some stability analyses as detailed in the interim design report (SunWater June 2013). The analyses follow good practice though the methodology and safety criteria which were followed have not been explicitly identified. There is potential for refinement and reduction of uncertainty. Consideration should be given to a range of flood loadings and to the probability of strong earthquake shaking during the period required for remedial work. It is desirable that the stability of the critical monoliths should be refined. Among other things possibly, there should be consideration of the following factors:

- Selection of the analysis methodology and safety criteria – the analysis methodology and criteria followed by SunWater in the interim design report seem to be those of the draft ANCOLD guidelines which have not yet been published (ANCOLD March 2012). But that is not said explicitly in the SunWater report. The earlier guidelines (ANCOLD 1991) are regarded as unsatisfactory and have been withdrawn from sale. The draft ANCOLD guidelines of 2012 carry this note: *This is a draft document and has not been released for use.* We understand there have been subsequent changes to the draft ANCOLD guidelines and that they are now almost print ready and may be issued in the near future. Defensibility is a legal rather than an engineering issue but it could affect the stability analyses. If legal opinion is against use of the draft ANCOLD guidelines and new guidelines will not issue in time there may be a need to select other guidelines. The latest well-regarded guidelines of which we are aware are those of FERC (2002). It would be preferable to use ANCOLD guidelines if that can be a defensible position.

- Potential extent of rock scour – the stability analyses would need to include scenarios with the outcomes of the rock scour analyses proposed under our preceding point.
- The latest understanding of the site geology – it is not clear from the interim design report how the analyses take into account the improved knowledge of foundation geology revealed by the deep scour. The baseline analyses use rock strength parameters from the original design, which would suggest that the latest understanding of geology has not entered into the analyses. In particular, there does not appear to have been consideration of the graphitic zone mentioned at the top of page 27 and the low strength properties of graphitic zones given in Table 4.4.2 of the interim design report (SunWater June 2013).
- Further consideration of the need for any reduction in effective tailwater level – the interim design report demonstrates an awareness of practice where the real tailwater depth is reduced because of the uncertainties of the actual pressures exerted on the dam face. Such practice is discussed in Section 3-3 (3) (b) of USACE (1995). In Table 7.1 of the interim report the tailwater pressures for the PMPDF and PMF cases were based on model tests but it is not clear what was done for the other flood cases.
- Any reliance on passive anchors – mobilization of the strength of passive anchors requires some movement on slide paths within the foundation, which raises questions of strength reductions toward residual strength. It is not clear what consideration has been given to such factors. Moreover it is recognized good practice to not rely on passive anchors in the long-term because there is no practicable way to monitor their load capacity.
- The analyses should yield some results which are as nearly as practicable “best estimate”.

Our proposal is that SunWater would have the stability analyses peer reviewed by independent recognized specialists, one in gravity dam analysis and the other in rock mechanics. If a person highly experienced in both fields can be found that would meet the need. The peer reviewers should be involved from the outset so as to comment on the scenarios to be analysed and the approach to be taken. The proposal for the involvement of a person with advanced skills in rock mechanics recognizes the critical importance of the rock strength values to the outcomes of the stability analyses.

9. Are any changes to SunWater’s practices or procedures desirable? – fifth issue

It is desirable that the risk assessments given in the interim design report be updated once the results from the preceding two points are available. SunWater's application of risk assessment following the damages to Paradise Dam is to be commended and the approach taken is essentially sound. Engineering judgment is an indispensible part of risk assessment and, in accordance with recognized good practice, SunWater relied on workshops of highly experienced engineers where the risks can be debated and thinking is clarified. Even so, it is beneficial to bolster judgment by science and empirical methods based on real experiences to the maximum practicable extent and to record the process which was followed.

There are some particular aspects that should be considered during the update process:

- In the traditional standards-based approach to safety risks are controlled by making conservative shifts in analyses. Thus the loads used in analysis are typically greater than the likely real loads and the strengths of elements used in analysis are typically less than the likely real strength. In risk assessment, the estimated risks are to be "best estimate". Engineers find it difficult to break free from their training in traditional standards-based analysis but analyses which inform risk analysis need to be as nearly as practicable "best estimate". In the case of Paradise Dam, this issue has not been addressed in the interim design report (SunWater June 2013). In Table 5.2 of that report there is no way of knowing whether any of the foundation strength cases is near to "best estimate" or what the relative probabilities of the various strengths are.

  As already discussed in this report, world experience would suggest that destruction of the dissipator apron by particle abrasion and the energy of the overflow cannot be ruled out, especially since both abrasion damage and pounding break-up have already occurred at Paradise Dam. In addition to the failure pathway outlined in Table 5.8 of the interim design report (SunWater June 2013), the updated risk analyses need to consider a parallel failure pathway involving destruction of the dissipator apron, whether of RCC or conventional concrete. The probability of loss of the apron should be informed firstly by a literature search of abrasion damage to stilling basins, there being quite a number of such experiences. A possible failure mechanism would be abrasion removing the top steel (in the case of the reconstructed sections of the apron) and much of the concrete and then the pounding of the overflow jet breaking up what is left of the concrete. It would be relevant to compare other dams to Paradise Dam in respect of such factors as extent of abrasion damage, volume of concrete removed, peak specific discharge, peak specific power, duration of overflow and other relevant factors. Secondly there should be careful consideration of the available store of gravel and rock remaining at Paradise Dam. Is there a sufficient store of particles remaining in the near vicinity of the dissipator? Might more particles be generated by further scour of the rock immediately downstream of the dissipator? Might a larger flood draw in a new store of particles from above the limits of the 2013 flood?

  The event tree branch for the probability of sliding, given deep scour to the dam toe, has been deleted in Table 5.8 of the interim design report (SunWater June 2013). Perhaps the analysts regarded sliding as certain for such scour. That branch should be included in risk assessments for two reasons. Firstly, it keeps before the reader the full failure mechanism. Secondly, it is unlikely that the probability of sliding would be 1.0 (certain) for all load scenarios. Providing the estimates of demand (load) and capacity (resistance) are “best estimate” the probability of sliding can be informed by some equations from *reliability analysis*, especially for low values of the sliding stability factor. These equations estimate the probability that the real sliding stability factor is less than 1.0 (the definition of failure), given the estimated value of the sliding stability factor. If the uncertainty in the sliding stability factor is Normally distributed, an estimated sliding stability factor of 1.0 equates to a probability of failure of 0.5 neglecting model error, which is generally unknown. It is usually accepted that a Normal distribution is a reasonably good assumption. The uncertainty of the sliding stability factor has little influence at values of the factor close to 1.0 but has a large influence for large values of the factor. **Figure 9** is based on two formulae from *reliability analysis*.

The first formula estimates the *reliability index.*

$$\beta = \frac{E[F]-1.0}{\sigma_F}$$

β = reliability index

E[F] = estimated factor of safety

σ_F =the standard deviation of the *probability density function* of F

The second formula computes probability from the standard Normal distribution function.

$$P_F = 1-\Phi(\beta)$$

P_F = probability of failure

Φ denotes the standard Normal distribution function

The unknown is σ_F the standard deviation of the *probability density function* of F. That value is difficult to estimate but has been estimated by Monte Carlo simulation.

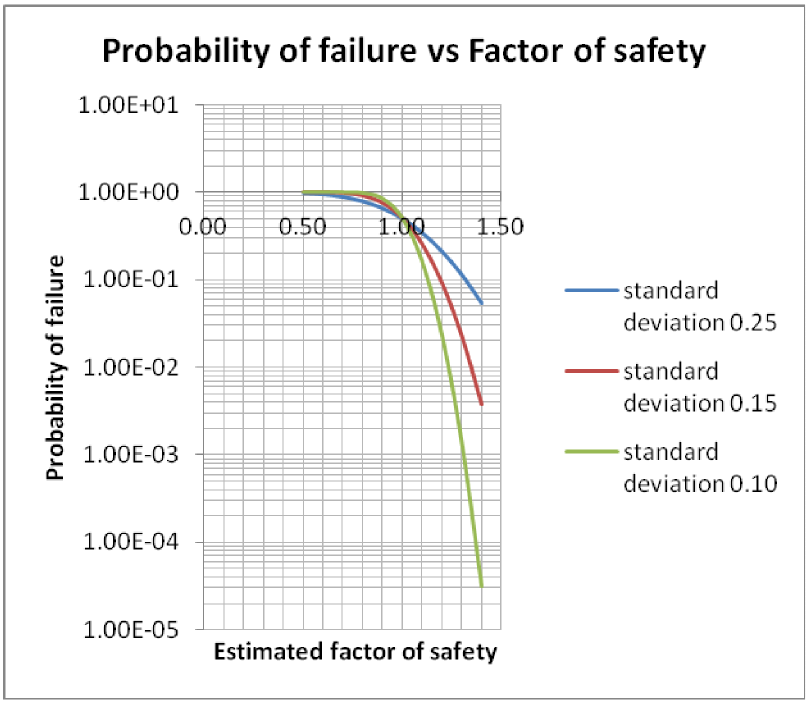

Figure 9 – Probability of Failure versus a Safety Factor

Analysts should not rely on **Figure 9** but should consult authoritative texts on *reliability analysis* and make their own assessments. A brief treatment of the concept can be found at pages 339 to 342 of Hartford and Baecher (2004).

- The outcomes of the work proposed under the two preceding issues (potential for further scour and dam stability) should inform the probability of deep scour and the probability of sliding.
- The underlying reasoning on which probability values are based needs to be fully documented. The discipline of documenting the reasoning improves the reliability of the risk analysis. Moreover it facilitates peer review. The Barneich et al. mapping scheme is often used to aid judgment of probability values – Table 8.1 of the risk guidelines (ANCOLD October 2003) refers. If that is done the documentation of the analyses should state the justification for selecting a particular category from that table. If there is other reasoning which underlies the probability values, that reasoning should be recorded.

10. Are any changes to SunWater's practices or procedures desirable? – sixth issue

A main purpose of the updated risk assessment would be to provide all concerned with a better appreciation of the risks. It is for the owner and regulator to decide how to respond. Among other things improved understanding would better inform the level of preparedness which SunWater should maintain during the coming wet season and the level of surveillance to be maintained at the dam in the event of a flood occurring. A precautionary approach is needed because:

- The analyses outlined necessarily have wide uncertainty, partly but not entirely because of the limited information available on the site geology;
- It is not reasonably practicable to know just what is happening in the energy dissipation zone during all but minor floods; and

- Public safety would potentially be at risk.

11. Are any changes to SunWater's practices or procedures desirable? – seventh issue

By letter dated 12 August 2013 the CEO of SunWater advised the Director of Dam Safety, DEWS, that independent peer reviewers engaged, or to be engaged, for the Phase 3 safety review had been consulted about the proposals set out in our preceding advices for analyses prior to the coming wet season. The letter indicates that the three reviewers are cautious about implementation of our proposed analyses because the results could be misleading without the geologic information which is to be generated during the Phase 3 investigations.

It seems desirable that our vision is stated more clearly. We see there are potentially three understandings of risk as follows:

- *Risk understanding A* – this is the current understanding, which is documented at sub-section 5.7 of the interim design report (SunWater 7 June 2013);
- *Risk understanding B* – this is the understanding which would result from the analyses proposed by us to be undertaken prior to the coming wet season. This understanding would take account of issues raised by us, of the latest available knowledge of the site geology and of other relevant factors. The knowledge and experience of the SunWater analysts would be enhanced by the knowledge and experience of the peer reviewers. This amounts to an earlier than previously planned commencement of analyses which are needed for the Phase 3 safety review;
- *Risk understanding C* – this understanding would result from an update of the analyses underpinning *Risk understanding B*, undertaken once the improved knowledge of the site geology and any other relevant factors generated by Phase 3 investigations is available. This understanding would likely not be available until well into 2014.

In our view the key question is not whether *Risk understanding C* differs from *Risk understanding B;* that is, whether *Risk understanding B* turned out to be misleading. It is likely that *Risk understanding C* will differ from *Risk understanding B* to some extent.

Rather we see that the key question is whether *Risk understanding B* is a more reliable and more defensible understanding than *Risk understanding A* – and a better basis for informing the level of readiness and surveillance which should be maintained during the coming wet season. On the evidence available to us it seems clear that there is potential to get a substantially more reliable understanding of risk prior to the coming wet season.

We should also clarify what is meant by "prior to the coming wet season". What is really meant is "as soon as reasonably practicable". Hopefully that would yield results prior to the onset of the wet season but if the work would continue somewhat into the wet season, that would not be a reason to abandon our proposed analyses.

Having put our view, it is necessary that alternative views are properly considered. The opinions of the SunWater peer reviewers deserve to be given a full hearing and to be carefully weighed in reaching a decision. This matter has been discussed with DEWS and its instruction is that a resolution of the issue lies outside the scope of this review.

The work under the items 8, 9 and 10 above may need to be done by consultants if SunWater personnel are fully committed on Phase 2 and Phase 3 activities. In that case, reviewers would need to be independent of both the consultants doing the work and SunWater. Whilst the analyses are extra work in the near term they would offset some work which would likely be part of the planned Phase 3 safety review.

By the time the work outlined above is done the wet season may not be far off or may have commenced. That emphasizes the urgency to have the work completed.

10.2 Second Term of Reference

1. **Was SunWater's response adequate before, during and after the flood event?**

   The evidence shows that SunWater responded adequately immediately before, during and immediately after the flood event. The EAP was activated and its procedures were followed. Once damage was apparent risk assessments were undertaken and progressively refined as knowledge of the damage grew. Plans were immediately put in hand to gain access to the damaged areas and to make releases through the environmental flow outlet. Emergency repairs were formulated and a three phase response program was developed.

   Following the identification of damage, the dam safety regulator was advised within the seven days required by the development permit conditions. The regulator was kept informed of progress with remedial work.

   SunWater determined a headwater level at which 24/7 surveillance would be provided and that protocol was followed from 1 March to 7 March 2013.

   A precautionary approach was taken by activating the EAP for a sunny day failure after the end of the flood event.

2. **Did SunWater adequately communicate with the disaster management groups in the Bundaberg area?**

   All of the evidence available to this review points to a very good relationship between SunWater and the disaster management groups. It is clear that there was an excellent level of communication and that the disaster management groups greatly valued the information provided by SunWater.

   There is evidence in the communication records indicating that the disaster management groups received reassuring advice about dam safety risks from SunWater but had been given more concerning indications of the safety status of the dam from other sources. This situation arose almost two weeks after the peak of the March flood when the dam safety risks were quite low, though needing to be further lowered as soon as practicable to protect against a possible recurrence of major flooding. All stakeholders should promote the SunWater dam safety engineers as the authoritative source of advice on the safety of the dam, since they best understand the dam and its risks.

3. **Given the circumstances, was the time taken to assess the damage and commence emergency repairs reasonable?**

   The focus here is on the emergency repairs to the dissipator apron and the area immediately downstream because those were the damages which directly threatened dam safety.

   As a start to consideration of this issue a timeline of some milestones will be of assistance. These are key dates:

   - **8 February 2013** – at 1439h the Storage Supervisor advised the SunWater head office of failed end sill left side, damage to apron with reinforcing bars protruding through the flow.
   - **18 February 2013** – at 0600h the headwater level reached 67.784m AHD, the lowest level since the flood peak of 28 January 2013.

- **20 February 2013** –The lowest headwater level during daylight was about 67.88m AHD, some 100mm higher than the minimum level reached on 18 February.
- **21 February 2013** – this was apparently the first day that dam safety engineers were on the site to observe signs of damage to the dissipator apron. Reinforcing bars were seen protruding out of the flow, the flow pattern suggested channels in the apron surface and end sills were seen to be destroyed. A photo (**Figure 10**), taken from the flood emergency event report (SunWater 2013), shows signs of damage with the tailwater almost up to about the highest level of the dissipator apron (37.600m AHD). At this time the depth of water over the lowest part of the dissipator apron was about 6.7m. The headwater level was about 67.97m AHD during the afternoon of that day. No reason was found for the lapse of time from first report of damage on 8 February to the engineer inspection of 21 February 2013, though continuing overflow may have been a consideration.
- **27 February 2013** – an internal SunWater briefing note reveals that the engineers had sufficient concerns about the safety of the dam to recommend 24/7 surveillance once the headwater level exceeded spillway crest level by 200mm, a level that was modified over following days as engineers made risk assessments.
- **1 March 2013** – 24/7 surveillance commenced because the headwater level exceeded the designated flood level. The dam safety regulator was briefed on damage to the dam, thereby just complying with the "seven days to notify" requirement of the development permit conditions, provided time ran from the engineer inspection on 21 February rather than from the first report of damage on 8 February or from engineer inspections made earlier than 21 February 2013.
- **7 March 2013** – 24/7 surveillance ceased because the headwater level had fallen below the designated flood level.
- **18 March 2013** – environmental release gate was made functional after considerable difficulty due to loss of power, the effects of flooding on the outlet building and the gate jammed by gravel in the wheel train.
- **19 March 2013** – this was the first date that the headwater level again reached as low a level as on 21 February. In between there was the March flood peak. From 19 March onwards the headwater level was kept below the spillway crest level by releases through the environmental flow gate.
- **5 April 2013** – this was the start date for site access and preparation.
- **8 April 2013** – work started on actual remedial work with demolition of the damaged RCC apron commencing.
- **11 June 2013** – the emergency repair works were completed.

There were 46 days from the first observation of dissipator damage to the commencement of remediation work. But 26 of those days were lost to a second flood, leaving 20 days for actual work on site. Whilst engineers could make plans in that lost time, they did not have an accurate picture of the damage for which they needed to plan. Knowledge of the true nature of the damage and scour emerged progressively, mainly up to early April but even beyond. For example, the weekly progress report of 26 April advised of a new scour hole found at Monolith J. Before remediation could commence, considerable work was needed to remove rock and gravel from the release channel, to get the environmental flow gate functional, to build a cofferdam around the area downstream of the dissipator, to build a culvert over the release channel, to dewater the area of the scour holes, to take care of lung fish and so on. A detailed examination of the bar chart program demonstrates that it was not reasonably practicable to commence remediation earlier. Throwing more resources at the task would not have achieved an earlier result because of problems such as unfamiliarity with the dam for planners and space limitations on the ground.

Figure 10 – End Sills Destroyed at Left End of Dissipator

The methods for determining the damage were reasonable. Consideration was given to reaching the left end of the dissipator from the northern bank of the river but that route appears to have presented difficulties – slipperiness after rain, permission needed and so on. The inescapable fact is that determination of damage could not be done properly until the site was dewatered and that required a cofferdam. The most reliable, and therefore the fastest access was from the right bank. A culvert at the release channel and access roads had to be constructed. Given the time available for planning, the engineers produced as good a plan as could reasonably be achieved.

4. Were reasonable methods used to assess the damage?

The application of risk assessment to assess the damage was a sound approach. The assembling of a group of engineers and geologists, with a detailed knowledge of the dam, in risk assessment workshops was in accord with recognized good practice.

5. Are there opportunities for improvements in practices/procedures for future flood events? – first issue

There are improvements to the approach which could be followed in any future event. These can be illustrated by reference to Table 4-2 of the flood damage report (SunWater March 2013). Suggested improvements are:

- Document risk analyses by fully describing failure mechanisms and the reasoning underlying the assigned probability values. The discipline of doing this actually improves the risk values as well as making the analyses comprehensible to reviewers and other stakeholders.

- Use "best estimate" probability values in all risk analyses. If it is desirable to take a precautionary approach by erring on the side of safety, do that after the "best estimate" results of risk assessment are known. In the subject table the probability of "scour dissipator floor" is 1.0 (certainty). Few things are certain. Table 4-2 can be contrasted with Table 1 of SunWater (19 April 2013) where "dissipator floor slab scour and loss" is given low probability values. Whether the two branches are meant to be the same event is not clear – note the previous point on documentation.
- Use fully constructed event trees or fault trees to describe the logic of failure mechanisms. In the subject table it is not clear how "scour dissipator floor" is a precursor to "undercut the spillway dissipator", since either would seem to open the possibility of rock scour toward the dam toe. Then there is no branch for the probability of sliding, given deep scour to the toe. The clarification of failure mechanisms by logic trees is not just for the benefit of other stakeholders. It also forces the analysts to define credible failure pathways and thereby improves the analysis.
- Bolster engineering judgment by science or experience to the maximum practicable extent. Where there is a relevant method of analysis, apply that if possible in the circumstances. Look to experience on comparable dams elsewhere in Australia or abroad. The Barneich et al. mapping scheme at Table 8.1 of the ANCOLD risk guides is meant to be one way of drawing in world experience.

6. Are there opportunities for improvements in practices/procedures for future flood events? – second issue

The first report of damage to the dissipator appears to be that made in an e-mail from the Storage Supervisor to head office at 1439h on 8 February 2013. The text of the message was:

Sill wall has been removed from the left side of the dissipator as shown in the attached photos. The base of the dissipator is also damaged with numerous pieces of reo bar protruding through the water; photo doesn't show it clearly at this discharge.

From the documents provided for this review, it appeared that the first inspection by engineers was made 13 days later on 21 February 2013. The material available for this review did not reveal the reason for the apparent lapse of time from notification of damage to inspection by engineers. Given what is now known, the Storage Supervisor's advice of seeing many reinforcing bars protruding through the flow should have triggered a prompt inspection by competent dam safety engineers even though the spillway continued to flow. The "time to notify" of seven days in the development permit condition DS 2 should run from the date of that engineer inspection. It should be clear which officer has the responsibility for notifying the regulator.

From the documents provided to the review, there appeared to be three aspects to this issue:

- Was it indeed the case that there was a lapse of 13 days from notification of what should have been concerning damage to inspection by dam safety engineers?
- If so, is there a need to revise SOP 42 or any other relevant standard or guiding document?

- Is it clear who is responsible for initiating notification of the regulator?

Following SunWater's review of our draft report, its CEO advised the Director of Dam Safety, DEWS, by letter dated 12 August 2013 that there had been earlier engineer inspections. Be that as it may, SunWater should amend procedures to ensure that engineer inspections are made urgently following a report of damage. It also needs to be clear from when time runs for notification of the dam safety regulator and who is responsible to see that notification occurs within the required time.

7. **Are there opportunities for improvements in practices/procedures for future flood events? – third issue**

The communication records during EAP activation appear to record all phone calls and other communications. Times and persons called were all recorded. It was generally not possible to know what the call was about. It seems obvious that the content of the message is meant to be recorded but frequently that field simply has "OK". A reviewer cannot be sure what is OK. SunWater should train its personnel to enter some brief words that will convey the subject of the call.

10.3 Third Term of Reference

1. **Could the time taken to complete the emergency repairs have been reduced?**

The emergency repairs were styled Phase 1. There were three risk milestone sub-phases and two sundry works, one preparatory and one remediation:

- Access and site preparation – preparatory work rather than remediation.
- P1A – replacement of damaged RCC in the dissipator apron by conventional concrete;
- P1B – repair of the scour hole at the right hand end of the dissipator;
- P1C - repair of the scour hole at the left hand end of the dissipator;
- Repair of a number of lesser scour holes.

Work under these phases was largely done in parallel. The times taken were:

- Access, preparation – 15 days from 5 April to 19 April 2013. The bar chart programs show 12 work items that were completed.
- P1A – 33 days from 8 April to 10 May 2013. There were 20 work items including removal of damaged RCC, drilling holes and installing anchor bars, placing reinforcement and pouring concrete. The work took place at three monoliths. There was a large number of angled anchor bars. Again much of the work was done in parallel.
- P1B – 22 days from 20 April to 11 May 2013. There were 17 work items, including clean out of scour hole, foundation preparation and six concrete pours.
- P1C – 55 days from 20 April to 13 June 2013. There were 25 work items, including vertical face protection, clean out of scour hole, foundation preparation, eight concrete pours and shotcreting of the vertical face.
- Lesser scour holes - 16 days from 29 May to 13 June 2013. There were 32 work items, including clean out of scour holes, foundation preparation and multiple concrete pours.

What could have been done to reduce the time required for the work? Three options are apparent:

- Work longer hours;
- Bring more personnel and assets to the site;
- Do repairs of a lesser standard.

Our understanding is that work proceeded for 12 hours a day, 7 days a week, including Anzac Day and the whole of the Easter holiday period. The only option to extend the hours was to work through the night. Some dams in Brazil are constructed 24 hours a day, 7 days a week. Why could that approach not have been taken at Paradise Dam? SunWater engaged a specialist firm in worker health and safety to undertake a risk assessment of night work at the dam. The report (RiskPro 2013) clearly demonstrated that risks would not be as low as reasonably practicable without substantial construction works. The time required for such construction would effectively negate any reduction in time from working longer hours. In most states, and presumably in Queensland, risks to worker safety are not legally defensible unless they are eliminated or, if it is not reasonably practicable to eliminate them, they are reduced as low as reasonably practicable. At Paradise Dam night work would not have significantly reduced the time required for repairs.

Bringing more people and assets to the site was not practicable, given that works were already proceeding in parallel and each work site was quite small. If consideration is given to **Photos 2 and 4** of **Appendix C**, even though they show Phase 2 work in progress, it is quite obvious that there was no room to fit more equipment and personnel into the left side scour hole without the extra resources getting in the way and actually impeding the work. Given that work proceeded in parallel at a number of locations during the emergency repairs, the conclusion is that extra resources would have been self-defeating. A reduction in time could not have been achieved.

In the interests of early completion the standard of the emergency repairs could have been reduced. That would have reduced the time required for repair. There are two points to make about the option. Firstly, the higher the standard of the repairs, the better they would stand up to another large flood. Such a flood could occur at any time but especially during the coming wet season. It is unlikely but it could happen. Secondly, it has not been feasible up to this time to conclusively determine whether the repairs will have a long-term role at the dam. It is prudent to assume that they will have a long-term role and to design accordingly. This applies especially to the repairs to the dissipator apron. The evidence is that SunWater was conscious of the opportunity to save time by reducing the standard of repair and did indeed make some compromises in quality. It would not have been sensible to further reduce quality.

Our conclusion is that it was not reasonably practicable to reduce the time required for the completion of the emergency repairs.

2. Were the emergency repairs appropriate?

The emergency repairs essentially comprised:

- Demolition of the damaged RCC apron and replacement by a deeply anchored conventional concrete slab;
- Cleaning out scour holes, anchoring and concrete filling; and
- Shotcreting the vertical face in the deep scour hole near the left end of the dissipator.

These three remedial works progressively reduced risks to dam safety. Failure to undertake the first item would have left the dam in a very vulnerable condition in the event of another large flood. The second item reduced the likelihood of scour holes being enlarged in the event of another large flood. The third item reduced the likelihood of undercutting of the apron in the event of another large flood.

All three items were needed and were appropriate.

3. Could the risk mitigation measures have been improved?

The risk mitigation measures comprised activation of the EAP for a sunny day failure. Doing this left the dam safety engineers free to concentrate on risk assessments and planning of remedial works. Bringing consultants in to devise risk mitigation measures was not a practicable option because of the work involved in arranging an engagement, briefing the consultants and getting them familiar with the whole emergency planning framework. Given the demands on the time of the dam safety engineers, it made sense to activate the EAP with which the SunWater and disaster response personnel were already familiar.

Activation of the EAP was a precautionary approach because it is highly unlikely that a gravity dam with the reservoir at or below FSL would fail after it has just survived the loading of a major flood. However, the time required for remedial works is such that the probability of strong earthquake shaking cannot be ruled out. No gravity dam has ever yet failed from earthquake shaking. An instructive case is that of Shih-Kung Dam in Taiwan, shown at **Figure 11**.

In the Shih-Kung Dam case a fault displacement of some 8m or more in the foundation of the dam destroyed two gravity blocks. But the significant point is that the adjacent blocks, though subjected to very strong shaking, did not fail and suffered little damage.

Nevertheless, at Paradise Dam, the possibility of a gravity dam in vulnerable condition due to deep scour being subjected to strong earthquake requires a precautionary approach. Activation of the EAP maintained a good state of readiness and kept the disaster management groups apprised of the situation at the dam and of progress with the emergency remedial works.

Figure 11 – Earthquake Damage to Shih-Kung Dam Taiwan

The dam safety engineers were fully occupied in estimating the risks to the dam and devising a program of remedial work. Attempts to improve the risk mitigation measures would have diverted them from those critically important tasks. In the circumstances, it was not reasonably practicable to improve the risk mitigation measures.

4. Could procedures be changed to provide better outcomes in the future?

The dam's performance in the 2010/2011 and the January to March 2013 floods has revealed the potential for damage to the dissipator apron and for deep scour close to the dam toe. The possibility of further damage in future floods cannot be ruled out. It would make sense to plan a risk mitigation response to further damage before any such damage occurs.

The first step in that task is to gain a better understanding of the risks. The actions proposed by us under the first Term of Reference would initiate that process. The aim is to identify potential damage scenarios and to estimate their likelihood. At this stage it seems to us to be plausible that a worst case of deep scour up to the dam toe could occur. If that occurs what is the likelihood of strong earthquake shaking over the period needed for remedial work and what is the probability of dam failure? What is the probability of another large flood over the same period and what is the probability of dam failure? Having gained a good understanding of the best estimate risks, the question would then be what is the best plan to protect public safety and community interests whilst the damage is repaired? A precautionary approach could be appropriate given that gravity dams fail rapidly with little or no warning.

Once a risk mitigation plan is devised, it would need to be written into the EAP.

10.4 Fourth Term of Reference

The advice provided under this term of reference is based on the versions of the EAP provided to us. We understand there are later drafts which respond to legislative changes following the Queensland Floods Commission of Inquiry recommendations. We have not reviewed those drafts.

The documents we reviewed are:

- SWA 502.001.1767 – updated November 2012; and
- SWA 502.001.2090 – updated March 2013.

The full review was of the November 2012 document and then sections 1 to 6 and 10 of the March 2013 document were reviewed, those being the only sections to change.

In addressing this Term of Reference, the EAP was judged against the requirements of Section 9 of the dam safety regulator's guidelines on dam safety management (NRM 2002). Compliance with those guidelines effectively means compliance with Section 8 of the ANCOLD guidelines (ANCOLD August 2003) on dam safety emergency plans, a sub-set of an EAP.

1. ***Are changes to the EAP or other documents desirable? – overview***

   The EAP has been checked off against Section 9 of the regulator's dam safety management guidelines (NRM 2002). All of the matters that are required to be covered in an EAP are dealt with in the Paradise Dam document. However, some of the matters need to be covered more fully for the EAP to be as effective as practicable in protecting public safety and community interests. Those matters are covered in following points.

2. ***Are changes to the EAP or other documents desirable? – first issue***

   If the advice under the first Term of Reference is followed, it is desirable that the EAP is revised to take account of the findings of the analyses which we have proposed should be undertaken. Those findings would inform the risk levels under flood conditions, and for earthquake during remediation periods, and the risk values in turn influence the matters to watch for, the level of surveillance and generally the level of alert which should be maintained. Among other things, damage to the energy dissipator and deep scour should feature somewhere in light of the recent experience.

3. ***Are changes to the EAP or other documents desirable? – second issue***

   As reported in **Appendix D** to this review, the feedback from the Disaster Management Support Officer, Bundaberg Disaster District included an observation that the EAP was not user friendly for the people involved with disaster management. Experience has commonly shown that it is difficult to write documents which are addressed to an audience with a wide variety of life experience and skills, because what an engineer may readily comprehend, a health professional or local businessman may struggle to understand. Of course the reverse situation applies also. It is not practicable, within the scope of this review, to suggest what improvements should be made to meet the concern which has been expressed. The best approach would be for SunWater officers and representatives of the disaster management group to work together to try and identify improvement which could be made.

   However in any such review the following matters might be considered.

   Firstly, the primary aim should be to devise a system which would ensure that all persons at risk are evacuated to safety before a dambreak flood wave arrives.

Secondly, the decision process set out at the EAP section 2 pages 7, 8 and 9 is complex. If feasible it should be made simpler.

Thirdly, it seems to be implicit in the process that there would be warning signs of dam failure. The laws of physics and experience show that gravity dams generally fail with little or no warning. Consideration should be given to such things as water level sensors or movement sensors which could trigger an alarm at multiple locations. Two out of three sensors in agreement is generally regarded as a true signal. There should be full time attendance at the dam during large floods.

Fourthly, the process currently relies on subjective judgments by individuals, either engineers or the dam duty officer. Is that reasonable, given that people could live or die according to the decision? “High likelihood” will be interpreted differently by different people. It would be good to give some objective guidance which is sanctioned by the dam owner and the dam safety regulator.

Fifthly, we believe it would be useful to estimate and to plot on to the one datum four timelines:

- The time of dam failure and the progress of the dambreak flood wave down the valley, noting the arrival times at the various PAR;
- The time to recognize a problem, move through the SunWater decision process, to warn close PAR and to send a signal to activate the disaster management groups;
- The time for the close PAR to self-evacuate to safety; and
- The time for the disaster management groups to move through their decision processes, to mobilize the ermergency responders and for the PAR to be safely evacuated.

The aim would be to ensure that all PAR are got to a safe location before the flood surge arrives.

4. *Are changes to the EAP or other documents desirable? – third issue*.

An e-mail from the emergency event co-ordinator (EEC) at 1101h on 28 January 2013 stated that power had failed at the Bundaberg office and there was no network available. The EEC was operating from home. Attempts to dial into a teleconference had failed.

This message, sent as the flood was nearing its peak, gave an impression, perhaps incorrect, that local systems were failing and that the work from home option was an unplanned eventuality. In any case, that message brought to mind the question of whether the Bundaberg office is vulnerable in very large floods and what back-up arrangement there is. We do not recall seeing discussion of the issue in the EAP. There is also the fact that a large flood could result in common cause failure of power, landline and e-mail. The whole - question of redundant systems for emergency management would benefit from further review in the EAP.

5. *Are changes to the EAP or other documents desirable? – fourth issue*

One of the purposes of documents such as an EAP is to provide ready information for persons who may be new to an organisation. It may well be the case that people currently involved with emergency management have extensive local knowledge and know how to respond with or without the EAP. But that is beside the point. As an example of the thought in our minds, under *List of Equipment Available During an Emergency* at section 3, page 12 there was just one item, an aluminium boat. There are various other items which could be required during an emergency. On 28 January 2013 there was need of a helicopter and someone to fly it. After the flood there was need of a 200 tonne crane to lift the jammed environmental flow gate. The EAP at section 7, page 2 refers to the need to place earth and rockfill to stabilize the dam. It is not clear just what is to be done and how but it would require dozers, loaders, trucks. In that same paragraph it is said that a *list of available equipment at the dam and/or equipment and materials suppliers including Local Councils* will be found at section 3. But there is no list of equipment and materials suppliers at section 3. Going through the Councils to find suppliers extends the communication chain and the time required to make contact. The EAP would be more useful if the names of firms, contact people and phone numbers were provided – and kept updated – so that emergency managers could immediately get plant, operators and materials.

6. Are changes to the EAP or other documents desirable? – fifth issue.

In a few places in the EAP the reader gets the impression that the EAP follows a template devised for the whole of the SunWater portfolio of dams. For example, at *Introduction to EAP,* page 4, the table, row 6 there is reference to internal erosion of the embankment. Such references do not promote confidence in the EAP. It is best that they be removed.

7. Are changes to the EAP or other documents desirable? – sixth issue.

Many acronyms appear without having first been defined. Some are defined much further on in the EAP and there may be some which are not defined anywhere. It would be best to have a list of acronyms and their meanings immediately following the table of contents.

8. Are changes to the EAP or other documents desirable? – seventh issue.

An e-mail from the EEC at 1217h on 28 January 2013 included this statement:

I will have an operator on site around noon and will provide a more accurate reading as soon as possible.

There were no SunWater operations personnel in attendance at the dam from around 1100h on 26 January 2013 until about 1300h on 28 January 2013. This was because the access road to the dam had been cut and weather conditions apparently prevented access by helicopter. SunWater arranged for the manager of the kiosk at the dam site to provide information on the headwater level. To provide some context, at this time the reservoir level was on the rising limb of the flood hydrograph a little under 7 hours before the peak outflow. The first inspection on 28 January was at 1320h when the headwater level was 8.488m above the spillway crest level of 67.60m AHD. This compares with the peak headwater level at about 1900h on 28 January of 8.65m above spillway crest level. Given what is now known of the performance of the dam it is troubling that no operations personnel were in attendance at headwater levels more than 8m above spillway crest level. On reading the EAP it is seen that when headwater is above the flood of record and rising fast the dam should be inspected every 4 hours. The inspection frequency rises until at the AEP of 1 in 10,000 flood the inspection is to be continuous. Given what is now known of the damages which can occur in the energy dissipation zone, there is a clear need to maintain a continuous surveillance of the dam at floods of much greater frequency. The EAP needs to be revised to require continuous surveillance in flood conditions where damage to the dissipator or deep scour could occur. SunWater would need to work out how such attendance could be arranged.

9. Are changes to the EAP or other documents desirable? – eighth issue.

For Actions 2 and 3 at section 2, pages 8 and 9 of the EAP, the Dam Safety Technical Advisor is to inspect the dam. However, we did not see any guidance on how urgently the inspection is to be made. This thinking was prompted by the experience in the aftermath of the January 2013 flood where the site personnel advised of damage to the dissipator on 8 February 2013 and dam safety engineers inspected on 21 February 2013. Similarly at section 5C, page 1, field 4, row 1 an inspection is to be arranged but urgency is not specified. The same issue occurs in other places. The EAP should be revised to ensure that engineer inspections are made with appropriate urgency.

10. *Are changes to the EAP or other documents desirable? – ninth issue.*

At sections 6A, 6B and 6C, among others, page 2 there is a requirement for inspecting officers to report any significant changes in observed conditions. The following statement appears:
The degree of urgency of this advice varies with the nature of the issue (or *matter* in some places).

That is unquestionably a true statement but it is vague guidance. It must surely be possible to give some more specific guidance. Among other things, examples could be given to guide the inspectors. Prompt advice of any change with potential implications for dam safety could prove to be vitally important. A principle of resolving doubt in favour of safety could be invoked. The EAP needs revision to give better guidance on the urgency of reporting changed conditions.

11. *Are changes to the EAP or other documents desirable? – tenth issue.*

No guidance was seen in the EAP of the impact of releases from the dam on downstream residents. Such releases may especially be necessary in the aftermath of a flood. It is accepted that the residents are always given notice of releases. But presumably some have pumps which draw out of the river, some may have boats and there could be other issues. Would it not be helpful to operations personnel to list some of the issues? Some consideration should be given to this issue.

12. *Are changes to the EAP or other documents desirable? – eleventh issue.*

At section 7 of the EAP, the normal access to the dam from the southern side of the river is described by a blue line on a satellite photograph. The alternative access is described by a very small scale map of the regional road network without any indication of the best options. Neither description conveys much useful information. Surely it would be simple to cover the following matters for access on both the southern and northern sides of the river and for alternate routes:

- Distance from Bundaberg (that being the normal source of resources);
- Travel time from Bundaberg and for key sectors;
- AADT values for key sectors if available;
- Speed limits;
- Formation width;
- Unpaved, gravel pavement or sealed;
- Pavement and seal widths;
- Maximum gradients;
- Load limits;
- Any needed permissions;
- Any vulnerabilities – for example, two wash-outs occurred at culverts on the normal access road in early 2013.

The local government authorities should have such information readily to hand.

Other travel modes should be covered. Aircraft charter options from Brisbane to Bundaberg could be covered. Helicopter charter options from Bundaberg to the dam should be covered. Where are there suitable landing pads? Are there any navigation aids? Is there a landing site on the north side of the river within walking distance of the dam? Is there any ground transport on the north side? When the dam ceases to spill the north end of the dissipator is exposed well before the central section but is not accessible from the southern bank, especially if large releases from the environmental flow gate are required.

13. Are changes to the EAP or other documents desirable? – twelfth issue.

In the EAP at section 9, page 3, paragraph 1 the last sentence reads:

Incremental effects of dambreak are the difference between the area inundated by the flood event with dambreak of Burnett River Dam and the same flood without dambreak.

The reference to "area inundated" could mislead disaster management personnel or other users of the EAP. A more accurate definition would be:

Incremental effects of dambreak are the difference between the consequences of the flood event due to dambreak of Paradise Dam and the consequences of the same flood without dambreak.

The reason is that there can be persons exposed to floodwaters within the natural flood footprint but in no real danger of harm because the depth and velocity are low but the same individuals could be in mortal danger from the same flood with dambreak. Similarly there could be homes within the footprint of the natural flood where floor coverings are ruined but the structure remains sound, whilst the same flood with dambreak could destroy the home. The point is that incremental effects are not necessarily confined to the zone between the natural flood footprint and the dambreak footprint.

14. Are changes to the EAP or other documents desirable? – thirteenth issue.

The base mapping for flood inundation is smaller scale and less accurate than is now commonly used for dambreak. For example, the NSW dam safety regulator indicates that the mapping should be at a scale of 1:10,000 with a contour interval of 2m or better accuracy (DSC 2010). Some dambreak inundation mapping in Australia has been based on specially flown 1:5,000 maps but that generates a large number of mapping sheets for long inundation zones.

There is also a rapidly growing trend to 2D hydraulic analysis for dambreak inundation mapping.

These are matters which could be given consideration in conjunction with the Phase 3 safety review planned for Paradise Dam.

15. Are changes to the EAP or other documents desirable? – fourteenth issue.

There are a number of references in the EAP which would seem to be outdated or otherwise inappropriate. Some examples are:

- Burnett River Dam – this name needs to stay in some places, such as in the development permit conditions. But in many other places it would seem the name could and should be changed to Paradise Dam.
- Department of Environment and Resource Management – is this still needed, given that no such department is now in existence.

- At section 10, page 4 of the EAP the references to *Dam Safety Act 1978* and *State Emergency and Rescue Management Act 1989* are references to NSW legislation. That is odd for a document with jurisdiction in Queensland. If the references are to be kept, it needs to be made clear that these are NSW Acts.

10.5 Fifth Term of Reference

There could be the potential to make improvements at the dam and to other infrastructure which would assist dam safety management generally and which would reduce the time taken for any future remediation work in particular. The proposal is that the feasibility of such improvements be investigated as part of the Phase 3 investigations. The key matters which have come to our attention are set out under the following points.

1. ***Improvements to the normal southern access road to the dam***

On the way to the site inspection, SunWater officers mentioned that the road had washed out at two culverts because of their limited flow capacity and that this had hindered the remediation program. The only evidence found in the documents provided was a note in the communications record of 20 February 2013 which records that the wash-outs were partially repaired. There are no data on the intensity of rainfall in the catchments of the culverts. Given the critical importance of reliable access to the dam, it would be worth investigating the feasibility of increasing the flow capacity of these and any other vulnerable culverts to reduce the likelihood of access being lost.

2. ***Improvements to the right bank access at the dam***

The access on the right bank at the dam site was washed out in both the 2010/2011 flood and in the January to March 2013 flood. If nothing changes, that will keep happening. Restoration of access added to the time required for emergency repairs following the January to March 2013 flood. There is a case to examine the feasibility of providing an access system which is less susceptible to flood damage.

3. ***Improvements to access on the north bank of the river***

The area of the energy dissipation zone which is most prone to damage is at, and close to, the left end of the spillway. When the spillway is discharging observation of any damage is made from the dam crest at the right end of the spillway, which is some 300m from the area of most interest. This is because the access on the northern side of the river is understood to be poor, with steep gradients, poor surface which gets slippery from rain, a bridge load limit and so on. The northern route goes through a national park. Once the spillway ceases to discharge the left end of the dissipator becomes accessible whilst the remainder is still flooded. This is because the dissipator apron is almost 7m higher at the left end than elsewhere. Early access for close inspection would be possible if there was better access to the north side of the river. It would be worth examining the feasibility of improving the road or of providing a helicopter landing pad. The second aspect to look at is the feasibility of providing an all weather road which would enable heavy equipment to reach the north side. That could possibly result in earlier completion of remedial work.

4. ***Improvement of access down the left bank to the dissipator apron***

Depending on the outcome of investigations under the preceding point, it could be worth investigating safe access for personnel down the left bank to the apron. At present access is over rough, steep rock. Any such access would need to be resistant to flood damage.

5. ***Measures to prevent ingress of gravel and other debris to the environmental flow gate chamber***

SunWater officers described the difficulty of lifting the environmental flow gate following the January to March 2013 flood. The hydraulic ram was inoperable. A 20 tonne lift should raise the gate. But it was necessary to bring a 200 tonne crane to site because the required lift was over 60 tonnes. This was because gravel had got into the gate wheel train and jammed the gate. The documents available to us support this account. If nothing is changed it could be expected that this problem will recur in every large flood. The problem increases the time needed for emergency repairs because the gate is the main means of preventing flows over the spillway from normal inflows to the reservoir. It is worth investigating measures which might prevent gravel and other debris being drawn into the gate chamber.

6. ***Measures to protect the hydraulic rams from damage***

The environmental flow gates are normally lifted by hydraulic rams located above the gate chamber. In the 2013 flood one of the rams was destroyed. This problem could be expected to recur in any future large floods unless the system is changed. Emergency repairs to the dam are hindered if the rams are not operable. It is worth investigating the feasibility of measures which would protect the rams from damage.

7. ***Measures to better protect the electric power system used to operate release facilities***

The January to March 2013 flood submerged switchboards and put the electric power system out of commission. Repairs require significant time. It was necessary to move heavy items such as the cross-connect bulkhead by block and tackle, a difficult and tedious operation. It needed a crane to open the release gate. These difficulties increase the time required for emergency repairs. The problem will recur in large floods unless changes are made. The feasibility of modifying the electric power system to make it less susceptible to serious damage is worth investigating.

8. ***Measures to increase the flow capacity of the release channel and cofferdam***

Following the January to March 2013 flood it was necessary to build a cofferdam to keep the energy dissipation zone dewatered. A culvert across the release channel was needed to provide access from the right bank to the dewatered area where remediation work was needed. The environmental flow gate is capable of releasing some 250m^3/s with the reservoir level close to spillway crest level. But the access road culvert overtops at 54m^3/s. It is not clear at what flow the cofferdam overtops. Since the release capacity is critically important in avoiding a spill which would flood the energy dissipation zone, any future remediation work would be facilitated if there was a greater discharge capacity for the release channel/cofferdam/road crossing system. It is worth investigating the feasibility of providing a greater flow capacity for the system and of making the system resistant to flood damage.

11 Advice

11.1 First Term of Reference

Was there any damage to the dam from previous flood events that had not been rectified by the January-March 2013 flood event. If there was such unrectified damage, may it have worsened the damage from the January-March 2013 flood event, or adversely affected SunWater's ability to respond to the flood event, both during it and immediately afterwards? Are any changes to SunWater's practices/procedures desirable?

Advice

1. ***There was damage from previous flood events that had not been rectified prior to the January-March 2013 flood event;***

2. ***The unrectified damages in the preceding point had no significant effect on the damages which occurred during the January to March 2013 flood event.***

3. ***The unrectified damages had no effect on SunWater's ability to respond to the January to March 2013 flood event.***

4. ***SunWater's documented procedures for dam safety are sound and in accordance with accepted industry practice, with the development permit conditions for the dam, with the regulator's guidelines (NRM 2002) and otherwise with ANCOLD guidelines, in particular with the guidelines on dam safety management (ANCOLD 2003).***

5. ***It is desirable that the SunWater standards, notably DS13, be amended to better cover the spillways of dams including the energy dissipation zone. SOP 19 would benefit from inclusion of training on case studies of gravity dam failures and their causes and consequences, and on case studies of damages to gravity dam energy dissipators and of rock scour.***

6. ***It is desirable that SunWater review its procedures for assessing the potential for rock scour at its dams, particularly those dams with high specific power discharges (peak power per metre length of spillway crest). If not already applied, the recognized methodologies for estimating rock scour should become part of the assessment procedure for those dams with high specific power discharges.***

7. ***It is desirable that the potential for further rock scour at Paradise Dam is estimated carefully before the coming wet season and the work is reviewed by an independent peer reviewer recognized for knowledge of and experience in rock scour estimation methodologies. The peer reviewer should be involved from the outset so as to comment on the analysis scenarios and approach. The outcome of the work should include a "best estimate" result. As a minimum the work should cover a range of flood magnitudes and two configurations:***

    - ***The configuration of the rock surface downstream of the dissipator as it will exist on completion of Phase 2 remedial works; and***
    - ***The situation where the dissipator apron has been subsequently destroyed and removed by floodwaters.***

8. ***It is desirable that the stability analysis of critical dam monoliths is refined before the coming wet season and the work is reviewed by two independent peer reviewers, one recognized for knowledge of and experience in gravity dam stability analysis and one a recognized specialist in rock mechanics (unless a suitable person highly skilled in both fields can be found). The peer reviewers should be involved from the outset so***

as to comment on the analysis scenarios and approach. The outcome of the work should include "best estimate" results as well as results of traditional standards-based analyses. At this stage it appears the analyses should give consideration to:

- ***The selection of analysis methodology and safety criteria for gravity dam stability;***
- ***The outcomes of the rock scour analyses under the preceding point;***
- ***The latest knowledge of foundation geology;***
- ***A further review of the stabilizing forces provided by tailwater;***
- ***Any proposed reliance on passive anchors, including the consideration that the load capacity cannot be monitored in the long term.***

9. ***It is desirable that the risk assessments be updated when results from the preceding two work items are available. Consideration should be given to these aspects of the risk analyses:***
   - ***The results should be "best estimate";***
   - ***In addition to the failure pathway in the interim design report there should be a parallel failure pathway involving destruction of the dissipator apron by abrasion and the energy of the overflow;***
   - ***An event tree branch for the probability of sliding, given deep scour to the dam toe, should be included;***
   - ***The results from the scour and stability analyses should inform the probability of deep scour and the probability of sliding***
   - ***The reasoning underlying the selection of the risk analysis values needs to be fully documented.***

10. ***It is desirable that the results of the updated risk assessment inform SunWater's level of preparedness for the coming wet season and level of surveillance at the dam in the event of a flood. A precautionary approach should be taken having regard to these facts:***
    - ***The analyses have wide uncertainty;***
    - ***It is not reasonably practicable to know exactly what is happening in the energy dissipation zone during a flood event; and***
    - ***Public safety would potentially be at risk.***

11. ***The reservations of SunWater's independent peer reviewers regarding the value of analyses before the coming wet season, as proposed in our preceding advices, need to be fully heard and carefully considered. Resolution of those reservations lies outside the scope of this review.***

11.2 Second Term of Reference

Consider the adequacy of SunWater's response immediately prior, during, and immediately after, the January-March 2013 flood event, and opportunities for improvements in practices/procedures. In making this assessment, the contractor should cover:

- *Communications between SunWater, the Local Disaster Management Groups, and emergency response groups more generally.*
- *Given the circumstances (especially the prevailing weather conditions), assess the time taken, and methodologies used, to assess the damage, and commence emergency repairs.*

Advice

1. ***SunWater responded adequately prior to, during and immediately after the flood event. A precautionary approach was taken by activating the EAP for a potential sunny day failure event after the flood had subsided and until the emergency repairs had reduced risks to target levels.***

2. ***The available evidence indicates that SunWater maintained an excellent level of communication with the disaster management groups in the Bundaberg area. SunWater dam safety engineers provided authoritative information on the safety status of the dam and the disaster management groups relied on that information.***

3. ***Given the circumstances it faced, SunWater commenced the emergency repairs within a reasonable time. The methods for initiating releases, gaining access and determining the damage were reasonable given the time pressures.***

4. ***The application of risk assessment to assess the damages in a workshop of experienced professional people was a sound approach to the estimation of dam safety risks.***

5. ***An opportunity for improvement of practices/procedures for any future events exists in the risk assessment process with regard to:***
    - ***Documentation of the risk assessment, particularly as regards the description of failure mechanisms and the reasoning which underlies probability values;***
    - ***Assigning "best estimate" risk values. If SunWater sees reasons to take a precautionary approach, that should be done after the "best estimate" risk assessment results are available;***
    - ***Use of event trees primarily, but also fault trees if appropriate, to fully define failure mechanisms; and***
    - ***Bolstering engineering judgment by science and world experience of dam performance to the maximum practicable extent.***

6. ***Given what is now known about the performance of the dam in floods, there would appear to be an opportunity of improving SOP 42, and possibly other guidance documents, with respect to:***
    - ***Ensuring that a dam safety engineer makes a site inspection as a matter of urgency after a report of damage which is potentially a dam safety incident as defined by the regulator;***
    - ***Specifying that "time to notify" under DS 2 of the development permit conditions runs from the date of the engineer's inspection provided the damage is confirmed as a "dam safety incident"; and***
    - ***Specifying who is responsible for initiating notification of the regulator and seeing that it is made within the required time of seven days.***

7. ***There is an opportunity to improve procedures by SunWater training its personnel to enter sufficient words in the "Message" field of Communication Records to enable others to comprehend the subject of the communication.***

11.3 Third Term of Reference

Consider, given all the circumstances e.g. incomplete knowledge of the repairs commencement, the appropriateness of the emergency repairs, the length of time to complete them, and whether this period could have reasonably been reduced. Could the risk mitigation measures in place, which were to minimise the consequences of dam failure, (while the emergency repairs were completed), been improved? Could SunWater's practices/procedures be changed to potentially produce better outcomes in similar, future events?

Advice

1. ***Given the circumstances it faced, it was not reasonably practicable for SunWater to reduce the time required for completion of the emergency repairs.***

2. ***The emergency repairs were an appropriate means of progressively reducing risk.***

3. ***The activation of the EAP for a sunny day failure scenario was a reasonable, though precautionary, means of risk mitigation and it was not reasonably practicable to improve the mitigation measures within the time available without detriment to other critical activities.***

4. ***The EAP should be revised to allow for the risks which are now known to exist at Paradise Dam. In particular, response plans should be devised for possible future damage scenarios.***

11.4 Fourth Term of Reference

Are changes to the dam's Emergency Action Plan, or other documentation and procedures, desirable? (Noting that significant changes will be required, in any event, to comply with new legislative requirements).

Advice

1. ***The EAP covers all of the content required by the dam safety regulator's guidelines, though not always as fully as is desirable.***

2. ***If the advice under the first Term of Reference is followed, it is desirable that the EAP is revised to take account of the findings of the analyses proposed under that TOR.***

3. ***It is desirable that SunWater work together with the disaster management groups in an effort to make the EAP more user friendly and to maximise the effectiveness of evacuation.***

4. ***It is desirable that the EAP be revised to better deal with redundant systems for emergency management.***

5. ***It is desirable that the EAP be revised to provide better information on assets and resources which may be required for emergency management.***

6. ***It is desirable that the EAP be reviewed to remove any content that is not applicable to Paradise Dam.***

7. ***It is desirable that there be a list of acronyms and their meaning immediately after the table of contents.***

8. ***It is desirable that the EAP be revised to make clear statements about the need for continuous attendance of surveillance personnel at the dam.***

9. ***It is desirable that the EAP be revised to make clear statements about the urgency for inspections by a dam safety engineer.***

10. ***It is desirable that the EAP be revised to give better guidance on the reporting by personnel at the site of changed conditions at the dam.***

11. ***It is desirable that consideration be given to revision of the EAP to give guidance on the impact of releases from the dam on downstream access and residents.***

12. ***It is desirable that the EAP be revised to provide more useful information on available access modes and routes to the dam.***

13. ***It is desirable that the EAP be revised to provide a more accurate definition of incremental flood effects.***

14. ***It is desirable that consideration be given to the value of 2D inundation modelling and to the preparation of more accurate mapping on which to plot inundation extent.***

15. ***It is desirable that the EAP be revised to remove any inappropriate or outdated references.***

11.5 Fifth Term of Reference

Other matters the contractor considers relevant, following prior written approval by the Director-General of the Department of Energy and Water Supply.

Advice

1. ***It is desirable that the feasibility of improvements at the dam, and to other infrastructure, be investigated as part of the Phase 3 work. These are improvements which may assist dam safety management generally and which may reduce the time required for any future remediation in particular. Some key matters to be examined are:***
    - ***Increasing the flow capacity of culverts on the normal southern access road to the dam to reduce the likelihood of wash-outs;***
    - ***Improvements to the right bank access at the dam that would avoid destruction of the access in every large flood;***
    - ***Improvements that could provide early access to the left bank at the dam for a) inspecting personnel and b) heavy equipment needed for remediation work;***
    - ***Subject to the outcome of the preceding point, provision of safe access down the left bank to the left end of the dissipator apron;***
    - ***Measures to prevent ingress of gravel or other debris to the environmental flow gate chamber;***
    - ***Measures to safeguard the hydraulic rams that are designed to open the environmental flow gates;***
    - ***Measures to better protect the electric power system used to operate release facilities and to reduce the time required for repair in the event power is lost in floods; and***
    - ***Improvements which would allow a greater release discharge without disrupting any potential future remediation work in the energy dissipation zone.***

12 Overview

Overall SunWater has a world class dam safety management system and it maintains an excellent level of communication with disaster management groups.

Hopefully the findings of this review will make an impressive dam safety management system even better.

There is a need to better understand the dam safety risks of Paradise Dam before the coming wet season.

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Appendix A TERMS OF REFERENCE

DRAFT TERMS OF REFERENCE: PARADISE DAM REVIEW

(01/05/13)

1. Background

In the January-March 2013 flood event, the dam's dissipator and related structures experienced significant damage.

The Department of Energy and Water Supply (DEWS) wishes to have an independent review undertaken of SunWater's action in managing the dam, so as to ensure any potential improvements in practices/procedures (and related matters).

2. Contractor

The contractor(s) undertaking the review must not have been employed by, or otherwise -- undertaken work for, SunWater since 24 June 2008.

The contractor must be able to commence work on 24 June 2013 of accepting the engagement and have a draft report within four weeks of accepting the engagement. A final report must be submitted within five working days of receiving DEWS' comments on it.

Note: It is important that SunWater staff focus on the emergency repairs to the dam. These are currently scheduled for completion by 16 June 2013, hence the commencement date for the review.

3. Terms of Reference

3.1 Was there any damage to the dam from previous flood events that had not been rectified by the January-March 2013 flood event. If there was such unrectified damage, may it have worsened the damage from the January-March 2013 flood event, or adversely affected SunWater's ability to respond to the flood event, both during it and immediately afterwards? Are any changes to SunWater's practices/procedures desirable?

3.2 Consider the adequacy of SunWater's response immediately prior, during, and immediately after, the January-March 2013 flood event, and opportunities for improvements in practices/procedures. In making this assessment, the contractor should cover:

- Communications between SunWater, the Local Disaster Management Groups, and emergency response groups more generally.

- Given the circumstances (especially the prevailing weather conditions), assess the time taken, and methodologies used, to assess the damage, and commence emergency repairs.

3.3 Consider, given all the circumstances e.g. incomplete knowledge of the repairs commencement, the appropriateness of the emergency repairs, the length of time to complete them, and whether this period could have reasonably been reduced. Could the risk mitigation measures in place, which were to minimise the consequences of dam failure, (while the emergency repairs were completed), been improved? Could SunWater's practices/procedures be changed to potentially produce better outcomes in similar, future events?

3.4 Are changes to the dam's Emergency Action Plan, or other documentation and procedures, desirable? (Noting that significant changes will be required, in any event, to comply with new legislative requirements)

3.5 Other matters the contractor considers relevant, following prior written approval by the Director-General of the Department of Energy and Water Supply.

4. Miscellaneous

SunWater, and DEWS, will make staff, and relevant documentation, available to the contractor.

The draft report should be supplied in electronic form to the Director, Dam Safety (DEWS) who will provide it to SunWater for their comment. The Director (Dam Safety) will provide SunWater and DEWS' comments (if any) on the draft report to the contractor.

Five copies of the final report, plus an electronic copy of it, are to be supplied to the Director (Dam Safety).

The contractor is to visit the dam site.

5. Fees and Expenses

The contract will be taken on an agreed hourly rate plus reimbursement of actual expenses. Estimated cost (including GST):

Appendix B DOCUMENTS PROVIDED BY SUNWATER

DOCUMENT IDENTIFICATION (provided by Allens Linklaters)

SWA.500.002.1234	SWA.502.001.2090	SWA.502.001.2862	SWA.502.001.2904
SWA.501.001.0121	SWA.502.001.2240	SWA.502.001.2863	SWA.502.001.2905
SWA.501.001.0136	SWA.502.001.2250	SWA.502.001.2864	SWA.502.001.2906
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SWA.501.004.0132	SWA.502.001.2306	SWA.502.001.2868	SWA.502.001.2910
SWA.501.004.0175	SWA.502.001.2309	SWA.502.001.2869	SWA.502.001.2911
SWA.501.004.0673	SWA.502.001.2311	SWA.502.001.2870	SWA.502.001.2912
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SWA.502.001.1157	SWA.502.001.2839	SWA.502.001.2881	SWA.502.001.3051
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SWA.502.001.2010	SWA.502.001.2850	SWA.502.001.2892	SWA.502.001.3213
SWA.502.001.2013	SWA.502.001.2851	SWA.502.001.2893	SWA.502.001.3244

SWA.502.001.2020	SWA.502.001.2852	SWA.502.001.2894	SWA.502.002.0001
SWA.502.001.2051	SWA.502.001.2853	SWA.502.001.2895	SWA.502.002.0115
SWA.502.001.2054	SWA.502.001.2854	SWA.502.001.2896	SWA.502.002.0135
SWA.502.001.2058	SWA.502.001.2855	SWA.502.001.2897	SWA.502.002.0137
SWA.502.001.2064	SWA.502.001.2856	SWA.502.001.2898	SWA.502.002.0138
SWA.502.001.2077	SWA.502.001.2857	SWA.502.001.2899	SWA.502.002.0141
SWA.502.001.2078	SWA.502.001.2858	SWA.502.001.2900	SWA.502.002.0143
SWA.502.001.2083	SWA.502.001.2859	SWA.502.001.2901	SWA.502.002.0145
SWA.502.001.2087	SWA.502.001.2860	SWA.502.001.2902	SWA.502.002.0148
Not used	SWA.502.001.2861	SWA.502.001.2903	SWA.502.002.0162

DOCUMENT IDENTIFICATION (provided by Allens Linklaters)

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SWA.502.002.0177	SWA.502.002.0295	SWA.506.001.0052	SWA.506.001.0187
SWA.502.002.0178	SWA.502.002.0303	SWA.506.001.0053	SWA.506.001.0191
SWA.502.002.0179	SWA.502.002.0304	SWA.506.001.0055	SWA.506.001.0193
SWA.502.002.0180	SWA.502.002.0312	SWA.506.001.0057	SWA.506.001.0196
SWA.502.002.0192	SWA.502.002.0314	SWA.506.001.0058	SWA.506.001.0200
SWA.502.002.0193	SWA.502.002.0316	SWA.506.001.0062	SWA.506.001.0202
SWA.502.002.0200	SWA.502.002.0320	SWA.506.001.0063	SWA.506.001.0204
SWA.502.002.0202	SWA.502.002.0324	SWA.506.001.0068	SWA.506.001.0208
SWA.502.002.0203	SWA.502.002.0325	SWA.506.001.0069	SWA.506.001.0210
SWA.502.002.0205	SWA.502.002.0326	SWA.506.001.0074	SWA.506.001.0214
SWA.502.002.0206	SWA.502.002.0333	SWA.506.001.0076	SWA.506.001.0215
SWA.502.002.0215	SWA.506.001.0001	SWA.506.001.0081	SWA.506.001.0219
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DOCUMENT IDENTIFICATION (provided by Allens Linklaters)

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Appendix C SELECTED PHOTOS FROM INSPECTION OF 2 JULY 2013

Photo 1 – Remedial Work

Photo 2 - Shear Feature (just right of concrete boom)

Photo 3 – Sill Block at Base of Left Abutment

Photo 4 – Preparing for Concrete to Protect Steep Scour Face at Left End of Spillway

Photo 5 – Scour Hole at Right End of Apron Repaired

Photo 6 – Condition of RCC Surface of the Dissipator Apron

Photo 7 – A 7 tonne sill block carried 150m

Photo 8 – Necking of Reinforcement Bars Indicating Tensile Overload

Photo 9 – Rock More Resistant to Scour

Photo 10 – Closely Fractured Rock Less Resistant to Scour

Photo 11 – Apron RCC Showing Separation at the Steel Level

Appendix D FEEDBACK FROM DISASTER MANAGEMENT GROUPS

REQUEST FOR FEEDBACK AND RESPONSE

On the morning of Tuesday 9 July 2013 an e-mail request was sent to:

1. Chairperson and District Disaster Coordinator, District Disaster Management Group (Bundaberg DDMG);
2. Disaster Management Support Officer, Bundaberg DDMG
3. Chair Bundaberg Local Disaster Management Group (LDMG)
4. Disaster Management Coordinator Bundaberg LDMG
5. Chair North Burnett LDMG
6. Disaster Management Coordinator North Burnett LDMG

The substance of the request was:

"My name is Len McDonald. I am an engineer acting for NSW Public Works (PW), a division of the NSW Department of Finance and Services. PW has been engaged by the Queensland Department of Energy and Water Supply (DEWS) to undertake an independent review of SunWater dam safety management actions prior to, during and following the January to March 2013 flood at Paradise Dam.

The second term of reference for the review is:

Consider the adequacy of SunWater's response immediately prior, during, and immediately after, the January-March 2013 flood event, and opportunities for improvements in practices/procedures. In making this assessment, the contractor should cover:

- *Communications between SunWater, the Local Disaster Management Groups, and emergency response groups more generally.*
- *Given the circumstances (especially the prevailing weather conditions), assess the time taken, and methodologies used, to assess the damage, and commence emergency repairs.*

This message of mine primarily relates to the first bullet point in this term of reference.

Accordingly it would be greatly appreciated if you are able to provide a response to these questions:

1. In your observation were those responsible for disaster management kept adequately informed by SunWater over the relevant period?
2. Do you feel that SunWater conveyed the risks related to the dam in a way that could be properly understood by those involved with disaster management?
3. Do you believe that the Emergency Action Plan (EAP) maximizes public safety and adequately safeguards community interests?
4. Do you have any suggestions for improvement of the EAP or other SunWater procedures?
5. Do you have any other relevant comment?

For reasons which we need not go into here, the PW review has become very urgent. It would be greatly appreciated if you are able to reply by the close of business on Monday 15 July."

A reminder was sent on the morning of Wednesday 17 July 2013.

Later that day a very helpful response was received from the Disaster Management Support Officer, Bundaberg Disaster District. The points made in that response are set out below. The questions posed in the request for feedback are underlined and the response is in italics.

Our responses to your questions are:

1. In your observation were those responsible for disaster management kept adequately informed by SunWater over the relevant period?

A/. Effective disaster management at all levels is based on positive relationships between all parties. At Bundaberg we have a close working relationship with our local Sunwater representatives, who actively participate in the Bundaberg District Disaster Management Group (DDMG) and attend meetings regularly. During the disaster events of 2013 we maintained this close relationship with Sunwater representatives, including initial notification and formal briefing of the damage to Paradise Dam. Sunwater also provided us with regular details as to dam heights and waters movements during the floods which assisted greatly in managing the disasters. Since the dam was damaged we have received regular updates as to its repair progress, including visits to the site to view the damage and repairs. To date we are still receiving regular updates as to the repair progress of Paradise Dam.

2. Do you feel that SunWater conveyed the risks related to the dam in a way that could be properly understood by those involved with disaster management?

A/. Our local Sunwater members were able to provide a prompt and more realistic and objective account of the damage to Paradise Dam, when others weren't. This was greatly appreciated. The information and explanation of the damage and likely causes were professional and relevant to our knowledge base. We (executive members of the Bundaberg DDMG) now have an improved understanding of the components and operations of a dam, including dissipators and monoliths.

3. Do you believe that the Emergency Action Plan (EAP) maximizes public safety and adequately safeguards community interests?

A/. I have no doubt that EAP's contain a lot of valuable information, but from a layman's point of view I don't believe it is suitable as an easy reference information tool and one that the public would not find easy to reference. This would obviously discourage the public from referring to it.

4. Do you have any suggestions for improvement of the EAP or other SunWater procedures?

A/. It may be more worthwhile creating a more simplistic and user friendly document which can be rapidly referred to during a disaster. The flood maps are too difficult to interpret as well.

5. Do you have any other relevant comment?

A/. Although the EAP's may not be completely suitable for our needs or the general public needs, any information or clarification required from a disaster management perspective is promptly and effectively provided by our local Sunwater representatives.