Hanna, Leanne

**From:** Jim Pruss [redacted]
**Sent:** Thursday, 17 February 2011 7:41 AM
**To:** Barton Maher
**Subject:** RE: Modellingof 75% in Wivenhoe with the releases of up to 400m3/s between EL64 and EL67

[illegible]

[illegible] My apologies once again for the reactive nature of all this. We are also speaking to terry about trying to link the outputs of your models to the Brisbane river models [illegible] models. I have asked them to talk to you for your input and help but not to lead this project

**From:** Barton Maher
**Sent:** Wednesday, 16 February 2011 12:56 PM
**To:** Jim Pruss
**Subject:** Modellingof 75% in Wivenhoe with the releases of up to 400m3/s between EL64 and EL67

[illegible]

Results as requested

| Flood Event | | | Option 0 - Existing Rules (Storage Level 100%) | | Storage Level 75% (Option 3) | | Storage Level 75% (Option 3 plus release below EL67)** | | Storage Level 50% | |
|---|---|---|---|---|---|---|---|---|---|---|
| Event description | Maximum Inflow ($m^3/s$) | Flood Volume (ML) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Maximum Outflow ($m^3/s$) | Flow Reduction % | Maximum Outflow ($m^3/s$) | Flow Reduction % | Maximum Outflow ($m^3/s$) | Flow Reduction % |
| 36 hour 1 in 200 design* | 8,214 | 1,544,119 | 3,861 | 71.43 | 2,356 | 39% | 1,935 | 50% | 1,134 | 71% |
| 36 hours 1 in 500 design | 10,455 | 1,624,119 | 5,125 | 72.22 | 3,693 | 28% | 2,417 | 53% | 2,213 | 57% |
| 36 hours 1 in 1000 design | 12,031 | 1,772,752 | 6,049 | 72.8 | 4,705 | 22% | 4,479 | 26% | 3,329 | 45% |
| 48 hours 1 in 5000 design | 14,278 | 2,562,553 | 9,083 | 74.71 | 8,339 | 8% | 8,204 | 10% | 7,397 | 19% |
| 72 hours 1 in 5000 design | 13,181 | 2,880,602 | 8,204 | 74.16 | 7,689 | 6% | 7,599 | 7% | 7,071 | 14% |
| 96 hours 1 in 5000 design | 11,870 | 2,948,032 | 7,550 | 73.75 | 7,017 | 7% | 6,906 | 9% | 6,404 | 15% |
| 120 hours 1 in 5000 design | 12,727 | 3,005,136 | 7,265 | 73.57 | 6,702 | 8% | 6,628 | 9% | 6,360 | 12% |
| January 2011 historic | 10,470 | 2,650,000 | 7,528 | 74.98 | 5,748 | 24% | 4,810 | 36% | 4,209 | 44% |

## Unknown

**From:** Jim Pruss [redacted]
**Sent:** Monday, 14 February 2011 10:57 AM
**To:** Barton Maher
**Subject:** another modelling run

Barton

Peter wants another model run, additional to the scenarios we have done ie. We have done (1) 75/100, (2) 75/75 (3) 75/whatever our draw down number is 430cumecs if we keep that going all the way back to 100% regardless of inflows? Wants to see what if any difference that makes. Ie. Not go let it go back to 100% in the early part of a flood event but just keep releasing at 430 and then kick manual in at appropriate level. Not sure how this is really different to what we have already done as we would be releasing at 430 either until we get to 75, while we were getting inflow between 75 and 100 either going up or down. We just haven't modelled the scenario I don't think

Can you have a look please or call if that doesn't make sense

Jim Pruss
Executive General Manager, Water Delivery
QLD Bulk Water Supply Authority *trading as* Seqwater

seqwater

Ph [redacted]
Level 4 240 Margaret Street, Brisbane City QLD 4000 Australia
PO Box 16146, City East QLD 4002
Website | www.seqwater.com.au

## Unknown

**From:** Jim Pruss [redacted]
**Sent:** Wednesday, 9 February 2011 5:56 PM
**To:** Barton Maher
**Subject:** Re: Time required to get to 75%

Thanks barton

Got it

**From**: Barton Maher
**Sent**: Wednesday, February 09, 2011 05:52 PM
**To**: Jim Pruss
**Subject**: Time required to get to 75%

Hi Jim,

Assuming we have no inflows to the dam and no flows downstream of the dam, the time to draw down the storage to 75% would be at least 8 days.

| Burton's Bridge Flow Rate | |
|---|---|
| m3/s | ML/day |
| 430 | 37,152 |

| Volume to release to get to 75% |
|---|
| 288,706 |

| Time | Time (days) | Release | Total Volume Released (ML) | Volume Remaining (ML) | |
|---|---|---|---|---|---|
| 0 - 12 hours | 0.5 | 14,860.80 | 14,860.80 | 273,845.20 | Ramp up over 12 hours giv |
| 24 hours | 1 | 37,152 | 52,013 | 236,693.20 | |
| 48 hours | 1 | 37,152 | 89,165 | 199,541.20 | |
| 72 hours | 1 | 37,152 | 126,317 | 162,389.20 | |
| 96 hours | 1 | 37,152 | 163,469 | 125,237.20 | |
| 120 hours | 1 | 37,152 | 200,621 | 88,085.20 | |
| 144 hours | 1 | 37,152 | 237,773 | 50,933.20 | |
| 168 hours | 1 | 37,152 | 274,925 | 13,781.20 | |
| 12 hours | 0.5 | 14860.8 | 289,786 | -1,079.60 | |
| **Total** | 8 | days | | | |

Realistically more like 9 to 10 days

Regards,
Barton Maher
Principal Dams & Water [illegible]
QLD Bulk Water Supply Authority [illegible]

**From:** Nathan, Rory J (SKM) [redacted]
**Sent:** Monday, 7 February 2011 3:36 PM
**To:** Barton Maher; Jim Pruss
**Subject:** RE: Impact Revised FSL - v3 .docx
**Attachments:** Impact Revised FSL - v3a .docx

Hi,

If not too late, I have include some additional linking text to provide results for all options considered, and have provided a simpler table. I am nervous about the level of detail and suggest that we should keep to as high a level as possible.

You probably do not need both the table and the figure, so one could be deleted – my preference would be to retain the figure as it is more imprecise and smooths out the effect of the differences due to specific design storm assumptions.

Happy to discuss,

Rory

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**From:** Barton Maher [redacted]
**Sent:** Monday, 7 February 2011 4:05 PM
**To:** Jim Pruss
**Cc:** Nathan, Rory J (SKM)
**Subject:** Impact Revised FSL - v3 .docx

Hi Jim,

Please find attached a simple report and graph with the table as requested.

Regards,
Barton

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# Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges

# 1 Introduction

This note provides a summary of a preliminary assessment into the impact of reducing the initial storage level of Wivenhoe Dam on the downstream discharges for major flood events. Information is provided on the impacts of reducing the Wivenhoe Dam initial storage level to 95%, 90%, 75% and 50% of the normal full supply level.

It should be stressed that the information presented here is based on approximate analyses to help inform discussion. More accurate estimates would require a detailed investigation and analysis of the whole river system utilising multiple flood events and a combination of hydrologic, hydraulic, and routing models. This review should thus be seen as providing an order of magnitude assessment of impacts and the results should not be utilised beyond that purpose.

# 2 Methodology

The analysis was undertaken using a computer model to simulate the gate opening sequence as provided in the Flood Manual during a "loss of communications" situation. During a loss of communications between the dam operators and the Flood Control Centre, operators would use predefined gate openings based solely on the Lake Level information available to them at the dams. It should be noted that in practice gate operations would normally seek to take advantage of additional information related to rainfall forecasts and tributary flows to ensure that flood peaks are reduced as far as possible without causing coincident flooding with downstream tributaries. Thus, while using the "loss of communications" flood operation rules provides a consistent means of comparing the efficacy of different mitigation options, the actual degree of flood reduction achievable is dependent on the characteristics of the specific event.

Flood inflows to the model were derived from an analysis of past historic events (1974, 1999, and 2011), in combination with "design hydrographs" developed previously for design and planning purposes (Wivenhoe Alliance, 2005[1]). These "design hydrographs" are obtained from models of both the rainfall and flood generation process, whereby floods of a given magnitude are assigned a specified probability of exceedance (eg a "1 in 200" event).

[1] Wivenhoe Alliance, "Design Discharges and Downstream Impacts of the Wivenhoe Dam Upgrade", [illegible] September 2005.

# 3 Options Considered

Five options are explored in this paper, as summarised in the table below.

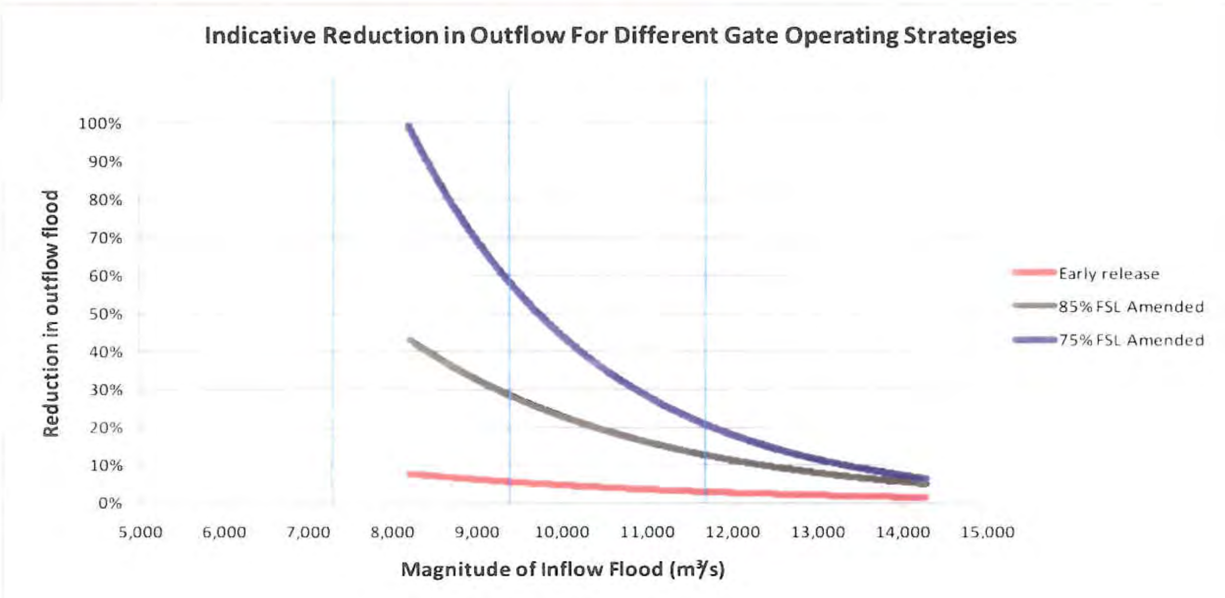
~~There are five options considered going forward.~~

| Option | Description | Comments |
|---|---|---|
| 0<br><br>"Do nothing" | Continue with the current approved flood operation rules – that is, maintain the status quo and continue to utilise the dam as originally designed. | This option has the least risks associated with it as the Strategies have been implemented and refined over several flood events and the manual was developed by a comprehensive study. |
| 1<br><br>"Early release" | Change the flood operating rules to ignore the early strategies designed to minimise disruption to the rural communities | Increase the release from the dam up to 1600 $m^3/s$ as soon as practicable after gate operations commence; it is assumed that no attempt would be made to maintain bridge access downstream of the dam other than Mt Crosby Weir Bridge and the Brisbane Valley Highway Bridge. |
| 2<br><br>"Pre-release" | Implementing a significant release of water once the notification of a major rainfall event has been received. | At present accurate Bureau of Meteorology forecasts are such that they do not allow the reservoir to be drawn down in a timely manner without causing appreciable "artificial" flooding downstream. |
| 3<br><br>"75% FSL" | Lower the storage level in Wivenhoe Dam to 75% of the current full supply level, and operate the dam under the current operating rules. | To safely lower the storage it is proposed that this option would be implemented by "Sunny Day" releases at a rate low enough to minimise disruption to the rural areas. This would be difficult to implement during a wet year where the risk of major flooding is greater. Once the storage level reached EL67 gate operations would commence as per the current flood manual. |
| 4<br><br>"85% FSL amended" | Lower the storage level in Wivenhoe Dam to 85% of the current full supply level and amend the current flood manual to commence releases once the storage level exceeds EL65.5 | The amended flood operating rules would retain the key level in the manual of EL74m, where the gates are opened until the flood level stops rising. This would require a change by the Queensland Government to the regulatory requirements and levels of service that the storage is operated under. |
| 5<br><br>"75% FSL amended" | Lower the storage level in Wivenhoe Dam to 75% of the current full supply level and amend the current flood manual to commence releases once the storage level exceeds EL65.5 | Same comment as for Option 4. |

# 4 Results

Analysis of the 1974 and 2011 historic events under Option 3, namely lowering the storage level in Wivenhoe Dam to 75% of the current full supply level and operating the dam under the current operating rules, achieve reductions in the magnitude of the outflow flood of 3.3% and 15%, respectively. Analysis of the rates at which the reservoir can be safely drawn down within a 2 to 3 day period indicate that the benefits are substantially less than that achievable with temporarily reducing the storage level down to 75% (Option 2).

Given the reasonably modest reductions achievable with Options 2 and 3, attention was focused on exploring the benefits of the other options. The results for these are illustrated in the figure below, and selected results are summarised in the following table.




| Event description | Maximum Inflow ($m^3/s$) | Maximum outflow under current operating rules (Option 0) ($m^3/s$) | Flow Reduction under Option 1 | Flow Reduction for Option 4 | Flow Reduction for Option 5 |
|---|---|---|---|---|---|
| 36 hour 1 in 200 design | 8,210 | 3,860 | 6% | 32% | 49% |
| 36 hours 1 in 500 design | 10,460 | 5,130 | 4% | 21% | 33% |
| 36 hours 1 in 1000 design | 12,030 | 6,050 | 3% | 17% | 26% |
| 48 hours 1 in 5000 design | 14,280 | 9,080 | 1% | 6% | 10% |
| January 2011 historic | 10,480 | 7,530 | 1% | 24% | 40% |
| 1974 historic | 5,950 | 3,280 | 4% | 16% | 24% |
| 1999 historic | 6,360 | 2,310 | 3% | 22% | 32% |

## 5 Conclusions

Reductions in outflow flood can be achieved by the adoption of different storage levels and release strategies. However, due to the large volumes of water associated with major flood events, it is necessary to consider large changes to the full supply level to achieve appreciable reductions in flood magnitude. The impact of different initial storage levels reduces as the magnitude of the event increases.

**From:** Nathan, Rory J (SKM) [redacted]
**Sent:** Monday, 7 February 2011 2:51 PM
**To:** Barton Maher
**Subject:** some draft text
**Attachments:** Impact Revised FSL - v3 .docx

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WATER FOR LIFE

# Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges

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# 2 Methodology

The analysis was undertaken using a computer model to simulate the gate opening sequence as provided in the Flood Manual during a "loss of communications" situation. During a loss of communications between the dam operators and the Flood Control Centre, operators would use predefined gate openings based solely on the Lake Level information available to them at the dams. It should be noted that in practice gate operations would normally seek to take advantage of additional information related to rainfall forecasts and tributary flows to ensure that flood peaks are reduced as far as possible without causing coincident flooding with downstream tributaries. Thus, while using the "loss of communications" flood operation rules provides a consistent means of comparing the efficacy of different mitigation options, the actual degree of flood reduction achievable is dependent on the characteristics of the specific event.

Flood inflows to the model were derived from an analysis of past historic events (1974, 1999, and 2011), in combination with "design hydrographs" developed previously for design and planning purposes (Wivenhoe Alliance, 2005[1]). These "design hydrographs" are obtained from models of both the rainfall and flood generation process, whereby floods of a given magnitude are assigned a specified probability of exceedance (eg a "1 in 200" event).

[1] Wivenhoe Alliance, "Design Discharges and Downstream Impacts of the Wivenhoe Dam Upgrade" (3109?) September 2005

## 3 Options Considered

Five options are explored in this paper, as summarised in the following table:

There are five options considered going forward.

| Option | Description | Comments |
|---|---|---|
| 0<br><br>"Do nothing" | Continue with the current approved flood operation rules – that is, maintain the status quo and continue to utilise the dam as originally designed. | This option has the least risks associated with it as the Strategies have been implemented and refined over several flood events and the manual was developed by a comprehensive study. |
| 1<br><br>"Early release" | Change the flood operating rules to ignore the early strategies designed to minimise disruption to the rural communities | Increase the release from the dam up to 1600 $m^3/s$ as soon as practicable after gate operations commence; it is assumed that no attempt would be made to maintain bridge access downstream of the dam other than Mt Crosby Weir Bridge and the Brisbane Valley Highway Bridge. |
| 2<br><br>"Pre-release" | Implementing a significant release of water once the notification of a major rainfall event has been received. | At present accurate Bureau of Meteorology forecasts are such that they do not allow the reservoir to be drawn down in a timely manner without causing appreciable "artificial" flooding downstream. |
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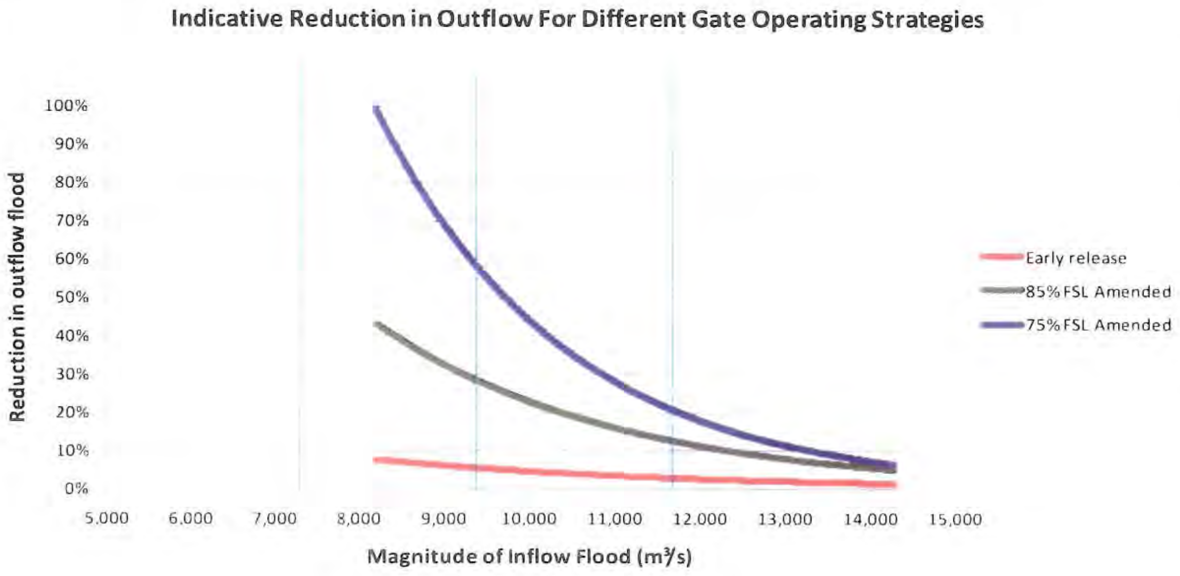
| 4<br><br>"85% FSL amended" | Lower the storage level in Wivenhoe Dam to 85% of the current full supply level and amend the current flood manual to commence releases once the storage level exceeds EL65.5 | The amended flood operating rules would retain the key level in the manual of EL74m, where the gates are opened until the flood level stops rising. This would require a change by the Queensland Government to the regulatory requirements and levels of service that the storage is operated under. |
| 5<br><br>"75% FSL amended" | Lower the storage level in Wivenhoe Dam to 75% of the current full supply level and amend the current flood manual to commence releases once the storage level exceeds EL65.5 | Same comment as for Option 4. |

# 4 Results

The results of this analysis is summarised in the following plot.

Further text here ...




# 5 Conclusions

Reductions in outflow flood can be achieved by the adoption of different storage levels and release strategies. However, due to the large volumes of water associated with major flood events, it is necessary to consider large changes to the full supply level to achieve appreciable reductions in flood magnitude. The impact of different initial storage levels reduces as the magnitude of the event increases.

|  |  |
|---|---|
| **From:** | Nathan, Rory J (SKM) [redacted] |
| **Sent:** | Monday, 7 February 2011 1:55 PM |
| **To:** | Barton Maher |
| **Subject:** | see yellow highlighted cells in summary tab |
| **Attachments:** | Flood peak assessment.xlsx |

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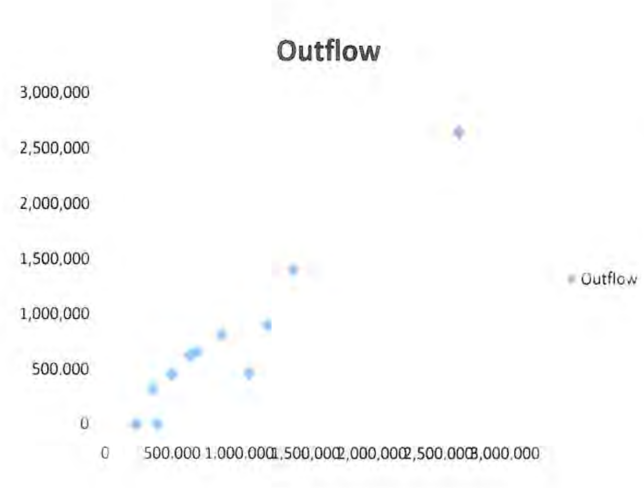
| [illegible] | Inflow | Outflow |
|---|---|---|
| [illegible] | 1,410,000 | 1,410,000 |
| [illegible] | 1,080,000 | 470,000 |
| [illegible] | 690,000 | 660,000 |
| [illegible] | 870,000 | 820,000 |
| [illegible] | 1,120,000 | 900,000 |
| [illegible] | 35,000 | 0 |
| [illegible] | 490,000 | 0 |
| [illegible] | 630,000 | 630,000 |
| [illegible] | 360,000 | 330,000 |
| [illegible] | 500,000 | 460,000 |
| [illegible] | 2,650,000 | 2,650,000 |



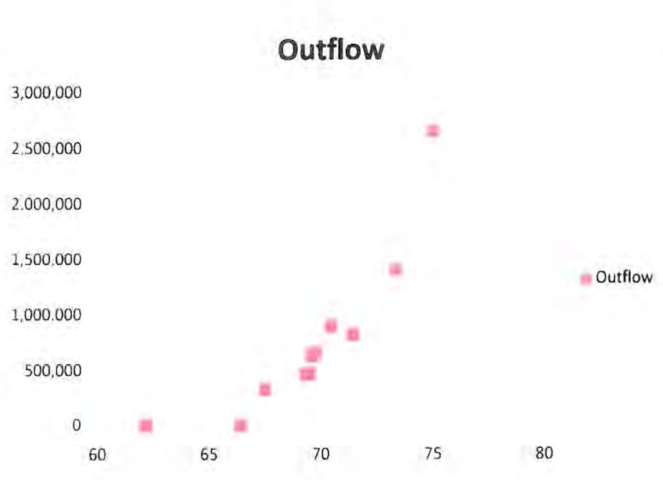
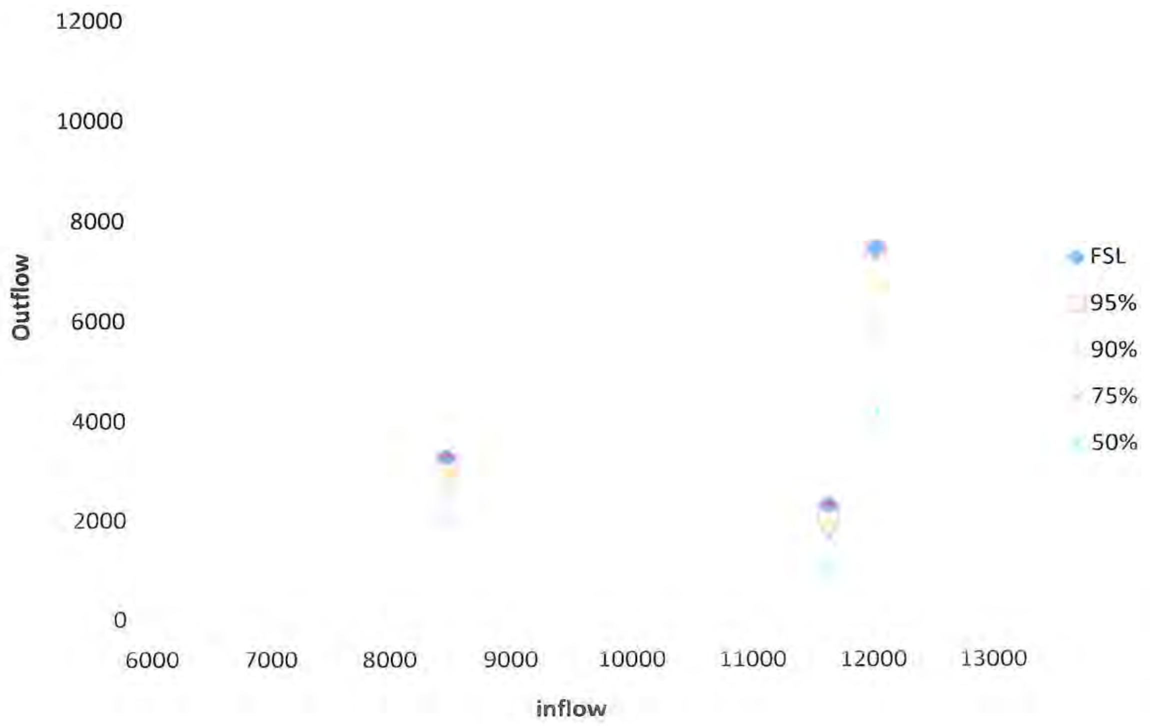



**Table 2**

| **historic events** | | outflows | | | | |
|---|---|---|---|---|---|---|
| Year | Inflow | FSL | 95% | 90% | 75% | 50% |
| 1974 | 8482 | 3275 | 3,153 | 2,974 | 2,618 | 2,067 |
| 1999 | 11641 | 2312 | 2,132 | 2,003 | 1,687 | 1,007 |
| 2011 | 12045 | 7468 | 7,453 | 6,756 | 5,748 | 4,209 |



| [illegible] | [illegible] | [illegible] | 10470 | 7528 | 6361 | 2312 |
|---|---|---|---|---|---|---|
| | 1974 event | | 2011 event | | 1999 event | |
| [illegible] | 74 Inflow | 74 Outflow | 11 inflow | 11 Outflow | 99 Inflow | 99 Outflow |
| [illegible] | [illegible] | 0.00 | 150.0 | 0.0 | 0 | 0 |
| [illegible] | [illegible] | 0.00 | 346.9 | 0.0 | 0 | 0 |
| [illegible] | [illegible] | 0.00 | 543.8 | 0.0 | 0 | 0 |
| [illegible] | [illegible] | 0.00 | 740.6 | 0.0 | 0 | 0 |
| [illegible] | [illegible] | 0.00 | 937.0 | 0.0 | 0 | 0 |
| [illegible] | [illegible] | 0.00 | 1132.7 | 0.0 | 0 | 0 |
| [illegible] | [illegible] | 0.00 | 1327.7 | 0.0 | 1 | 0 |
| [illegible] | [illegible] | 0.00 | 1521.7 | 0.0 | 1 | 0 |
| [illegible] | [illegible] | 0.00 | 1714.4 | 0.0 | 2 | 0 |
| [illegible] | [illegible] | 0.00 | 1706.8 | 0.0 | 2 | 0 |
| [illegible] | [illegible] | 0.00 | 1699.2 | 0.0 | 36 | 0 |
| [illegible] | [illegible] | 0.00 | 1691.7 | 0.0 | 40 | 0 |
| [illegible] | [illegible] | 0.00 | 1684.2 | 0.0 | 52 | 0 |
| [illegible] | [illegible] | 0.00 | 1480.1 | 0.0 | 53 | 0 |
| [illegible] | [illegible] | 0.00 | 1277.6 | 0.0 | 64 | 0 |
| [illegible] | [illegible] | 0.00 | 1076.5 | 0.0 | 63 | 0 |
| [illegible] | [illegible] | 0.00 | 876.6 | 0.0 | 94 | 0 |
| [illegible] | [illegible] | 0.00 | 677.8 | 0.0 | 118 | 0 |
| [illegible] | [illegible] | 0.00 | 479.7 | 0.0 | 292 | 0 |
| [illegible] | [illegible] | 0.00 | 282.2 | 0.0 | 344 | 0 |
| [illegible] | [illegible] | 0.00 | 85.0 | 0.0 | 341 | 0 |
| [illegible] | [illegible] | 0.00 | 82.6 | 0.0 | 374 | 0 |
| [illegible] | [illegible] | 0.00 | 80.3 | 0.0 | 402 | 0 |
| [illegible] | [illegible] | 0.00 | 78.1 | 0.0 | 479 | 0 |
| [illegible] | [illegible] | 0.00 | 75.9 | 0.0 | 552 | 0 |
| [illegible] | [illegible] | 0.00 | 73.7 | 0.0 | 588 | 0 |
| [illegible] | [illegible] | 0.00 | 71.7 | 0.0 | 621 | 0 |
| [illegible] | [illegible] | 0.00 | 69.7 | 0.0 | 647 | 0 |
| [illegible] | [illegible] | 0.00 | 67.7 | 0.0 | 660 | 0 |
| [illegible] | [illegible] | 0.00 | 65.8 | 0.0 | 665 | 0 |
| [illegible] | [illegible] | 0.00 | 64.0 | 0.0 | 750 | 0 |
| [illegible] | [illegible] | 0.00 | 62.4 | 0.0 | 1202 | 0 |
| [illegible] | [illegible] | 0.00 | 61.0 | 0.0 | 1912 | 0 |
| [illegible] | [illegible] | 0.00 | 59.3 | 0.0 | 1990 | 0 |
| [illegible] | [illegible] | 0.00 | 57.7 | 0.0 | 2103 | 0 |
| [illegible] | [illegible] | 0.00 | 56.2 | 0.0 | 2053 | 50 |
| [illegible] | [illegible] | 0.00 | 55.0 | 0.0 | 1998 | 50 |
| [illegible] | [illegible] | 50.29 | 120.7 | 0.0 | 1950 | 51 |
| [illegible] | [illegible] | 50.47 | 76.6 | 0.0 | 2047 | 51 |
| [illegible] | [illegible] | 50.67 | 64.9 | 0.0 | 2083 | 102 |
| [illegible] | [illegible] | 101.81 | 61.9 | 0.0 | 2230 | 102 |
| [illegible] | [illegible] | 102.25 | 59.3 | 0.0 | 2311 | 102 |
| [illegible] | [illegible] | 102.65 | 57.0 | 0.0 | 2440 | 103 |
| [illegible] | [illegible] | 154.06 | 55.0 | 0.0 | 2561 | 154 |
| [illegible] | [illegible] | 154.57 | 53.1 | 0.0 | 2673 | 155 |
| [illegible] | [illegible] | 155.04 | 51.4 | 0.0 | 3312 | 155 |
| [illegible] | [illegible] | 206.14 | 49.7 | 0.0 | 3651 | 207 |
| [illegible] | [illegible] | 206.69 | 48.2 | 0.0 | 4466 | 208 |
| [illegible] | [illegible] | 207.24 | 46.7 | 0.0 | 4873 | 259 |
| [illegible] | [illegible] | 207.80 | 45.3 | 0.0 | 5192 | 311 |
| [illegible] | [illegible] | 258.57 | 43.9 | 0.0 | 5353 | 361 |
| [illegible] | [illegible] | 259.27 | 42.5 | 0.0 | 5552 | 418 |
| [illegible] | [illegible] | 259.97 | 41.2 | 0.0 | 5770 | 474 |
| [illegible] | [illegible] | 310.10 | 40.0 | 0.0 | 5964 | 526 |
| [illegible] | [illegible] | 310.81 | 38.8 | 0.0 | 6248 | 585 |
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| [illegible] | [illegible] | 360.70 | 36.4 | 0.0 | 6353 | 704 |
| [illegible] | [illegible] | 361.36 | 35.3 | 0.0 | 6274 | 764 |
| [illegible] | [illegible] | 361.97 | 34.3 | 0.0 | 6191 | 825 |
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| [illegible] | [illegible] | 416.58 | 32.2 | 0.0 | 5940 | 947 |
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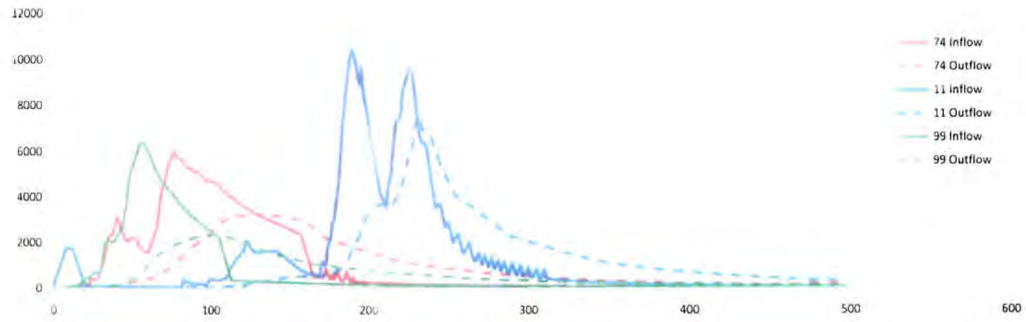
| [illegible] | [illegible] | 417.98 | 30.3 | 0.0 | 5597 | 1071 |



| | | | | | | |
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| 63 | 2137 | 418.82 | 29.4 | 0.0 | 5420 | 1189 |
| 64 | 2352 | 473.60 | 28.5 | 0.0 | 5251 | 1252 |
| 65 | 2618 | 474.76 | 27.6 | 0.0 | 5094 | 1313 |
| 66 | 3027 | 524.69 | 26.8 | 0.0 | 4953 | 1374 |
| 67 | 3618 | 526.52 | 26.0 | 0.0 | 4830 | 1431 |
| 68 | 4235 | 583.41 | 25.2 | 0.0 | 4722 | 1494 |
| 69 | 4407 | 586.15 | 24.5 | 0.0 | 4627 | 1498 |
| 70 | 4515 | 644.12 | 23.8 | 0.0 | 4540 | 1561 |
| 71 | 4921 | 702.50 | 23.1 | 0.0 | 4458 | 1622 |
| 72 | 5301 | 761.63 | 22.4 | 0.0 | 4376 | 1684 |
| 73 | 5516 | 821.34 | 21.7 | 0.0 | 4293 | 1688 |
| 74 | 5664 | 881.71 | 21.1 | 0.0 | 4210 | 1749 |
| 75 | 5871 | 943.08 | 20.5 | 0.0 | 4128 | 1810 |
| 76 | 5953 | 948.21 | 19.9 | 0.0 | 4045 | 1814 |
| 77 | 5840 | 1010.40 | 19.3 | 0.0 | 3961 | 1873 |
| 78 | 5719 | 1128.20 | 18.7 | 0.0 | 3879 | 1877 |
| 79 | 5701 | 1190.94 | 18.3 | 0.0 | 3796 | 1937 |
| 80 | 5657 | 1254.03 | 19.3 | 0.0 | 3715 | 1940 |
| 81 | 5589 | 1315.75 | 22.3 | 0.0 | 3635 | 2000 |
| 82 | 5467 | 1377.73 | 234.6 | 0.0 | 3556 | 2003 |
| 83 | 5383 | 1493.28 | 385.1 | 0.0 | 3478 | 2064 |
| 84 | 5312 | 1556.77 | 247.1 | 0.0 | 3403 | 2066 |
| 85 | 5244 | 1619.49 | 220.2 | 0.0 | 3329 | 2069 |
| 86 | 5238 | 1625.09 | 198.9 | 0.0 | 3258 | 2127 |
| 87 | 5220 | 1688.15 | 187.7 | 0.0 | 3188 | 2129 |
| 88 | 5179 | 1750.39 | 179.8 | 0.0 | 3121 | 2131 |
| 89 | 5102 | 1812.77 | 173.3 | 0.0 | 3057 | 2189 |
| 90 | 5069 | 1874.21 | 173.0 | 0.0 | 2996 | 2190 |
| 91 | 5037 | 1935.81 | 163.4 | 0.0 | 2935 | 2192 |
| 92 | 5028 | 1998.65 | 157.1 | 0.0 | 2876 | 2193 |
| 93 | 4989 | 2004.05 | 151.0 | 0.0 | 2817 | 2195 |
| 94 | 4895 | 2067.02 | 145.2 | 0.0 | 2759 | 2196 |
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| 97 | 4681 | 2193.52 | 131.2 | 0.0 | 2589 | 2253 |
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| 106 | 4376 | 2739.76 | 317.7 | 51.3 | 1948 | 2312 |
| 107 | 4301 | 2854.18 | 335.7 | 51.3 | 1698 | 2254 |
| 108 | 4231 | 2968.46 | 367.5 | 51.3 | 1454 | 2253 |
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| 128 | 3255 | 3274.95 | 1555.8 | 210.6 | 255 | 1747 |
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| 130 | 3183 | 3274.72 | 1519.8 | 211.3 | 249 | 1686 |
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| | | | | | | |
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| 231 | 148 | 1007.52 | 7067.1 | 7528.4 | 81 | 527 |
| 232 | 146 | 1006.59 | 6519.5 | 7524.5 | 80 | 527 |
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| 235 | 140 | 947.07 | 6292.4 | 6817.9 | 78 | 526 |
| 236 | 139 | 946.24 | 6232.1 | 6814.4 | 77 | 526 |
| 237 | 137 | 945.41 | 5736.0 | 6810.5 | 76 | 525 |
| 238 | 135 | 944.57 | 5258.6 | 6804.0 | 75 | 525 |
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| 244 | 125 | 883.32 | 3648.5 | 5599.4 | 71 | 475 |
| 245 | 124 | 882.58 | 3715.1 | 5409.9 | 70 | 475 |
| 246 | 122 | 881.82 | 3345.6 | 5224.3 | 70 | 474 |
| 247 | 121 | 881.07 | 2990.9 | 5157.2 | 69 | 474 |
| 248 | 119 | 824.49 | 2650.0 | 4973.2 | 68 | 474 |
| 249 | 118 | 823.84 | 2762.4 | 4790.0 | 68 | 474 |
| 250 | 117 | 823.18 | 2876.9 | 4609.8 | 67 | 473 |
| 251 | 115 | 822.52 | 2553.3 | 4546.0 | 66 | 473 |
| 252 | 114 | 821.86 | 2241.1 | 4368.0 | 66 | 473 |
| 253 | 113 | 821.19 | 1939.4 | 4247.0 | 65 | 419 |
| 254 | 111 | 820.53 | 2086.7 | 4069.5 | 64 | 419 |
| 255 | 110 | 764.35 | 2233.8 | 4006.7 | 64 | 419 |
| 256 | 109 | 763.77 | 2380.2 | 3944.7 | 63 | 418 |
| 257 | 107 | 763.19 | 2087.4 | 3939.8 | 63 | 418 |
| 258 | 106 | 762.61 | 1803.4 | 3821.4 | 62 | 418 |
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| 263 | 100 | 704.37 | 1988.5 | 3622.7 | 59 | 417 |

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| 265 | 98 | 703.36 | 1453.2 | 3500.6 | 58 | 417 |
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| 271 | 92 | 700.30 | 1027.8 | 3188.0 | 55 | 362 |
| 272 | 91 | 644.79 | 1219.1 | 3182.4 | 54 | 362 |
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| 275 | 88 | 643.49 | 913.9 | 3001.7 | 53 | 362 |
| 276 | 87 | 643.05 | 1109.1 | 2996.6 | 53 | 361 |
| 277 | 86 | 642.61 | 1300.8 | 2880.0 | 52 | 361 |
| 278 | 85 | 642.17 | 1055.9 | 2876.3 | 52 | 361 |
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| 304 | 65 | 475.24 | 655.8 | 1893.0 | 41 | 260 |
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| 320 | 56 | 417.75 | 320.0 | 1574.1 | 36 | 259 |
| 321 | 56 | 417.55 | 315.2 | 1572.3 | 36 | 259 |
| 322 | 55 | 417.34 | 310.5 | 1512.0 | 36 | 259 |
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| 357 | 41 | 310.15 | 191.9 | 1015.3 | 28 | 207 |
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| 359 | 40 | 309.92 | 187.1 | 956.3 | 27 | 206 |
| 360 | 40 | 309.80 | 184.8 | 955.5 | 27 | 206 |
| 361 | 40 | 309.68 | 182.5 | 954.7 | 27 | 206 |
| 362 | 39 | 260.19 | 180.2 | 954.0 | 27 | 206 |
| 363 | 39 | 260.11 | 178.0 | 953.2 | 26 | 206 |
| 364 | 39 | 260.03 | 175.8 | 952.4 | 26 | 206 |
| 365 | 38 | 259.95 | 173.6 | 894.6 | 26 | 206 |
| 366 | 38 | 259.87 | 171.5 | 893.9 | 26 | 206 |
| 367 | 38 | 259.79 | 169.4 | 893.2 | 26 | 206 |
| 368 | 37 | 259.71 | 167.3 | 892.5 | 26 | 206 |
| 369 | 37 | 259.63 | 165.3 | 891.8 | 25 | 155 |
| 370 | 37 | 259.55 | 163.3 | 891.1 | 25 | 155 |
| 371 | 37 | 259.47 | 161.3 | 890.4 | 25 | 155 |
| 372 | 36 | 259.39 | 159.4 | 833.3 | 25 | 155 |
| 373 | 36 | 259.31 | 157.5 | 832.6 | 25 | 155 |
| 374 | 36 | 259.22 | 155.6 | 832.0 | 25 | 155 |
| 375 | 35 | 259.14 | 153.8 | 831.4 | 24 | 155 |
| 376 | 35 | 259.06 | 152.0 | 830.8 | 24 | 155 |
| 377 | 35 | 258.98 | 150.2 | 830.2 | 24 | 155 |
| 378 | 35 | 258.90 | 148.4 | 829.5 | 24 | 155 |
| 379 | 34 | 258.82 | 146.7 | 828.9 | 24 | 155 |
| 380 | 34 | 258.73 | 145.0 | 772.2 | 24 | 155 |
| 381 | 34 | 258.65 | 143.3 | 771.7 | 23 | 155 |
| 382 | 34 | 258.57 | 141.7 | 771.1 | 23 | 155 |
| 383 | 33 | 208.31 | 140.1 | 770.6 | 23 | 155 |
| 384 | 33 | 208.26 | 138.4 | 770.1 | 23 | 155 |
| 385 | 33 | 208.21 | 136.9 | 769.5 | 23 | 155 |
| 386 | 33 | 208.16 | 135.3 | 769.0 | 23 | 155 |
| 387 | 32 | 208.11 | 133.8 | 768.4 | 23 | 155 |
| 388 | 32 | 208.06 | 132.3 | 767.9 | 22 | 155 |
| 389 | 32 | 208.01 | 130.8 | 711.5 | 22 | 155 |
| 390 | 32 | 207.96 | 129.3 | 711.0 | 22 | 155 |
| 391 | 31 | 207.91 | 127.9 | 710.5 | 22 | 155 |
| 392 | 31 | 207.85 | 126.5 | 710.0 | 22 | 155 |
| 393 | 31 | 207.80 | 125.1 | 709.6 | 22 | 155 |
| 394 | 31 | 207.75 | 123.7 | 709.1 | 22 | 155 |
| 395 | 31 | 207.70 | 122.3 | 708.6 | 21 | 155 |
| 396 | 30 | 207.65 | 121.0 | 708.1 | 21 | 155 |
| 397 | 30 | 207.60 | 119.6 | 707.6 | 21 | 155 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 398 | 30 | 207.55 | 118.3 | 651.6 | 21 | 154 |
| 399 | 30 | 207.50 | 117.1 | 651.2 | 21 | 154 |
| 400 | 29 | 207.44 | 115.8 | 650.8 | 21 | 154 |
| 401 | 29 | 207.39 | 114.5 | 650.4 | 21 | 154 |
| 402 | 29 | 207.34 | 113.3 | 650.0 | 20 | 154 |
| 403 | 29 | 207.29 | 112.1 | 649.6 | 20 | 154 |
| 404 | 29 | 207.24 | 110.9 | 649.2 | 20 | 154 |
| 405 | 28 | 207.18 | 109.7 | 648.7 | 20 | 154 |
| 406 | 28 | 207.13 | 108.6 | 648.3 | 20 | 154 |
| 407 | 28 | 207.08 | 107.4 | 592.5 | 20 | 154 |
| 408 | 28 | 207.03 | 106.3 | 592.1 | 20 | 154 |
| 409 | 28 | 206.97 | 105.2 | 591.8 | 20 | 154 |
| 410 | 27 | 206.92 | 104.1 | 591.4 | 19 | 154 |
| 411 | 27 | 206.87 | 103.0 | 591.1 | 19 | 154 |
| 412 | 27 | 206.82 | 101.9 | 590.7 | 19 | 154 |
| 413 | 27 | 206.76 | 100.9 | 590.4 | 19 | 154 |
| 414 | 27 | 206.71 | 99.8 | 590.0 | 19 | 154 |
| 415 | 27 | 206.66 | 98.8 | 589.6 | 19 | 154 |
| 416 | 26 | 206.60 | 97.8 | 589.3 | 19 | 154 |
| 417 | 26 | 206.55 | 96.8 | 588.9 | 19 | 154 |
| 418 | 26 | 206.50 | 95.8 | 533.5 | 19 | 154 |
| 419 | 26 | 206.45 | 94.8 | 533.2 | 18 | 154 |
| 420 | 26 | 206.39 | 93.9 | 532.9 | 18 | 154 |
| 421 | 25 | 206.34 | 92.9 | 532.6 | 18 | 154 |
| 422 | 25 | 206.29 | 92.0 | 532.3 | 18 | 154 |
| 423 | 25 | 206.23 | 91.0 | 532.0 | 18 | 154 |
| 424 | 25 | 206.18 | 90.1 | 531.7 | 18 | 154 |
| 425 | 25 | 206.13 | 89.2 | 531.4 | 18 | 154 |
| 426 | 25 | 206.07 | 88.4 | 531.1 | 18 | 154 |
| 427 | 24 | 206.02 | 87.5 | 530.8 | 18 | 154 |
| 428 | 24 | 155.34 | 86.6 | 530.5 | 17 | 103 |
| 429 | 24 | 155.31 | 85.8 | 530.2 | 17 | 103 |
| 430 | 24 | 155.29 | 84.9 | 480.8 | 17 | 103 |
| 431 | 24 | 155.26 | 84.1 | 480.6 | 17 | 103 |
| 432 | 24 | 155.23 | 83.3 | 480.3 | 17 | 103 |
| 433 | 24 | 155.20 | 82.5 | 480.1 | 17 | 103 |
| 434 | 23 | 155.17 | 81.7 | 479.9 | 17 | 103 |
| 435 | 23 | 155.14 | 80.9 | 479.6 | 17 | 103 |
| 436 | 23 | 155.11 | 80.1 | 479.4 | 17 | 103 |
| 437 | 23 | 155.09 | 79.3 | 479.1 | 17 | 103 |
| 438 | 23 | 155.06 | 78.6 | 478.9 | 16 | 103 |
| 439 | 23 | 155.03 | 77.8 | 478.7 | 16 | 103 |
| 440 | 22 | 155.00 | 77.1 | 478.4 | 16 | 103 |
| 441 | 22 | 154.97 | 76.3 | 478.2 | 16 | 103 |
| 442 | 22 | 154.94 | 75.6 | 423.6 | 16 | 103 |
| 443 | 22 | 154.91 | 74.9 | 423.5 | 16 | 103 |
| 444 | 22 | 154.88 | 74.2 | 423.3 | 16 | 103 |
| 445 | 22 | 154.85 | 73.5 | 423.1 | 16 | 102 |
| 446 | 22 | 154.82 | 72.8 | 422.9 | 16 | 102 |
| 447 | 22 | 154.79 | 72.1 | 422.7 | 16 | 102 |
| 448 | 21 | 154.76 | 71.5 | 422.5 | 16 | 102 |
| 449 | 21 | 154.73 | 70.8 | 422.3 | 15 | 102 |
| 450 | 21 | 154.70 | 70.1 | 422.1 | 15 | 102 |
| 451 | 21 | 154.67 | 69.5 | 421.9 | 15 | 102 |
| 452 | 21 | 154.65 | 68.8 | 421.7 | 15 | 102 |
| 453 | 21 | 154.62 | 68.2 | 421.5 | 15 | 102 |
| 454 | 21 | 154.59 | 67.6 | 421.3 | 15 | 102 |
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| 456 | 20 | 154.53 | 66.4 | 421.0 | 15 | 102 |
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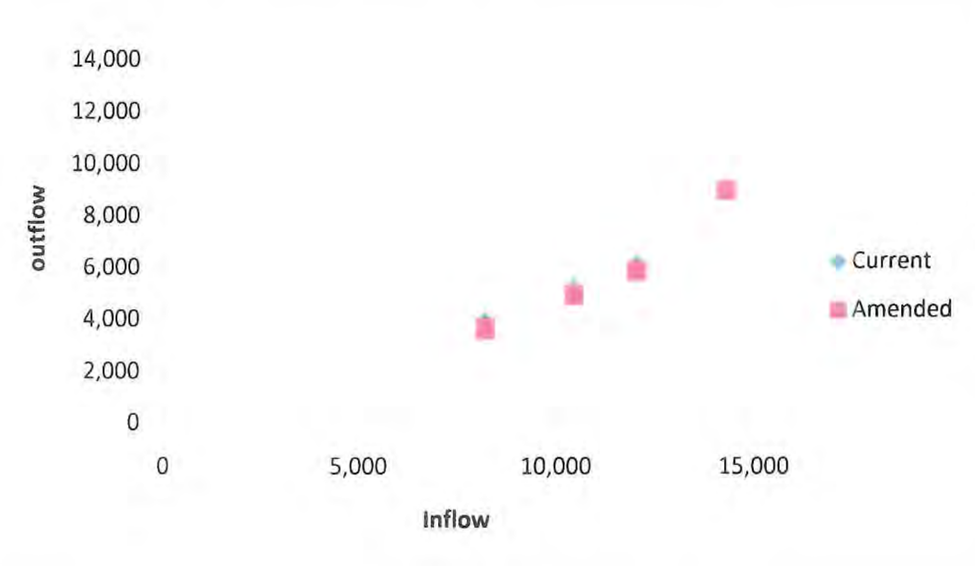
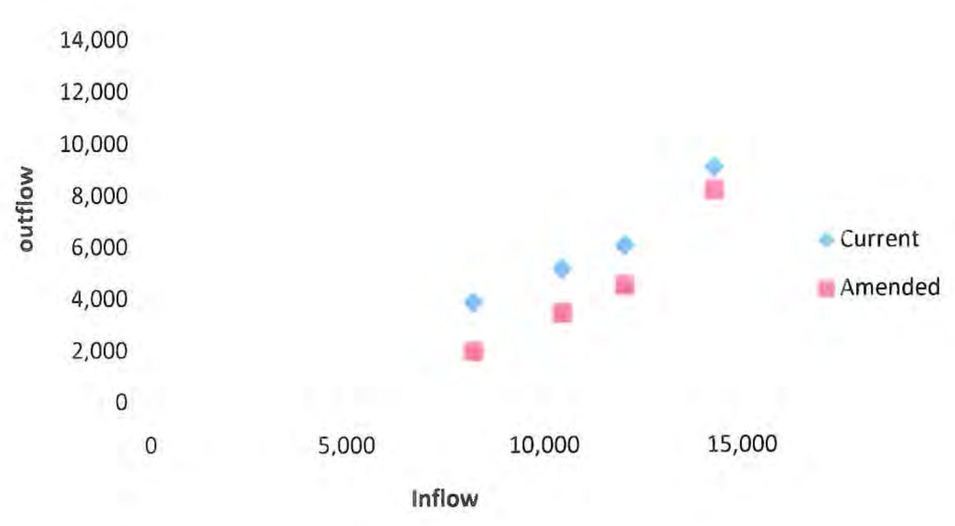
| 460 | 20 | 154.41 | 64.0 | 366.4 | 15 | 102 |
| 461 | 20 | 154.38 | 63.4 | 366.2 | 14 | 102 |
| 462 | 20 | 154.35 | 62.9 | 366.1 | 14 | 102 |
| 463 | 19 | 154.32 | 62.3 | 365.9 | 14 | 102 |
| 464 | 19 | 154.29 | 61.7 | 365.8 | 14 | 102 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 465 | 19 | 154.26 | 61.2 | 365.6 | 14 | 102 |
| 466 | 19 | 154.23 | 60.7 | 365.5 | 14 | 102 |
| 467 | 19 | 154.20 | 60.1 | 365.3 | 14 | 102 |
| 468 | 19 | 154.17 | 59.6 | 365.2 | 14 | 102 |
| 469 | 19 | 154.14 | 59.1 | 365.0 | 14 | 102 |
| 470 | 19 | 154.11 | 58.5 | 364.9 | 14 | 102 |
| 471 | 19 | 154.08 | 58.0 | 364.7 | 14 | 102 |
| 472 | 18 | 154.05 | 57.5 | 364.6 | 14 | 102 |
| 473 | 18 | 154.02 | 57.0 | 315.2 | 14 | 102 |
| 474 | 18 | 153.99 | 56.5 | 315.1 | 13 | 102 |
| 475 | 18 | 204.09 | 56.1 | 315.0 | 13 | 102 |
| 476 | 18 | 204.03 | 55.6 | 314.9 | 13 | 102 |
| 477 | 18 | 203.98 | 55.1 | 314.8 | 13 | 102 |
| 478 | 18 | 203.92 | 54.6 | 314.7 | 13 | 102 |
| 479 | 18 | 203.86 | 54.2 | 314.6 | 13 | 102 |
| 480 | 18 | 203.81 | 53.7 | 314.5 | 13 | 102 |
| 481 | 18 | 203.75 | 53.3 | 314.4 | 13 | 102 |
| 482 | 17 | 203.70 | 52.9 | 314.2 | 13 | 102 |
| 483 | 17 | 203.64 | 52.5 | 314.1 | 13 | 102 |
| 484 | 17 | 203.58 | 52.1 | 314.0 | 13 | 102 |
| 485 | 17 | 203.53 | 51.7 | 313.9 | 13 | 102 |
| 486 | 17 | 203.47 | 51.3 | 313.8 | 13 | 102 |
| 487 | 17 | 203.41 | 50.9 | 313.7 | 13 | 102 |
| 488 | 17 | 203.36 | 50.6 | 313.6 | 13 | 102 |
| 489 | 17 | 203.30 | 50.2 | 313.5 | 12 | 102 |
| 490 | 17 | 203.24 | 49.8 | 313.4 | 12 | 102 |
| 491 | 17 | 203.18 | 49.5 | 313.2 | 12 | 102 |
| 492 | 16 | 203.13 | 49.1 | 263.1 | 12 | 102 |
| 493 | 16 | 203.07 | 48.7 | 263.1 | 12 | 102 |
| 494 | 16 | 203.01 | 48.4 | 263.0 | 12 | 102 |
| 495 | 16 | 202.96 | 48.0 | 262.9 | 12 | 102 |
| 496 | 16 | 202.90 | 47.7 | 262.8 | 12 | 102 |
| 497 | 16 | 202.84 | 47.4 | 262.8 | 12 | 102 |

| ARI | inflow | Current | Amended |
|---|---|---|---|
| 200 | 8,214 | 3,861 | 3,613 |
| 500 | 10,455 | 5,125 | 4,915 |
| 1000 | 12,031 | 6,049 | 5,854 |
| 5000 | 14,278 | 9,083 | 8,994 |

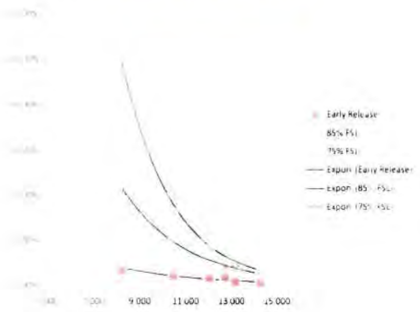


| ARI | Inflow | Current | Amended |
|---|---|---|---|
| 200 | 8,214 | 3,861 | 1,971 |
| 500 | 10,455 | 5,125 | 3,446 |
| 1000 | 12,031 | 6,049 | 4,504 |
| 5000 | 14,278 | 9,083 | 8,217 |

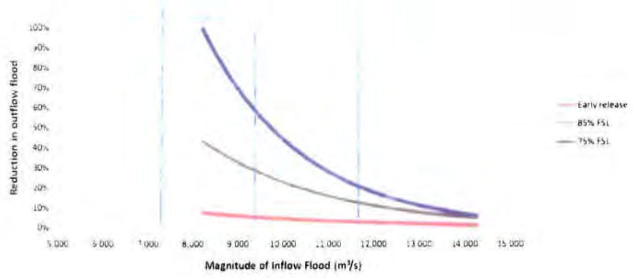


| ow Peak | Current | Early Release | 85% FSL | 75% FSL |
|---|---|---|---|---|
| 8 224 | 3814 | 6.40% | 31.60% | 94.83% |
| 10 455 | 5983 | 4.10% | 32.70% | 42.40% |
| 12 031 | 6010 | 3.20% | 16.30% | 25.06% |
| 12 727 | 7227 | 3.80% | 6.60% | 8.19% |
| 13 781 | 8190 | 1.30% | 4.50% | 7.09% |
| 14 278 | 9066 | 1.00% | 5.90% | 9.36% |

Minor
Moderate
Major
extreme



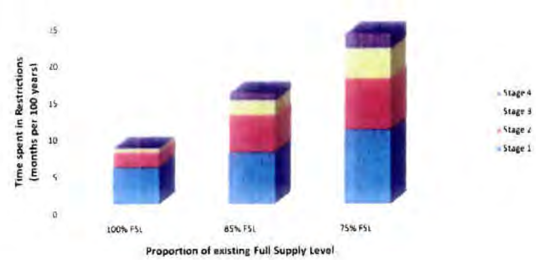

Indicative Reduction in Outflow For Different Gate Operating Strategies




junk data!!!

| FSL | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
|---|---|---|---|---|
| 100% FSL | 5 | 2 | 0.5 | 0.01 |
| 85% FSL | 7 | 5 | 2 | 1 |
| 75% FSL | 10 | 7 | 4 | 2 |

Increase in Restrictions for Different Storage Levels (JUNK DATA!)

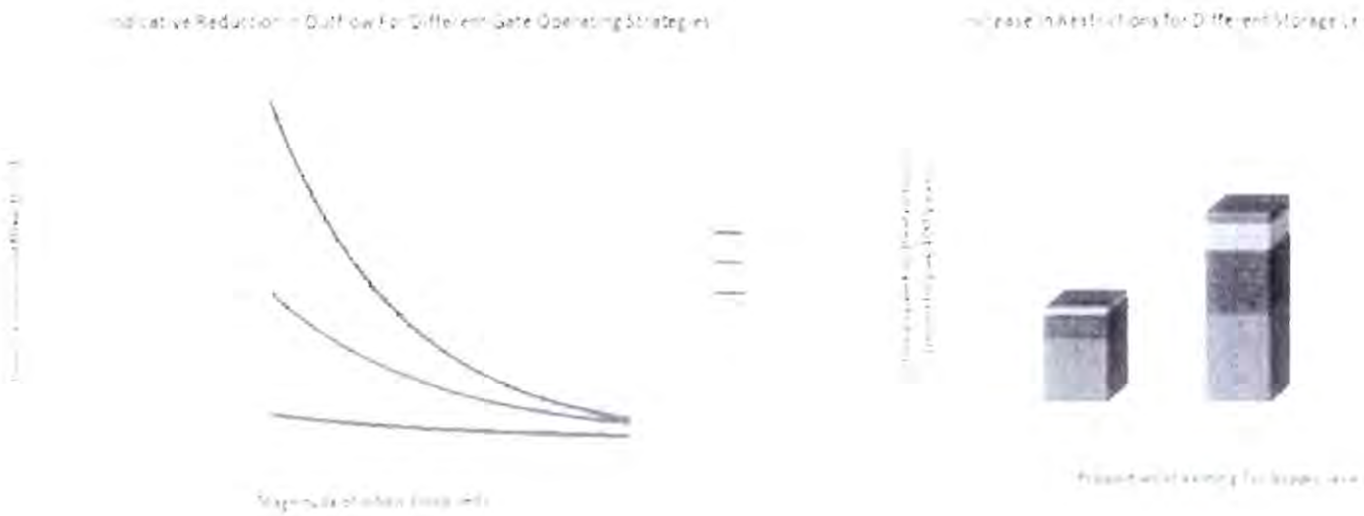


**From:** Nathan, Rory J (SKM) [redacted]
**Sent:** Monday, 7 February 2011 12:40 PM
**To:** Barton Maher
**Cc:** Jim Pruss; Rob Drury; Alex Fisher; Hill, Peter I (SKM)
**Subject:** RE: Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V2 070211.docx
**Attachments:** Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V2 070211.docx; ATT299688.txt

Hi Barton,

I have looked through the new version, and my comments and suggested (minor) changes are provided in track changes mode in the attached document. In short, I agree with the main messages, but I am a little concerned that the numbers for the design events (in Tables 4, 5 and 6) are not in total agreement where they need to be – either this reflects some typos, or possibly the hydrographs are not all scaled exactly the same way when entered into the spreadsheets. I do think these need to be checked again, for any meaningful differences will undermine confidence by the wider audience reading this.

I imagine the timelines for gold-plating this are probably too tight, but given the focus this will get it would be good to pre-empt some questions around the impact. As I indicated on Friday we could consider including a couple of plots along the lines of the following:



where the left hand panel provides a high level summary (only to make it easier for the reader) and the right hand panel presents information (if it can be made available) that highlights the implications to water supply security that may not be evident. Very happy if you decide not to include the above, I am just checking that my earlier suggestion didn't get lost in the email traffic.

I am now tied up till 1:30 (your time) at another meeting – but if you need to discuss urgently then please text me on my mobile and I will ring you ASAP.

Regards

Rory

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**From:** Barton Maher [redacted]
**Sent:** Monday, 7 February 2011 12:06 PM
**To:** Nathan, Rory J (SKM)
**Cc:** Jim Pruss; Rob Drury; Alex Fisher
**Subject:** Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V2 070211.docx

Hi Rory,

As discussed, I have updated the report to reflect your comments from Friday. The inconsistency in the discharges was from my error in transferring the numbers from the spreadsheet. I have checked them and updated the table to reflect the real data as sent to you. I have also added in the additional information as requested.

The only thing I am short of is the 1 in 100 AEP design event as the Alliance started with the 1 in 200 event.

.nave also added background data to assist in understanding the source of the flood events and provide some context on the design of the spillway.

If you have any questions please give me a call on my mobile.

Regards,

[redacted]

www.seqwater.com.au

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WATER FOR LIFE

# Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges

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# 1 Contents



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# 2 Introduction

Seqwater staff have been asked to investigate the impact of reducing the storage level of Wivenhoe Dam on the downstream discharges for major flood events. This memo details the investigations carried out and provides a preliminary assessment of the reduction in flood flows that could be achieved by reducing the Wivenhoe Dam storage level to 95%, 90%, 75% and 50% of the normal water supply volume.

The comments in this report are provided to give an indication of the impacts of a reduced storage level of Wivenhoe Dam on discharges during major flood events. It must be noted that it is very preliminary, as to get accurate results a full investigation and analysis of the whole river system utilising multiple flood events and a combination of hydrologic, hydraulic, and routing models would be required. This review was requested to provide an order of magnitude assessment of impacts and the results should not be utilised beyond that purpose.

# 3 Definitions

For the purposes of this report the following definitions have been adopted as per the Wivenhoe – Somerset Flood manual:

| | |
|---|---|
| Fresh | This causes only very low-level bridges to be submerged. |
| Minor Flooding | This causes inconvenience such as closing minor roads and the submergence of low-level bridges. Some urban properties are affected. |
| Moderate Flooding | This causes inundation of low-lying areas and may require the evacuation of some houses and/or business premises. Traffic bridges may be closed. |
| Major Flooding | This causes flooding of appreciable urban areas. Properties may become isolated. Major disruption occurs to traffic. Evacuation of many houses and business premises may be required. |
| Extreme Flooding | This causes flooding well in excess of floods in living memory and general evacuation of whole areas are likely to be required. |
| "$m^3/s$" | Means an instantaneous flow rate expressed as cubic meters of water per second. |
| "AEP" | Means annual exceedance probability, the probability of a specified event being exceeded in any year; |
| "AHD" | Means Australian Height Datum; |
| "EL" | Means elevation in metres from Australian Height Datum; |
| "ML" | Means a million litres of water |

# 4 Background

## 4.1 Previous Flood Studies

The original design of Wivenhoe Dam was to provide both water supply for South East Queensland and flood mitigation for the city of Brisbane. There have been several flood studies prepared for the dam as discussed below.

Wivenhoe Dam has a catchment area of about 7,048 $km^2$. The [illegible] spillway capacity of Wivenhoe Dam [illegible] based on a P[illegible] M[illegible] F[illegible] inflow of 15,090 $m^3/s$ [illegible]

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was made estimated by the Queensland Water Resource Commission (WRC) in 1977 (Hausler and Porter, 1977). This estimate was based on a 48-hour duration probable maximum precipitation (PMP) estimate of 480 mm and synthetic unit graphs using the Clarke Johnson method.

WRC revised the design flood estimates in 1983 when the dam was in its final phase of construction. This revision was brought about because the Commonwealth Bureau of Meteorology (BOM) had revised their estimate of the Probable Maximum Precipitation (PMP) for the Wivenhoe catchment.

In addition, better rainfall-runoff-routing techniques were available at that time to derive design flows. The revised PMF estimate was revised inflow estimated in 1983 to be was 48,000 m$^3$/s, which is some 220% above the 1977 estimate. The increase was mainly attributed to the changes in the PMP, which increased to 1,000 mm for the 48-hour duration storm.

The Department of Natural Resources (DNR) (formally WRC) revised the design flows again as part of a comprehensive safety review of the dam undertaken between 1990 and 1994. Rainfall-runoff-routing models of the catchment were developed together with a dam flood routing model used to derive outflows from Somerset and Wivenhoe Dams taking into account the flood operating procedures used at that time. Somerset Dam, which has a catchment area of 1,331 km$^2$ drains into Wivenhoe Dam.

As part of the review, the BOM was requested to update the PMP estimates for the catchment (BOM, 1991). The revised PMP estimates were used in the 1994 analysis to estimate the PMF. DNR estimated the PMF inflow to be 39,880 m$^3$/s, which is lower than the 1983 estimate but still substantially higher than the 1977 estimate. The lower PMF estimate were mainly attributed (again) to changes in the PMP, which was revised down to 870 mm for the 48-hour duration storm. The development and calibration of the rainfall runoff routing model was also much more comprehensive than previous studies. Flood operating procedures were also incorporated into the models to estimate design outflows.

A detailed review of the previous studies is provided in Report No. 8a of the DNR flood study reports (1994).

The BOM updated the PMP estimates in 2002/2003 for the Wivenhoe catchment using the revised Generalised Tropical Storm Method (BOM, 2003). This report also provides the latest information on temporal patterns and spatial rainfall weightings to be used with the new PMP data. The 2003 PMP estimates are some 20% higher than PMP estimates used by DNR in the 1994 study. As a result, the new PMF estimate for the catchment using this data is significantly higher than the 1994 estimate. The new estimate was used for the upgrade of the dam in 2004/2005 by the Wivenhoe Alliance. The DNR models (1994) were used to estimate design flows for Wivenhoe Alliance.

For the purposes of this study investigation design hydrographs from the Wivenhoe Alliance have been used along with recorded data from three historic flood events.

## 1.2 Flood Mitigation

The Design Report for Wivenhoe Dam (DPI 1994) provides a summary on the design of the flood mitigation component of the dam. The report indicates that *the estimated PMF was used to assess the safety of the dam against overtopping. In additon, inflow hydrographs from various historical*

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*floods (eg the 1893 and the 1974 floods) and for floods synthesised from storm frequency data were developed in order to provide data for the benefit – cost analysis for the flood mitigation component of the dam.*

*For the flood mitigation benfit – costs studies, the historic and synthesised floods were routed through the dam and the ouflow routed down the Brisbane River. The objectives were to limit outflow below a damaging level for Brisbane with the available storage and to empty the dam within a reasonable time, say 5 or 6 days, after the reservoir had reached the maximum level.*

*The results of the flood routing for the economic studies are summarised in a report by Grigg. The 1974 flood, which reached 5.45m on the Brisbane City Gauge, would have been lowered by 2.6m if Wivenhoe Dam had then been in existence. The damage caused by the 1974 flood was estimated at $178M, and the savings produced by the lowering the flood level would have been $140M.*

*The flood mitigation studies indicated that all major historical floods could be controlled with outflows not exceeeding 3,200m3/s. If no other inflows occur below the dam, prolonged outflow of this magnitude would cause little or no damage to Brisbane. The dam would then be able to be emptied in a reasonable time frame after a major flood such as the 1893 flood.*

An extract of the design report detailing the design of the spillway is presented as Attachment 2.

# 5 Assessment of the Impact of Lowering the Full Supply Level

Lowering the full supply level was assessed to determine the impact on the peak flood levels and discharges.

## 5.1 Analysis Methodology

The analysis was undertaken using a model to simulate ~~spreadsheet developed to model~~ the gate opening sequence as provided in the Flood Manual during a loss of communications situation. During a loss of communications between the dam operators and the Flood Control Centre, operators would use predefined gate openings based solely on the Lake Level information available to them at the dams. It should be stressed that in practice gate operations would normally seek to take advantage of additional information related to rainfall forecasts and tributary flows to ensure that flood peaks are reduced as far as possible without causing coincident flooding with downstream tributaries. Thus, while using the "loss of communications" flood operation rules provides a consistent means of comparing the efficacy of different mitigation options, the actual degree of flood reduction achievable is dependent on the characteristics of the specific event.

A history of floods in the Brisbane River is presented in Table 1.

Table 1 - Summary of Significant Flood Events of the Brisbane River

| Event | Somerset Dam | | | Wivenhoe Dam | | |
|---|---|---|---|---|---|---|
| | Peak Elevation | Inflow Volume | Outflow Volume | Peak Elevation | Total Inflow Flood Volume | Outflow Flood Volume |
| | m AHD | ML | ML | m AHD | ML | ML |
| Jan 1974# | 106.57 | 620,000 | 450,000 | 73.31 | 1,410,000 | 1,410,000 |
| Jun 1983 | 101.58 | 260,000 | 280,000 | 69.49 | 1,080,000 | 470,000 |
| Mar 1989 | 102.59 | 370,000 | 380,000 | 69.78 | 690,000 | 660,000 |
| Apr 1989 | 102.69 | 340,000 | 350,000 | 71.45 | 870,000 | 820,000 |
| Feb 1999 | 102.96 | 450,000 | 280,000 | 70.45 | 1,220,000 | 900,000 |
| May 2009 | 99.62 | 110,000 | 110,000 | 62.19 | 235,000 | 0 |
| Mar 2010 | 99.41 | 210,000 | 200,000 | 66.43 | 390,000 | 0 |
| Oct 2010 | 101.37 | 250,000 | 270,000 | 69.61 | 630,000 | 630,000 |
| Mid Dec 2010 | 100.42 | 150,000 | 140,000 | 67.50 | 360,000 | 330,000 |
| Late Dec 2010 | 99.98 | 120,000 | 130,000 | 69.35 | 500,000 | 460,000 |
| Jan 2011 | 105.11 | 825,000 | 820,000 | 74.97 | 2,650,000 | 2,650,000 |

# Presence of Wivenhoe Dam simulated

The assessment has investigated the impacts of the lowered storage level on the three largest historic events for which suitable records are available – the 1974 flood, the 1999 flood and the 2011 flood.

Plots of the inflow and estimated outflow for these events (assuming the storage was initially at full supply level) are presented in Figure 1.

Comment [RJN1]: I think this is correct?

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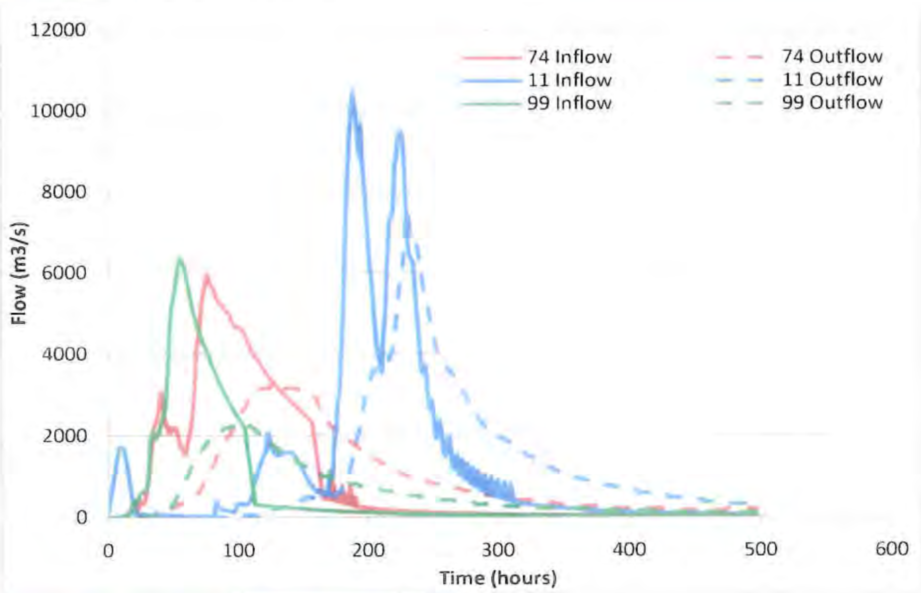


Figure 1 - Plots of Historic Events with Simulated Outflows

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## 5.2 Analysis Results

A summary of the results of the modelling is presented in Table 2.

**Table 2 – Reduction in flood peak due to adoption of different initial storage levels**

| | | Wivenhoe Dam | | Somerset Dam | | Lockyer Creek | Lowood | Bremer River | Moggill | Reduction at Moggill |
|---|---|---|---|---|---|---|---|---|---|---|
| Storage Level at Start | % of Full Supply Volume | Peak Inflow ($m^3/s$) | Peak Outflow ($m^3/s$) | Peak Inflow ($m^3/s$) | Peak Outflow ($m^3/s$) | Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) | Peak Flow[1] ($m^3/s$) | % |
| 1974 Flood | | | | | | | | | | |
| 67.0 | 100 | 5,953 | 3,275 | 5,019 | 3,548 | 3,260 | 5,110 | 4,241 | 7,948 | |
| 66.5 | 95 | 5,953 | 3,153 | 5,019 | 3,480 | 3,260 | 4,799 | 4,241 | 7,910 | 0.5% |
| 65.8 | 90 | 5,953 | 2,974 | 5,019 | 3,419 | 3,260 | 4,524 | 4,241 | 7,897 | 0.6% |
| 64.0 | 75 | 5,953 | 2,618 | 5,019 | 3,302 | 3,260 | 4,117 | 4,241 | 7,683 | 3.3% |
| 60.0 | 50 | 5,953 | 2,067 | 5,019 | 3,040 | 3,260 | 3,342 | 4,241 | 7,423 | 6.6% |
| 1999 Flood | | | | | | | | | | |
| 67.0 | 100 | 6,358 | 2,312 | 7,540 | 3,837 | 663 | 2,556 | 308 | 2,593 | |
| 66.5 | 95 | 6,358 | 2,132 | 7,540 | 3,662 | 663 | 2,434 | 308 | 2,479 | 4.4% |
| 65.8 | 90 | 6,358 | 2,003 | 7,540 | 3,470 | 663 | 2,284 | 308 | 2,319 | 10.6% |
| 64.0 | 75 | 6,358 | 1,687 | 7,540 | 3,214 | 663 | 1,906 | 308 | 1,936 | 25.3% |
| 60.0 | 50 | 6,358 | 1,007 | 7,540 | 2,798 | 663 | 1,186 | 308 | 1,214 | 53.2% |
| 2011 Flood | | | | | | | | | | |
| 67.0 | 100 | 10,470 | 7,528 | 3,824 | 2,814 | 3,040 | 10,495 | 2,793 | 13,104 | |
| 66.5 | 95 | 10,470 | 7,453 | 3,824 | 2,798 | 3,040 | 10,445 | 2,793 | 13,004 | 0.8% |
| 65.8 | 90 | 10,470 | 6,756 | 3,824 | 2,815 | 3,040 | 9,791 | 2,793 | 12,302 | 6.1% |
| 64.0 | 75 | 10,470 | 5,748 | 3,824 | 2,680 | 3,040 | 8,788 | 2,793 | 11,110 | 15.2% |
| 60.0 | 50 | 10,470 | 4,209 | 3,824 | 1,595 | 3,040 | 7,249 | 2,793 | 9,582 | 26.9% |

The preliminary work done by Seqwater before Christmas 2010 showed that for the October 2010 event, reducing the level of Wivenhoe by small amounts would have had minimal impact on the flood releases. From the Table 2Table 2 the following comments are applicable:

- Similarly to work completed previously, reducing levels by small amounts prior to the January 2011 event (if it was feasible) would have had little impact on the peak level in Wivenhoe Dam as shown in the Table 2. The reason for this is that the total event inflow volume of 2,600,000 ML is well in excess of the useable flood storage combined with the available water supply storages shown in the table. Large reductions to the storage level of the dam (25 to 50%) would be required if significant impacts on flooding are to be achieved.
- For the 1999 flood, where most of the flooding occurred upstream of the Wivenhoe Dam, there is a dramatic reduction in the peak outflow if the storage is lowered. However, this is of little

[1] Note the flows quoted for Moggill are based on the addition of outflows from the dam and the measured flows at Lockyer Creek and the Bremer River. They do not have any allowance for routing of the flows through the river system and the subsequent reduction in flows that were observed during the flood events.

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benefit as the flood would not have resulted in damaging flows downstream of the dam even if the storage was full.

- The 1974 flood simulation is based on the recorded flows being routed through the both Somerset and Wivenhoe. The presence of Wivenhoe would have reduced the flooding damage in Brisbane during the 1974 event, however there is very little change to the flood mitigation benefits by varying the storage level in Wivenhoe. As most of the flood flows in 1974 were downstream of the dam and the flood in the Brisbane River was relatively small compared to the downstream flooding the event is insensitive to the starting level in Wivenhoe.
- It should be noted that the increasing early releases from Wivenhoe was investigated during the Brisbane Valley Flood Damages Study as part of a review of the operation of the dam. Releasing more water earlier on from Wivenhoe dam was shown to lessen the flood mitigation benefits compared with the existing flood manual release strategies.

The key point being that each flood event is unique and presents varying opportunities to mitigate flows through Brisbane.

## 5.3 Downstream Water Level Changes

E~~The e~~val~~at~~uation of~~e~~ the ~~specific~~ impact on the Lower Brisbane River of these reduced dam outflows from lowering the initial storage level requires the use of a complex hydraulic model. The results of ~~this~~ such modelling would still contain a degree of uncertainty as illustrated by the difficulties in estimating the final flood peak in Brisbane during the event. The uncertainty was partly due to the rapid closure of the Wivenhoe gates after the peak inflow of the flood and the attenuation achieved in the downstream river system. It is extremely difficult to model accurately.

Comment [RJN2]: I am not clear about this – are you pointing out the uncertainty associated with the 2011 event in particular or in general? I think text needs clarification.

Given the timeframe of this report it is not possible to ~~generate any~~ provide a reliable estimate of the changes to the water level at the Port Office Gauge due to a number of confounding factors, namely: tidal influences, the need to interpolate between previously modelled results that vary markedly between differing events, the availability of verified data, and the uncertainty surrounding the timing of peak flows for the differing scenarios.

However, an approximate estimate of the impact on flood levels at the Brisbane Port gauge can be made at this time. Table 3 shows a comparison of the peak water level for each of the various starting levels for the 2011 fFlood Eevent. It should be noted that each scenario results in the storage level exceeding EL74 requiring the gates to be opened until the storage rise is stopped. These estimates of flood levels at the Port Office are based on the interpolation and scaling of previously modelled results – it needs to be stressed that these estimates need ~~should thus~~ to be regarded as indicative only until more detailed analyses can be undertaken.

**Table 3 - Preliminary Estimate of Brisbane Levels Changes due to Lowering Wivenhoe for the 2011 flood**

| Wivenhoe Dam | | | | Approximate reduction in level |
|---|---|---|---|---|
| Starting Level | | Peak Height | Capacity at Peak Height | Brisbane Port Gauge |
| % | m AHD | m AHD | % | m |
| 100 | 67.0 | 74.98 | 191.1 | 0 |
| 95 | 66.5 | 74.93 | 190.6 | 0 to 0.1 |
| 90 | 65.8 | 74.88 | 189.9 | 0.1 to 0.3 |

Comment [RJN3]: In Table 1 this level is quoted as 74.97

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| | | | | |
|---|---|---|---|---|
| 75 | 64.0 | 74.63 | 186.5 | 0.2 to 0.6 |
| 50 | 60.0 | 74.11 | 179.6 | 0.4 to 0.9 |

It is seen that appreciable reductions could only have been achieved when the storage is drawn down towards the lowest levels considered.

It should also be noted that to accurately calculate the impacts of reducing the storage levels of Wivenhoe Dam at the start of a major flood event requires considerable study as rainfall events of different intensity, duration, peak, location and spread will give very different outcomes. In addition, there is the need to do detailed hydraulic analysis of the river system for each scenario to more accurately determine impacts.

### 5.4 Summary

Due to the large volumes of water associated with major flood events in the Brisbane River (that is with events with annual exceedance probabilities rarer than 1 in 100), to effectively reduce flood peak discharges significantly would require the storage level of Wivenhoe Dam to be lowered by at least 25 to 50%.

## 6 Contingency Options

There is the possibility of further flood events in the South East Queensland during the 2010/2011 wet season. To reduce the risk of flooding in Brisbane should a major rainfall event be predicted it has been requested that lowering of the storage level of Wivenhoe Dam be investigated to determine if this is a feasible option to further mitigate flood flows.

The assessment carried out by Seqwater has indicated that to have any significant impact on releases downstream of Wivenhoe Dam during a major flood event it would be necessary to lower the storage level by 25 to 50%.

There are five options considered going forward:

- "Option 0" - Continue with the current approved flood manual strategies
- "Option 1" - Commence drawing down the storage at a safe rate to bring it down to say 75%.
- "Option 2" - Pre-release water from the dam following the prediction of a major rainfall event
- "Option 3" - Change the flood manual strategies to ignore the early strategies designed to minimise disruption to the rural communities.
- "Option 4" - Temporarily reduce the full supply of Wivenhoe Dam and amend the flood releases to commence flood operations from the lowered full supply level.

### 6.1 Do Nothing Option – Continue with the Current Flood Manual

This option maintains the status quo and continues to utilise the dam as originally designed. This option has the least risks associated with it as the Strategies have been implemented and refined over several flood events and the manual was developed by a comprehensive study. The strategies in the flood manual have proved adequate for more frequent flood events.

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## 6.2 Option 1 – Vary the early strategies for the Flood Manual

It has been proposed that increasing the releases from the dam up to 1,600m$^3$/s as soon as practicable after gate operations commence may deliver reduced peak flood levels. This has been investigated to assess the impact of attempting to release more water at the very start of an event.

This option has been assessed using a range of design events from the Wivenhoe Alliance Design hydrology. To model the impacts of increasing releases up to 1,600 m$^3$/s as soon as practicable a range of design flood events from the Wivenhoe Alliance were compared using the program FLROUTE. . It was assumed that no attempt would be made to maintain bridge access downstream of the dam other than Mt Crosby Weir Bridge and the Brisbane Valley Highway Bridge.

The results for the model runs are presented in Table 4.

Table 4 - Comparison of Release Strategies

| Flood Event | | | Existing Rules | | Amended Rules | | |
|---|---|---|---|---|---|---|---|
| Event description | Maximum Inflow (m$^3$/s) | Flood Volume (ML) | Maximum Outflow (m$^3$/s) | Maximum Lake Level (m AHD) | Maximum Outflow (m$^3$/s) | Maximum Lake Level (m AHD) | Flow Reduction % |
| 36 hour 1 in 200 design* | 8,214 | 1,544,119 | 3,861 | 71.43 | 3,613 | 71.27 | 6% |
| 36 hours 1 in 500 design | 10,455 | 1,624,119 | 5,125 | 72.22 | 4,915 | 72.09 | 4% |
| 36 hours 1 in 1000 design | 12,031 | 1,772,752 | 6,049 | 72.[illegible] | 5,854 | 72.68 | 3% |
| 48 hours 1 in 5000 design | 14,278 | 2,562,553 | 9,083 | 74.71 | 8,994 | 74.66 | 1% |
| 72 hours 1 in 5000 design | 13,181 | 2,880,602 | 8,204 | 74.16 | 8,101 | 74.10 | 1% |
| 96 hours 1 in 5000 design | 11,870 | 2,948,032 | 7,550 | 73.75 | 7,426 | 73.67 | 2% |
| 120 hours 1 in 5000 design | 12,727 | 3,005,136 | 7,265 | 73.57 | 6,986 | 73.39 | 4% |
| January 2011 historic | 10,470 | 2,650,000 | 7,528 | 74.98 | 7,452 | 74.95 | 1% |
| 1974 historic | 5,953 | 1,410,000 | 3,275 | 73.31 | 3,159 | 73.26 | 4% |
| 1999 historic | 6,358 | 1,220,000 | 2,312 | 72.23 | 2,251 | 72.504 | 3% |

It should be noted that predicted flood levels greater than EL 74 require the gates to be opened until the water level stabilises. This is fundamental to the dam's safety. In addition, any reduction in starting level, which does not achieve a peak lower than EL 74, is unlikely to have any impact upon peak release rate.

It can be clearly seen from Table 4 that changes to the early releases adopted for the flood manual strategies have minimal impact on the maximum outflow for the dam. The influence of reduced initial starting level decreases with increasing flood magnitude. For the major flood events investigated the reduction in peak outflow for the dam is negligible. Note that this analysis does not consider the downstream flooding in the Lockyer and Bremer Rivers.

However, it should be noted that there is the real risk that the release of additional water from the dam early in the flood event may make local flooding impacts in Brisbane worse. Due to the travel time of releases, uncertainty in forecast rainfall, and the low lying local catchment areas between Wivenhoe Dam and the urban areas of Brisbane, it is likely that for some events the increased early

**Comment [RJN4]:** Is there a note attached to this asterisk?

**Comment [RJN5]:** In Table 1 the max level quoted was 70.45 – did it start below FSL in 99 or different rules used?

**Comment [RJN6]:** Why is the peak level higher here when the peak outflow is lower?

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releases will exacerbate local flooding in Brisbane. This is potentially a significant risk as this flooding is directly attributable to the dam releases and could be avoided if the dam was operated according to the current strategy.

The flood strategies for Wivenhoe and Somerset are based on holding back flood waters until the rain has occurred and downstream flooding has peaked. Releasing early in an event compromises some of the flood mitigation capacity for the intermediate flood events.

## 6.3 Option 2 – Pre-release water when a major event is forecast

This option involves implementing a significant release of water once the notification of a major rainfall event has been received. This option is reliant on the accuracy of forecasts and having predefined approval processes in place.

The Bureau of Meteorology was approached by the SEQWater Corporation in 2006 to discuss the ability of the provision of short term forecasts of large rainfall events. Their response is included in Attachment A. The summary of their advice from the meeting was:

*"In light of the demand for water in southeast Queensland and the highly variable nature of rainfall in the area the project has many obvious attractions. However the capability of the science to provide sufficiently reliable 24 to 48 hour advance predictions of high catchment average rainfalls is limited. The Bureau would be willing to participate in future discussions on the subject and maybe able to assist with some service that would assist."*

There are also physical constraints on the amount of water that can be released. To reduce Wivenhoe to 75% in 48 hours requires water to be released at a rate that would close all of the road crossings over the Brisbane River between the dam and the Jindalee Bridge (peak flow of over 1,900 $m^3/s$) and result in a final volume in Wivenhoe of around 66.8% during the third day if the gates were closed down using the established closure sequence after the 48 hours. If the high rainfall did occur, then the gates would no doubt remain open.

It is not possible to lower Wivenhoe to 50% within 3 days due to the incremental opening of the gates required for safety, the reduction in discharge through the gates with the dropping dam level, and the need to limit discharges below damaging flows through Brisbane.

In light of the above comment, pre-releases (i.e. releasing water prior to an event based on predicted rainfall) has significant risks associated with the strategy in terms of:

- The difficulty in actually releasing significant volumes of water,
- The potential impacts downstream if rainfall doesn't eventuate (disrupting the downstream community, causing minor damage to low lying areas, creating a "sunny day" flood event totally attributable to the dam, someone could be injured or washed away in such a release).
- The risk of exacerbating flooding by making releases that then add to flood levels downstream occurring after the pre-release. (i.e. the predicted rainfall occurs downstream of the dam while the river level is elevated due to the pre-release's from the dam combining to create a damaging flood)

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- Predicting rainfall 2 days before an event is highly variable even according to the Bureau of Meteorology and 3 days is problematic.

## 6.4 Option 5 – Lower the Storage Level by Sunny Day Releases to 75% and operate under the current flood manual

This option involves effectively lowering the Full Supply Level of Wivenhoe Dam to increase the flood mitigation storage at the commencement of a flood event. As discussed previously, the storage would need to be lowered by 25 to 50% to provide a significant reduction in peak flows for a major flood event. Once the storage level reached EL67 gate operations would commence as per the current flood manual.

To safely lower the storage it is proposed that this option would be implemented by "Sunny Day" releases at a rate low enough to minimise disruption to the rural areas. This would be difficult to implement during a wet year where the risk of major flooding is greater.

In the 25 days leading up to the January 2011 Flood event, three flood events impacting on Wivenhoe Dam were experienced, with gate releases being made on all but five of those days. The total outflow from these events was around 790,000 ML.

During these events, multiple requests were received from Councils and residents impacted by bridge closures downstream of the dam to curtail releases as soon and as quickly as possible. Additionally, the 2 January end date of the flood event prior to the January 2011 Flood event meant that significant draw down of the dam prior to the onset of the January 2011 Flood event that commenced on 6 January 2011, was not possible without major bridge inundation downstream of the dam and without exceeding minor flood levels in the lower Brisbane River.

Additionally, a flood event was also experienced in October 2010 that resulted in a release of 640,000 ML from the dam. Accordingly, to draw down the dam below full supply level prior to the start of the first December event would not have been possible without significant bridge inundation and without exceeding minor flood levels (as defined by BOM and BCC) in the lower Brisbane River.

In other words, preceding rainfall events to the January 2011 Major Flood event had created flooding that would have maintained the storage at the current FSL and prevent drawdown of the storage if such a strategy was proposed.

Risks to this strategy are:

- Compromising water security for South East Queensland by lowering the storage at the end of the each event. The impact on yield needs to be quantified.
- Having preceding rainfall events fill up the dam and prevent it from being lowered before a major flood event. Effectively compromising any effectiveness associated with this strategy.
- The limited discharges that can be utilised during sunny day flows in the river system. To reduce levels prior to summer would take some time without inundating any bridges and without any further inflows. To reduce from 100% to 50% and only impact on Twin Bridges and Savages Crossings and keep Colleges Crossing open could take some 5 to 6 weeks. Even if levels are reduced in Wivenhoe prior to

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summer, as occurred this summer, multiple rain events can fill the dam and would require significant releases to keep the storage level down.

## 6.5 Option 4 - Temporarily Lower the Full Supply Level to 85% and Amend the Flood Operations Manual

It was requested that the option of temporarily lowering the storage to 85% of the current storage capacity (for this option make EL65.25 the FSL, down from EL67) and amend the current flood manual to commence releases once the storage level exceeds EL65.5. The amended manual would retain the key level in the manual of EL74m, where the gates are opened until the flood level stops rising. This would require a change by the Queensland Government to the regulatory requirements and levels of service that the storage is operated under.

This amended change would result in flow reductions similar to that obtained from Option 3.

Table 5 - Impact of temporarily Lowering FSL to 85%

| Flood Event | | | Existing Rules | | Temporarily Reducing FSL. | | |
|---|---|---|---|---|---|---|---|
| Event description | Maximum Inflow (m³/s) | Flood Volume (ML) | Maximum Outflow (m³/s) | Maximum Lake Level (m AHD) | Maximum Outflow (m³/s) | Maximum Lake Level (m AHD) | Flow Reduction % |
| 36 hour 1 in 200 design* | 8,214 | 1,544,119 | 3,861 | 71.4 | 2,639 | 70.66 | 32% |
| 36 hours 1 in 500 design | 10,455 | 1,624,119 | 5,985 | 72.2 | 4,028 | 71.53 | 33% |
| 36 hours 1 in 1000 design | 12,031 | 1,772,752 | 6,010 | 72.78 | 5,031 | 72.16 | 16% |
| 48 hours 1 in 5000 design | 14,278 | 2,562,553 | 9,066 | 74.7 | 8,535 | 74.37 | 6% |
| 72 hours 1 in 5000 design | 13,181 | 2,880,602 | 8,204 | 74.15 | 7,821 | 73.92 | 5% |
| 96 hours 1 in 5000 design | 11,870 | 2,948,032 | 7,534 | 73.74 | 7,135 | 73.49 | 5% |
| 120 hours 1 in 5000 design | 12,727 | 3,005,136 | 7,227 | 73.55 | 6,751 | 73.25 | 7% |
| January 2011 historic | 10,470 | 2,650,000 | 7,528 | 74.98 | 5,746 | 74.62 | 24% |
| 1974 historic | 5,953 | 1,410,000 | 3,275 | 73.3 | 2,737 | 72.91 | 16% |
| 1999 historic | 6,358 | 1,220,000 | 2,312 | 72.23 | 1,814 | 71.89 | 22% |

* Design event characteristics obtained from WA (2005)

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Comment [RJN7]: Max outflows for rows 2 to 7 of this table differ markedly from those reported in table 4

Comment [RJN8]: 0.01 different to values cited in table 4 – suggest making identical

## 6.6 Option 5 - Temporarily Lower the Full Supply Level to 75% and Amend the Flood Operations Manual

It was requested that the option of temporarily lowering the storage to 75% of the current storage capacity (for this option make EL64 the FSL, down from EL67) and amend the current flood manual to commence releases once the storage level exceeds EL64. The amended manual would retain the key level in the manual of EL74m, where the gates are opened until the flood level stops rising. This would require a change by the Queensland Government to the regulatory requirements and levels of service that the storage is operated under.

As can be seen in Table 6 lowering the FSL to EL64 (75% of the current FSL) and commencing flood operations at this level has a profound impact on the discharges for the shorter duration flood

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events with smaller flood volumes. However, once the flood volume exceeds the 2,000,000 ML mark the effectiveness of this change in the operating level is diminished resulting in only a 10% reduction in the peak outflows for the dam.

Given the January 2011 Event had a volume of over 2,500,000 ML, the benefits from lowering the storage level would not have resulted in any major change to the extent of flood inundation. It would however have reduced the depth of inundation with a corresponding reduction in the number of house and commercial properties flooded.

Table 6 Impact of temporarily lowering FSL to 75%

| Flood Event | | | | Existing Rules | | Temporarily Reducing FSL. | |
|---|---|---|---|---|---|---|---|
| Event description | Maximum Inflow ($m^3/s$) | Flood Volume (ML) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Maximum Outflow ($m^3/s$) | Maximu m Lake Level (m AHD) | Flow Reduction % |
| 36 hour 1 in 200 design* | 8,214 | 1,544,119 | 3141 | 71.4 | 1,971 | 70.24 | 94% |
| 36 hours 1 in 500 design | 10,455 | 1,624,119 | 5983 | 72.2 | 3,446 | 71.17 | 42% |
| 36 hours 1 in 1000 design | 12,031 | 1,772,752 | 6010 | 72.78 | 4,504 | 71.83 | 25% |
| 48 hours 1 in 5000 design | 14,278 | 2,562,553 | 9066 | 74.7 | 8,217 | 74.17 | 9% |
| 72 hours 1 in 5000 design | 13,181 | 2,880,602 | 8190 | 74.15 | 7,609 | 73.79 | 7% |
| 96 hours 1 in 5000 design | 11,870 | 2,948,032 | 7534 | 73.74 | 6,916 | 73.35 | 8% |
| 120 hours 1 in 5000 design | 12,727 | 3,005,136 | 7227 | 73.55 | 6,635 | 73.17 | 8% |
| January 2011 historic | 10,470 | 2,650,000 | 7,528 | 74.98 | 4,512 | 74.25 | 40% |
| 1974 historic | 5,953 | 1,410,000 | 3,275 | 73.3 | 2,493 | 72.71 | 24% |
| 1999 historic | 6,358 | 1,220,000 | 2,312 | 72.23 | 1,561 | 71.48 | 33% |

* Design event characteristics obtained from WA (2005)

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Comment [RJN9]: Again, these differ significantly from previous table

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It can be seen from the comparison of Table 5 and Table 6 that the reduction of the storage level to 75% can provide a significant reduction on the outflows from the dam when combined with an amended release strategy, but again this impact reduces as the magnitude of the event increases. This is consistent with the previous observations that reductions of at least 25% of the storage volume are required to significantly alter the outflows from the dam.

It is also important to note that even with the reduction of the storage level to 75% and the amended flood operation rules, the storage level still exceeds EL74 for the January 2011 Flood Event. The changes would result in reduced flood levels downstream but would not prevent damaging flows through Brisbane.

# 7 References


DPI (1995) Department of Primary Industries Qld, Water Commercial, "Wivenhoe Dam Design Report – Volume 1 – Text", WS094, September 1995


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WA (2005) Wivenhoe Alliance, "Design Discharges and Downstream Impacts of the Wivenhoe Dam Upgrade, Q1091, September 2005

WRM (2006) WRM Water and Environment, "Brisbane Valley Flood Damage Minimisation Study – Brisbane City Flood Damage Assessment, Brisbane City Council City Design, October 2006

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## 8 Attachment A

# Rainfall Forecasting for the Wivenhoe Dam Catchment

**Background**

1. On 6 July, Chris Russell, of Connell Wagner, met with Mike Bergin and Peter Baddiley seeking advice regarding the predictability of significant rain events over the Wivenhoe Dam catchment. Connell Wagner has been engaged by SEQWCo to provide advice on the feasibility of maintaining the water level in the Wivenhoe storage at one metre above Full Supply Level. As a part of the dam operations under that scenario, it would be required that the additional storage above FSL be released ahead of a major inflow into Wivenhoe Dam. This would require some 24 to 48 hour advance prediction of catchment average rainfalls in the order of 300mm in 24 hours; 375mm in 36 hours and/or 430mm in 48 hours.

2. Wivenhoe Dam catchment is located to the north-west of Brisbane and has an area of about 7,000 square kilometres. For meteorological forecasting, the catchment is broadly about 100 km in the north-south direction, and 70 kilometres wide (east-west); bounded in the west by the Dividing Range with its eastern boundary varying from about 40 to 80 kilometres inland from the coast. The distribution of rainfall over the catchment is significantly influenced by the topography in major events.

**Discussion**

3. As discussed at the meeting, the experience of Meteorologists and Hydrologists in the Brisbane office of the Bureau is that the short to medium term (0 to 48 hour) prediction of rainfall for the purpose of objective use in flood forecasting models is a difficult task. Quantitative Precipitation Forecasts (QPF) are available from the Australian and international Numerical Weather Prediction (NWP) models and have been used subjectively in the Brisbane office for many years. Whilst the NWP models have shown improvement in the accuracy of QPF over the past decade or so, there is still at times considerable error or uncertainty, in the prediction of the location, amount and timing of rainfall events at the catchment scale.

4. The improved skill of NWP models in recent years has particularly been in forecasting the development and movement of broad-scale synoptic features that would be likely to produce the threshold rainfall amounts in question. These large-scale features include decaying tropical cyclones, east coast low pressure systems and significant upper level troughs. However while these systems maybe well forecast on a time scale of 2 to 3 days the very heavy rainfall concentrations are dependent on finer scale (mesoscale) and convective features. Whilst there is often the ability to forecast the potential for a significant rain event to occur in the southeast Qld-northern NSW region, it is difficult (if not impossible) to predict the actual location of the heaviest rain, even with only a few hours notice.

5. Examples of high rainfall events that have occurred in the past 10 to 15 years in this region, some of which had little to no advance prediction of the "precise" location and/or magnitude of resulting rainfall, include Feb 1991, Dec 1991, Feb 1992, May 1996, Feb 1999, Mar 2001 and June 2005.

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Several of these events were not produced by large-scale features but by slow moving convergence zones which the current modelling capability cannot adequately predict. The two most recent events in 2001 and 2005 were relatively short-lived events and occurred at different times of the day – 2001 in the afternoon and 2005 overnight. While one could reasonably expect that most really significant rainfall events are most likely through the warmer months, winter extreme events are by no means rare.

6. Considerable effort is being applied to derive improved deterministic and probabilistic QPFs from NWP models. In the near future, the Bureau will be providing a publicly available rainfall forecasting service via a website. The rainfall predictions will be generated automatically by combining the outlooks from a suite of Australian and international. Forecast rainfall amounts for 24 hour periods will be given for 4 days ahead, together with the chance of exceeding various amounts from 1mm to 50mm. The latter is a "pseudo" measure of probability based on the consistency in the forecast rain amounts given by up to eight NWP models used in deriving the rainfall forecast. Whilst it is not considered that this will provide a sufficiently accurate method for objective decision making for pre-releases from Wivenhoe Dam, the probabilistic rain forecasts may provide a basis for a risk management approach. There may need to be further studies on risk quantification for prediction of high to extreme rainfall events to support this approach. Given that there are large levels of uncertainty in rainfall forecasts, the forecasting of hydrological response may require an ensemble of future rain scenarios to be considered for the Wivenhoe Dam application.

7. As for a potential service provided by the Bureau an alert type product would seem to be the best alternative where the potential for an extreme rainfall event in the following 2 to 3 days across southeast Queensland was given a rating on say a 3 level scale. If that rating was high then a second phase could be activated which could provide more detailed forecast of expected rainfall amounts and location. However I emphasise that this type of service can be expected to not provide the required 2 days advice of an event on some occasions and may fail to provide anything more than a few hours notice, such is the nature of the predictability of the mesoscale components of these events.

8. Currently the Bureau provides a QPF service for the dams in Southeast Queensland. This twice-daily service predicts the average rainfall across the catchments in the following 24-hour period. We have not undertaken any verification of the service. However it is likely that verification would show reasonable skill in identifying rainfall events but quite poor skill in predicting extreme events. This service is to be reviewed in the next few months and we may commence charging for the product as it is essentially not a basic service and should not be publicly funded. We have yet to commence discussions with the client so these comments should be kept confidential. This issue is raised because any future customized product provided in support of dam operations will certainly be on a fee for service basis. There is also the issue of whether the Bureau would have the capacity to provide such a service at all and that would have to be part of any future discussions.

**Summary**

9. In light of the demand for water in southeast Queensland and the highly variable nature of rainfall in the area the project has many obvious attractions. However the capability of the science to provide sufficiently reliable 24 to 48 hour advance predictions of high catchment average rainfalls is

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limited. The Bureau would be willing to participate in future discussions on the subject and maybe able to assist with some service that would assist.

Mike Bergin
Manager Weather Services,
Bureau of Meteorology, Queensland.

Peter Baddiley
Supervising Engineer Hydrology
Bureau of Meteorology, Queensland

24 July 2006

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# 9 Attachment 2 – Extracts from the Wivenhoe Design Report

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**From:** Terry Malone [redacted]
**Sent:** Monday, 7 February 2011 2:05 PM
**To:** Rob Drury
**Cc:** Barton Maher
**Subject:** Brisbane URBS Model

Gents

I worked on the Brisbane URBS model over the weekend to improve its ability to reproduce the flood levels in the lower Brisbane River in significant events from March 1955 to Jan 2011.

I'm reasonably confident it could be used to assess the impact of modified out hydrographs from Wivenhoe on flood levels from Moggill to the City.

Let me know if you're interested.

Cheers


Terry Malone
Principal Hydrologist
[illegible]

seqwater
WATER FOR LIFE

Level 3, 240 Margaret St, Brisbane City QLD 4000 [illegible]
PO Box 16146, City East QLD 4002
P [redacted]

| | |
|---|---|
| **From:** | Nathan, Rory J (SKM) [redacted] |
| **Sent:** | Monday, 7 February 2011 1:13 PM |
| **To:** | Barton Maher |
| **Subject:** | Tel call |

Hi Barton,

I left a voicemail, but I understand that you are revising the report to a more concise form – under tight time pressure! – do let me know if you need assistance in preparation of this document, or when it is ready for review.

Perhaps best to text me so that I can quickly respond.

Best wishes,

ory

[redacted]

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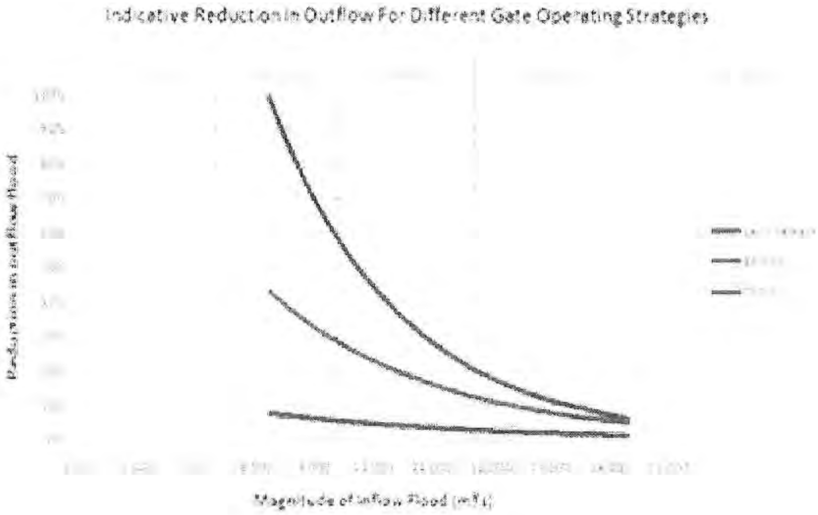
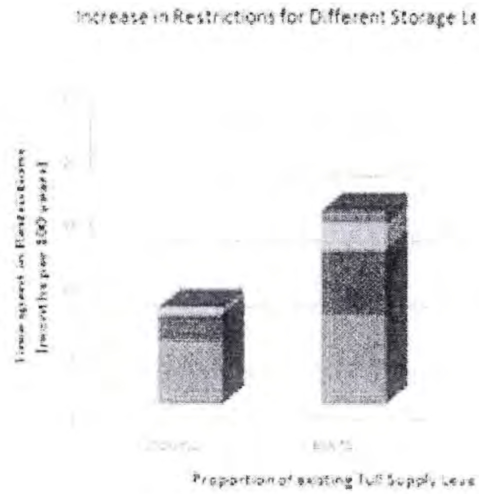
**From:** Nathan, Rory J (SKM)
**Sent:** Monday, 7 February 2011 1:40 PM
**To:** 'Barton Maher'
**Cc:** Jim Pruss; Rob Drury; Alex Fisher; Hill, Peter I (SKM)
**Subject:** RE: Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V2 070211.docx

Hi Barton,

I have looked through the new version, and my comments and suggested (minor) changes are provided in track anges mode in the attached document. In short, I agree with the main messages, but I am a little concerned that the numbers for the design events (in Tables 4, 5 and 6) are not in total agreement where they need to be – either this reflects some typos, or possibly the hydrographs are not all scaled exactly the same way when entered into the spreadsheets. I do think these need to be checked again, for any meaningful differences will undermine confidence by the wider audience reading this.

I imagine the timelines for gold-plating this are probably too tight, but given the focus this will get it would be good to pre-empt some questions around the impact. As I indicated on Friday we could consider including a couple of plots along the lines of the following:




nere the left hand panel provides a high level summary (only to make it easier for the reader) and the right hand panel presents information (if it can be made available) that highlights the implications to water supply security that may not be evident. Very happy if you decide not to include the above, I am just checking that my earlier suggestion didn't get lost in the email traffic.

I am now tied up till 1:30 (your time) at another meeting – but if you need to discuss urgently then please text me on my mobile and I will ring you ASAP.

Regards,

Rory

Dr Rory Nathan | General Manager Technology & Practice | Sinclair Knight Merz
PO Box 312 Flinders Lane Melbourne VIC 8009 Australia | Level 11 452 Flinders Street Melbourne VIC 3000 Australia
Tel [redacted]

Please consider the environment before printing this e-mail

**From:** Barton Maher [redacted]
**Sent:** Monday, 7 February 2011 12:06 PM
**To:** Nathan, Rory J (SKM)
**Cc:** Jim Pruss; Rob Drury; Alex Fisher
**Subject:** Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V2 070211.docx

Hi Rory,

As discussed, I have updated the report to reflect your comments from Friday. The inconsistency in the discharges was from my error in transferring the numbers from the spreadsheet. I have checked them and updated the table to reflect the real data as sent to you. I have also added in the additional information as requested.

The only thing I am short of is the 1 in 100 AEP design event as the Alliance started with the 1 in 200 event

I have also added background data to assist in understanding the source of the flood events and provide some context on the design of the spillway.

If you have any questions please give me a call on my mobile.

Regards

Barton Maher
Principal Dams & Weirs Planning
QLD Bulk Water Supply Authority *trading* as Seqwater

Ph [redacted]
Karalee Office, 68 Junction Rd Karalee QLD 4306 Australia
PO Box 2437 North Ipswich QLD 4305
Website | www.seqwater.com.au

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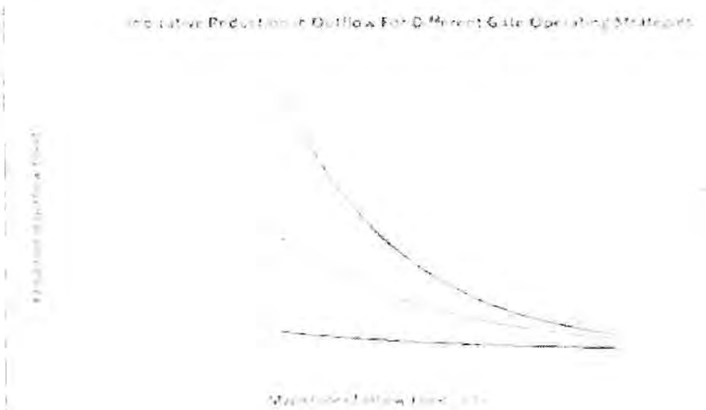
**From:** Nathan, Rory J (SKM) [redacted]
**Sent:** Friday, 4 February 2011 5:30 PM
**To:** Barton Maher
**Cc:** Nixon, Pat W (SKM); Hill, Peter I (SKM)
**Subject:** RE: Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V1.docx
**Attachments:** Flood peak assessment.xlsx; ATT252511.txt

Hi Barton,

I have attached a spreadsheet that illustrates how a summary might be presented on the tension between reduced flood peaks and some index of supply reliability – the former is obtained from an exponential fit to your modelled results, and the latter is fictional data for illustration purposes only. I haven't bothered to line up the flood categories with the specific flood limits, but if you want that feature in you can adjust as required.

he key plot is as presented below, but this is for ideas only and perhaps we can discuss on Monday morning.



Have a good weekend!

est regards,

Rory

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**From:** Nathan, Rory J (SKM)
**Sent:** Friday, 4 February 2011 10:18 AM
**To:** Barton Maher
**Cc:** Nixon, Pat W (SKM); Hill, Peter I (SKM)
**Subject:** RE: Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V1.docx

Hi Barton

We have provided comments in the attached document along with some suggested text changes

I will ring and discuss shortly as I am a little uncomfortable about some of the apparent inconsistencies in the numbers – pointers to this are in the attached doc.

The spreadsheet just provides some graphical sanity checking which highlights some of the difficulties we are having with the numbers.

Let's talk soon,

Rory

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**From:** Barton Maher [redacted]
**Sent:** Thursday, 3 February 2011 6:19 PM
**To:** Nathan, Rory J (SKM); Hill, Peter I (SKM)
**Cc:** Nixon, Pat W (SKM)
**Subject:** Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V1.docx

Hi Gents,

Latest draft - I was asked to include differing options for the CEO I am working on the plots as suggested but I need to get home to see the family and will send them through later tonight.

Regards,

[redacted]

www.seqwater.com.au

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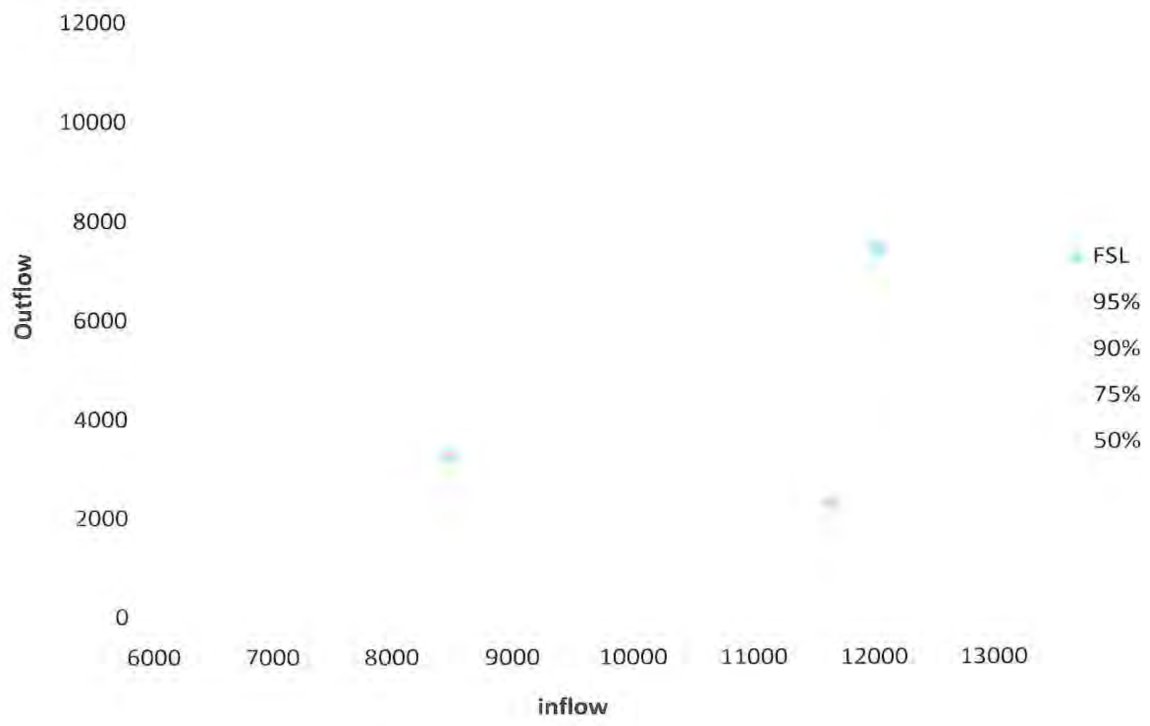
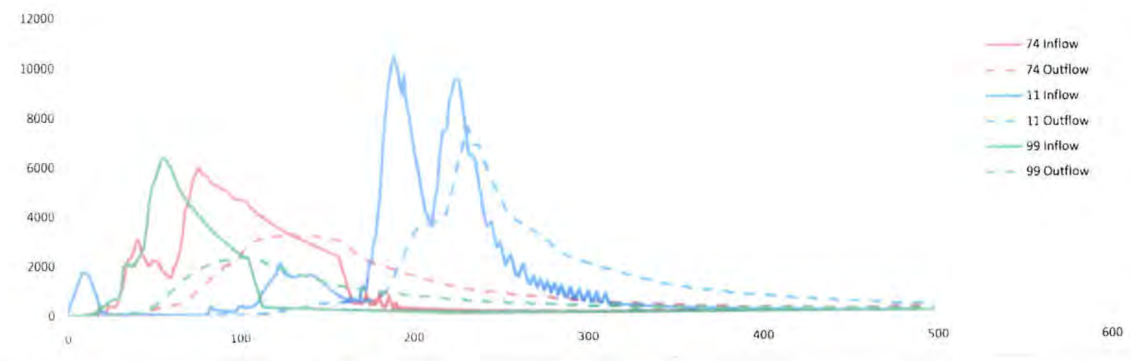
**Table 2**

| **historic events** | | outflows | | | | |
|---|---|---|---|---|---|---|
| Year | Inflow | FSL | 95% | 90% | 75% | 50% |
| 1974 | 8482 | 3275 | 3,153 | 2,974 | 2,618 | 2,067 |
| 1999 | 11641 | 2312 | 2,132 | 2,003 | 1,687 | 1,007 |
| 2011 | 12045 | 7468 | 7,453 | 6,756 | 5,748 | 4,209 |



| | | | | | | |
|---|---|---|---|---|---|---|
| Max | [illegible] | 5275 | 10470 | 7528 | 6361 | 2312 |
| | 1974 event | | 2011 event | | 1999 event | |
| [illegible] | 74 Inflow | 74 Outflow | 11 inflow | 11 Outflow | 99 Inflow | 99 Outflow |
| [illegible] | | 0.00 | 150.0 | 0.0 | 0 | 0 |
| [illegible] | | 0.00 | 346.9 | 0.0 | 0 | 0 |
| [illegible] | | 0.00 | 543.8 | 0.0 | 0 | 0 |
| [illegible] | | 0.00 | 740.6 | 0.0 | 0 | 0 |
| [illegible] | | 0.00 | 937.0 | 0.0 | 0 | 0 |
| [illegible] | | 0.00 | 1132.7 | 0.0 | 0 | 0 |
| [illegible] | | 0.00 | 1327.7 | 0.0 | 1 | 0 |
| [illegible] | | 0.00 | 1521.7 | 0.0 | 1 | 0 |
| [illegible] | | 0.00 | 1714.4 | 0.0 | 2 | 0 |
| [illegible] | | 0.00 | 1706.8 | 0.0 | 2 | 0 |
| [illegible] | | 0.00 | 1699.2 | 0.0 | 36 | 0 |
| [illegible] | | 0.00 | 1691.7 | 0.0 | 40 | 0 |
| [illegible] | | 0.00 | 1684.2 | 0.0 | 52 | 0 |
| [illegible] | [illegible] | 0.00 | 1480.1 | 0.0 | 53 | 0 |
| [illegible] | [illegible] | 0.00 | 1277.6 | 0.0 | 64 | 0 |
| [illegible] | [illegible] | 0.00 | 1076.5 | 0.0 | 63 | 0 |
| [illegible] | [illegible] | 0.00 | 876.6 | 0.0 | 94 | 0 |
| [illegible] | [illegible] | 0.00 | 677.8 | 0.0 | 118 | 0 |
| [illegible] | [illegible] | 0.00 | 479.7 | 0.0 | 292 | 0 |
| [illegible] | [illegible] | 0.00 | 282.2 | 0.0 | 344 | 0 |
| [illegible] | [illegible] | 0.00 | 85.0 | 0.0 | 341 | 0 |
| [illegible] | [illegible] | 0.00 | 82.6 | 0.0 | 374 | 0 |
| [illegible] | [illegible] | 0.00 | 80.3 | 0.0 | 402 | 0 |
| [illegible] | [illegible] | 0.00 | 78.1 | 0.0 | 479 | 0 |
| [illegible] | [illegible] | 0.00 | 75.9 | 0.0 | 552 | 0 |
| [illegible] | [illegible] | 0.00 | 73.7 | 0.0 | 588 | 0 |
| [illegible] | [illegible] | 0.00 | 71.7 | 0.0 | 621 | 0 |
| [illegible] | [illegible] | 0.00 | 69.7 | 0.0 | 647 | 0 |
| [illegible] | [illegible] | 0.00 | 67.7 | 0.0 | 660 | 0 |
| [illegible] | [illegible] | 0.00 | 65.8 | 0.0 | 665 | 0 |
| [illegible] | [illegible] | 0.00 | 64.0 | 0.0 | 750 | 0 |
| [illegible] | [illegible] | 0.00 | 62.4 | 0.0 | 1202 | 0 |
| [illegible] | [illegible] | 0.00 | 61.0 | 0.0 | 1912 | 0 |
| [illegible] | [illegible] | 0.00 | 59.3 | 0.0 | 1990 | 0 |
| [illegible] | [illegible] | 0.00 | 57.7 | 0.0 | 2103 | 0 |
| [illegible] | [illegible] | 0.00 | 56.2 | 0.0 | 2053 | 50 |
| [illegible] | [illegible] | 0.00 | 55.0 | 0.0 | 1998 | 50 |
| [illegible] | [illegible] | 50.29 | 120.7 | 0.0 | 1950 | 51 |
| [illegible] | [illegible] | 50.47 | 76.6 | 0.0 | 2047 | 51 |
| [illegible] | [illegible] | 50.67 | 64.9 | 0.0 | 2083 | 102 |
| [illegible] | [illegible] | 101.81 | 61.9 | 0.0 | 2230 | 102 |
| [illegible] | [illegible] | 102.25 | 59.3 | 0.0 | 2311 | 102 |
| [illegible] | [illegible] | 102.65 | 57.0 | 0.0 | 2440 | 103 |
| [illegible] | [illegible] | 154.06 | 55.0 | 0.0 | 2561 | 154 |
| [illegible] | [illegible] | 154.57 | 53.1 | 0.0 | 2673 | 155 |
| [illegible] | [illegible] | 155.04 | 51.4 | 0.0 | 3312 | 155 |
| [illegible] | [illegible] | 206.14 | 49.7 | 0.0 | 3651 | 207 |
| [illegible] | [illegible] | 206.69 | 48.2 | 0.0 | 4466 | 208 |
| [illegible] | [illegible] | 207.24 | 46.7 | 0.0 | 4873 | 259 |
| [illegible] | [illegible] | 207.80 | 45.3 | 0.0 | 5192 | 311 |
| [illegible] | [illegible] | 258.57 | 43.9 | 0.0 | 5353 | 361 |
| [illegible] | [illegible] | 259.27 | 42.5 | 0.0 | 5552 | 418 |
| [illegible] | [illegible] | 259.97 | 41.2 | 0.0 | 5770 | 474 |
| [illegible] | [illegible] | 310.10 | 40.0 | 0.0 | 5964 | 526 |
| [illegible] | [illegible] | 310.81 | 38.8 | 0.0 | 6248 | 585 |
| [illegible] | [illegible] | 311.46 | 37.6 | 0.0 | 6361 | 644 |
| [illegible] | [illegible] | 360.70 | 36.4 | 0.0 | 6353 | 704 |
| [illegible] | [illegible] | 361.36 | 35.3 | 0.0 | 6274 | 764 |



| | | | | | | |
|---|---|---|---|---|---|---|
| 58 | 1546 | 361.97 | 34.3 | 0.0 | 6191 | 825 |
| 59 | 1513 | 362.55 | 33.2 | 0.0 | 6080 | 886 |
| 60 | 1538 | 416.58 | 32.2 | 0.0 | 5940 | 947 |
| 61 | 1816 | 417.22 | 31.2 | 0.0 | 5773 | 1009 |
| 62 | 1980 | 417.98 | 30.3 | 0.0 | 5597 | 1071 |
| 63 | 2137 | 418.82 | 29.4 | 0.0 | 5420 | 1189 |
| 64 | 2352 | 473.60 | 28.5 | 0.0 | 5251 | 1252 |
| 65 | 2618 | 474.76 | 27.6 | 0.0 | 5094 | 1313 |
| 66 | 3027 | 524.69 | 26.8 | 0.0 | 4953 | 1374 |
| 67 | 3618 | 526.52 | 26.0 | 0.0 | 4830 | 1431 |
| 68 | 4235 | 583.41 | 25.2 | 0.0 | 4722 | 1494 |
| 69 | 4407 | 586.15 | 24.5 | 0.0 | 4627 | 1498 |
| 70 | 4515 | 644.12 | 23.8 | 0.0 | 4540 | 1561 |
| 71 | 4921 | 702.50 | 23.1 | 0.0 | 4458 | 1622 |
| 72 | 5301 | 761.63 | 22.4 | 0.0 | 4376 | 1684 |
| 73 | 5516 | 821.34 | 21.7 | 0.0 | 4293 | 1688 |
| 74 | 5664 | 881.71 | 21.1 | 0.0 | 4210 | 1749 |
| 75 | 5871 | 943.08 | 20.5 | 0.0 | 4128 | 1810 |
| 76 | 5953 | 948.21 | 19.9 | 0.0 | 4045 | 1814 |
| 77 | 5840 | 1010.40 | 19.3 | 0.0 | 3961 | 1873 |
| 78 | 5719 | 1128.20 | 18.7 | 0.0 | 3879 | 1877 |
| 79 | 5701 | 1190.94 | 18.3 | 0.0 | 3796 | 1937 |
| 80 | 5657 | 1254.03 | 19.3 | 0.0 | 3715 | 1940 |
| 81 | 5589 | 1315.75 | 22.3 | 0.0 | 3635 | 2000 |
| 82 | 5467 | 1377.73 | 234.6 | 0.0 | 3556 | 2003 |
| 83 | 5383 | 1493.28 | 385.1 | 0.0 | 3478 | 2064 |
| 84 | 5312 | 1556.77 | 247.1 | 0.0 | 3403 | 2066 |
| 85 | 5244 | 1619.49 | 220.2 | 0.0 | 3329 | 2069 |
| 86 | 5238 | 1625.09 | 198.9 | 0.0 | 3258 | 2127 |
| 87 | 5220 | 1688.15 | 187.7 | 0.0 | 3188 | 2129 |
| 88 | 5179 | 1750.39 | 179.8 | 0.0 | 3121 | 2131 |
| 89 | 5102 | 1812.77 | 173.3 | 0.0 | 3057 | 2189 |
| 90 | 5069 | 1874.21 | 173.0 | 0.0 | 2996 | 2190 |
| 91 | 5037 | 1935.81 | 163.4 | 0.0 | 2935 | 2192 |
| 92 | 5028 | 1998.65 | 157.1 | 0.0 | 2876 | 2193 |
| 93 | 4989 | 2004.05 | 151.0 | 0.0 | 2817 | 2195 |
| 94 | 4895 | 2067.02 | 145.2 | 0.0 | 2759 | 2196 |
| 95 | 4797 | 2127.87 | 139.9 | 0.0 | 2701 | 2251 |
| 96 | 4724 | 2188.72 | 135.1 | 0.0 | 2645 | 2252 |
| 97 | 4681 | 2193.52 | 131.2 | 0.0 | 2589 | 2253 |
| 98 | 4680 | 2252.59 | 209.5 | 0.0 | 2535 | 2254 |
| 99 | 4653 | 2314.68 | 327.5 | 0.0 | 2483 | 2254 |
| 100 | 4630 | 2376.81 | 350.0 | 0.0 | 2432 | 2312 |
| 101 | 4638 | 2492.62 | 354.9 | 0.0 | 2383 | 2312 |
| 102 | 4618 | 2553.88 | 322.4 | 0.0 | 2335 | 2312 |
| 103 | 4614 | 2615.20 | 311.9 | 0.0 | 2290 | 2312 |
| 104 | 4554 | 2675.52 | 310.1 | 0.0 | 2246 | 2312 |
| 105 | 4455 | 2679.68 | 310.0 | 51.3 | 2204 | 2312 |
| 106 | 4376 | 2739.76 | 317.7 | 51.3 | 1948 | 2312 |
| 107 | 4301 | 2854.18 | 335.7 | 51.3 | 1698 | 2254 |
| 108 | 4231 | 2968.46 | 367.5 | 51.3 | 1454 | 2253 |
| 109 | 4162 | 2971.55 | 417.2 | 51.4 | 1215 | 2251 |
| 110 | 4099 | 2974.48 | 488.4 | 51.4 | 981 | 2195 |
| 111 | 4040 | 3032.14 | 586.6 | 51.4 | 752 | 2193 |
| 112 | 3985 | 3034.67 | 822.7 | 51.5 | 527 | 2190 |
| 113 | 3933 | 3037.05 | 901.3 | 51.5 | 306 | 2131 |
| 114 | 3883 | 3039.30 | 1001.9 | 51.6 | 302 | 2127 |
| 115 | 3834 | 3041.42 | 1119.2 | 51.7 | 299 | 2068 |
| 116 | 3786 | 3153.66 | 1224.6 | 51.7 | 295 | 2065 |
| 117 | 3738 | 3155.30 | 1324.7 | 103.7 | 291 | 2004 |
| 118 | 3691 | 3156.80 | 1354.6 | 103.9 | 288 | 2001 |
| 119 | 3643 | 3158.18 | 1494.5 | 104.1 | 284 | 1998 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 120 | 3596 | 3159.43 | 1577.8 | 104.3 | 281 | 1938 |
| 121 | 3549 | 3160.55 | 1593.6 | 104.5 | 277 | 1935 |
| 122 | 3504 | 3161.55 | 1993.4 | 104.7 | 274 | 1876 |
| 123 | 3459 | 3162.43 | 2070.4 | 157.1 | 271 | 1873 |
| 124 | 3416 | 3163.19 | 1924.2 | 157.5 | 268 | 1814 |
| 125 | 3374 | 3274.52 | 1739.7 | 157.9 | 264 | 1812 |
| 126 | 3333 | 3274.77 | 1662.2 | 158.2 | 261 | 1809 |
| 127 | 3294 | 3274.91 | 1601.9 | 210.2 | 258 | 1750 |
| 128 | 3255 | 3274.95 | 1555.8 | 210.6 | 255 | 1747 |
| 129 | 3219 | 3274.88 | 1541.9 | 211.0 | 252 | 1688 |
| 130 | 3183 | 3274.72 | 1519.8 | 211.3 | 249 | 1686 |
| 131 | 3147 | 3274.45 | 1513.6 | 211.7 | 246 | 1684 |
| 132 | 3113 | 3163.43 | 1517.1 | 212.1 | 243 | 1624 |
| 133 | 3080 | 3163.29 | 1526.9 | 263.7 | 240 | 1622 |
| 134 | 3047 | 3163.06 | 1539.7 | 264.2 | 237 | 1620 |
| 135 | 3014 | 3162.75 | 1553.5 | 264.6 | 236 | 1561 |
| 136 | 2982 | 3162.35 | 1567.1 | 265.0 | 235 | 1559 |
| 137 | 2951 | 3161.87 | 1579.4 | 316.0 | 234 | 1557 |
| 138 | 2919 | 3161.31 | 1589.0 | 316.5 | 232 | 1497 |
| 139 | 2888 | 3160.67 | 1594.0 | 317.1 | 231 | 1495 |
| 140 | 2857 | 3159.94 | 1592.2 | 317.6 | 228 | 1493 |
| 141 | 2826 | 3159.14 | 1581.7 | 367.8 | 226 | 1434 |
| 142 | 2796 | 3158.26 | 1561.1 | 368.4 | 224 | 1432 |
| 143 | 2765 | 3157.30 | 1530.2 | 369.0 | 221 | 1430 |
| 144 | 2734 | 3156.26 | 1489.5 | 369.5 | 218 | 1377 |
| 145 | 2703 | 3155.15 | 1440.4 | 424.4 | 216 | 1375 |
| 146 | 2671 | 3153.95 | 1384.5 | 425.0 | 213 | 1373 |
| 147 | 2640 | 3042.45 | 1324.4 | 425.5 | 211 | 1316 |
| 148 | 2608 | 3041.42 | 1261.5 | 425.9 | 208 | 1314 |
| 149 | 2576 | 3040.31 | 1199.6 | 426.4 | 206 | 1313 |
| 150 | 2544 | 3039.13 | 1174.4 | 426.8 | 203 | 1255 |
| 151 | 2512 | 3037.86 | 1082.6 | 481.8 | 201 | 1254 |
| 152 | 2480 | 3036.51 | 1019.7 | 482.2 | 198 | 1252 |
| 153 | 2447 | 3035.09 | 960.2 | 482.5 | 196 | 1251 |
| 154 | 2415 | 3033.58 | 904.2 | 482.7 | 194 | 1192 |
| 155 | 2383 | 2977.11 | 851.8 | 483.0 | 191 | 1191 |
| 156 | 2350 | 2975.62 | 804.6 | 483.2 | 189 | 1190 |
| 157 | 2318 | 2974.05 | 765.9 | 483.3 | 187 | 1131 |
| 158 | 2069 | 2972.40 | 729.0 | 483.5 | 185 | 1130 |
| 159 | 1825 | 2970.13 | 690.8 | 483.6 | 182 | 1129 |
| 160 | 1585 | 2967.25 | 657.0 | 483.7 | 180 | 1128 |
| 161 | 1350 | 2853.09 | 627.9 | 483.8 | 178 | 1071 |
| 162 | 1120 | 2738.95 | 603.3 | 483.9 | 176 | 1070 |
| 163 | 893 | 2679.15 | 587.5 | 484.0 | 174 | 1069 |
| 164 | 670 | 2619.16 | 573.1 | 484.0 | 172 | 1068 |
| 165 | 449 | 2614.81 | 639.1 | 484.1 | 170 | 1011 |
| 166 | 447 | 2496.59 | 570.9 | 484.2 | 168 | 1010 |
| 167 | 444 | 2436.59 | 559.7 | 484.2 | 166 | 1009 |
| 168 | 440 | 2376.93 | 552.0 | 484.3 | 164 | 1008 |
| 169 | 434 | 2315.56 | 562.5 | 484.3 | 162 | 1007 |
| 170 | 429 | 2311.77 | 982.8 | 534.1 | 160 | 1006 |
| 171 | 423 | 2250.77 | 1148.6 | 534.4 | 159 | 1005 |
| 172 | 631 | 2192.98 | 966.2 | 534.8 | 157 | 947 |
| 173 | 836 | 2189.99 | 986.3 | 535.1 | 155 | 947 |
| 174 | 607 | 2131.49 | 1720.3 | 535.6 | 153 | 946 |
| 175 | 382 | 2128.62 | 2063.8 | 536.5 | 151 | 945 |
| 176 | 376 | 2125.33 | 2204.2 | 593.0 | 150 | 944 |
| 177 | 584 | 2066.41 | 2881.5 | 594.4 | 148 | 943 |
| 178 | 360 | 2063.68 | 2959.5 | 596.0 | 146 | 886 |
| 179 | 568 | 2002.98 | 3538.5 | 653.8 | 145 | 885 |
| 180 | 773 | 2000.39 | 4151.4 | 712.1 | 143 | 885 |
| 181 | 546 | 1998.17 | 4752.3 | 715.1 | 141 | 884 |

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|---|---|---|---|---|---|---|
| 182 | 323 | 1938.21 | 5856.3 | 775.0 | 140 | 883 |
| 183 | 317 | 1935.37 | 6909.7 | 836.3 | 138 | 882 |
| 184 | 312 | 1876.44 | 7814.1 | 899.0 | 137 | 882 |
| 185 | 521 | 1873.75 | 8619.8 | 1021.3 | 135 | 825 |
| 186 | 726 | 1871.41 | 9249.1 | 1143.7 | 134 | 824 |
| 187 | 501 | 1813.59 | 9718.5 | 1269.8 | 132 | 824 |
| 188 | 279 | 1811.39 | 10184.3 | 1394.7 | 131 | 823 |
| 189 | 275 | 1808.82 | 10469.8 | 1518.4 | 129 | 822 |
| 190 | 483 | 1749.56 | 10175.6 | 1706.3 | 128 | 822 |
| 191 | 263 | 1747.48 | 9966.9 | 1834.4 | 126 | 821 |
| 192 | 259 | 1688.53 | 9608.0 | 1961.3 | 125 | 820 |
| 193 | 254 | 1686.26 | 9138.3 | 2090.8 | 124 | 764 |
| 194 | 251 | 1683.98 | 8878.3 | 2216.6 | 122 | 764 |
| 195 | 247 | 1624.37 | 9688.4 | 2401.3 | 121 | 763 |
| 196 | 243 | 1622.24 | 8788.1 | 2585.4 | 120 | 763 |
| 197 | 239 | 1620.09 | 8262.5 | 2769.4 | 119 | 762 |
| 198 | 236 | 1560.86 | 7933.9 | 3006.4 | 118 | 761 |
| 199 | 232 | 1558.87 | 7526.6 | 3073.7 | 116 | 761 |
| 200 | 228 | 1556.88 | 6999.4 | 3196.4 | 115 | 760 |
| 201 | 225 | 1497.07 | 6525.1 | 3318.2 | 114 | 704 |
| 202 | 222 | 1495.21 | 6120.9 | 3382.3 | 112 | 704 |
| 203 | 218 | 1493.35 | 5856.0 | 3501.5 | 111 | 703 |
| 204 | 215 | 1433.90 | 5383.7 | 3507.6 | 110 | 703 |
| 205 | 212 | 1432.18 | 4985.2 | 3624.9 | 109 | 702 |
| 206 | 209 | 1430.45 | 4597.0 | 3628.5 | 108 | 702 |
| 207 | 206 | 1376.57 | 4185.1 | 3631.0 | 106 | 701 |
| 208 | 203 | 1374.97 | 4002.2 | 3632.3 | 105 | 701 |
| 209 | 200 | 1373.37 | 3839.0 | 3633.1 | 104 | 700 |
| 210 | 197 | 1315.55 | 3673.1 | 3633.5 | 102 | 645 |
| 211 | 194 | 1314.08 | 3535.0 | 3633.4 | 101 | 644 |
| 212 | 192 | 1312.60 | 4370.1 | 3634.2 | 100 | 644 |
| 213 | 189 | 1255.11 | 4736.1 | 3692.9 | 99 | 644 |
| 214 | 186 | 1253.76 | 5183.8 | 3696.2 | 98 | 643 |
| 215 | 184 | 1252.40 | 6110.1 | 3701.4 | 96 | 643 |
| 216 | 181 | 1251.04 | 6736.0 | 3821.6 | 95 | 642 |
| 217 | 179 | 1192.24 | 7372.9 | 3943.9 | 94 | 642 |
| 218 | 176 | 1191.00 | 7360.1 | 4011.2 | 93 | 641 |
| 219 | 174 | 1189.76 | 7403.9 | 4021.9 | 92 | 586 |
| 220 | 171 | 1131.26 | 7662.9 | 4260.7 | 91 | 586 |
| 221 | 169 | 1130.13 | 8736.3 | 4559.5 | 90 | 585 |
| 222 | 167 | 1129.00 | 8831.9 | 4863.0 | 89 | 585 |
| 223 | 164 | 1127.87 | 9172.3 | 5171.3 | 88 | 585 |
| 224 | 162 | 1070.44 | 9440.3 | 5485.9 | 87 | 584 |
| 225 | 160 | 1069.43 | 9473.8 | 5807.2 | 86 | 584 |
| 226 | 158 | 1068.41 | 9468.7 | 6135.8 | 86 | 584 |
| 227 | 156 | 1067.38 | 9376.3 | 6151.0 | 85 | 583 |
| 228 | 154 | 1010.29 | 8800.4 | 6553.8 | 84 | 583 |
| 229 | 152 | 1009.37 | 8214.5 | 6965.8 | 83 | 582 |
| 230 | 150 | 1008.44 | 7633.5 | 7387.4 | 82 | 528 |
| 231 | 148 | 1007.52 | 7067.1 | 7528.4 | 81 | 527 |
| 232 | 146 | 1006.59 | 6519.5 | 7524.5 | 80 | 527 |
| 233 | 144 | 1005.66 | 6435.3 | 7098.4 | 79 | 527 |
| 234 | 142 | 947.89 | 6359.9 | 6889.6 | 79 | 526 |
| 235 | 140 | 947.07 | 6292.4 | 6817.9 | 78 | 526 |
| 236 | 139 | 946.24 | 6232.1 | 6814.4 | 77 | 526 |
| 237 | 137 | 945.41 | 5736.0 | 6810.5 | 76 | 525 |
| 238 | 135 | 944.57 | 5258.6 | 6804.0 | 75 | 525 |
| 239 | 133 | 943.73 | 4799.7 | 6597.5 | 75 | 525 |
| 240 | 132 | 942.89 | 4359.4 | 6392.1 | 74 | 525 |
| 241 | 130 | 885.55 | 3937.3 | 6189.6 | 73 | 476 |
| 242 | 129 | 884.81 | 3533.0 | 5990.0 | 72 | 475 |
| 243 | 127 | 884.07 | 3587.6 | 5791.8 | 72 | 475 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 244 | 125 | 883.32 | 3648.5 | 5599.4 | 71 | 475 |
| 245 | 124 | 882.58 | 3715.1 | 5409.9 | 70 | 475 |
| 246 | 122 | 881.82 | 3345.6 | 5224.3 | 70 | 474 |
| 247 | 121 | 881.07 | 2990.9 | 5157.2 | 69 | 474 |
| 248 | 119 | 824.49 | 2650.0 | 4973.2 | 68 | 474 |
| 249 | 118 | 823.84 | 2762.4 | 4790.0 | 68 | 474 |
| 250 | 117 | 823.18 | 2876.9 | 4609.8 | 67 | 473 |
| 251 | 115 | 822.52 | 2553.3 | 4546.0 | 66 | 473 |
| 252 | 114 | 821.86 | 2241.1 | 4368.0 | 66 | 473 |
| 253 | 113 | 821.19 | 1939.4 | 4247.0 | 65 | 419 |
| 254 | 111 | 820.53 | 2086.7 | 4069.5 | 64 | 419 |
| 255 | 110 | 764.35 | 2233.8 | 4006.7 | 64 | 419 |
| 256 | 109 | 763.77 | 2380.2 | 3944.7 | 63 | 418 |
| 257 | 107 | 763.19 | 2087.4 | 3939.8 | 63 | 418 |
| 258 | 106 | 762.61 | 1803.4 | 3821.4 | 62 | 418 |
| 259 | 105 | 762.03 | 1527.7 | 3815.3 | 61 | 418 |
| 260 | 104 | 761.45 | 1478.5 | 3696.2 | 61 | 418 |
| 261 | 103 | 760.86 | 1650.7 | 3689.8 | 60 | 417 |
| 262 | 101 | 760.28 | 1820.8 | 3627.9 | 60 | 417 |
| 263 | 100 | 704.37 | 1988.5 | 3622.7 | 59 | 417 |
| 264 | 99 | 703.87 | 1717.2 | 3618.0 | 59 | 417 |
| 265 | 98 | 703.36 | 1453.2 | 3500.6 | 58 | 417 |
| 266 | 97 | 702.86 | 1195.8 | 3494.9 | 58 | 416 |
| 267 | 96 | 702.35 | 1162.6 | 3376.9 | 57 | 363 |
| 268 | 95 | 701.84 | 1348.8 | 3370.9 | 56 | 363 |
| 269 | 94 | 701.33 | 1531.9 | 3309.9 | 56 | 362 |
| 270 | 93 | 700.81 | 1276.8 | 3305.2 | 55 | 362 |
| 271 | 92 | 700.30 | 1027.8 | 3188.0 | 55 | 362 |
| 272 | 91 | 644.79 | 1219.1 | 3182.4 | 54 | 362 |
| 273 | 90 | 644.36 | 1407.1 | 3066.1 | 54 | 362 |
| 274 | 89 | 643.92 | 1157.7 | 3062.0 | 53 | 362 |
| 275 | 88 | 643.49 | 913.9 | 3001.7 | 53 | 362 |
| 276 | 87 | 643.05 | 1109.1 | 2996.6 | 53 | 361 |
| 277 | 86 | 642.61 | 1300.8 | 2880.0 | 52 | 361 |
| 278 | 85 | 642.17 | 1055.9 | 2876.3 | 52 | 361 |
| 279 | 84 | 641.73 | 816.3 | 2760.4 | 51 | 361 |
| 280 | 83 | 641.29 | 1014.5 | 2699.5 | 51 | 361 |
| 281 | 82 | 585.95 | 1209.0 | 2639.3 | 50 | 361 |
| 282 | 81 | 585.58 | 967.9 | 2578.8 | 50 | 360 |
| 283 | 81 | 585.21 | 731.8 | 2518.2 | 49 | 312 |
| 284 | 80 | 584.84 | 932.2 | 2514.4 | 49 | 312 |
| 285 | 79 | 584.47 | 1129.1 | 2455.0 | 49 | 311 |
| 286 | 78 | 584.10 | 891.1 | 2396.2 | 48 | 311 |
| 287 | 77 | 583.73 | 657.9 | 2335.3 | 48 | 311 |
| 288 | 76 | 583.36 | 644.7 | 2332.0 | 47 | 311 |
| 289 | 76 | 582.98 | 847.3 | 2270.9 | 47 | 311 |
| 290 | 75 | 582.61 | 1046.3 | 2213.3 | 46 | 311 |
| 291 | 74 | 527.67 | 811.4 | 2211.1 | 46 | 311 |
| 292 | 73 | 527.36 | 581.2 | 2208.5 | 46 | 311 |
| 293 | 73 | 527.05 | 570.2 | 2149.0 | 45 | 311 |
| 294 | 72 | 526.74 | 774.4 | 2146.1 | 45 | 310 |
| 295 | 71 | 526.44 | 975.0 | 2087.3 | 45 | 310 |
| 296 | 71 | 526.12 | 742.8 | 2085.3 | 44 | 310 |
| 297 | 70 | 525.81 | 515.0 | 2082.9 | 44 | 310 |
| 298 | 69 | 525.50 | 505.7 | 2021.9 | 43 | 310 |
| 299 | 68 | 525.19 | 711.1 | 2019.2 | 43 | 310 |
| 300 | 68 | 524.88 | 913.0 | 2016.9 | 43 | 310 |
| 301 | 67 | 524.57 | 683.1 | 1957.0 | 42 | 260 |
| 302 | 66 | 475.74 | 457.3 | 1954.8 | 42 | 260 |
| 303 | 66 | 475.49 | 449.5 | 1952.3 | 42 | 260 |
| 304 | 65 | 475.24 | 655.8 | 1893.0 | 41 | 260 |
| 305 | 65 | 474.99 | 858.7 | 1891.0 | 41 | 260 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 306 | 64 | 474.73 | 630.7 | 1889.2 | 41 | 260 |
| 307 | 63 | 474.48 | 406.8 | 1887.1 | 40 | 260 |
| 308 | 63 | 474.23 | 400.1 | 1828.2 | 40 | 260 |
| 309 | 62 | 473.97 | 607.1 | 1825.9 | 40 | 260 |
| 310 | 61 | 473.72 | 810.8 | 1766.6 | 39 | 260 |
| 311 | 61 | 473.46 | 584.5 | 1765.1 | 39 | 259 |
| 312 | 60 | 473.21 | 362.1 | 1763.2 | 39 | 259 |
| 313 | 60 | 472.95 | 356.4 | 1760.9 | 38 | 259 |
| 314 | 59 | 418.95 | 350.9 | 1701.7 | 38 | 259 |
| 315 | 59 | 418.75 | 345.4 | 1699.6 | 38 | 259 |
| 316 | 58 | 418.55 | 340.1 | 1639.6 | 38 | 259 |
| 317 | 58 | 418.35 | 334.9 | 1637.6 | 37 | 259 |
| 318 | 57 | 418.15 | 329.8 | 1635.6 | 37 | 259 |
| 319 | 57 | 417.95 | 324.8 | 1576.0 | 37 | 259 |
| 320 | 56 | 417.75 | 320.0 | 1574.1 | 36 | 259 |
| 321 | 56 | 417.55 | 315.2 | 1572.3 | 36 | 259 |
| 322 | 55 | 417.34 | 310.5 | 1512.0 | 36 | 259 |
| 323 | 55 | 417.14 | 305.9 | 1510.3 | 36 | 208 |
| 324 | 54 | 416.94 | 301.4 | 1508.6 | 35 | 208 |
| 325 | 54 | 416.73 | 297.0 | 1506.9 | 35 | 208 |
| 326 | 53 | 416.52 | 292.7 | 1447.0 | 35 | 208 |
| 327 | 53 | 416.32 | 288.5 | 1445.4 | 34 | 208 |
| 328 | 52 | 362.70 | 284.3 | 1443.8 | 34 | 208 |
| 329 | 52 | 362.55 | 280.2 | 1389.5 | 34 | 208 |
| 330 | 51 | 362.39 | 276.2 | 1388.0 | 34 | 208 |
| 331 | 51 | 362.24 | 272.3 | 1386.5 | 33 | 208 |
| 332 | 50 | 362.08 | 268.5 | 1328.2 | 33 | 208 |
| 333 | 50 | 361.92 | 264.7 | 1326.9 | 33 | 208 |
| 334 | 49 | 361.77 | 261.0 | 1325.5 | 33 | 208 |
| 335 | 49 | 361.61 | 257.4 | 1324.1 | 32 | 208 |
| 336 | 49 | 361.45 | 253.8 | 1266.2 | 32 | 208 |
| 337 | 48 | 361.29 | 250.3 | 1264.9 | 32 | 208 |
| 338 | 48 | 361.14 | 246.9 | 1263.7 | 32 | 208 |
| 339 | 47 | 360.98 | 243.5 | 1204.4 | 31 | 208 |
| 340 | 47 | 360.82 | 240.2 | 1203.2 | 31 | 207 |
| 341 | 47 | 360.66 | 236.9 | 1202.1 | 31 | 207 |
| 342 | 46 | 360.51 | 233.7 | 1200.9 | 31 | 207 |
| 343 | 46 | 311.77 | 230.6 | 1142.0 | 31 | 207 |
| 344 | 45 | 311.66 | 227.5 | 1140.9 | 30 | 207 |
| 345 | 45 | 311.54 | 224.5 | 1139.9 | 30 | 207 |
| 346 | 45 | 311.43 | 221.5 | 1138.8 | 30 | 207 |
| 347 | 44 | 311.31 | 218.6 | 1080.9 | 30 | 207 |
| 348 | 44 | 311.20 | 215.7 | 1080.0 | 29 | 207 |
| 349 | 44 | 311.08 | 212.9 | 1079.0 | 29 | 207 |
| 350 | 43 | 310.97 | 210.1 | 1078.1 | 29 | 207 |
| 351 | 43 | 310.85 | 207.4 | 1020.5 | 29 | 207 |
| 352 | 43 | 310.73 | 204.7 | 1019.6 | 29 | 207 |
| 353 | 42 | 310.62 | 202.0 | 1018.8 | 28 | 207 |
| 354 | 42 | 310.50 | 199.4 | 1017.9 | 28 | 207 |
| 355 | 41 | 310.38 | 196.9 | 1017.0 | 28 | 207 |
| 356 | 41 | 310.27 | 194.4 | 1016.2 | 28 | 207 |
| 357 | 41 | 310.15 | 191.9 | 1015.3 | 28 | 207 |
| 358 | 40 | 310.03 | 189.5 | 957.1 | 27 | 207 |
| 359 | 40 | 309.92 | 187.1 | 956.3 | 27 | 206 |
| 360 | 40 | 309.80 | 184.8 | 955.5 | 27 | 206 |
| 361 | 40 | 309.68 | 182.5 | 954.7 | 27 | 206 |
| 362 | 39 | 260.19 | 180.2 | 954.0 | 27 | 206 |
| 363 | 39 | 260.11 | 178.0 | 953.2 | 26 | 206 |
| 364 | 39 | 260.03 | 175.8 | 952.4 | 26 | 206 |
| 365 | 38 | 259.95 | 173.6 | 894.6 | 26 | 206 |
| 366 | 38 | 259.87 | 171.5 | 893.9 | 26 | 206 |
| 367 | 38 | 259.79 | 169.4 | 893.2 | 26 | 206 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 368 | 37 | 259.71 | 167.3 | 892.5 | 26 | 206 |
| 369 | 37 | 259.63 | 165.3 | 891.8 | 25 | 155 |
| 370 | 37 | 259.55 | 163.3 | 891.1 | 25 | 155 |
| 371 | 37 | 259.47 | 161.3 | 890.4 | 25 | 155 |
| 372 | 36 | 259.39 | 159.4 | 833.3 | 25 | 155 |
| 373 | 36 | 259.31 | 157.5 | 832.6 | 25 | 155 |
| 374 | 36 | 259.22 | 155.6 | 832.0 | 25 | 155 |
| 375 | 35 | 259.14 | 153.8 | 831.4 | 24 | 155 |
| 376 | 35 | 259.06 | 152.0 | 830.8 | 24 | 155 |
| 377 | 35 | 258.98 | 150.2 | 830.2 | 24 | 155 |
| 378 | 35 | 258.90 | 148.4 | 829.5 | 24 | 155 |
| 379 | 34 | 258.82 | 146.7 | 828.9 | 24 | 155 |
| 380 | 34 | 258.73 | 145.0 | 772.2 | 24 | 155 |
| 381 | 34 | 258.65 | 143.3 | 771.7 | 23 | 155 |
| 382 | 34 | 258.57 | 141.7 | 771.1 | 23 | 155 |
| 383 | 33 | 208.31 | 140.1 | 770.6 | 23 | 155 |
| 384 | 33 | 208.26 | 138.4 | 770.1 | 23 | 155 |
| 385 | 33 | 208.21 | 136.9 | 769.5 | 23 | 155 |
| 386 | 33 | 208.16 | 135.3 | 769.0 | 23 | 155 |
| 387 | 32 | 208.11 | 133.8 | 768.4 | 23 | 155 |
| 388 | 32 | 208.06 | 132.3 | 767.9 | 22 | 155 |
| 389 | 32 | 208.01 | 130.8 | 711.5 | 22 | 155 |
| 390 | 32 | 207.96 | 129.3 | 711.0 | 22 | 155 |
| 391 | 31 | 207.91 | 127.9 | 710.5 | 22 | 155 |
| 392 | 31 | 207.85 | 126.5 | 710.0 | 22 | 155 |
| 393 | 31 | 207.80 | 125.1 | 709.6 | 22 | 155 |
| 394 | 31 | 207.75 | 123.7 | 709.1 | 22 | 155 |
| 395 | 31 | 207.70 | 122.3 | 708.6 | 21 | 155 |
| 396 | 30 | 207.65 | 121.0 | 708.1 | 21 | 155 |
| 397 | 30 | 207.60 | 119.6 | 707.6 | 21 | 155 |
| 398 | 30 | 207.55 | 118.3 | 651.6 | 21 | 154 |
| 399 | 30 | 207.50 | 117.1 | 651.2 | 21 | 154 |
| 400 | 29 | 207.44 | 115.8 | 650.8 | 21 | 154 |
| 401 | 29 | 207.39 | 114.5 | 650.4 | 21 | 154 |
| 402 | 29 | 207.34 | 113.3 | 650.0 | 20 | 154 |
| 403 | 29 | 207.29 | 112.1 | 649.6 | 20 | 154 |
| 404 | 29 | 207.24 | 110.9 | 649.2 | 20 | 154 |
| 405 | 28 | 207.18 | 109.7 | 648.7 | 20 | 154 |
| 406 | 28 | 207.13 | 108.6 | 648.3 | 20 | 154 |
| 407 | 28 | 207.08 | 107.4 | 592.5 | 20 | 154 |
| 408 | 28 | 207.03 | 106.3 | 592.1 | 20 | 154 |
| 409 | 28 | 206.97 | 105.2 | 591.8 | 20 | 154 |
| 410 | 27 | 206.92 | 104.1 | 591.4 | 19 | 154 |
| 411 | 27 | 206.87 | 103.0 | 591.1 | 19 | 154 |
| 412 | 27 | 206.82 | 101.9 | 590.7 | 19 | 154 |
| 413 | 27 | 206.76 | 100.9 | 590.4 | 19 | 154 |
| 414 | 27 | 206.71 | 99.8 | 590.0 | 19 | 154 |
| 415 | 27 | 206.66 | 98.8 | 589.6 | 19 | 154 |
| 416 | 26 | 206.60 | 97.8 | 589.3 | 19 | 154 |
| 417 | 26 | 206.55 | 96.8 | 588.9 | 19 | 154 |
| 418 | 26 | 206.50 | 95.8 | 533.5 | 19 | 154 |
| 419 | 26 | 206.45 | 94.8 | 533.2 | 18 | 154 |
| 420 | 26 | 206.39 | 93.9 | 532.9 | 18 | 154 |
| 421 | 25 | 206.34 | 92.9 | 532.6 | 18 | 154 |
| 422 | 25 | 206.29 | 92.0 | 532.3 | 18 | 154 |
| 423 | 25 | 206.23 | 91.0 | 532.0 | 18 | 154 |
| 424 | 25 | 206.18 | 90.1 | 531.7 | 18 | 154 |
| 425 | 25 | 206.13 | 89.2 | 531.4 | 18 | 154 |
| 426 | 25 | 206.07 | 88.4 | 531.1 | 18 | 154 |
| 427 | 24 | 206.02 | 87.5 | 530.8 | 18 | 154 |
| 428 | 24 | 155.34 | 86.6 | 530.5 | 17 | 103 |
| 429 | 24 | 155.31 | 85.8 | 530.2 | 17 | 103 |

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|---|---|---|---|---|---|---|
| 430 | 24 | 155.29 | 84.9 | 480.8 | 17 | 103 |
| 431 | 24 | 155.26 | 84.1 | 480.6 | 17 | 103 |
| 432 | 24 | 155.23 | 83.3 | 480.3 | 17 | 103 |
| 433 | 24 | 155.20 | 82.5 | 480.1 | 17 | 103 |
| 434 | 23 | 155.17 | 81.7 | 479.9 | 17 | 103 |
| 435 | 23 | 155.14 | 80.9 | 479.6 | 17 | 103 |
| 436 | 23 | 155.11 | 80.1 | 479.4 | 17 | 103 |
| 437 | 23 | 155.09 | 79.3 | 479.1 | 17 | 103 |
| 438 | 23 | 155.06 | 78.6 | 478.9 | 16 | 103 |
| 439 | 23 | 155.03 | 77.8 | 478.7 | 16 | 103 |
| 440 | 22 | 155.00 | 77.1 | 478.4 | 16 | 103 |
| 441 | 22 | 154.97 | 76.3 | 478.2 | 16 | 103 |
| 442 | 22 | 154.94 | 75.6 | 423.6 | 16 | 103 |
| 443 | 22 | 154.91 | 74.9 | 423.5 | 16 | 103 |
| 444 | 22 | 154.88 | 74.2 | 423.3 | 16 | 103 |
| 445 | 22 | 154.85 | 73.5 | 423.1 | 16 | 102 |
| 446 | 22 | 154.82 | 72.8 | 422.9 | 16 | 102 |
| 447 | 22 | 154.79 | 72.1 | 422.7 | 16 | 102 |
| 448 | 21 | 154.76 | 71.5 | 422.5 | 16 | 102 |
| 449 | 21 | 154.73 | 70.8 | 422.3 | 15 | 102 |
| 450 | 21 | 154.70 | 70.1 | 422.1 | 15 | 102 |
| 451 | 21 | 154.67 | 69.5 | 421.9 | 15 | 102 |
| 452 | 21 | 154.65 | 68.8 | 421.7 | 15 | 102 |
| 453 | 21 | 154.62 | 68.2 | 421.5 | 15 | 102 |
| 454 | 21 | 154.59 | 67.6 | 421.3 | 15 | 102 |
| 455 | 20 | 154.56 | 67.0 | 421.2 | 15 | 102 |
| 456 | 20 | 154.53 | 66.4 | 421.0 | 15 | 102 |
| 457 | 20 | 154.50 | 65.8 | 366.8 | 15 | 102 |
| 458 | 20 | 154.47 | 65.2 | 366.7 | 15 | 102 |
| 459 | 20 | 154.44 | 64.6 | 366.5 | 15 | 102 |
| 460 | 20 | 154.41 | 64.0 | 366.4 | 15 | 102 |
| 461 | 20 | 154.38 | 63.4 | 366.2 | 14 | 102 |
| 462 | 20 | 154.35 | 62.9 | 366.1 | 14 | 102 |
| 463 | 19 | 154.32 | 62.3 | 365.9 | 14 | 102 |
| 464 | 19 | 154.29 | 61.7 | 365.8 | 14 | 102 |
| 465 | 19 | 154.26 | 61.2 | 365.6 | 14 | 102 |
| 466 | 19 | 154.23 | 60.7 | 365.5 | 14 | 102 |
| 467 | 19 | 154.20 | 60.1 | 365.3 | 14 | 102 |
| 468 | 19 | 154.17 | 59.6 | 365.2 | 14 | 102 |
| 469 | 19 | 154.14 | 59.1 | 365.0 | 14 | 102 |
| 470 | 19 | 154.11 | 58.5 | 364.9 | 14 | 102 |
| 471 | 19 | 154.08 | 58.0 | 364.7 | 14 | 102 |
| 472 | 18 | 154.05 | 57.5 | 364.6 | 14 | 102 |
| 473 | 18 | 154.02 | 57.0 | 315.2 | 14 | 102 |
| 474 | 18 | 153.99 | 56.5 | 315.1 | 13 | 102 |
| 475 | 18 | 204.09 | 56.1 | 315.0 | 13 | 102 |
| 476 | 18 | 204.03 | 55.6 | 314.9 | 13 | 102 |
| 477 | 18 | 203.98 | 55.1 | 314.8 | 13 | 102 |
| 478 | 18 | 203.92 | 54.6 | 314.7 | 13 | 102 |
| 479 | 18 | 203.86 | 54.2 | 314.6 | 13 | 102 |
| 480 | 18 | 203.81 | 53.7 | 314.5 | 13 | 102 |
| 481 | 18 | 203.75 | 53.3 | 314.4 | 13 | 102 |
| 482 | 17 | 203.70 | 52.9 | 314.2 | 13 | 102 |
| 483 | 17 | 203.64 | 52.5 | 314.1 | 13 | 102 |
| 484 | 17 | 203.58 | 52.1 | 314.0 | 13 | 102 |
| 485 | 17 | 203.53 | 51.7 | 313.9 | 13 | 102 |
| 486 | 17 | 203.47 | 51.3 | 313.8 | 13 | 102 |
| 487 | 17 | 203.41 | 50.9 | 313.7 | 13 | 102 |
| 488 | 17 | 203.36 | 50.6 | 313.6 | 13 | 102 |
| 489 | 17 | 203.30 | 50.2 | 313.5 | 12 | 102 |
| 490 | 17 | 203.24 | 49.8 | 313.4 | 12 | 102 |
| 491 | 17 | 203.18 | 49.5 | 313.2 | 12 | 102 |

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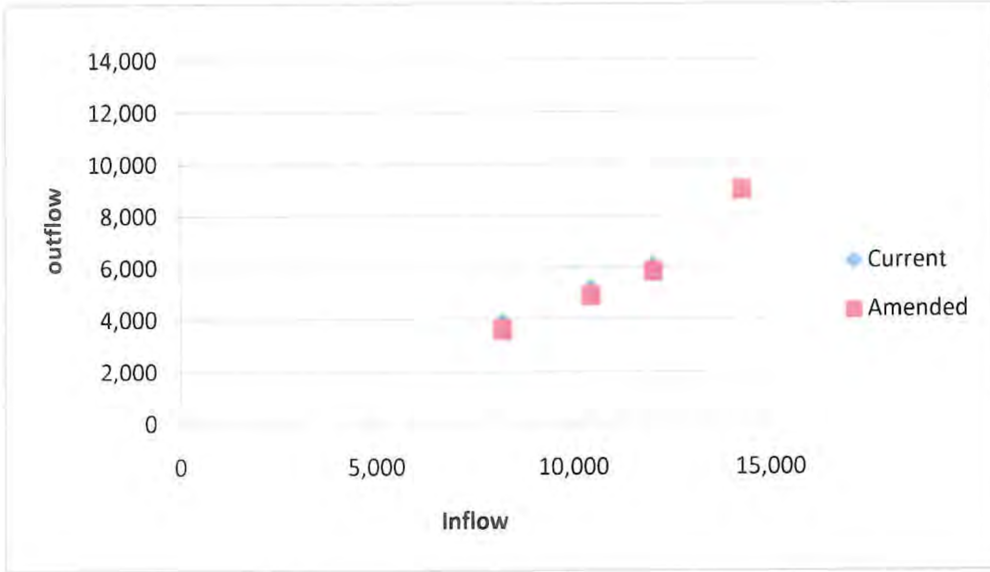
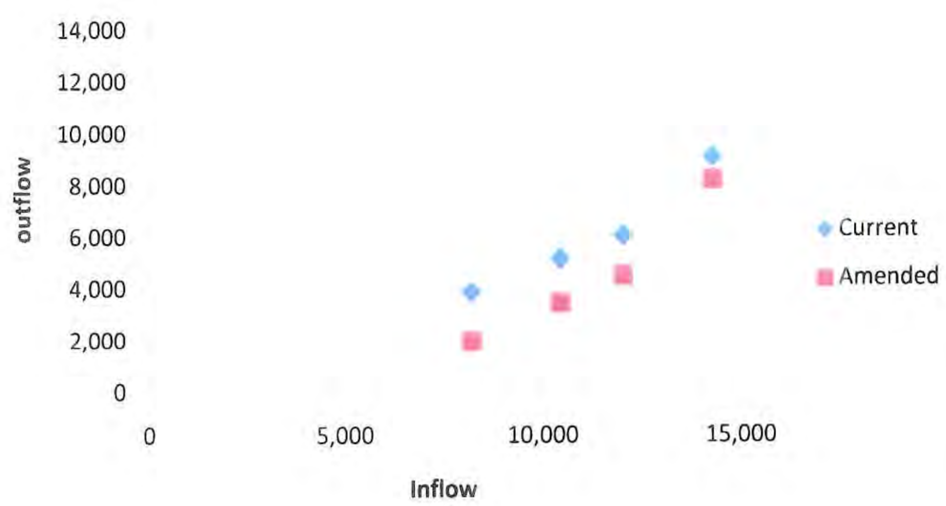
|---|---|---|---|---|---|---|
| 492 | 16 | 203.13 | 49.1 | 263.1 | 12 | 102 |
| 493 | 16 | 203.07 | 48.7 | 263.1 | 12 | 102 |
| 494 | 16 | 203.01 | 48.4 | 263.0 | 12 | 102 |
| 495 | 16 | 202.96 | 48.0 | 262.9 | 12 | 102 |
| 496 | 16 | 202.90 | 47.7 | 262.8 | 12 | 102 |
| 497 | 16 | 202.84 | 47.4 | 262.8 | 12 | 102 |

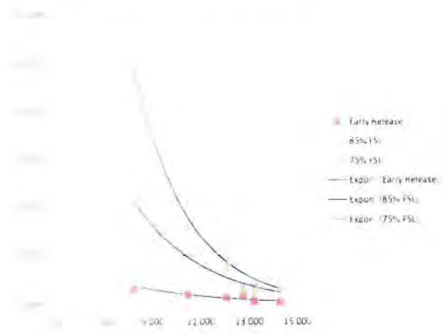
| ARI | Inflow | Current | Amended |
|---|---|---|---|
| 200 | 8,214 | 3,861 | 3,613 |
| 500 | 10,455 | 5,125 | 4,915 |
| 1000 | 12,031 | 6,049 | 5,854 |
| 5000 | 14,278 | 9,083 | 8,994 |



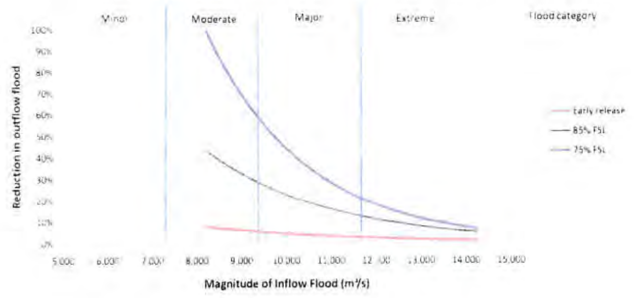
| ARI | Inflow | Current | Amended |
|---|---|---|---|
| 200 | 8,214 | 3,861 | 1,971 |
| 500 | 10,455 | 5,125 | 3,446 |
| 1000 | 12,031 | 6,049 | 4,504 |
| 5000 | 14,278 | 9,083 | 8,217 |



| [illegible] | [illegible] | Early Release | 85% FSL | 75% FSL |
|---|---|---|---|---|
| [illegible] | 5813 | 6.40% | 31.60% | 94.83% |
| [illegible] | 5987 | 4.10% | 32.70% | 42.40% |
| [illegible] | 6020 | 3.20% | 16.30% | 25.06% |
| [illegible] | 7227 | 3.80% | 6.60% | 8.19% |
| [illegible] | 8196 | 1.30% | 4.50% | 7.09% |
| [illegible] | 9005 | 1.00% | 5.90% | 9.36% |



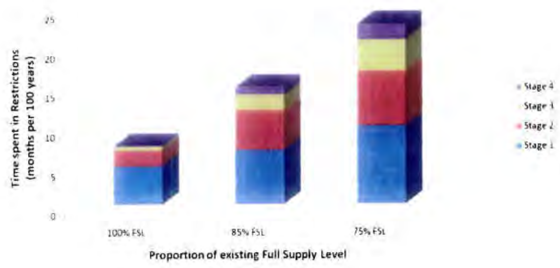

Indicative Reduction in Outflow For Different Gate Operating Strategies




junk data!!

| FSL | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
|---|---|---|---|---|
| 100% FSL | 5 | 2 | 0.5 | 0.01 |
| 85% FSL | 7 | 5 | 2 | 1 |
| 75% FSL | 10 | 7 | 4 | 2 |

Increase in Restrictions for Different Storage Levels (JUNK DATA!)



-------------------------------Safe Stamp-----------------------------------
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**From:** Barton Maher [redacted]
**Sent:** Thursday, 3 February 2011 5:19 PM
**To:** Rory Nathan [redacted]
**Cc:** PAT NIXON [redacted]
**Subject:** Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V1.docx
**Attachments:** Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V1.docx

Hi Gents,

Latest draft - I was asked to include differing options for the CEO. I am working on the plots as suggested but I need to get home to see the family and will send them through later tonight.

Regards,

Barton Maher
Principal Dams & Weirs Planning
QLD Bulk Water Supply Authority (trading as Seqwater)

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# Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges

## Introduction

Seqwater staff have been asked to investigate the impact of reducing the storage level of Wivenhoe Dam on the downstream discharges for major flood events. This memo details the investigations carried out and provides a preliminary assessment of the reduction in flood flows that could be achieved by reducing the Wivenhoe Dam storage level to 5%, 10%, 25% and 50% of the normal water supply volume.

The comments in this report are provided to give an indication of the impacts of a reduced storage level of Wivenhoe Dam on discharges during major flood events. It must be noted that it is very preliminary, as to get accurate results a full investigation and analysis of the whole river system utilising multiple flood events and models would be required. This review was requested to provide an order of magnitude assessment of impacts and the results should not be utilised beyond that purpose.

## Definitions

For the purposes of this report the following definitions have been adopted as per the Wivenhoe – Somerset Flood manual:

| | |
|---|---|
| Fresh | This causes only very low-level bridges to be submerged. |
| Minor Flooding | This causes inconvenience such as closing minor roads and the submergence of low-level bridges. Some urban properties are affected. |
| Moderate Flooding | This causes inundation of low-lying areas and may require the evacuation of some houses and/or business premises. Traffic bridges may be closed. |
| Major Flooding | This causes flooding of appreciable urban areas. Properties may become isolated. Major disruption occurs to traffic. Evacuation of many houses and business premises may be required. |
| Extreme Flooding | This causes flooding well in excess of floods in living memory and general evacuation of whole areas are likely to be required. |
| "$m^3/s$" | Means an instantaneous flow rate expressed as cubic meters of water per second. |
| "AEP" | means annual exceedance probability, the probability of a specified event being exceeded in any year; |
| "AHD" | means Australian Height Datum; |
| "EL" | means elevation in metres from Australian Height Datum; |
| "ML" | Means a million litres of water |

## Analysis Methodology

The analysis was undertaken using a spreadsheet developed to model the gate opening sequence as provided in the Flood Manual during a loss of communications situation. During a loss of communications between the dam operators and the Flood Control Centre, operators would use predefined gate openings based solely on the Lake Level information available to them at the dams. Utilising this spreadsheet takes out the role of weather predictions with openings based on dam levels and allows a consistent methodology to compare various flood events.

A history of floods in the Brisbane River is presented in Table 1.

Table 1 – Summary of Significant Flood Events in the Brisbane River

| Event | Somerset Dam | | | Wivenhoe Dam | | |
|---|---|---|---|---|---|---|
| | Peak Elevation | Inflow | Outflow | Peak Elevation | Total Flood Volume | Outflow Flood Volume |
| | m AHD | ML | ML | m AHD | ML | ML |
| Jan 1974# | 106.57 | 620,000 | 450,000 | na | 1,410,000 | 1,410,000 |
| Jun 1983 | 101.58 | 260,000 | 280,000 | | 1,080,000 | 470,000 |
| Mar 1989 | 102.59 | 370,000 | 380,000 | 69.78 | 690,000 | 660,000 |
| Apr 1989 | 102.69 | 340,000 | 350,000 | 71.45 | 870,000 | 820,000 |
| Feb 1999 | 102.96 | 450,000 | 280,000 | 70.45 | 1,220,000 | 900,000 |
| May 2009 | 99.62 | 110,000 | 110,000 | 62.19 | 235,000 | 0 |
| Mar 2010 | 99.41 | 210,000 | 200,000 | 66.43 | 390,000 | 0 |
| Oct 2010 | 101.37 | 250,000 | 270,000 | 69.61 | 630,000 | 630,000 |
| Mid Dec 2010 | 100.42 | 150,000 | 140,000 | 67.50 | 360,000 | 330,000 |
| Late Dec 2010 | 99.98 | 120,000 | 130,000 | 69.35 | 500,000 | 460,000 |
| Jan 2011 | 105.11 | 825,000 | 820,000 | 74.97 | 2,650,000 | 2,650,000 |

# No Wivenhoe Dam   * Upper Brisbane R only

The assessment has investigated the impacts of the lowered storage level on the three largest events – the 1974 flood, the 1999 flood and the 2011 flood.

## Analysis Results

A summary of the results of the modelling is presented in Table 2.

Table 2 - Results of the Analysis

| | | Wivenhoe Dam | | Somerset Dam | | Lockyer Creek | Lowood | Bremer River | Moggill | Reduction at Moggill |
|---|---|---|---|---|---|---|---|---|---|---|
| Storage Level at Start | % of FS Volume | Peak Inflow ($m^3/s$) | Peak Outflow ($m^3/s$) | Peak Inflow ($m^3/s$) | Peak Outflow ($m^3/s$) | Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) | Peak Flow[1] ($m^3/s$) | % |
| 1974 Flood | | | | | | | | | | |
| 67 | 100 | 8,482 | 3,275 | 5,019 | 3,548 | 3,260 | 5,110 | 4,241 | 7,948 | |
| 66.5 | 95 | 8,482 | 3,153 | 5,019 | 3,480 | 3,260 | 4,799 | 4,241 | 7,910 | 0.5% |
| 65.8 | 90 | 8,482 | 2,974 | 5,019 | 3,419 | 3,260 | 4,524 | 4,241 | 7,897 | 0.6% |
| 64 | 75 | 8,482 | 2,618 | 5,019 | 3,302 | 3,260 | 4,117 | 4,241 | 7,683 | 3.3% |
| 60 | 50 | 8,482 | 2,067 | 5,019 | 3,040 | 3,260 | 3,342 | 4,241 | 7,423 | 6.6% |
| 1999 Flood | | | | | | | | | | |
| 67 | 100 | 11,641 | 2,312 | 7,540 | 3,837 | 663 | 2,556 | 308 | 2,593 | |
| 66.5 | 95 | 11,641 | 2,132 | 7,540 | 3,662 | 663 | 2,434 | 308 | 2,479 | 4.4% |
| 65.8 | 90 | 11,641 | 2,003 | 7,540 | 3,470 | 663 | 2,284 | 308 | 2,319 | 10.6% |
| 64 | 75 | 11,641 | 1,687 | 7,540 | 3,214 | 663 | 1,906 | 308 | 1,936 | 25.3% |
| 60 | 50 | 11,641 | 1,007 | 7,540 | 2,798 | 663 | 1,186 | 308 | 1,214 | 53.2% |
| 2011 Flood | | | | | | | | | | |
| 67 | 100 | 12,045 | 7,468 | 3,824 | 2,814 | 3,040 | 10,495 | 2,793 | 13,104 | |
| 66.5 | 95 | 12,045 | 7,453 | 3,824 | 2,798 | 3,040 | 10,445 | 2,793 | 13,004 | 0.8% |
| 65.8 | 90 | 12,045 | 6,756 | 3,824 | 2,815 | 3,040 | 9,791 | 2,793 | 12,302 | 6.1% |
| 64 | 75 | 12,045 | 5,748 | 3,824 | 2,680 | 3,040 | 8,788 | 2,793 | 11,110 | 15.2% |
| 60 | 50 | 12,045 | 4,209 | 3,824 | 1,595 | 3,040 | 7,249 | 2,793 | 9,582 | 26.9% |

The preliminary work done by Seqwater before Christmas 2010 showed that for the October 2010 event, reducing the level of Wivenhoe by small amounts would have had minimal impact on the flood releases. From the

Table 2 the following comments are applicable:

[1] Note the flows quoted for Moggill are based on the addition of outflows from the dam and the measured flows at Lockyer Creek and the Bremer River. They do not have any allowance for routing of the flows through the river system and the subsequent reduction in flows that were observed during the flood events.

- Similarly to work completed previously, reducing levels by small amounts prior to the January 2011 Event (if it was feasible) would have had little impact on the peak level in Wivenhoe Dam as shown in the Table 2. The reason for this is that the total event inflow volume of 2,600,000 ML is well in excess of the useable flood storage combined with the available water supply storages shown in the table. Large reductions to the storage level of the dam (25 to 50%) would be required if significant impacts on flooding are to be achieved.
- For the 1999 flood, where most of the flooding occurred upstream of the Wivenhoe Dam, there is a dramatic reduction in the peak outflow if the storage is lowered. However, this is of little benefit as the flood would not have resulted in damaging flows downstream of the dam even if the storage was full.
- The 1974 flood simulation is based on the recorded flows being routed through the both Somerset and Wivenhoe. The presence of Wivenhoe would have reduced the flooding damage in Brisbane during the 1974 event, however there is very little change to the flood mitigation benefits by varying the storage level in Wivenhoe. As most of the flood flows in 1974 were downstream of the dam and the flood in the Brisbane River was relatively small compared to the downstream flooding the event is insensitive to the starting level in Wivenhoe.
- It should be noted that the increasing early releases from Wivenhoe was investigated during the Brisbane Valley Flood Damages Study as part of a review of the operation of the dam. Releasing more water earlier on from Wivenhoe dam was shown to lessen the flood mitigation benefits compared with the existing flood manual release strategies.

The key point being that each flood event is unique and presents varying opportunities to mitigate flows through Brisbane.

## Downstream Water Level Changes

To evaluate the specific impact on the Lower Brisbane River of these reduced dam outflows from lowering the storage requires the use of a complex hydraulic model. The results of this modelling would still contain a degree of uncertainty as illustrated by the difficulties in estimating the final flood peak in Brisbane during the event. The uncertainty was partly due to the rapid closure of the Wivenhoe gates after the peak inflow of the flood and the attenuation achieved in the downstream river system. It is extremely difficult to model accurately.

Given the timeframe of this report it is not possible to generate any reliable estimate of the changes to the water level at the Port Office Gauge due to tidal influences, the need to interpolate between previously modelled results that vary markedly between differing events, the availability of verified data, and the uncertainty surrounding the timing of peak flows for the differing scenarios.

Table 3 shows a comparison of the peak water level for each of the various starting levels for the 2011 Flood Event. It should be noted that each scenario results in the storage level exceeding EL74 requiring the gates to be opened until the storage rise is stopped.

[illegible]

| | | Wivenhoe | |
|---|---|---|---|
| Starting Level | | Peak Height | Capacity at Peak Height |
| % | m AHD | m AHD | % |
| 100 | 67.0 | 74.98 | 191 |

| | | | |
|---|---|---|---|
| 95 | 66.5 | 74.93 | 190.6 |
| 90 | 65.8 | 74.88 | 189.9 |
| 75 | 64.0 | 74.63 | 186.5 |
| 50 | 60.0 | 74.11 | 179.6 |

Again it should be noted that minor changes to the storage level of Wivenhoe would have negligible impacts on the flooding in Brisbane.

It should be noted that to accurately calculate the impacts of reducing the storage levels of Wivenhoe Dam at the start of a major flood event requires considerable study as rainfall events of different intensity, duration, peak, location and spread will give very different outcomes. In addition, there is the need to do detailed hydraulic analysis of the river system for each scenario to more accurately determine impacts.

## Summary

Due to the large volumes of water associated with major flood events (with an AEP of 1:100 or less) in the Brisbane River, to effectively reduce flood peak discharges significantly (such as for the January 2011 flood) would require the storage level of Wivenhoe Dam to be lowered by at least 25 to 50%.

## Contingency Options

There is the possibility of further flood events in the South East Queensland during the 2010/2011 wet season. To reduce the risk of flooding in Brisbane should a major rainfall event be predicted it has been requested that lowering of the storage level of Wivenhoe Dam be investigated to determine if this is a feasible option to further mitigate flood flows.

The assessment carried out by Seqwater has indicated that to have any significant impact on releases downstream of Wivenhoe Dam during a major flood event it would be necessary to lower the storage level by 25 to 50%.

There are five options considered going forward:

1. Continue with the current approved flood manual strategies
2. Commence drawing down the storage at a safe rate to bring it down to say 75%.
3. Pre-release water from the dam following the prediction of a major rainfall event
4. Change the flood manual strategies to ignore the early strategies designed to minimise disruption to the rural communities.
5. Temporarily reduce the full supply of Wivenhoe Dam and amend the flood releases to commence flood operations from the lowered full supply level.

## Do Nothing Option – Continue with the Current Flood Manual

This option maintains the status quo and continues to utilise the dam as originally designed. This option has the least risks associated with it as the strategies have been implemented and [illegible] over several flood events and the manual was developed by a comprehensive study. The strategies in the flood manual have proved adequate for more frequent flood events.

## Option 1 – Vary the early strategies for the Flood Manual

It has been proposed that increasing the releases from the dam up to 1,600cumecs as soon as practicable after gate operations commence may deliver reduced peak flood levels. This has been investigated to assess the impact of attempting to release more water at the very start of an event.

This option has been assessed using a range of design events from the Wivenhoe Alliance Design hydrology. To model the impacts of increasing releases up to 1,600cumecs as soon as practicable a range of design flood events from the Wivenhoe Alliance were compared using the program FLROUTE. . It was assumed that no attempt would be made to maintain bridge access downstream of the dam other than Mt Crosby Weir Bridge and the Brisbane Valley Highway Bridge.

The results for the model runs are presented in Table 4.

Table 4 - Comparison of Release Strategies

| Flood Event | | | | Existing Rules | | Amended Rules | | |
|---|---|---|---|---|---|---|---|---|
| Duration (hours) | Annual Exceedance Probability | Maximum Inflow ($m^3/s$) | Flood Volume (ML) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Flow Reduction % |
| 36 hours | 1 in 200 | 8,214 | 1,544,119 | 3,861 | 71.43 | 3,613 | 71.27 | 6.4% |
| 36 hours | 1 in 500 | 10,455 | 1,624,119 | 5,125 | 72.22 | 4,915 | 72.09 | 4.1% |
| 36 hours | 1 in 1000 | 12,031 | 1,772,752 | 6,049 | 72.8 | 5,854 | 72.68 | 3.2% |
| 48 hours | 1 in 5000 | 14,278 | 2,562,553 | 9,083 | 74.71 | 8,994 | 74.66 | 1.0% |
| 72 hours | 1 in 5000 | 13,181 | 2,880,602 | 8,204 | 74.16 | 8,101 | 74.10 | 1.3% |
| 96 hours | 1 in 5000 | 11,870 | 2,948,032 | 7,550 | 73.75 | 7,426 | 73.67 | 1.6% |
| 120 hours | 1 in 5000 | 12,727 | 3,005,136 | 7,265 | 73.57 | 6,986 | 73.39 | 3.8% |

It should be noted that predicted flood levels greater than EL 74 require the gates to be opened until the water level stabilises. This is fundamental to the dam's safety. In addition, any reduction in starting level, which does not achieve a peak lower than EL 74, is unlikely to have any impact upon peak release rate.

It should also be noted that that design flows used from the Alliance bear no resemblance to actual recorded flood events. This is demonstrated by the Jan 2011 flood which had dual peak inflows of about 10,000 and 12,000 m3/s with a flood volume of 2,650,000ML, placing it in the 1 in 1,000 to 1 in 5,000 AEP according to Table 4

It can be clearly seen from Table 4 that changes to the early releases adopted for the flood manual strategies have minimal impact on the maximum outflow for the dam. The greatest benefit is for the 1 in 200 AEP events. For the flood events investigate the reduction in peak outflow for the dam is negligible. Note that this analysis does not consider the downstream flooding in the Lockyer and Bremer Rivers.

However, it should be noted that there is the real risk that the release of additional water from the dam early in the flood event may make local flooding impacts in Brisbane worse. Due to the travel time of releases, uncertainty in forecast rainfall, and the low lying local catchment areas between Wivenhoe Dam and the urban areas of Brisbane, it is likely that for some events the increased early releases will exacerbate local flooding in Brisbane. This is potentially a significant risk as this flooding is directly attributable to the dam releases and could be avoided if the dam was operated according to the current strategy.

The flood strategies for Wivenhoe and Somerset are based on holding back flood waters until the rain has occurred and downstream flooding has peaked. Releasing early in an event compromises some of the flood mitigation capacity for the intermediate flood events.

## Option 2 – Pre-release water when a major event is forecast

This option involves implementing a significant release of water once the notification of a major rainfall event has been received. This option is reliant on the accuracy of forecasts and having predefined approval processes in place.

The Bureau of Meteorology was approached by the SEQWater Corporation to discuss the ability of the provision of short term forecasts of large rainfall events. Their response is included in attachment A. The summary of their advice from the meeting was

"In light of the demand for water in southeast Queensland and the highly variable nature of rainfall in the area the project has many obvious attractions. However the capability of the science to provide sufficiently reliable 24 to 48 hour advance predictions of high catchment average rainfalls is limited. The Bureau would be willing to participate in future discussions on the subject and maybe able to assist with some service that would assist."

There are also physical constraints on the amount of water that can be released. To reduce Wivenhoe to 75% in 48 hours requires water to be released at a rate that would close all of the road crossings over the Brisbane River between the dam and the Jindalee Bridge (peak flow of over 1,900cu.m/s) and result in a final volume in Wivenhoe of around 66.8% during the third day if the gates were closed down using the established closure sequence after the 48 hours. If the high rainfall did occur, then the gates would no doubt remain open.

It is not possible to lower Wivenhoe to 50% within 3 days due to the incremental opening of the gates required for safety, the reduction in discharge through the gates with the dropping dam level, and the need to limit discharges below damaging flows through Brisbane.

In light of the above comment, pre releases (i.e. releasing water prior to an event (based on predicted rainfall) has significant risks associated with the strategy in terms of

- The difficulty in actually releasing significant volumes of water,
- The potential impacts downstream if rainfall doesn't eventuate (disrupting the downstream community, causing minor damage to low lying areas, creating a "sunny day" flood event totally attributable to the dam, someone could be injured or washed away in such a release).
- The risk of exacerbating flooding by making releases that then add to flood levels downstream occurring after the pre-release. (i.e. the predicted rainfall occurs downstream of the dam while the river level is elevated due to the pre-release's from the dam combining to create a damaging flood).
- Predicting rainfall 2 days before an event is highly variable even according to the Bureau of Meteorology and 3 days is problematic.

## Option 3 – Lower the Storage Level by Sunny Day Releases to 75% and operate under the current flood manual

This option involves effectively lowering the Full Supply Level of Wivenhoe Dam to increase the flood mitigation storage at the commencement of a flood event. As discussed previously, the storage would need to be lowered by 25 to 50% to provide a significant reduction in peak flows for a major flood event. Once the storage level reached EL67 gate operations would commence as per the current flood manual.

To safely lower the storage it is proposed that this option would be implemented by "Sunny Day" releases at a rate low enough to minimise disruption to the rural areas. This would be difficult to implement during a wet year where the risk of major flooding is greater.

In the 25 days leading up to the January 2011 Flood event, three flood events impacting on Wivenhoe Dam were experienced, with gate releases being made on all but five of those days. The total outflow from these events was around 790,000ML.

During these events, multiple requests were received from Councils and residents impacted by bridge closures downstream of the dam to curtail releases as soon and as quickly as possible. Additionally, the 2 January end date of the flood event prior to the January 2011 Flood event meant that significant draw down of the dam prior to the onset of the January 2011 Flood event that commenced on 6 January 2011, was not possible without major bridge inundation downstream of the dam and without exceeding minor flood levels in the lower Brisbane River.

Additionally, a flood event was also experienced in October 2010 that resulted in a release of 640,000ML from the dam. Accordingly, to drain down the dam below full supply level prior to the start of the first December event would not have been possible without significant bridge inundation and without exceeding minor flood levels (as defined by BOM and BCC) in the lower Brisbane River.

In other words, preceding rainfall events to the January 2011 Major Flood event had created flooding that would have maintained the storage at the current FSL and prevent drawdown of the storage if such a strategy was proposed

- Compromising water security for South East Queensland by lowering the storage at the end of the each event. The impact on yield needs to be quantified.
- Having preceding rainfall events fill up the dam and prevent it from being lowered before a major flood event. Effectively compromising any effectiveness associated with this strategy.
- The limited discharges that can be utilised during sunny day flows in the river system. To reduce levels prior to summer would take some time without inundating any bridges and without any further inflows. To reduce from 100% to 50% and only impact on Twin Bridges and Savages Crossings and keep Colleges Crossing open could take some 5 to 6 weeks. Even if levels are reduced in Wivenhoe prior to summer, as occurred this summer, multiple rain events can fill the dam and would require significant releases to keep the storage level down.

## Option 4 - Temporarily Lower the Full Supply Level to 85% and Amend the Flood Operations Manual

It was requested that the option of temporarily lowering the storage to 85% of the current storage capacity (for this option make EL65.25 the FSL, down from EL67) and amend the current flood manual to commence releases once the storage level exceeds EL65.5. The amended manual would retain the key level in the manual of EL74m, where the gates are opened until the flood level stops rising. This would require a change by the Queensland Government to the regulatory requirements and levels of service that the storage is operated under.

This amended change would result in flow reductions similar to that obtained from Option 3.

Table 5 - Impact of Temporarily Lowering FSL to 85%

| Flood Event | | | | Existing Rules | | Temporarily Reducing FSL. | | |
|---|---|---|---|---|---|---|---|---|
| Duration (hours) | Annual Exceedance Probability | Maximum Inflow ($m^3/s$) | Flood Volume (ML) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Flow Reduction % |
| 36 hours | 1 in 200 | 8,214 | 1,544,119 | 3,861 | 71.4 | 2,639 | 70.66 | 31.6% |
| 36 hours | 1 in 500 | 10,455 | 1,624,119 | 5,983 | 72.2 | 4,028 | 71.53 | 32.7% |
| 36 hours | 1 in 1000 | 12,031 | 1,772,752 | 6,010 | 72.78 | 5,031 | 72.16 | 16.3% |
| 48 hours | 1 in 5000 | 14,278 | 2,562,553 | 9,066 | 74.7 | 8,535 | 74.37 | 5.9% |
| 72 hours | 1 in 5000 | 13,181 | 2,880,602 | 8,190 | 74.15 | 7,821 | 73.92 | 4.5% |
| 96 hours | 1 in 5000 | 11,870 | 2,948,032 | 7,534 | 73.74 | 7,135 | 73.49 | 5.3% |
| 120 hours | 1 in 5000 | 12,727 | 3,005,136 | 7,227 | 73.55 | 6,751 | 73.25 | 6.6% |
| January 2011 | - | 12,045 | 2,650,000 | 7,468 | 74.98 | 5,746 | 74.62 | 23.1% |
| 1974 | | 8,842 | 1,410,000 | 3,275 | 73.305 | 2,737 | 72.91 | 16.4% |
| 1999 | | 11,641 | 1,220,000 | 1,949 | 72.23 | 1,814 | 71.89 | 6.9% |

## Option 5 – Temporarily Lower the Full Supply Level to 75% and Amend the Flood Operations Manual

It was requested that the option of temporarily lowering the storage to 75% of the current storage capacity (for this option make EL64 the FSL, down from EL67) and amend the current flood manual to commence releases once the storage level exceeds EL64. The amended manual would retain the key level in the manual of EL74m, where the gates are opened until the flood level stops rising. This would require a change by the Queensland Government to the regulatory requirements and levels of service that the storage is operated under.

As can be seen in Table 6 lowering the FSL to EL64 (75% of the current FSL) and commencing flood operations at this level has a profound impact on the discharges for the shorter duration flood events with smaller flood volumes. However, once the flood volume exceeds the 2,000,000ML mark the effectiveness of this change in the operating level is diminished resulting in only a 10% reduction in the peak outflows for the dam.

Given the January 2011 Event had a volume of over 2,500,000Ml the benefits from lowering the storage level would not have resulted in any major change to the extent of flood inundation. It would however have reduced the depth of inundation with a corresponding reduction in the number of house and commercial properties flooded.

Table 6 Impact of Temporarily Lowering FSL to 75%

| Flood Event | | | | Existing Rules | | Temporarily Reducing FSL. | | |
|---|---|---|---|---|---|---|---|---|
| Duration (hours) | Annual Exceedance Probability | Maximum Inflow ($m^3/s$) | Flood Volume (ML) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Flow Reduction % |
| 36 hours | 1 in 200 | 8,214 | 1,544,119 | 38141 | 71.4 | 1,971 | 70.24 | 94.83% |
| 36 hours | 1 in 500 | 10,455 | 1,624,119 | 5983 | 72.2 | 3,446 | 71.17 | 42.40% |
| 36 hours | 1 in 1000 | 12,031 | 1,772,752 | 6010 | 72.78 | 4,504 | 71.83 | 25.06% |
| 48 hours | 1 in 5000 | 14,278 | 2,562,553 | 9066 | 74.7 | 8,217 | 74.17 | 9.36% |
| 72 hours | 1 in 5000 | 13,181 | 2,880,602 | 8190 | 74.15 | 7,609 | 73.79 | 7.09% |
| 96 hours | 1 in 5000 | 11,870 | 2,948,032 | 7534 | 73.74 | 6,916 | 73.35 | 8.20% |
| 120 hours | 1 in 5000 | 12,727 | 3,005,136 | 7227 | 73.55 | 6,635 | 73.17 | 8.19% |
| January 2011 | - | 12,045 | 2,650,000 | 7,468 | 74.98 | 4,512 | 74.25 | 39.6% |
| 1974 | - | 8,842 | 1,410,000 | 3,275 | 73.305 | 2,493 | 72.71 | 23.9% |
| 1999 | - | 11,641 | 1,220,000 | 1,949 | 72.23 | 1,561 | 71.48 | 19.9% |

It can be seen from the comparison of Table 5 and Table 6 that the reduction of the storage level to 75% has a much more significant reduction on the outflows from the dam. This is consistent with the previous observations that reductions of at least 25% of the storage volume are required to significantly alter the outflows from the dam.

It is also important to note that even with the reduction of the storage level to 75% and the amended flood operation rules, the storage level still exceeds EL74 for the January 2011 Flood Event. The changes would result in reduced flood levels downstream but would not prevent damaging flows through Brisbane.

# Attachment A

# Rainfall Forecasting for the Wivenhoe Dam Catchment

## Background

1. On 6 July, Chris Russell, of Connell Wagner, met with Mike Bergin and Peter Baddiley seeking advice regarding the predictability of significant rain events over the Wivenhoe Dam catchment. Connell Wagner has been engaged by SEQWCo to provide advice on the feasibility of maintaining the water level in the Wivenhoe storage at one metre above Full Supply Level. As a part of the dam operations under that scenario, it would be required that the additional storage above FSL be released ahead of a major inflow into Wivenhoe Dam. This would require some 24 to 48 hour advance prediction of catchment average rainfalls in the order of 300mm in 24 hours; 375mm in 36 hours and/or 430mm in 48 hours.

2. Wivenhoe Dam catchment is located to the north-west of Brisbane and has an area of about 7,000 square kilometres. For meteorological forecasting, the catchment is broadly about 100 km in the north-south direction, and 70 kilometres wide (east-west); bounded in the west by the Dividing Range with its eastern boundary varying from about 40 to 80 kilometres inland from the coast. The distribution of rainfall over the catchment is significantly influenced by the topography in major events.

## Discussion

3. As discussed at the meeting, the experience of Meteorologists and Hydrologists in the Brisbane office of the Bureau is that the short to medium term (0 to 48 hour) prediction of rainfall for the purpose of objective use in flood forecasting models is a difficult task. Quantitative Precipitation Forecasts (QPF) are available from the Australian and international Numerical Weather Prediction (NWP) models and have been used subjectively in the Brisbane office for many years. Whilst the NWP models have shown improvement in the accuracy of QPF over the past decade or so, there is still at times considerable error or uncertainty, in the prediction of the location, amount and timing of rainfall events at the catchment scale.

4. The improved skill of NWP models in recent years has particularly been in forecasting the development and movement of broad-scale synoptic features that would be likely to produce the threshold rainfall amounts in question. These large-scale features include decaying tropical cyclones, east coast low pressure systems and significant upper level troughs. However while these systems maybe well forecast on a time scale of 2 to 3 days the very heavy rainfall concentrations are dependent on finer scale (mesoscale) and convective features. Whilst there is often the ability to forecast the potential for a significant rain event to occur in the southeast Qld-northern NSW region, it is difficult (if not impossible) to predict the actual location of the heaviest rain, even with only a few hours notice.

5. Examples of high rainfall events that have occurred in the past 10 to 15 years in this region, some of which had little to no advance prediction of the "precise" location and/or magnitude of resulting rainfall, include Feb [illegible], Dec 1991, Feb [illegible], May 1996, Feb 1999, Mar 2001 and June [illegible]. Several of these events were not produced by large scale features but by slow moving convergence

zones which the current modelling capability cannot adequately predict. The two most recent events in 2001 and 2005 were relatively short-lived events and occurred at different times of the day – 2001 in the afternoon and 2005 overnight. While one could reasonably expect that most really significant rainfall events are most likely through the warmer months, winter extreme events are by no means rare.

6. Considerable effort is being applied to derive improved deterministic and probabilistic QPFs from NWP models. In the near future, the Bureau will be providing a publicly available rainfall forecasting service via a website. The rainfall predictions will be generated automatically by combining the outlooks from a suite of Australian and international. Forecast rainfall amounts for 24 hour periods will be given for 4 days ahead, together with the chance of exceeding various amounts from 1mm to 50mm. The latter is a "pseudo" measure of probability based on the consistency in the forecast rain amounts given by up to eight NWP models used in deriving the rainfall forecast. Whilst it is not considered that this will provide a sufficiently accurate method for objective decision making for pre-releases from Wivenhoe Dam, the probabilistic rain forecasts may provide a basis for a risk management approach. There may need to be further studies on risk quantification for prediction of high to extreme rainfall events to support this approach. Given that there are large levels of uncertainty in rainfall forecasts, the forecasting of hydrological response may require an ensemble of future rain scenarios to be considered for the Wivenhoe Dam application.

7. As for a potential service provided by the Bureau an alert type product would seem to be the best alternative where the potential for an extreme rainfall event in the following 2 to 3 days across southeast Queensland was given a rating on say a 3 level scale. If that rating was high then a second phase could be activated which could provide more detailed forecast of expected rainfall amounts and location. However I emphasise that this type of service can be expected to not provide the required 2 days advice of an event on some occasions and may fail to provide anything more than a few hours notice, such is the nature of the predictability of the mesoscale components of these events.

8. Currently the Bureau provides a QPF service for the dams in Southeast Queensland. This twice-daily service predicts the average rainfall across the catchments in the following 24-hour period. We have not undertaken any verification of the service. However it is likely that verification would show reasonable skill in identifying rainfall events but quite poor skill in predicting extreme events. This service is to be reviewed in the next few months and we may commence charging for the product as it is essentially not a basic service and should not be publicly funded. We have yet to commence discussions with the client so these comments should be kept confidential. This issue is raised because any future customized product provided in support of dam operations will certainly be on a fee for service basis. There is also the issue of whether the Bureau would have the capacity to provide such a service at all and that would have to be part of any future discussions.

**Summary**

9. In light of the demand for water in southeast Queensland and the highly variable nature of rainfall in the area the project has many obvious attractions. However the capability of the science to provide sufficiently reliable 24 to 48 hour advance predictions of high catchment average rainfalls is limited. The Bureau would be willing to participate in future discussions on the subject and maybe able to assist with some service that would assist.

Mike Bergin

Manager Weather Services,

Bureau of Meteorology, Queensland.

Peter Baddiley

Supervising Engineer Hydrology

Bureau of Meteorology, Queensland

24 July 2006

**From:** Barton Maher [redacted]
**Sent:** Thursday, 3 February 2011 10:31 AM
**To:** Rory Nathan [redacted]
**Cc:** PAT NIXON [redacted]
**Subject:** Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V1.docx
**Attachments:** Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges V1.docx

Gents,

I have been addressing your comments – please find attached the report as it stands so far.

Kind Regards,


Barton Maher
Principal Dams & Weirs Planning
Q Bulk Water Supply Authority

seqwater

[redacted]

Website | www.seqwater.com.au

# Impact of Reducing the Full Supply Level of Wivenhoe on Flood Discharges

## Introduction

Seqwater staff have been asked to investigate the impact of reducing the storage level of Wivenhoe Dam on the downstream discharges for major flood events. This memo details the investigations carried out and provides a preliminary assessment of the reduction in flood flows that could be achieved by reducing the Wivenhoe Dam storage level to 5%, 10%, 25% and 50% of the normal water supply volume.

The comments in this report are provided to give an indication of the impacts of a reduced storage level of Wivenhoe Dam on discharges during major flood events. It must be noted that it is very preliminary, as to get accurate results a full investigation and analysis of the whole river system utilising multiple flood events and models would be required. This review was requested to provide an order of magnitude assessment of impacts and the results should not be utilised beyond that purpose.

## Definitions

For the purposes of this report the following definitions have been adopted as per the Wivenhoe – Somerset Flood manual:

| | |
|---|---|
| Fresh | This causes only very low-level bridges to be submerged. |
| Minor Flooding | This causes inconvenience such as closing minor roads and the submergence of low-level bridges. Some urban properties are affected. |
| Moderate Flooding | This causes inundation of low-lying areas and may require the evacuation of some houses and/or business premises. Traffic bridges may be closed. |
| Major Flooding | This causes flooding of appreciable urban areas. Properties may become isolated. Major disruption occurs to traffic. Evacuation of many houses and business premises may be required. |
| Extreme Flooding | This causes flooding well in excess of floods in living memory and general evacuation of whole areas are likely to be required. |
| "$m^3/s$" | Means an instantaneous flow rate expressed as cubic meters of water per second. |
| "AEP" | means annual exceedance probability, the probability of a specified event being exceeded in any year; |
| "AHD" | means Australian Height Datum; |
| "EL" | means elevation in metres from Australian Height Datum; |
| "ML" | Means a million litres of water |

## Analysis Methodology

The analysis was undertaken using a spreadsheet developed to model the gate opening sequence as provided in the Flood Manual during a loss of communications situation. During a loss of communications between the dam operators and the Flood Control Centre, operators would use predefined gate openings based solely on the Lake Level information available to them at the dams. Utilising this spreadsheet takes out the role of weather predictions with openings based on dam levels and allows a consistent methodology to compare various flood events.

A history of floods in the Brisbane River is presented in Table 1.

Table 1 – Summary of Significant Flood Events in the Brisbane River

| Event | Somerset Dam | | | Wivenhoe Dam | | | |
|---|---|---|---|---|---|---|---|
| | Peak Elevation | Inflow | Outflow | Peak Elevation | Inflow* | Total Volume | Outflow |
| | m AHD | ML | ML | m AHD | ML | ML | ML |
| Jan 1974# | 106.57 | 620,000 | 450,000 | na | 960,000 | 1,410,000 | 1,410,000 |
| Jun 1983 | 101.58 | 260,000 | 280,000 | | 800,000 | 1,080,000 | 470,000 |
| Mar 1989 | 102.59 | 370,000 | 380,000 | 69.78 | 310,000 | 690,000 | 660,000 |
| Apr 1989 | 102.69 | 340,000 | 350,000 | 71.45 | 520,000 | 870,000 | 820,000 |
| Feb 1999 | 102.96 | 450,000 | 280,000 | 70.45 | 940,000 | 1,220,000 | 900,000 |
| May 2009 | 99.62 | 110,000 | 110,000 | 62.19 | 125,000 | 235,000 | 0 |
| Mar 2010 | 99.41 | 210,000 | 200,000 | 66.43 | 190,000 | 390,000 | 0 |
| Oct 2010 | 101.37 | 250,000 | 270,000 | 69.61 | 360,000 | 630,000 | 630,000 |
| Mid Dec 2010 | 100.42 | 150,000 | 140,000 | 67.50 | 220,000 | 360,000 | 330,000 |
| Late Dec 2010 | 99.98 | 120,000 | 130,000 | 69.35 | 370,000 | 500,000 | 460,000 |
| Jan 2011 | 105.11 | 825,000 | 820,000 | 74.97 | 1,830,000 | 2,650,000 | 2,650,000 |

# No Wivenhoe Dam

* Upper Brisbane R only

The assessment has investigated the impacts of the lowered storage level on the three largest events – the 1974 flood, the 1999 flood and the 2011 flood.

## Analysis Results

A summary of the results of the modelling is presented in Table 2.

Table 2 - Results of the Analysis

| | | Wivenhoe Dam | | Somerset Dam | | Lockyer Creek | Lowood | Bremer River | Moggill | Reduction at Moggill |
|---|---|---|---|---|---|---|---|---|---|---|
| Storage Level at Start | % of FS Volume | Peak Inflow ($m^3/s$) | Peak Outflow ($m^3/s$) | Peak Inflow ($m^3/s$) | Peak Outflow ($m^3/s$) | Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) | Peak Flow[1] ($m^3/s$) | % |
| 1974 Flood | | | | | | | | | | |
| 67 | 100 | 8,482 | 3,275 | 5,019 | 3,548 | 3,260 | 5,110 | 4,241 | 7,948 | |
| 66.5 | 95 | 8,482 | 3,153 | 5,019 | 3,480 | 3,260 | 4,799 | 4,241 | 7,910 | 0.5% |
| 65.8 | 90 | 8,482 | 2,974 | 5,019 | 3,419 | 3,260 | 4,524 | 4,241 | 7,897 | 0.6% |
| 64 | 75 | 8,482 | 2,618 | 5,019 | 3,302 | 3,260 | 4,117 | 4,241 | 7,683 | 3.3% |
| 60 | 50 | 8,482 | 2,067 | 5,019 | 3,040 | 3,260 | 3,342 | 4,241 | 7,423 | 6.6% |
| 1999 Flood | | | | | | | | | | |
| 67 | 100 | 11,641 | 2,312 | 7,540 | 3,837 | 663 | 2,556 | 308 | 2,593 | |
| 66.5 | 95 | 11,641 | 2,132 | 7,540 | 3,662 | 663 | 2,434 | 308 | 2,479 | 4.4% |
| 65.8 | 90 | 11,641 | 2,003 | 7,540 | 3,470 | 663 | 2,284 | 308 | 2,319 | 10.6% |
| 64 | 75 | 11,641 | 1,687 | 7,540 | 3,214 | 663 | 1,906 | 308 | 1,936 | 25.3% |
| 60 | 50 | 11,641 | 1,007 | 7,540 | 2,798 | 663 | 1,186 | 308 | 1,214 | 53.2% |
| 2011 Flood | | | | | | | | | | |
| 67 | 100 | 12,045 | 7,468 | 3,824 | 2,814 | 3,040 | 10,495 | 2,793 | 13,104 | |
| 66.5 | 95 | 12,045 | 7,453 | 3,824 | 2,798 | 3,040 | 10,445 | 2,793 | 13,004 | 0.8% |
| 65.8 | 90 | 12,045 | 6,756 | 3,824 | 2,815 | 3,040 | 9,791 | 2,793 | 12,302 | 6.1% |
| 64 | 75 | 12,045 | 5,748 | 3,824 | 2,680 | 3,040 | 8,788 | 2,793 | 11,110 | 15.2% |
| 60 | 50 | 12,045 | 4,209 | 3,824 | 1,595 | 3,040 | 7,249 | 2,793 | 9,582 | 26.9% |

The preliminary work done by Seqwater before Christmas 2010 showed that for the October 2010 event, reducing the level of Wivenhoe by small amounts would have had minimal impact on the flood releases. From the

Table 2 the following comments are applicable:

[1] Note the flows quoted for Moggill are based on the addition of outflows from the dam and the measured flows at Lockyer Creek and the Bremer River. They do not have any allowance for routing of the flows through the river system and the subsequent reduction in flows that were observed during the flood events.

- Similarly to work completed previously, reducing levels by small amounts prior to the January 2011 event (if it was feasible) would have had little impact on the peak level in Wivenhoe Dam as shown in the Table 2. The reason for this is that the total event inflow volume of 2,600,000 ML is well in excess of the useable flood storage combined with the available water supply storages shown in the table. Large reductions to the storage level of the dam (25 to 50%) would be required if significant impacts on flooding are to be achieved.
- For the 1999 flood, where most of the flooding occurred upstream of the Wivenhoe Dam, there is a dramatic reduction in the peak outflow if the storage is lowered. However, this is of little benefit as the flood would not have resulted in damaging flows downstream of the dam even if the storage was full.
- The 1974 flood simulation is based on the recorded flows being routed through the both Somerset and Wivenhoe. The presence of Wivenhoe would have reduced the flooding damage in Brisbane during the 1974 event, however there is very little change to the flood mitigation benefits by varying the storage level in Wivenhoe. As most of the flood flows in 1974 were downstream of the dam and the flood in the Brisbane River was relatively small compared to the downstream flooding the event is insensitive to the starting level in Wivenhoe.
- It should be noted that the increasing early releases from Wivenhoe was investigated during the Brisbane Valley Flood Damages Study as part of a review of the operation of the dam. Releasing more water earlier on from Wivenhoe dam was shown to lessen the flood mitigation benefits compared with the existing flood manual release strategies.

The key point being that each flood event is unique and presents varying opportunities to mitigate flows through Brisbane.

## Downstream Water Level Changes

To evaluate the specific impact on the Lower Brisbane River of these reduced dam outflows from lowering the storage requires the use of a complex hydraulic model. The results of this modelling would still contain a degree of uncertainty as illustrated by the difficulties in estimating the final flood peak in Brisbane during the event. The uncertainty was partly due to the rapid closure of the Wivenhoe gates after the peak inflow of the flood and the attenuation achieved in the downstream river system. It is extremely difficult to model accurately.

Given the timeframe of this report it is not possible to generate any reliable estimate of the changes to the water level at the Port Office Gauge due to tidal influences, the need to interpolate between previously modelled results that vary markedly between differing events, the availability of verified data, and the uncertainty surrounding the timing of peak flows for the differing scenarios.

Table 3 shows a comparison of the peak water level for each of the various starting levels for the 2011 Flood Event. It should be noted that each scenario results in the storage level exceeding EL74 requiring the gates to be opened until the storage rise is stopped.

| Wivenhoe | | | |
|---|---|---|---|
| Starting Level | | Peak Height | Capacity at Peak Height |
| % | m AHD | m AHD | [illegible] |
| 100 | 67.0 | 74.98 | [illegible] |

| | | | |
|---|---|---|---|
| 95 | 66.5 | 74.93 | 190.6 |
| 90 | 65.8 | 74.88 | 189.9 |
| 75 | 64.0 | 74.63 | 186.5 |
| 50 | 60.0 | 74.11 | 179.6 |

Again it should be noted that minor changes to the storage level of Wivenhoe would have negligible impacts on the flooding in Brisbane.

It should be noted that to accurately calculate the impacts of reducing the storage levels of Wivenhoe Dam at the start of a major flood event requires considerable study as rainfall events of different intensity, duration, peak, location and spread will give very different outcomes. In addition, there is the need to do detailed hydraulic analysis of the river system for each scenario to more accurately determine impacts.

## Summary

Due to the large volumes of water associated with major flood events (with an AEP of 1:100 or less) in the Brisbane River, to effectively reduce flood peak discharges significantly (such as for the January 2011 flood) would require the storage level of Wivenhoe Dam to be lowered by at least 25 to 50%.

## Contingency Options

There is the possibility of further flood events in the South East Queensland during the 2010/2011 wet season. To reduce the risk of flooding in Brisbane should a major rainfall event be predicted it has been requested that lowering of the storage level of Wivenhoe Dam be investigated to determine if this is a feasible option to further mitigate flood flows.

The assessment carried out by Seqwater has indicated that to have any significant impact on releases downstream of Wivenhoe Dam during a major flood event it would be necessary to lower the storage level by 25 to 50%.

There are five options considered going forward:

1. Continue with the current approved flood manual strategies
2. Commence drawing down the storage at a safe rate to bring it down to say 75%.
3. Pre-release water from the dam following the prediction of a major rainfall event
4. Change the flood manual strategies to ignore the early strategies designed to minimise disruption to the rural communities.
5. Temporarily reduce the full supply of Wivenhoe Dam and amend the flood releases to commence flood operations from the lowered full supply level.

## Option 1 – Continue with the Current Flood Manual

This option maintains the status quo and continues to utilise the dam as originally designed. This option has the least risk associated with it as the Strategies have been implemented and refined over several flood events and the manual was developed by a comprehensive study. The strategies in the flood manual have proved adequate for more frequent flood events.

## Option 2 – Lower the Storage Level by Sunny Day Releases

This option involves effectively lowering the Full Supply Level of Wivenhoe Dam to increase the flood mitigation storage. As discussed previously, the storage would need to be lowered by 25 to 50% to provide a significant reduction in peak flows for a major flood event. This would be difficult to implement during a wet year where the risk of major flooding is greater.

In the 25 days leading up to the Major January Flood event, three flood events impacting on Wivenhoe Dam were experienced, with gate releases being made on all but five of those days. The total outflow from these events was around 790,000ML.

During these events, multiple requests were received from Councils and residents impacted by bridge closures downstream of the dam to curtail releases as soon and as quickly as possible. Additionally, the 2 January end date of the flood event prior to the January Major Flood event meant that significant draw down of the dam prior to the onset of the January Major Flood event that commenced on 6 January 2011, was not possible without major bridge inundation downstream of the dam and without exceeding minor flood levels in the lower Brisbane River.

Additionally, a flood event was also experienced in October 2010 that resulted in a release of 640,000ML from the dam. Accordingly, to drain down the dam below full supply level prior to the start of the first December event would not have been possible without significant bridge inundation and without exceeding minor flood levels (as defined by BOM and BCC) in the lower Brisbane River.

In other words, preceding rainfall events to the January 2011 Major Flood event had created flooding that would have maintained the storage at the current FSL and prevent drawdown of the storage if such a strategy was proposed.

Risks to this strategy are:

- Compromising water security for South East Queensland by lowering the storage at the end of the each event. The impact on yield needs to be quantified.
- Having preceding rainfall events fill up the dam and prevent it from being lowered before a major flood event. Effectively compromising any effectiveness associated with this strategy.
- The limited discharges that can be utilised during sunny day flows in the river system. To reduce levels prior to summer would take some time without inundating any bridges and without any further inflows. To reduce from 100% to 50% and only impact on Twin Bridges and Savages Crossings and keep Colleges Crossing open could take some 5 to 6 weeks. Even if levels are reduced in Wivenhoe prior to summer, as occurred this summer, multiple rain events can fill the dam and would require significant releases to keep the storage level down

## Option 3 – Pre-release water when a major event is forecast

This option involves implementing a significant release of water once the notification of a major rainfall event has been received. This option is reliant on the accuracy of forecasts and having predefined approval processes in place.

The Bureau of Meteorology was approached by the SEQWater Corporation to discuss the ability of the provision of short term forecasts of large rainfall events. Their response is included in attachment A. The summary of their advice from the meeting was

"In light of the demand for water in southeast Queensland and the highly variable nature of rainfall in the area the project has many obvious attractions. However the capability of the science to provide sufficiently reliable 24 to 48 hour advance predictions of high catchment average rainfalls is limited. The Bureau would be willing to participate in future discussions on the subject and maybe able to assist with some service that would assist."

There are also physical constraints on the amount of water that can be released. To reduce Wivenhoe to 75% in 48 hours requires water to be released at a rate that would close all of the road crossings over the Brisbane River between the dam and the Jindalee Bridge (peak flow of over 1,900cu.m/s) and result in a final volume in Wivenhoe of around 66.8% during the third day if the gates were closed down using the established closure sequence after the 48 hours. If the high rainfall did occur, then the gates would no doubt remain open.

It is not possible to lower Wivenhoe to 50% within 3 days due to the incremental opening of the gates required for safety, the reduction in discharge through the gates with the dropping dam level, and the need to limit discharges below damaging flows through Brisbane.

In light of the above comment, pre-releases (i.e. releasing water prior to an event based on predicted rainfall) has significant risks associated with the strategy in terms of:

- The difficulty in actually releasing significant volumes of water,
- The potential impacts downstream if rainfall doesn't eventuate (disrupting the downstream community, causing minor damage to low lying areas, creating a "sunny day" flood event totally attributable to the dam, someone could be injured or washed away in such a release).
- The risk of exacerbating flooding by making releases that then add to flood levels downstream occurring after the pre-release. (i.e. the predicted rainfall occurs downstream of the dam while the river level is elevated due to the pre-release's from the dam combining to create a damaging flood).
- Predicting rainfall 2 days before an event is highly variable even according to the Bureau of Meteorology and 3 days is problematic.

## Option 4 – Vary the early strategies for the Flood Manual

It has been proposed that increasing the releases from the dam up to 1,600cumecs as soon as practicable after gate operations commence may deliver reduced peak flood levels. This has been investigated to assess the impact of attempting to release more water at the very start of an event.

This option has been assessed using a range of design events from the Wivenhoe Alliance Design hydrology. To model the impacts of increasing releases up to 1,600cumecs as soon as practicable a range of design flood events from the Wivenhoe Alliance were compared using the program FLROUTE. . It was assumed that no attempt would be made to maintain bridge access downstream of the dam other than Mt Crosby Weir Bridge and the Brisbane Valley Highway Bridge.

The results for the model runs are presented in Table 4.

Table 4 - Comparison of Release Strategies

| Flood Event | | | | Existing Rules | | Fixed Rules | | |
|---|---|---|---|---|---|---|---|---|
| Duration (hours) | Annual Exceedance Probability | Maximum Inflow ($m^3/s$) | Flood Volume (ML) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Flow Reduction % |
| 36 hours | 1 in 200 | 8,214 | 1,544,119 | 3,861 | 71.43 | 3,613 | 71.27 | 6.4% |
| 36 hours | 1 in 500 | 10,455 | 1,624,119 | 5,125 | 72.22 | 4,915 | 72.09 | 4.1% |
| 36 hours | 1 in 1000 | 12,031 | 1,772,752 | 6,049 | 72.8 | 5,854 | 72.68 | 3.2% |
| 48 hours | 1 in 5000 | 14,278 | 2,562,553 | 9,083 | 74.71 | 8,994 | 74.66 | 1.0% |
| 72 hours | 1 in 5000 | 13,181 | 2,880,602 | 8,204 | 74.16 | 8,101 | 74.10 | 1.3% |
| 96 hours | 1 in 5000 | 11,870 | 2,948,032 | 7,550 | 73.75 | 7,426 | 73.67 | 1.6% |
| 120 hours | 1 in 5000 | 12,727 | 3,005,136 | 7,265 | 73.57 | 6,986 | 73.39 | 3.8% |

It should be noted that predicted flood levels greater than EL 74 require the gates to be opened until the water level stabilises. This is fundamental to the dam's safety. In addition, any reduction in starting level, which does not achieve a peak lower than EL 74, is unlikely to have any impact upon peak release rate.

It should also be noted that that design flows used from the Alliance bear no resemblance to actual recorded flood events. This is demonstrated by the Jan 2011 flood which had dual peak inflows of about 10,000 and 12,000 m3/s with a flood volume of 2,650,000ML, placing it in the 1 in 1,000 to 1 in 5,000 AEP according to Table 4.

It can be clearly seen from Table 4 that changes to the early releases adopted for the flood manual strategies have minimal impact on the maximum outflow for the dam. The greatest benefit is for the 1 in 200 AEP events. For the flood events investigate the reduction in peak outflow for the dam is negligible. Note that this analysis does not consider the downstream flooding in the Lockyer and Bremer Rivers.

However, it should be noted that there is the real risk that the release of additional water from the dam early in the flood event may make local flooding impacts in Brisbane worse. Due to the travel time of releases, uncertainty in forecast rainfall, and the low lying local catchment areas between Wivenhoe Dam and the urban areas of Brisbane, it is likely that for some events the increased early releases will exacerbate local flooding in Brisbane. This is potentially a significant risk as this flooding is directly attributable to the dam releases and could be avoided if the dam was operated according to the current strategy.

The flood strategies for Wivenhoe and Somerset are based on holding back flood waters until the rain has occurred and downstream flooding has peaked. Releasing early in an event compromises some of the flood mitigation capacity for the intermediate flood events.

## Option 5 – Temporarily Lower the Storage Level

It was requested that the option of temporarily lowering the storage and commence the releases as per the current flood manual from the lowered storage level (e.g. make EL64 the FSL, down from EL67) be investigated. However, it is proposed that the key level in the manual of EL74m, where the gates are opened until the flood level stops rising, would be maintained. This would require a change by the Queensland Government to the regulatory requirements and levels of service that the storage is operated under.

As can be seen in Table 5 lowering the FSL to EL64 and commencing flood operations at this level has a profound impact on the discharges for the shorter duration flood events with smaller flood volumes. However, once the flood volume exceeds the 2,000,000ML mark the effectiveness of this change in the operating level is diminished resulting in only a 10% reduction in the peak outflows for the dam.

Given the January Major Flood had a volume of over 2,500,000Ml the benefits from lowering the storage level would not have resulted in any major change to the extent of flood inundation. It would however have reduced the depth of inundation with a corresponding reduction in the number of house and commercial properties flooded.

Table 5 - Impact of Temporally Lowering FSL

| Flood Event | | | | Existing Rules | | Temporarily Reducing FSL. | | |
|---|---|---|---|---|---|---|---|---|
| Duration (hours) | Annual Exceedance Probability | Maximum Inflow ($m^3/s$) | Flood Volume (ML) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Maximum Outflow ($m^3/s$) | Maximum Lake Level (m AHD) | Flow Reduction % |
| 36 hours | 1 in 200 | 8,214 | 1,544,119 | 38141 | 71.4 | 1,971 | 70.24 | 94.83% |
| 36 hours | 1 in 500 | 10,455 | 1,624,119 | 5983 | 72.2 | 3,446 | 71.17 | 42.40% |
| 36 hours | 1 in 1000 | 12,031 | 1,772,752 | 6010 | 72.78 | 4,504 | 71.83 | 25.06% |
| 48 hours | 1 in 5000 | 14,278 | 2,562,553 | 9066 | 74.7 | 8,217 | 74.17 | 9.36% |
| 72 hours | 1 in 5000 | 13,181 | 2,880,602 | 8190 | 74.15 | 7,609 | 73.79 | 7.09% |
| 96 hours | 1 in 5000 | 11,870 | 2,948,032 | 7534 | 73.74 | 6,916 | 73.35 | 8.20% |
| 120 hours | 1 in 5000 | 12,727 | 3,005,136 | 7227 | 73.55 | 6,635 | 73.17 | 8.19% |

# Attachment A

# Rainfall Forecasting for the Wivenhoe Dam Catchment

## Background

1. On 6 July, Chris Russell, of Connell Wagner, met with Mike Bergin and Peter Baddiley seeking advice regarding the predictability of significant rain events over the Wivenhoe Dam catchment. Connell Wagner has been engaged by SEQWCo to provide advice on the feasibility of maintaining the water level in the Wivenhoe storage at one metre above Full Supply Level. As a part of the dam operations under that scenario, it would be required that the additional storage above FSL be released ahead of a major inflow into Wivenhoe Dam. This would require some 24 to 48 hour advance prediction of catchment average rainfalls in the order of 300mm in 24 hours; 375mm in 36 hours and/or 430mm in 48 hours.

2. Wivenhoe Dam catchment is located to the north-west of Brisbane and has an area of about 7,000 square kilometres. For meteorological forecasting, the catchment is broadly about 100 km in the north-south direction, and 70 kilometres wide (east-west); bounded in the west by the Dividing Range with its eastern boundary varying from about 40 to 80 kilometres inland from the coast. The distribution of rainfall over the catchment is significantly influenced by the topography in major events.

## Discussion

3. As discussed at the meeting, the experience of Meteorologists and Hydrologists in the Brisbane office of the Bureau is that the short to medium term (0 to 48 hour) prediction of rainfall for the purpose of objective use in flood forecasting models is a difficult task. Quantitative Precipitation Forecasts (QPF) are available from the Australian and international Numerical Weather Prediction (NWP) models and have been used subjectively in the Brisbane office for many years. Whilst the NWP models have shown improvement in the accuracy of QPF over the past decade or so, there is still at times considerable error or uncertainty, in the prediction of the location, amount and timing of rainfall events at the catchment scale.

4. The improved skill of NWP models in recent years has particularly been in forecasting the development and movement of broad-scale synoptic features that would be likely to produce the threshold rainfall amounts in question. These large-scale features include decaying tropical cyclones, east coast low pressure systems and significant upper level troughs. However while these systems maybe well forecast on a time scale of 2 to 3 days the very heavy rainfall concentrations are dependent on finer scale (mesoscale) and convective features. Whilst there is often the ability to forecast the potential for a significant rain event to occur in the southeast Qld-northern NSW region, it is difficult (if not impossible) to predict the actual location of the heaviest rain, even with only a few hours notice.

5. Examples of high rainfall events that have occurred in the past 10 to 15 years in this region, some of which had little to no advance prediction of the "precise" location and/or magnitude of resulting rainfall, include [illegible] Dec 1991, Feb 1992, May 1996, Feb 1999, Mar 2001 and June 2005. Several of these events were not produced by large scale features but by slow moving convergence

zones which the current modelling capability cannot adequately predict. The two most recent events in 2001 and 2005 were relatively short-lived events and occurred at different times of the day – 2001 in the afternoon and 2005 overnight. While one could reasonably expect that most really significant rainfall events are most likely through the warmer months, winter extreme events are by no means rare.

6. Considerable effort is being applied to derive improved deterministic and probabilistic QPFs from NWP models. In the near future, the Bureau will be providing a publicly available rainfall forecasting service via a website. The rainfall predictions will be generated automatically by combining the outlooks from a suite of Australian and international. Forecast rainfall amounts for 24 hour periods will be given for 4 days ahead, together with the chance of exceeding various amounts from 1mm to 50mm. The latter is a "pseudo" measure of probability based on the consistency in the forecast rain amounts given by up to eight NWP models used in deriving the rainfall forecast. Whilst it is not considered that this will provide a sufficiently accurate method for objective decision making for pre-releases from Wivenhoe Dam, the probabilistic rain forecasts may provide a basis for a risk management approach. There may need to be further studies on risk quantification for prediction of high to extreme rainfall events to support this approach. Given that there are large levels of uncertainty in rainfall forecasts, the forecasting of hydrological response may require an ensemble of future rain scenarios to be considered for the Wivenhoe Dam application.

7. As for a potential service provided by the Bureau an alert type product would seem to be the best alternative where the potential for an extreme rainfall event in the following 2 to 3 days across southeast Queensland was given a rating on say a 3 level scale. If that rating was high then a second phase could be activated which could provide more detailed forecast of expected rainfall amounts and location. However I emphasise that this type of service can be expected to not provide the required 2 days advice of an event on some occasions and may fail to provide anything more than a few hours notice, such is the nature of the predictability of the mesoscale components of these events.

8. Currently the Bureau provides a QPF service for the dams in Southeast Queensland. This twice-daily service predicts the average rainfall across the catchments in the following 24-hour period. We have not undertaken any verification of the service. However it is likely that verification would show reasonable skill in identifying rainfall events but quite poor skill in predicting extreme events. This service is to be reviewed in the next few months and we may commence charging for the product as it is essentially not a basic service and should not be publicly funded. We have yet to commence discussions with the client so these comments should be kept confidential. This issue is raised because any future customized product provided in support of dam operations will certainly be on a fee for service basis. There is also the issue of whether the Bureau would have the capacity to provide such a service at all and that would have to be part of any future discussions.

**Summary**

9. In light of the demand for water in southeast Queensland and the highly variable nature of rainfall in the area the project has many obvious attractions. However the capability of the science to provide sufficiently reliable 24 to 48 hour advance predictions of high catchment average rainfalls is limited. The Bureau would be willing to participate in future discussions on the subject and maybe able to assist with some service that would assist.

Mike Bergin

Manager Weather Services,

Bureau of Meteorology, Queensland.

Peter Baddiley

Supervising Engineer Hydrology

Bureau of Meteorology, Queensland

24 July 2006

**From:** Hill, Peter I (SKM) [redacted]
**Sent:** Thursday, 3 February 2011 9:59 AM
**To:** Barton Maher
**Cc:** Nathan, Rory J (SKM)
**Subject:** RE: Forecasting rainfall in Wivenhoe Dam catchment [SEC=UNCLASSIFIED]

Barton,

Although I note the words of caution below from Peter Baddiley, the rainfall forecasts have come a long way in the last 5 years and so it might be worth checking back with the Bureau (and possibly head office in Melbourne) regarding the suitability of their forecast rainfall for helping dam operations.

We are aware of a couple of other dam owners with large gated storages that do consider the Bureau's forecast rainfall out to 4 days in their decision making. The Bureau have recently started making the forecasts publicly available on the web and so there is heightened public awareness of their potential application.

We are not advocating complete reliance on these forecasts or their use in full quantitative analysis, however feel that they do provide a reasonably robust indication of whether significant rainfall is likely and therefore suggest that the wording is modified accordingly.

Happy to discuss further.

Regards,

Peter Hill
Principal

SINCLAIR KNIGHT MERZ (SKM)
452 Flinders Street, Melbourne, 3000
PO Box 312 Flinders Lane, Melbourne VIC 8009 Australia
[redacted]

For further information visit www.skmconsulting.com

**From:** Barton Maher [redacted]
**Sent:** Thursday, 3 February 2011 10:08 AM
**To:** Nathan, Rory J (SKM)
**Cc:** Hill, Peter I (SKM)
**Subject:** FW: Forecasting rainfall in Wivenhoe Dam catchment [SEC=UNCLASSIFIED]

Hi Rory and Peter,

I will rewrite the report to make it clearer – but here is our advice from Peter Baddiley on rainfall forecasting at Wivenhoe

Peter Baddiley
Supervising Engineer Hydrology & Flood Warning
Bureau of Meteorology
GPO Box 413
BRISBANE QLD 4001
AUSTRALIA
Phone: [redacted]
WWW : www.bom.gov.au/hydro/flood/qld

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***

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WATER FOR LIFE

Ph[redacted]
Karalee Office, 68 Junction Rd Karalee QLD 4306 Australia
PO Box 2437, North Ipswich QLD 4305
Website | www.seqwater.com.au

**From:** Rob Drury
**Sent:** Thursday, 3 February 2011 8:51 AM
**To:** Barton Maher
**Subject:** FW: Forecasting rainfall in Wivenhoe Dam catchment [SEC=UNCLASSIFIED]

**From:** Peter Baddiley [redacted]
**Sent:** Wednesday, 1 December 2010 9:44 AM
**To:** Rob Drury
**Subject:** FW: Forecasting rainfall in Wivenhoe Dam catchment [SEC=UNCLASSIFIED]

Rob
A small miracle - I found the Bureau's 2006 response/advice regarding forecasting rainfall for the Wivenhoe catchment.

As briefly discussed today, whilst weather prediction models are steadily improving, the forecast of rainfall amounts over catchment time/space scales is recognised as one of the most challenging/difficult tasks. Detailed rainfall forecasting is not deterministic - the uncertainties involved are often expressed in probablistic forecasts, an example of which is at our website at: http://www.bom.gov.au/jsp/watl/rainfall/pme.jsp . Click on the "chance of rainfall' radio button.

regards, peter

Peter Baddiley
Regional Hydrology Manager
[illegible] & Water Division
Bureau of Meteorology
Level 21, [illegible] Ann Street
[illegible]
[redacted]
[illegible] www.bom.gov.au

**From:** Peter Baddiley
**Sent:** Monday, 24 July 2006 4:59 PM
**To:** [redacted]
**Cc:** Mike Bergin
**Subject:** Forecasting rainfall in Wivenhoe Dam catchment

Chris
[illegible]

[illegible]

Regards, Peter

**From:** Terry Malone [redacted]
**Sent:** Monday, 31 January 2011 8:06 AM
**To:** Barton Maher; Rob Drury
**Subject:** RE: Flood Changes

Barton

A few spelling mistakes and inconsistent units (I prefer m3/s).

I suggest that it should be stated predicted levels greater than EL 74 require the gates to be opened until the water level stabilises. Any reduction in starting level which does not achieve a peak lower than EL 74 is unlikely to have any impact upon peak release rate.

I would also make the point that design flows bear no resemblance to actual events. This is demonstrated by the Jan 2011 flood - dual peak inflows of about 10,000 and 12,000 m3/s ith a flood volume of 2,650,000ML, placing it in the 1 in 1,000 to 1 in 5,000 AEP ccording to Table 4.

Terry

-----Original Message-----
From: Barton Maher
Sent: Monday, 31 January 2011 1:22 AM
To: Rob Drury
Cc: Terry Malone
Subject: Flood Changes

FY Review

Barton Maher
Program Director - Dams & Weirs
QLD Bulk Water Supply Authority trading as Seqwater

Ph [redacted] Karalee
fice, 68 Junction Rd Karalee QLD 4306 Australia PO Box 2437, North Ipswich QLD 4305
ebsite | www.seqwater.com.au

-----Original Message-----
From: Rob Drury
Sent: Sunday, 30 January 2011 10:02 PM
To: Barton Maher
Subject:

Sorry for late email. Just to clarify, The 3 things we need to cover are 1. Weather which I will do 2. What are benefits of reduced levels in dam, re discharges and damages in brisbane and some indication of accuracy 3. Contingencies. There are maybe 4 of them, do no different, slow drawdown, pre release days before event and inherent risks, adjusted release ignoring bridges. If go with last one we ramp straight to say 1900cumecs but give some indication of damage curves [nil in city I guess] and what release equates to damage [3000cumecs I guess] to show what we can release depending on lockyer and bremer and local creeks
Rob

From: Terry Malone [redacted]
Sent: Sunday, 30 January 2011 5:12 PM
To: Rob Drury; Barton Maher
Subject: Flood Volumes

| Event | Somerset Dam | | | Wivenhoe Dam | | | |
|---|---|---|---|---|---|---|---|
| | Peak Elevation | Inflow | Outflow | Peak Elevation | Inflow* | Total | Outflow |
| | m AHD | ML | ML | m AHD | ML | | ML |
| Jan 1974# | 106.57 | 620,000 | 450,000 | na | 960,000 | 1,410,000 | 1,410,000 |
| Jun 1983 | 101.58 | 260,000 | 280,000 | | 800,000 | 1,080,000 | 470,000 |
| Mar 1989 | 102.59 | 370,000 | 380,000 | 69.78 | 310,000 | 690,000 | 660,000 |
| Apr 1989 | 102.69 | 340,000 | 350,000 | 71.45 | 520,000 | 870,000 | 820,000 |
| b 1999 | 102.96 | 450,000 | 280,000 | 70.45 | 940,000 | 1,220,000 | 900,000 |
| May 2009 | 99.62 | 110,000 | 110,000 | 62.19 | 125,000 | 235,000 | 0 |
| Mar 2010 | 99.41 | 210,000 | 200,000 | 66.43 | 190,000 | 390,000 | 0 |
| Oct 2010 | 101.37 | 250,000 | 270,000 | 69.61 | 360,000 | 630,000 | 630,000 |
| Mid Dec 2010 | 100.42 | 150,000 | 140,000 | 67.50 | 220,000 | 360,000 | 330,000 |
| Late Dec 2010 | 99.98 | 120,000 | 130,000 | 69.35 | 370,000 | 500,000 | 460,000 |
| Jan 2011 | 105.11 | 825,000 | 820,000 | 74.97 | 1,830,000 | 2,650,000 | 2,650,000 |

# No Wivenhoe Dam

* Upper Brisbane R only

Terry Malone
Principal Hydrologist
Queensland Bulk Water Supply Authority trading as Seqwater

seqwater

[redacted]

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