Notes on Wivenhoe Dam and Somerset Dam – Flood operations

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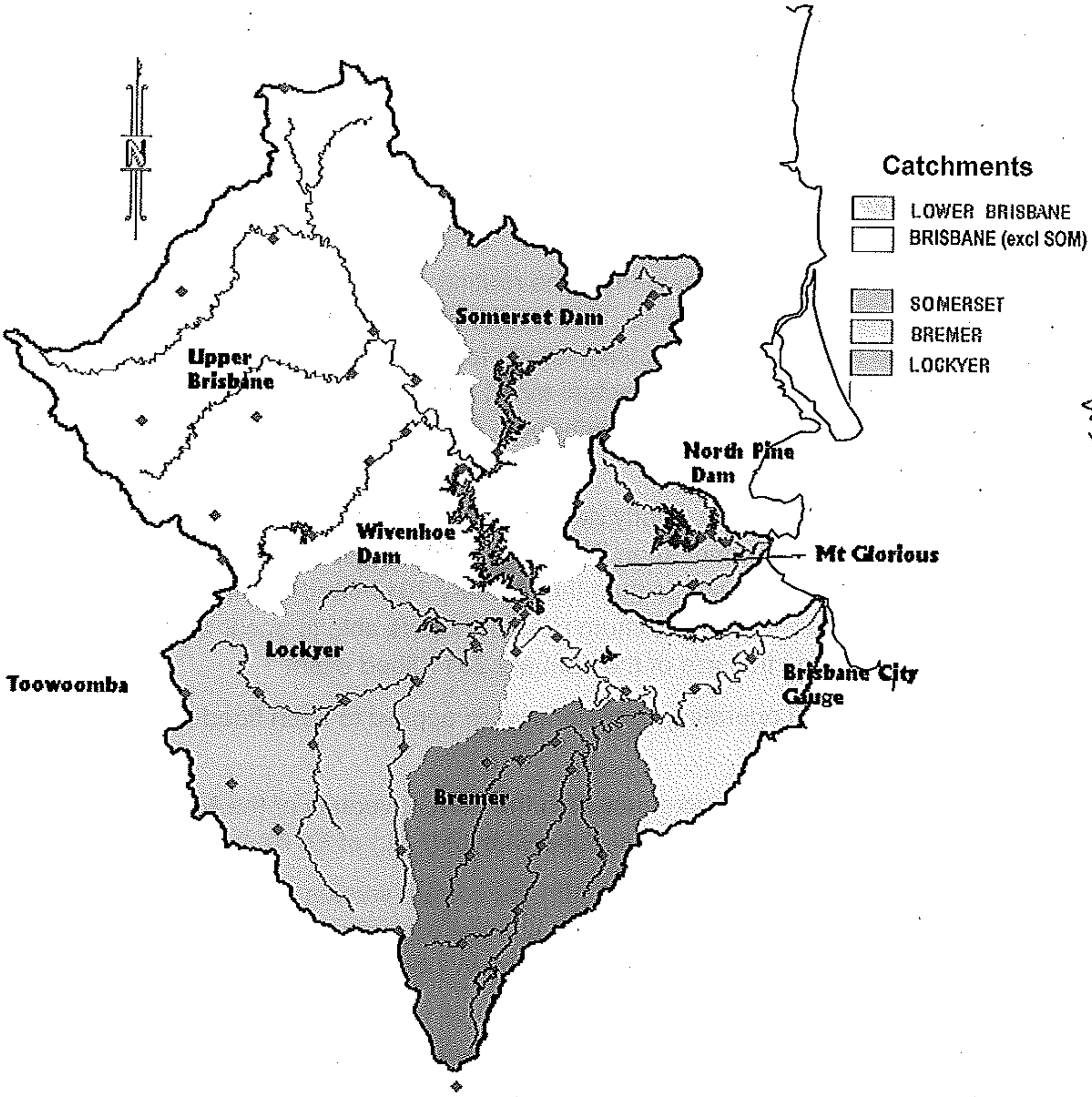
Modelling of Flood Operations

1. Detailed modelling of the performance of Wivenhoe and Somerset dams during flood events is an extremely complex exercise requiring extensive detailed modelling of the overall Brisbane River system for a range of inputs and processes across a wide range of options. Indeed, it needs to be recognised that damaging floods can arise from virtually any major sub-catchment and, because Wivenhoe only commands about 50% of the overall Brisbane River catchment, Wivenhoe may not be able to have any mitigating effect on some damaging flood events.



2. These notes have been assembled following the January 2011 flood event to demonstrate the capacity of the dams to mitigate flooding effects in Brisbane and Ipswich.

3. An EXCEL spreadsheet was developed following the event to model the operations of Wivenhoe Dam and Somerset Dam for a series of historical floods and 'design' floods through both dams. Macros were developed to mimic the strategies contained in the *Manual of Operational Procedures for Flood Mitigation for Wivenhoe Dam and Somerset Dam* (version 7, November 2010) (the Manual).

4. This modelling has been based on inflow hydrographs for a range of 'design' flood hydrographs provided to me by Seqwater following the January 2011 flood. These design flood hydrographs are theoretical flood events developed in accordance with the provisions of Australian Rainfall and Runoff. They bear little resemblance to those of the January 2011 flood event. However, the outcomes do give an appreciation to what type of flood mitigation performance can be achieved by the dams. The performance of the dams depends on:

   - the magnitude of the flood event coming into dams
   - the timing and the magnitude of downstream inflows
   - the initial storage levels in each reservoir

   The flood events considered included the:

   - 48hr duration design flood events having probabilities ranging from 1:50 Annual Exceedance Probability (AEP) through to 1: 100,000 AEP
   - February 1893 flood events
   - January 1974 flood event

5. I have not yet completed my assessment of the routing of the January 2011 flood event through Wivenhoe and Somerset dams. This is a far more detailed task than the analyses contained in this paper because it needs to take into account, on a periodic basis, the uncertainties involved in the actual event and the circumstances surrounding each modelling run the flood engineers undertook. As such it will take far longer to simulate.

6. However, the available flood data clearly demonstrates that the January 2011 flood was much larger upstream of Wivenhoe than the January 1974 flood event. It also demonstrates that much larger floods than the January 2011 flood event can occur. Indeed, in dam design terms, the maximum possible floods able to occur are of the order of three to four times the size of the January 2011 flood event.

7. The following sets of flood operating conditions were applied to each flood event. These were:

   Case 1: Flood operations in accordance with the current version of the Manual with each storage beginning at Full Supply Level (FSL) of EL 67.0 mAHD.

   Case 2: Flood operations in accordance with the current version of the Manual with Wivenhoe beginning at 75% of FSL storage capacity (EL 64.0 mAHD) and Somerset beginning at FSL with strategy W1 being initiated at EL 67.25 mAHD.

   Case 3: Flood operations in accordance with the current version of the Manual with Wivenhoe beginning at 75% of FSL storage capacity and Somerset beginning at FSL but with the 'trigger' levels for Strategy W1 reduced by three metres to give the same elevations relative to the starting storage levels i.e. W1 being initiated at EL 64.25 mAHD.

8. The following series of 48 hour duration flood events and historical flood events were routed through the spreadsheet:

Event	Wivenhoe Dam Inflow Flood Peak (m^3/sec)		Wivenhoe Dam Inflow Flood Volume (Million ML)	
AEP	48hr Design Flood	Jan 2011	48hr Design Flood	Jan 2011
50	4,092		0.791	
100	5,044		0.941	
200	6,028		1.019	
500	7,573		1.264	
1,000	8,866		1.469	
2,000	10,244	≈11,560	1.683	≈1.72
5,000	12,551		2.038	
10,000	14,935		2.401	
22,000	18,562		2.940	
50,000	23,723		3.696	
100,000	29,607		4.545	
Jan 1974	5019		1.23	
Feb 1893	9085		2.32	

Note that the peak inflows and the flood volumes referred to in the above Table are the inflows into Wivenhoe Dam from the Brisbane River catchment which is exclusive of Somerset Dam discharges.

9. By way of comparison with the peak inflows and flood volumes for January 2011 flood event into Wivenhoe (exclusive of Somerset) are also included in the Table. The January 2011 flood event the peak inflow into Wivenhoe (exclusive of Somerset) was about 11,560 m^3/sec and the flood volume was about 1.7 million ML. Therefore for this comparison, the January 2011 flood event would seem to be equivalent to something between the 1:2000 to 1:5000 AEP design flood events.

Limitations of Modelling

10. Any such modelling is always intrinsically an approximation of what might actually occur in real life. Usually, the more detailed the modelling the more accurate the results will be. However, there are a number of limitations on this modelling which limit the ability to transfer the results to actual events. These include:

(a) The processes used in this series of analyses were designed to determine the relative impacts of varying the initial storage level and the triggers for strategy W1 rather than to precisely simulate these events. As such, the results are more 'a relative indication' of what might occur for these events rather than an accurate simulation.

(b) In particular, when routing these floods through the Wivenhoe and Somerset dams system, no specific account was able to be taken of:

- Bureau of Meteorology (BoM) rainfall forecasts or of the impacts of rain already on the 'ground' in the catchment.
- Antecedent reservoir conditions which could mean that these storages were naturally drawn down prior to the event. This was the case for the February 1999 event when the initial level in Wivenhoe was about 75% full and the initial level in Somerset was about 53% full. To some extent this was included by analysing Cases 2 and 3.
- Local flooding effects in downstream areas – this was especially important, for instance, in the January 1974 flood when there was major local flooding which coincided with the arrival of the peak of the Brisbane River in Brisbane and Ipswich. This was not really the case in the January 2011 event.

(c) Operating decisions for this modelling were made at the time of each gate movement without the ability to take into account what the flood operations engineers might know when making operating decisions. This was not a simple task but the process was a rudimentary attempt to take some of the circumstances/environment surrounding flood operations decisions into account. It was especially important for the rarer events (such as 1:5,000 AEP and rarer) when trying to limit downstream consequences under procedures W2, W3 and W4.

(d) This modelling was based on historical and design flood events. As such, the magnitude and the timing of the flood hydrographs were 'known'. This meant that the dams could be operated 'aggressively' without fear of 'getting it wrong' and right up to the limits specified in the Manual. To a limited extent, this is balanced in real time events by the ability to take forecasts of rainfall and runoff into account but there is a significant uncertainty in taking these into account.

(e) No specific attempts were made to avoid the triggering of fuse plugs.

(f) Because it didn't specifically affect the results, no great care was taken to model the drainage of the reservoirs following the event peaks. In actual events, greater care would be taken to limit the rates of drawdown following the event to limit bank slumping. However, the extent to which this can actually be done can be limited by incoming weather events.

(g) The model does not take into account any of the attenuation effects as the flood peaks from the dams move downstream. Instead the discharges from the Lockyer were lagged by 2 hours and the discharges from the Bremer were lagged by 15 hours to take into account the approximate travel time between Wivenhoe Dam and the locations where these tributaries enter the Brisbane River.

To account for the attenuation effects properly would require the use of a hydraulic model. Such attenuation would progressively reduce the flood peaks from the dam and increase the time base of flood event as it moves downstream. However, it should be sufficient for the comparative purposes used here.

Historical Floods

February 1893

11. There were three flood events which occurred in February 1893. The first and third events were the major ones and they occurred nearly two weeks apart. For this analysis they have been analysed as one event. It is the current 'flood of record' for the Brisbane River. The primary differences between it and the 2011 event were that:

(a) It occurred prior to the construction of both Wivenhoe and Somerset dams

(b) When compared to the 2011 event:

- the flood peak arising from above Somerset was relatively greater than arising from the remainder of the Wivenhoe catchment.
- The flood volumes were much greater for the total event although the magnitude of the first peak was similar to the January 2011 event.
- The combined Bremer River and Lockyer Creek had a significantly lower flood peak which allowed greater use of Strategies W1, W2 and W3.

12. The estimated magnitude of the event with the dams in place is summarised in the following Table.

Catchment	Peak Inflow (m^3/sec)	Flood Volume (1,000 ML)
Wivenhoe (excl Somerset)	9085	2323
Somerset	4602	1944
Lockyer	3089	962
Bremer	1845	426

13. By comparison with the 1974 flood event, the 1893 inflow into Wivenhoe and Somerset was much greater and outflow from the downstream Bremer catchment was much less. The other factor is that with the introduction of Wivenhoe Dam, the 2nd peak is virtually absorbed into the drainage operations of Wivenhoe from the first peak with non-damaging flows being maintained at Brisbane and Ipswich.

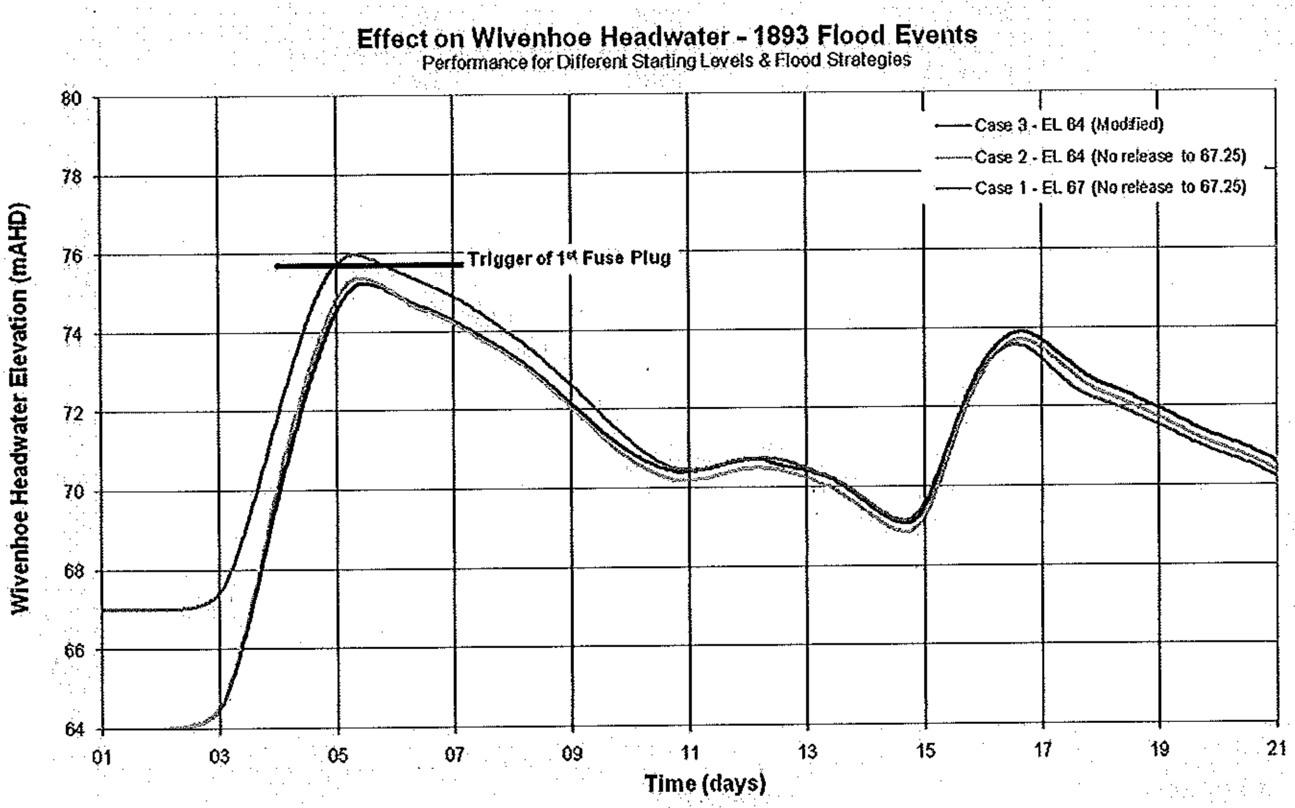
14. Also, because the 3rd peak occurred nearly two weeks after the main first peak, there would have been sufficient time to drain most of the flood storage from Wivenhoe and Somerset prior to the onset of 3rd peak inflows.

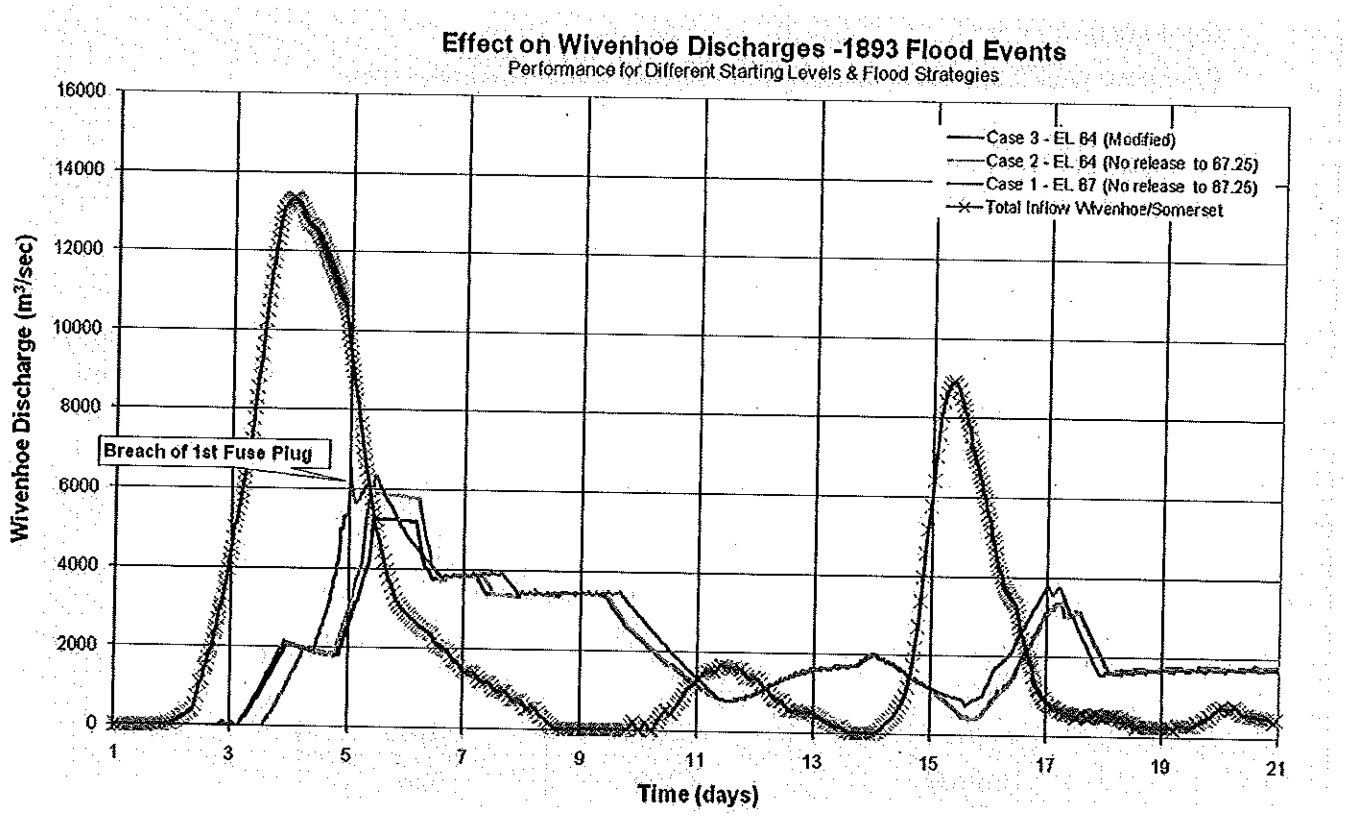
15. The following Table summarises the results of these comparative analyses for the February 1893 event.

Feb 1893 Events		Case 1	Case 2	Case 3
Starting Levels	Wivenhoe	67 mAHD	64 mAHD	64 mAHD
	Somerset	99 mAHD	99 mAHD	99 mAHD
Strategy 1A commences		67.25 mAHD	67.25 mAHD	64.25 mAHD
Peak Inflows	Som Inflow	4602	4602	4602
	Wiv Inflow	9085	9085	9085
	Wiv + Som	13351	13351	13351
Headwater Peaks	Wivenhoe	75.983	75.372	75.233
	Somerset	106.901	107.057	106.972
Max discharge	Wivenhoe	6547	5899	5258
	Somerset	4002	4094	3813
	Lowood	7997	6668	5901
	Moggill	8056	6701	5931
Degree flood Mitigation		49%	44%	39%

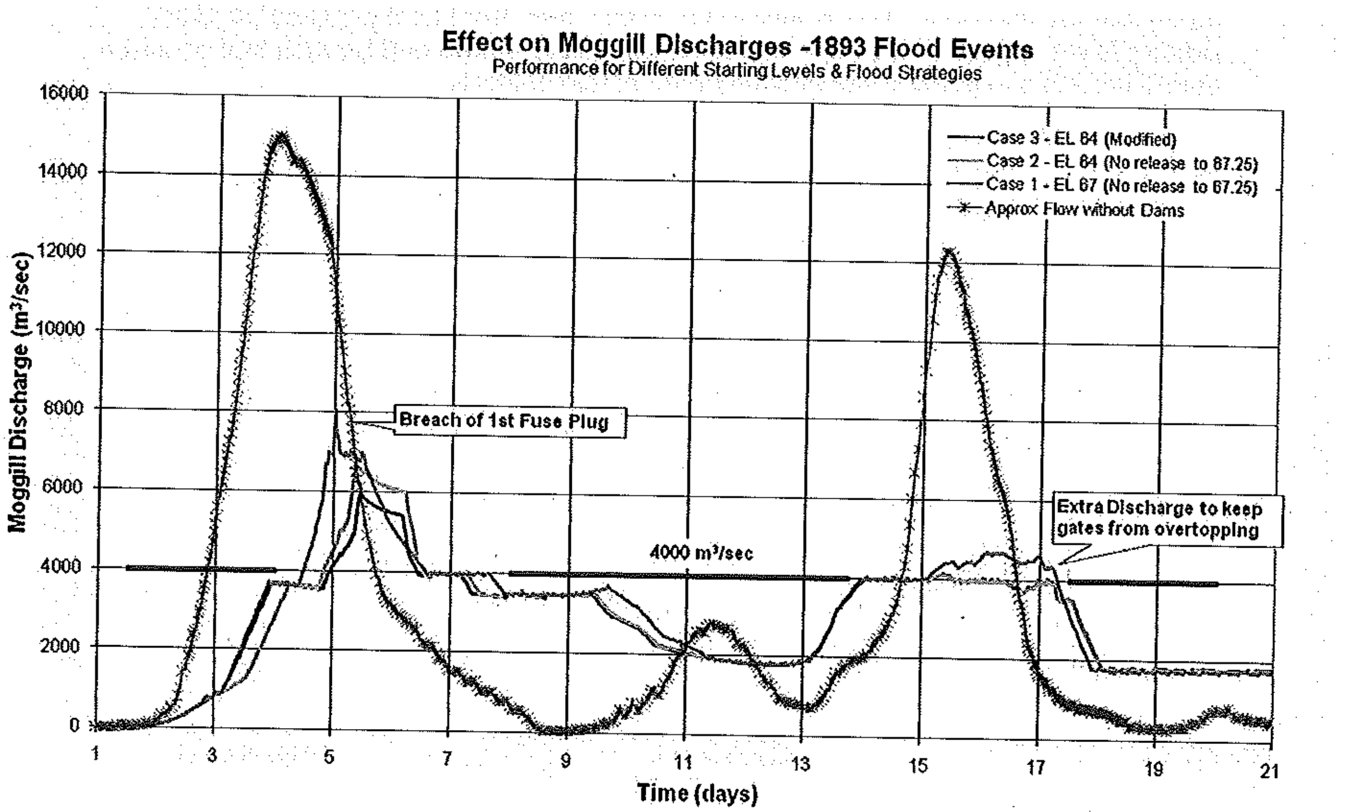
16. This Table indicates that, in this instance, there would have been significant benefits in reducing the headwater level in Wivenhoe Dam prior to the event. By lowering the starting headwater level to EL 64 mAHD without any other changes, the maximum discharge through Brisbane would have been reduced from about 8,000 m^3/sec to about 6,700 m^3/sec. By further amending the trigger levels for Strategy W1 down by 3 metres, the discharge through Brisbane would have been reduced down to about 5,900 m3/sec. In today's terms, this would have significantly reduced the cost of the consequent damages.

17. The results are summarised in the following figures.





Effect on Wivenhoe Discharges -1893 Flood Events
Performance for Different Starting Levels & Flood Strategies
Wivenhoe Discharge (m³/sec)
Time (days)
Case 3 - EL 64 (Modified)
Case 2 - EL 64 (No release to 67.25)
Case 1 - EL 67 (No release to 67.25)
Total Inflow Wivenhoe/Somerset
Breach of 1st Fuse Plug



Effect on Moggill Discharges -1893 Flood Events
Performance for Different Starting Levels & Flood Strategies
Moggill Discharge (m³/sec)
Time (days)
Case 3 - EL 64 (Modified)
Case 2 - EL 64 (No release to 67.25)
Case 1 - EL 67 (No release to 67.25)
Approx Flow without Dams
Breach of 1st Fuse Plug
4000 m³/sec
Extra Discharge to keep gates from overtopping

January 1974

18. The January 1974 flood event was the last major Brisbane River flood event that people in Brisbane and Ipswich remember (before the January 2011 event). The primary differences between it and the 2011 event were that:
    (a) It occurred prior to the construction of Wivenhoe Dam
    (b) There was major local flooding in the Ipswich and Brisbane area
    (c) This local flooding largely coincided with the natural peak of the Brisbane River flooding moving downstream from the Upper Brisbane catchment.
    (d) When compared to the 2011 event:
    - the flood peak arising from above Somerset was relatively greater than that arising from the remainder of the Wivenhoe catchment.
    - The combined Bremer River and Lockyer Creek flow was much greater than the 1893 and the January 2011 events and it would have caused significant damage even without any releases from Wivenhoe.
19. The estimated magnitude of the event is summarised in the following Table.

Catchment	Peak Inflow (m^3/sec)	Flood Volume (1,000 ML)
Wivenhoe (excl Somerset)	5019	1228
Somerset	3463	607
Lockyer	3260	675
Bremer	4241	594

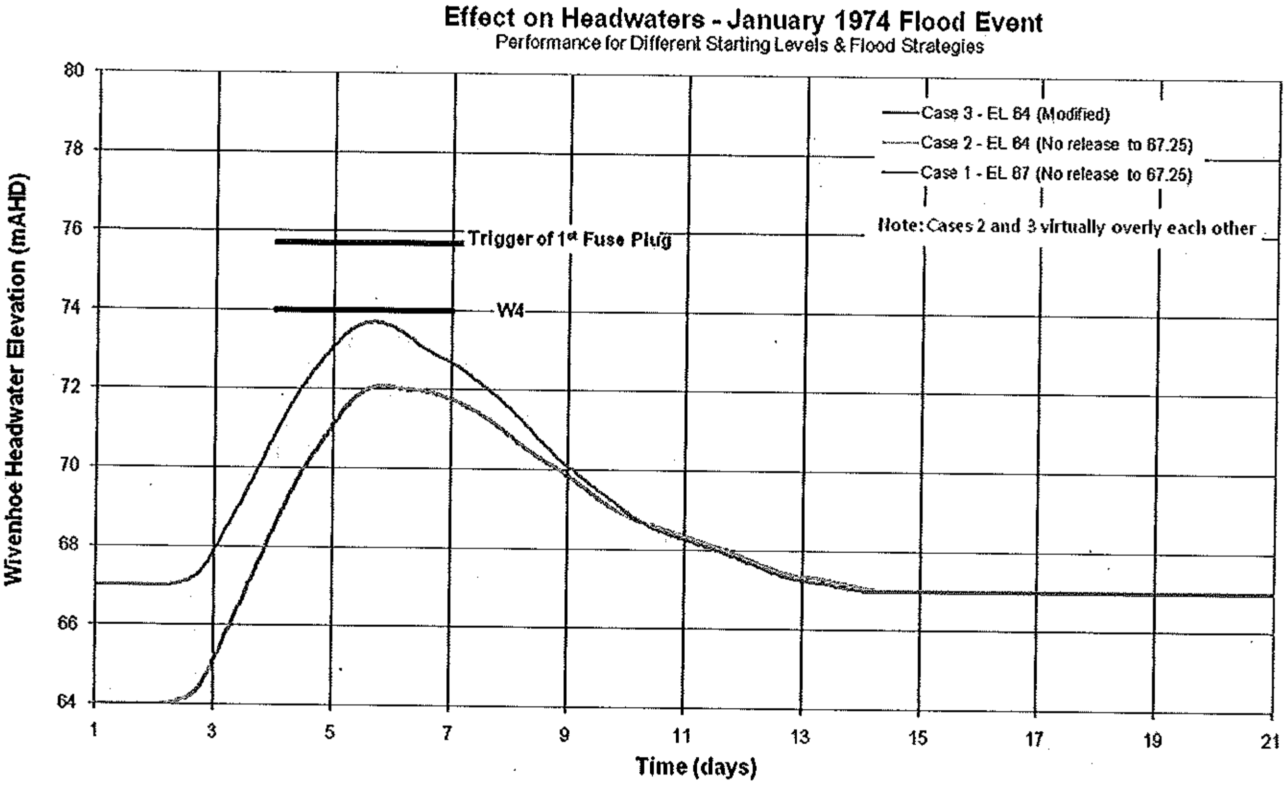
20. Because of the relatively high discharges from the Bremer River especially, there would already have been significant flooding in Brisbane before any discharge from Wivenhoe arrived. This required a variation to the Manual Strategy W3 which virtually applies from the beginning of discharges from Wivenhoe. It becomes a case of trying not to aggravate the damages already inflicted by discharges from Lockyer Creek and the Bremer River. Note that the severe local flooding in Brisbane and Ipswich that occurred during the 1974 event was not accounted for in this analysis.

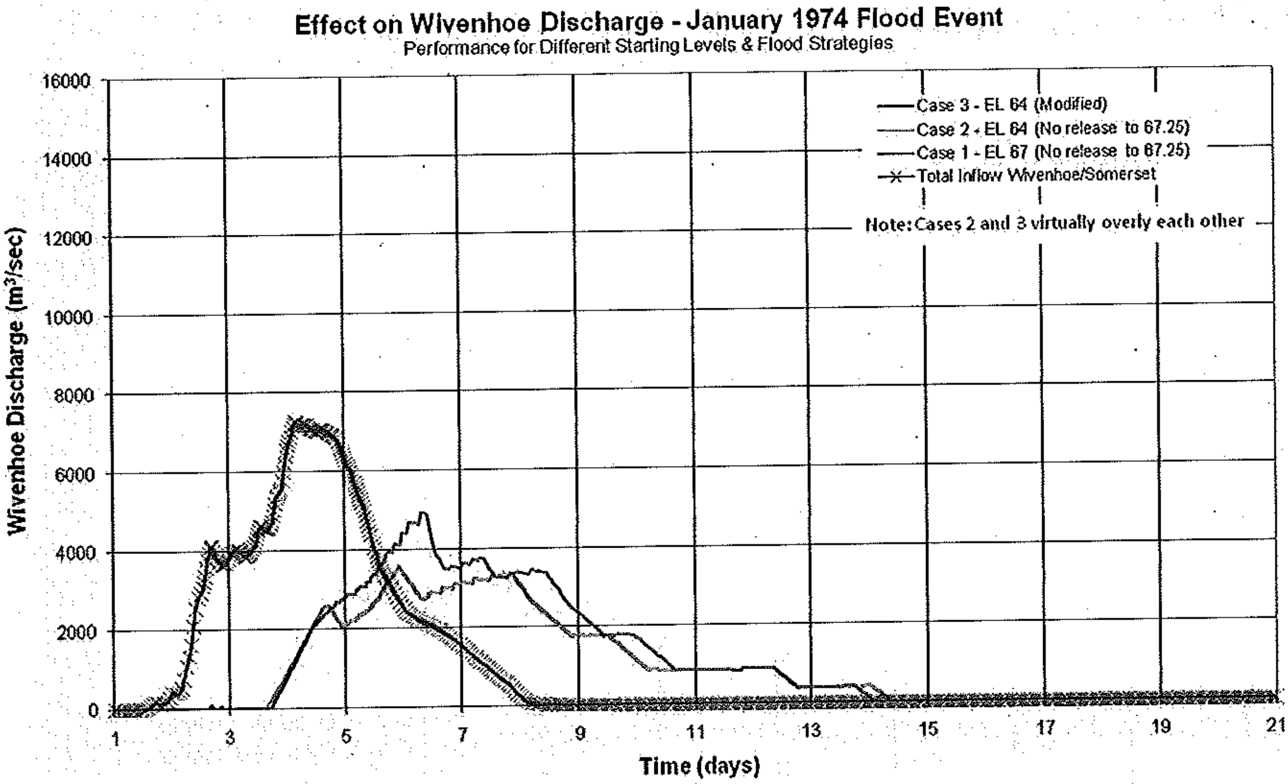
Jan 1974 Event		Case 1	Case 2	Case 3
Starting Levels	Wivenhoe	67 mAHD	64 mAHD	64 mAHD
	Somerset	99 mAHD	99 mAHD	99 mAHD
Strategy 1A commences		67.25 mAHD	67.25 mAHD	64.25 mAHD
Peak Inflows	Som Inflow	3463	3463	3463
	Wiv Inflow	5019	5019	5019
	Wiv + Som	7273	7273	7273
Headwater Peaks	Wivenhoe	73.236	72.098	72.184
	Somerset	103.938	103.864	103.895
Max discharge	Wivenhoe	4611	3549	3561
	Somerset	2003	1978	1978
	Lowood	5943	4985	4983
	Moggill	6159	5881	5851
Degree flood Mitigation		63%	49%	49%

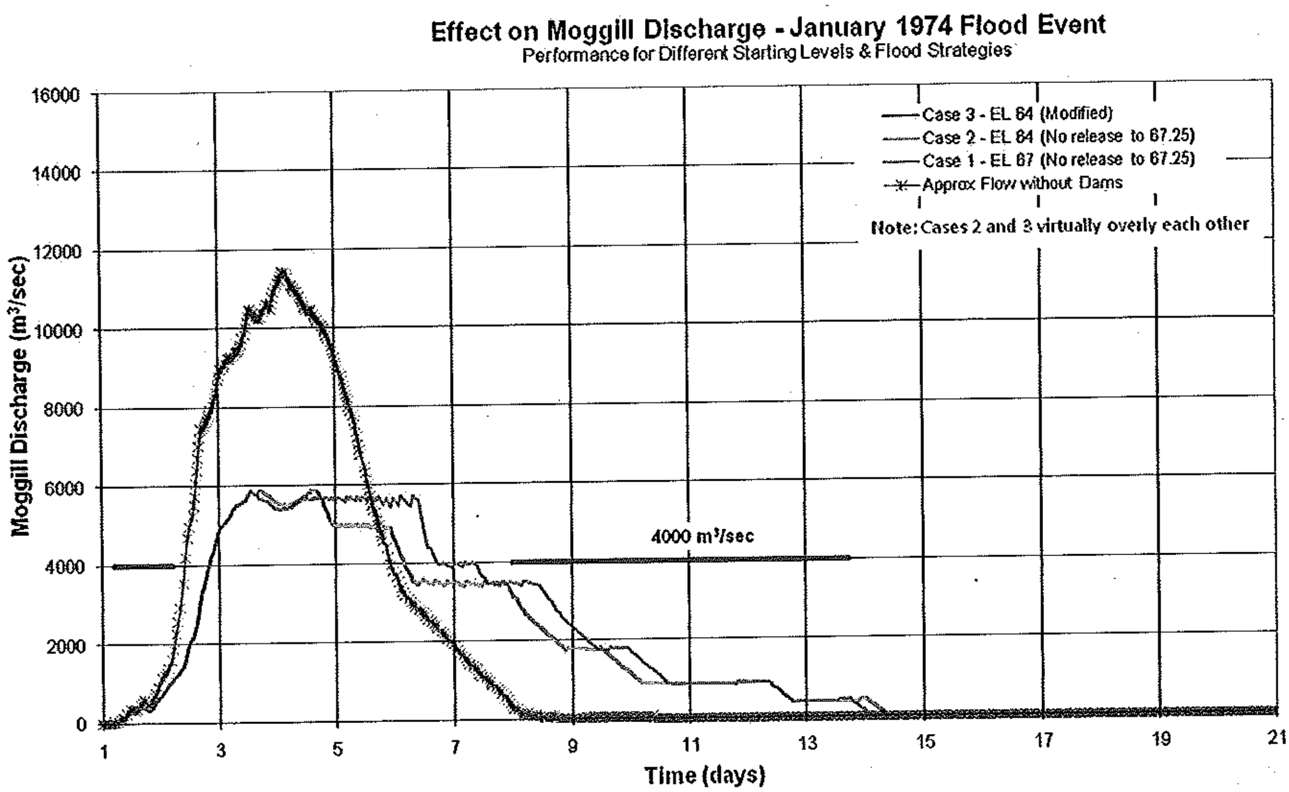
21. Ultimately, the reality with this event is that the dams have sufficient capacity to reduce the peak discharge through Brisbane down to that which occurs naturally with the discharges from Lockyer Creek and the Bremer River. As such providing additional flood storage capacity in Wivenhoe Dam provides very little additional benefit to Brisbane and Ipswich although some additional benefit is provided to areas upstream of the junction of the Bremer and the Brisbane Rivers.

22. Similarly, because of the inability to discharge water from Wivenhoe early in the event, there is virtually no benefit in rearranging Strategy W1 to allow discharge when the water just gets above EL 64.25 mAHD (instead of EL 67.25 mAHD).

23. These results are summarised in the following figures.




Effect on Wivenhoe Discharge - January 1974 Flood Event
Performance for Different Starting Levels & Flood Strategies
Case 3 - EL 64 (Modified)
Case 2 - EL 64 (No release to 67.25)
Case 1 - EL 67 (No release to 67.25)
Total Inflow Wivenhoe/Somerset
Note: Cases 2 and 3 virtually overly each other
Wivenhoe Discharge (m³/sec)
Time (days)
16000
14000
12000
10000
8000
6000
4000
2000
0
1
3
5
7
9
11
13
15
17
19
21


Effect on Moggill Discharge - January 1974 Flood Event
Performance for Different Starting Levels & Flood Strategies
Case 3 - EL 64 (Modified)
Case 2 - EL 64 (No release to 67.25)
Case 1 - EL 67 (No release to 67.25)
Approx Flow without Dams
Note: Cases 2 and 3 virtually overly each other
4000 m³/sec
Moggill Discharge (m³/sec)
Time (days)
16000
14000
12000
10000
8000
6000
4000
2000
0
1
3
5
7
9
11
13
15
17
19
21

February 1999

24. The February 1999 flood event was the first significant flood event following the introduction of the Real Time Flood Model. It was a relatively small event in that the peak inflow into Wivenhoe (exclusive of Somerset) was about 6,000 m^3/sec and the total flood volume into Wivenhoe and Somerset was about 1.2 million ML.

25. Note that the operations for this modelling do not reflect what actually occurred during the February 1999 event because of the changes made to the 'Target Line' in Revision 7 of the Manual. The main difference of those changes were that in the current manual the sluices are opened sooner than they were in 1999. The other change was that Burton's Bridge was raised subsequent to the February 1999 event so that the trigger for closing the bridge was raised from 250 m^3/sec to 430 m^3/sec.

26. The estimated magnitude of the event is summarised in the following Table.

Catchment	Peak Inflow (m^3/sec)	Flood Volume (1,000 ML)
Wivenhoe (excl Somerset)	7274	826
Somerset	4141	489
Lockyer	132	25
Bremer	424	57

27. It is also important to note that because of the relatively small floods arising out of the Lockyer especially, gate operating decisions were relatively simple because there was only a relatively minor risk of inundating bridge unexpectedly.

28. There were significant initial storage deficits in both Somerset and Wivenhoe prior to the event. Somerset was at EL 93.67 mAHD (53% full) and Wivenhoe was at EL 64.02 mAHD (75% full). For this reason, I have treated the actual starting levels as the 'base' case and Case 2 was with both storages starting at their respective Full Supply Levels.

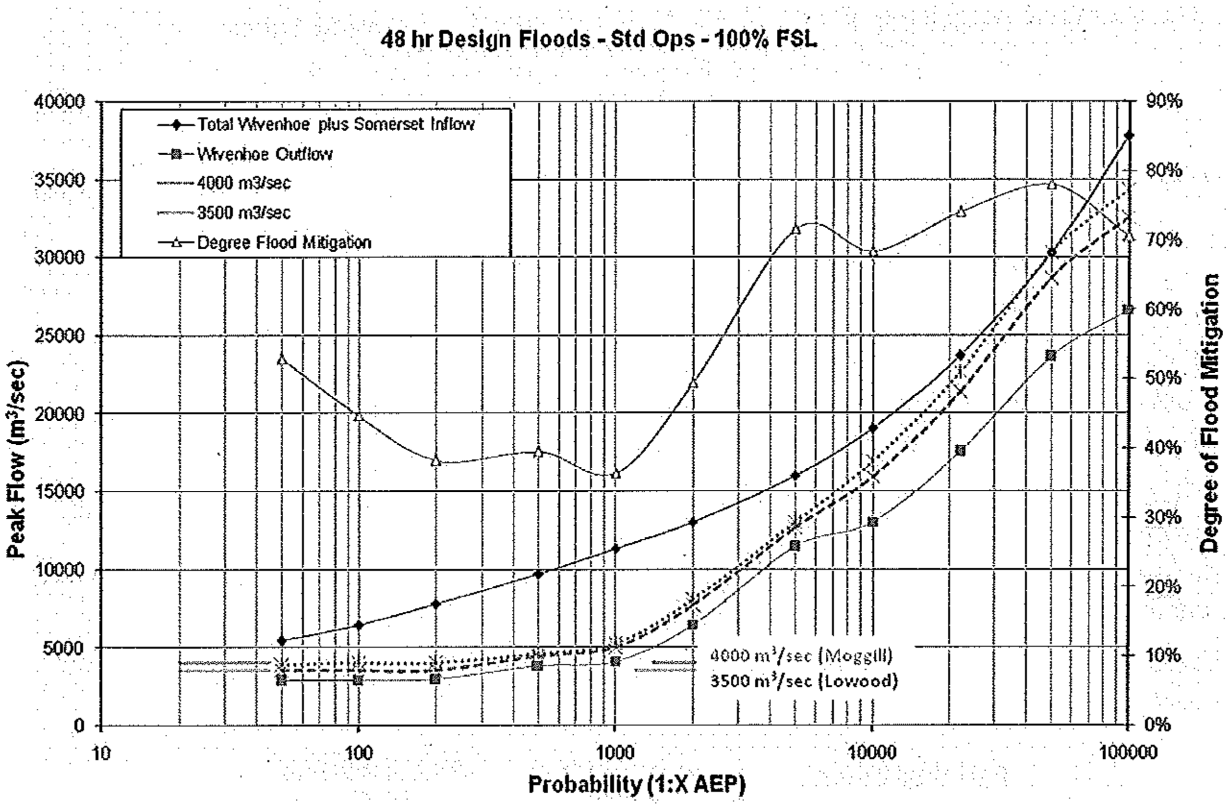
29. As seen in the following Table, there was very little benefit in terms of maximum discharges to starting the event with 75% storage in Wivenhoe Dam.

Feb 1999 Event		FSL starting levels	Actual starting levels
Starting Levels	Wivenhoe	67	64.020
	Somerset	99	99.37
Strategy 1A commences		67.25	67.25
Peak Inflows	Som Inflow	4142	4142
	Wiv Inflow	7274	7274
	Wiv + Som	11053	11053
Headwater Peaks	Wivenhoe	72.657	70.454
	Somerset	104.516	103.200
Max discharge	Wivenhoe	1837	1787
	Somerset	1856	1072
	Lowood	1893	1799
	Moggill	2220	2154
Degree flood Mitigation		17%	16%

30. As seen in the above Table, there was very little benefit in terms of maximum discharges from the dams. The principal benefit is in the lower headwaters that resulted in the dams.

Design Floods

31. A full range of 48 hour duration 'design floods' were also run through the model. The following figure summarises the results for both dams starting the event at the current Full Supply Level EL 67.0 mAHD.



32. These results tend to indicate for these design events that:

(a) A significant degree of flood mitigation is provided up until about the 1:1000 AEP event. The reason the 'Degree of Flood Mitigation' falls from the 1:50 AEP flood event to the 1:1000 AEP flood event is largely due to the upper limits of Strategies W2 and W3. On the smaller events, the discharge is pushed up to these limits in order to maximise the chance that these discharges will not be exceeded.

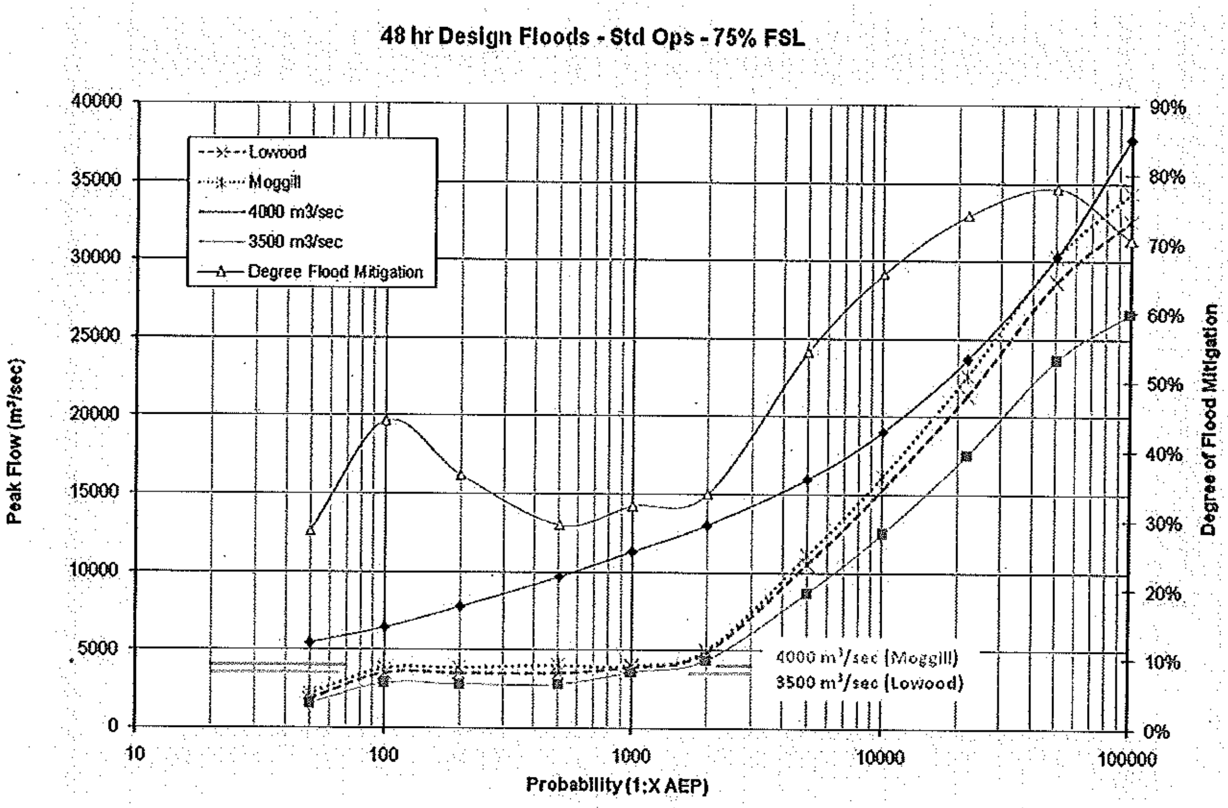
(b) As the magnitude of the floods exceeds the 1 in 1000 AEP event, the effect of the triggering of Strategy W4 'kicks in' and discharges are significantly increased in order to minimise the risk to the dam at the expense of the flood mitigation objective. As the magnitude of the event increases, the Degree of Flood Mitigation steadily rises as the outflow more closely matches the magnitude of the inflows.

(c) For this operating Case, the first fuse triggers for a 1: 2000 AEP flood event

(d) The ability of Wivenhoe Dam to limit the peak discharge at Lowood and Moggill to a value similar to the discharge from Wivenhoe is significantly reduced beyond the 1:5000 AEP flood event.

(e) When the current Full Supply Level (FSL) is used as the starting headwater level, minimal flood damages in Ipswich and Brisbane cannot be maintained beyond the 1:in 200 AEP flood event.

33. A series of modelling runs was undertaken to determine the effect of reducing the initial level of Wivenhoe Dam to 75% of the storage capacity at FSL (i.e Case 2). These results for Case 2 for the Design Flood events are summarised in the following figure.



34. By reducing the starting headwater level to that of 75% Full Supply Level storage capacity, the damages in Ipswich and Brisbane can be maintained at minimal levels up to about the 1:1000 AEP flood event.

35. Full hydrographs for representative flood events are presented in Appendix 1.

Table 1 Summary of Results for Case 1: Both Wivenhoe and Somerset at FSL with operations in accordance with current Manual

AEP	Inflows			Headwater Peaks		Max discharge				Degree flood Mitigation[1]	No. of fuse plugs triggered
	Som Inflow	Wiv Inflow	Wiv + Som	Wiv	Som	Wiv	Som	Lowood	Moggill		
50	1895	4092	5421	70.703	101.634	2861	1528	3497	3845	53%	
100	2271	5044	6451	71.639	102.123	2873	1780	3499	3995	45%	
200	2481	6028	7768	72.467	102.462	2964	1827	3500	4000	38%	
500	3023	7573	9670	74.087	103.392	3809	1853	4425	4599	39%	
1000	3472	8866	11299	75.469	104.059	4105	1806	4997	5243	36%	
2000	3869	10244	13034	76.177	104.836	6429	1894	7671	8043	49%	1
5000	4742	12551	15995	76.121	105.943	11436	2344	12677	12997	71%	1
10000	5548	14935	19054	76.289	106.719	13021	2393	15894	16914	68%	1
22000	6757	18562	23682	76.757	107.641	17514	3678	21329	22617	74%	2
50000	8469	23723	30267	77.845	108.498	23596	4920	28640	30276	78%	3
100000	10407	29607	37759	79.431	109.832	26602	5948	32537	34333	70%	3

Table 2 Summary of Results for Case 2: Wivenhoe at 75% and Somerset at FSL with operations in accordance with current Manual

AEP	Inflows			Headwater Peaks		Max discharge				Degree flood Mitigation	No. of fuse plugs triggered
	Som Inflow	Wiv Inflow	Wiv + Som	Wiv	Som	Wiv	Som	Lowood	Moggill		
50	1895	4092	5421	70.172	101.699	1538	1515	1800	2188	28%	
100	2271	5044	6451	70.559	101.797	2850	1767	3499	3784	44%	
200	2481	6028	7768	71.257	102.172	2832	1817	3499	3853	36%	
500	3023	7573	9670	72.728	103.554	2829	1537	3497	3998	29%	
1000	3472	8866	11299	74.110	104.567	3613	1247	3914	3999	32%	
2000	3869	10244	13034	75.595	104.760	4394	1858	4867	4998	34%	
5000	4742	12551	15995	75.869	105.903	8683	1820	10534	11130	54%	1
10000	5548	14935	19054	75.860	106.673	12501	2953	15319	16199	66%	1
22000	6757	18562	23682	76.778	107.785	17545	3968	21341	22642	74%	2
50000	8469	23723	30267	77.845	108.498	23596	4920	28640	30276	78%	3
100000	10407	29607	37759	79.431	109.832	26602	5948	32537	34333	70%	3

[1] For these figures, the 'Degree of Flood Mitigation' has been defined as the ratio of the 'Peak Discharge from Wivenhoe Dam' to the 'Peak Total Inflow into Wivenhoe and Somerset Dams' (Wiv + Som).

Conclusions

36. It is evident from the above results that:

(a) The degree of flood mitigation offered by Wivenhoe and Somerset dams is very dependent on where the flooding originates from and the magnitude of this flooding.

(b) Significant flood mitigation for floods arising from catchments upstream of Wivenhoe Dam is achievable for floods up to about the size of the January 1974 flood. The degree of flood mitigation will reduce significantly for larger floods such as the January 2011 flood event.

(c) Had Wivenhoe been built at the time of the January 1974 flood and it had been at Full Supply Level prior to the event, the peak storage level in Wivenhoe could have been about EL 73.3 mAHD and strategy W4 may not have been triggered. Pre-releasing from Wivenhoe prior to the event would not have significantly reduced the peak discharges from the dam because the magnitude of the flood damages in Ipswich and Brisbane would have been controlled by discharges from the Lockyer and the Bremer. i.e. when significant flooding occurs from catchments downstream of the dam (such as in the 1974 flood event) there will be a much reduced benefit in pre-releasing storage from Wivenhoe prior to the event.

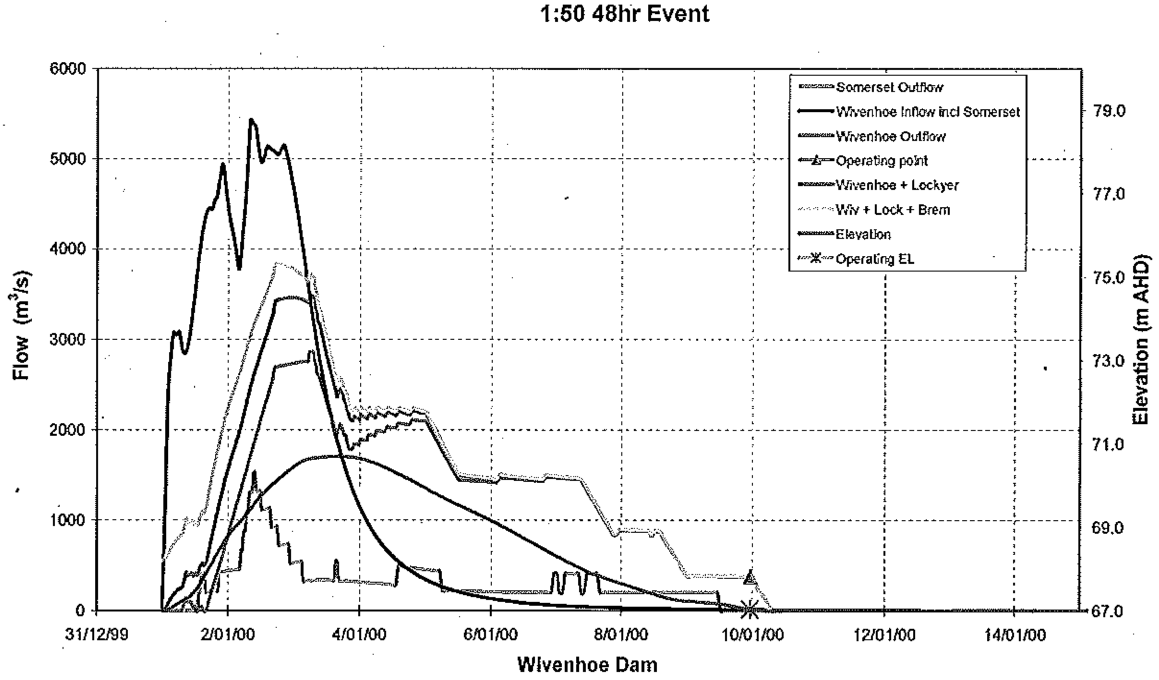
(d) If Wivenhoe and Somerset dams had been built at the time of the February 1893 floods and they both had started the event at Full Supply Level, the peak storage level in Wivenhoe would have been about EL 76 mAHD during the first peak and it would have triggered the first fuse plug. Pre-releasing storage down to 75% would have reduced the maximum discharge from Wivenhoe by about 10%. In addition to this, modifying the operational strategies to begin strategy W1 at EL 64.25 provides a further 10% reduction in peak discharge from Wivenhoe.

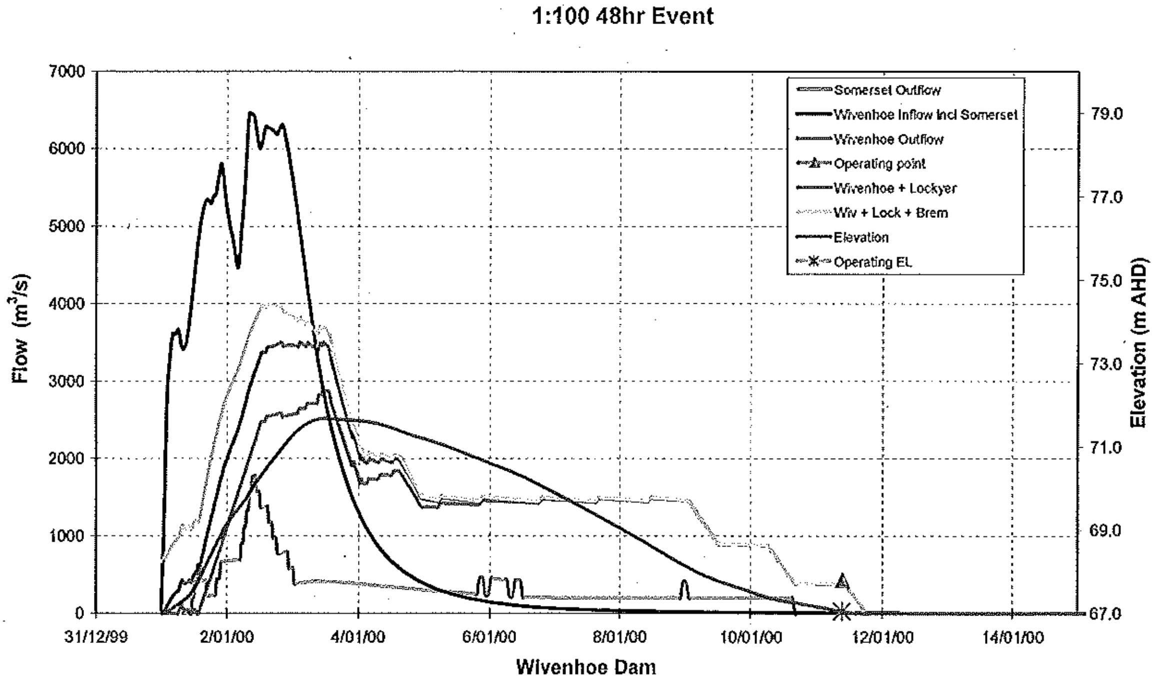
(e) It is possible for Somerset and Wivenhoe dams to safely pass the 48 hour duration 1:100,000 AEP design flood event.

(f) Irrespective of the flood release strategies adopted and the initial starting levels, there will be major events occur that will inundate large areas of Brisbane and Ipswich.

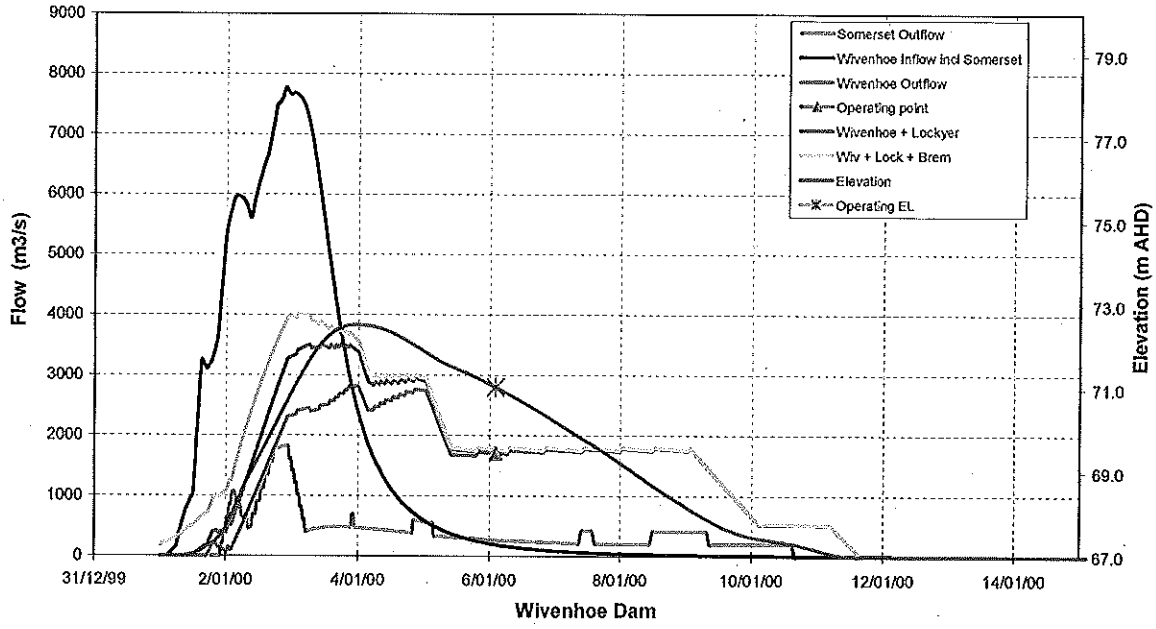
Appendix 1 Hydrographs of a range of Design Flood Events

Assuming Wivenhoe Dam starts event at Full Supply Level (EL 67.0 mAHD)

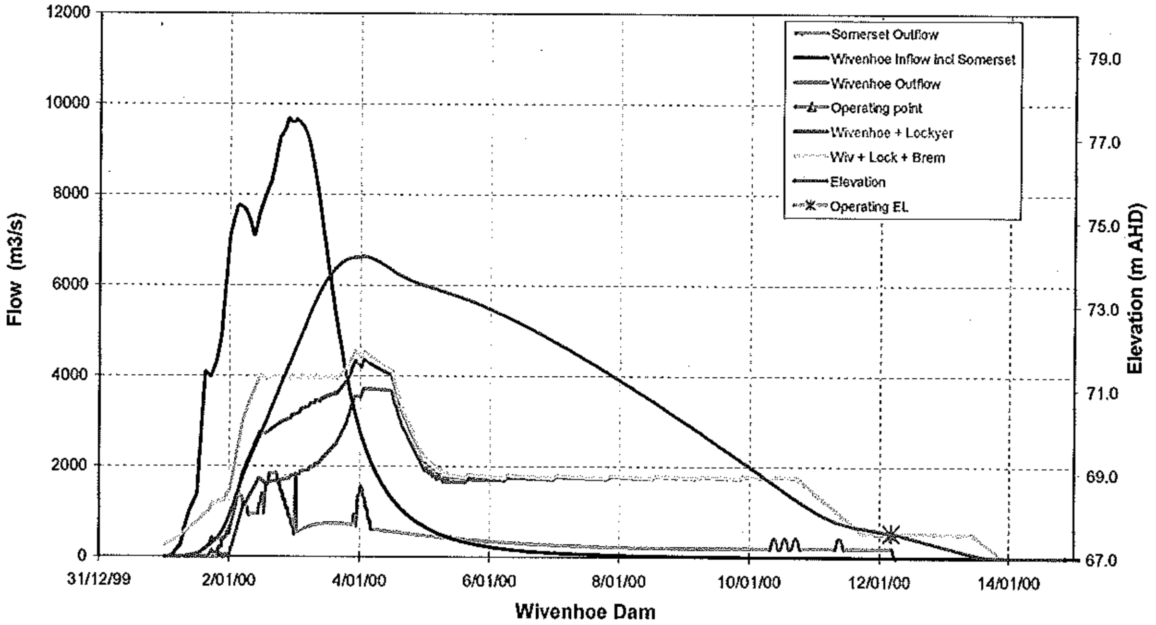




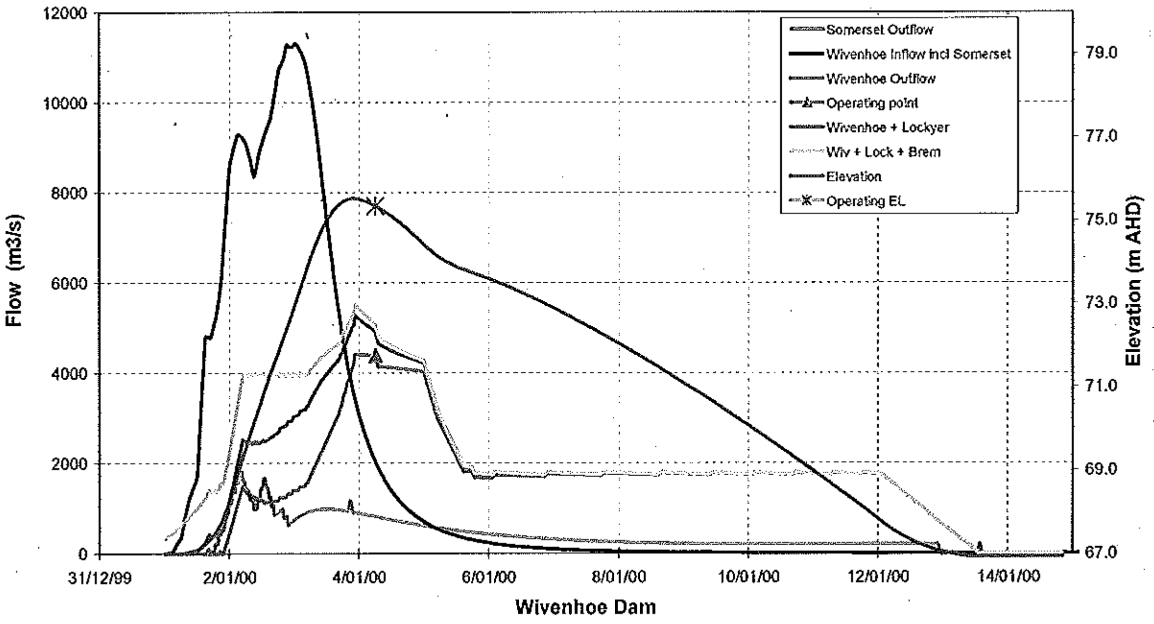
1:200 48hr Event



1:500 48hr Event



1:1,000 48hr Event



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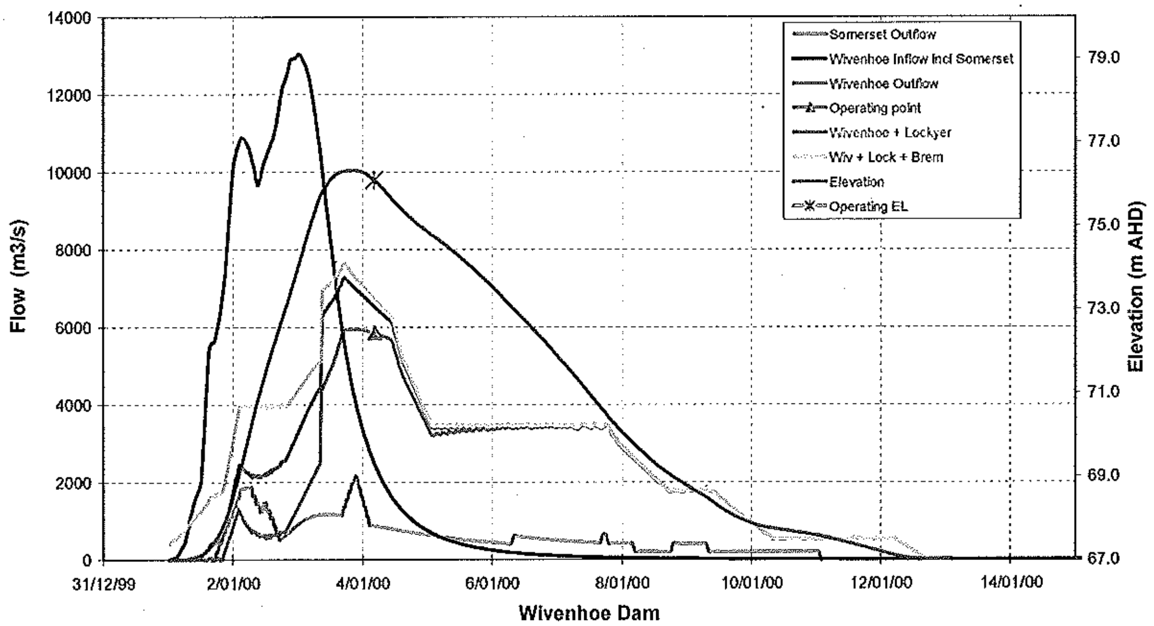

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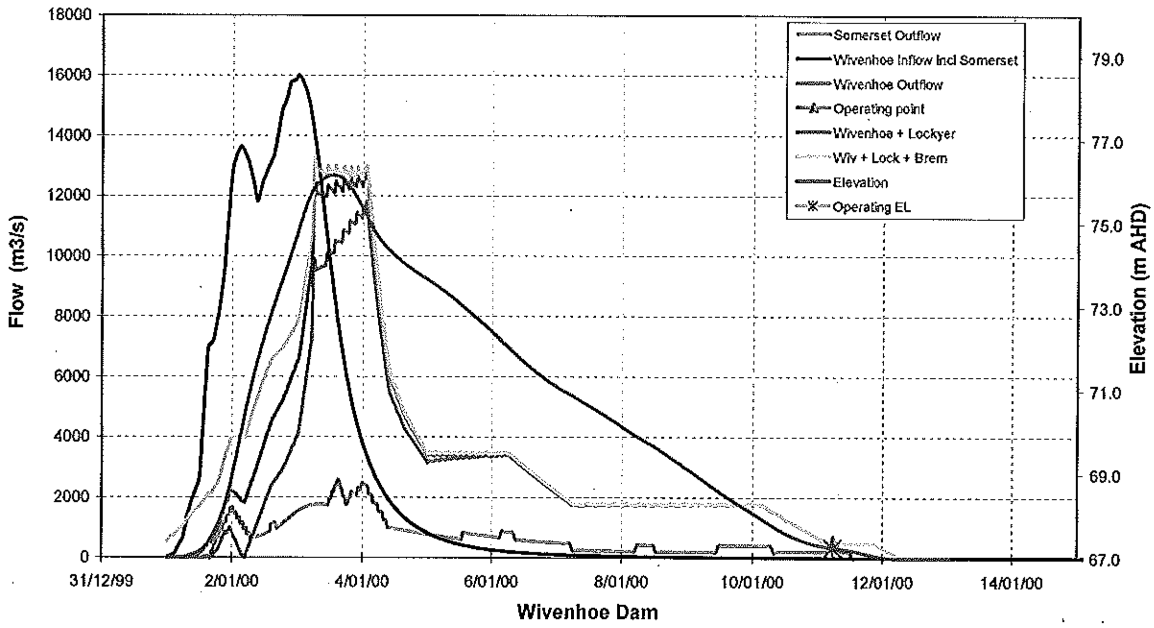

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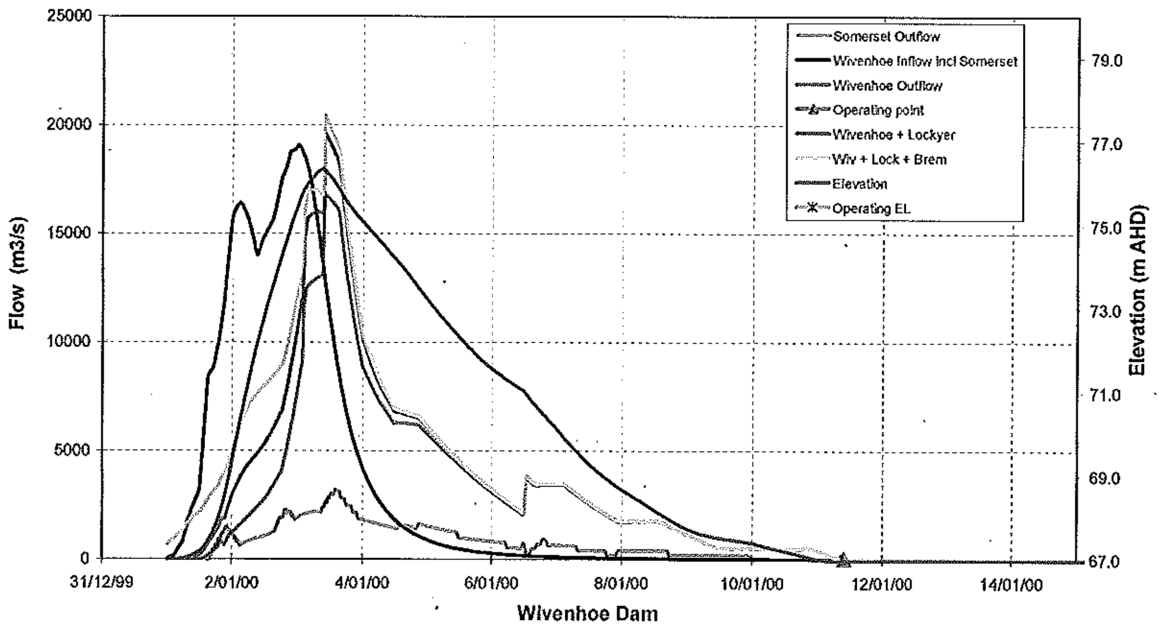

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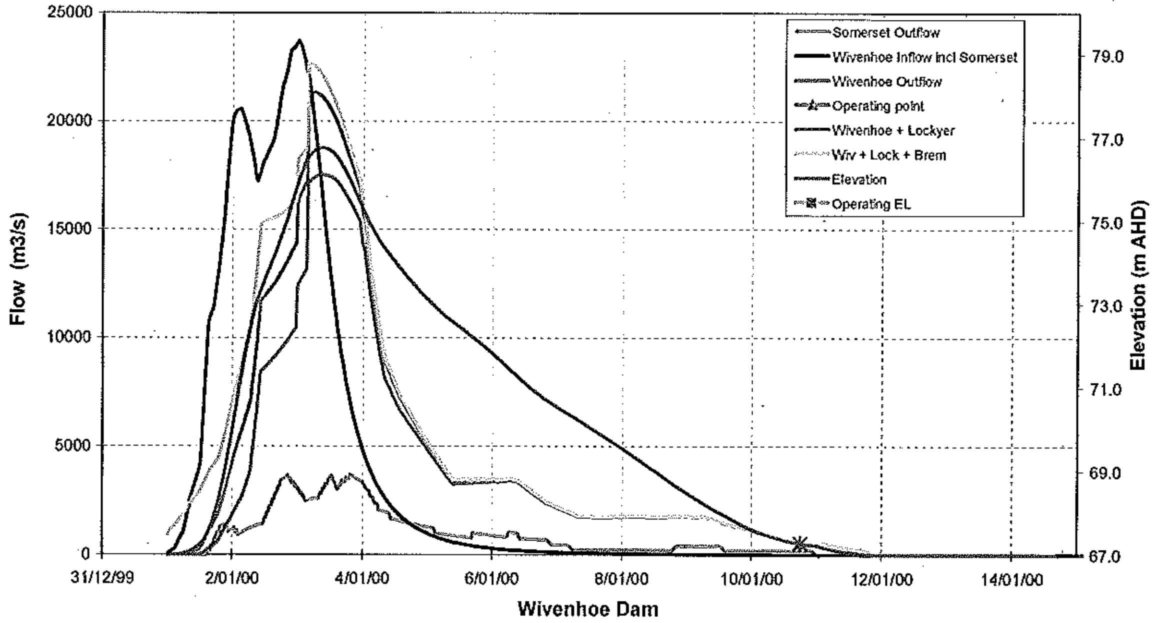

1:100,000 48hr Event