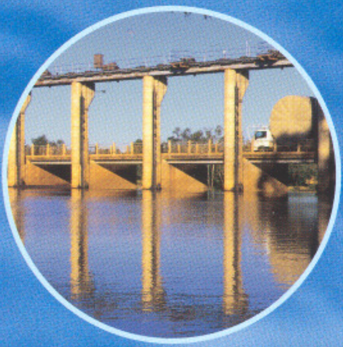


Report

Wivenhoe Dam

Assessment of Wivenhoe Dam Full Supply Level on Flood Impacts

Date: December 2007
Ref: P-AEXP-1802-AE-02
File: 07-006242/001

SunWater

Prepared by:

SunWater

120 Edward Street, Brisbane
PO Box 15536 City East
Brisbane Queensland Australia 4002

Tel: [redacted]
Fax:
www.sunwater.com.au

Author: [redacted]

Mr Terry Malone
Senior Engineer, Hydrology
Asset Solutions

Approved: [redacted]

Mr Rob Ayre RPEQ 4887
Engineering Design Manager
Asset Solutions

Report

Wivenhoe Dam

Assessment of Wivenhoe Dam Full Supply Level on Flood Impacts

Date: December 2007
Ref: P-AEXP-1802-AE-02
File: 07-006242/001

Prepared for:
SEQWater

EXECUTIVE SUMMARY

SEQWater requested SunWater to investigate the impact of the raising of the FSL of Wivenhoe Dam on Wivenhoe and Somerset Dam and flooding of areas downstream. The raising is being considered as an option to assist to secure South-East Queensland's water supplies.

The program WIVOPS was used to simulate the current gate operation procedures for three scenarios of FSL 67m AHD (current), FSL 68m AHD and FSL 69m AHD under different assumptions. A range of events from 1 in 50 AEP up to the PMPDF and durations from 24 to 120 hours were considered. Existing trigger levels for gate operations were adopted with the increased FSLs. This assumption results in a reduction in the available flood storage volume. Modifications to the gate operation triggers for small floods were also investigated but found to have little or no impact on the range of events tested. In the second case, the impact of one gate inoperable at Wivenhoe was also considered.

Based on a number of height and flow criteria, the result of these analyses show that raising the FSL of Wivenhoe Dam would marginally increase the vulnerability of Somerset Dam and significantly increase the vulnerability of Wivenhoe Dam. It would have a significant effect on the ability of the dams to mitigate floods in the Brisbane River. The main results are summarised as follows:

- The impact on Somerset Dam is generally minor with only small increases in peak headwater levels and a negligible impact in the risk of DCF and structurally damaging floods.
- At Wivenhoe Dam, there is a significant increase in the risk of reaching the critical gate operating level from an AEP of 1 in 330 to 1 in 100. Similarly, the risk of fuse plug initiation increases from 1 in 4,500 AEP to 1 in 2,300 AEP. The impact on the design flood level remains unchanged.
- The risk of damaging floods downstream of Wivenhoe increases from about 1 in 260 to 300 AEP and 150 to 220 AEP, depending on the location.

- With one gate inoperable at Wivenhoe, the trend is for a noticeable increased risk of reaching criteria levels and damaging flows within the Brisbane River.

This investigation has also identified a number of limitations of the scope of the study and methodology adopted. Given the assumptions made, the findings of this study should only be viewed as indicative of the impacts that could be expected to the risk of flooding in the Brisbane River, should Wivenhoe FSL be increased.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

ABREVIATIONS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
DCF	Dam Crest Flood
EL	Elevated Level
FSL	Full Supply Level
NR&W	Department of Natural Resources and Water (formerly NRM)
PMF	Probable Maximum Flood
PMPDF	Probable Maximum Design Flood

1.0 INTRODUCTION

SEQWater requested SunWater to investigate the impact of the raising of the FSL of Wivenhoe Dam on Wivenhoe and Somerset Dams and flooding at locations downstream. The raising is being considered as an option to assist to secure South-East Queensland's water supplies.

The aim of the study was to objectively assess the risk to the structures themselves and to flooding downstream of the dams. As such, estimates of flow and height have not been rounded in order to assess relativity.

2.0 DESIGN FLOODS

A full range of design events from 1 in 50 AEP up to the PMPDF was considered for storm durations from 24 to 120 hours. In addition, the historical events in 1893, 1974 and 1999 were also considered.

The design hydrological data for these events has been previously derived in several studies. The design flood estimates were based upon design rainfall, loss rate data and temporal and spatial data described in the Wivenhoe Alliance study (2005). In that study, design rainfalls were assumed to be spatially varied in the catchments above Wivenhoe Dam.

Downstream of Wivenhoe Dam, the design flows were assumed to be those resulting from uniform design rainfall 60% of those depths above the dam. This is a relatively simplistic assumption which does not necessarily reflect the patterns of historical events.

3.0 FSL SCENARIOS

The assessment required SunWater to compare impacts based upon the scenarios outlined in Table 3-1.

Table 3-1: FSL Scenarios

Scenario	Full Supply Level (m AHD)	Operating Procedures
1	67.0	Current Operating Procedures
2	68.0	Current Operating Procedures
3	68.0	Modified Operating Procedures
4	69.0	Current Operating Procedures
5	69.0	Modified Operating Procedures

4.0 OPERATING PROCEDURES

The assessment also required SunWater to examine the impact of the altered FSL based upon Current Operating Procedures and Modified Operating Procedures.

The Current Operating Procedures are summarised in Table 4-1 and details can be found in Table 8.5 of *Manual of Operational Procedures for Flood Mitigation for Wivenhoe and Somerset Dam* (SEQWater Dec 2004).

The manual currently defines a target level of EL 77.0m AHD in Wivenhoe Dam for the operation of Somerset Dam (Table 9.2). It is understood that a recommendation has been made to SEQWater to increase this level to EL 80.0m AHD and this is reflected in the draft of the new manual. As such, a target level of EL 80m AHD has been adopted in this study.

Table 4-1: Current Operating Procedures

Procedure	Reservoir Level	Criteria
0	EL < 67.25	QWivenhoe = 0
1A	67.25 < EL < 67.50	QWivenhoe <110 m3/s
1B	67.25 < EL < 67.50	QWivenhoe < 380 m3/s
1C	67.75 < EL < 68.00	QWivenhoe < 500 m3/s
1D	68.00 < EL < 68.25	QWivenhoe < 900 m3/s
1E	68.25 < EL < 68.50	QWivenhoe < 1500 m3/s
2	68.50 < EL < 74.00	QLowood < 3,500 m3/s
3	68.50 < EL < 74.00	QLowood < 3,500 m3/s
4	EL > 74.00	Gates fully open

The Modified Operating Procedures involved the following changes:

- Procedure 1B & 1C combined to a new Procedure with a limiting Wivenhoe discharge of 1,000 m3/s, and;
- Procedure 1D & 1E combined to a new Procedure with a limiting Wivenhoe discharge of 1,500 m3/s.

The trigger levels for the Modified Operating Procedures are dependent upon the adopted FSL and are as shown in Table 4-2.

Table 4-2: Modified Operating Procedures

Procedure	Reservoir Level	Criteria
0	EL < (FSL+0.25)	$Q_{Wivenhoe} = 0$
1A	(FSL+0.25) < EL < (FSL+0.50)	$Q_{Wivenhoe}$ <110 m^3/s
1B&C	(FSL+0.25) < EL < (FSL+0.50)	$Q_{Wivenhoe}$ < 1000 m^3/s
1D&E	(FSL+0.75) < EL < (FSL+1.00)	$Q_{Wivenhoe}$ < 1500 m^3/s
2	(FSL+1.00) < EL < (FSL+1.25)	Q_{Lowood} < 3,500 m^3/s
3	(FSL+1.25) < EL < (FSL+1.50)	Q_{Lowood} < 3,500 m^3/s
4	(FSL+1.50) < EL < 74.00	Gates fully open

There is some argument that the trigger level for the fully open gates should be increased to accommodate the increase in FSL so as to maintain the current available flood storage volume above EL 74.0m AHD. This would result in more frequent triggering of the fuse plugs and reduced flood immunity for Wivenhoe Dam. As such, at this stage, it was decided not to increase this trigger level for Case 1. However, it might be considered in future investigations.

In addition, the study required an assessment of the impact of a single gate failure for critical durations for selected AEPs (Q_{1000}, Q_{2000}, Q_{5000}, Q_{10000} and Q_{50000}).

Based on the number of scenarios, the number of durations, AEPs and historical events to be investigated nearly 450 runs are required. Within each run, height and/or flow information is generated for the following locations:

- Somerset Dam - Inflow, outflow and ELs;
- Wivenhoe Dam - Inflow, outflow and ELs;
- Lockyer Creek – outflow;
- Bremer River – outflow;
- Lowood – flow;
- Moggill – flow.

5.0 METHODOLOGY

5.1 WIVOPS

The FORTRAN program, WIVOPS, is used to determine the operational procedures for Wivenhoe and Somerset gate movements based upon the criteria summarised in Tables 4-1 and 4-2. There is little documentation available on WIVOPS and the code has been modified on several occasions to meet changing dam configurations (fuse plugs) and to investigation changes to operating procedures.

The general strategy of the WIVOPS program is to:

1. Route flows through Wivenhoe Dam, initially assuming no outflow from Somerset Dam.
2. Route flows through Somerset Dam using the computed headwater elevations of Wivenhoe Dam.
3. Iterate (1) & (2) until convergence of the computed headwater elevations is achieved. Comparison of the Somerset Dam headwater level determines when an iteration is complete.

The overall principal for the operation of Wivenhoe gates is to test what the result will be at the end of the next time step. The options are then to open or close the next gate, or to leave gates 'as is'. Note the program only provides for gate operations for Wivenhoe Dam and does not take into account regulator openings.

Full hydrographs of flow and height are generated for several locations.

Besides the design or historical inflow hydrographs, WIVOPS requires a number of input files:

- wvstorge.dat - Stage/storage relationship for Wivenhoe Dam;
- somstorg.csv - Stage/storage relationship for Somerset Dam;
- wvrating.csv - Stage/gate height/gate flow relationship for 1 gate of Wivenhoe Dam;
- gateopen.dat - Gate opening/closing sequence for Wivenhoe Dam;

- fuse_data4.dat - Fuse plug configuration and failure flow characteristics;
- wiv_param2.txt - Dam starting conditions and run parameters;
- proclims2.dat - Dam operating procedures.

For the scenarios investigated, modifications are required to the dam starting conditions and run parameter file, wiv_param2.txt, and to the dam operating procedures file, proclims2.dat. Samples of these files are contained in Appendix A.

The current FSL of Wivenhoe (EL 67.0m AHD) was hard coded into the existing version of the program, making the assessment of changes to FSL difficult to carry out. A contractor, experienced with the code, was engaged to allow for changes to the FSL and modifications to the operating procedures to be assessed.

The modified WIVOPS program was then extensively tested and compared with the results of previous studies to ensure consistency pre and post modifications. The graph below, Figure 5-1, shows a comparison of the results from the 2005 Wivenhoe Alliance study and runs from the modified WIVOPS.

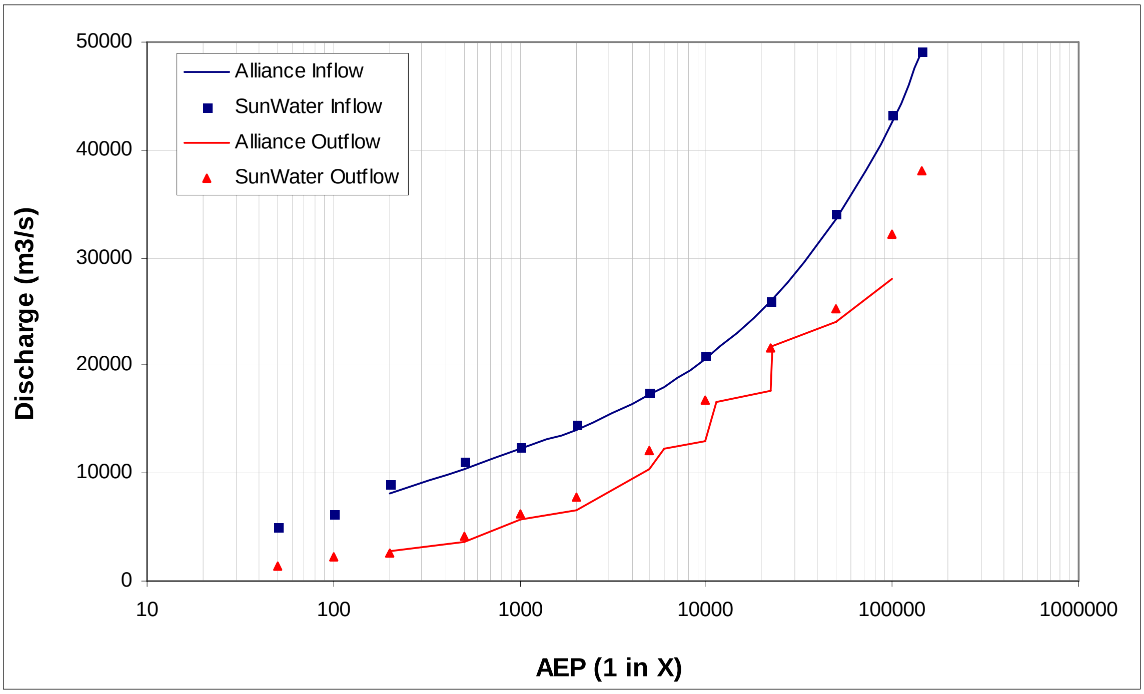


Figure 5-1: Design Flow Comparison

Not surprisingly, Figure 5-1 shows that there is very good consistency between the inflows used in both studies. There is also reasonable consistency between the modelled outflows in both studies up to the 1 in 100,000 AEP. It should be noted that the Alliance used the FLRoute model to determine the outflow hydrographs for events which initiated a fuse plug i.e. events > 1 in 6,000 AEP.

The steps in the Alliance outflow plot reflect the operation of the fuse plugs at these design inflows.

The comparison between the two studies gives confidence that the modifications to WIVOPS will be able to model changes in the FSL and adopted operating procedure.

5.2 COMPARISON OF SCENARIOS

At the commencement of the study, it was felt that modified operating procedures under Scenario 3 and Scenario 5 would produce only minor differences from Scenario 2 and 4 in the smaller floods.

The smallest event being investigated is the Q_{50} flood. In this event, under the current operating procedures, the modelled peak outflow from Wivenhoe Dam is estimated to be range from 1,489 m^3/s in the 24 hour event to 946 m^3/s in the 120 hour event. With procedure 1 applicable only up to a Wivenhoe outflow of 1,500 m^3/s, it is considered that the modified operating procedures will have little or no impact upon the majority of the events being investigated.

This was confirmed by running the 36 hour duration for the 1 in 500 AEP event for the 5 operating scenarios. In this event shown in Figure 5-2 and Figure 5-3, there was no discernable difference between Scenario 2 & 3 and Scenario 4 & 5 in terms of the peak level reached neither in Wivenhoe Dam nor in the outflow from the dam.

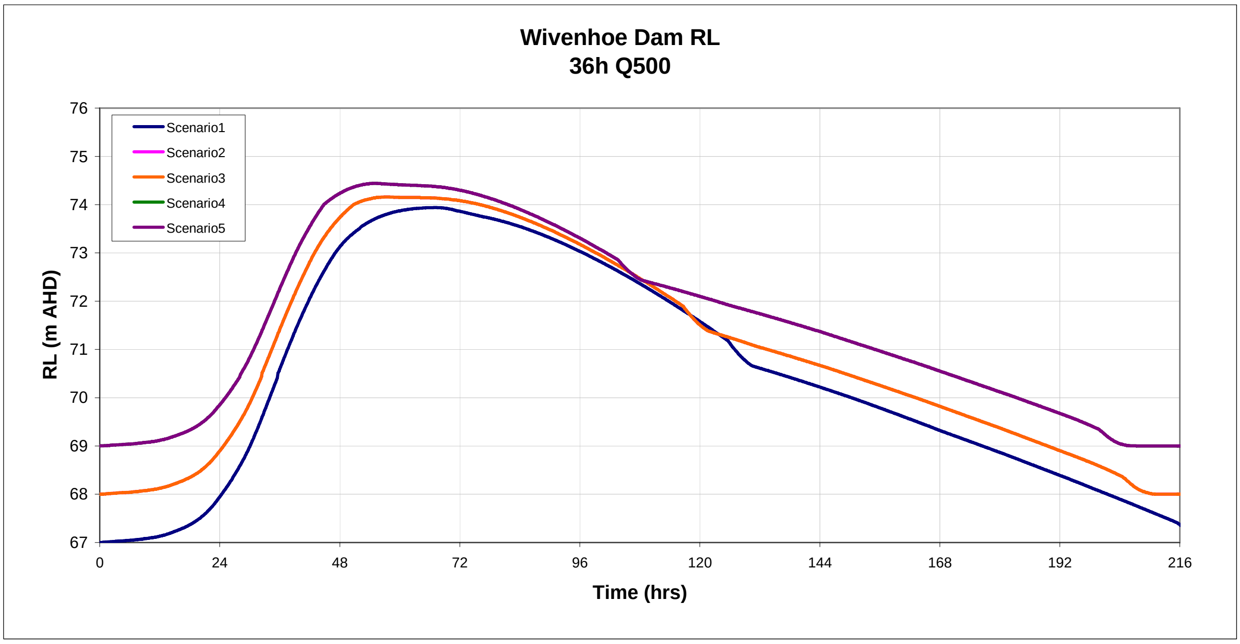


Figure 5-2: Comparison of Operating Scenarios on Wivenhoe Levels

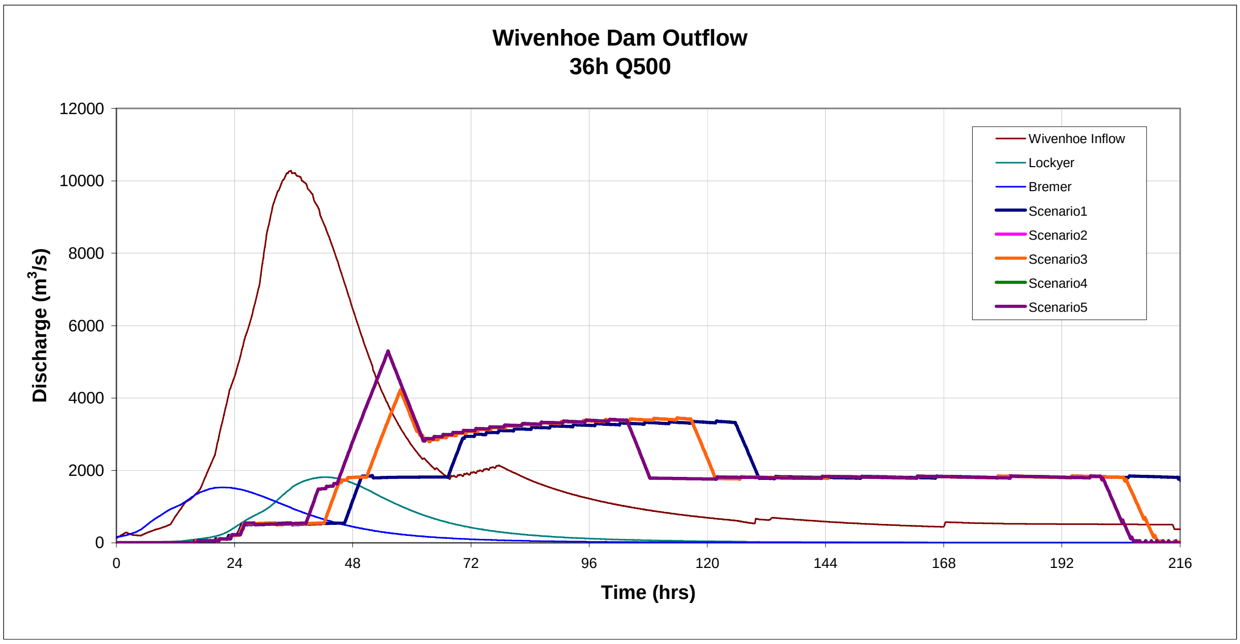


Figure 5-3: Comparison of Operating Scenarios on Flows

As such, it was decided to limit the investigation to two cases:

1. Case 1 – Full range of AEPs and durations for a target level of EL 74.0m AHD with all gates operable at Wivenhoe
2. Case 2 – Full range of AEPs for the critical duration for one gate inoperable at Wivenhoe

6.0 RESULTS

WIVOPS gives comprehensive details of the inflows, outflows, dam levels and downstream flows at several locations. In order to generate meaningful results, it was decided to report the impact of the change in Wivenhoe FSL on peaks of:

- Somerset Dam headwater level
- Wivenhoe Dam headwater level
- Wivenhoe outflow
- Lowood flow
- Moggill flow

Tables of the impact of changes to FSL on these parameters are contained in Appendix B.

The results presented below are summaries of the output of the WIVOPS program only and do not include any subjective judgement that might be applied to operation of the dams during actual events to improve mitigation. As such, the relative impact of the various FSL scenarios can be objectively assessed.

Both Somerset and Wivenhoe Dams are assumed to be full at the commencement of each event. This gives overly conservative estimates of the risk of particular floods. However, a joint probability approach of initial starting levels and design floods is beyond the scope of this investigation but might be considered in future studies.

6.1 CASE 1 RESULTS

In Case 1, the trigger level for Wivenhoe gate operations is set at EL 74m AHD. As a consequence, the available flood storage decreases with the increases in FSL under each scenario. This enables an assessment of the impact of the change in FSL at specific critical levels or flows. The graphs below show the absolute peak water level or flow over all duration events for a specific AEP.

6.1.1 Somerset Dam EL

The impact of raising the FSL of Wivenhoe Dam on peak flood levels in Somerset Dam is shown in Figure 6-1.

- Under Scenario 2 in a specific duration event, the peak of the water level can range from a 0.42m decrease in the 120h Q500 to a 0.69m increase in the 72h Q10000.
- Under Scenario 4 in a specific duration event, the peak of the water level ranges from a 0.82m decrease in the 120h Q100 to a 0.78m increase in the 24h Q50000.
- In the Q2000 over all durations, the increase in Wivenhoe FSL actually results in a slight decrease of up to 0.4 m in the peak level in Somerset Dam. This is due to the early full operation of the Wivenhoe gates.
- The risk of the DCF reduces from about 1 in 6,500 AEP to about 1 in 8,000 with increasing Wivenhoe FSL.
- The AEP of the structurally damaging flood appears to be independent of the Wivenhoe FSL, remaining at about 1 in 45,000 AEP.
- Table 6-1 shows the impact on Somerset Dam peak water level on increasing the FSL in Wivenhoe Dam. Generally, there would be a small reduction in Somerset water level during such events.

Table 6-1: Impact on Somerset Dam Level during Historical Events

Event	EL (m AHD)	Change (m)	
	FSL 67	FSL 68	FSL 69
1893	107.57	-0.14	-0.14
1974	105.91	-0.19	-0.22
1999	105.06	-0.25	+0.01

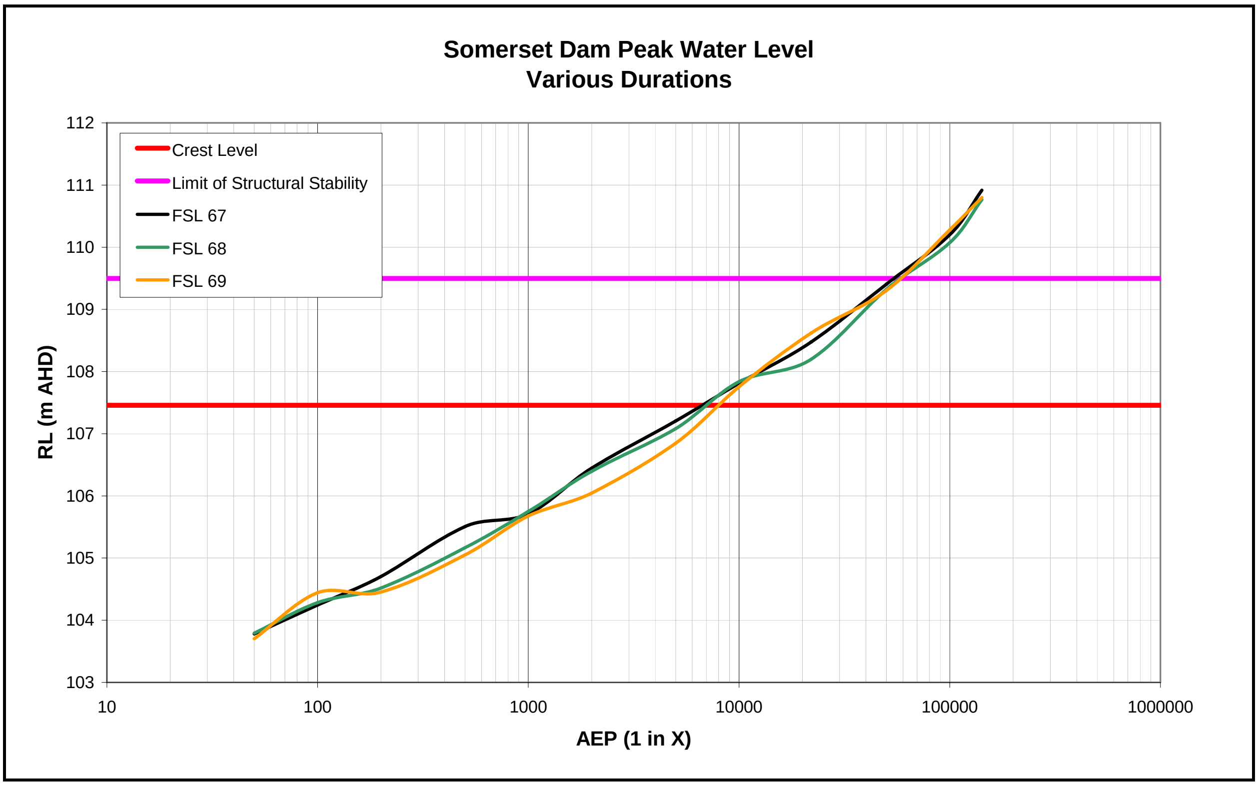


Figure 6-1: Somerset Dam Peak Water Level

6.1.2 Wivenhoe Dam EL

The impact of raising the FSL of Wivenhoe Dam on peak flood levels in the dam is shown in Figure 6-2.

- Under Scenario 2 in a specific duration event, the peak of the water level in Wivenhoe Dam can range from a 0.09m decrease in the 72h Q_{50000} to a 0.83m increase in the 96h Q_{50} and 120h Q_{50}.
- Under Scenario 4 in a specific duration event, the peak of the water level in Wivenhoe Dam ranges from a 0.51m decrease in the 24h Q_{50000} to a 1.89m increase in the 120h Q_{50}.
- Over the full range of AEPs, there in an increase in the peak Wivenhoe level under Scenario 2 and 4. This increase is greatest for the more frequent events and negligible for events with AEPs less than 1 in 20,000.

- The AEP of the flood which reaches the critical levels increases with the increases in FSL, as shown in the table below. It is noted that risk of fuse plug initiation derived in this study is slightly higher than that derived by the Alliance study (Wivenhoe Alliance 2005). However, the relativity of the risk with increasing FSL should be maintained.

Table 6-2: Water Level Increases - Wivenhoe Dam

Criteria	EL m AHD	AEP (1in X)		
		FSL 67	FSL 68	FSL 69
Critical Gate Operating Level	74.00	450	325	100
Fuse Plug 1 Initiation Level	75.80	4,500	3,500	2,300

- Table 6-3 shows the impact on Wivenhoe Dam peak water level on increasing the FSL. Not surprisingly, there is an increase in peak water levels under all scenarios.

Table 6-3: Impact on Wivenhoe Dam Level during Historical Events

Event	EL (m AHD)	Change (m)	
	FSL 67	FSL 68	FSL 69
1893	75.13	+0.06	+0.12
1974	74.15	+0.13	+0.24
1999	72.84	+0.37	+0.84

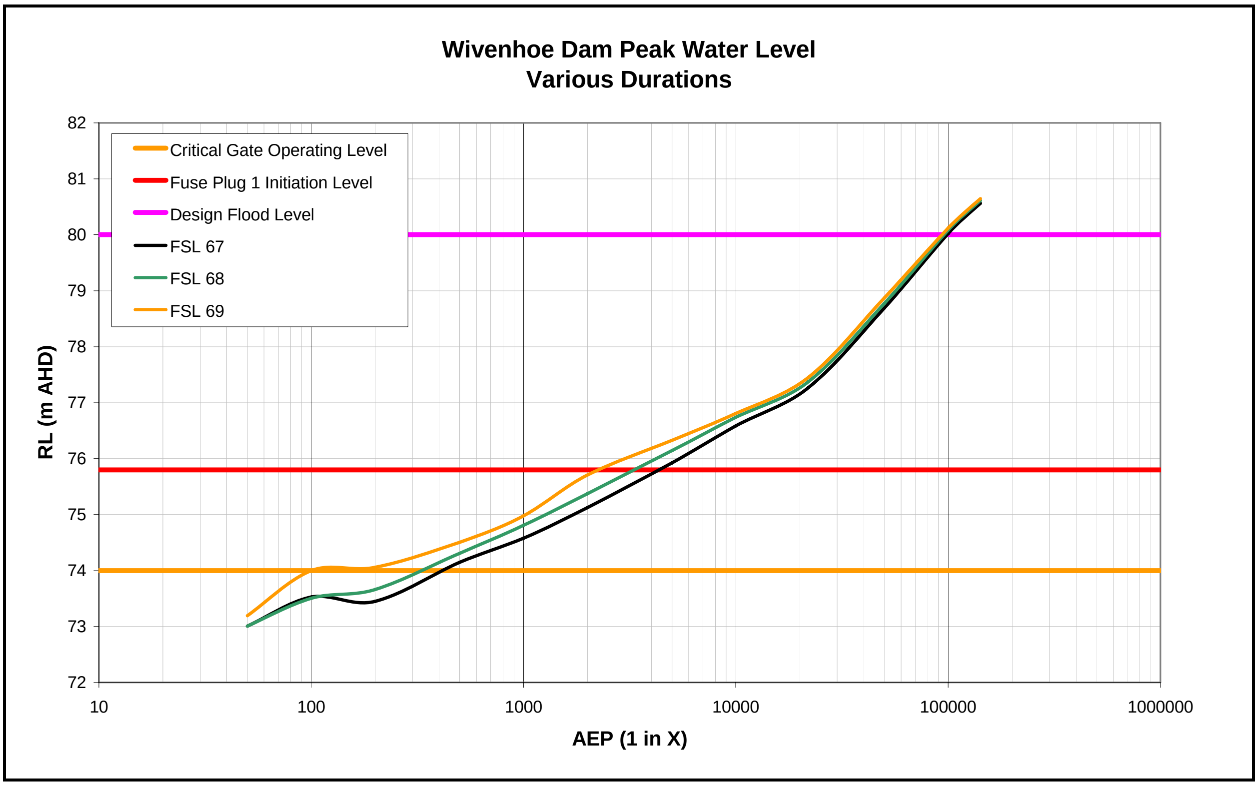


Figure 6-2: Wivenhoe Dam Peak Water Levels

6.1.3 Wivenhoe Dam Outflow

The impact of raising the FSL of Wivenhoe Dam on peak outflows from the dam is shown in Figure 6-3.

- Under Scenario 2 in a specific duration event, the peak of the Wivenhoe outflow ranges from a 14% decrease in the 72h Q_{10000} to a 45% increase in the 96h Q_{200}.
- Under Scenario 4 in a specific duration event, the peak of the Wivenhoe outflow can range from a 37% decrease in the 24h Q_{50} to a 68% increase in the 120h Q_{100}.
- In all AEPs more frequent than 1 in 2000, there is an increase in Wivenhoe outflow under Scenario 2 and 4 compared with the existing conditions.
- The risk of damaging floods (> 3,500 m^3/s) increases from about 1 in 300 AEP under current conditions to about 1 in 200 AEP under Scenario 4.
- Table 6-4 shows the impact on the outflow from Wivenhoe Dam peak on increasing the FSL. In all scenarios, discharge from Wivenhoe is increased, in some circumstances significantly.

Table 6-4: Impact on Wivenhoe Dam Outflow during Historical Events

Event	Peak Flow (m^3/s)	Change (%)	
	FSL 67	FSL 68	FSL 69
1893	9,512	+3	+6
1974	4,104	+25	+45
1999	1,484	+29	+25

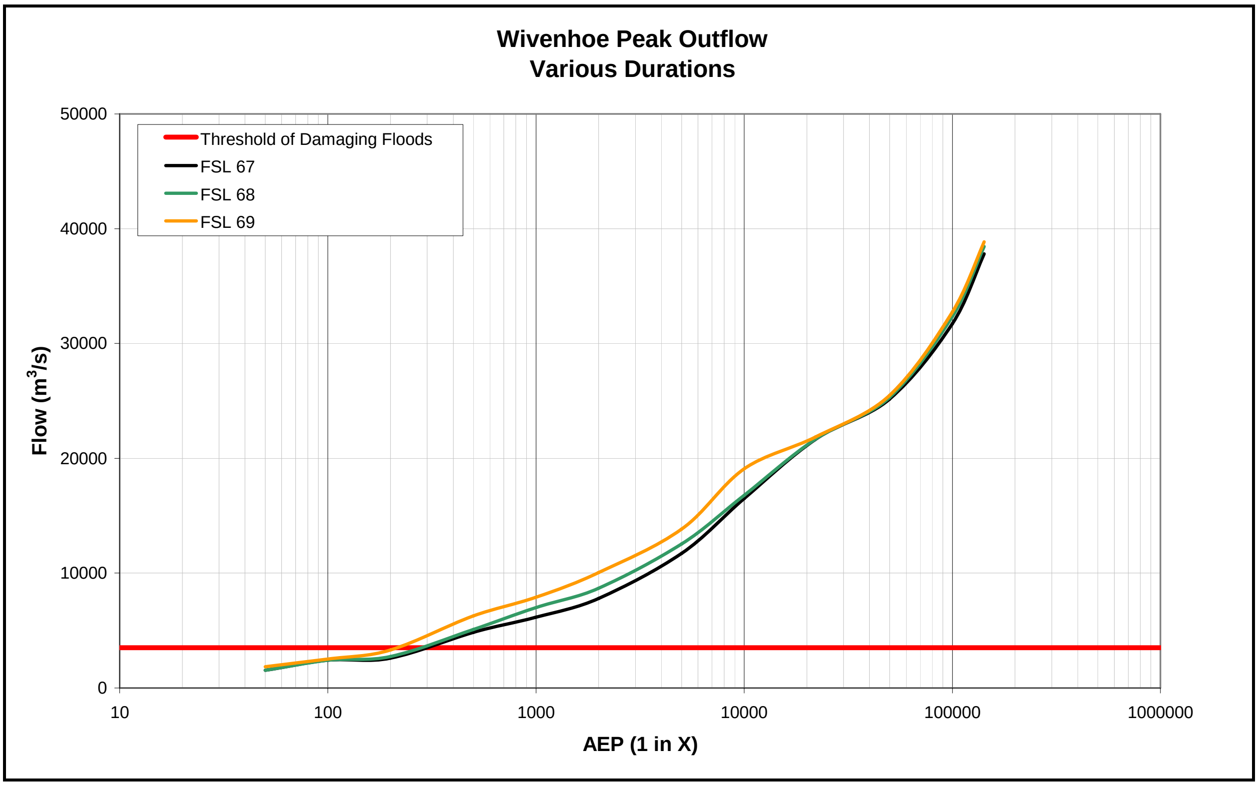


Figure 6-3: Wivenhoe Peak Outflows

6.1.4 Lowood Flow

The impact of raising the FSL of Wivenhoe Dam on peak flows at Lowood is shown in Figure 6-4.

- Under Scenario 2 in a specific duration event, the peak of the flow at Lowood ranges from a 20% decrease in the 120h Q_{100000} to a 79% increase in the 36h Q_{100}.
- Under Scenario 4 in a specific duration event, the peak of the flow at Lowood can range from a 37% decrease in the 24h Q_{50} to an 99% increase in the 36h Q_{500}.
- In all AEPs, there is an increase in Lowood flow under Scenario 2 and 4 compared with the existing conditions.
- The risk of damaging floods (> 3,500 m^3/s) increases from about 1 in 300 under current conditions to about a 1 in 150 AEP under Scenario 4.
- Table 6-5 shows the impact on the flow at Lowood on increasing the FSL in Wivenhoe. In all scenarios, flow at Lowood is increased, in some circumstances significantly.

Table 6-5: Impact on Flow at Lowood during Historical Events

Event	Peak Flow (m^3/s)	Change (%)	
	FSL 67	FSL 68	FSL 69
1893	11,154	+10	+5
1974	6,249	+19	+33
1999	1,485	+32	+30

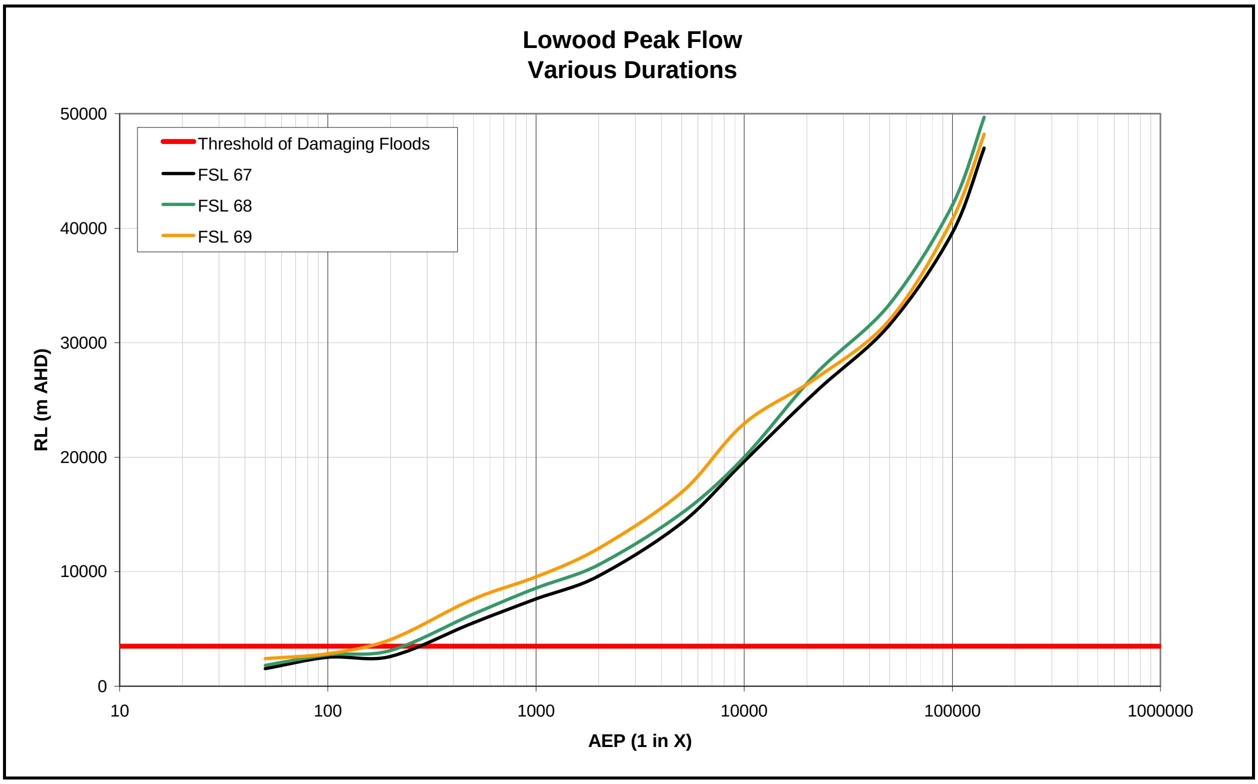


Figure 6-4: Lowood Flows

6.1.5 Moggill Flow

The impact of raising the FSL of Wivenhoe Dam on peak flows at Lowood is shown in Figure 6-5.

- Under Scenario 2 in a specific duration event, the peak of the design flow ranges from a 2% decrease in the 72h Q_{10000} to a 52% increase in the 24h Q_{1000}.
- Under Scenario 4 in a specific duration event, the peak of the design flow can range from a 39% decrease in the 24h Q_{50} to an 89% increase in the 36h Q_{500}.
- In all AEPs, there is an increase in the design flow at Moggill under Scenario 2 and 4 compared with the existing conditions. However, this difference is negligible in the rarer events.
- The risk of damaging floods (> 3,500 m^3/s) is similar under current conditions and Scenario2, about 1 in 250 AEP, and increases to about 1 in 150 AEP under Scenario 4.
- The threshold for damaging floods could be reached as soon as a 1 in 100 AEP event under an FSL of 69m AHD.
- Table 6-6 in all scenarios, flow at Moggill is increased, in some circumstances significantly.

Table 6-6: Impact on Flow at Moggill during Historical Events

Event	Peak Flow (m^3/s)	Change (%)	
	FSL 67	FSL 68	FSL 69
1893	11,220	+3	+5
1974	6,487	+20	+34
1999	1,553	+44	+47

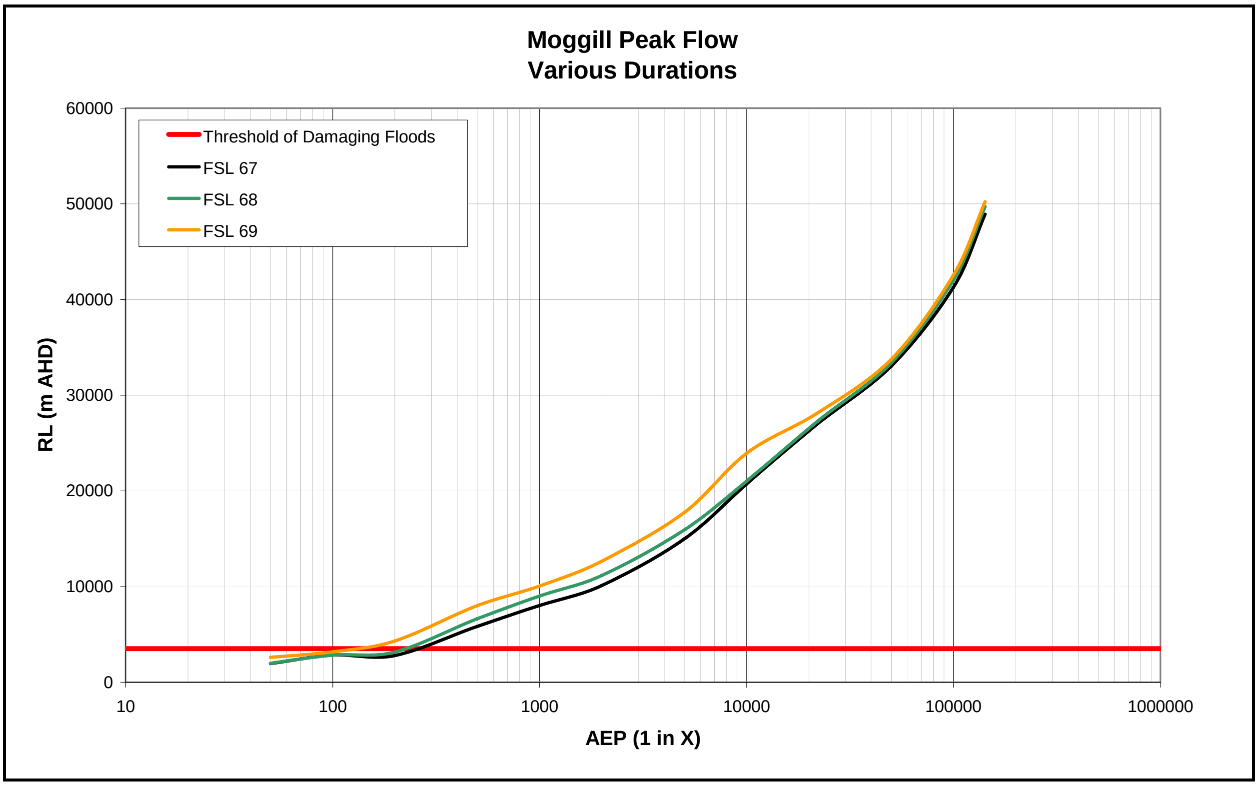


Figure 6-5: Moggill Flows

6.1.6 Case 1 Summary

The numbers of instances in which selected criteria are exceed in the range of durations and AEPs investigated are shown in Table 6-7. Not surprisingly, there is a marked increase in the number of instances with increasing Wivenhoe FSL.

Table 6-7: Occurrence of Selected Criteria

Location	Exceedance of…	Value	Unit	Scenario		
				FSL 67	FSL 68	FSL 69
Somerset Dam	Crest Level	107.46	m AHD	13	15	12
	Limit of Structural Stability	109.50	m AHD	11	10	12
Wivenhoe Dam	Critical Gate Operating Level	74.00	m AHD	18	21	24
	Fuse Plug 1 Initiation Level	75.80	m AHD	28	27	28
	Design Flood Level	80.00	m AHD	4	5	4
	Threshold of Damaging Floods	3,500	m^3/s	49	60	60
Lowood	Threshold of Damaging Floods	3,500	m^3/s	49	62	64
Moggill	Threshold of Damaging Floods	3,500	m^3/s	51	54	56

Specifically of note in Table 6-7 is, with increasing Wivenhoe FSL:

- The number of occurrences of the exceedance of the crest level and the limit of structural stability of Somerset Dam effectively remains constant.
- The number of occurrences of exceedance of the critical gate operating level increases significantly. However, the number of occurrences of the exceedance of fuse plug initiation and the design flood level effectively remains the same.

- The number of occurrences that the threshold of damaging floods in the reach between Wivenhoe and the Bremer junction increases significantly. However, the increase in the number of occurrences of damaging floods downstream of the Bremer junction is only small.

Table 6-8 contains the range of changes that occur in selected parameters under Scenario 2 (FSL 68m) and Scenario 4 (FSL 69m) for specific durations and AEPs.

Table 6-8: Maximum & Minimum Changes to Selected Criteria

Location	Criteria	Unit	FSL 68				FSL 69			
			Max Decrease		Max Increase		Max Decrease		Max Increase	
			Diff	Dur/AEP	Diff	Dur/AEP	Diff	Dur/AEP	Diff	Dur/AEP
Somerset Dam	EL	m	-0.42	120h Q_{500}	0.69	72h Q_{100000}	-0.82	120h Q_{100}	0.78	24h Q_{50000}
Wivenhoe Dam	EL	m	-0.09	72h Q_{50000}	0.83	96h Q_{50} 120h Q_{50}	-0.51	24h Q_{50000}	1.89	120h Q_{50}
Wivenhoe	Outflow	%	-14	72h Q_{10000} 96h Q_{100000}	45	96h Q_{200}	-37	24h Q_{50}	68	120h Q_{100}
Lowood	Flow	%	-20	120h Q_{100000}	79	36h Q_{100}	-37	24h Q_{50}	99	36h Q_{500}
Moggill	Flow	%	-2	72h Q_{10000}	52	24h Q_{1000}	-39	24h Q_{50}	89	36h Q_{500}

In the three historical floods considered, peak water levels in Somerset Dam are mostly lower but peak water levels in Wivenhoe are higher by as much as 0.84 metres. The raising of the FSL of Wivenhoe significantly increases the peak discharges downstream of the dam by as much as 33%.

Finally, Table 6-9 shows the risk of occurrence of the selected criteria previously analysed. The impact of raising Wivenhoe FSL on Somerset Dam appears to be minimal. However, at Wivenhoe Dam itself and for locations downstream, there is an increased risk of selected criteria being reached or exceeded.

The risk of reaching the critical operating level of EL 74m AHD increases from 1 in 430 to 1 in 100 AEP. Similarly, the risk of the fuse plugs being initiated nearly halves while the risk of reaching the threshold for damaging floods also increases significantly.

It should also be noted that the raising of Wivenhoe FSL will affect the critical duration for various criteria. It is difficult to accurate assess the impact to the critical storm durations due to the relatively large 24 hour time step between the durations considered. However, it is appears likely that the duration of the critical storms will decrease with increasing FSL. This effect is demonstrated by the reduction in the critical duration for damaging floods.

Table 6-9: Risk of Occurrence

Location	Exceedance of	Value	Unit	FSL 67		FSL 68		FSL 69	
				AEP (1 in ..)	Crit Dur (hrs)	AEP (1 in ..)	Crit Dur (hrs)	AEP (1 in ..)	Crit Dur (hrs)
Somerset Dam	Crest Level	107.46	m AHD	6,500	48	7,000	72	8,000	48
	Limit of Structural Stability	109.50	m AHD	55,000	48	55,000	48	55,000	48
Wivenhoe Dam	Critical Gate Operating Level	74.00	m AHD	430	72	330	48	100	48
	Fuse Plug 1 Initiation Level	75.80	m AHD	4,500	36	3,500	36	2,300	36
	Design Flood Level	80.00	m AHD	95,000	36	95,000	36	95,000	36
	Threshold of Damaging Floods	3,500	m^3/s	300	72	300	48	220	48
Lowood	Threshold of Damaging Floods	3,500	m^3/s	280	72	240	48	160	48
Moggill	Threshold of Damaging Floods	3,500	m^3/s	260	72	230	48	150	48

6.2 CASE 2 RESULTS

In Case 2, the impact of having one gate inoperable at Wivenhoe for critical durations for selected AEPs (Q_{1000}, Q_{2000}, Q_{5000}, Q_{10000} and Q_{50000}) was investigated.

Examination of the results in Table 6-9 indicates that the critical duration for the initiation of the fuse plugs and reaching the design flood level is 36 hours and the threshold of damaging floods is 48 hours. For investigation of Case 2, the 36 hour duration has been selected as this will have greatest impact on Wivenhoe Dam itself.

Under current the operation procedures, with one gate inoperable, the opening of the remaining gates is adjusted to achieve the same discharge. This cannot be carried out in the existing WIVOPS which has the number of available gates (five) hard coded into the program. As a first pass, the input rating for one gate was reduced by 20% to account for one gate inoperable. It is recognised that this produces an overly conservative result up to EL 73m AHD at which level the inoperable gate would be over topped.

Further modifications will be required to WIVOPS to correctly model the outflow from the dam with one gate inoperable.

Similarly to Case 1, the results are presented in graphs which show the criteria in scenario 1 with all gates operating and the criteria with 1 gate inoperable under the three scenarios considered.

6.2.1 Somerset Dam EL

As shown in Figure 6-6, there are no appreciable differences between all gates operating and one gate inoperable with increasing Wivenhoe FSL, except in the vicinity of the 1 in 2,000 AEP flood where peak levels are about 0.3 metres under Wivenhoe FSL of 69m AHD.

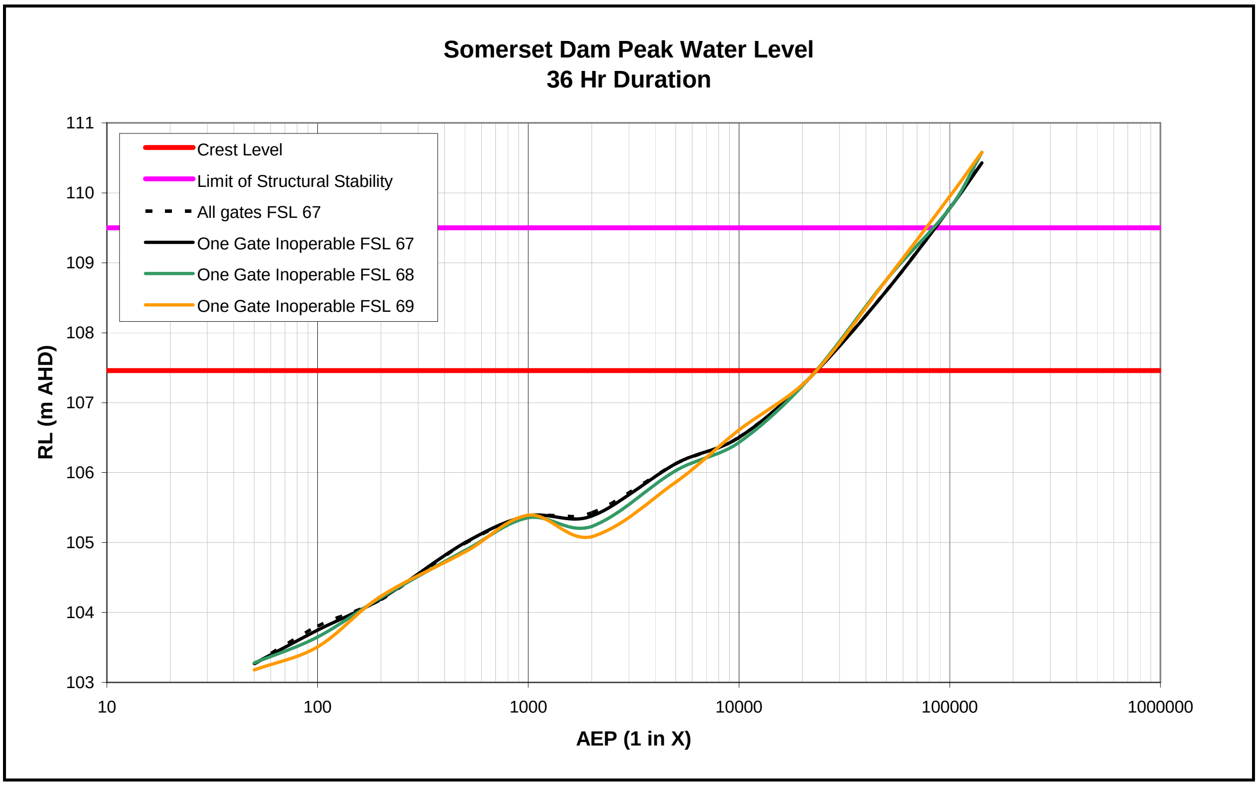


Figure 6-6: Somerset Dam Peak Water Level (One Gate Inoperable)

6.2.2 Wivenhoe Dam EL

Figure 6-7 shows that, for an FSL of 67m, the impact of one gate inoperable at Wivenhoe has little impact on floods up to 1 in 1,000 AEP. For rarer floods, peaks levels in Wivenhoe are up to 0.3 m higher.

However, peak flood levels under the scenarios of FSL of 68m AHD and 69m AHD are significantly higher. For floods which peak higher than EL 75.8m AHD, the level of the fuse plug, there are only small differences between the scenarios.

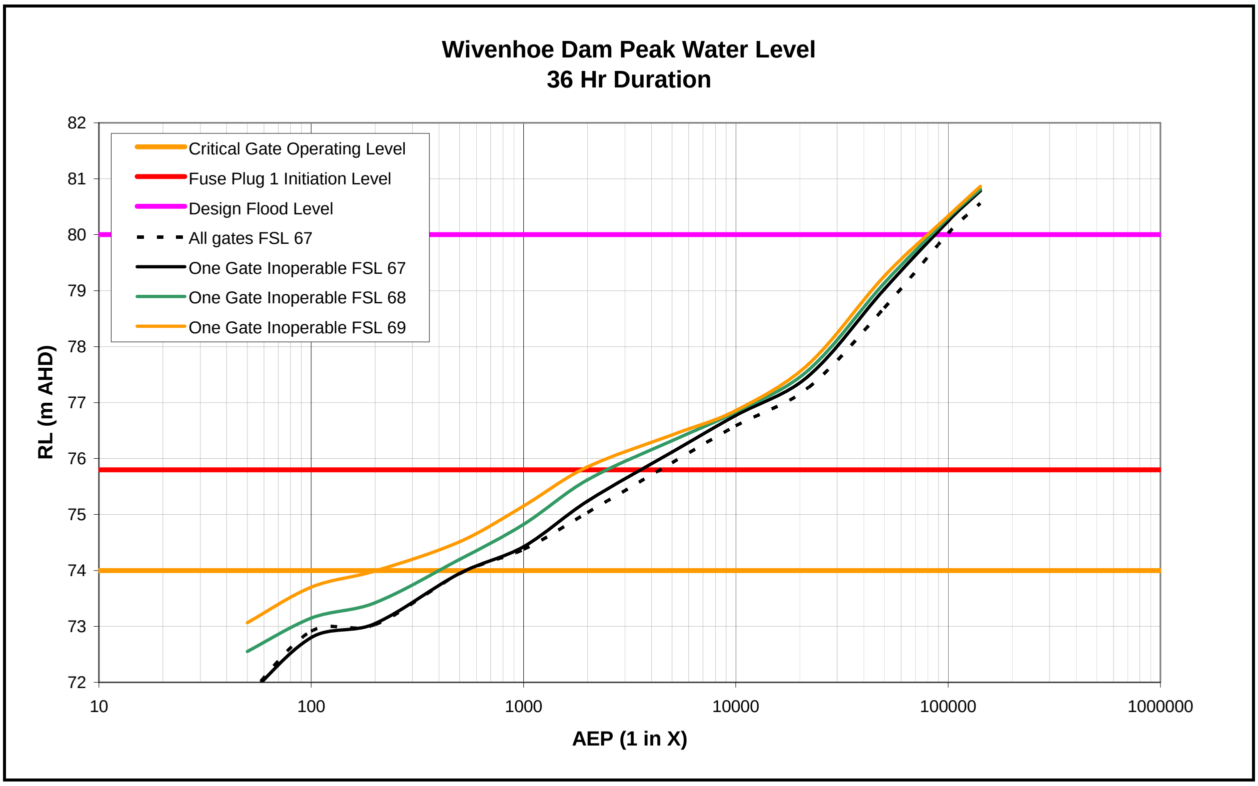


Figure 6-7: Wivenhoe Dam Peak Water Level (One Gate Inoperable)

6.2.3 Wivenhoe Dam Outflow

Generally, as shown in Figure 6-8, there is little difference between all gates operating and one gate inoperable for an FSL of 67m AHD.

Outflow from the dam is higher with one gate inoperable up until fuse plug initiation. Beyond this point, there are only small increases between the scenarios.

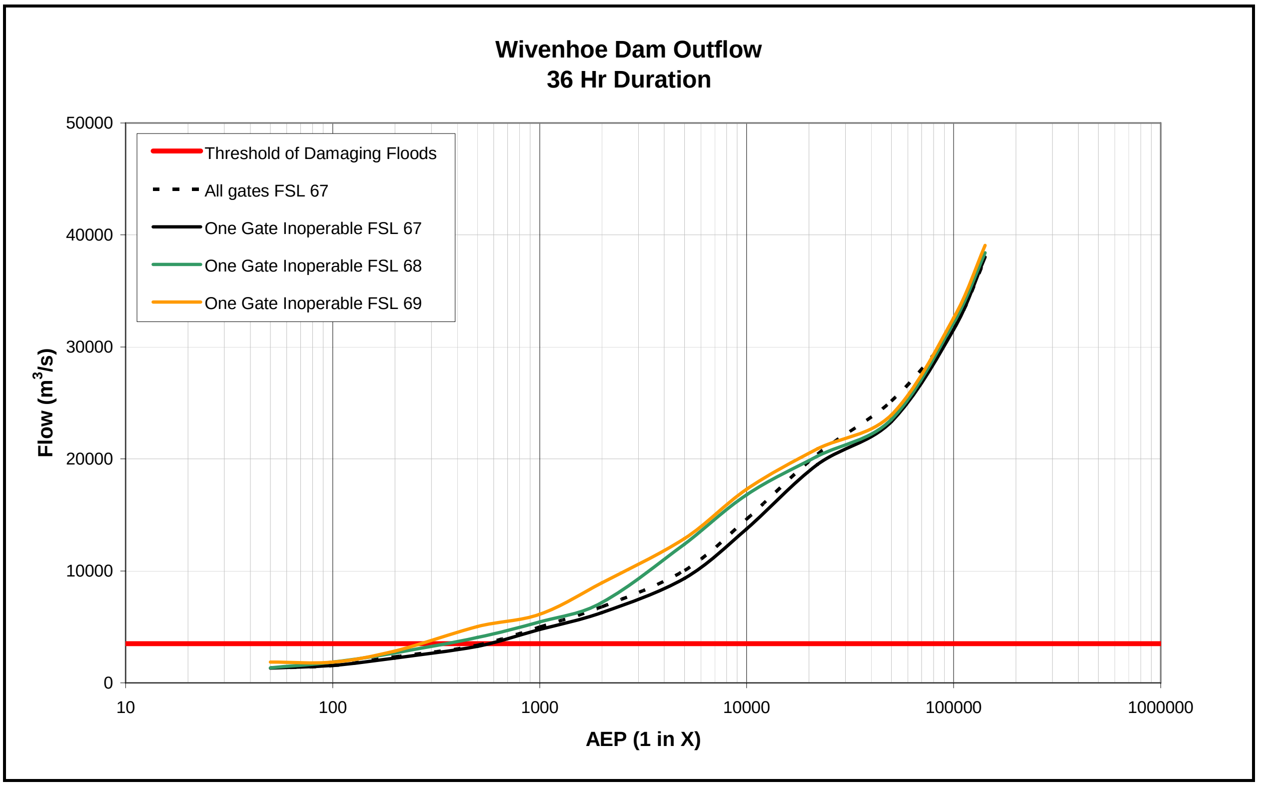


Figure 6-8: Wivenhoe Dam Outflow (One Gate Inoperable)

6.2.4 Lowood Flow

The raising of Wivenhoe FSL with one gate inoperable has a similar impact on the flows at Lowood and Moggill as that of the Wivenhoe outflows.

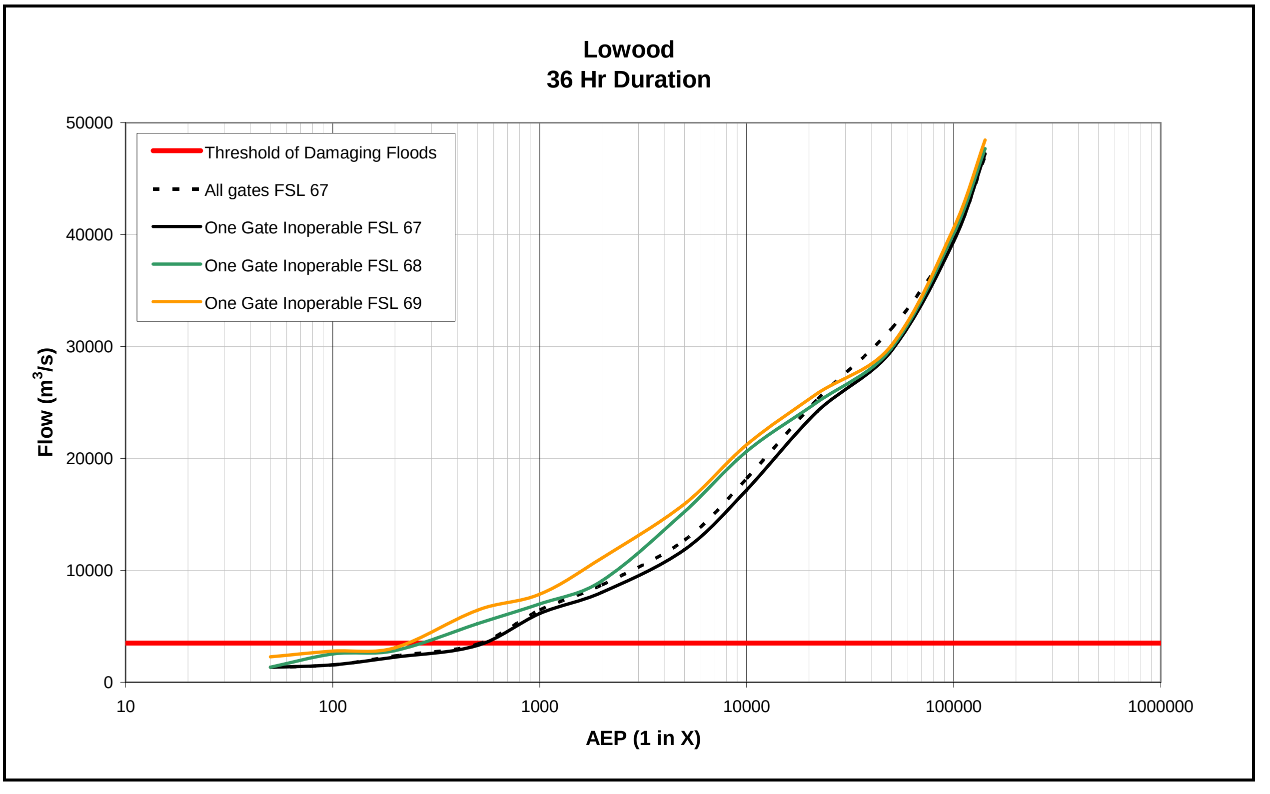


Figure 6-9: Lowood Flow (One Gate Inoperable)

6.2.5 Moggill Flow

The raising of Wivenhoe FSL with one gate inoperable has a similar impact on the flows at Lowood and Moggill as that of the Wivenhoe outflows.

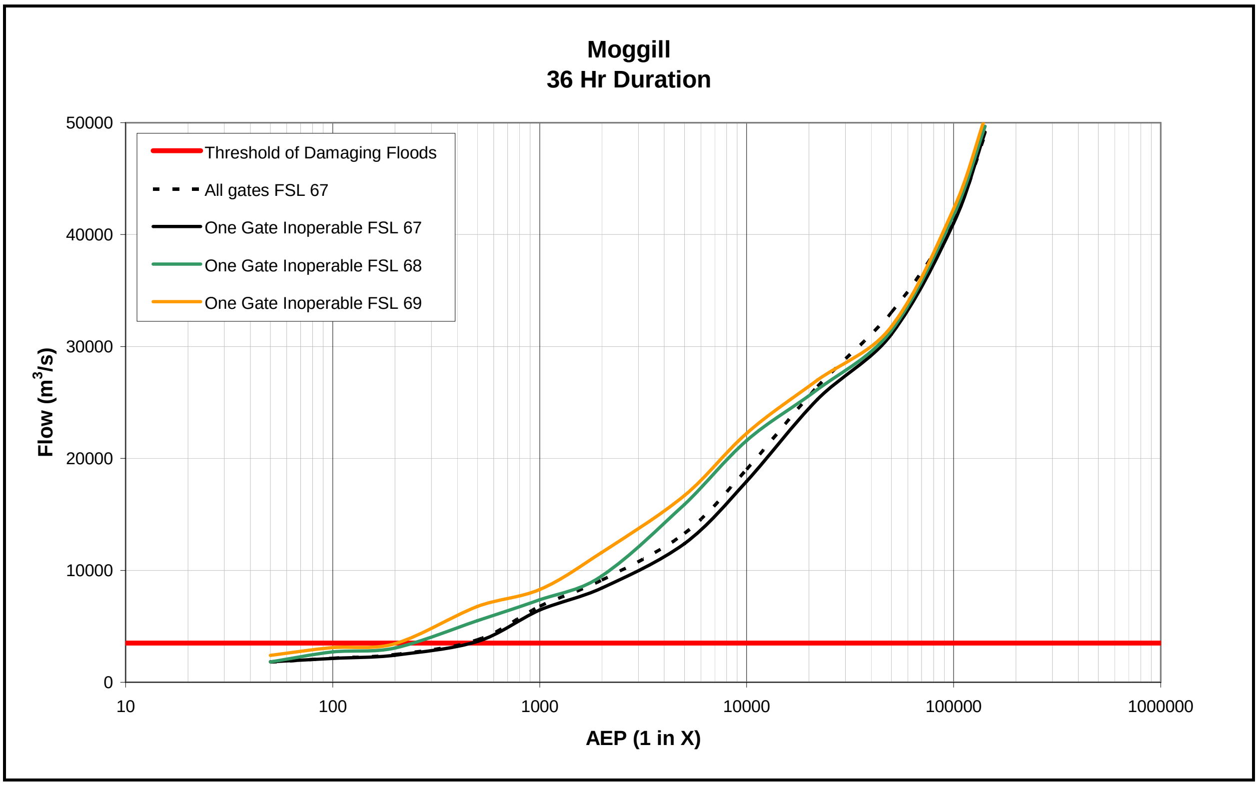


Figure 6-10: Moggill Flow (One Gate Inoperable)

6.2.6 Case 2 Summary

Generally, with one gate inoperable, peak flood levels and flows are higher for particular floods than with all gates operating up to the failure of the fuse plugs. Beyond this point, the operational availability of gates on Wivenhoe has little consequence on flood behaviour.

The risk of occurrence for selected criteria in a 36 hour event is shown in Table 6-10. Note that the AEPs for Case 1 – FSL 67m AHD may be different to those in Table 6-9 due to differing critical durations.

Again the most significant increase in risk due to raising of the FSL is for the critical gate operating level and fuse plug initiation. With one gate inoperable, the risk fuse plug initiation increases from 1 in 4,500 to 1 in 3,500. Similarly, the risk of damaging floods downstream of Wivenhoe also increases.

Table 6-10: Risk of Occurrence (36 Hour Duration)

Location	Exceedance of …	Value	Unit	Case 1	Case 2		
				FSL 67	FSL 67	FSL 68	FSL 69
Somerset Dam	Crest Level	107.46	m AHD	15,000	15,000	15,000	15,000
	Limit of Structural Stability	109.50	m AHD	85,000	85,000	85,000	85,000
Wivenhoe Dam	Critical Gate Operating Level	74.00	m AHD	550	550	400	200
	Fuse Plug 1 Initiation Level	75.80	m AHD	4,500	3,500	2500	1,800
	Design Flood Level	80.00	m AHD	95,000	85,000	85,000	80,000
	Threshold of Damaging Floods	3,500	m^3/s	560	560	350	260
Lowood	Threshold of Damaging Floods	3,500	m^3/s	550	550	180	140
Moggill	Threshold of Damaging Floods	3,500	m^3/s	480	480	250	220

7.0 DISCUSSION

In the conduct of this study a number of issues regarding the adopted methodology, assumptions and the use of WIVOPS were identified in discussion with NR&W, outlined in Appendix C. The salient aspects of these and other discussions are outlined below:

- Modifications to Procedure 1 had little impact on the range of floods considered in this study. The discharge in the smallest event, Q_{50}, was close to or above the upper limit for Procedure 1. NR&W has suggested that the smaller floods also be investigated.
    - *It is recommended that the range of events in future studies be expanded to include events impact of the operation of Procedure 1.*
- The assumption in this study that the trigger point for the operation of the gates remain at EL 74m AHD despite increases to the FSL results in the reduction of the volume of the available storage to mitigate floods. NR&W suggested that the trigger point might be increased to partly or wholly maintain the volume of the available flood storage.
    - *It is recommended that the impact of changes to the trigger level be considered in any future studies investigating changes to Wivenhoe FSL.*
- A target correlation level was adopted as EL 80m AHD in this study. This was the same value was that adopted in the SunWater (2006) investigation, in which it was identified the correlation relationship between Wivenhoe and Somerset be investigated further.
    - *As previously suggested, it is recommended that the correlation relationship between Wivenhoe and Somerset be investigated further.*
- In this study, it has been assumed that both Somerset and Wivenhoe Dams were full at the onset of the design event. This generates overly conservative risk factors. A joint probability approach incorporating storage states might produce more realistic risk factors. However, it should be noted that ideal nature of the design storms may still largely contribute to the uncertainty of risk assessment.
    - *It is recommended that the any future studies investigate a joint probability approach incorporating dam status and design flows to more accurate assess risk factors.*

- Because of limitations in the code, it was not possible to accurate model the impact of one gate inoperable at Wivenhoe as the program has five gates hard coded and the input data is the rating for one gate. The approach adopted of assuming 80% capacity of one gate is not strictly correct and modifications need to be made to the code to more accurately model limited gate operations.
- The WIVOPS program was written in FORTRAN by NR&M in July 2000. It has been modified several times since by various programmers in response to physical changes at the dam and for operational reasons. At this time, the code consists of some 3,500 lines. The philosophy behind the code remains the same, i.e. protection of the structures and mitigating the impact of floods in the Brisbane River but the code is somewhat inflexible (may variables are hard coded) and may not be easily ported to any new real time forecasting system. The risk of failure of the program is heightened by a lack of detailed documentation and a decreasing pool of experienced hydrologists with an understanding of the code.
    - *It is recommended that the WIVOPS program be extensively revised to incorporate more up to date computing techniques to ensure its flexibility and portability. It is also recommended this upgrade be accompanied by suitable documentation.*

The set of events considered in this investigation are design events, the patterns of which are unlikely to occur in reality. It should be recognised that the purpose of the study was to objectively assess the impact of changing the Wivenhoe FSL on this set of events. It is recognised that, under actual conditions, the operation of Wivenhoe gates may quite different to these ideal events.

8.0 CONCLUSION

This study has examined the potential impact of raising the FSL for Wivenhoe Dam from EL 67m AHD to EL 68m AHD and EL 69m AHD. Initially, three FSL scenarios with and without modified operating procedures were considered for a range of AEPs from 1 in 50 to the PMPDF and durations from 24 to 120 hours. However, early investigations showed that the modified operating procedures mostly impact upon flood more frequent than the 1 in 50 event. As such, the modified procedures were discarded from further consideration.

The program WIVOPS was used to investigate the impact of raising the Wivenhoe FSL on a number of height and flow criteria with the basin.

The results of these analyses show that raising the FSL would have a significant effect on the ability of the Somerset and Wivenhoe Dams to mitigate floods. The main results are summarised as follows:

- The impact on Somerset Dam is generally minor with only small increase in peak headwater levels and a negligible impact on the risk of DCF and structurally damaging floods.
- At Wivenhoe Dam, there is a significant increase in the risk of reaching the critical gate operating level from 1 in 330 to 1 in 100. Similarly, the risk of the fuse plug initiation increases from 1 in 4,500 AEP to 1 in 2,3000 AEP. The impact on the design flood level remains unchanged.
- The risk of damaging floods downstream of Wivenhoe increases from about 1 in 260 to 300 AEP, and 150 to 220 AEP, depending on the location.
- With one gate inoperable at Wivenhoe, the trend is for a noticeable increased risk of reaching criteria levels and damaging flows with the Brisbane River.

This investigation has also identified a number of limitations of the scope of the study and methodology adopted. The findings should be viewed as indicative of the impacts that could be expected to the risk of flooding in the Brisbane River should Wivenhoe FSL be increased.

9.0 REFERENCES

SEQWater (2004), “Manual of Operational Procedures for Flood Mitigation for Wivenhoe Dam and Somerset Dam”, FM QD 1.1 Revision No 6, December 2004.

SunWater (2005), “Report on Modifications to WIVOPS”, G-81802-06-01, May 2005.

Wivenhoe Alliance (2005), “Design Discharges and Downstream Impacts of Wivenhoe Dam Upgrade’, Q1091, September 2005.

DPI Water Resources (1993), “Brisbane River Flood Hydrology Report – Design Estimation for Somerset Dam and Wivenhoe Dam”, March 1993.

APPENDIX A

SAMPLE INPUT FOR WIVOPS

SCENARIO 1 – FSL 67

wiv_param2.txt

```
67           !WIVENHOE FULL SERVICE LEVEL
67           !INITIAL WIVENHOE LEVEL
99           !INITIAL SOMERSET LEVEL
inflow.txt   !INPUT COMPONENT HYDROGRAPHS
n            !NO SCALING OF HYDROGRAPH
0            !START TIME OFFSET
y            !SLUICE GATE OVERIDE (y=ON)
7            !DAYS TO DRAIN DOWN
20           !TIME INTERVAL BETWEEN GATE CLOSURES
74           !WIVENHOE LEVEL FOR PROCEDURE 4
6            !PROCEDURE 4 GATE OPENING INTERVAL
1            !CURRENT POINT OF GATE SEQUENCE (1 = ALL CLOSED)
0.2          !SENSITIVITY TO RESTART (HYSTERESIS)
4 8 8        !AVAILABLE REGS,SLUICES,GATES SOMERSET
0 0 8        !OPEN REGS,SLUICES,GATES SOMERSET
300          !FINAL CLOSURE INTERVAL
0.9          !INITIAL DAMPING FACTOR ON DRAINING
80           !TARGET POINT LEVEL FOR SOMERSET OPERATIONS
```

proclims2.dat

```
c  WIVENHOE OPERATIONAL NOTES
c
c  The data table below does not cover all conditions - some are in the code as indicated in comments below
c  In the table, levels of 999 m AHD and flows of 99999 m3/sec indicate no controlling limits for those instances.
c  Savages Crossing is not currently controlled in the code. Only the Bremer delay time was used in previous code.
c
c  For Procedures 1 to 3 inclusive, basic flow tests on QWivenhoe QMoggill and Qlowood, may decide gate closure.
c  On passing basic flow tests, decisions regarding gate operations are based on other criteria including bridge flooding.
c
c  Procedures 1A-1E are defined by minimum and maximum Wivenhoe levels as indicated (at start of current timestep).
c  On passing basic flow tests, the routine seeks to keep the maximum number of bridges open.
c
c  Procedures 2 and 3 have the same minimum and maximum Wivenhoe levels.
c  Procedure 3 applies at these levels when either peak QLockyer or peak QBremer exceed 3,500 m3/sec.
c  On passing basic flow tests, Procedure 2 seeks to minimise the effects on bridges.
c
c  Procedure 4 is dam safety without downsteam flow restrictions.
c  Continue to open gates (if possible) while level is not falling OR peak of Wivenhoe hydrograph has not passed.
c  Gate closure may be considered IF net outflow from Wivenhoe, and Wivenhoe level < 77.0 metres AHD.
c  IF net inflow to Wivenhoe, then REVERT to gate opening mode.
c
c  Drainage phase is entered:
c          (For Procedures 1 to 3) when Wivenhoe level is dropping and Wivenhoe peak inflow has passed.
c          (For Procedure 4) when Wivenhoe level is dropping, peak has passed, net outflow, AND Qlowood is < 3,500 m3/sec.
c  Drainage phase is exited:
c          When drainage complete (exit from Wivenhoe subroutine), OR  subsequent rise in Wivenhoe of more than 0.2 metres.
c          [ drainage complete = Wivenhoe hydrograph complete + FSL 67.0 m AHD + all gates closed ].
c  Within the Drainage phase:
c          A target drainage flow (Qlowood)to determined to meet discharge time target.
c          Overall drainage flow rate limit is 3,500 m3/sec at Lowood.
c          Lesser drainage flow rates are increased to the rate that does not submerge the next bridge above that rate.
c
c                          | BASIC FLOW LIMITS HERE     |  BRIDGE FLOW LIMITS HERE
Index Name  MinEL  MaxEL   QLowood QWivenhoe QMoggill    QTwin QSavages  QColleges  QBurtons  QKholo QMtCrosby  Bremer
 1    0     0.0    67.25   99999.0       0.0  99999.0  99999.0  99999.0    99999.0   99999.0 99999.0   99999.0
 2    1A    67.25  67.50    3500.0     110.0   4000.0     85.0    125.0      175.0     250.0   550.0    1850.0
 3    1B    67.50  67.75    3500.0     210.0   4000.0  99999.0    125.0      175.0     250.0   550.0    1850.0
 4    1C    67.75  68.00    3500.0     500.0   4000.0  99999.0  99999.0    99999.0     250.0   550.0    1850.0
 5    1D    68.00  68.25    3500.0     900.0   4000.0  99999.0  99999.0    99999.0   99999.0   550.0    1850.0
 6    1E    68.25  68.50    3500.0    1500.0   4000.0  99999.0  99999.0    99999.0   99999.0   550.0    1850.0
 7    2     68.50  74.00    3500.0   99999.0   4000.0     85.0    125.0      175.0     250.0   550.0    1850.0
 8    3     68.50  74.00    3500.0   99999.0   4000.0  99999.0  99999.0    99999.0   99999.0 99999.0   99999.0
 9    4     74.00 999.00   99999.0   99999.0  99999.0  99999.0  99999.0    99999.0   99999.0 99999.0   99999.0
10    D     67.00 999.00    3500.0   99999.0  99999.0     85.0    125.0      175.0     250.0   550.0    1850.0
 Time_Delays(hrs):             2.0                         2.5      4.0       12.0       6.0     9.5      12.0    16.0
 Bridge_names:              Twin_Bridges Savages_Crossing Colleges_Crossing Burtons_Noogoorah Kholo Mt_Crosby
```

SCENARIO 2 – FSL 68

wiv_param2.txt

```
68              !WIVENHOE FULL SUPPLY LEVEL (m AHD)
68              !INITIAL WIVENHOE LEVEL (m AHD)
99              !INITIAL SOMERSET LEVEL (m AHD)
inflow.txt      !INPUT HYDROGRAPHS FILE
n               !SCALING OF INPUT HYDROGRAPHS (?/N)
0               !START TIME OFFSET (hrs)
y               !SLUICE GATE OVERIDE (y=ON)
7               !DRAIN TIME (days)
20              !TIME INTERVAL BETWEEN GATE CLOSURES (mins)
74              !WIVENHOE LEVEL FOR PROCEDURE 4 (m AHD)
6               !PROCEDURE 4 GATE OPENING INTERVAL (mins)
1               !CURRENT POINT OF GATE SEQUENCE (1 = ALL CLOSED)
0.2             !SENSITIVITY TO RESTART (HYSTERESIS)
4 8 8           !NUMBER OF AVAILABLE REGS,SLUICES,GATES AT SOMERSET
0 0 8           !OPEN REGS,SLUICES,GATES SOMERSET
300             !FINAL CLOSURE INTERVAL (secs)
0.9             !INITIAL DAMPING FACTOR ON DRAINING
80              !TARGET POINT LEVEL FOR SOMERSET OPERATIONS (m AHD)
```

proclims2.dat

```
c  WIVENHOE OPERATIONAL NOTES
c
c  The data table below does not cover all conditions - some are in the code as indicated in comments below
c  In the table, levels of 999 m AHD and flows of 99999 m3/sec indicate no controlling limits for those instances.
c  Savages Crossing is not currently controlled in the code. Only the Bremer delay time was used in previous code.
c
c  For Procedures 1 to 3 inclusive, basic flow tests on QWivenhoe QMoggill and Qlowood, may decide gate closure.
c  On passing basic flow tests, decisions regarding gate operations are based on other criteria including bridge flooding.
c
c  Procedures 1A-1E are defined by minimum and maximum Wivenhoe levels as indicated (at start of current timestep).
c  On passing basic flow tests, the routine seeks to keep the maximum number of bridges open.
c
c  Procedures 2 and 3 have the same minimum and maximum Wivenhoe levels.
c  Procedure 3 applies at these levels when either peak QLockyer or peak QBremer exceed 3,500 m3/sec.
c  On passing basic flow tests, Procedure 2 seeks to minimise the effects on bridges.
c
c  Procedure 4 is dam safety without downsteam flow restrictions.
c  Continue to open gates (if possible) while level is not falling OR peak of Wivenhoe hydrograph has not passed.
c  Gate closure may be considered IF net outflow from Wivenhoe, and Wivenhoe level < 77.0 metres AHD.
c  IF net inflow to Wivenhoe, then REVERT to gate opening mode.
c
c  Drainage phase is entered:
c          (For Procedures 1 to 3) when Wivenhoe level is dropping and Wivenhoe peak inflow has passed.
c          (For Procedure 4) when Wivenhoe level is dropping, peak has passed, net outflow, AND Qlowood is < 3,500 m3/sec.
c  Drainage phase is exited:
c          When drainage complete (exit from Wivenhoe subroutine), OR  subsequent rise in Wivenhoe of more than 0.2 metres.
c          [ drainage complete = Wivenhoe hydrograph complete + FSL 67.0 m AHD + all gates closed ].
c  Within the Drainage phase:
c          A target drainage flow (Qlowood)to determined to meet discharge time target.
c          Overall drainage flow rate limit is 3,500 m3/sec at Lowood.
c          Lesser drainage flow rates are increased to the rate that does not submerge the next bridge above that rate.
c
c                         | BASIC FLOW LIMITS HERE     |  BRIDGE FLOW LIMITS HERE
Index Name  MinEL  MaxEL   QLowood QWivenhoe QMoggill    QTwin QSavages  QColleges  QBurtons  QKholo QMtCrosby  Bremer
 1    0     0.0    68.25   99999.0       0.0  99999.0  99999.0  99999.0    99999.0   99999.0 99999.0   99999.0
 2    1A    68.25  68.50    3500.0     110.0   4000.0     85.0    125.0      175.0     250.0   550.0    1850.0
 3    1B    68.50  68.75    3500.0     210.0   4000.0  99999.0    125.0      175.0     250.0   550.0    1850.0
 4    1C    68.75  69.00    3500.0     500.0   4000.0  99999.0  99999.0    99999.0     250.0   550.0    1850.0
 5    1D    69.00  69.25    3500.0     900.0   4000.0  99999.0  99999.0    99999.0   99999.0   550.0    1850.0
 6    1E    69.25  69.50    3500.0    1500.0   4000.0  99999.0  99999.0    99999.0   99999.0   550.0    1850.0
 7    2     69.50  74.00    3500.0   99999.0   4000.0     85.0    125.0      175.0     250.0   550.0    1850.0
 8    3     69.50  74.00    3500.0   99999.0   4000.0  99999.0  99999.0    99999.0   99999.0 99999.0   99999.0
 9    4     74.00 999.00   99999.0   99999.0  99999.0  99999.0  99999.0    99999.0   99999.0 99999.0   99999.0
10    D     68.00 999.00    3500.0   99999.0  99999.0     85.0    125.0      175.0     250.0   550.0    1850.0
 Time_Delays(hrs):             2.0                        2.5      4.0       12.0       6.0     9.5      12.0    16.0
 Bridge_names:              Twin_Bridges Savages_Crossing Colleges_Crossing Burtons_Noogoorah Kholo Mt_Crosby
```

SCENARIO 4 – FSL 69

wiv_param2.txt

```
69            !WIVENHOE FULL SERVICE LEVEL
69            !INITIAL WIVENHOE LEVEL
99            !INITIAL SOMERSET LEVEL
inflow.txt    !INPUT COMPONENT HYDROGRAPHS
n             !NO SCALING OF HYDROGRAPH
0             !START TIME OFFSET
y             !SLUICE GATE OVERIDE (y=ON)
7             !DAYS TO DRAIN DOWN
20            !TIME INTERVAL BETWEEN GATE CLOSURES
74            !WIVENHOE LEVEL FOR PROCEDURE 4
6             !PROCEDURE 4 GATE OPENING INTERVAL
1             !CURRENT POINT OF GATE SEQUENCE (1 = ALL CLOSED)
0.2           !SENSITIVITY TO RESTART (HYSTERESIS)
4 8 8         !AVAILABLE REGS,SLUICES,GATES SOMERSET
0 0 8         !OPEN REGS,SLUICES,GATES SOMERSET
300           !FINAL CLOSURE INTERVAL
0.9           !INITIAL DAMPING FACTOR ON DRAINING
80            !TARGET POINT LEVEL FOR SOMERSET OPERATIONS
```

proclims2.dat

```
c  WIVENHOE OPERATIONAL NOTES
c
c  The data table below does not cover all conditions - some are in the code as indicated in comments below
c  In the table, levels of 999 m AHD and flows of 99999 m3/sec indicate no controlling limits for those instances.
c  Savages Crossing is not currently controlled in the code. Only the Bremer delay time was used in previous code.
c
c  For Procedures 1 to 3 inclusive, basic flow tests on QWivenhoe QMoggill and Qlowood, may decide gate closure.
c  On passing basic flow tests, decisions regarding gate operations are based on other criteria including bridge flooding.
c
c  Procedures 1A-1E are defined by minimum and maximum Wivenhoe levels as indicated (at start of current timestep).
c  On passing basic flow tests, the routine seeks to keep the maximum number of bridges open.
c
c  Procedures 2 and 3 have the same minimum and maximum Wivenhoe levels.
c  Procedure 3 applies at these levels when either peak QLockyer or peak QBremer exceed 3,500 m3/sec.
c  On passing basic flow tests, Procedure 2 seeks to minimise the effects on bridges.
c
c  Procedure 4 is dam safety without downsteam flow restrictions.
c  Continue to open gates (if possible) while level is not falling OR peak of Wivenhoe hydrograph has not passed.
c  Gate closure may be considered IF net outflow from Wivenhoe, and Wivenhoe level < 77.0 metres AHD.
c  IF net inflow to Wivenhoe, then REVERT to gate opening mode.
c
c  Drainage phase is entered:
c           (For Procedures 1 to 3) when Wivenhoe level is dropping and Wivenhoe peak inflow has passed.
c           (For Procedure 4) when Wivenhoe level is dropping, peak has passed, net outflow, AND Qlowood is < 3,500 m3/sec.
c  Drainage phase is exited:
c           When drainage complete (exit from Wivenhoe subroutine), OR  subsequent rise in Wivenhoe of more than 0.2 metres.
c           [ drainage complete = Wivenhoe hydrograph complete + FSL 67.0 m AHD + all gates closed ].
c  Within the Drainage phase:
c           A target drainage flow (Qlowood)to determined to meet discharge time target.
c           Overall drainage flow rate limit is 3,500 m3/sec at Lowood.
c           Lesser drainage flow rates are increased to the rate that does not submerge the next bridge above that rate.
c
c                          | BASIC FLOW LIMITS HERE     |  BRIDGE FLOW LIMITS HERE
Index Name  MinEL  MaxEL   QLowood QWivenhoe QMoggill    QTwin QSavages  QColleges  QBurtons  QKholo QMtCrosby  Bremer
 1    0     0.0    69.25   99999.0       0.0  99999.0  99999.0  99999.0    99999.0   99999.0 99999.0   99999.0
 2    1A    68.25  69.50    3500.0     110.0   4000.0     85.0    125.0      175.0     250.0   550.0    1850.0
 3    1B    68.50  69.75    3500.0     210.0   4000.0  99999.0    125.0      175.0     250.0   550.0    1850.0
 4    1C    68.75  70.00    3500.0     500.0   4000.0  99999.0  99999.0    99999.0     250.0   550.0    1850.0
 5    1D    69.00  70.25    3500.0     900.0   4000.0  99999.0  99999.0    99999.0   99999.0   550.0    1850.0
 6    1E    69.25  70.50    3500.0    1500.0   4000.0  99999.0  99999.0    99999.0   99999.0   550.0    1850.0
 7    2     69.50  74.00    3500.0   99999.0   4000.0     85.0    125.0      175.0     250.0   550.0    1850.0
 8    3     69.50  74.00    3500.0   99999.0   4000.0  99999.0  99999.0    99999.0   99999.0 99999.0   99999.0
 9    4     74.00 999.00   99999.0   99999.0  99999.0  99999.0  99999.0    99999.0   99999.0 99999.0   99999.0
10    D     69.00 999.00    3500.0   99999.0  99999.0     85.0    125.0      175.0     250.0   550.0    1850.0
 Time_Delays(hrs):             2.0                         2.5      4.0       12.0       6.0     9.5      12.0    16.0
 Bridge_names:              Twin_Bridges Savages_Crossing Colleges_Crossing Burtons_Noogoorah Kholo Mt_Crosby
```

APPENDIX B

CASE 1 RESULTS

Somerset Dam Peak Water Level

AEP	Scenario																	
	1						2						4					
	Peak Level (m AHD)						Peak Level (m AHD)						Peak Level (m AHD)					
	Storm Duration						Storm Duration						Storm Duration					
	24	36	48	72	96	120	24	36	48	72	96	120	24	36	48	72	96	120
50	102.74	103.27	103.50	103.78	101.57	102.66	102.74	103.28	103.48	103.79	101.57	102.67	103.18	103.18	103.39	103.70	101.57	102.35
100	103.36	103.80	103.92	104.24	103.49	103.68	103.36	103.64	103.87	104.29	103.45	103.69	103.51	103.51	103.33	104.44	103.49	102.85
200	103.86	104.19	104.26	104.47	104.46	104.70	103.71	104.21	104.33	104.52	104.18	104.47	104.24	104.24	104.35	104.45	103.92	104.17
500	104.41	104.99	105.13	105.04	105.09	105.51	104.46	104.88	105.12	105.16	104.88	105.09	104.84	104.84	105.05	104.99	104.75	104.80
1000	104.88	105.37	105.71	105.44	105.27	105.29	104.75	105.27	105.75	105.55	105.12	105.13	105.36	105.36	105.68	105.25	105.17	105.15
2000	105.14	105.42	106.45	105.83	105.76	105.41	105.11	105.23	106.40	106.02	105.62	105.37	105.08	105.08	106.05	105.83	105.58	105.30
5000	105.73	106.12	107.21	106.80	106.71	105.90	105.67	106.04	107.08	106.95	106.74	105.93	105.85	105.85	106.85	106.83	106.60	105.69
10000	105.86	106.50	107.81	107.15	107.81	106.42	105.78	106.43	107.72	107.84	107.77	106.89	106.61	106.61	107.76	107.47	107.08	106.46
22000	106.89	107.38	108.47	107.74	107.97	108.25	106.79	107.38	108.20	107.80	107.94	108.01	107.38	107.38	108.62	107.90	107.64	108.02
50000	107.98	108.60	109.41	108.58	108.93	109.33	107.90	108.76	109.25	108.42	108.71	109.33	108.76	108.76	109.09	108.49	108.45	109.30
100000	109.38	109.78	110.20	109.87	109.60	109.90	109.30	109.78	110.07	109.95	109.50	109.90	109.95	109.95	110.28	109.90	109.50	109.58
142000	110.01	110.43	110.92	110.47	110.33	110.76	110.01	110.43	110.77	110.60	110.20	110.58	110.58	110.58	110.80	110.55	110.25	110.26
1893	107.57						107.43						107.43					
1974	105.91						105.72						105.69					
1999	105.06						104.81						105.07					

107.46	Crest Level
109.50	Limit of Structural Stability

Wivenhoe Dam Peak Water Level

AEP	Scenario																	
	1						2						4					
	Peak Level (m AHD)						Peak Level (m AHD)						Peak Level (m AHD)					
	Storm Duration						Storm Duration						Storm Duration					
	24	36	48	72	96	120	24	36	48	72	96	120	24	36	48	72	96	120
50	71.32	71.76	72.15	73.00	70.79	70.72	72.12	72.54	72.78	73.00	71.62	71.55	72.61	73.05	73.13	73.19	72.45	72.61
100	72.06	72.91	73.00	73.53	71.65	71.94	72.83	73.13	73.25	73.50	72.27	72.70	73.15	73.68	74.00	73.93	73.00	73.15
200	72.67	73.03	73.19	73.45	72.75	73.06	73.08	73.39	73.66	73.43	73.06	73.29	73.66	73.97	74.06	73.89	73.40	73.66
500	73.25	73.94	74.10	74.14	73.76	74.01	73.76	74.16	74.31	74.13	74.03	74.06	74.23	74.44	74.50	74.22	74.11	74.23
1000	73.96	74.38	74.58	74.32	74.16	74.22	74.19	74.69	74.81	74.33	74.21	74.27	74.45	74.96	74.98	74.59	74.38	74.45
2000	74.25	75.03	75.13	74.89	74.40	74.44	74.56	75.37	75.30	74.87	74.63	74.65	74.83	75.71	75.44	75.09	74.81	74.83
5000	74.99	75.92	75.89	75.70	75.29	75.39	75.31	76.14	75.91	75.67	75.44	75.48	75.70	76.33	75.92	75.70	75.55	75.70
10000	75.90	76.58	76.33	76.30	75.91	76.04	76.16	76.74	76.32	76.25	75.99	76.18	76.25	76.81	76.32	76.28	76.09	76.25
22000	76.71	77.27	76.82	76.83	76.62	76.59	76.83	77.38	76.83	76.81	76.63	76.67	76.64	77.45	76.82	76.81	76.66	76.64
50000	77.77	78.69	77.73	77.64	77.32	77.40	77.94	78.77	77.76	77.55	77.36	77.33	77.26	78.87	77.75	77.63	77.40	77.26
100000	79.32	80.02	79.58	79.20	79.07	78.95	79.44	80.08	79.64	79.16	79.11	78.92	78.97	80.12	79.64	79.21	79.13	78.97
142000	80.07	80.56	80.33	79.92	79.98	79.83	80.14	80.62	80.37	79.90	80.02	79.83	79.85	80.65	80.38	79.97	80.02	79.85
1893	75.13						75.19						75.25					
1974	74.15						74.28						74.39					
1999	72.84						73.21						73.68					

74.00	Critical Gate Operating Level
75.80	Fuse Plug 1 Initiation Level
80.00	Design Flood Level

Wivenhoe Peak Outflow

AEP	Scenario 1						Scenario 2						Scenario 4					
	Peak Flow (m3/s)						Peak Flow (m3/s)						Peak Flow (m3/s)					
	Storm Duration						Storm Duration						Storm Duration					
	24	36	48	72	96	120	24	36	48	72	96	120	24	36	48	72	96	120
50	1490	1338	1322	1540	876	946	1507	1312	1336	1538	889	966	938	1843	1844	1845	859	938
100	1738	1537	1482	2414	1062	1096	1744	1847	1848	2412	1049	1111	1844	1850	1850	2528	1113	1844
200	1847	2332	2585	2315	1271	1966	1847	2691	2740	2313	1847	2157	1850	2818	3302	2293	1846	1850
500	2771	3361	3872	4837	2552	3181	3131	4219	5093	4892	3439	3866	3432	5295	6280	4554	3530	3432
1000	3450	4990	6171	5853	4781	4320	4335	6008	7006	5730	4848	4552	4277	6775	7898	5767	5155	4277
2000	4512	6793	7796	6713	6000	5311	5376	7723	8684	6643	6240	5413	6861	9681	10035	7236	7004	6861
5000	6651	10029	11728	9677	7899	7890	7418	10954	12552	8977	8645	8739	10448	13834	12562	9980	9587	10448
10000	9862	14613	16491	13801	11142	10975	10641	15463	16787	11860	11883	11138	12234	19089	16788	12793	12765	12234
22000	14682	20431	21661	19147	17317	15716	17874	21153	21675	20035	17322	16734	17339	21852	21664	19959	17365	17339
50000	21758	25155	23348	23181	22590	22740	22631	25303	23392	23018	22665	22606	22482	25491	23385	23166	22730	22482
100000	26704	31744	28261	26180	25872	25654	27318	32365	28667	26063	25957	25588	25689	32757	28674	26206	25983	25689
142000	32222	37817	35035	30787	31348	30080	33006	38458	35486	30658	31750	30088	30230	38846	35650	31208	31681	30230
1893	9512						9792						10114					
1974	4104						5148						5942					
1999	1484						1912						1850					

(Red) Threshold of Damaging Floods

Lowood Peak Flow

AEP	Scenario 1 Peak Flow (m3/s) Storm Duration						Scenario 2 Peak Flow (m3/s) Storm Duration						Scenario 4 Peak Flow (m3/s) Storm Duration					
	24	36	48	72	96	120	24	36	48	72	96	120	24	36	48	72	96	120
50	1493	1340	1323	1542	877	950	1511	1826	1338	1540	891	966	942	2361	2417	2353	861	942
100	1742	1539	1483	2544	1065	1102	1748	2751	2572	2538	1051	1111	2070	2838	2742	2732	1115	2070
200	1912	2353	2617	2368	1274	1972	2489	3127	2846	2365	2108	2157	2293	3133	4083	2505	2400	2293
500	2822	3401	4886	5545	2557	3206	3270	5706	6307	5595	3569	3866	3971	6759	7610	5453	4257	3971
1000	3491	6449	7637	6960	5484	4962	5623	8054	8576	6839	5826	4552	5365	8613	9562	7013	6361	5365
2000	5908	8700	9625	8181	7225	6433	7045	10231	10615	8096	7647	5413	8301	11956	12037	8868	8552	8301
5000	8676	12691	14259	11066	9818	9697	9622	14383	15121	11054	10685	8739	12498	16938	15122	12019	11727	12498
10000	12609	18183	19639	15520	13783	13445	13529	19996	19933	14672	14600	11138	14915	22942	19938	15680	15537	14915
22000	18640	25276	25689	23131	20955	19308	22231	27269	25690	23908	20967	16734	21062	26873	25696	23951	21001	21062
50000	27379	31569	28535	28388	27479	27787	28349	33384	28559	28238	27555	22606	27514	32005	28558	28359	27605	27514
100000	34061	39612	34650	32429	32009	31909	34728	42037	35086	32367	32099	25588	31952	40791	35096	32438	32121	31952
142000	40687	46995	42524	37833	38382	36978	41606	49701	42987	37722	38820	30088	37260	48205	43165	38324	38760	37260
1893	11154						11428						11721					
1974	6249						7444						8284					
1999	1485						1962						1933					

(Red shading) Threshold of Damaging Floods

Moggill Peak Flow

	Scenario																	
	1						2						4					
	Peak Flow (m3/s)						Peak Flow (m3/s)						Peak Flow (m3/s)					
	Storm Duration						Storm Duration						Storm Duration					
AEP	**24**	**36**	**48**	**72**	**96**	**120**	**24**	**36**	**48**	**72**	**96**	**120**	**24**	**36**	**48**	**72**	**96**	**120**
50	1962	1806	1940	1789	1054	1172	1982	1826	1961	1789	1073	1193	1204	2505	2588	2558	1039	1204
100	2318	2137	2253	2831	1326	1410	2339	2751	2784	2824	1339	1431	2207	3166	3088	3170	1310	2207
200	2464	2481	2793	2626	1645	2008	2650	3127	3155	2621	2203	2358	2573	3530	4306	2886	2616	2573
500	3053	3776	5134	5840	2783	3349	3633	5706	6627	5881	3719	4617	4372	7124	7994	5898	4531	4372
1000	3889	6781	8010	7528	5761	5444	5916	8054	9002	7404	6219	5876	5880	9065	10065	7710	6863	5880
2000	6214	9130	10095	9013	7747	7025	7421	10231	11148	8922	8251	7439	9007	12516	12647	9769	9219	9007
5000	9111	13289	14976	12209	10698	10593	10107	14383	15908	12224	11620	11561	13512	17739	15973	13241	12717	13512
10000	13191	19006	20707	16587	15049	14667	14152	19996	21013	16216	15904	14992	16201	23925	20994	17249	16886	16201
22000	19473	26418	26995	25180	22736	20937	23219	27269	27056	25962	22754	22012	22702	28143	26949	25989	22786	22702
50000	28532	33041	29928	31051	29854	29948	29541	33384	29937	30903	29929	29808	29666	33743	29941	31026	29978	29666
100000	35646	41281	36077	35907	35065	34592	36305	42037	36524	35844	35155	34517	34636	42537	36537	35920	35176	34636
142000	42334	48917	44216	41797	41871	40078	43301	49701	44706	41683	42309	40142	40340	50229	44901	42277	42249	40340
1893	11220						11507						11824					
1974	6487						7771						8712					
1999	1553						2234						2286					

Threshold of Damaging Floods

APPENDIX C

DISCUSSIONS WITH NRM

Comments 11 May 2007 – Preliminary Results of Assessment of Changes to Wivenhoe FSL

- ❑ The operating procedures analysed need to be better defined with the inclusion of the relevant trigger levels of Procedures 1A – E, 2 and 3. My perception is they should be about the same relative to the nominated full supply level, while Procedure 4 should operate from close to EL74.0 to ensure the fuse plugs did not operate prematurely.

Relevant trigger levels were adjusted in the procedures but not explicitly listed in the preliminary results report. They will be fully listed in the full report.

I will reserve comment until I see the final report.

- ❑ Can variations in the limit for Procedure 1E be partially compensated for by changes in the limits for Procedures 1A to 1D? Changes in these levels for discharges up to the drowning out of Mount Crosby at 1900 m^3/sec are less likely to have significant impact … they might just mean earlier closure of the bridges and crossings.

Changes to Procedure 1 will have little impact upon this investigation. The smallest flood being considered is the Q50 which is generally larger than the upper limit for Procedure 1.

Maybe then we have to try a number of smaller floods OR examine the effects of the floods with starting levels less than FSL and see what happens. This could ultimately be fine tuning … but I think it needs to be examined.

- ❑ The following Table gives the trigger levels for the flood procedures if the same relative flood storages were adopted:

Nominated FSL (m AHD)	67.0	68.0	69.0
Limit for Procedure 1 (m AHD)	68.5	69.421	70.350
Flood storage available for Procedure 1 (ML)	168,577	168,577	168,577
Trigger for Procedure 4 (m AHD)	74.0	74.714	75.446
Flood storage available for Procedures 2 and 3 (ML)	741,863	741,863	741,863

While we are not advocating that these trigger levels be adopted, it might be appropriate that higher trigger levels be adopted for the higher FSLs. The impacts of adopting higher trigger levels include more frequent triggering of the fuseplugs and reduced overall flood immunity of the dam. The payoff would be that the maximum discharges would be mitigated.

At the very least, this needs to be investigated and perhaps a compromise solution developed. It also needs to be remembered that there is perhaps some scope for accommodating some of this increase in peak water levels with the Stage 2 fuseplug on the left bank.

As noted, the increase in the trigger level for Procedure 4 will result in a decrease in the flood immunity of the dam. Is this desirable? It is suggested that this investigation adopt the existing trigger level of 74 for Procedure 4 and note that the suggested higher levels should be considered in any future investigations.

I think it needs to be assessed. We may need to go some way to compensate for higher initial levels in Wivenhoe.

- ❑ In the Table on Page 2 of 11, the report indicates that the peak discharge for Procedure 1E is 1500 m^3/sec. Where does this come from? I thought it was 1900m^3/sec.

These values are consistent with Table 8.5 of the manual. The 1500 m^3/sec is for Wivenhoe outflow while the 1900 m^3/sec is for flow at Mt Crosby.

The manual only refers to 1900 m^3/sec in Table 8.4 and 1500 m^3/sec in Table 8.5. This needs to be resolved. If there is virtually no flow from other sources, I would expect Wivenhoe to discharge at 1900 m^3/sec under these circumstances.

- ❑ Under the current Procedure 4, the gates are to be opened until reservoir level begins to fall. Once it begins to fall, the drainage phase begins with the proviso that the maximum discharge is not to exceed the previous maximum with the discharge being brought back to a non-damaging flow of 3500 m^3/sec and drainage of the flood storage in 7 days. Is the reason that the Wivenhoe discharge is reduced below 3500 m^3/sec after the peak due to the downstream tributary flows? These peaks occur at 50+ hours ... has the rain stopped at this time and is there scope, with improved forecasting, for holding the flow at a lower level for longer to reduce the peak discharge?

It is recognised that there is scope for adjusting operations during an actual event. However, this investigation is limited to using the same fixed operational procedure for all design events so as to enable an objective comparison of the results.

Maybe this needs to be stated.

- ❑ Also we would expect these sharp spikes to attenuate significantly by the time they reach Moggill. Is this the case? Could we see concurrent plots of the hydrographs at Moggill say for the same floods for the different FSLs? Of particular interest would be floods that produce Moggill discharges close to the 4,000 m^3/sec damaging flow in Brisbane.

It is suggested that there will be very little attenuation of the flow between Lowood and Moggill as the flow will be confined within the channel.

How much??

Plots of a couple of selected floods at Moggill (near the damaging threshold) for different FSLs will be included in the final report. –

Agreed.

- ❑ We would be interested to see the headwater level plots that correspond to the discharge plots for the example plots given of 36 hr Q500 on page 4. For this example, it would also be beneficial if the inflow into Wivenhoe and the flows in the Lockyer and Bremer were also provided. It might help interpretation.

These will be included in the final report.

Agreed.

- The results in the Tables at the back of the report for Scenarios 2 and 4 48 hour duration rainfall events are identical. I think the results are actually for Scenario 2. They don't fit in with the trends of other results for Scenario 4. I am not sure whether this affects other results.

Finger trouble by the reporter. The scenario 4 48 hour are, in fact, different.

I assume the correct data will be in the final report.

- How much effect does changing the target correlation between flood levels in Wivenhoe and Somerset Dams for the operation of Somerset Dam have? The EL77.0 point is based on the pre-embankment upgrade and fuseplug construction situation. More is probably known about Somerset Dam now too. Should these target levels be updated and what impact might they have on the results?

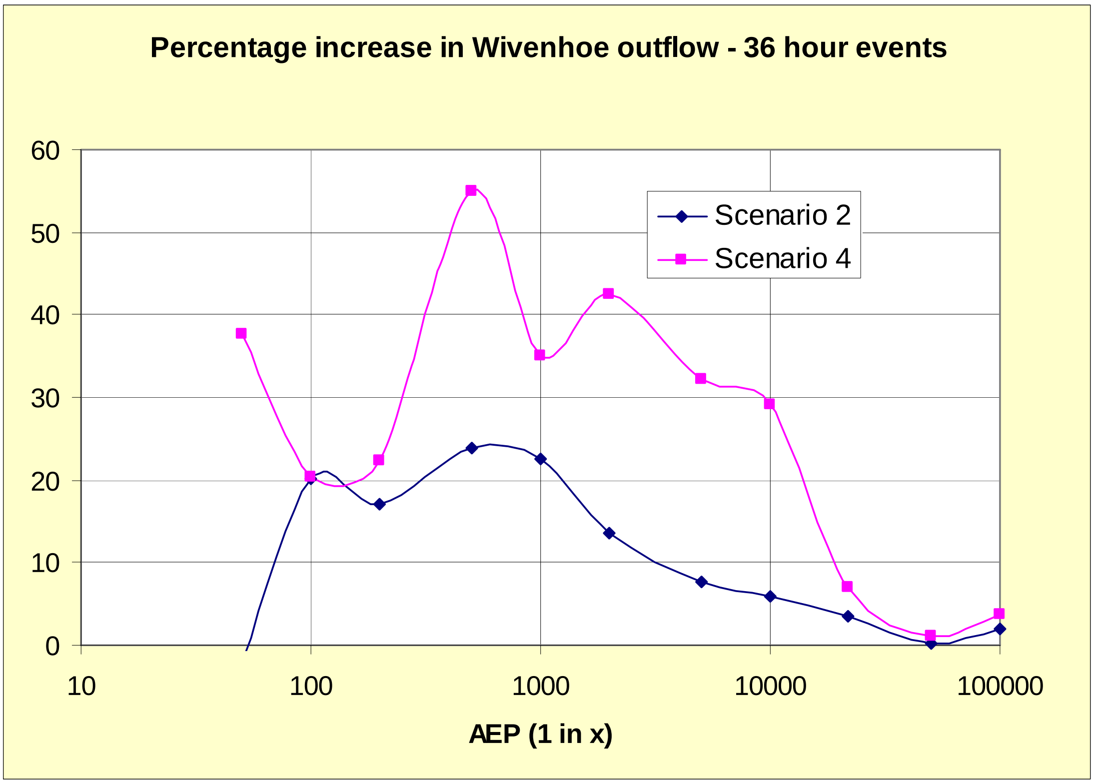
The target correlation has been adopted as 77.0 as defined in our original brief. While it is possible to easily change it to RL 80.0, this is considered to be outside our brief.

Perhaps something to be considered in future investigations?

I note that SunWater have changed the target level to EL 80. Is this reasonable in terms of the loadings on the various structures? Fuseplug initiation levels also need to be factored in.

- As far as presenting and interpreting results, it is interesting to compare particular events … for example, by looking at the series of 36 hour duration events and come up with the results in the table and following graph. These results were taken from the Wivenhoe Peak Outflow table. Differences in events not causing 'damaging flow' are perhaps of limited concern in that they are part of a continuum but they could be the 'headline' figures that are reported in the press.

AEP	Scenario 1	Scenario 2			Scenario 4		
	36 Hours	36 hour	Increase from 1	%age	36 hour	Increase from 1	%age
50	1338	1312	-26	-1.94	1843	505	37.74
100	1537	1847	310	20.17	1850	313	20.36
200	2304	2696	392	17.01	2819	515	22.35
500	3457	4279	822	23.78	5357	1900	54.96
1000	5182	6351	1169	22.56	6995	1813	34.99
2000	6795	7724	929	13.67	9681	2886	42.47
5000	10472	11278	806	7.70	13845	3373	32.21
10000	14613	15464	851	5.82	18859	4246	29.06
22000	20430	21153	723	3.54	21852	1422	6.96
50000	25311	25370	59	0.23	25568	257	1.02
100000	32249	32909	660	2.05	33441	1192	3.70
PMP	38089	38745	656	1.72	39386	1297	3.41



The results are not surprising as they are as expected (the increase in FSL will reduce flood immunity). We can only report the technical outcomes of the study and it will be up to SEQ Water to manage the 'headlines'.
I suppose what NRW is after is a suitable compromise and to ensure that the data is adequately presented. I don't want to create the impression that it is 'good for all' when clearly it isn't. Inclusion of this type of curve might present the costs more clearly to some.

- ❑ Provided the questions raised above are addressed, we are in general agreement with the recommendations for further works.

This comment remains valid.

SunWater

Website: www.sunwater.com.au