IN THE MATTER OF
THE QUEENSLAND FLOODS COMMISSION OF INQUIRY

A COMMISSION OF INQUIRY UNDER THE
COMMISSIONS OF INQUIRY ACT 1950

AND PURSUANT TO
COMMISSIONS OF INQUIRY ORDER (NO. 1) 2011

FURTHER STATEMENT OF PETER WILLIAM CARE

I, **Peter William Care**, of c/- [redacted] Ellengowan Street, Urangan, Hervey Bay, say as follows:

1. I am currently employed by Wide Bay Water Corporation ("***the Corporation***") as Chief Operating Officer.

2. I make this statement in response to a requirement dated 17 November 2011 issued by Justice Catherine E Holmes, Commissioner of Inquiry, pursuant to section 5(1)(d) of the *Commissions of Inquiry Act 1950* (Qld).

Current Status of Gates

3. As described in paragraph 27 of my previous statement dated 14 September 2011 (***Previous Statement***), the gates system at Lenthalls Dam (***Dam***) is comprised of five gates. I believe that Gates 1, 2, 3 and 4 are presently capable of "automatic" opening (that is, manual intervention in the form of opening the inlet valves is not required to cause these gates to lower in a flood event), but this cannot be confirmed until an actual flood event occurs. With the exception of Gate 5 (discussed at paragraphs 8 and 9 below), I believe that all gates are expected to open in an automatic fashion during the coming wet season.

4. All of the crest gates (including Gate 5) are designed so that they can also be manually opened. When required, the gates are manually operated by the Corporation's staff opening an inlet valve for each gate, which allows the gate to fill with water and systematically lower to release water from the Dam.

5. Where the opening of the inlet valves does not cause a gate to lower, Gates 1 and 5 can also be manually opened by applying external force using a hydraulic jack in combination with the inflow of water to the gate via the valve.

Filed by Wide Bay Water Corporation

[redacted]

6. As mentioned in paragraph 113 of my Previous Statement, the Corporation has installed snorkels on the top of the access hatches on each of the gates to aid the release of air from the gates while the gates fill with water. This was referred to as the "temporary solution" to the air venting problems described in paragraphs 88 to 92 of my Previous Statement. With the exception of Gate 5, this temporary solution has proven to be effective in enabling the manual opening of the gates (a flood event is required to test the effectiveness of the solution in automatically opening the gates). It is likely Gate 5 will additionally require external hydraulic jacking in order to lower.

7. As mentioned in my evidence before the Commission of Inquiry on 12 October 2011 and in paragraph 116 of my Previous Statement, Glen Hobbs of Glen Hobbs & Associates (***GHA***) has been engaged to undertake a peer review of GHD's proposed solution to the problems experienced with the Dam gates. In a letter dated 11 November 2011, Glen Hobbs stated the preliminary findings from his ongoing review. In his preliminary findings, Glen Hobbs states that the "temporary solution" has proven to be successful with respect to the air venting problems and that he considers that a similar arrangement could be adopted on a permanent basis. The letter from Glen Hobbs dated 11 November 2011 is at Annexure 1 of this statement.

8. The Corporation has experienced ongoing problems with Gate 5 since the crest gates were installed. Gate 5 has never opened automatically. With the exception of one previous occasion (immediately following the implementation of the Seal Improvement Program referred to in paragraphs 54 to 59 of my Previous Statement), the Corporation has only ever been able open Gate 5 by applying external force using a hydraulic jack.

9. Gate 5 was successfully opened using a hydraulic jack on 12 October 2011. On the same day, I gave evidence before the Commission of Inquiry that the Corporation managed to successfully open Gate 5 that morning, for the first time in 12 months. Gate 5 has subsequently been opened using a hydraulic jack several times, including on 25 October 2011 and 3 November 2011.

10. While I expect that Gates 1, 2, 3 and 4 will open automatically during flood events (with Gate 5 to be manually opened using a hydraulic jack), it has been identified that although the gates initially lower as designed, they do not stay down during flood events. Instead, the gates partially rise until they reach an equilibrium position and stabilise. I made reference to this "rising" behaviour of the gates in paragraph 114 of my Previous Statement.

11. The gates designer, GHD, has been working with the Corporation to investigate the gate "rising" problem. Desktop modelling of the Dam gates by GHD has indicated that equilibrium position for the gates when operating at full supply level is approximately

550mm above the spillway crest level. GHD's memorandum dated 3 October 2011 contains a summary of GHD's desktop modelling of the Dam gates. This memorandum is attached as Annexure 2 to this statement.

Solution to the "Rising" of Dam Gates

12. GHD is presently in the process of identifying a solution to the gate "rising" problem. Two potential solutions have been considered by GHD to date. The first involved the installation of a hydraulic spoiler to the Dam gates. Computer-based modelling has revealed that fitting a spoiler to the gates is not a workable solution.

13. The second solution involves constructing a flow deflector upstream of the existing gates. GHD is currently carrying out computer-based modelling and concept development of the flow deflector to determine if the flow deflector will be an effective solution to the gate "rising" problem. If GHD concludes that the flow deflector is an effective solution that should be implemented on a permanent basis, Glen Hobbs of GHA will be engaged to undertake a peer review of the proposal.

14. Following Glen Hobbs' review, comment on the proposed flow deflector would be sought from the Dam Safety Regulator (***DSR***) and a recommendation will be submitted to the Corporation's Board of Directors (***Board***) for its consideration. It is anticipated that a recommendation will be made to the Board in the first quarter of 2012.

15. If the Board makes a decision to proceed with the proposed flow deflector, GHD will undertake detailed design and prepare a construction specification and contract documentation to enable the project to be tendered for construction. This process is expected to take approximately 3 months.

16. Without a detailed design it is difficult to estimate the time frame for completion of construction works, however I believe that, if approved by the Board, flow deflector construction work would take at least six months to be completed, once a contract has been awarded. To minimise any delay, the Corporation is presently preparing a shortlist of potential contractors who have the capability and expertise required to carry out the relevant work.

Preparation for Wet Season

17. Each of the five gates is now opened on a rotating basis to ensure that each gate remains operable and to release water from the Dam to the lower impoundments.

18. As of 22 November 2011, water levels at the Dam were at 88.5% of full capacity, due to each of the gates being systematically lowered on a rotating basis. The Corporation now records the manual operation of the crest gates and the volume of releases from the Dam

[redacted]

through the gates in the daily Water Log. An extract from the Water Log showing the entries from 1 September 2011 to 22 November 2011 is attached as Annexure 3 to this statement. The daily Water Log for the period prior to 1 September 2011 was provided as Annexure 2 to my Previous Statement.

19. If the Corporation continues to open each of the gates on a rotating basis, consistent with recent practice, I expect that Dam levels will be down to 85% by 1 December 2011.

20. In light of the public comments to the effect that Queensland can expect to receive above average rainfall in the coming wet season by the Bureau of Meteorology (***BOM***) and State Government disaster management groups, the Corporation will continue to monitor rainfall levels to determine if water levels in the Dam need to be lowered further to address potential inflows.

21. The District Disaster Management Group and the Fraser Coast Local Disaster Management Group (***DMGs***) receive regular updates on potential long term forecast rainfall events from the BOM. The Corporation receives regular notifications from the DMGs about the forecast seasonal rain, which are used by the Corporation to prepare for potential seasonal flood events.

22. As mentioned in paragraphs 35 and 36 of my Previous Statement, the Standard Operating Procedures (***SOPs***) and the Operation and Maintenance Manual (***O&M Manual***) set out the procedures that need to be undertaken for the maintenance of the Dam. In November 2011, prior to the start of the current wet season and pursuant to the requirements of the O&M Manual and the SOPs, all gate air vents and inlet feed pipes were cleared to ensure that there were no blockages.

23. The Corporation is investigating the potential installation and use of closed circuit television cameras and inclinometers to identify the opening position of each of the Dam gates. Specification and procurement options are currently being considered by the Corporation, for implementation as soon as practicable.

24. On 25 November 2011, the Corporation will convene a disaster management simulation exercise. The exercise consists of a flood event simulation. All staff who are likely to be involved in Dam operation during this flood season will take part in the exercise. The exercise gives the Corporation's staff an opportunity to practice the discharge of their responsibilities in a way that achieves the outcomes set out the Emergency Action Plan (***EAP***) during a flood event.

25. As noted in paragraphs 102 to 105 of my Previous Statement, the Corporation made a number of amendments to its EAP based on the experience of the 2010/11 wet season. The Corporation amended the EAP trigger levels in the latest version of the EAP

[redacted]

(Revision 12, August 2011), as I had concerns that the trigger levels were occurring too early. For example, the former "trigger event" 4.4, which occurred at RL 25m, is now trigger "F1" which occurs at RL 25.7m. Following concerns raised by two upstream landowners, the Corporation also amended the EAP contact procedure. No further amendments to the EAP are proposed at this time.

Status of Investigations into the Operability of the Dam

26. As mentioned at paragraphs 114 and 116 of my Previous Statement and in my evidence before the Commission of Inquiry, Peter Hill of Sinclair Knight Merz (***SKM***) and Glen Hobbs of GHA have been engaged to undertake peer reviews of the work undertaken by GHD in relation to the crest gates, in particular, the findings in the 2011 Flood Report and the Crest Gates Report referred to in my Previous Statement.

27. As noted above, Glen Hobbs' preliminary findings are set out in his letter dated 11 November 2011. Glen Hobbs' preliminary findings address the three main difficulties experienced with the Dam gates since the raising of the Dam.

28. Glen Hobbs' findings with respect to the air venting problems is addressed in paragraph 7 above. With respect to the problems with seal friction, Glen Hobbs concludes that the Seal Improvement Program, implemented by the Corporation in early 2009, has been effective in dramatically reducing the high lintel seal frictional forces on the gates and that the forces are now in keeping with that expected for such an application.

29. With respect to the gate "rising" problem, Glen Hobbs agrees with GHD's view that that the spoiler concept is unlikely to resolve the uplift problem. Glen Hobbs has undertaken a detailed review of the forces on the crest gates while investigating the gate "rising" issue, but he will not be in a position to complete his investigation until GHD develops a final solution to the uplift problem that has resulted in the gates "rising".

30. Peter Hill's hydrology review is nearing completion. His draft report dated 17 November 2011 is attached as Annexure 4 to this statement.

31. A further memorandum was prepared by Peter Hill dated 23 November 2011, which is attached as Annexure 5 to this statement.

32. Peter Hill's report and further memorandum, referred to above, consider the Annual Exceedance Probability (***AEP***) for a Dam Crest Flood (***DCF***) event for a number of scenarios with different gate openings.

33. On the basis of Peter Hill's draft report and further memorandum, referred to above, I make the following comments:

(a) The average annual probability of a flood event occurring that would overtop the dam embankment (that is, a DCF), assuming all are gates closed, is 1 in 70,000 AEP. This is the "worst case scenario". The Dam spillway is designed to pass a 1 in 2,000,000 AEP flood event, assuming all gates operate as designed.

(b) Assuming that all gates are open to 1.45m due to the "rising" behaviour of the gates (550mm from fully open), if the Dam is at FSL, the AEP of a DCF is 1 in 830,000. If the gates rise up further as the water level increases, the AEP also increases, eventually reaching 1 in 70,000 once all gates are closed.

34. For the purposes of comparison only, I note that even in an 'all gates closed' scenario the Lenthalls Dam would satisfy the minimum flood discharge capability requirements set out in Table 3: Schedule for Dam Safety Upgrades on page 18 of the *Guidelines on Acceptable Flood Capacity for Dams* (February, 2007).

35. The Corporation has been proactively engaging with the DSR to keep the DSR informed about the difficulties experienced with the Dam gates and the steps taken to resolve them.

36. On 22 November 2011, the Corporation provided a written update to the DSR regarding the status of the review being undertaken by each of GHD, SKM and GHA. The letter to the DSR dated 22 November 2011 is attached as Annexure 6 to this statement. The previous correspondences between the DSR and the Corporation were provided as Annexure 12 to my Previous Statement.

37. On 23 November 2011, [redacted], the Chief Executive Officer of the Corporation, and I attended a meeting with Peter Allen, the DSR, to discuss the various measures taken by the Corporation to resolve the issues experienced with the Dam gates.

38. The Corporation will continue to pursue effective solutions to the problems and will continue to keep the DSR informed of progress.

Signed by **Peter William Care** in the presence of:

[redacted]
Witness Signature

[redacted]
Signature

[redacted]
Print Name 24/11/2011

Glen Hobbs & Associates P/L
32/103 Majors Bay Rd
Concord
NSW 2137

11th November 2011

Bill McCredie
Allens Arthur Robinson
123 Eagle Street
Brisbane Qld 4000

STRICTLY PRIVATE AND CONFIDENTIAL
SUBJECT TO LEGAL PROFESSIONAL PRIVILEGE

Dear Bill

Lenthall Dam – update and preliminary findings

I refer to my engagement to peer review and consider matters set out in the draft *Report for Lenthall Dam: Crest Gate Operational Issues and Modification* (June 2011) prepared by GHD (***Crest Gate Report***).

1. **Update**

As you know, I have been provided with significant additional material prepared by GHD subsequent to the preparation of the Crest Gate Report. The additional material relates to GHD's ongoing investigation of possible solutions to the observed 'rising behaviour' of the gates (discussed below). At the time of writing no permanent solution to this behaviour has developed by GHD.

In the absence of such information I set out below an update of my progress and outline my preliminary findings based on the material made available to me. In accordance with the brief, my findings will be developed in a detailed report to be provided separately.

Once further information becomes available from GHD on any proposed solution, I will undertake a further review and provide my concluded opinions. As you are aware, I am overseas from 12 November 2011 until Christmas.

2. **The Crest Gate Report**

The Crest Gate Report discussed the forces acting on gates at Lenthall Dam. The discussion considers the forces due to: gate weight, buoyancy effects, hydrostatic water forces (including vertical and horizontal) and frictional forces (including lintel seal, side seal and trunnions).

The Crest Gate Report stated that hydrodynamic forces had not been considered due to difficulties in quantification. The Crest Gate Report also stated that when the gates are open (fully down) the flow over the gates will create uplift forces which are difficult to calculate without model studies.

The Crest Gate Report included a spreadsheet of gate weights in Appendix B of the Crest Gate Report and Force/Moment calculations in Appendix C of the Crest Gate Report. The Crest Gate Report provided a useful basis for considering the forces acting on the gates before and after the lintel seal modification, plus the effects of storage level on gate opening. The Crest Gate Report also considered the forces involved in raising the gates and concluded that the 'apparent floating behaviour' of the gates could not be overcome through an increase in gate weight.

On the basis of my review of the calculation of forces presented by GHD, I agree with this conclusion.

3. Site Tests

I undertook a site visit to Lenthall Dam on 16 September 2011. During the site inspection I observed test releases from Gate 1 by the manual operation of the air inlet valve by WBW operations staff. The sequence and timing of the manual operation and response of the gate was observed. Of note, during the test release, Gate 1 was observed to fully open, and then rise to stabilise about 550mm above the fully lowered position. Following closure of the air inlet valve the gate closed over a period of about 30 minutes.

4. Preliminary Findings

From my review of the materials and the site inspection my preliminary findings are set out below. My calculations, assumptions and any qualifications will be set out in the detailed report to follow separately.

(a) Seal modifications

The seal modifications undertaken by GHD in late 2008 / early 2009 have been effective in dramatically reducing the high lintel seal frictional forces and the forces are now in keeping with that expected for such an application. However it is evident from the force balance calculations that the lintel seal, whilst not stopping the opening of the gates, could still be a significant contributor to initial opening forces.

There is uncertainty with regards the actual friction coefficient to be used: it could vary between 0.8 and 1.3 (or more). It is suggested that the effect of lintel seal friction should be reviewed in any final force analysis when options for overcoming uplift forces are considered, following the CFD analysis. The effect of side seal friction is not significant.

(b) The air venting system

The most notable of the observations made by GHD as set out in the Crest Gate Report include:

- Following clearing of the air intake system with compressed air, all gates operate as intended during manual testing;
- Following flood events, when the gates have remained lowered for significant periods of time, the gates rise as expected but then do not lower subsequently, either in flood conditions or under manual operation; and

- When the gates do not operate, either in flood or under manual operation, bubbles are observed to emerge from the rear of the gates.

The venting of the buoyancy tanks is critical to the satisfactory operation of the gates.

The temporary 'snorkel' solution trialled recently by WBW with 15mm orifices has proven to be successful, and it is considered that a similar arrangement could be adopted as a permanent installation.

The permanent solution proposed by GHD in the Crest Gate Report has some significant practical constraints. GHD had proposed the modification of the existing tank vent system by installing a T piece and connecting pipework in the base of the U-bend in the trunnion. This proposal would be cumbersome to implement and fraught with difficulty considering the diver installation requirements and reported poor visibility.

(c) Performance of the gate following venting modifications

It was noted at the site test that the gates stabilised at a position about 500mm above the sill. It was also noted in the Crest Gate Report that the gates rise during flood events.

This opening behaviour of the gates indicates that hydrodynamic forces are influencing the opening position. That is, the gates fully open and then rise and appear to 'hover' about a position before reaching an equilibrium position.

GHD has been continuing its investigation of this behaviour, and has developed a Computational Fluid Dynamic (CFD) model to estimate the hydrodynamic loads on the gates. The initial CFD Model predicted a stabilised position for the gates under FSL flows of 400mm, close to the observed 500mm.

The CFD Model has been used to calculate the effect of various sized spoilers fitted to the downstream edge of the gates, with a view to assessing whether the installation of a spoiler would provide sufficient downward force on the gates.

GHD's most recent analysis of larger spoilers indicates at higher flow velocities due to increased head over the gates, the negative lift characteristics are quickly swamped.

This accords with my view that the spoiler concept may not provide a suitable solution because:

- At high flood flows the spoiler's effectiveness will probably be drowned out, unless a large spoiler is used;
- The spoiler may vibrate at certain flows, this can be of concern if it matches resonant frequency of components or could lead to fatigue failure. It may be possible to design out the vibration;
- The spoilers will reduce the discharge coefficient of the gates - depending on the size of the spoiler, this may or may not be a concern; and
- There is a risk that introducing flow devices such as spoilers may introduce other forces that lead to instability of the gates. Instability can be sometimes dampened by frictional forces but in this case the friction at partially opened positions is only due to side seal and trunnion bearing and the values appear to be low. There is a

conundrum here because we do not want increase friction to solve one problem but create another.

Therefore, there is a possibility that the use of a spoiler may not solve the uplift problem.

5. Suggested further investigations

While GHD are continuing to explore possible hydrodynamic solutions to the operational performance issues, it is highly likely that if a hydrodynamic solution is not found then some mechanical device will be required. The reliability of such devices will have to be closely considered.

Regards

[redacted]

Glen Hobbs

Memorandum

03 October 2011

To	Wide Bay Water, Peter Care		
Copy to			
From	[redacted]	Tel	(07)[redacted]
Subject	Update on Lenthalls Crest Gates modelling	Job no.	41/19335/04

Peter,

This memorandum is a summary of progress of our desktop modelling of the crest gates at Lenthalls Dam.

The installation of snorkels on top of the gates has enabled direct measurement of the position of the gates, a parameter which has not been available to date. This shows that the gates sit at the levels above the crest listed in Table 1, instead of dropping fully:

Table 1 Measured position of gates

Gate	Stable level above crest, reservoir at FSL (mm)
1	550
2	800
3	300
4	500

GHD's initial calculations to review the gate performance were based on static water forces. A much more complex CFD model is required to determine the dynamic load of the water flow over the gates to investigate the measured behaviour.

Within the last few days we have reached the stage where we can combine the results of the CFD (Computational Fluid Dynamics) modelling with the force balance work we have previously performed to obtain a desktop verification of the behaviour of the crest gates. We now have a calibrated analysis system which is giving the same answer as the observed behaviour for the 15m gates, namely that the equilibrium position for these gates when operating at FSL is approximately 550mm above the spillway crest level.

Our next steps will be to investigate various solutions, like flow spoilers, to determine which method effectively and safely prevents the undesirable floating behaviour.

Some figures are provided below for your information.

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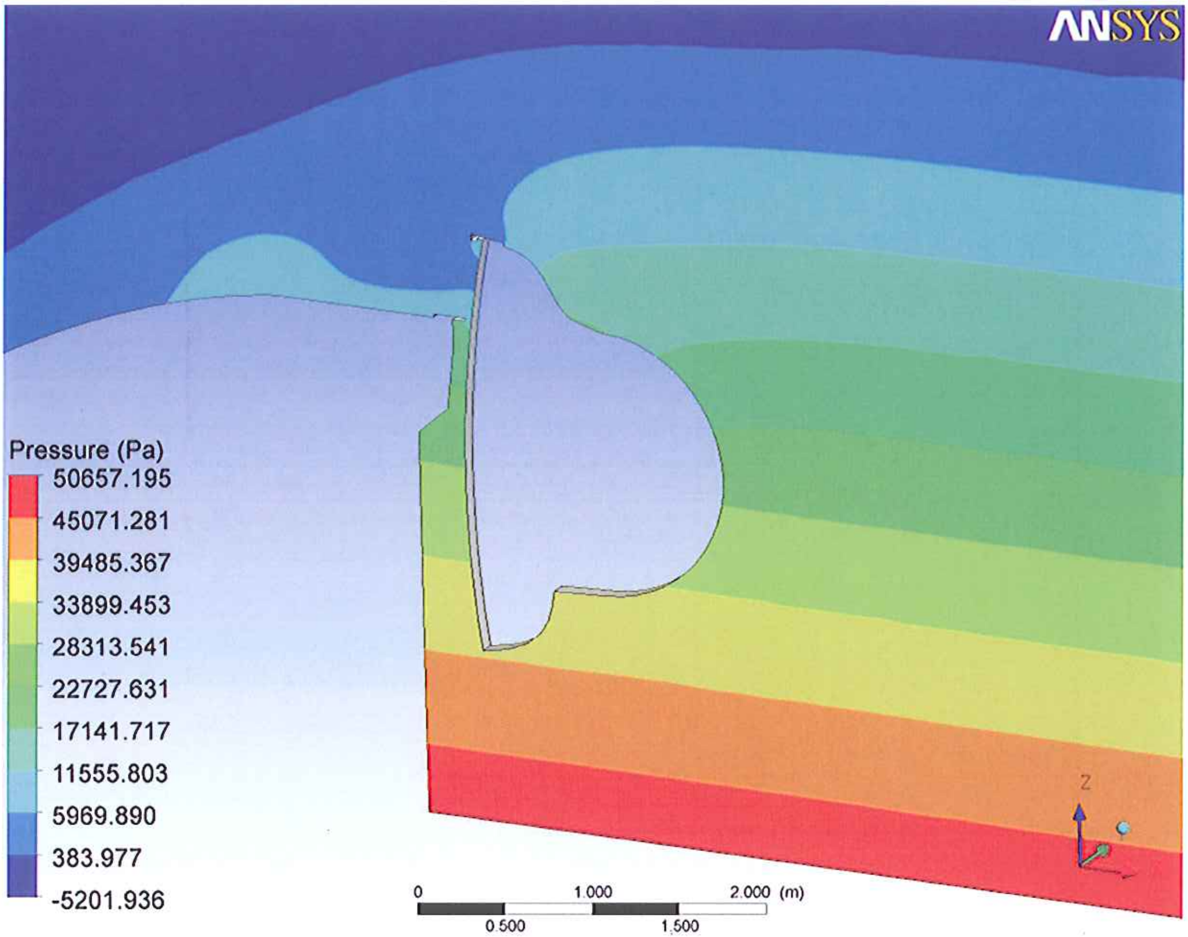

Figure 1: Gate 550 above crest, pressure distribution

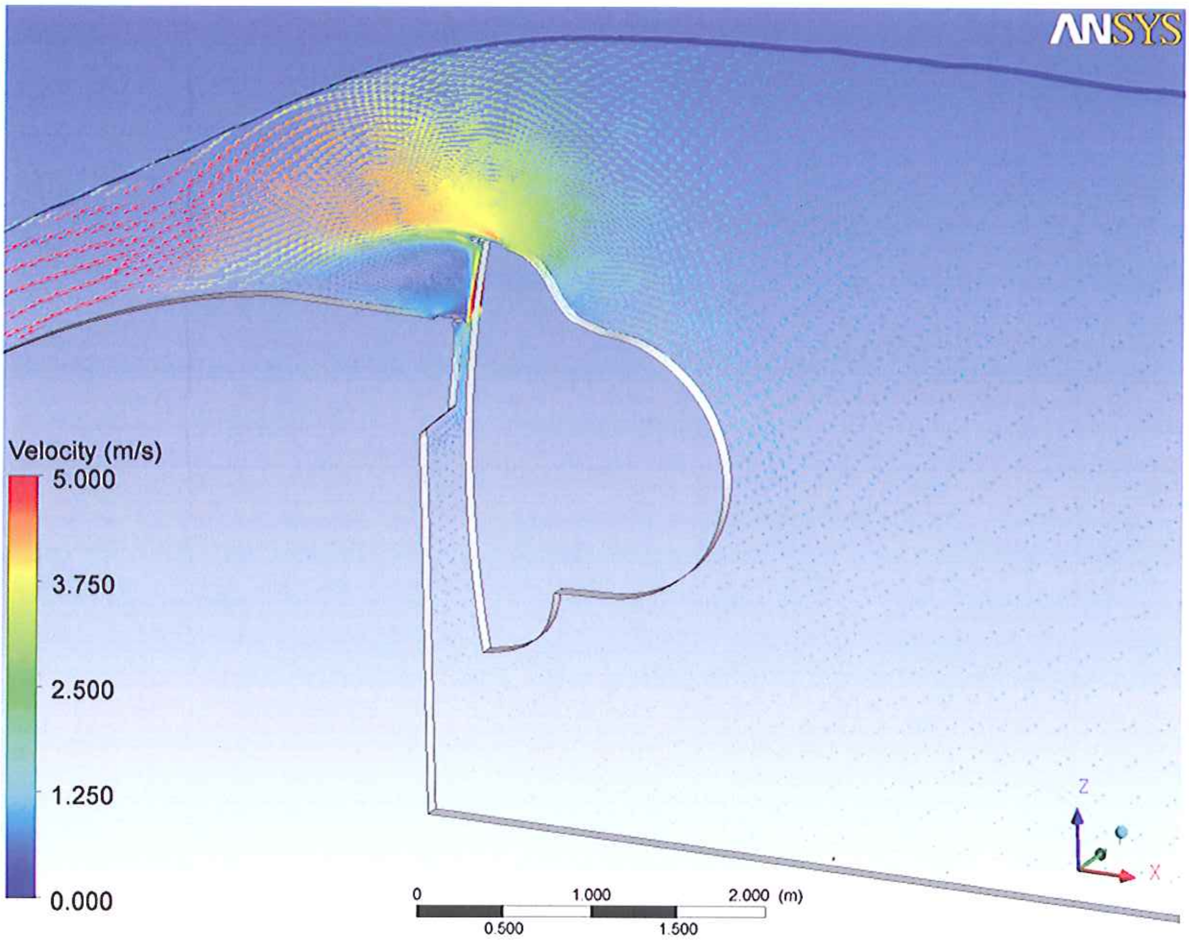

Figure 2: Gate 550 above crest, flow vectors

Regards

Amanda Ament
Senior Structural Engineer - Dams

Lenthalls Dam

REVIEW OF HYDROLOGICAL MODELLING

- Draft A
- 17 November 2011

Lenthalls Dam

REVIEW OF HYDROLOGICAL MODELLING

- Draft A
- 17 November 2011

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1. Introduction

1. This report has been prepared in response to a Brief from Allens Arthur Robinson to review the hydrologic model prepared by GHD in relation to the December 2010 flood event at Lenthalls Dam.

2. Specifically, the Brief required a response to the following issues:

   a) *"the accuracy of the hydrologic modelling undertaken by GHD, including the exceedance probabilities, of the December 2010 flood event set out in Lenthalls Dam Flooding: December 2010 Event (August 2011) report;*

   b) *The accuracy of GHD's analysis of the December 2010 flood event as set out in the August 2011 report, including the inferences regarding gate performance during the flood event;*

   c) *The impact of partial gate opening on the probability of overtopping of the dam and the consequence increase in the risk of dam failure; and*

   d) *The suitability of the existing hydrometric network for providing information on inflows during a flood event, in order to facilitate decision making regarding the operation of the gates during flood events."*

3. A summary of the qualifications and experience of the author of this report is provided in Section 8.

2. Data

4. The following references were used in preparation of this review:

- GHD (2004) Lenthalls Dam Probable Maximum Flood Review. Report for Wide Bay Water. October 2004. (Provided as Appendix B of 2006 Design Report).
- GHD (2006) Lenthalls Dam Raising Design Report for Wide Bay Water. May 2006
- GHD (2009) Lenthalls Dam Flooding Draft Report for Wide Bay Water. February 2009.
- GHD (2011) Lenthalls Dam Flooding Draft Report for Wide Bay Water. August 2011
- Macready and Associates (2010) Lenthalls dam 2010 Annual Dam Safety Inspection Report. Rev1 November 2010

In addition to these reports the following data and information was also utilised:

- Observations during site inspection of Lenthalls Dam on 16 September
- WBW video of a trial on Gate 5 undertaken in November 2010 provided by Peter Care
- GHD RORB catchment and calibration files provided by WBW on 9 September 2011
- GHD spreadsheet used to derive Figure 4-20 in the GHD August 2011 report including recorded water levels at Lenthalls Dam and Howards Alert and rating curve for Howards Alert river gauge
- Recorded rainfall data for the December 2010 event from the Bureau of Meteorology website

3. Hydrologic Modelling of December 2010 Event

5. This section covers the review of modelling undertaken by GHD of the December 2010 flood event as described in their August 2011 draft report. The focus of this review is on the estimated exceedance probability of the flood and the inferences regarding the gate performance during the flood event.

6. The calibration of a hydrologic model for Lenthalls Dam is confounded by lack of reliable hydrologic data. Specifically:

   - there are only two rainfall gauges available in the catchment, namely Musket Flat (040902) and Lenthalls Dam Alert (040906);
   - the catchment of the dam consists of 5 main tributaries and none of them are gauged;
   - the reservoir level is recorded however this cannot be reliably used to estimate outflow because of uncertainty regarding the opening of the gates during an event (e.g. for the December 2010 event Gate 5 did not open at all and it is suspected that the remaining gates were only partially open through the event as discussed below in points 19 and 20); and,
   - the levels recorded at Howard Alert reporting gauge located at Burrum No 1 Weir can be used to estimate flow however there is an additional approximately 100 km^2 catchment area downstream of Lenthalls Dam that is ungauged.

7. The general approach adopted by GHD is consistent with that outlined in the national flood guideline - Australian Rainfall and Runoff (ARR) published by Engineers Australia (Engineers Australia, 1999).

8. The GHD study utilised the RORB rainfall-runoff routing model which is widely used in Australia for such studies and is suitable for modelling flood events such as December 2010 and deriving design floods of desired annual exceedance probabilities (AEPs).

9. The RORB model configuration was based upon earlier studies by DNR (2000) and GHD (2002) as referenced in GHD (2004). The 2000 and 2002 reports were not included in this review but the catchment model appears to be suitably configured.

10. RORB has two parameters which control the routing characteristics; m which represents the model non-linearity and k_c which represents the overland and channel routing. An m value of 0.8 was adopted which is consistent with the recommendations in ARR and the value of k_c of 30 is within the expected range of values. Routing characteristics are considered to be a property of the catchment and therefore the values of m and k_c should be reasonably consistent between events.

11. Infiltration and interception (ie the rainfall that does not become surface runoff) is incorporated through the application of loss parameters and GHD adopted an initial loss – continuing loss model. This is the most commonly adopted loss model and is appropriate for this catchment. For the February 2009 flood an initial loss of 8 mm and a continuing loss of 2 mm/hr were adopted and these values are considered reasonable. As distinct from the routing parameters, the loss values (particularly the initial loss) is sensitive the antecedent moisture conditions and therefore the values of loss are expected to vary between events based upon the preceding rainfall.

12. GHD (2011) developed spillway rating curves (which relate the reservoir level to flow through the spillway) for all gates fully open, 4 gates fully open with 1 gate closed, and all gates closed. The calculations were not reviewed but the approach and resulting rating curves look reasonable.

13. Since the August 2011 GHD report, it has been noted that the gates partially close under flow. Because the flow is passing over the top of the crest gates it is difficult to ascertain the exact gate opening, but based upon observations on 16 September and subsequent estimates by WBW (GHD memo of 3 October 2011), it is estimated that the gates close to an opening of approximately 1.45 m (ie 550 mm above spillway crest). Thus, as part of this review spillway rating curves were derived for 4 or 5 gates opened to different amounts. The rating curves were derived using the approach outlined in GHD (2006) and the resulting rating curves are consistent with those derived by GHD. These rating curves were subsequently used to explore potential gate opening scenarios during the December 2010 event (refer points 19 and 20).

14. GHD (2011) also analysed the level data recorded downstream at Howard Alert (040907) which is located at Burrum No 1 Weir. This site has the advantage that once the rating curve has been established there is a consistent relationship between water level and flow because of the fixed crest. This data provides some additional insights into the Lenthalls Dam outflows, however any such inferences need to consider the approximately 100 km^2 of additional catchment area between the dam and Burrum No. 1.

15. A rating curve for Burrum No. 1 was developed by GHD in 1993 and is presented in Figure 4-16 of GHD (2011). The calculation of the rating curve was not reviewed but the relationship is consistent with empirical formula up to the point at which the weir drowns out (ie to the point where the flow is affected by the water level downstream of the dam); this is considered a reliable basis for estimating the flow, however there does appear to be an inconsistency in the datum used to estimate flows as discussed in point 16.

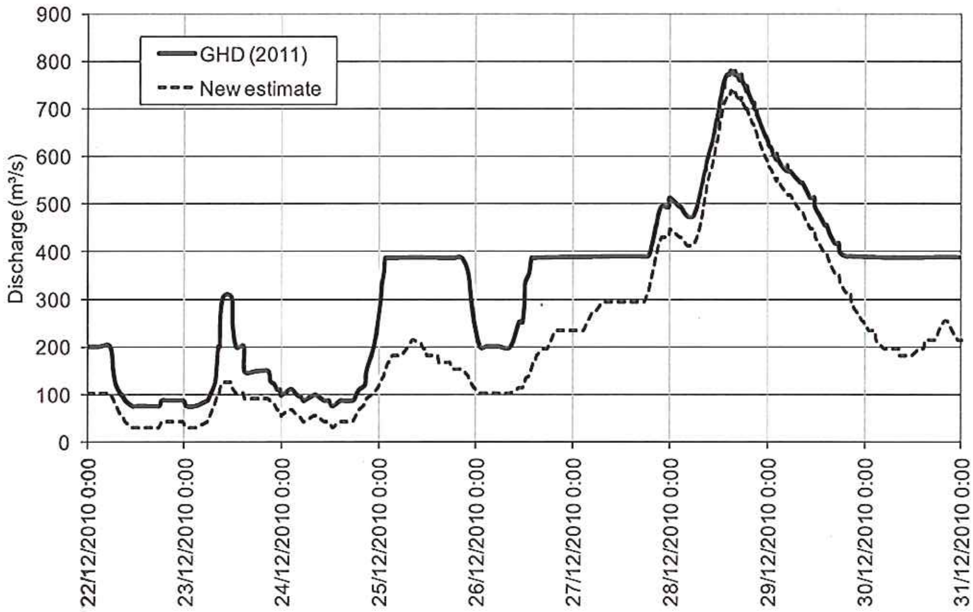
16. GHD (2011) used the derived rating curve with the recorded levels to estimate the flow during the December 2010 event. In Figure 4-20 of GHD (2011) the resulting flows are compared to

outflow from Lenthalls Dam for different assumptions regarding gate openings. This analysis was used by GHD to support their conclusion that the gates were likely to have shut closed during the peak of the storm event. The conclusion that the gates did malfunction during the event is supported (refer points 19 and 20), however there are a couple of inconsistencies that confound interpretation of the flows:

- *Datum* - It appears that there is a discrepancy in the datum used to estimate flows in the GHD (2011) study. The levels shown in the rating curve for Howard Alert in Figure 4-16 are expressed as m RL and flow commences at an elevation of 4.685m. The recorded water levels provided by the Bureau of Meteorology relate to Australian Height Datum (AHD) and they give the elevation of the weir as 4.87 mAHD. Thus, 0.185 m need to be subtracted from the recorded flows before applying the rating curve derived by GHD and therefore it is likely that the GHD (2011) report overestimates the flow. Once the change of datum is incorporated there is a reduction in the estimated volume of the flood (refer Figure 1).
- *Rating curve* - it is evident in Figure 4-20 of the GHD (2011) report that there are periods of constant flow of approximately 400 m^3/s during 25, 26 and 30 December and the GHD report attributes this to regulation of flow from the operation of the Lenthalls Dam spillway gates. The spreadsheet used to derive the flows in Figure 4-20 was obtained from GHD and an error was noted in how the values from the rating table were interpolated. The corrected flows are shown in Figure 1 and it can be seen that the periods of constant flow have been replaced with a more realistic shaped hydrograph.

17. It is evident from Figure 4-20 of the GHD (2011) report that the volume of the Lenthalls Dam inflow and outflows estimated by GHD are significantly less than the volume of the flow estimated at Howards Alert using gauged water level data. For the period from 22 to 31 December 2010 the volume of the inflow and outflow estimated by GHD is approximately half the volume of flow estimated at Howard Alert. This indicates that the inflows and outflow for the December 2010 event estimated by GHD (2011) are potentially too low.

18. In order to derive an inflow and outflow from Lenthalls Dam which has a volume consistent with the recorded flow at Howards Alert, the GHD (2011) RORB model of the December 2010 event was re-run with lower losses (ie an initial loss of 0 mm and a continuing loss of 0.5 mm/h) which are consistent with the wet conditions leading up to the December 2010 event. The resulting inflow hydrograph at Lenthalls Dam is shown in Figure 3. Although there remains uncertainty in the estimated hydrographs the estimated inflow has a volume that is more consistent with the flow recorded downstream at Howards Alert (after allowances for the additional catchment area and the contribution of baseflow).



- **Figure 1 Comparison of flows derived using the recorded levels from the Howards Alert gauge during the December 2010 event**

19. There is considerable uncertainty regarding the gate openings during the December 2010 event. A simple routing model was therefore developed which estimated outflows for different gate openings. Rating curves were derived for Gate 5 closed and the remaining 4 gates either closed or opened 0.5m, 1.0m, 1.55m or 2.0m. To illustrate one potential gate opening scenario it was assumed that all 4 gates operated in a consistent manner (ie they opened and closed at the same rate). The gate openings were then adjusted until the modelled reservoir levels were consistent with the recorded levels. The resulting peak water levels and inferred gate openings for the 4 gates are shown in Figure 2 and the estimated outflows are shown in Figure 3. This analysis suggests that 4 of the gates were likely to be open 1.45 m (ie 550 mm from fully open) for the first few days of the event but as the reservoir level increased the 4 gates closed and were fully closed for large periods of 28 and 29 December.

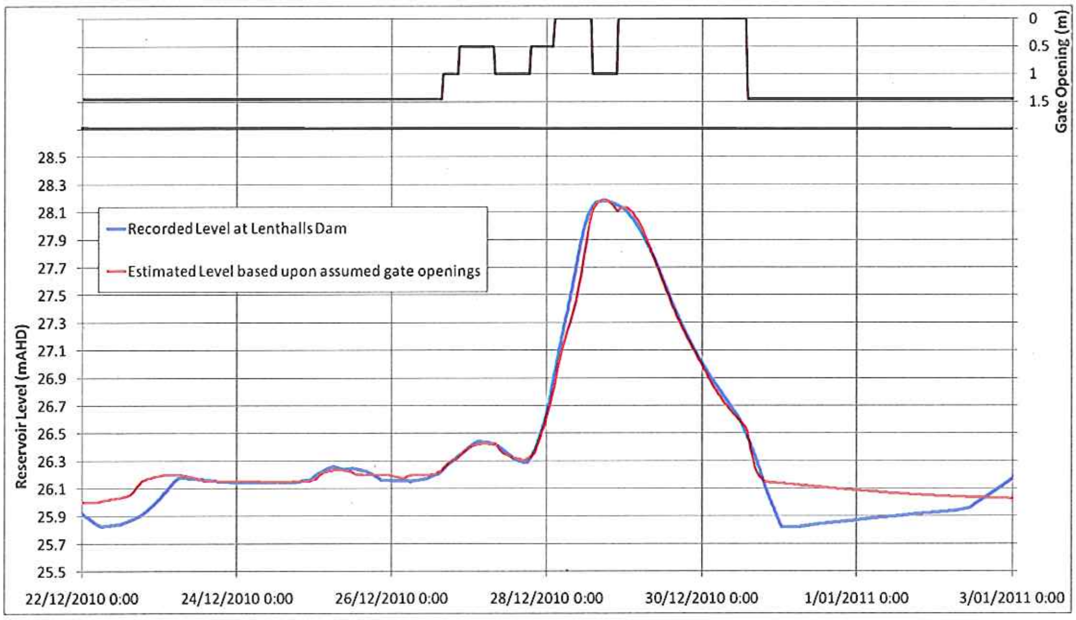


Figure 2 Recorded and modelled Lenthalls reservoir levels during the December 2010 event showing inferred approximate gate openings for 4 gates (Gate 5 remained closed throughout the event)

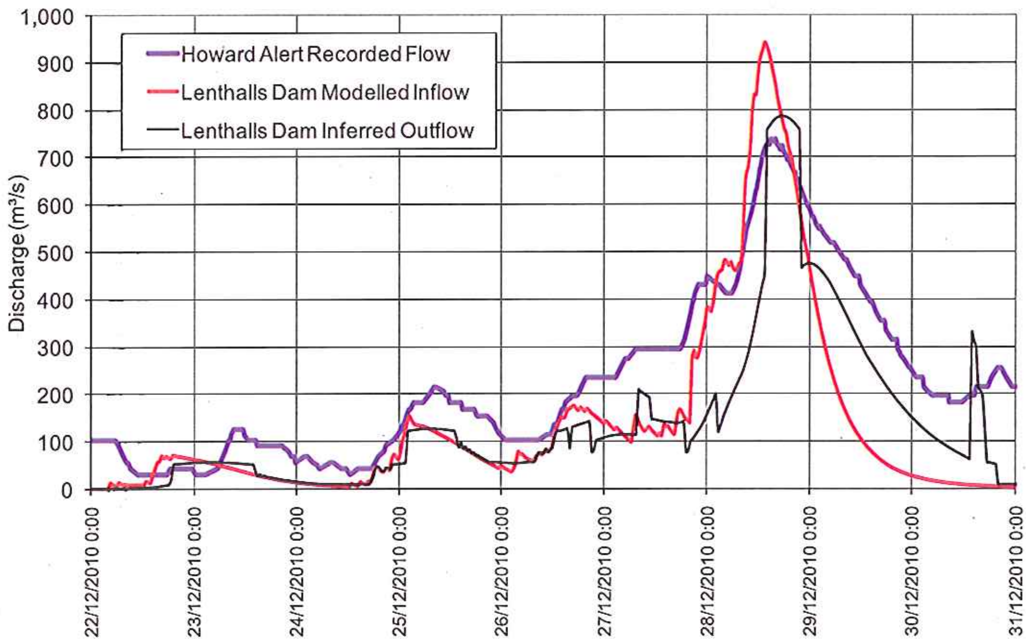


Figure 3 Comparison of modelled inflows and inferred outflows from Lenthalls Dam and estimated flows at Howards Alert for December 2010 event

20. The analysis outlined above is somewhat speculative as the exact gate openings throughout the event are unknown and similar reservoir levels could be achieved using slightly different combinations of loss values and gate openings, however there is sufficient evidence to conclude that the gates did not remain fully open throughout the event. The analysis produces results which are consistent with the recorded peak water levels at both Lenthalls Dam and Burrum No 1, recorded rainfall and WBW observations regarding the gate openings and partial closure of the gates under flow. It supports the GHD (2011) conclusion that Gate 5 did not open and the remaining 4 gates did not remain fully open throughout the December 2010 flood event.

21. From the above analysis it is estimated that the peak inflow to Lenthalls Dam was approximately 930 m^3/s (compared to the GHD estimate of approximately 700 m^3/s). Based upon the inflow flood frequency derived in GHD (2009), an inflow of 930 m^3/s would be assigned an AEP of approximately 1 in 5. This is slightly rarer than estimated by GHD (2011) but supports their main conclusions that the 2011 flood was significantly smaller than a 1 in 50 AEP flood.

4. Implications for overtopping of the dam

22. The spillway has been designed to safely pass the PMP Design Flood (GHD, 2006) which is consistent with the requirements of the deterministic fallback provision in the ANCOLD guidelines on Acceptable Flood Capacity (ANCOLD, 2000). For Lenthalls Dam the AEP of the PMP Design Flood is estimated to be 1 in 2,000,000. To achieve this capacity all gates are required to operate and remain fully open during the flood.

23. It has been noted that the gates partially close under flow and therefore modelling was undertaken to determine the sensitivity of the spillway capacity to the gate openings. The GHD RORB model with the design inputs from GHD (2006) was rerun with the different spillway ratings which represent different gate openings. The resulting spillway capacities and AEP of the Dam Crest Flood (DCF; reflects the annual probability that the reservoir level exceeds the crest of the main embankment) are shown in Table 1.

Table 1 Sensitivity of the probability of overtopping to gate openings

Scenario	Spillway Capacity (m^3/s)	% of AFC	AEP of DCF	Source
All gates closed	3,300	58%	1 in 70,000	Interpolated from Table 6 of GHD (2006)
5 gates open 0.5 m	4,000	70%	1 in 370,000	Application of GHD RORB model
5 gates open 1.0 m	4,300	75%	1 in 560,000	Application of GHD RORB model
5 gates open 1.45 m	4,600	81%	1 in 830,000	Application of GHD RORB model
5 gates fully open	5,700	100%	1 in 2,000,000	Table 6 of GHD (2006)

24. The results in Table 1 above clearly show that the capacity of the spillway to safely pass extreme floods is compromised if the gates partially close during a flood. The nominal design capacity of 1 in 2,000,000 is reduced to 1 in 560,000 if the gates are half closed and this reduces further to an AEP of 1 in 70,000 if all gates are closed. This reinforces the importance of ensuring that all gates operate and remain fully open during flood events.

5. Adequacy of existing hydrometric network

25. As noted in point 6, there are only two rainfall gauges available in the catchment; Musket Flat (040902) and Lenthalls Dam Alert (040906) and there are no streamflow gauges upstream of the dam. The sparse network of rain gauges means that there is considerable uncertainty in the spatial distribution of rainfall for a particular event. This not only affects the ability to understand the severity of an event in real time but also hinders the application of a rainfall-runoff model to analyse past events (e.g. to explore gate openings during the December 2010 event).

26. There is no applicable Australian standard on the number of rainfall gauges required to provide adequate coverage of a catchment. However information on the number of operational rainfall gauges for some other catchments from around Australia with gated spillways was collated from the Water Resources Station Catalogue maintained by the Bureau of Meteorology. The catalogue was last updated in February 2007 and thus provides a useful, if not wholly accurate, basis for comparison.

27. The number of operational gauges in the catchment is summarised in the third column of the table below, where the density of the network (expressed as the average catchment area per individual gauge) is shown in the fourth column. This table demonstrates that the density of gauges in the Lenthalls Dam catchment is less than that for the other catchments.

28. Increasing the number of rain gauges in the catchment would also allow greater redundancy in case of equipment or telemetry failure during an event and hence provide a more robust network.

Table 2 Comparison of rainfall gauge densities for some other Australian catchments with gated dams

Catchment	Area (km^2)	No. of gauges	Network density km^2 / gauge
Upper Brisbane River	5678	27	210
Stanley River	1312	8	164
Ross River	1347	22	61
Onkaparinga	931	9	103
Lenthalls Dam	512	2	256

29. Similarly, installation of a streamflow gauge on a tributary upstream of the dam would also assist both real-time operation and the subsequent modelling of historic flood events. This would reduce the uncertainty in the calibration of rainfall-runoff models and may lead to the adoption of different model parameters which would change the estimated flood risk.

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6. Conclusions

The following conclusions are structured around the 4 issues identified in the Brief:

the accuracy of the hydrologic modelling undertaken by GHD, including the exceedance probabilities, of the December 2010 flood event set out in Lenthalls Dam Flooding: December 2010 Event (August 2011) report

30. The general approach adopted by GHD (2011) is consistent with that outlined in the national flood guideline - Australian Rainfall and Runoff (Engineers Australia, 1999). The study used RORB which is a suitable model and the configuration appears appropriate.

31. The analysis of the December 2010 event is confounded by the lack of recorded streamflow upstream of the dam and no information on the gate openings during the peak of the event, which means that there is considerable uncertainty in the estimated inflows and outflows from the dam. It is estimated that the peak inflow was around 930 m^3/s which has an AEP of approximately 1 in 5. This supports the GHD conclusion that the 2011 flood was significantly smaller than a 1 in 50 AEP flood.

The accuracy of GHD's analysis of the December 2010 flood event as set out in the August 2011 report, including the inferences regarding gate performance during the flood event

32. From the analysis of recorded water levels in Lenthalls Dam and downstream at Howard Alert (040907) located at Burrum No 1 Weir, GHD concluded that "*the Lenthalls Dam gates did operate, and opened and closed, during the early stage of the December 2010 event. However, as the water levels in the dam rose, the gates malfunctioned and shut closed. The gates then appeared to work again after passage of the storm peak.*" As part of this review an alternative set of flows at Lenthalls dam were derived, however the outcomes supported the GHD (2011) conclusion that during the December 2011 Gate 5 did not open and the remaining 4 gates did not remain fully open throughout the event.

The impact of partial gate opening on the probability of overtopping of the dam and the consequence increase in the risk of dam failure; and

33. The spillway has been designed to safely pass an extreme flood with an AEP of 1 in 2,000,000 and this capacity is consistent with the prevailing ANCOLD guidelines on acceptable flood capacity. This capacity requires all gates to operate and remain fully open during the flood, however, the capacity of the spillway to safely pass extreme floods is compromised if one or more gates do not operate or the gates partially close. For example if all gates fail to operate the AEP of overtopping the embankment increases to approximately 1 in 70,000. This reinforces the importance of ensuring that all gates operate and remain fully open during flood events.

The suitability of the existing hydrometric network for providing information on inflows during a flood event, in order to facilitate decision making regarding the operation of the gates during flood events."

34. There are only two rainfall gauges and no streamflow gauges available in the catchment upstream of Lenthalls Dam. The sparse network of rain gauges means that there is considerable uncertainty in the spatial distribution of rainfall which affects the ability to understand the magnitude of an event in real time but also hinders the application of a rainfall-runoff model to analyse past events. Although there are no accepted standards on the number of rainfall gauges required to provide adequate coverage of a catchment, the current density of rain gauges is less than some other Australian catchments with gated spillways. Increasing the number of rain gauges in the catchment would also allow greater redundancy in case of equipment or telemetry failure during an event and hence provide an operationally more robust network. Similarly, installation of a streamflow gauge on a tributary upstream of the dam would also assist both real-time operation and the subsequent modelling of historic flood events.

7. Curriculum Vitae

CV

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Peter Hill

[redacted]

Principal
Senior Hydrologist

Qualifications

- Master of Engineering Science (Civil), University of Adelaide 1993
- Bachelor of Engineering, (Civil) (Hons.), University of Adelaide, 1991

Affiliations

- Member, Engineers Australia, CPEng
- Member, Australian Water Association
- Member of International Water Association

Professional Activities

- Committee Member of Engineers Australia's National Committee on Water Engineering
- Committee Member for revision of ANCOLD Guidelines on Assessment of the Consequences of Dam Failure
- Convenor for ANCOLD Acceptable Flood Capacity Guidelines
- Past Chairman, Victorian Water Eng. Branch, Engineers Australia

Fields of Special Competence

- Flood hydrology
- Dam safety risk assessment
- Environmental hydrology

Awards

- Project Manager of the "Spatial Query Tool for Statewide Estimates of Water Use for Key Land Use Types" winner of the 5th Annual Victorian Spatial Excellence Awards 2009 Environment and Sustainability Award
- Co-author of paper which received the Sternbeck Medal for the best paper at the joint NSW and Victorian Flood Management Conference – Albury Wodonga 16 – 20 February 2009
- Project Manager for winning project AWA SA Water Award 2002 in categories of Water, Environment and Society and also Studies, Plans and Investigations and winner SA Australian Planning Institute Award for Environment 2003
- 2001 ACEA Future Leaders Award - Silver Award of Highly Commended
- Best presentation – Water 99 Joint Congress - 25th Hydrology and Water Resources Symposium, Brisbane, July 1999
- Best presentation – Hydrology and Water Resources Symposium, Hobart, 1996
- Best Student or recent graduate surface water paper presentation Water Down Under'94 Adelaide 21-25 November 1994
- AWWA's Inaugural HJN Hodgson Award for excellence on water related studies by undergraduate students, December 1991

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Relevant experience

SINCLAIR KNIGHT MERZ, Australia

October 1996 to current

Dam Safety Risk Assessment

- Review of G-MW flood operations (Vic.)
- Review of 2010-2011 Flood Warnings and Response (Comrie Review) - Review into the operation of storages during flooding (Vic.)
- Hydrology, dambreak modelling and consequence estimation for Upper Yarra dam (Vic.)
- Review of filling curves for Eppalock and Eildon dams (Vic.)
- Peer review panel for Malmsbury dam safety upgrade (Vic.)
- Flood hydrology and dambreak study of Sturt Creek Flood Control Dam (SA)
- Assessment of target filling curves for Eppalock and Eildon dams (Vic.)
- Hydraulic modelling ofe the lower Brisbane River to assess operating scenarios for the January 2011 flood to assist Seqwater respond to the Commission of Inquiry (Qld)
- Development of an extreme flood operations manual for Hume Dam (NSW)
- Development of a guidance note on assessing ALARP for dam safety risk applications (Vic.)
- Peer review of SEQ Water's submission to the Commission of Enquiry into the January 2011 floods (Qld)
- Flood hydrology, dambreak modelling and consequence assessment – including benchmarking different methods of estimating loss of life for Buffalo and Newlyn dams (Vic.)
- Review of consequences and hazard assessment for Aireys Inlet WWTP lagoons (Vic.)
- Flood hydrology study for Mt Bold Dam (SA)
- Peer review of flood hydrology study for Chichester Dam (NSW)
- Modelling of surcharge options for Eildon Dam (Vic.)
- Flood hydrology study for Beetaloo Dam (SA)
- Application of CRC-FORGE method for deriving design rainfalls (NSW)
- Assessment of potential impact of climate change on spillway adequacy for Dartmouth Dam (Vic.)
- Flood hydrology study for Myponga Dam (SA)
- Peer Review of Wyaralong Flood Hydrology Study (Qld)
- Construction flood risk assessment for William Hovell Dam (Vic.)
- Comparative analysis of dam safety regulation frameworks (Vic.)
- Detailed hydrology, dambreak modelling and consequence assessment for Scrivener Dam (Lake Burley Griffin) (ACT)
- Hume Dam hydrology assurance review (NSW)
- Peer review of Blue Rock hydrology (Vic.)
- Hydrology and construction flood risk for Toorourrong Dam (Vic)
- Hydrology and construction flood risk for Tarrago Dam (Vic)
- Detailed hydrology, dambreak modelling and consequence assessment for McKay Dam (Vic.)
- Peer review of dambreak modelling and consequence assessment for Tillegra Dam (NSW)
- Detailed hydrology study for Middle River Dam (SA).
- Seasonal construction flood risk for Blowering Dam (NSW)

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- Seasonal construction flood risk for Laanecoorie Dam (Vic)
- Dambreak modelling and consequence assessment for Upper Coliban, Lauriston and Malmsbury Dams (Vic).
- Detailed hydrology study for Bundaleer, Barossa and Warren Dams (SA).
- Development of guidelines and state-wide database for statement of obligations reporting on dam safety risks (Vic.)
- Modelling flood operation of Eildon spillway gates for different surcharge conditions (Vic.)
- Extreme flood hydrology for Googong Dam (ACT)
- Detailed flood hydrology for upgrade of Hinze Dam (Qld.)
- Extreme flood hydrology for Corrin, Cotter and Bendora Dams including joint probability initial reservoir level in cascade of correlated storages (ACT)
- Extreme flood hydrology for Tallowa Dam (NSW)
- Hydraulic modelling of Keepit Reservoir to determine velocities upstream of proposed auxiliary spillways (NSW)
- Review of ANCOLD Hazard Category for 6 dams for Wannon Water (Vic.)
- Dambreak modelling and risk assessment for Sunday Creek Reservoir (Vic.)
- Peer review of Meander Dam Hydrology Study (Tas.)
- Detailed review of hydrology for Upper Coliban, Malmsbury and Lauriston Reservoirs including accounting for correlated initial drawdowns and gate failure scenarios (Vic.)
- Preliminary risk investigation for Montpellier No.2 Dam (Vic.)
- Assessment of conceptual upgrade options for Painkalac Dam (Vic.)
- Review of statement of obligations from water authorities for Department of Sustainability and Environment (Vic.)
- Estimation of construction flood risks for Ross River (Qld).
- Review of flood surcharge levels for Eildon Dam (Vic.)
- Application of Risk Analysis Prioritisation Tool to Central Highland Water's portfolio of dams (Vic.)
- Estimation of potential loss of life and economic consequences for Millbrook and Kangaroo Creek Dams (SA)
- Assessing issues relating to gate operation and reservoir surcharge for Goulburn-Murray Water (Vic.)
- Application of Risk Analysis Prioritisation Tool to Coliban Water's portfolio of dams (Vic.)
- Detailed review of hydrology and estimation of Probable Maximum Flood for Kangaroo Creek Dam (SA)
- Review of hydrology and dambreak modelling for Laanecoorie Dam (Vic.)
- Review of hydrology and dambreak modelling for William Hovell Dam (Vic.)
- Development of Portfolio Risk Analysis Tool for Barwon Water (Vic.)
- Hydraulic modelling and inundation mapping upstream and downstream of Cairn Curran Dam for spillway upgrade options (Vic.)
- Provision of hydrologic inputs to upgrade of Eildon Dam (Vic.)
- Specialist hydrology input to Ross River Dam Stages 2 to 5 Upgrade Study (Qld.)
- Tender evaluation panel member for Ross River Dam Stages 2 to 5 Upgrade Study (Qld.)
- Assessment of downstream impact of Dartmouth Regulation Pond for Southern Hydro (Vic.)
- Review of hydrology and estimation of Probable Maximum Flood for Little Para Dam (SA)
- Review of Barwon Water Business Risk Analysis in light of ANCOLD Risk Guidelines (Vic.)

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- Review of hydrology and estimation of Probable Maximum Flood for Nillahcootie Dam (Vic.)
- Detailed review of hydrology for Cairn Curran Dam (Vic.)
- Hazard assessment and assessment of acceptable flood capacity for Dartmouth Slimes Dam (Vic.)
- Modelling cascade failure of Talbingo, Jounama and Blowering Dams (NSW)
- Detailed review of hydrology for Millbrook Dam (SA)
- Hydraulic modelling and inundation mapping to assess the downstream impacts of final upgrade options for Keepit Dam for State Water (NSW).
- Estimation of the flood risk at Cairn Curran Dam during upgrade of filters. (Vic.)
- Review of hydrology and dambreak modelling for Tullaroop Dam (Vic.)
- Detailed review of hydrology for Dartmouth Dam (Vic.)
- Review of hydrology using a Monte-Carlo flood estimation approach, event tree modelling and risk analyses for the Ross River Upgrade Project (Qld.)
- Review of hydrology of Dartmouth Slimes Dam (Vic.)
- Hydraulic modelling and inundation mapping to assess the downstream impacts of interim upgrade options for Keepit Dam for State Water (NSW).
- Review of spillway adequacy, dambreak modelling and consequence assessment for Moondara and Pine Gully Dams for Gippsland Water (Vic.)
- Review of hydrology and first order risk analysis for Millbrook Dam for SA Water (SA).
- Developed upgrade options to provide additional flood capacity for Cairn Curran Dam for Goulburn Murray Water (Vic.)
- Detailed risk investigations for 10 dams for Central Highland Water (Vic.)(refer Civil Engineers Australia, April 2001)
- Assessment of consequence of failure for Blowering, Split Rock, Keepit and Burrinjuck dams including damage to infrastructure, agriculture, potential loss of life and qualitative assessment of damage to the environment. (NSW)
- Application of the CRC-FORGE method of estimating extreme design rainfalls to South-Australia (SA)
- Review of hydrology and dambreak modelling of all 17 of SA Water Corporations large dams as part of a portfolio risk assessment (SA)
- Event tree modelling and risk analysis as part of the portfolio risk analysis for South-East Queensland Water Board (Qld.)
- Review of hydrologic risk, dambreak analyses and preparation of inundation maps for Eppalock, Eildon, Cairn Curran and Nillahcootie dams (Vic.)
- Expert input on event tree modelling for Portfolio Risk Assessment for HEC (Tas.)
- Hydrologic and hydraulic modelling of impact of fuse plug spillway for Keepit Dam on incremental flooding in the Peel River (NSW).
- Dambreak modelling for Blowering Dam including the cascade failure of Talbingo and Jounama dams (NSW)
- Dambreak modelling for Dartmouth Dam as part of the Hume-Dartmouth Risk Analysis (NSW)
- Detailed review of hydrologic risk for Brogo Dam (NSW)
- Hydrologic inputs for Dartmouth and Hume Dam risk analysis. (Vic.)
- Detailed review of hydrologic risk for Rocky Valley Dam incorporating joint probability of inflows and initial reservoir levels and the impact of snowmelt (Vic.)
- Dambreak modelling of Rocky Valley Dam (Vic).
- Portfolio evaluation of hydrologic risk for Goulburn-Murray Water (Vic.)

- Preliminary review of hydrologic risk and dambreak modelling of the dams in the Kiewa Hydro scheme (Vic.)
- Review of spillway adequacy for the Snowy Scheme (NSW)
- Review of hydrology, dambreak modelling and assessment of potential loss of life for Sunday Creek Dam. (Vic.)

Hydrology

- Statewide estimates of Evapotranspiration for 2010/11 Victorian water accounts (Vic.)
- Water balance modelling for assessing the water impacts of land use changes in 14 priority catchments (Vic.)
- Peer review of flood hydrology for Brownhill and Keswick Creeks (SA)
- State-wide assessment of the impact of land use change on streamflow yields for drier climate (Vic.)
- Review of hydrologic impact of softwood plantation in the Oberon catchment (NSW)
- Peer review of Melbourne Water's Flood Risk Assessment Framework (Vic.)
- Australian Rainfall and Runoff Update Project 7 - Baseflow for Catchment Simulation
- Development of flood forecasting tool for the Gippsland Lakes (Vic.)
- Identification of Hydrologic Impact Zones based upon assessment of current hydrologic stress and impact of land use change (Vic.)
- Baseline assessment of intercepting activities across Australia for NWC
- Comparison of evapotranspiration estimates from CAT and Soilflux models for Corrangamite and Gippsland regions (Vic)
- Hydrologic impact of 2006/07 bushfires on streamflow yield (Vic.)
- State-wide assessment of the impact of land use change on streamflow yields involving modelling the evapotranspiration of key vegetations types across Victoria. (Vic.)
- Seasonal forecasting of Victorian streamflow using regionally based climate indices (Vic.)
- Water Resource Assessment for the Murray Darling Basin modelling impact of future climate and landuse on streamflow yield – collaborative project with CSIRO and winner of CSIRO's 2009 Chairman's Award.
- Collation of water resource information for assessing bushfire risk (Vic.)
- Literature review of the impact of logging on in-stream water quality for the Melbourne Water Supply Catchments (Vic.)
- Hydrologic impact of 2003 Alpine bushfires as part of DSE's Bushfire Recovery Project – in conjunction with University of Melbourne and CSIRO (Vic.)
- Modelling impact of low flow bypasses on farm dams for the Onkaparinga River Catchment (SA).
- Land use Planning and Environmental Water Provisions for the Onkaparinga River Catchment (SA)
- Impact of landuse change on water quality and quantity in south-western Victoria and south-eastern South Australia (Vic & SA)
- Determination of the impact of forest management on streamflow yield and water quality for the Otway Ranges (Vic)
- Determination of Environmental Water Requirements for the Onkaparinga Catchment - winner AWA SA Water Award 2002 in categories of Water, Environment and Society and also Studies, Plans and Investigations and winner SA Australian Planning Institute Award for Environment

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2003, Highly commended Engineers Australia's SA Division 2003 Engineering Excellence Awards (SA).

- Salt and Water Balance Study of the Avon-Richardson Catchment (Vic.)
- Preparation of the flood component of the Catchment Plan for the Northern Adelaide and Barossa Catchment Water Management Board (SA)
- Development of a method to assess low flow homogeneity in the Hawkesbury Nepean Catchment (NSW)
- Development of a method to estimate yield for ungauged catchments in Victoria in order to determine the impact of farm dams (Vic)
- Assessment of the impact of forest management on water quality and quantity in 3 regional forest agreement regions (NSW)
- Floodplain management study of the Avon-Richardson Catchment (Vic)
- Analysis of low flow hydrology of the Hawkesbury Nepean River System as part of a study of environmental flows (NSW)
- Environmental Assessment of the Wannon River (Vic)

Cooperative Research Centre for Catchment Hydrology, Monash University
April 1993 to October 1996

Research Assistant and then Project Leader

- managed research project on loss modelling for flood estimation
- published 4 papers and 7 research reports
- reported to reference and review panels
- supervised a team of several research staff including joint supervision of a M.Eng.Sc. (research) student
- presented a number of seminars and organised 2 workshops on yield modelling
- undertook research on loss modelling and real-time flood forecasting

Sample Papers

Vreugdenhil, R., Hill, P.I., Perera, S., Ryan, S. (2011) Towards increased clarity in the application of ALARP. 2011 ANCOLD Conference on Dams.

Lang, S., Meneses, C., Hill, P.I., Sih, K. (2011) Comparing methods for estimating loss of life from dambreak flooding for two Australian dams. 2011 ANCOLD Conference on Dams.

Nathan, R.J., Hill, P.I., Weinmann, P.E. (2011) Achieving consistency in derivation of the Probable Maximum Flood. 2011 ANCOLD Conference on Dams.

Nathan, R.J., Hill, P.I., (2011) Factors Influencing the Estimation of Extreme Floods. 2011 ANCOLD Conference on Dams.

Hill, P.I. (2011) Towards Improved Loss Parameters for Design Flood Estimation in Australia. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Sih, K., Fowler, K., Jordan, P.W., Hill, P.I., Nandakumar, N, Weinmann, E, Nathan, R.J. (2011) Has there been a change in rainfall maxima? – implications for design rainfalls, 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Murphy, R.E., Graszkiewicz, Z, Hill, P.I., Neal, B.P., Nathan, R.J. (2011) Predicting baseflow contributions to design flood events in Australia. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Graszkiewicz, Z, Murphy, R.E, Hill, P.I., Nathan, R.J (2011) Review of techniques for estimating the contribution of baseflow to flood hydrographs. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Kinkela, K., Pearce, L.J., Murphy, R.E., Graszkiewicz, Z, Hill, P.I. (2011) Assessment of Baseflow Seasonality and Application to Design Flood Events in South-West Western Australia. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Jordan, P.W., Sih, K., Hill, P.I., Nandakumar, N, Weinmann, P.E., Nathan, R.J. (2011) Areal Reduction Factors for Estimation of Design Rainfall Intensities for New South Wales and the Australian Capital Territory. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Fowler, K., Hill, P.I., Jordan, P.W., Nathan, R.J., Sih, K. (2010) Application of Available Climate Science to Assess the Impact of Climate Change on Spillway Adequacy. ANCOLD 2010 Conference on Dams. Hobart.

Sih, K., Hill, P.I., Ryan, S., Perera, S. (2010) Regulating Dam Safety: How do we compare? ANCOLD 2010 Conference on Dams. Hobart

Fowler, K., Jordan, P.W., Hill, P.I., Nathan, R.J., Sih, K. (2010) A framework for incorporating available climate Science in Extreme Flood Estimates. Practical Response to Climate Change Conference. Melbourne.

Murphy, R.E., Moran, R., Hill, P.I., Jusuf, K. (2010) Quantifying the post-1997 climate shift in Victoria. Practical Response to Climate Change Conference. Melbourne.

Westra, S., Varley, I., Jordan, P.W., Nathan, R.J., Ladson, A.R., Sharma, A., Hill, P.I. (2010) Addressing climatic non-stationarity in the assessment of flood risk. *Australian Journal of Water Resources*. Institution of Engineers Australia. Vol 14 No 1. pp1-16.

Hill, P.I., Murphy, R.E., Daamen, C., Williams, K., Moran, R., Berg, S. (2009) Statewide estimates of water use for key land use types. *32nd Engineers Australia Hydrology and Water Resources Symposium*. Newcastle 1 – 3 December 2009

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Memo

SINCLAIR KNIGHT MERZ
SKM

To	[redacted]	Date	23 November 2011
From	Peter Hill	Project No	VW06478
Copy	1 pdf		
Subject	**Lenthalls Dam: Likelihood of Overtopping Assuming Gate 5 Fails to Open**		

This memo provides a preliminary analysis of the likelihood of Lenthalls Dam crest overtopping if gate 5 fails to open and the other gates open by differing amounts. The rating curves (relationship between reservoir water level and outflow through the spillway) for each of the scenarios have been derived using the formulation described in GHD (2006). The RORB model and design parameters have also been adopted from GHD (2006). The results are shown in Table 1.

- **Table 1: Comparison of spillway capacity compared to the acceptable flood capacity (AFC) and the annual exceedance probability (AEP) of the dam crest flood (DCF) for different gate opening scenarios for Lenthalls Dam.**

Scenario	Spillway Capacity	% of AFC	AEP of DCF
All gates closed[1]	3300	58%	1 in 70,000
All gates fully open[1]	5700	100%	1 in 2,000,000
All gates open 0.5 m[2]	4000	70%	1 in 370,000
All gates open 1.0 m[2]	4300	75%	1 in 560,000
All gates open 1.45 m[2]	4600	81%	1 in 830,000
Gate 5 closed, others open 0.5 m	4100	72%	1 in 380,000
Gate 5 closed, others open 1.0 m	4300	75%	1 in 530,000
Gate 5 closed, others open 1.45 m	4500	79%	1 in 580,000

[1] Interpolation from Table 6 of GHD (2006) Design Report.
[2] Provided in SKM (2011).

It is evident from these results that the spillway capacity is not sensitive to gate 5 failing to open. This is a function of the method used to derive the spillway rating curves, and in particular the formulation for estimating flow over a gate in the closed position. It is recommended that the spillway rating curves be further investigated using the results of the CFD modelling.

Yours sincerely,

Peter Hill
Principal
Phone: [redacted]
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22 November 2011

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By email - [redacted]

Dear Mr Allen

Lenthalls Dam (Dam ID 309)

I refer to my letter dated 30 September 2011 and outline subsequent progress by Wide Bay Water Corporation regarding the continuing investigations concerning the operation of the Lenthalls Dam crest gates.

1. **Air venting system**
As foreshadowed in my previous letter, the Corporation has now installed snorkels on each crest gate as a 'temporary solution' to problems associated with the air venting system. Since the installation of the snorkels, the Corporation has been able to manually open all of the gates 1 to 4, without using external force. As yet, gate 5 can only be opened using external force.

2. **'Lifting' of the gates**
GHD has continued to investigate potential solutions to address the lifting of the gates during flood events, as indicated in my previous correspondence.

   I enclose five memoranda prepared by GHD, which outline the findings of their investigations to date. GHD has considered a number of potential solutions, including installing spoilers on the gates. I note that in its memorandum dated 7 November 2011, GHD advised that fitting spoilers to the gates is not in itself a workable solution.

   GHD is currently investigating a potential solution involving the construction of an upstream flow deflector. Further investigations are required in order to identify a suitable solution to the Lenthalls Dam gate issues. The Corporation will continue to work with GHD in order to find an effective solution and will continue to keep you informed of progress.

3. **Independent review of GHD's findings**
As noted in my previous letters, the Corporation has engaged Peter Hill, of Sinclair Knight Merz (SKM), and Glen Hobbs, of Glen Hobbs and Associates, to undertake an independent review of GHD's investigations.

(a) **Hydrological analysis**

Peter Hill's independent review is nearing completion. I enclose a copy of his draft report, dated 17 November 2011, which addresses the following:

- the accuracy of the hydrological modelling undertaken by GHD;
- the accuracy of GHD's analysis of the December 2010 flood events, including the inferences regarding gate performance;
- impact of partial gate openings on the probability of overtopping of the dam and the consequent increase in the risk of dam failure; and
- the suitability of the existing hydrometric network.

I note that Table 1 on page 9 of Peter Hill's report provides that even in an 'all gates closed' scenario the Acceptable Flood Capacity (ACF) of the Lenthalls Dam is 58% and the Annual Exceedance Probability (AEP) of the Dam Crest Flood (DCF) is 1 in 70,000.

For the purposes of comparison only, it is noted that even in an 'all gates closed' scenario the Lenthalls Dam would satisfy the minimum flood discharge capability requirements set out in Table 3: Schedule for Dam Safety Upgrades on page 18 of the Guidelines on Acceptable Flood Capacity for Dams (February, 2007) (AFC Guidelines).

Please let us know if you have any comments or require any clarification with respect to matters addressed by Peter Hill in the draft report. Should you have any queries, I will request they be addressed by Peter on finalisation of his report. Once finalised the Corporation will provide you with a copy.

I also enclose a file note prepared by SKM dated 18 October 2011 with preliminary comments in relation to the static head on the gates in certain scenarios. This note has been provided to Glen Hobbs for consideration in relation to his scope of work.

(b) **Design and forces analysis**

The Corporation has engaged Glen Hobbs to undertake an independent review of the design solutions prepared by GHD to address the Lenthalls Dam gate problems. Glen Hobbs has undertaken a detailed review of the forces on the crest gates, but he will not be in a position to complete his investigation until GHD develops a final solution for the gate performance issues.

In the interim, I enclose a letter by Glen Hobbs setting out his preliminary findings. The final report by Glen Hobbs will be provided to you when it becomes available.

I would be happy to discuss the above with you further in person when Peter Care and myself meet with you this coming Wednesday afternoon at 2 pm in your City offices.

Yours faithfully

[redacted]

CHIEF EXECUTIVE OFFICER

SINCLAIR KNIGHT MERZ

SKM

Lenthalls Dam

REVIEW OF HYDROLOGICAL MODELLING

- Draft A
- 17 November 2011

Lenthalls Dam

REVIEW OF HYDROLOGICAL MODELLING

- Draft A
- 17 November 2011

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Contents

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1. Introduction

1. This report has been prepared in response to a Brief from Allens Arthur Robinson to review the hydrologic model prepared by GHD in relation to the December 2010 flood event at Lenthalls Dam.

2. Specifically, the Brief required a response to the following issues:

   a) *"the accuracy of the hydrologic modelling undertaken by GHD, including the exceedance probabilities, of the December 2010 flood event set out in Lenthalls Dam Flooding: December 2010 Event (August 2011) report;*

   b) *The accuracy of GHD's analysis of the December 2010 flood event as set out in the August 2011 report, including the inferences regarding gate performance during the flood event;*

   c) *The impact of partial gate opening on the probability of overtopping of the dam and the consequence increase in the risk of dam failure; and*

   d) *The suitability of the existing hydrometric network for providing information on inflows during a flood event, in order to facilitate decision making regarding the operation of the gates during flood events."*

3. A summary of the qualifications and experience of the author of this report is provided in Section 8.

2. Data

4. The following references were used in preparation of this review:

- GHD (2004) Lenthalls Dam Probable Maximum Flood Review. Report for Wide Bay Water. October 2004. (Provided as Appendix B of 2006 Design Report).
- GHD (2006) Lenthalls Dam Raising Design Report for Wide Bay Water. May 2006
- GHD (2009) Lenthalls Dam Flooding Draft Report for Wide Bay Water. February 2009.
- GHD (2011) Lenthalls Dam Flooding Draft Report for Wide Bay Water. August 2011
- Macready and Associates (2010) Lenthalls dam 2010 Annual Dam Safety Inspection Report. Rev1 November 2010

In addition to these reports the following data and information was also utilised:

- Observations during site inspection of Lenthalls Dam on 16 September
- WBW video of a trial on Gate 5 undertaken in November 2010 provided by Peter Care
- GHD RORB catchment and calibration files provided by WBW on 9 September 2011
- GHD spreadsheet used to derive Figure 4-20 in the GHD August 2011 report including recorded water levels at Lenthalls Dam and Howards Alert and rating curve for Howards Alert river gauge
- Recorded rainfall data for the December 2010 event from the Bureau of Meteorology website

3. Hydrologic Modelling of December 2010 Event

5. This section covers the review of modelling undertaken by GHD of the December 2010 flood event as described in their August 2011 draft report. The focus of this review is on the estimated exceedance probability of the flood and the inferences regarding the gate performance during the flood event.

6. The calibration of a hydrologic model for Lenthalls Dam is confounded by lack of reliable hydrologic data. Specifically:

   - there are only two rainfall gauges available in the catchment, namely Musket Flat (040902) and Lenthalls Dam Alert (040906);
   - the catchment of the dam consists of 5 main tributaries and none of them are gauged;
   - the reservoir level is recorded however this cannot be reliably used to estimate outflow because of uncertainty regarding the opening of the gates during an event (e.g. for the December 2010 event Gate 5 did not open at all and it is suspected that the remaining gates were only partially open through the event as discussed below in points 19 and 20); and,
   - the levels recorded at Howard Alert reporting gauge located at Burrum No 1 Weir can be used to estimate flow however there is an additional approximately 100 km^2 catchment area downstream of Lenthalls Dam that is ungauged.

7. The general approach adopted by GHD is consistent with that outlined in the national flood guideline - Australian Rainfall and Runoff (ARR) published by Engineers Australia (Engineers Australia, 1999).

8. The GHD study utilised the RORB rainfall-runoff routing model which is widely used in Australia for such studies and is suitable for modelling flood events such as December 2010 and deriving design floods of desired annual exceedance probabilities (AEPs).

9. The RORB model configuration was based upon earlier studies by DNR (2000) and GHD (2002) as referenced in GHD (2004). The 2000 and 2002 reports were not included in this review but the catchment model appears to be suitably configured.

10. RORB has two parameters which control the routing characteristics; m which represents the model non-linearity and k_c which represents the overland and channel routing. An m value of 0.8 was adopted which is consistent with the recommendations in ARR and the value of k_c of 30 is within the expected range of values. Routing characteristics are considered to be a property of the catchment and therefore the values of m and k_c should be reasonably consistent between events.

SINCLAIR KNIGHT MERZ
SKM

11. Infiltration and interception (ie the rainfall that does not become surface runoff) is incorporated through the application of loss parameters and GHD adopted an initial loss – continuing loss model. This is the most commonly adopted loss model and is appropriate for this catchment. For the February 2009 flood an initial loss of 8 mm and a continuing loss of 2 mm/hr were adopted and these values are considered reasonable. As distinct from the routing parameters, the loss values (particularly the initial loss) is sensitive the antecedent moisture conditions and therefore the values of loss are expected to vary between events based upon the preceding rainfall.

12. GHD (2011) developed spillway rating curves (which relate the reservoir level to flow through the spillway) for all gates fully open, 4 gates fully open with 1 gate closed, and all gates closed. The calculations were not reviewed but the approach and resulting rating curves look reasonable.

13. Since the August 2011 GHD report, it has been noted that the gates partially close under flow. Because the flow is passing over the top of the crest gates it is difficult to ascertain the exact gate opening, but based upon observations on 16 September and subsequent estimates by WBW (GHD memo of 3 October 2011), it is estimated that the gates close to an opening of approximately 1.45 m (ie 550 mm above spillway crest). Thus, as part of this review spillway rating curves were derived for 4 or 5 gates opened to different amounts. The rating curves were derived using the approach outlined in GHD (2006) and the resulting rating curves are consistent with those derived by GHD. These rating curves were subsequently used to explore potential gate opening scenarios during the December 2010 event (refer points 19 and 20).

14. GHD (2011) also analysed the level data recorded downstream at Howard Alert (040907) which is located at Burrum No 1 Weir. This site has the advantage that once the rating curve has been established there is a consistent relationship between water level and flow because of the fixed crest. This data provides some additional insights into the Lenthalls Dam outflows, however any such inferences need to consider the approximately 100 km² of additional catchment area between the dam and Burrum No. 1.

15. A rating curve for Burrum No. 1 was developed by GHD in 1993 and is presented in Figure 4-16 of GHD (2011). The calculation of the rating curve was not reviewed but the relationship is consistent with empirical formula up to the point at which the weir drowns out (ie to the point where the flow is affected by the water level downstream of the dam); this is considered a reliable basis for estimating the flow, however there does appear to be an inconsistency in the datum used to estimate flows as discussed in point 16.

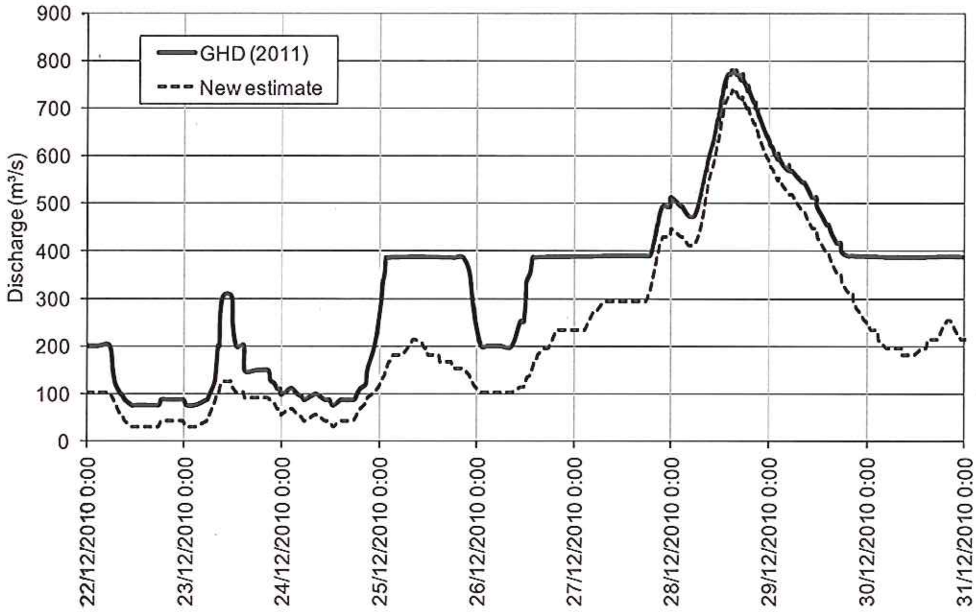
16. GHD (2011) used the derived rating curve with the recorded levels to estimate the flow during the December 2010 event. In Figure 4-20 of GHD (2011) the resulting flows are compared to

outflow from Lenthalls Dam for different assumptions regarding gate openings. This analysis was used by GHD to support their conclusion that the gates were likely to have shut closed during the peak of the storm event. The conclusion that the gates did malfunction during the event is supported (refer points 19 and 20), however there are a couple of inconsistencies that confound interpretation of the flows:

- *Datum* - It appears that there is a discrepancy in the datum used to estimate flows in the GHD (2011) study. The levels shown in the rating curve for Howard Alert in Figure 4-16 are expressed as m RL and flow commences at an elevation of 4.685m. The recorded water levels provided by the Bureau of Meteorology relate to Australian Height Datum (AHD) and they give the elevation of the weir as 4.87 mAHD. Thus, 0.185 m need to be subtracted from the recorded flows before applying the rating curve derived by GHD and therefore it is likely that the GHD (2011) report overestimates the flow. Once the change of datum is incorporated there is a reduction in the estimated volume of the flood (refer Figure 1).
- *Rating curve* - it is evident in Figure 4-20 of the GHD (2011) report that there are periods of constant flow of approximately 400 m^3/s during 25, 26 and 30 December and the GHD report attributes this to regulation of flow from the operation of the Lenthalls Dam spillway gates. The spreadsheet used to derive the flows in Figure 4-20 was obtained from GHD and an error was noted in how the values from the rating table were interpolated. The corrected flows are shown in Figure 1 and it can be seen that the periods of constant flow have been replaced with a more realistic shaped hydrograph.

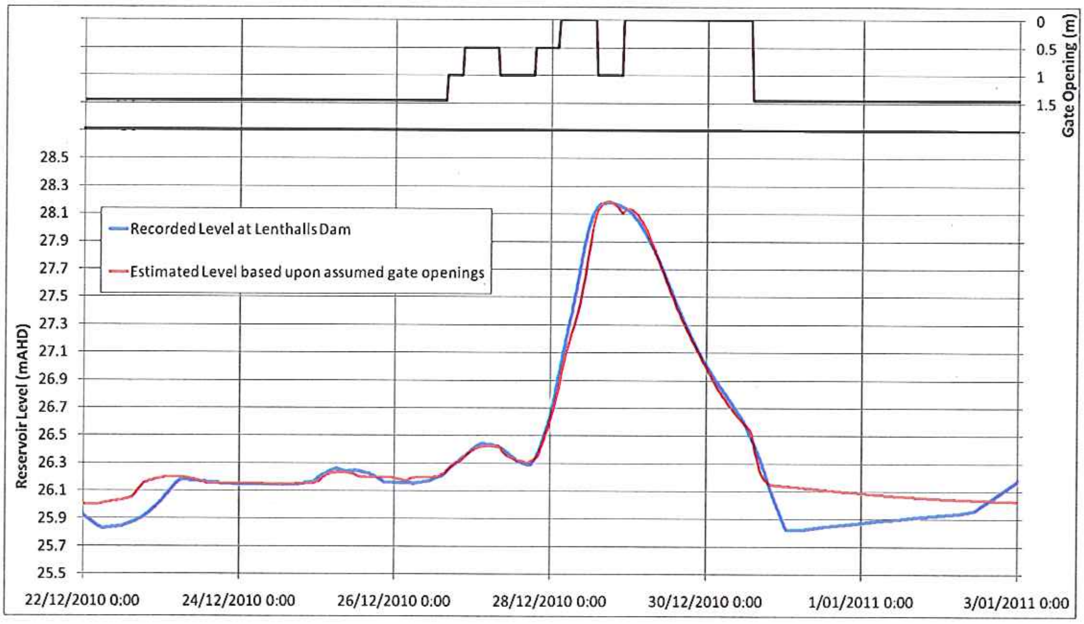
17. It is evident from Figure 4-20 of the GHD (2011) report that the volume of the Lenthalls Dam inflow and outflows estimated by GHD are significantly less than the volume of the flow estimated at Howards Alert using gauged water level data. For the period from 22 to 31 December 2010 the volume of the inflow and outflow estimated by GHD is approximately half the volume of flow estimated at Howard Alert. This indicates that the inflows and outflow for the December 2010 event estimated by GHD (2011) are potentially too low.

18. In order to derive an inflow and outflow from Lenthalls Dam which has a volume consistent with the recorded flow at Howards Alert, the GHD (2011) RORB model of the December 2010 event was re-run with lower losses (ie an initial loss of 0 mm and a continuing loss of 0.5 mm/h) which are consistent with the wet conditions leading up to the December 2010 event. The resulting inflow hydrograph at Lenthalls Dam is shown in Figure 3. Although there remains uncertainty in the estimated hydrographs the estimated inflow has a volume that is more consistent with the flow recorded downstream at Howards Alert (after allowances for the additional catchment area and the contribution of baseflow).

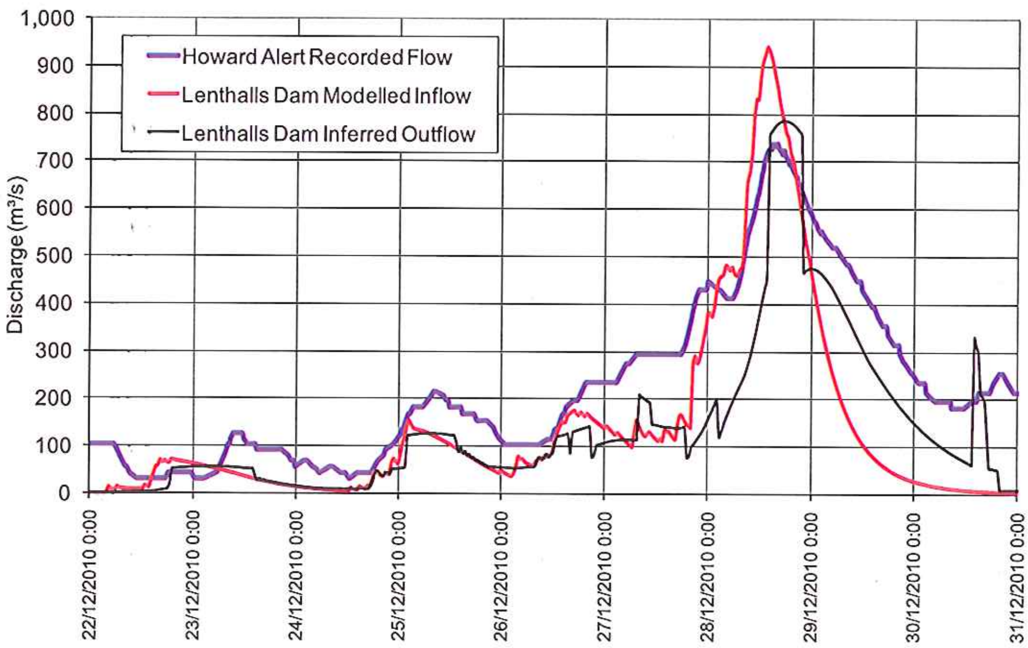


- **Figure 1 Comparison of flows derived using the recorded levels from the Howards Alert gauge during the December 2010 event**

19. There is considerable uncertainty regarding the gate openings during the December 2010 event. A simple routing model was therefore developed which estimated outflows for different gate openings. Rating curves were derived for Gate 5 closed and the remaining 4 gates either closed or opened 0.5m, 1.0m, 1.55m or 2.0m. To illustrate one potential gate opening scenario it was assumed that all 4 gates operated in a consistent manner (ie they opened and closed at the same rate). The gate openings were then adjusted until the modelled reservoir levels were consistent with the recorded levels. The resulting peak water levels and inferred gate openings for the 4 gates are shown in Figure 2 and the estimated outflows are shown in Figure 3. This analysis suggests that 4 of the gates were likely to be open 1.45 m (ie 550 mm from fully open) for the first few days of the event but as the reservoir level increased the 4 gates closed and were fully closed for large periods of 28 and 29 December.



- **Figure 2 Recorded and modelled Lenthalls reservoir levels during the December 2010 event showing inferred approximate gate openings for 4 gates (Gate 5 remained closed throughout the event)**



- **Figure 3 Comparison of modelled inflows and inferred outflows from Lenthalls Dam and estimated flows at Howards Alert for December 2010 event**

20. The analysis outlined above is somewhat speculative as the exact gate openings throughout the event are unknown and similar reservoir levels could be achieved using slightly different combinations of loss values and gate openings, however there is sufficient evidence to conclude that the gates did not remain fully open throughout the event. The analysis produces results which are consistent with the recorded peak water levels at both Lenthalls Dam and Burrum No 1, recorded rainfall and WBW observations regarding the gate openings and partial closure of the gates under flow. It supports the GHD (2011) conclusion that Gate 5 did not open and the remaining 4 gates did not remain fully open throughout the December 2010 flood event.

21. From the above analysis it is estimated that the peak inflow to Lenthalls Dam was approximately 930 m^3/s (compared to the GHD estimate of approximately 700 m^3/s). Based upon the inflow flood frequency derived in GHD (2009), an inflow of 930 m^3/s would be assigned an AEP of approximately 1 in 5. This is slightly rarer than estimated by GHD (2011) but supports their main conclusions that the 2011 flood was significantly smaller than a 1 in 50 AEP flood.

4. Implications for overtopping of the dam

22. The spillway has been designed to safely pass the PMP Design Flood (GHD, 2006) which is consistent with the requirements of the deterministic fallback provision in the ANCOLD guidelines on Acceptable Flood Capacity (ANCOLD, 2000). For Lenthalls Dam the AEP of the PMP Design Flood is estimated to be 1 in 2,000,000. To achieve this capacity all gates are required to operate and remain fully open during the flood.

23. It has been noted that the gates partially close under flow and therefore modelling was undertaken to determine the sensitivity of the spillway capacity to the gate openings. The GHD RORB model with the design inputs from GHD (2006) was rerun with the different spillway ratings which represent different gate openings. The resulting spillway capacities and AEP of the Dam Crest Flood (DCF; reflects the annual probability that the reservoir level exceeds the crest of the main embankment) are shown in Table 1.

Table 1 Sensitivity of the probability of overtopping to gate openings

Scenario	Spillway Capacity (m^3/s)	% of AFC	AEP of DCF	Source
All gates closed	3,300	58%	1 in 70,000	Interpolated from Table 6 of GHD (2006)
5 gates open 0.5 m	4,000	70%	1 in 370,000	Application of GHD RORB model
5 gates open 1.0 m	4,300	75%	1 in 560,000	Application of GHD RORB model
5 gates open 1.45 m	4,600	81%	1 in 830,000	Application of GHD RORB model
5 gates fully open	5,700	100%	1 in 2,000,000	Table 6 of GHD (2006)

24. The results in Table 1 above clearly show that the capacity of the spillway to safely pass extreme floods is compromised if the gates partially close during a flood. The nominal design capacity of 1 in 2,000,000 is reduced to 1 in 560,000 if the gates are half closed and this reduces further to an AEP of 1 in 70,000 if all gates are closed. This reinforces the importance of ensuring that all gates operate and remain fully open during flood events.

5. Adequacy of existing hydrometric network

25. As noted in point 6, there are only two rainfall gauges available in the catchment; Musket Flat (040902) and Lenthalls Dam Alert (040906) and there are no streamflow gauges upstream of the dam. The sparse network of rain gauges means that there is considerable uncertainty in the spatial distribution of rainfall for a particular event. This not only affects the ability to understand the severity of an event in real time but also hinders the application of a rainfall-runoff model to analyse past events (e.g. to explore gate openings during the December 2010 event).

26. There is no applicable Australian standard on the number of rainfall gauges required to provide adequate coverage of a catchment. However information on the number of operational rainfall gauges for some other catchments from around Australia with gated spillways was collated from the Water Resources Station Catalogue maintained by the Bureau of Meteorology. The catalogue was last updated in February 2007 and thus provides a useful, if not wholly accurate, basis for comparison.

27. The number of operational gauges in the catchment is summarised in the third column of the table below, where the density of the network (expressed as the average catchment area per individual gauge) is shown in the fourth column. This table demonstrates that the density of gauges in the Lenthalls Dam catchment is less than that for the other catchments.

28. Increasing the number of rain gauges in the catchment would also allow greater redundancy in case of equipment or telemetry failure during an event and hence provide a more robust network.

Table 2 Comparison of rainfall gauge densities for some other Australian catchments with gated dams

Catchment	Area (km^2)	No. of gauges	Network density km^2 / gauge
Upper Brisbane River	5678	27	210
Stanley River	1312	8	164
Ross River	1347	22	61
Onkaparinga	931	9	103
Lenthalls Dam	512	2	256

29. Similarly, installation of a streamflow gauge on a tributary upstream of the dam would also assist both real-time operation and the subsequent modelling of historic flood events. This would reduce the uncertainty in the calibration of rainfall-runoff models and may lead to the adoption of different model parameters which would change the estimated flood risk.

6. Conclusions

The following conclusions are structured around the 4 issues identified in the Brief:

the accuracy of the hydrologic modelling undertaken by GHD, including the exceedance probabilities, of the December 2010 flood event set out in Lenthalls Dam Flooding: December 2010 Event (August 2011) report

30. The general approach adopted by GHD (2011) is consistent with that outlined in the national flood guideline - Australian Rainfall and Runoff (Engineers Australia, 1999). The study used RORB which is a suitable model and the configuration appears appropriate.

31. The analysis of the December 2010 event is confounded by the lack of recorded streamflow upstream of the dam and no information on the gate openings during the peak of the event, which means that there is considerable uncertainty in the estimated inflows and outflows from the dam. It is estimated that the peak inflow was around 930 m^3/s which has an AEP of approximately 1 in 5. This supports the GHD conclusion that the 2011 flood was significantly smaller than a 1 in 50 AEP flood.

The accuracy of GHD's analysis of the December 2010 flood event as set out in the August 2011 report, including the inferences regarding gate performance during the flood event

32. From the analysis of recorded water levels in Lenthalls Dam and downstream at Howard Alert (040907) located at Burrum No 1 Weir, GHD concluded that "*the Lenthalls Dam gates did operate, and opened and closed, during the early stage of the December 2010 event. However, as the water levels in the dam rose, the gates malfunctioned and shut closed. The gates then appeared to work again after passage of the storm peak.*" As part of this review an alternative set of flows at Lenthalls dam were derived, however the outcomes supported the GHD (2011) conclusion that during the December 2011 Gate 5 did not open and the remaining 4 gates did not remain fully open throughout the event.

The impact of partial gate opening on the probability of overtopping of the dam and the consequence increase in the risk of dam failure; and

33. The spillway has been designed to safely pass an extreme flood with an AEP of 1 in 2,000,000 and this capacity is consistent with the prevailing ANCOLD guidelines on acceptable flood capacity. This capacity requires all gates to operate and remain fully open during the flood, however, the capacity of the spillway to safely pass extreme floods is compromised if one or more gates do not operate or the gates partially close. For example if all gates fail to operate the AEP of overtopping the embankment increases to approximately 1 in 70,000. This reinforces the importance of ensuring that all gates operate and remain fully open during flood events.

The suitability of the existing hydrometric network for providing information on inflows during a flood event, in order to facilitate decision making regarding the operation of the gates during flood events."

34. There are only two rainfall gauges and no streamflow gauges available in the catchment upstream of Lenthalls Dam. The sparse network of rain gauges means that there is considerable uncertainty in the spatial distribution of rainfall which affects the ability to understand the magnitude of an event in real time but also hinders the application of a rainfall-runoff model to analyse past events. Although there are no accepted standards on the number of rainfall gauges required to provide adequate coverage of a catchment, the current density of rain gauges is less than some other Australian catchments with gated spillways. Increasing the number of rain gauges in the catchment would also allow greater redundancy in case of equipment or telemetry failure during an event and hence provide an operationally more robust network. Similarly, installation of a streamflow gauge on a tributary upstream of the dam would also assist both real-time operation and the subsequent modelling of historic flood events.

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7. Curriculum Vitae

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Peter Hill

Principal
Senior Hydrologist

[redacted]

Qualifications

- Master of Engineering Science (Civil), University of Adelaide 1993
- Bachelor of Engineering, (Civil) (Hons.), University of Adelaide, 1991

Affiliations

- Member, Engineers Australia, CPEng
- Member, Australian Water Association
- Member of International Water Association

Professional Activities

- Committee Member of Engineers Australia's National Committee on Water Engineering
- Committee Member for revision of ANCOLD Guidelines on Assessment of the Consequences of Dam Failure
- Convenor for ANCOLD Acceptable Flood Capacity Guidelines
- Past Chairman, Victorian Water Eng. Branch, Engineers Australia

Fields of Special Competence

- Flood hydrology
- Dam safety risk assessment
- Environmental hydrology

Awards

- Project Manager of the "Spatial Query Tool for Statewide Estimates of Water Use for Key Land Use Types" winner of the 5th Annual Victorian Spatial Excellence Awards 2009 Environment and Sustainability Award
- Co-author of paper which received the Sternbeck Medal for the best paper at the joint NSW and Victorian Flood Management Conference – Albury Wodonga 16 – 20 February 2009
- Project Manager for winning project AWA SA Water Award 2002 in categories of Water, Environment and Society and also Studies, Plans and Investigations and winner SA Australian Planning Institute Award for Environment 2003
- 2001 ACEA Future Leaders Award - Silver Award of Highly Commended
- Best presentation – Water 99 Joint Congress - 25th Hydrology and Water Resources Symposium, Brisbane, July 1999
- Best presentation – Hydrology and Water Resources Symposium, Hobart, 1996
- Best Student or recent graduate surface water paper presentation Water Down Under'94 Adelaide 21-25 November 1994
- AWWA's Inaugural HJN Hodgson Award for excellence on water related studies by undergraduate students, December 1991

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Relevant experience

SINCLAIR KNIGHT MERZ, Australia

October 1996 to current

Dam Safety Risk Assessment

- Review of G-MW flood operations (Vic.)
- Review of 2010-2011 Flood Warnings and Response (Comrie Review) - Review into the operation of storages during flooding (Vic.)
- Hydrology, dambreak modelling and consequence estimation for Upper Yarra dam (Vic.)
- Review of filling curves for Eppalock and Eildon dams (Vic.)
- Peer review panel for Malmsbury dam safety upgrade (Vic.)
- Flood hydrology and dambreak study of Sturt Creek Flood Control Dam (SA)
- Assessment of target filling curves for Eppalock and Eildon dams (Vic.)
- Hydraulic modelling ofe the lower Brisbane River to assess operating scenarios for the January 2011 flood to assist Seqwater respond to the Commission of Inquiry (Qld)
- Development of an extreme flood operations manual for Hume Dam (NSW)
- Development of a guidance note on assessing ALARP for dam safety risk applications (Vic.)
- Peer review of SEQ Water's submission to the Commission of Enquiry into the January 2011 floods (Qld)
- Flood hydrology, dambreak modelling and consequence assessment – including benchmarking different methods of estimating loss of life for Buffalo and Newlyn dams (Vic.)
- Review of consequences and hazard assessment for Aireys Inlet WWTP lagoons (Vic.)
- Flood hydrology study for Mt Bold Dam (SA)
- Peer review of flood hydrology study for Chichester Dam (NSW)
- Modelling of surcharge options for Eildon Dam (Vic.)
- Flood hydrology study for Beetaloo Dam (SA)
- Application of CRC-FORGE method for deriving design rainfalls (NSW)
- Assessment of potential impact of climate change on spillway adequacy for Dartmouth Dam (Vic.)
- Flood hydrology study for Myponga Dam (SA)
- Peer Review of Wyaralong Flood Hydrology Study (Qld)
- Construction flood risk assessment for William Hovell Dam (Vic.)
- Comparative analysis of dam safety regulation frameworks (Vic.)
- Detailed hydrology, dambreak modelling and consequence assessment for Scrivener Dam (Lake Burley Griffin) (ACT)
- Hume Dam hydrology assurance review (NSW)
- Peer review of Blue Rock hydrology (Vic.)
- Hydrology and construction flood risk for Toorourrong Dam (Vic)
- Hydrology and construction flood risk for Tarrago Dam (Vic)
- Detailed hydrology, dambreak modelling and consequence assessment for McKay Dam (Vic.)
- Peer review of dambreak modelling and consequence assessment for Tillegra Dam (NSW)
- Detailed hydrology study for Middle River Dam (SA).
- Seasonal construction flood risk for Blowering Dam (NSW)

- Seasonal construction flood risk for Laanecoorie Dam (Vic)
- Dambreak modelling and consequence assessment for Upper Coliban, Lauriston and Malmsbury Dams (Vic).
- Detailed hydrology study for Bundaleer, Barossa and Warren Dams (SA).
- Development of guidelines and state-wide database for statement of obligations reporting on dam safety risks (Vic.)
- Modelling flood operation of Eildon spillway gates for different surcharge conditions (Vic.)
- Extreme flood hydrology for Googong Dam (ACT)
- Detailed flood hydrology for upgrade of Hinze Dam (Qld.)
- Extreme flood hydrology for Corrin, Cotter and Bendora Dams including joint probability initial reservoir level in cascade of correlated storages (ACT)
- Extreme flood hydrology for Tallowa Dam (NSW)
- Hydraulic modelling of Keepit Reservoir to determine velocities upstream of proposed auxiliary spillways (NSW)
- Review of ANCOLD Hazard Category for 6 dams for Wannon Water (Vic.)
- Dambreak modelling and risk assessment for Sunday Creek Reservoir (Vic.)
- Peer review of Meander Dam Hydrology Study (Tas.)
- Detailed review of hydrology for Upper Coliban, Malmsbury and Lauriston Reservoirs including accounting for correlated initial drawdowns and gate failure scenarios (Vic.)
- Preliminary risk investigation for Montpellier No.2 Dam (Vic.)
- Assessment of conceptual upgrade options for Painkalac Dam (Vic.)
- Review of statement of obligations from water authorities for Department of Sustainability and Environment (Vic.)
- Estimation of construction flood risks for Ross River (Qld).
- Review of flood surcharge levels for Eildon Dam (Vic.)
- Application of Risk Analysis Prioritisation Tool to Central Highland Water's portfolio of dams (Vic.)
- Estimation of potential loss of life and economic consequences for Millbrook and Kangaroo Creek Dams (SA)
- Assessing issues relating to gate operation and reservoir surcharge for Goulburn-Murray Water (Vic.)
- Application of Risk Analysis Prioritisation Tool to Coliban Water's portfolio of dams (Vic.)
- Detailed review of hydrology and estimation of Probable Maximum Flood for Kangaroo Creek Dam (SA)
- Review of hydrology and dambreak modelling for Laanecoorie Dam (Vic.)
- Review of hydrology and dambreak modelling for William Hovell Dam (Vic.)
- Development of Portfolio Risk Analysis Tool for Barwon Water (Vic.)
- Hydraulic modelling and inundation mapping upstream and downstream of Cairn Curran Dam for spillway upgrade options (Vic.)
- Provision of hydrologic inputs to upgrade of Eildon Dam (Vic.)
- Specialist hydrology input to Ross River Dam Stages 2 to 5 Upgrade Study (Qld.)
- Tender evaluation panel member for Ross River Dam Stages 2 to 5 Upgrade Study (Qld.)
- Assessment of downstream impact of Dartmouth Regulation Pond for Southern Hydro (Vic.)
- Review of hydrology and estimation of Probable Maximum Flood for Little Para Dam (SA)
- Review of Barwon Water Business Risk Analysis in light of ANCOLD Risk Guidelines (Vic.)

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- Review of hydrology and estimation of Probable Maximum Flood for Nillahcootie Dam (Vic.)
- Detailed review of hydrology for Cairn Curran Dam (Vic.)
- Hazard assessment and assessment of acceptable flood capacity for Dartmouth Slimes Dam (Vic.)
- Modelling cascade failure of Talbingo, Jounama and Blowering Dams (NSW)
- Detailed review of hydrology for Millbrook Dam (SA)
- Hydraulic modelling and inundation mapping to assess the downstream impacts of final upgrade options for Keepit Dam for State Water (NSW).
- Estimation of the flood risk at Cairn Curran Dam during upgrade of filters. (Vic.)
- Review of hydrology and dambreak modelling for Tullaroop Dam (Vic.)
- Detailed review of hydrology for Dartmouth Dam (Vic.)
- Review of hydrology using a Monte-Carlo flood estimation approach, event tree modelling and risk analyses for the Ross River Upgrade Project (Qld.)
- Review of hydrology of Dartmouth Slimes Dam (Vic.)
- Hydraulic modelling and inundation mapping to assess the downstream impacts of interim upgrade options for Keepit Dam for State Water (NSW).
- Review of spillway adequacy, dambreak modelling and consequence assessment for Moondara and Pine Gully Dams for Gippsland Water (Vic.)
- Review of hydrology and first order risk analysis for Millbrook Dam for SA Water (SA).
- Developed upgrade options to provide additional flood capacity for Cairn Curran Dam for Goulburn Murray Water (Vic.)
- Detailed risk investigations for 10 dams for Central Highland Water (Vic.)(refer Civil Engineers Australia, April 2001)
- Assessment of consequence of failure for Blowering, Split Rock, Keepit and Burrinjuck dams including damage to infrastructure, agriculture, potential loss of life and qualitative assessment of damage to the environment. (NSW)
- Application of the CRC-FORGE method of estimating extreme design rainfalls to South-Australia (SA)
- Review of hydrology and dambreak modelling of all 17 of SA Water Corporations large dams as part of a portfolio risk assessment (SA)
- Event tree modelling and risk analysis as part of the portfolio risk analysis for South-East Queensland Water Board (Qld.)
- Review of hydrologic risk, dambreak analyses and preparation of inundation maps for Eppalock, Eildon, Cairn Curran and Nillahcootie dams (Vic.)
- Expert input on event tree modelling for Portfolio Risk Assessment for HEC (Tas.)
- Hydrologic and hydraulic modelling of impact of fuse plug spillway for Keepit Dam on incremental flooding in the Peel River (NSW).
- Dambreak modelling for Blowering Dam including the cascade failure of Talbingo and Jounama dams (NSW)
- Dambreak modelling for Dartmouth Dam as part of the Hume-Dartmouth Risk Analysis (NSW)
- Detailed review of hydrologic risk for Brogo Dam (NSW)
- Hydrologic inputs for Dartmouth and Hume Dam risk analysis. (Vic.)
- Detailed review of hydrologic risk for Rocky Valley Dam incorporating joint probability of inflows and initial reservoir levels and the impact of snowmelt (Vic.)
- Dambreak modelling of Rocky Valley Dam (Vic).
- Portfolio evaluation of hydrologic risk for Goulburn-Murray Water (Vic.)

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- Preliminary review of hydrologic risk and dambreak modelling of the dams in the Kiewa Hydro scheme (Vic.)
- Review of spillway adequacy for the Snowy Scheme (NSW)
- Review of hydrology, dambreak modelling and assessment of potential loss of life for Sunday Creek Dam. (Vic.)

Hydrology

- Statewide estimates of Evapotranspiration for 2010/11 Victorian water accounts (Vic.)
- Water balance modelling for assessing the water impacts of land use changes in 14 priority catchments (Vic.)
- Peer review of flood hydrology for Brownhill and Keswick Creeks (SA)
- State-wide assessment of the impact of land use change on streamflow yields for drier climate (Vic.)
- Review of hydrologic impact of softwood plantation in the Oberon catchment (NSW)
- Peer review of Melbourne Water's Flood Risk Assessment Framework (Vic.)
- Australian Rainfall and Runoff Update Project 7 - Baseflow for Catchment Simulation
- Development of flood forecasting tool for the Gippsland Lakes (Vic.)
- Identification of Hydrologic Impact Zones based upon assessment of current hydrologic stress and impact of land use change (Vic.)
- Baseline assessment of intercepting activities across Australia for NWC
- Comparison of evapotranspiration estimates from CAT and Soilflux models for Corrangamite and Gippsland regions (Vic)
- Hydrologic impact of 2006/07 bushfires on streamflow yield (Vic.)
- State-wide assessment of the impact of land use change on streamflow yields involving modelling the evapotranspiration of key vegetations types across Victoria. (Vic.)
- Seasonal forecasting of Victorian streamflow using regionally based climate indices (Vic.)
- Water Resource Assessment for the Murray Darling Basin modelling impact of future climate and landuse on streamflow yield – collaborative project with CSIRO and winner of CSIRO's 2009 Chairman's Award.
- Collation of water resource information for assessing bushfire risk (Vic.)
- Literature review of the impact of logging on in-stream water quality for the Melbourne Water Supply Catchments (Vic.)
- Hydrologic impact of 2003 Alpine bushfires as part of DSE's Bushfire Recovery Project – in conjunction with University of Melbourne and CSIRO (Vic.)
- Modelling impact of low flow bypasses on farm dams for the Onkaparinga River Catchment (SA).
- Land use Planning and Environmental Water Provisions for the Onkaparinga River Catchment (SA)
- Impact of landuse change on water quality and quantity in south-western Victoria and south-eastern South Australia (Vic & SA)
- Determination of the impact of forest management on streamflow yield and water quality for the Otway Ranges (Vic)
- Determination of Environmental Water Requirements for the Onkaparinga Catchment - winner AWA SA Water Award 2002 in categories of Water, Environment and Society and also Studies, Plans and Investigations and winner SA Australian Planning Institute Award for Environment

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2003, Highly commended Engineers Australia's SA Division 2003 Engineering Excellence Awards (SA).

- Salt and Water Balance Study of the Avon-Richardson Catchment (Vic.)
- Preparation of the flood component of the Catchment Plan for the Northern Adelaide and Barossa Catchment Water Management Board (SA)
- Development of a method to assess low flow homogeneity in the Hawkesbury Nepean Catchment (NSW)
- Development of a method to estimate yield for ungauged catchments in Victoria in order to determine the impact of farm dams (Vic)
- Assessment of the impact of forest management on water quality and quantity in 3 regional forest agreement regions (NSW)
- Floodplain management study of the Avon-Richardson Catchment (Vic)
- Analysis of low flow hydrology of the Hawkesbury Nepean River System as part of a study of environmental flows (NSW)
- Environmental Assessment of the Wannon River (Vic)

Cooperative Research Centre for Catchment Hydrology, Monash University
April 1993 to October 1996

Research Assistant and then Project Leader

- managed research project on loss modelling for flood estimation
- published 4 papers and 7 research reports
- reported to reference and review panels
- supervised a team of several research staff including joint supervision of a M.Eng.Sc. (research) student
- presented a number of seminars and organised 2 workshops on yield modelling
- undertook research on loss modelling and real-time flood forecasting

Sample Papers

Vreugdenhil, R., Hill, P.I., Perera, S., Ryan, S. (2011) Towards increased clarity in the application of ALARP. 2011 ANCOLD Conference on Dams.

Lang, S., Meneses, C., Hill, P.I., Sih, K. (2011) Comparing methods for estimating loss of life from dambreak flooding for two Australian dams. 2011 ANCOLD Conference on Dams.

Nathan, R.J., Hill, P.I., Weinmann, P.E. (2011) Achieving consistency in derivation of the Probable Maximum Flood. 2011 ANCOLD Conference on Dams.

Nathan, R.J., Hill, P.I., (2011) Factors Influencing the Estimation of Extreme Floods. 2011 ANCOLD Conference on Dams.

Hill, P.I. (2011) Towards Improved Loss Parameters for Design Flood Estimation in Australia. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Sih, K., Fowler, K., Jordan, P.W., Hill, P.I., Nandakumar, N, Weinmann, E, Nathan, R.J. (2011) Has there been a change in rainfall maxima? – implications for design rainfalls, 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Murphy, R.E., Graszkiewicz, Z, Hill, P.I., Neal, B.P., Nathan, R.J. (2011) Predicting baseflow contributions to design flood events in Australia. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

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Graszkiewicz, Z, Murphy, R.E, Hill, P.I., Nathan, R.J (2011) Review of techniques for estimating the contribution of baseflow to flood hydrographs. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Kinkela, K., Pearce, L.J., Murphy, R.E., Graszkiewicz, Z, Hill, P.I. (2011) Assessment of Baseflow Seasonality and Application to Design Flood Events in South-West Western Australia. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Jordan, P.W., Sih, K., Hill, P.I., Nandakumar, N, Weinmann, P.E., Nathan, R.J. (2011) Areal Reduction Factors for Estimation of Design Rainfall Intensities for New South Wales and the Australian Capital Territory. 34th IAHR World Congress. 26 June to 1 July 2011 Brisbane, Australia.

Fowler, K., Hill, P.I., Jordan, P.W., Nathan, R.J., Sih, K. (2010) Application of Available Climate Science to Assess the Impact of Climate Change on Spillway Adequacy. ANCOLD 2010 Conference on Dams. Hobart.

Sih, K., Hill, P.I., Ryan, S., Perera, S. (2010) Regulating Dam Safety: How do we compare? ANCOLD 2010 Conference on Dams. Hobart

Fowler, K., Jordan, P.W., Hill, P.I., Nathan, R.J., Sih, K. (2010) A framework for incorporating available climate Science in Extreme Flood Estimates. Practical Response to Climate Change Conference. Melbourne.

Murphy, R.E., Moran, R., Hill, P.I., Jusuf, K. (2010) Quantifying the post-1997 climate shift in Victoria. Practical Response to Climate Change Conference. Melbourne.

Westra, S., Varley, I., Jordan, P.W., Nathan, R.J., Ladson, A.R., Sharma, A., Hill, P.I. (2010) Addressing climatic non-stationarity in the assessment of flood risk. *Australian Journal of Water Resources*. Institution of Engineers Australia. Vol 14 No 1. pp1-16.

Hill, P.I., Murphy, R.E., Daamen, C., Williams, K., Moran, R., Berg, S. (2009) Statewide estimates of water use for key land use types. *32nd Engineers Australia Hydrology and Water Resources Symposium*. Newcastle 1 – 3 December 2009

Mannik, R.D, Hill, P.I, Murphy, R.E., Herron, A., Moran, R (2009) Estimating the change in streamflow resulting from the 2003 and 2006/07 bushfires in south eastern Australia. *32nd Engineers Australia Hydrology and Water Resources Symposium* Newcastle 1 – 3 December 2009

Murphy, R.E., Hill, P.I., Grace, D., Bell, A.B., Day, G. Moran, R. (2009) Implications of climate change on changes in evapotranspiration resulting from afforestation in North Eastern Victoria *32nd Engineers Australia Hydrology and Water Resources Symposium*. Newcastle 1 – 3 December 2009

Smith. A.E., Hossain, A., Hill. P.I. (2009) Flood Risk to People – Towards a framework for incorporating life safety risk in Australian floodplain management. *Joint NSW and Victorian Flood Management Conference – Albury Wodonga* 16 – 20 February 2009

Westra, S., Varley, I., Jordan, P.W., Hill, P.I., Ladson, A.R. (2009) Recent Developments in Climate Science: Implications for Flood Guidelines, *Joint NSW and Victorian Flood Management Conference – Albury Wodonga* 16 – 20 February 2009

Hill, P.I., Jordan, P.W., Nathan, R.J., Payne, E. (2008) Estimating Construction Flood Risk. *2008 ANCOLD Conference on Dams*. Gold Coast November 2008

Hill, P.I., Mordue, A. Nathan, R.J., Daamen, C.C., William, K., Murphy, R.E. (2008) Modelling the Hydrologic Response of Bushfires at the Catchment Scale. *Australian Journal of Water Resources* Vol 12. No. 3 and *Water Down Under 2008 (incorporating 31st Engineers Australia Hydrology and Water Resources Symposium)*. pp1472-1480.

Jordan, P.W., Wiesenfeld, C.R., Hill, P.I., Morden, R.A., Chiew F.H.S. (2008) An assessment of the future impact of farm dams on runoff in the Murray Darling Basin, Australia. *Water Down Under 2008 (incorporating 31st Engineers Australia Hydrology and Water Resources Symposium)*. pp1618-1629.

Sih, K., Hill, P.I., Nathan, R.J., (2008) Evaluation of simple approaches to incorporating variability in design temporal patterns. *Water Down Under 2008 (incorporating 31st Engineers Australia Hydrology and Water Resources Symposium)*. pp1049 -1059.

Hill, P.I., McDonald, L Payne, E. (2007) Incremental consequences of dam failure and the ANCOLD hazard classification system. *2007 NZSOLD/ANCOLD Conference on Dams.* Christchurch November 2007

Mittiga, L. Nathan, R.J., Hill, P.I., Weinmann, P.E. (2007) Treatment of Correlated Cascade Drawdown and Uncertainty in the Flood Hydrology for Dams. *Australian Journal of Water Resources* Vol 11 No. 2. pp169-176

Hill, P.I., Nathan, R.J., Jordan, P.W. (2006) Development and Application of a Risk Analysis and Prioritisation Tool (RAPT) for Dam Safety Management. *2006 ANCOLD Conference on Dams.* Sydney November 2006

Jordan, P.W., Hill, P.I. (2006) Use of radar rainfall data to improve calibration of rainfall runoff routing model parameters. *Australian Journal of Water Resources* Vol 10 No. 2. pp139-149

Jordan, P.W., Murphy, R., Hill, P.I., Nathan, R.J., (2006) Seasonal Response of Catchment Runoff to Forest Age. 30th Engineers Australia Hydrology and Water Resources Symposium. Launceston December 2006

Hill, P.I, Sih, K., Nathan, R.J., Jordan, P.W. (2006) The Extremes of Tropical Hydrology. *ANCOLD Bulletin* Issue No. 133 August 2006 and *2005 ANCOLD Conference on Dams 21-22 November 2005 Fremantle.*

Jordan, P.W., Hill, P.I. (2005) Use of radar rainfall data to improve calibration of rainfall runoff routing model parameters. *29th Hydrology and Water Resources Symposium 21–23 February 2005, Canberra.*

Gatti, S., Hill, P.I., Griffith, H., Smith, S. (2004) Where's the water going to come from? Environmental flows for the Onkaparinga River and estuary. *2004 River Symposium* Brisbane, 2004.

Hill, P.I., Bowles, D., Jordan, P., Nathan, R.J. (2004) Estimating Overall Risk of Dam Failure: Practical Considerations in Combining Failure Probabilities. *ANCOLD Bulletin* No. 127 pp 63-72

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Memorandum

03 October 2011

To	Wide Bay Water, Peter Care		
Copy to			
From	[redacted]	Tel	(07) [redacted]
Subject	Update on Lenthalls Crest Gates modelling	Job no.	41/19335/04

Peter,

This memorandum is a summary of progress of our desktop modelling of the crest gates at Lenthalls Dam.

The installation of snorkels on top of the gates has enabled direct measurement of the position of the gates, a parameter which has not been available to date. This shows that the gates sit at the levels above the crest listed in Table 1, instead of dropping fully:

Table 1 Measured position of gates

Gate	Stable level above crest, reservoir at FSL (mm)
1	550
2	800
3	300
4	500

GHD's initial calculations to review the gate performance were based on static water forces. A much more complex CFD model is required to determine the dynamic load of the water flow over the gates to investigate the measured behaviour.

Within the last few days we have reached the stage where we can combine the results of the CFD (Computational Fluid Dynamics) modelling with the force balance work we have previously performed to obtain a desktop verification of the behaviour of the crest gates. We now have a calibrated analysis system which is giving the same answer as the observed behaviour for the 15m gates, namely that the equilibrium position for these gates when operating at FSL is approximately 550mm above the spillway crest level.

Our next steps will be to investigate various solutions, like flow spoilers, to determine which method effectively and safely prevents the undesirable floating behaviour.

Some figures are provided below for your information.

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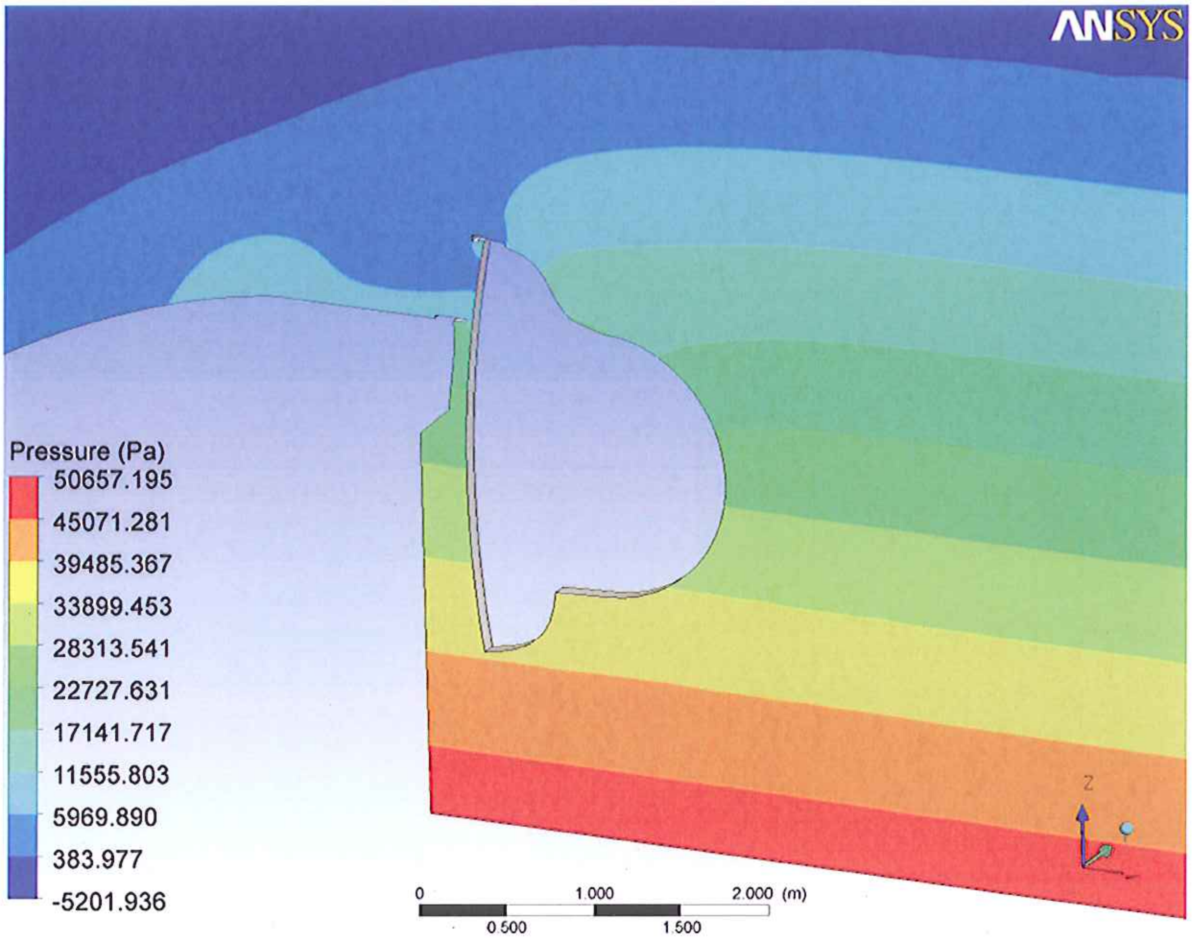

Figure 1: Gate 550 above crest, pressure distribution

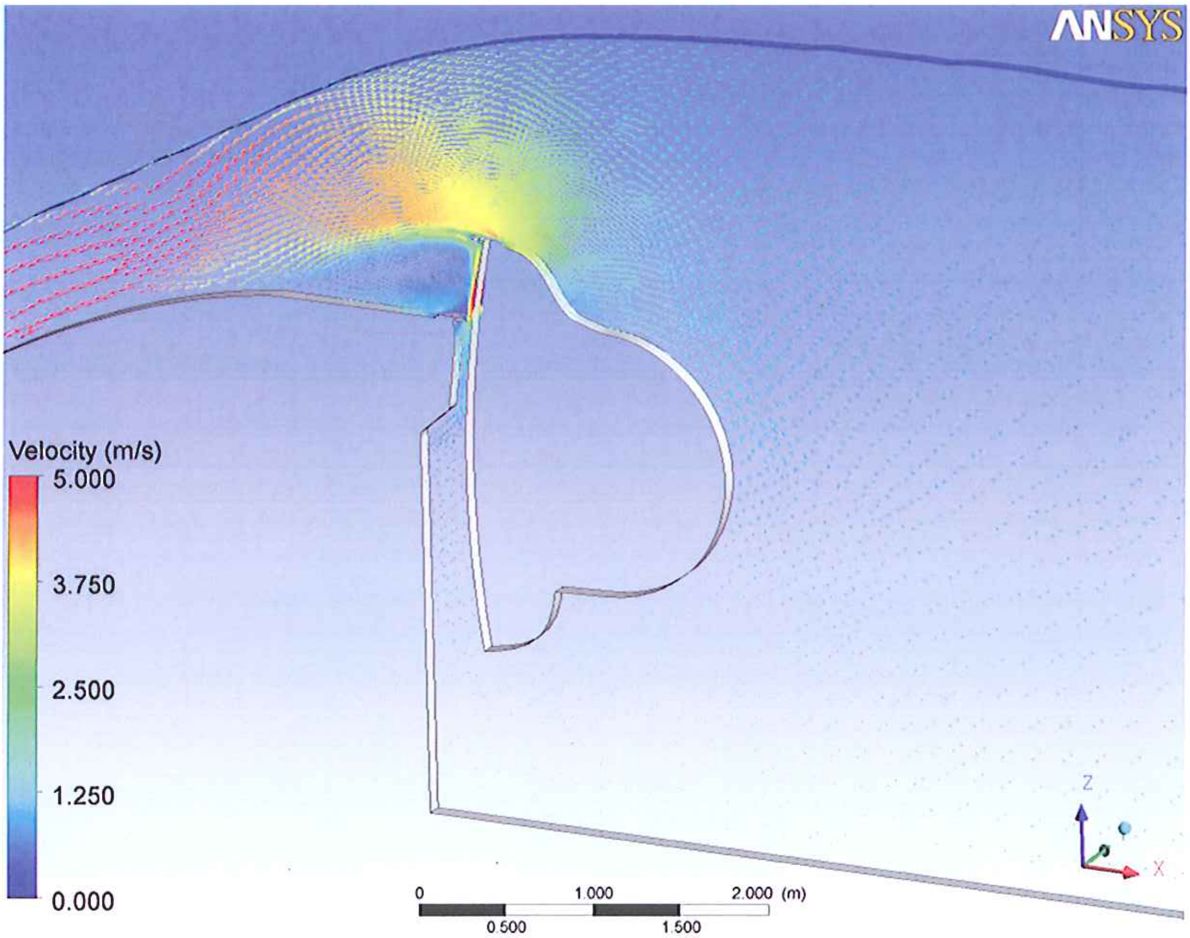

Figure 2: Gate 550 above crest, flow vectors

Regards

Amanda Ament
Senior Structural Engineer - Dams

Memorandum

11 October 2011

To	Wide Bay Water, Peter Care		
Copy to			
From	[redacted]	Tel	(07)[redacted]
Subject	Progress on Lenthalls Crest Gate solution	Job no.	41/19335/06

Peter,

This memorandum updates you on the progress of work on the Lenthalls Dam crest gates.

We have been investigating a number of different forms and configurations of "add-ons" to the crest gates to identify the most effective shape at disrupting the accelerating flow over the head of the gates. It is this accelerating flow which is generating the hydrodynamic uplift forces.

At present, the most effective shape is a 150mm long fin mounted at approximately 45° to the flow, for the full length of the gate. This shape reduces the hydrodynamic uplift force on the gates by approximately 10%. Output from the CFD modelling showing the effect of this fin can be seen in Figure 1 below.

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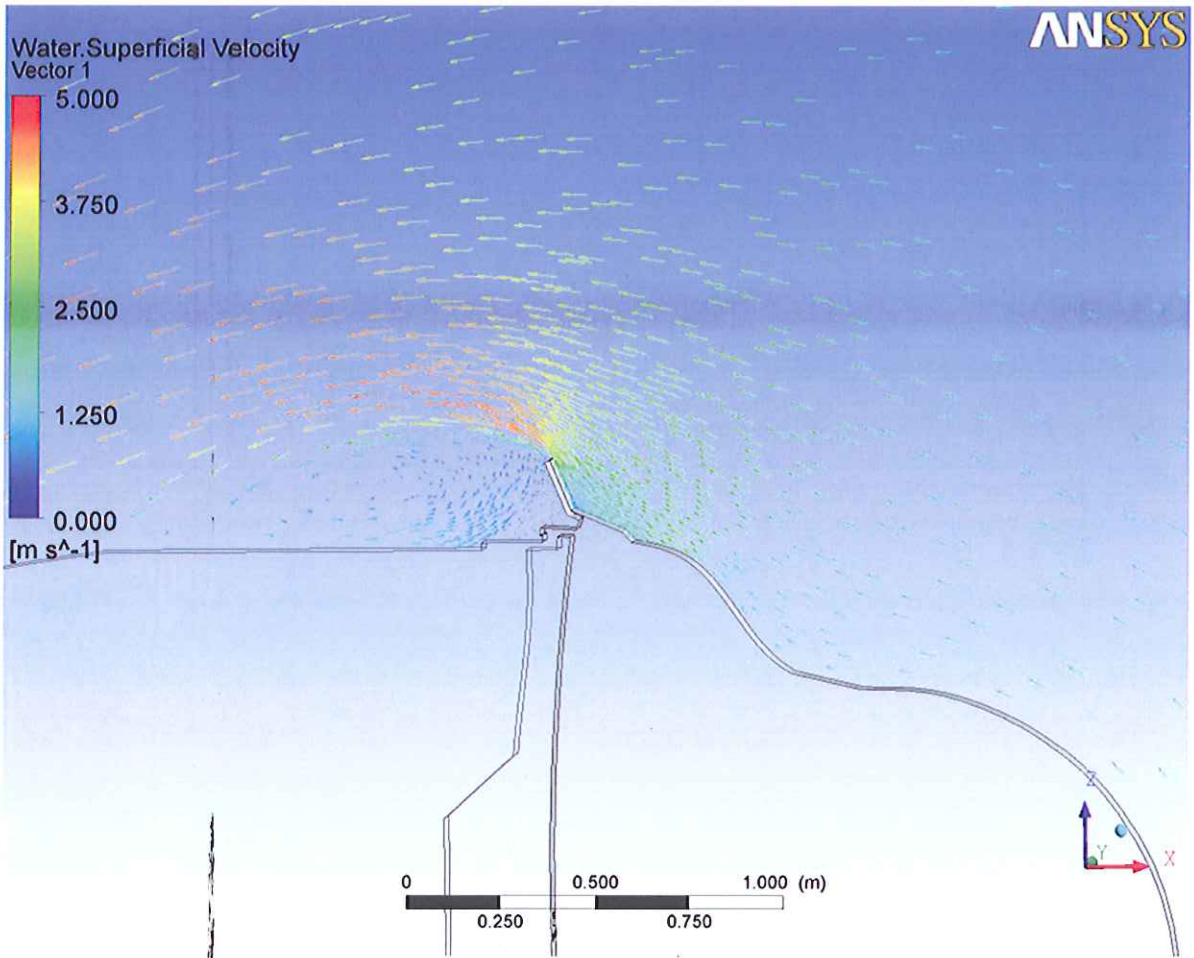


Figure 1 Effect of 45° fin on flow over gate

Further modelling is required to map the hydrodynamic response of the gates under increasing water levels, to ensure the floating behaviour issue will be permanently solved. Additionally, verification that the gates will be able to rise with the altered uplift is required.

Regards

Amanda Ament
Senior Structural Engineer - Dams

File Note

Date	18 October 2011
Project No	VW06478
Subject	**Lenthalls Dam - preliminary estimate of static head on gate**

This file note describes preliminary analysis of the static head on the bottom skin of the Lenthalls Dam spillway gates.

The calculations are based upon a number of reports and drawings provided for the purpose of peer review of the flood hydrology and no attempt was made to verify this data or explore whether additional details are available in other sources. The intention of the preliminary analysis reported here is to provide a timely input to the investigation of gate stability by Glen Hobbs and Associates.

It is understood that a CFD model is currently being developed by GHD and it would be expected that the results of such modelling would supersede these preliminary estimates.

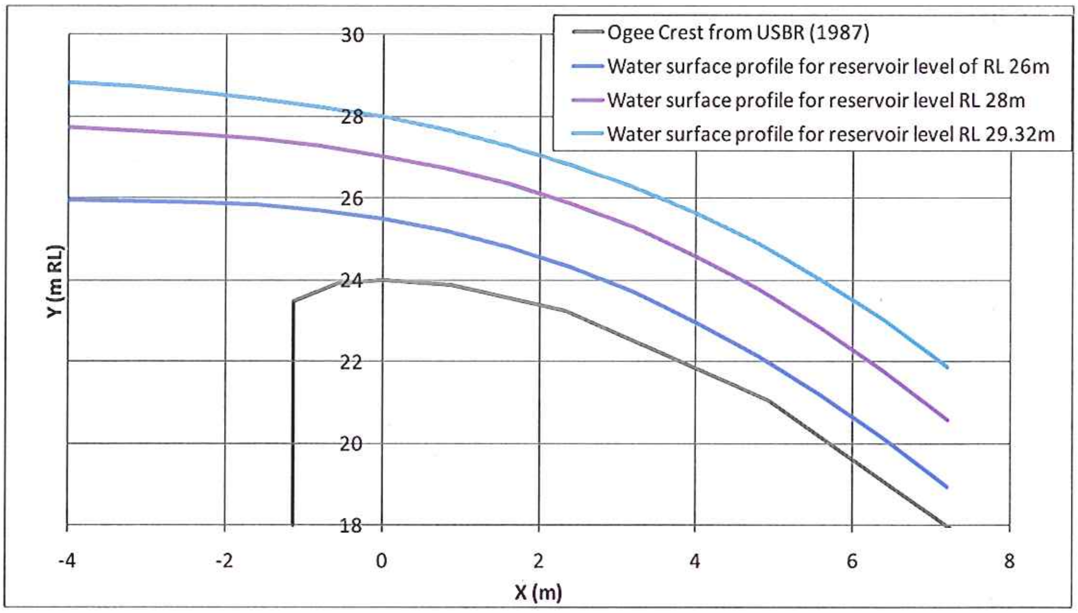
This preliminary analysis was performed for two scenarios:

- The gates are fully opened, so that the crest of the ogee controls the flow; and,
- The gates are 550 mm above the crest of the ogee, and therefore the surface water profile is similar to that of a sharp crested weir.

The derivation of the water surface profile for each of these scenarios is described in Sections 1 and 2, and the derivation of the static head on the bottom skin of the gate is described in Section 3.

1. Gates are fully opened

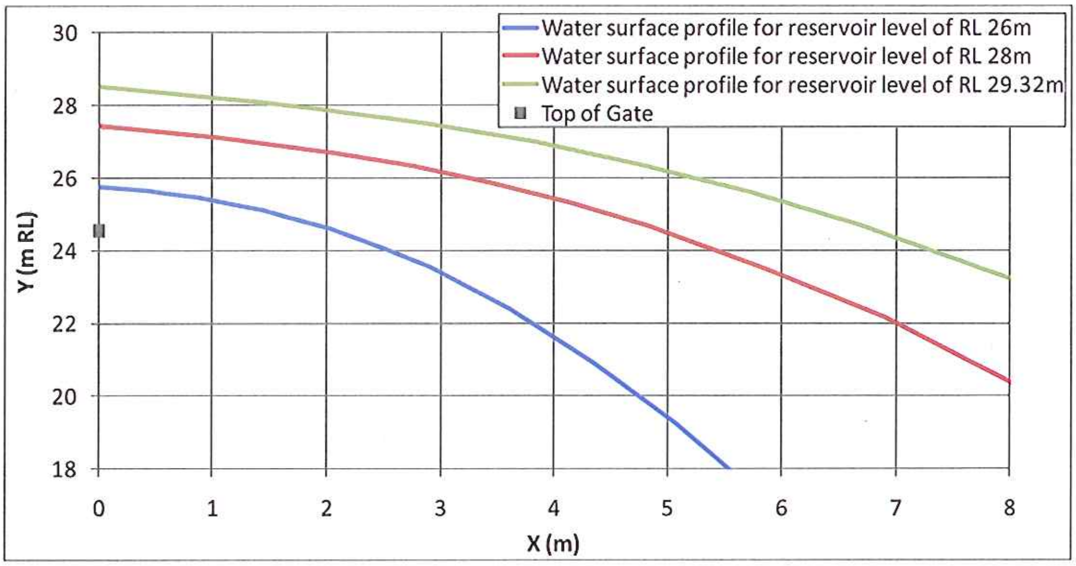
From the information provided, it appears that the construction of gates on the spillway did not involve altering the downstream shape of the ogee crest. From the original design reports of the spillway, it was found that the ogee crest was designed with a design head of 4 metres (GHD, 1982). It has been assumed that the constructed shape of the Lenthalls Dam ogee crest meets these specifications. Therefore, this information was used to determine the crest shape of the ogee using Design of Small Dams (1982), which was then used to locate the upstream face of the ogee. The coordinates of the water surface profile was then determined for different heads over the spillway crest using the USACE Hydraulic Design Criteria (sheets 111-11 to 111-14). This design criteria provides nappe coordinates for the head being 0.5, 1 and 1.33 times the design head. The results of this analysis are shown in Figure 1-1.



- **Figure 1-1: Preliminary water surface profiles over the Lenthalls Dam ogee crested spillway for different heads.**

2. Gates are 550 mm above the crest of the ogee

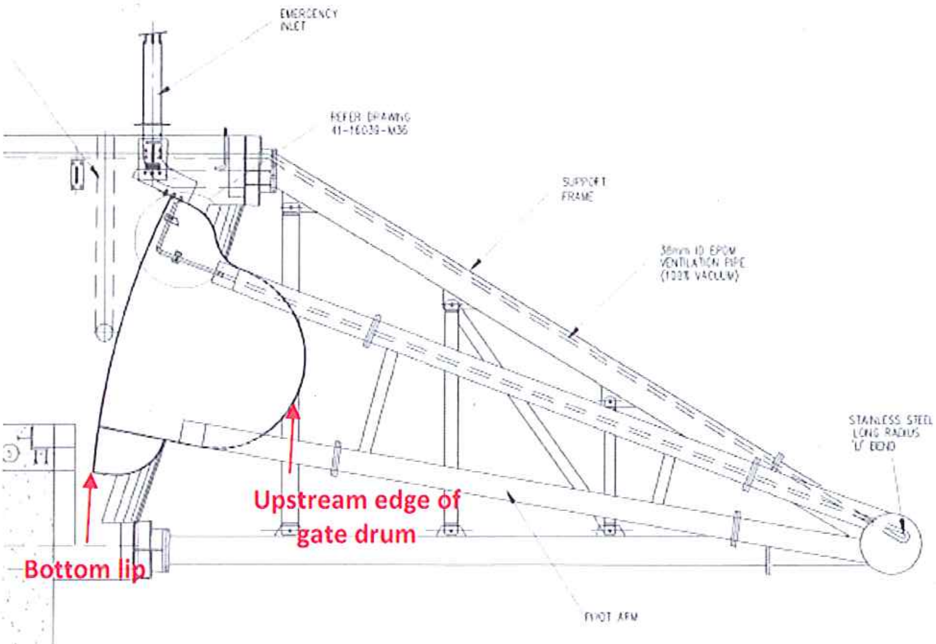
When a gate is 550 mm above the crest of the ogee, the edge of the gate controls the flow, and it has been assumed to act similarly to a sharp crested weir. The water surface profile for a sharp crested weir was obtained from Şentürk (1994). This reference provides coordinates of the water surface profile as it passes over the sharp crested weir, dependent on the head on the crest. The resultant water surface profiles for the three different heads used in Section 1 was determined, as shown in Figure 2-1. This profile assumes that the top of the sharp crested weir is approximately at an x-coordinate of 0.



- **Figure 2-1: Preliminary water surface profiles over the Lenthalls Dam gates when the top of the gates are 550 mm above the spillway crest (ie. at RL46.55m).**

3. Static Head on Gates

The static head was determined above two different locations on the gates, the bottom lip, and the most upstream edge of the gate drum. These locations are shown in Figure 3-1 and are described in the following sub-sections.



- **Figure 3-1: Two locations at which the static head has been determined for different reservoir water elevations.**

3.1 Bottom lip of gate

In order to determine the static head at the bottom lip of a gate, the elevation of this bottom lip was estimated using drawings 411-16039-M00 and 411-16039-M47 as:

- Gates fully opened – RL 21.455 m
- Gates 550mm above spillway crest – RL 22.042 m

To determine the static head above the bottom lip of a gate, it was assumed that the bottom lip is located at the upstream face of the ogee crest (x position -1.136 in Figure 1-1) where the gates are fully opened, and directly below the top of the gate crest (x position 0 in Figure 2-1) where the gates sit 550mm above the spillway crest.

The static head of water above the bottom edge of the skin of the gates is provided in Table 3-1. These results should be viewed in line with the assumptions listed throughout this file note. In particular, it should be noted that the basis of these results are the water surface profiles derived in Sections 1 and 2 which have been derived from theoretical results for a range of crest shapes.

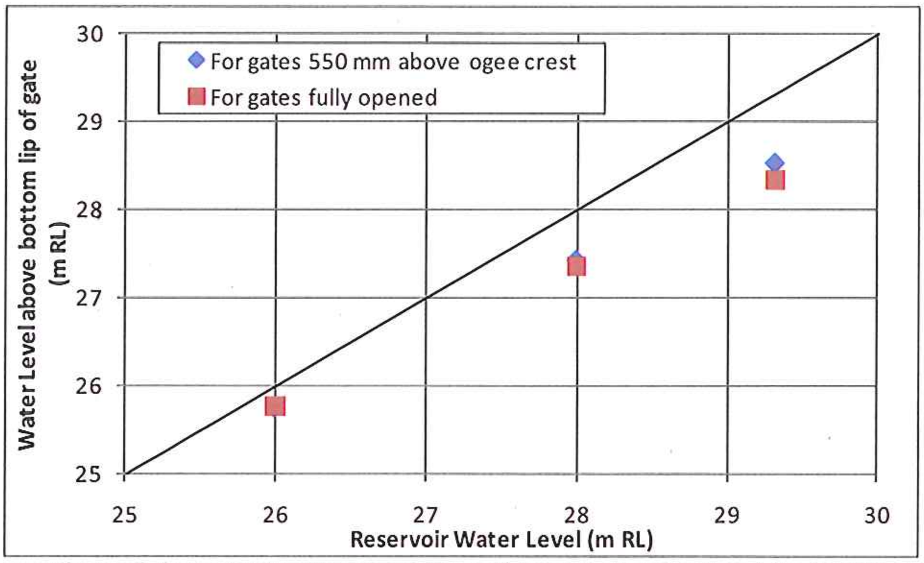
Figure 3-2 compares the reservoir elevation (ie. the total head) to the water surface elevation above the bottom of the gates, and this shows that for higher total heads, there is a greater velocity head component, which is the difference between the 1 to 1 line and the water levels above the bottom lip of the gate.

- **Table 3-1: Preliminary estimate of static head above the bottom lip of the gates.**

Reservoir Elevation (mRL)	Gates fully opened[1]		Gates 550mm above ogee crest[2]	
	Water surface profile above bottom lip of gate (mRL)	Static head above bottom lip of gate (m)	Water surface profile above bottom lip of gate (mRL)	Static head above bottom lip of gate (m)
26.00	25.76	4.30	25.75	3.71
28.00	27.36	5.90	27.42	5.37
29.32	28.32	6.87	28.51	6.47

[1] This assumes the ogee crest forms the hydraulic control. See Section 1.

[2] This assumes that the top of the gate acts as a sharp crested weir. See Section 2.



- **Figure 3-2: Preliminary comparison of reservoir water level (ie. total head) and the water level above the bottom lip of the gate.**

3.2 Upstream edge of gate drum

The static force on the most upstream edge of the gate drum was also calculated. The upstream edge of the drum was determined to be at a location of:

- 1678 mm from the lip described in Section 3.1 for the case where the gate is fully closed;
- 1677 mm from the lip described in Section 3.1 for the case where the gate is 550 mm above the crest of the spillway.

The elevation of the most upstream face of the drum was determined to be:

- 22.789 mRL for the case where the gate is fully closed; and,
- 23.247 mRL for the case where the gate is 550mm above the crest of the spillway.

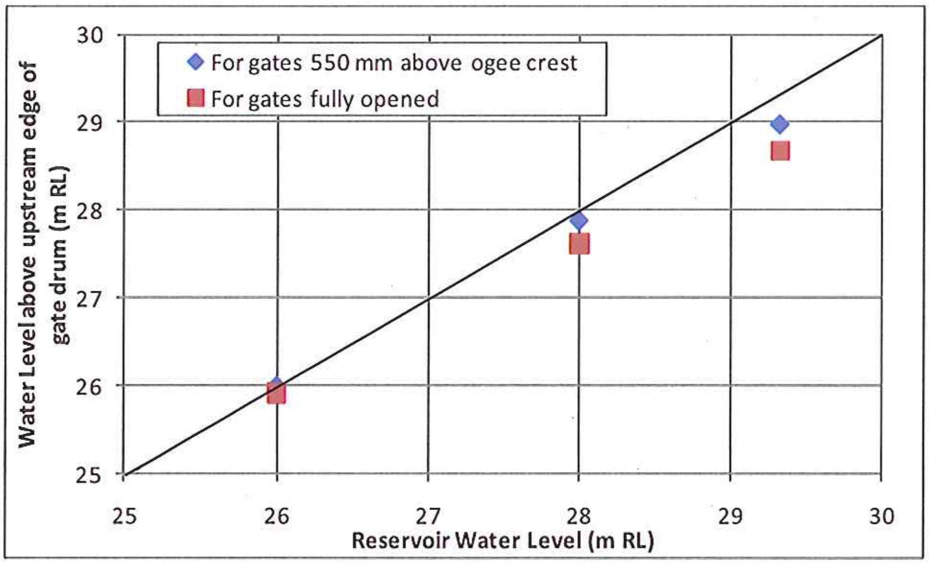
The results of this analysis are shown in Table 3-2 and Figure 3-3. Note that the results for the case where the gates are 550mm above the ogee crest have been linearly extrapolated outside of the relationship described in Section 2 to provide an approximate level upstream of the sharp crested weir. Figure 3-3 shows that at the upstream face of the gate drum, the static head is higher, and therefore the velocity head is lower than at the bottom lip of the gate (discussed in Section 3.1).

- **Table 3-2: Preliminary estimate of static head above the upstream edge of the gate drum.**

Reservoir Elevation (mRL)	Gates fully opened[1]		Gates 550mm above ogee crest[2]	
	Water surface profile above bottom lip of gate (mRL)	Static head above bottom lip of gate (m)	Water surface profile above bottom lip of gate (mRL)	Static head above bottom lip of gate (m)
26	25.92	3.13	26.00	2.75
28	27.62	4.83	27.89	4.64
29.32	28.67	5.89	28.98	5.74

[1] This assumes the ogee crest forms the hydraulic control. See Section 1.

[2] This assumes that the top of the gate acts as a sharp crested weir. Note that these results were extrapolated past the values provided in Şentürk (1994). See Section 2.



■ **Figure 3-3: Preliminary comparison of reservoir water level (ie. total head) and the water level above the upstream edge of the gate drum.**

4. References

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Memorandum

19 October 2011

To	Wide Bay Water, Peter Care		
Copy to			
From	[redacted]	Tel	[redacted]
Subject	Progress on Lenthalls crest gates solution	Job no.	41/19335/06

Peter,

Progress this week has been good, with a number of 2D CFD models run with three different spoiler sizes, to gain an understanding of the relative effectiveness of each, and their effect on discharge. The three spoiler sizes are 125 mm, 250 mm and 500 mm. Output from the CFD models showing the effect on the flow over the crest are included below for each spoiler size. The spoiler itself can be seen on the top lip of the gate, angled at approximately 45 degrees towards the downstream direction.

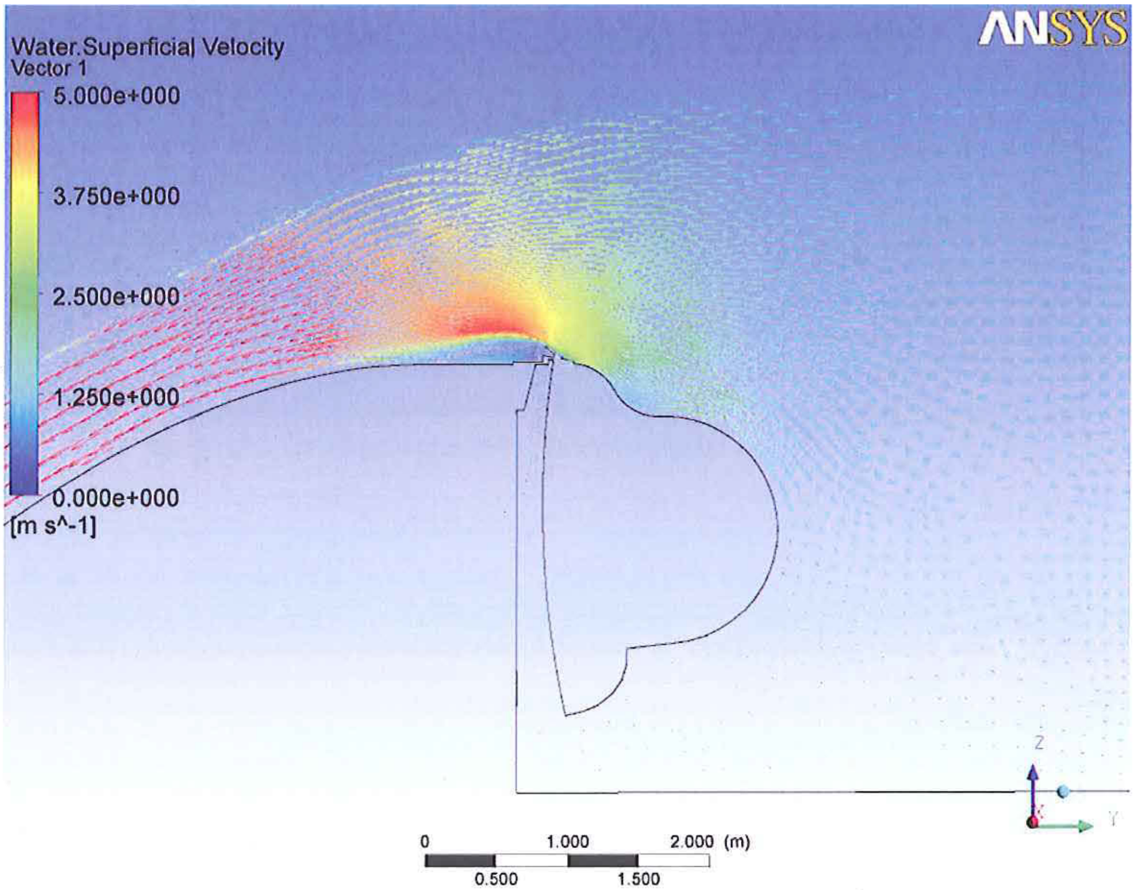

Figure 1 Flow vectors for 125 mm spoiler

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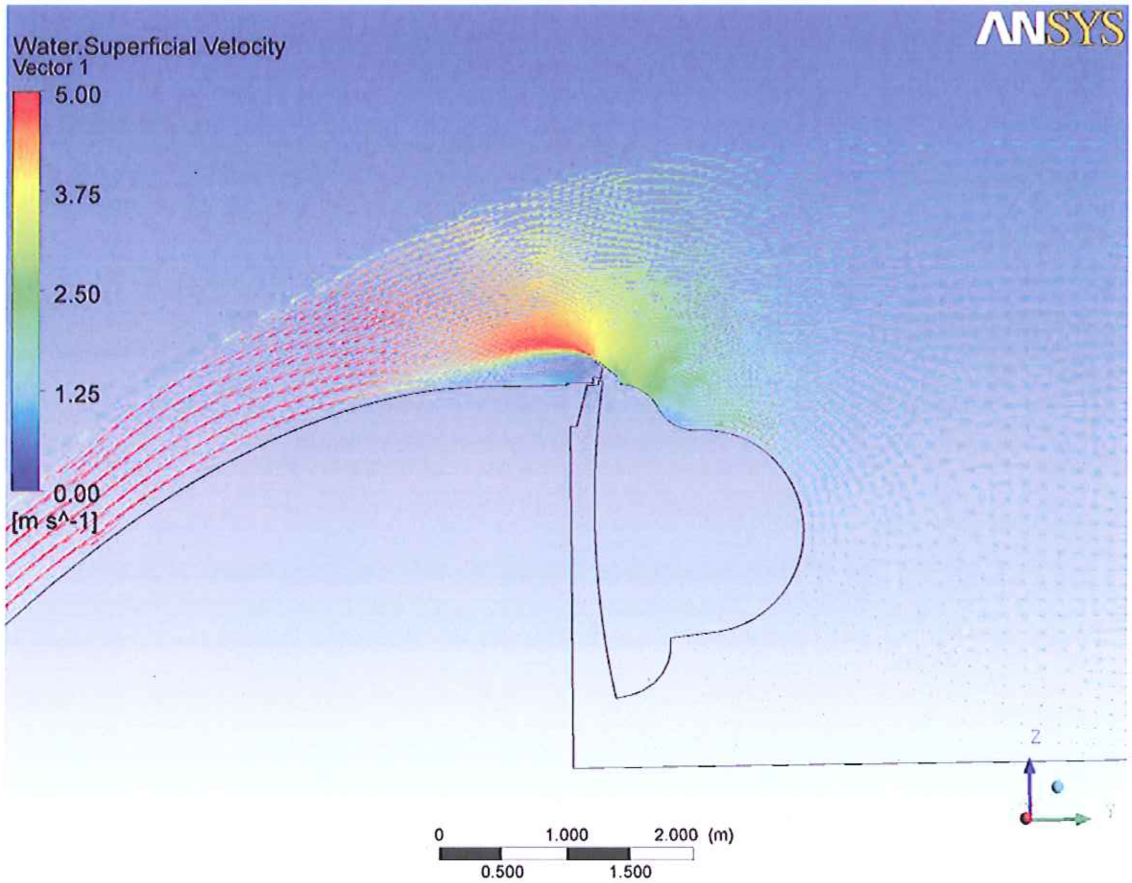


Figure 2 Flow vectors for 250 mm spoiler

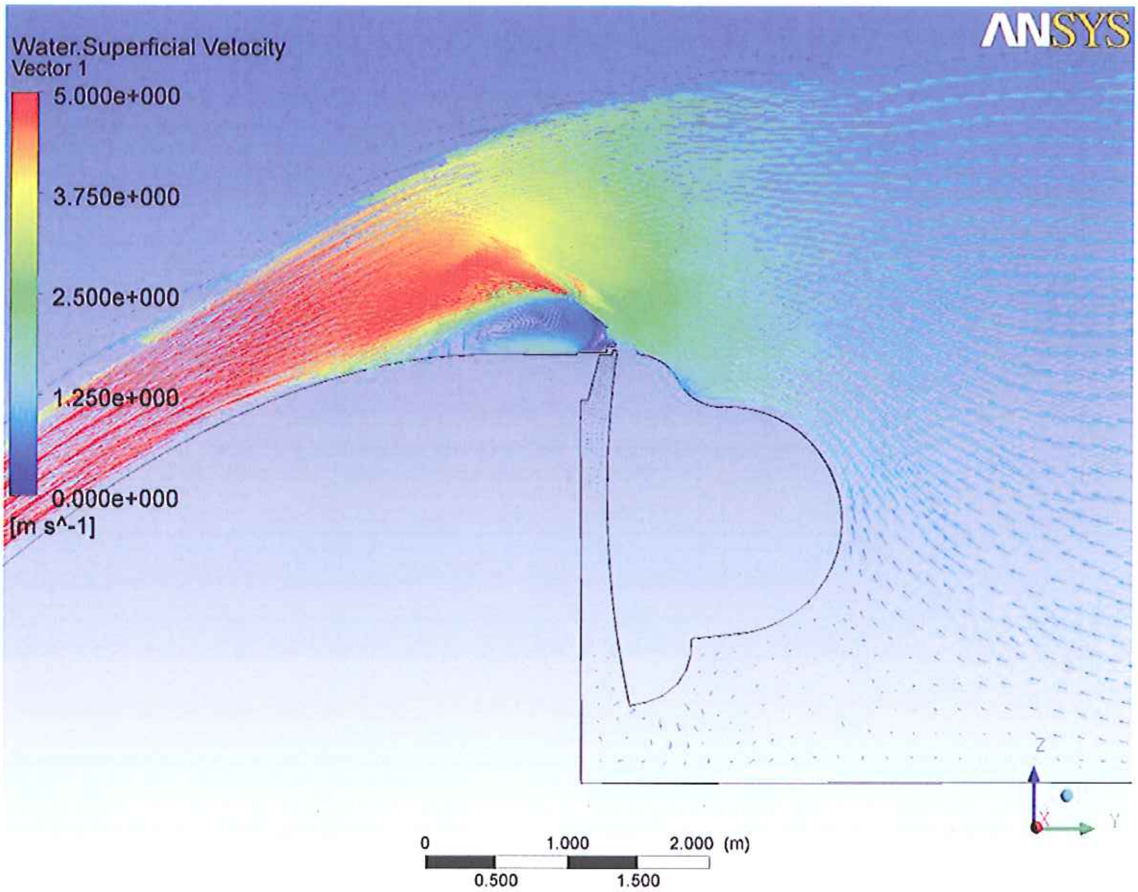
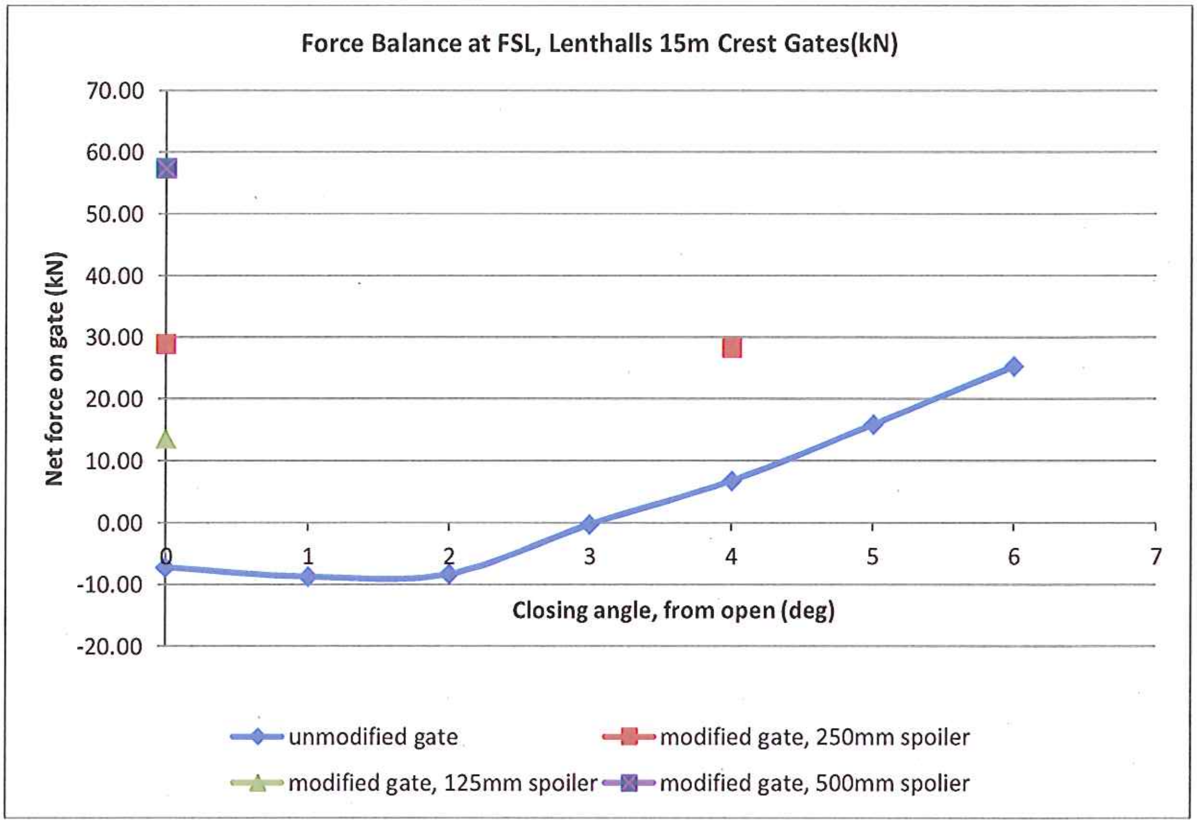


Figure 3 Flow vectors for 500 mm spoiler

A plot of the net gate forces for each size can be seen below, assuming that each spoiler is fixed to the top of the gate for the full length of the buoyancy tank. This will not be the final proposed arrangement, as it is intended to make the spoilers discontinuous across the top of the buoyancy tank, to aid in the visual understanding that these modifications will not increase the FSL.

This plot will be expanded as more data is obtained from the modelling runs.



It can be seen from the plot how the modelling predicts a position of neutral buoyancy for the unmodified gate at a closing angle of approximately 3 deg. 3 deg closed corresponds to a vertical displacement of around 400mm above crest level. This is consistent with observations on site.

The next steps to be performed in the design will be:

- Selection of spoiler size
- Conduct 2D CFD runs with selected spoiler for the closing angles of 1 deg to 6 deg inc, similar to the unmodified gate
- Confirm ability of gate to close and open effectively with the new spoiler
- Conduct 2D CFD runs at the following flood levels, with selected spoiler and unmodified gate for comparison
  - 2011 flood level of RL 28.12 m
  - Intermediate flood level (1:500ARI) of RL 29.55 m
  - PMP DF flood level of RL 34.57 m
- Create 3D CFD model to finalise design of spoiler extents along buoyancy tank

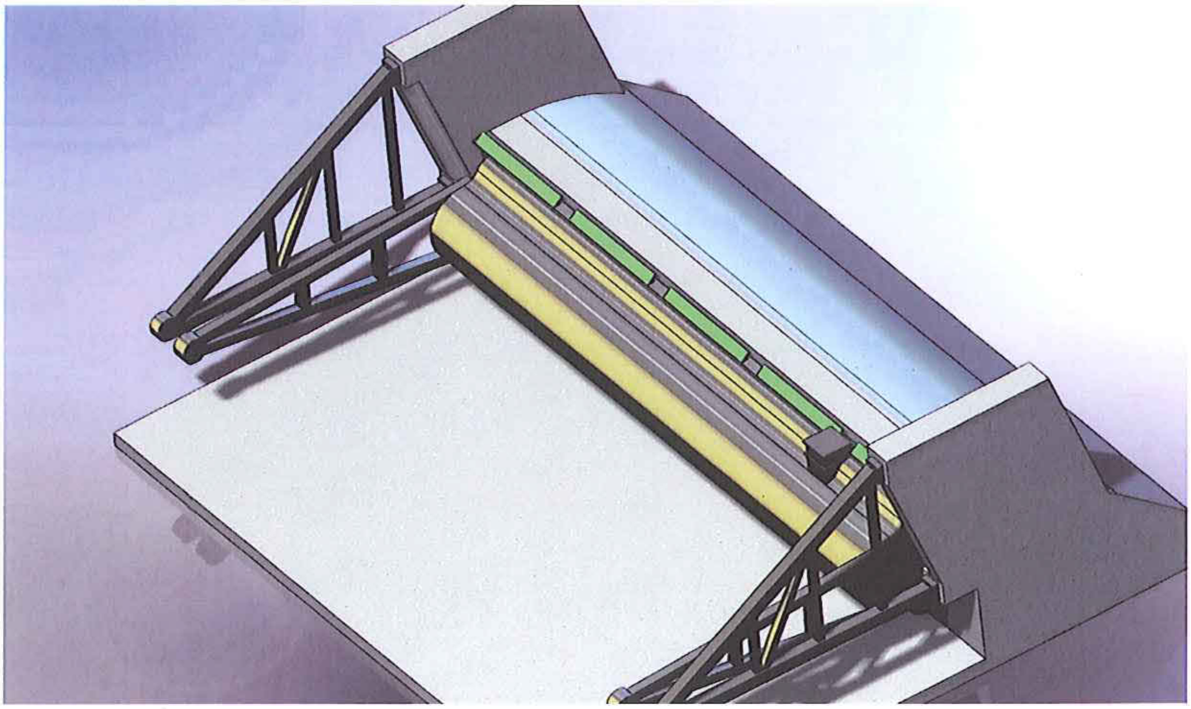


Figure 4 Current Solidworks model showing possible spoiler layout

The discharge coefficient for the spillway will be altered by the addition of the spoiler. From the 2D modelling, the discharge coefficient at FSL is altered by the spoilers as seen in Table 1:

Table 1 Influence of Spoiler Size on Discharge Coefficient at FSL

Gate arrangement	Discharge coefficient
Unmodified	2.14
125 mm spoiler	2.02
250 mm spoiler	1.95
500 mm spoiler	1.79

We expect that once the effect of the discontinuous installation of the spoilers is captured in the 3D model, the above discharge coefficients should increase.

Regards

[redacted]

Senior Structural Engineer - Dams

Memorandum

07 November 2011

To	Wide Bay Water, Peter Care		
Copy to			
From	[redacted]	Tel	[redacted]
Subject	Concept development, Lenthalls Crest Gates	Job no.	41/19335/04

Peter,

Since the last memorandum, dated 19 October 2011, a number of spoiler layouts and sizes have been investigated, gaining further understanding into the relative efficiency of the different spoiler shapes and fixing locations. All of this work was performed with the reservoir at FSL, consistent with previous runs.

Subsequently, investigations began into the performance of the spoiler concept in flood conditions. A plot has been included below.

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