Department of Energy and Water Supply

Wivenhoe and Somerset Dams Optimisation Study

Report

March 2014

Great state. Great opportunity.

Queensland Government

1. Aerial view of Lake Wivenhoe (Wivenhoe Dam on the left, middle). Courtesy of Tourism Queensland. Photographer: Barry Goodwin
2. Wivenhoe Dam with centre gate spilling. Source: Seqwater, Revision 11 Flood Manual, Appendix H, Figure 8

This publication has been compiled by the Department of Energy and Water Supply

Contents

List of tables

List of figures

Preface

The Wivenhoe and Somerset Dams Optimisation Study (WSDOS) delivers a Queensland Government commitment to implement the recommendations of the Queensland Floods Commission of Inquiry. The study into possible improvements to the flood operations of the existing dams is the first major review of operations since Wivenhoe Dam was constructed in the late 1970s.

The study was initiated to review the operation of Wivenhoe and Somerset dams and in the process, inform future reviews of the operational procedures in the flood mitigation manual. Undertaking the study promotes continuous improvement and application of best practice flood risk management.

The January 2011 inflows into Wivenhoe and Somerset dams were among the largest on record, necessitating the highest discharges since the dams were constructed. The Brisbane River floods were the largest in nearly 40 years. The big wet of October 2010 to January 2011 was preceded by the Millennium Drought resulting in the key supply storages reaching critical levels in 2007.

WSDOS is the product of two years of cooperation and knowledge sharing between Queensland Government entities and the Brisbane River catchment councils (Brisbane City, Ipswich City, Lockyer Valley Regional and Somerset Regional councils). The cooperation and knowledge sharing between state and local government has ensured the assessments and findings of WSDOS are evidence based and informed by specialist studies.

Much of the work undertaken is possible now because of the experience and learnings and the data that became available during and after the 2010 / 2011 wet season, and because of hydrologic and other techniques that are now possible with advances in computer technology. The current demands for water supply and recent upgrades of infrastructure capacity and configuration in south east Queensland provides a different context to those in 1977 when the original feasibility and impact assessments for Wivenhoe Dam were completed.

The purpose of WSDOS is to assess and present various operational options to enable the government to make informed decisions on the future operation of Wivenhoe and Somerset dams. The optimisation study extends beyond alternative flood operations of the dams to also consider potential alternative water supply operations.

The options have been assessed against competing objectives for dam operations, in particular balancing water supply security, dam safety, flood inundation impacts downstream of the dam and economic outcomes. Optimisation of the operation of Wivenhoe and Somerset dams is particularly challenging because releases from these dams must take into account flows emanating from downstream tributaries (which cannot be controlled by the dams). Ultimately, trade-offs must be made between the key considerations of flood mitigation, water supply security and the structural safety of the dams whilst having regard to bank slumping and erosion and impacts on flora and fauna.

Some of the options assessed in this report will require more detailed investigations to fully detail all the implications before they could be implemented. This is the case where, for example, dam safety risks have been identified and the construction of new infrastructure may be required. Additionally, new data and enhanced understanding is occurring through studies such as the Brisbane River Catchment Flood Study.

Late in 2014, the Queensland Government will make a decision on the future operation of both Wivenhoe and Somerset dams, and North Pine Dam, following consideration of the results of community consultation.

Acknowledgments

The Department of Energy and Water Supply (DEWS) would like to thank officers from the following organisations who undertook significant assessments as part of the study:

- Seqwater
- Department of Science, Information Technology, Innovation and the Arts
- Department of Transport and Main Roads

DEWS would like to thank officers from the following organisations who provided data and information used in the assessments undertaken as part of the study:

- Brisbane City Council
- Ipswich City Council
- Somerset Regional Council
- Lockyer Valley Regional Council

Glossary

Terms

AAD	Average Annual Damage – the total damage caused by all floods over a long period of time divided by the number of years in that period (CSIRO 2000).
AAI	Average Annual Impact – the total impact caused by all floods over a long period of time divided by the number of years in that period.
Act	*Water Supply (Safety and Reliability) Act 2008* (QLD)
AFC	Acceptable Flood Capacity for a referable dam – varies dependent on the hazard category (DEWS 2013b).
AEP	Annual Exceedance Probability – is a measure of the likelihood (expressed as a probability) of a flood event reaching or exceeding a particular magnitude in any one year. A 1% (AEP) flood has a 1% (or 1 in 100) chance of occurring or being exceeded at a location in any year.
AHD	Australian Height Datum
SEQ water supply system	The system supplying water to water service providers in SEQ. Currently made up of 12 SEQ water storages, raw water treatment plants and associated bulk water distribution mains (including the Northern Pipeline, Southern Regional Pipeline, Eastern Pipeline Inter-connectors), the Western Corridor Recycled Water Scheme, and the Gold Coast Desalination Plant.
Cumulative probability	The probability of an event occurring over a period of time, any time in that period. This probability increases over time.
Dam Crest Flood	Dam Crest Flood – the flood which just overtops the crest of the dam wall
Design flood event	Hypothetical flood events based on a design rainfall event of a given probability of occurrence (i.e. AEP). The probability of occurrence for a design flood event is assumed to be the same as the probability of rainfall event upon which it is based (IEAust 2003).
EAP	Emergency Action Plan that is approved under section 352I(1)(a) or taken to be an approved emergency action plan under section 352Q(2) of the *Water Supply (Safety and Reliability) Act 2008* (QLD).
EL (mAHD)	Elevation (in metres) above the Australian Height Datum
Flood Forecasting System	Flood Forecasting System – suite of computer programs that Seqwater use to forecast flood flows and assist decision making during flood events using real-time data.
Flood mitigation manual (Flood	A flood mitigation manual approved under section 371E(1)(a) or 372(3) of the *Water Supply (Safety and Reliability) Act 2008* (QLD).

Manual)

FOSM Flood Operations Simulation Model (refer Seqwater 2014a)

Floodplain Area of land adjacent to a creek, river, estuary, lake, dam or artificial channel, which is subject to inundation by the PMF. (CSIRO 2000).

FSL Full Supply Level - maximum normal water supply storage level of a reservoir behind a dam.

FSV Full Supply Volume – volume of the reservoir at FSL.

GIS Geographic Information System

GCDP Gold Coast Desalination Plant

GL Gigalitres = 1,000,000,000 litres

Hydrologic / Hydrology Relating to rainfall and runoff.

Hydraulic Relating to flow characteristics – level, depth, velocity and extent and combinations thereof.

Hydrodynamic Relating to time-variant hydraulic characteristics

IAM Integrated Assessment Methodology used for determining the overall costs and benefits of flood mitigation options.

IQQM Integrated Quantity and Quality Model for water resources planning.

LiDAR LiDAR (combination of the words light and radar) is a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light.

LOS Level of service refers to objectives specifying the level of performance that SEQ residents can expect from their bulk water supply system.

ML Megalitres = 1,000,000 litres

m^3/s Cubic metre per second - unit of measurement for flow or discharge

NPC Net Present Cost

NPDOS North Pine Dam Optimisation Study

PMF Probable Maximum Flood – the largest flood that could conceivably occur at a particular location, resulting from the PMP. (CSIRO 2000) and Australia Rainfall and Runoff, 2003 (IEAust, 2003)

PMP Probable Maximum Precipitation – the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends. (CSIRO 2000; IEAust 2003).

Population at risk (PAR)	In relation to dam safety considerations – the population living within a failure impact zone (DEWS 2013b)
Purified recycled water (PRW)	Purified recycled water is wastewater that has been treated to a very high standard using an advanced water treatment process (including microfiltration, reverse osmosis and ultraviolet light).
QFCoI	Queensland Floods Commission of Inquiry
RSM	Regional Stochastic Model - for water supply headworks simulation modelling in SEQ (see WATHNET)
SEQ	south east Queensland
SEQ water storages	Key water supply system storages: • Wivenhoe Dam • Somerset Dam • North Pine Dam • Leslie Harrison Dam • Lake Kurwongbah • Baroon Pocket Dam • Ewen Maddock Dam • Cooloolabin Dam • Wappa Dam • Lake Macdonald • Hinze Dam • Little Nerang Dam
Stochastic flood event	Statistically generated synthetic flood event. Stochastic flood events include variability in flood input parameters (eg. temporal and spatial rainfall patterns) compared to design flood events. Stochastic flood events by their method of generation exhibit a greater degree of variability and randomness compared to design flood events (See also *Design flood event*).
Synthetic flood event	See *Stochastic flood event*.
TFSL	Temporary Full Supply Level
WATHNET	A suite of programs capable of simulating the operation of a wide range of water supply headworks and transfer systems serving urban, industrial, irrigation and in-stream demands.
WCRWS	Western Corridor Recycled Water Scheme
WSDOS	Wivenhoe and Somerset dams Optimisation Study

Abbreviations of organisations and agencies

BCC	Brisbane City Council
BoM	Bureau of Meteorology
DEWS	Queensland Department of Energy and Water Supply
DNRM	Queensland Department of Natural Resources and Mines
DSDIP	Queensland Department of State Development and Infrastructure Planning
DSITIA	Queensland Department of Science, Information Technology, Innovation and the Arts
DTMR	Queensland Department of Transport and Main Roads
ICC	Ipswich City Council
IEAust	Engineers Australia (formerly known as the Institution of Engineers Australia)
LVRC	Lockyer Valley Regional Council
Seqwater	SEQ bulk water authority trading as Seqwater
SRC	Somerset Regional Council

Summary

S1. Purpose

Wivenhoe Dam and Somerset Dam are located in the Brisbane River Basin and are operated by Seqwater for water supply and mitigation of floods in the lower Brisbane River.

The Wivenhoe and Somerset Dams Optimisation Study (WSDOS) was initiated in response to the Queensland Floods Commission of Inquiry (QFCoI) to investigate potential alternative operations of the existing dams during floods.

Consideration was given to relevant sections/recommendations of the QFCoI March 2012 Final Report and the August 2011 Interim Report. The key QFCoI recommendations influencing this study were the Final Report recommendation 17.3 and the Interim Report recommendation 2.13. Other QFCoI recommendations relevant to the operations of Wivenhoe and Somerset dams are outlined in Table 1.6 and Table 1.7 of Chapter 1.

QFCoI Final Report recommendation 17.3 states that the Queensland Government should consider a wide range of options, prioritise differing objectives for the operation of the dam, and consider implications over a wide range of flood events for inundation of urban and rural areas; water supply security; dam safety; submergence of bridges; bank slumping and erosion; and riparian fauna and flora.

QFCoI Interim Report recommendation 2.13 states that modelling work should be carried out to: analyse a range of water supply levels, operating strategies and flood events (historical, design and stochastic (synthetically generated)); test the robustness of relying on rainfall forecasts; and assess the probability of closely spaced flood peaks using historical records.

WSDOS has investigated options to optimise the operations of the dams with a view to improving the mitigation of urban and rural flooding in Brisbane and Ipswich City Council and Somerset Regional Council areas.The study considered the possibility of increased releases from Wivenhoe Dam that may be possible if bridges and crossings were raised. However, the provision of new or augmented infrastructure (such as upgrades to the dams, the raising of bridges, provision of an alternative transport route, and flood retention basins), planning and development controls and other local initiatives (such as property buy back, river bank stabilisation and backflow prevention) were not within the scope of this study.

S2. Parallel Studies

The Brisbane River Catchment Flood Study (BRCFS) being managed by the Department of Natural Resources and Mines is currently being prepared. It will result in revised hydrologic and hydraulic models, focussing on the Brisbane River downstream of Wivenhoe Dam. Up to date floodplain risk assessment information will be generated from the flood study, and through the Brisbane River Floodplain Management Study and the Brisbane River Floodplain Management Plan, being managed by the Department of State Development Infrastructure and Planning (DSDIP).

S3. Project management

The Department of Energy and Water Supply (DEWS) managed the optimisation studies with substantial input from:

- Seqwater on water supply security investigations and flood management and dam operations investigations, including dam safety.

- the Department of Science Information Technology Innovation and the Arts (DSITIA) on the frequency of submergence of low level bridges and crossings, historical occurrence of closely spaced flood peaks, bank slumping and erosion and riparian fauna and flora, and
- the Department of Transport and Main Roads (DTMR) on the transport implications of submerging bridges and river crossings.

Brisbane City (BCC), Ipswich City (ICC) and Somerset Regional (SRC) councils provided available information on flood inundation assessments and transport implications. The Bureau of Meteorology (BoM) advised on the reliability of forecast rainfall products.

S4. Operational options

WSDOS is an integrated assessment of 32 operational options undertaken to assist consideration of the necessary trade-offs involving flood inundation, water supply security, dam safety, submergence of bridges and crossings, bank slumping and erosion, and riparian fauna and flora.

The operational options involve:

- increasing flood storage available for flood mitigation
- increasing downstream target flows at bridges and Moggill with the view to enabling larger releases from Wivenhoe Dam during the earlier stages of a flood event so as to preserve the amount of flood mitigation storage available should larger inflows eventuate.

Essentially, assessment of the operational options available involves trade-off considerations between increasing or reducing:

- flood mitigation
- water supply security
- dam safety and
- the extent of disruption to the downstream community through bridge and road closures.

The integrated assessment undertaken in Chapter 15 seeks to quantify these trade-offs within the limitations that is possible under such an assessment. Bank slumping and erosion, and impacts on riparian fauna and flora ultimately were not trade-off considerations as it was difficult to establish that flood operations have increased impacts above that which would have occurred naturally. Few strategies were identified that may reduce impacts on the downstream environment. However, useful observations have been made regarding the status of erosion along the Brisbane River and the factors most likely to be contributing.

Numerous assumptions have been made and there are uncertainties associated with the complex hydrologic assessments for dam operations and water supply security, as well as the information underpinning the net present cost assessments. Hence the results of this study should be used as a guide to decision making helping to understand the likely relative performance of operational options rather than providing the definitive answer when comparisons are made.

The Base Case (Option1) for comparative purposes was the existing dams operated using the 2013 ‘Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam’ (Flood Manual). The outcomes of all other options were compared with the Base Case over a range of historical, stochastic and selected design flood events.

Under the Flood Manual, the four strategies for Wivenhoe Dam to achieve the objectives for flood mitigation are:

- Strategy WR (Rural Strategy) which aims to minimise disruption to rural life by keeping bridges and crossings open while limiting inundation of urban areas and protecting the safety of the dam
- Strategy WU (Urban Strategy) which aims to limit inundation of urban areas while protecting the safety of the dam
- Strategy WS (Dam Safety Strategy) which aims to protect the structural safety of the dam
- Strategy DD (Drain-down Strategy) which seeks to drain both dams to near their full supply levels (FSLs) within seven days, whilst minimising impacts on rural and urban areas and riparian flora and fauna.

Figure S1 shows the current allocation of Wivenhoe storage capacity to water supply, rural flood mitigation, urban flood mitigation and dam safety purposes.

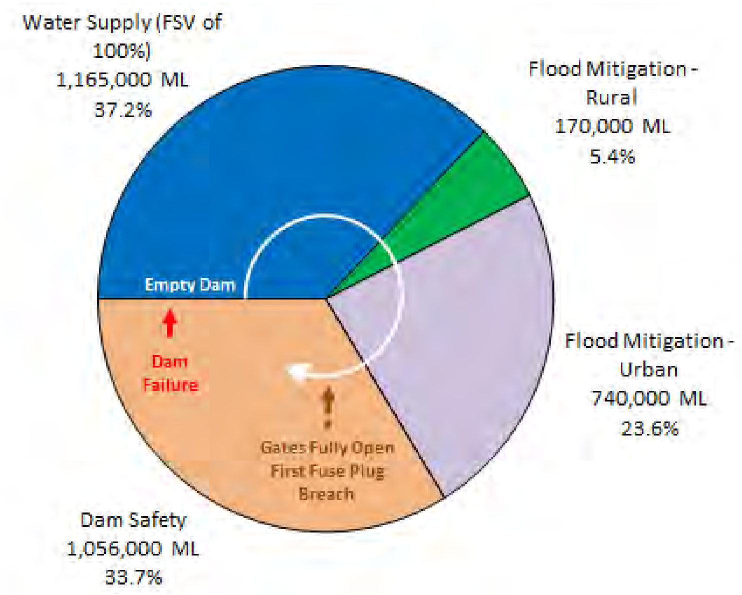


Figure S1 Apportionment of Wivenhoe Dam storage to water supply and flood operations

The QFCoI Interim Report recommendation 2.13 has been addressed by completing modelling of 32 operational options across a range of supply levels, operating strategies and flood events (historical, design and stochastic (synthetically generated)). The operational options (Refer Figure S2) comprised:

- four water supply full supply volume (FSV) scenarios for Wivenhoe Dam (including the current 100% FSV)
- eight alternative flood operations for Wivenhoe and Somerset dams, including:
  - the Base Case (existing operations)
  - six variations of operating procedures (and parameters) in the Flood Manual, and
  - one case of prescribed operations for Wivenhoe Dam which is different to the concepts in the Flood Manual and does not have regard for downstream catchment inflows.

Owing to the intricacies of the flood operations variations, especially in the Urban Strategy, Table S1 was prepared to allow ‘at a glance’ identification some of the main differences. Table S2 needs to be referred to for details of the flood operations variations.

Figure S2 illustrates the 32 options modelled in terms of the proportions of:

- the storage in Wivenhoe Dam allocated to various Flood Manual strategies; and
- how the storage for the Urban Strategy is utilised relative to target flow at Moggill.

Table S1 Summary of flood operations alternatives

Operational Alternative	*Rural Strategy* FSL[1] + 1.5 m	*Urban Strategy* FSL + 1.5 m to *Dam Safety Strategy* Level		*Dam Safety Strategy* Level (EL mAHD[2])
		Target Flow at Moggill (m³/s)	Max Target Flow at Moggill (m³/s)	
Base Case	Yes	Flood Manual	4,000	74.0
Bypass Rural	No	Flood Manual	4,000	74.0
Alt Urban 1a	Yes	Stepped change to 4,000	4,000	74.0
Alt Urban 1b	No	Stepped change to 4,000	4,000	74.0
Alt Urban 2	No	Stepped change to 3,300	6,000	74.5
Alt Urban 3	No	Linear increases to 6,000	6,000	75.0
Alt Urban 4	Yes	Same as Base Case up to EL 74 mAHD	4,000	76.2
Prescribed Operations	Simple rules to maximise available storage in dams (Refer Table S1). Responds to Wivenhoe Level & does not consider downstream flows.			NA

Notes:
1. FSL – full supply level
2. EL mAHD – elevation metres Australian Height Datum (AHD)

The 32 operational options are preliminary in their design and could be further optimised.

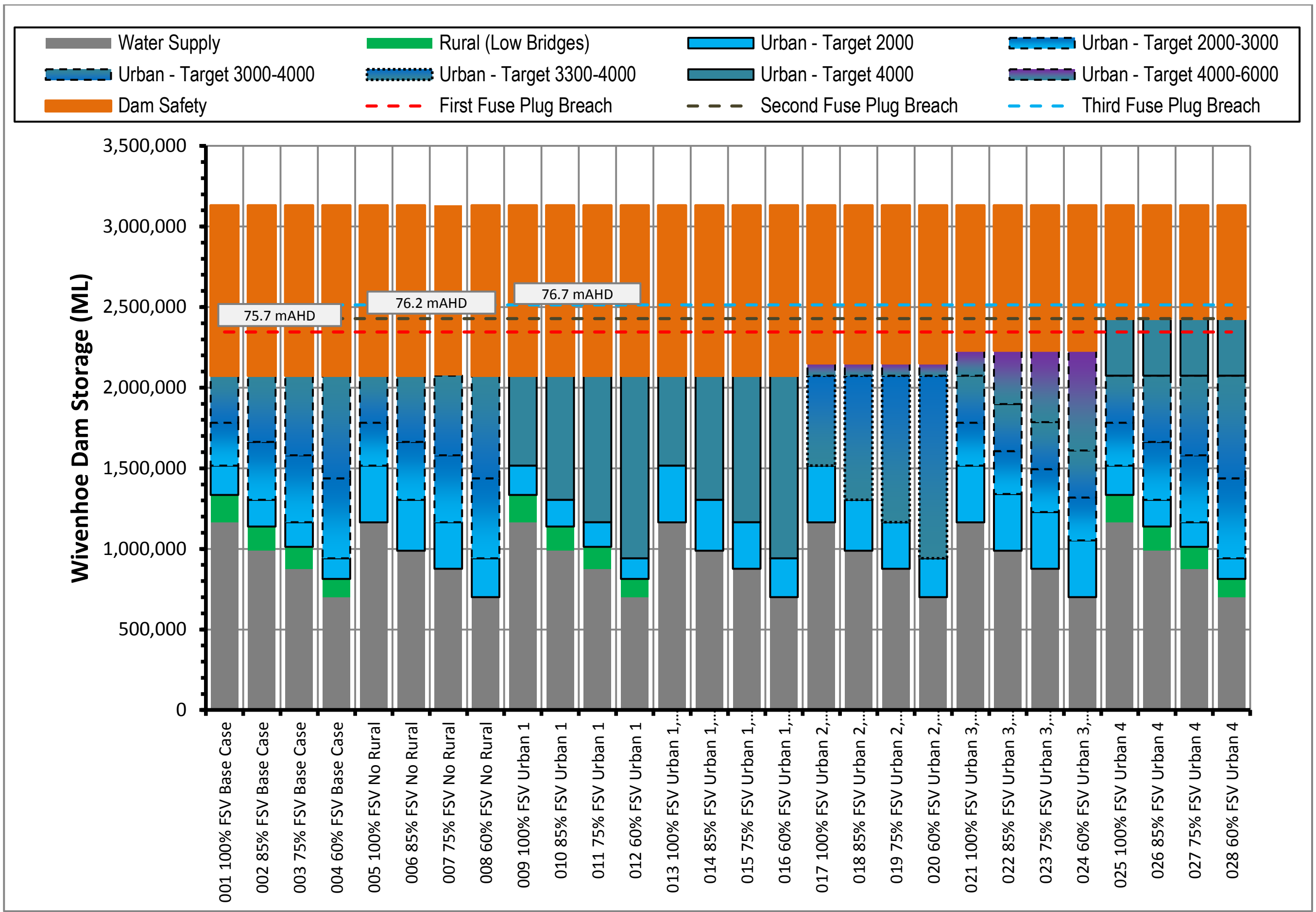
QFCoI recommended modelling assessments were addressed as follows:

- Moving to a higher release rate earlier in the Rural Strategy was addressed by bypassing the Rural Strategy operational alternative (options 005 to 008), alternative Urban 1b (options 013 to 016), alternative Urban 2 (options 017 to 020) and alternative Urban 3 (options 021 to 024) and described in Table S1 and Table S2.
- Modelling of the stepped change from the Urban Strategy to the Dam Safety Strategy was addressed in operational alternatives Urban 1a and 1b, Urban 2 and Urban 3. These operational alternatives also incorporated either or both increases in the maximum target flow (which allows higher releases) and raised triggers for the Dam Safety Strategy.
- Operating the dam gates in conjunction with initiation of the fuse plugs was addressed by modelling operational alternative Urban 4 (options 025 to 028).

DSITIA's analysis of the probability of flood peaks using historical records supports the current Flood Manual Drain-down Strategy which seeks to drain both dams to near their FSLs within seven days of the end of a flood event.

Advice was sought from the BoM on simulations to test the robustness of relying on rainfall forecasts. While the science underpinning rainfall forecasts is continually being improved, BoM advised that forecast '*models have less skill for higher rainfall intensities and while guidance may indicate that a heavy rainfall event is possible, it is only guidance and should be used in that way*.' At present, there are temporal and spatial uncertainties with forecast rainfall which undermine confidence in their use for flood operations. Thus, Seqwater has been in discussion with BoM about potential collaborative research and investigation into the potential future use of rainfall forecasts in dam operations.

Water supply assessments assume the existing south east Queensland bulk water supply system (SEQ water supply system) operated as regulated in subordinate legislation - the System Operating Plan (SOP). Level of service objectives articulated in the SOP are currently under review. Once the revised objectives are prescribed in regulation (expected in 2014) the SOP will cease to have effect and Seqwater will develop a Water Security Program setting out how the objectives will be achieved.



Source: Seqwater 2014a, Figure 5-12

Figure S2 Operational options

Flood severity classifications used in this study were:

- minor flood - peak flow at Moggill < 3,000 m^3/s i.e. more frequent than about a 1 in 10 AEP – property inundation in the order of hundreds
- moderate flood - peak flow at Moggill 3,000 m^3/s to 6,000 m^3/s i.e. about a 1 in 10 AEP to about 1 in 50 AEP flood – property inundation in the order of hundreds to thousands
- major flood - peak flow at Moggill > 6,000 m^3/s i.e. less frequent than about a 1 in 50 AEP flood – property inundation in the order of 1,000s to 10,000s.

  (Note: These are different to those adopted by BoM.)
- The onset of significant overfloor urban dwelling flooding has been assumed to occur at about 4,000 m^3/s, however urban inundation and other impacts occur for flows above 2,000 m^3/s. Submergence of the Mt Crosby and Brisbane Valley Highway bridges occurs at between 1,800 m^3/s and 2,000 m^3/s. The flood threshold and flood severity classification provided the basis for the selection of the target flows at Moggill shown in Table S2.

Table S2 Description of flood operations alternatives

Operational Alternative	Strategies 2013 Flood Manual	Variation from 2013 Flood Manual (WR –Rural Strategy, WU – Urban Strategy, WS – Dam Safety Strategy, DD – Drain Down Strategy)	Option Number[1]
Base Case (Flood Manual)	WR, WU, WS and DD	As per flood manual	1 to 4
Bypass Rural	WR	No stepped flow targets when flow below 2,000 m^3/s at Moggill or dam level below FSL+3 m	5 to 8
	WU	No change	
	WS	No change	
	DD	No change	
Alternative Urban 1a	WR	No change	9 to 12
	WU	Once FSL+3 m exceeded, target flow at Moggill lifted to 4,000 m^3/s. Target remains until WS trigger EL 74 m	
	WS	No change	
	DD	No change	
Alternative Urban 1b	WR	Bypassed. No stepped flow targets when flow below 2,000 m^3/s at Moggill or level below FSL+3 m	13 to 16
	WU	As for Urban 1a	
	WS	No change	
	DD	No change	
Alternative Urban 2	WR	Bypassed	17 to 20
	WU	• Once FSL+3 m exceeded, target flow at Moggill immediately lifted to 3,300 m^3/s • Once predicted flow reaches 3,300 m^3/s, target then transitions to 4,000 m^3/s at EL 74 m • Increase in WU compartment size (dam safety trigger raised to EL 74.5 m) • Gradual increase in downstream target flows from 4,000 m^3/s at EL 74 m to 6,000 m^3/s at EL 74.5 m	
	WS	• Dam safety trigger raised to EL 74.5. Flow to be 6,000 m^3/s at EL 74.5 m • Decrease in volume of dam safety owing to 0.5 m increase in WS trigger	
	DD	No change	
Alternative Urban 3	WR	Bypassed	21 to 24
	WU	• Same as Base Case (100% FSV) up to EL 74 m • For other FSVs, flow targets based on maintaining same WR and WU volumes as for 100% FSV case • Increase in WU compartment size, owing to raising of dam safety trigger to EL 75 m • Downstream target flows increase from 4,000 m^3/s at EL 74 m to 6,000 m^3/s at EL 75 m	
	WS	Decrease in WS compartment size (matches increase in WU compartment size)	
	DD	No change	
Alternative Urban 4	WR	No change	25 to 28
	WU	• Same as Base Case to 74 m • Increase in WU compartment size by raising dam safety trigger to Fuse Plug 2 initiation (EL 76.2 m) • Flow set at 4,000 m^3/s from EL 74 m to EL 76.2 m	
	WS	• Dam safety trigger raised to EL 76.2 m • Decrease in WS compartment size (matches increase in WU compartment)	
	DD	No change	
Prescribed Option	WR, WU, WS & DD	Strategies replaced by prescribed gate openings, which do not consider downstream flows	29 to 32

[1] In each case, the four options are based on 100%, 85%, 75% and 60% FSV

S5. Conclusions

The QFCoI Final Report recommendation 17.3 required that the Queensland Government be presented with options, rather than specific policy recommendations governing the operations of Wivenhoe and Somerset dams. The QFCoI stated in its Interim Report '*It is for the Queensland Government, based on advice as to the results of the review of the Wivenhoe manual and studies into water security and the impact on the floodplain, to endorse a set of strategies which best satisfies the needs of the community. Any decision by government should follow extensive consultation with councils and the community*.'

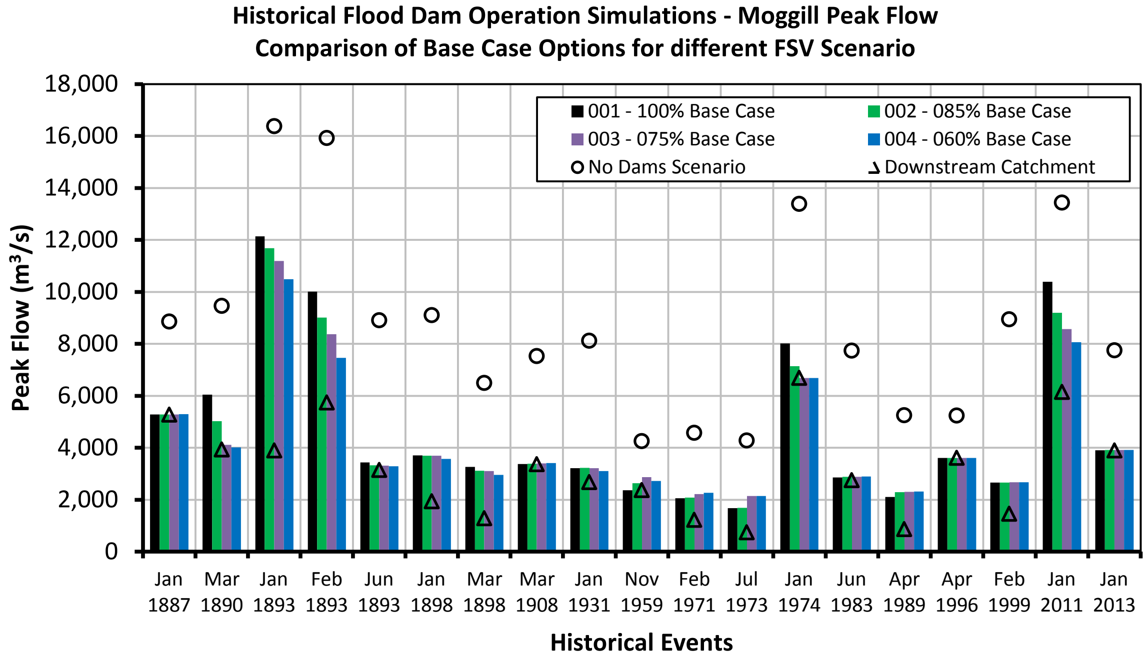
Some broad overall findings are apparent from the body of work completed, which will assist the consideration of how to best balance the potentially competing objectives. These are summarised below.

S5.1 General

- Flood mitigation performance can generally be improved by increasing the available flood mitigation storage volume. This can be done in two ways that both involve trade-offs. One way is to lower the full supply volumes of the dams (reduces water supply security), the other way is to increase the dam safety strategy trigger level for Wivenhoe Dam (increases the likelihood of both fuse plug initiation and flood overtopping of Wivenhoe Dam).
- For very large floods, flood mitigation performance can be improved by increasing downstream target flows during flood operations with a view to preserving the flood mitigation storage for longer. This approach carries with it the risk of flooding houses unnecessarily if the expected large flood does not eventuate.
- The integrated assessment was based on a range of flood and water supply security assessments and net present cost economic assessments of tangible costs.
- These assessments can only be used as a guide for decision making as the quality of analysis underpinning the flood mitigation, water supply security and economic assessments was limited by the availability and accessibility of suitable base data.
- The study has identified that there is no simple solution that demonstrates a marked reduction in total costs. Reducing the Wivenhoe Dam full supply volume
    - reduces expected flood damage and impact costs, but
    - the reduced flood cost is of similar order-of-magnitude to or less than the increase in bulk water infrastructure and operational costs.
    - given the order of accuracy of the work completed, the total cost comparison does not support a permanent lowering of the FSV of Wivenhoe Dam.
- Separate assessment of new infrastructure alternatives to increase flood storage may be warranted to determine if there is a net benefit.
- Only operational alternatives Urban 3 and Urban 4 provide a small reduction in net present costs from the Base Case – with the reduction in costs reducing as the dam levels are lowered. However the dam safety implications of adopting these options are not considered in the calculated net present costs.
- These conclusions are sensitive to the availability of manufactured water and study assumptions but are considered to be well within the accuracy of the assessment and the uncertainty and variability of natural flood and drought conditions.
- The dams cannot eliminate flood inundation during moderate and major floods.

S5.2 Flood operations modelling

- The flood operations simulation model used to compare the operational options makes definitive decisions based on good knowledge of forecast catchment flows. This may not reflect the modelling uncertainty that can occur during real time operations. The model also does not attempt to account for professional judgement decisions made by engineers during actual flood events.
- Therefore in an actual flood event, flood operations may produce better or worse outcomes than predicted by the model depending on the information available in real time to the flood operations engineers and the operational decisions taken.
- The results of historical modelling simulations (Figure S3 and Figure S4) of peak flows at Moggill show that the existing dams under current operations have a significant flood mitigating effect for all the major historical floods. Without the dams, flood impacts for all floods would be worse.
- The modelling indicates that any increase in flood storage achieved under the eight alternatives (including the Base Case) based on operations under the 2013 Flood Manual offers little benefit (and may create a dis-benefit) for minor and low end moderate floods but larger potential benefits for high end moderate and major floods. This is because the additional flood storage created in Wivenhoe Dam is not fully utilised (needed) in the smaller floods.
- While there may be a tendency for some operational options to improve high end moderate and major flood mitigation outcomes, for other options the flood mitigation outcomes could be worse.

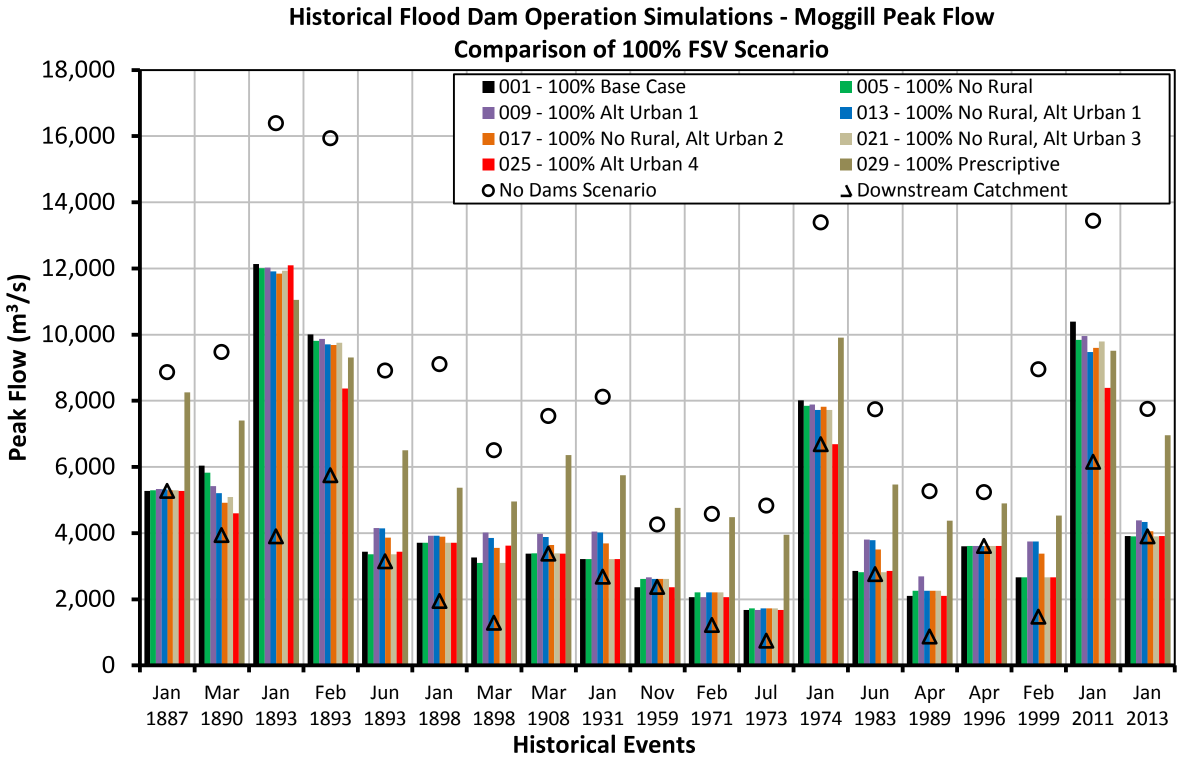


Notes:

1. Estimated peak flows without the dams shown as circles with contribution from flows downstream of Wivenhoe shown as triangles.
2. Results assume good knowledge of forecasted catchment flows - in practice this quality of information may not be available for real-time operations

Source: Based on Seqwater 2014a, App C1

Figure S3 Historical simulations comparing peak flows at Moggill for Base Case and different FSVs



Notes: (refer Figure S3)

Source: Based on Seqwater 2014a, App C1

Figure S4 Historical simulations comparing peak flows at Moggill for the eight operational alternatives

- Any decision to change the flood operations strategies in the 2013 Flood Manual requires consideration of the trade-offs between flood mitigation, water supply security and disruption caused by bridge submergence and for each location trade-offs between:
  - increased flooding from minor and lower end moderate floods, and
  - reduced flooding in high end moderate and major floods.
- When compared to current operations under the 2013 Flood Manual:
  - Increasing flood mitigation storage (either by lowering the full supply volume or by raising the dam safety strategy trigger level) has a greater impact on improving flood mitigation performance than does increasing downstream target flows during flood operations.
  - Increasing downstream target flows in the Rural Strategy under the 2013 Flood Manual increases the likelihood that minor to moderate flooding will occur.
  - Increasing downstream target flows in the Urban Strategy under the 2013 Flood Manual is likely to increase moderate level flooding and reduce major flooding.
  - Increasing the dam safety strategy trigger level to store more flood water increases the likelihood that the fuse plugs will be initiated during a flood event.

- For all locations, operational alternative Urban 3 is likely to on average:
    - slightly increase minor and low end moderate flooding and inconvenience due to bridge submergence because the Rural Strategy is bypassed.
    - slightly reduce high end moderate and major flooding due to increased flood mitigation storage and downstream target flows.
    - Minimally reduce the duration of submergence of downstream and upstream bridges

  Note: The average influence on flooding in Ipswich of changing operations across many floods does not appear to be significant.
- For operational alternative Urban 3, it should be noted that:
    - while the alternative tends to produce better flood mitigation outcomes during high end moderate and major flooding, for some floods the flooding outcomes could be worse.
    - the slight increase in minor and low end moderate flooding and consequential inconvenience due to bridge submergence can be minimised by including a Rural Strategy, but this would slightly reduce the performance of the alternative.
- For all locations, operational alternative Urban 4 tends to produce better flood mitigation outcomes as an average over the full range of floods analysed but would also result in more frequent initiation of the fuse plugs. This would pose a dam safety threat that would need further investigation and rectification if required before it could be implemented. This alternative would increase the duration of submergence of upstream bridges.
- The dam overtopping assessments indicate that none of the alternatives significantly impact the dam overtopping risk in terms of the acceptable flood capacity expressed as a percentage of the probable maximum flood. Despite this finding, it is considered that additional investigations should be completed to better understand the risks prior to implementation of any option that raises the Dam Safety Strategy trigger level such as alternative Urban 3 and alternative Urban 4.

* When Wivenhoe Dam safety upgrades are implemented, the upgrades should consider how some of the potential flood mitigation benefits of alternative Urban 4 could be realised while protecting the safety of Wivenhoe Dam.
* Flooding downstream of the dams is a complex interaction of downstream tributary inflows (particularly Bremer River and Lockyer Creek), other inflows to the Brisbane River and releases from Wivenhoe Dam. For example, in some floods the Bremer River is the dominant influence on flood levels in the Ipswich central business district.
* In order to be able to better specify downstream flow targets, it will be necessary for the body of work leading to the preparation of the Brisbane River Flood Study the Brisbane River Floodplain Management Study and the Brisbane River Floodplain Management Plan to better define the relationship between flood flows, flood heights, and flood inundation impacts.
* The interaction of dam releases and downstream catchment flows explains the clearly inferior modelled flood mitigation performance of options based on prescribed operations which do not consider downstream inflows. Hence it is not proposed to consider this alternative further.

S5.3 Future investigation and research

- Potential future investigation and research includes:
    - joint research with BoM into the potential for advance or increased releases in response to: seasonal forecasts; imminent flood event rainfall forecasts; and in response to actual and forecast inflows to the dam during a flood event (Seqwater has applied for a forecast rain research project with BoM and other leading research partners.)
    - a systematic long term (river morphology and vegetation structure) data collection and analysis program to help establish a better baseline reference for the future management of the river system.

Summary of studies

S6. Studies undertaken

Significant specialist studies (Figure S5) that were completed to evaluate the 32 operational options included:

1. Dam operations and associated hydrologic assessments by Seqwater
2. Water supply security assessments by DEWS and Seqwater
3. Bank slumping, erosion and flora and fauna studies by DSITIA
4. Traffic studies by DTMR, and
5. Integrated assessment of the options commissioned by DEWS.

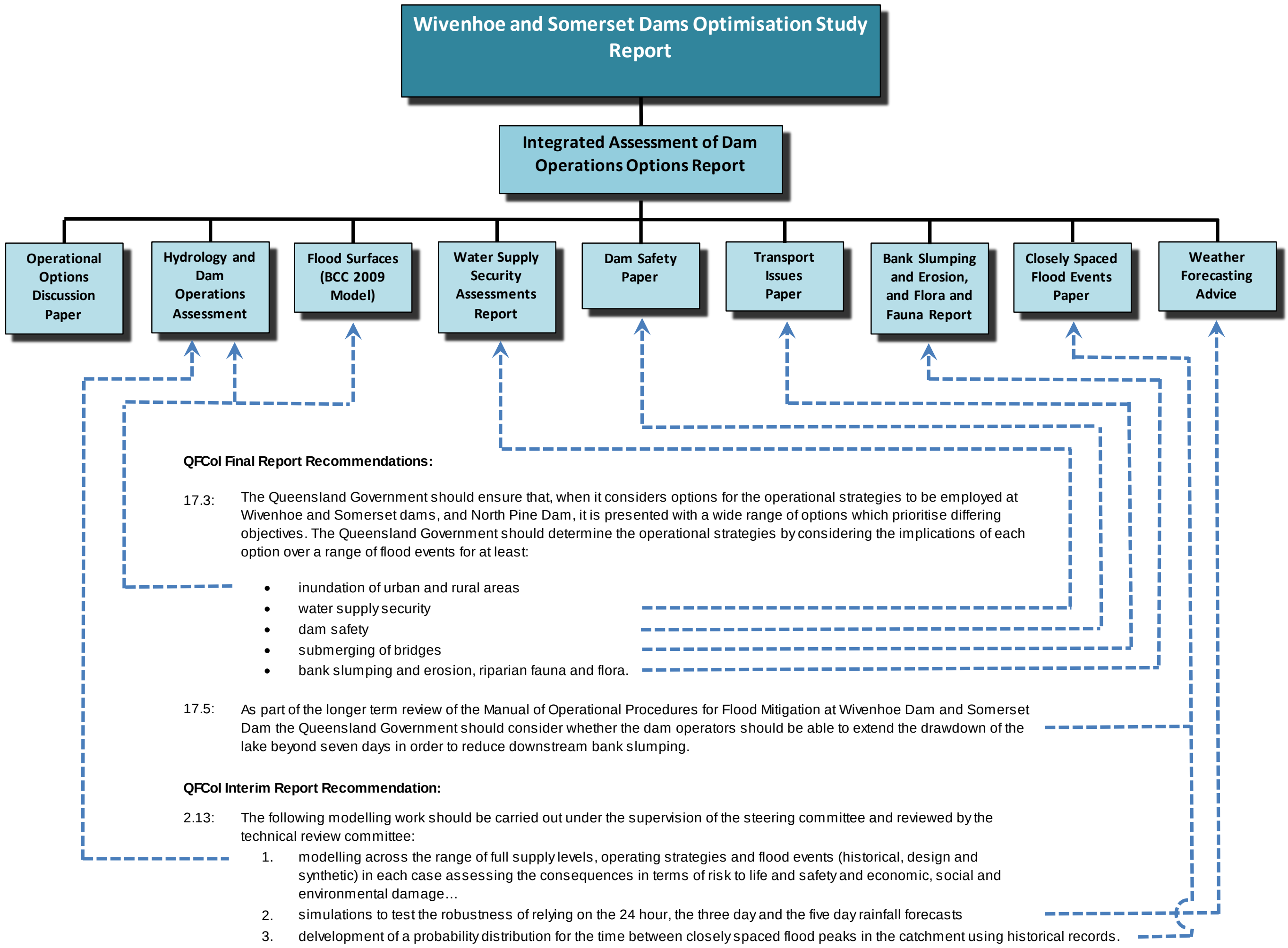
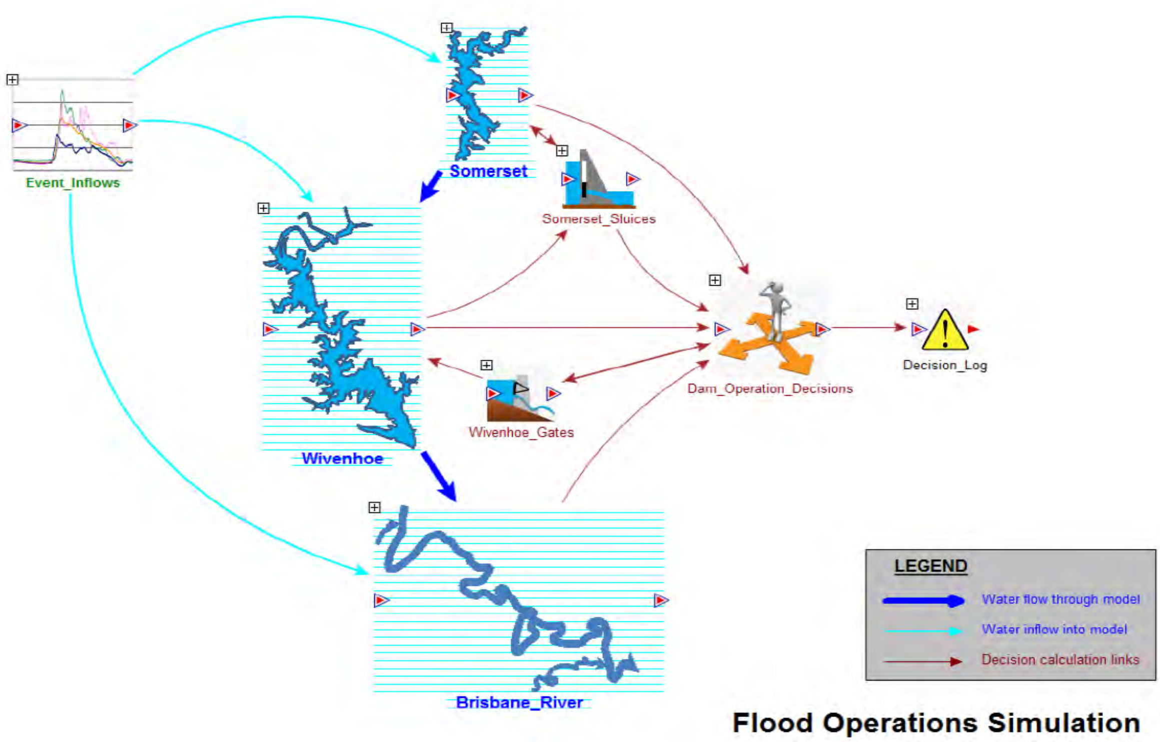


Figure S5 Relationship of specialist studies and advice to main report

Other inputs to the project included:

1. Operational Options Discussion Paper by DEWS
2. Provision of flood surfaces data prepared in 2009 by BCC
3. Residential and non-residential buildings data by councils
4. Dam safety review by Seqwater and DEWS
5. Flood warning review by DEWS
6. Advice from the Bureau of Meteorology on the use of rainfall forecasts for dam operations
7. Assessment of the probability of closely spaced flood events by DSITIA to inform Drain-down Strategy decisions.

Hydrologic modelling and flood operations assessments were the most significant inputs to the study. A flood operations simulation model (FOSM) was developed by Seqwater in order to test the 32 operational options. The model accepts inputs in terms of event inflows for Somerset, Wivenhoe and locations downstream of Wivenhoe, predicts lake levels in the dams, and applies operating rules for the gates at Wivenhoe and the sluices at Somerset, in accordance with the operational alternatives in Table S2.



Source: Seqwater 2014a

Figure S6 **Schematic of Flood Operation Simulation Model (FOSM)**

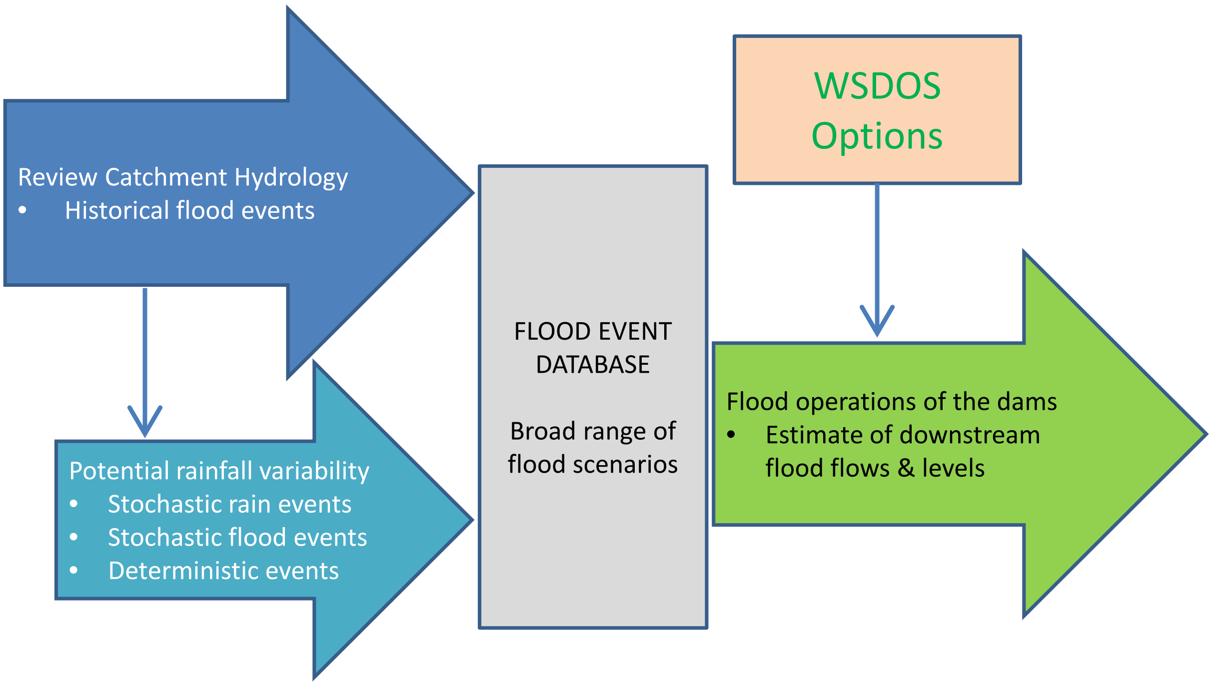
S7. Flood events modelled

The FOSM model (Figure S6) was run for a broad range of floods, comprising:

- The large historical flood events from the last 125 years (comprising 1887, 1890, three floods from 1893, two floods from 1898, 1908, 1931, 1959, 1971, 1973, 1974, 1983, 1989, 1996, 1999, 2011 and 2013)
- 3,840 stochastically generated events ranging from 150 mm to 600 mm catchment average rainfall
- Over 100 extreme flood events for estimation of the probable maximum flood (PMF) and to assess the impact of options on dam safety (in terms of Acceptable Flood Capacity[2] – AFC).

The flood hydrographs for each of the above events have been combined into a flood database, which was then used as input into the FOSM, as illustrated in Figure S7.

Whilst results have been presented for each historic flood, an averaging of results[3] has been required to compare options for the stochastic flood event simulations.



Source: Seqwater 2014a, Figure 1-1

Figure S7 Overview of dam operations modeling process and generation of flood hydrographs

[2] Refer Chapter 9 – Dam Safety
[3] Refer Chapter 7, Figure 7.27.

S8. Key points

When undertaking the necessary trade-off considerations between flood mitigation, water supply security, dam safety and disruption to the community, it is not possible to optimise the outcomes in all the key consideration areas for every flood. Optimising the outcomes requires balancing the key findings described under each of the specific objectives, along with the findings of the integrated assessment of the net present costs of the direct and indirect tangible impacts.

A balanced solution is required as, not only will there be different perspectives held by stakeholders, by individuals and by the community as a whole, but each flood is different and the degree of mitigation actually achieved will vary accordingly.

Hence, the investigative approach under WSDOS has been to determine how well each of the identified operational options satisfies specific objectives relating to:

- minimising urban flood inundation
- minimising impacts on water supply security
- not compromising dam safety, and
- reducing the impacts of submergence of bridges and crossings.
- Trade-off considerations did not involve reducing bank slumping and erosion, and riparian fauna and flora impacts as a consistent, direct relationship with river flows modified by dam releases could not be established based on current information and understandings. Hence, no options were identified as being better or worse in this regard.

The following sections summarise the outcomes of investigations relating to the above objectives.

S8.1 Dam flood operations

- The dams cannot eliminate flood inundation during moderate and major floods.
- The flood operations modelling undertaken is advanced, however the reasonable limit of confidence in modelled downstream flood results in the mid and lower Brisbane River is 16,000 m^3/s which is the estimated peak in the first 1893 flood.
- The operational alternatives (other than the prescribed alternative) for flood operations modify the Rural and Urban strategies in the 2013 Flood Manual with operational decisions being based on levels in the dams and predicted flood flows at critical downstream locations (such as significant bridges and Moggill).
- Predicted flood flows at critical downstream locations are a better indicator of likely downstream flood damages and impacts than outflows from Wivenhoe Dam as downstream impacts are affected by downstream inflows as well as dam releases.
- Flooding downstream of the dams is a complex interaction of downstream tributary inflows (particularly Bremer River and Lockyer Creek), other inflows to the Brisbane River and releases from Wivenhoe Dam. In some floods, the Bremer River is the dominant influence on flood levels in the Ipswich central business district.
- Optimising the operations of Wivenhoe and Somerset dams requires recognition that every flood will be different and that operational strategies need to provide good outcomes across a wide range of possible floods not just for one particular flood.

Table S3 Flood mitigation impacts - comparative summary of options (relative change of average over many floods)

Operational Option	2 to 4	5	9	17	21	25	29
Operational Alternative	85% , 75% and 60% FSV Base Cases(1)	100% FSV No Rural Strategy	100% FSV Alt Urban 1a 100% FSV Alt Urban 1b	100% FSV Alt Urban 2	100% FSV `Alt Urban 3	100% FSV Alt Urban 4	100% FSV Prescribed Operations (4)
Flood Mitigation – Mid Brisbane River and Lower Brisbane River							
Major flood, peak flow at Moggill (2)	5-20% lower	0-2% lower	0-5% lower	0-5% lower	0-10% lower	0-20% lower	Up to 20% higher
Moderate flood, peak flow at Moggill (2)	0-10% lower	0-2% lower	0-10% higher	0-5% higher	0-5% lower	0-10% lower	Up to 50% higher
Minor flood, peak flow at Moggill (2)	Nil	Nil	0-20% higher	0-10% higher	Nil	Nil	Up to 80% higher (4)
Probability exceed 4,000 m^3/s flow at Moggill	Lower	Minimal	Higher	Higher	Nil	Nil	Much higher
Delay time(3) to the onset of 4,000 m^3/s flow at Moggill	0-4 hours later	Minimal	8 hours earlier	4 hours earlier	Minimal	Minimal	15 hours earlier
Flood Mitigation – Bremer River at Ipswich							
Peak level at Ipswich 10 to 15 m	Nil	Nil	+1 m	+0.5 m	Minimal	Minimal	+2 to 3 m
Peak level at Ipswich above 15 m	Nil	Nil	Minimal	Minimal	Minimal	Minimal	+1 to 2 m
Probability exceed 11.7 m flood level at Ipswich	Nil	Minimal	Higher	Higher	Minimal	Minimal	Much higher
Delay time(3) to the onset of 11.7 m flood level at Ipswich	Minimal	Minimal	3 hours earlier	2 hours earlier	Minimal	Minimal	7 hours earlier

Legend	Better than Base Case operations & 100% FSV	Minimal Change from Base Case operations & 100% FSV	Worse than Base Case operations & 100% FSV

Notes:

Unless noted otherwise below, changes due to variation of dam operations is for the 100% FSV scenario

(1) This specifically compares Base Case lower FSV scenarios against the Base Case 100% FSV scenario

(2) Range represents potential change due to variation of dam operations for 100% FSV.

(3) Less delay (earlier) is an adverse impact and more delay (later) is a positive benefit. Findings based on historical floods.

(4) Prescribed options could often actually amplify minor floods (peak flow higher than 'no dams' scenario)

Results for flood mitigation are presented for average performance over many floods. It is important to recognise that flood mitigation performance in any individual flood could be worse or better. The probability of significantly worse outcomes in any single flood event compared to the average is low, but it remains possible.

- Use of the 20 largest historical floods provides the best basis for assessing operational alternatives until better information is made available through the Brisbane River Catchment Flood Study (BRCFS), the Brisbane River Floodplain Management Study and the Brisbane River Floodplain Management Plan. Nevertheless, stochastic (statistically generated synthetic events) floods are valuable in testing possible variations to dam operations, but are not yet suitable to directly define probabilities of flood events.
- Flood operations modelling results (refer Table S3) for the 32 options are preliminary and further refinement of operational strategies may be possible.
- The modelling (Figure S3 and Figure S4) simulations show that the existing dams under existing operations significantly reduce the flood impacts in Brisbane for the major historical floods with only six causing extensive urban flooding (above 4,000 m^3/s).
- The modelling also indicates that some additional flood mitigation benefit for the largest historical flood events could occur by:
    - lowering the FSV to increase the flood storage
    - raising the Dam Safety Strategy trigger level to increase the flood storage
    - increasing the target flows at Moggill in the Rural Strategy and Urban Strategy which increases flood releases and therefore preserves the flood storage
- The modelling indicates that stepped increases (i.e. alternatives Urban 1 and 2) in the target flows at Moggill in the Urban Strategy can result in worse flooding than would occur under 2013 Flood Manual operations in minor and moderate flood events.
- Operational alternatives Urban 3 and 4 show most promise in improving flood mitigation outcomes over a range of floods. The disadvantage of these options is increased risk to dam safety - with Urban 4 posing most risk. Operational alternative Urban 4 would require comprehensive assessment of the risks due to the significantly increased probability of breaching the fuse plugs. The probability of breaching the fuse plug for alternative Urban 4 would not meet the Queensland Acceptable Flood Capacity guidelines and other best practice guidelines.
- Increasing the flood storage available (by either lowering the FSV, raising the Dam Safety Strategy trigger level or increasing early discharges) can decrease peak downstream flows in major floods and larger moderate floods but does not improve the mitigation of smaller moderate floods and minor floods. This is because the additional flood storage is not utilised in smaller events.
- Changing dam operations has mixed influences on peak flood flows and levels (some better, some worse, and some no change). In Ipswich, some benefits occur for floods where there are reduced backwater effects from large floods in the Brisbane River. However, there are smaller reductions to Ipswich flood levels in events where Ipswich flood levels are dominated by Bremer River flows. The average influence on flooding in Ipswich of changing operations across many floods is not significant.

S8.2 Floodplain risk assessment

- Flood surfaces data prepared by BCC in 2009 (BCC 2009) were used to undertake preliminary assessments of flood damages and impacts for input into the integrated assessment of the operational options.
- If a flood with a peak flow of around 10,000 m^3/s at Moggill can be reduced by 500 m^3/s and 2,000 m^3/s then there would be a corresponding reduction in the total number of residential and non-residential buildings flooded by between 500 and 3,000 buildings. In a flood with a peak flow of around 10,000 m^3/s at Moggill, it is estimated that approximately 12,000 buildings are flooded above habitable floor level.

- Better floodplain risk assessment information will become available through the Brisbane River Catchment Flood Study, the Brisbane River Floodplain Management Study and the Brisbane River Floodplain Management Plan.
- The results of the integrated assessments conducted for this study may need to be reviewed when such information becomes available

S8.3 Water supply security

- Water is supplied to the SEQ region via a networked system of bulk water supplies and distribution mains.
- Under the *Water Act 2000*, these are operated and managed by Seqwater in accordance with the SEQ System Operating Plan (SOP).
- The integrated assessment of trade-offs between flood mitigation and water supply security outcomes is impacted by water supply modelling limitations which may not properly reflect the water supply risks.
- The Wivenhoe and Somerset dams system is central to and provides approximately 60% of SEQ's water supply. The effect of the 2001 to 2007 drought was to significantly downgrade the system yield. This experience cautions against any significant lowering of Wivenhoe Dam especially on a permanent basis.
- Uncertainties in using stochastic modelling techniques impact the reliability of yield assessments which are dependent on the representativeness of the historical record for predicting future rainfalls and stream flows. For example, estimated water supply yields for SEQ are significantly lower when the historical data set used as the basis for generating the stochastic inflow sequences includes rather than excludes the 2001 to 2007 drought.
- Assuming operations under the System Operating Plan, the modelling indicates that the yield of the bulk water supply system delivering the currently specified level of service for SEQ generally remains constant at around 430,000 ML/a when varying the FSVs in both Wivenhoe Dam and North Pine Dam from 100% down to 75%.
- This outcome seems counter-intuitive, but is the result of complex interactions in the regionally networked model reflecting:
  - The flexibility provided under the current level of service (LOS) specification defined in subordinate legislation in the System Operating Plan
  - Earlier production of desalinated water and introduction of water restriction as the dam levels lower
  - Consequential adjustments to water transfers between the northern system (Sunshine Coast areas), the central system (Brisbane, Ipswich, Logan and western areas), and the southern system (Gold Coast areas)
  - That the northern and southern systems are more likely to run out of water in an extreme drought, and
  - The current LOS yield is governed by the first objective that fails (which is currently the Baroon Pocket Dam dead storage criterion)
- DEWS is currently reviewing the desired level of service objectives for SEQ and subsequently it is proposed that Seqwater establish a new water security program for the SEQ water supply system in late 2015.

- The formulation of the water security program should further consider the risks of lowering the water supply levels in Wivenhoe Dam as a flood mitigation measure to develop a stronger understanding of changes in water usage and dam levels during severe drought.
- Under the assumed most likely projected demands and assuming that the Western Corridor Recycled Water Scheme can be brought on line when the combined storage in the bulk water supply system drops to 40% (as per the current SOP), augmentation of the supply yield of the bulk supply system would need to commence around 2031.
- Without purified recycled water (PRW) from the Western Corridor Recycled Water Scheme, the system yield reduces to 415,000 ML/a and the SEQ water storages drop below 20% much more frequently while there is also the risk that the Brisbane storages could reach minimum operating level.
- Without both PRW and desalinated water from the Gold Coast Desalination Plant the system yield drops to about 355,000 ML/a.
- The corresponding timelines for augmentation of supply would be brought forward to 2028 (no PRW) and 2019 (no PRW and no desalination) allowing for construction and commissioning.
- The probabilities of reaching manufactured water production triggers (60% and 40% of the SEQ water storage) in the next 10 to 20 years increase if there is a lowering of the levels in Wivenhoe Dam.
- The probabilities of reaching these trigger levels increase further if one or both of the manufactured water sources (PRW and desalination) are not available.
- Continued use of the seasonally[4] declared temporary FSLs for Wivenhoe Dam is a way of delivering improved flood mitigation potential while at the same time seeking to minimise water supply security risk compared to a permanent lowering of the dam.
- Given that current water supply usage in SEQ in the 2012–13 financial year was 282,000 ML, the modelling and discussion above suggests that the Wivenhoe Dam level can be lowered in the shorter term at least on a declared temporary full supply level basis having regard to catchment conditions, weather forecasts and dam levels at the time.

S8.4 Dam safety

- Wivenhoe and Somerset Dams are classified as extreme hazard dams using established risk assessment and standards based methodologies. Based on the current standards-based methodology outlined in the Queensland dam regulation guidelines (DEWS 2013b) on Acceptable Flood Capacity for dams, it will ultimately be necessary to augment the dams to ensure that they can both safely pass their respective PMFs.
- The Annual Exceedance Probability of the maximum flood event that Wivenhoe Dam can safely pass with all radial gates assumed operable has been estimated (Seqwater 2014a) at approximately 1 in 65,000; while the Annual Exceedance Probability of the maximum flood event that Somerset Dam can pass with all sluice and radial gates operational has been estimated as approximately 1 in 25,000. There may be advantages in changing the flood operations rules to better balance the dam failure risks across both dams to reduce the likelihood of a cascade failure of both dams.

[4] A seasonally declared temporary FSL is generally a pre-wet season decision made by the Minister for Energy and Water Supply in accordance with the *Water Supply (Safety and Reliability) Act 2008* to lower the full supply level in the dam in response to forecasts by BoM of above average rainfall.

- A policy position needs to be established on whether the probability of failure of Somerset Dam should be reduced such that failure of Wivenhoe Dam becomes more likely to occur before the failure of Somerset Dam. Such a preferential order is likely to reduce the risk of cascade failure of both dams and preserve any residual water supply. This would need to be reflected in both the operating target line (Interaction line refer Chapter 9 – Figure 9.2) for the joint operation of Wivenhoe and Somerset Dams and also in the design of the dam upgrades.
- Options for upgrading the dams to be able to pass 100% of the PMF require further detailed investigations to understand both the engineering feasibility and whether they have implications for future development and flood risk management downstream. Thus, it is vital that planning for the upgrades is undertaken in the near future.
- The hydrologic modelling undertaken indicates that of the operational alternatives considered in this study only operational alternative Urban 4 significantly increases the current risk to dam safety (refer Table S4).

Table S4 Dam safety impacts - comparative summary of options (relative change over many floods)

Operational Option	2 to 4	5	9	17	21	25	29
Operational Alternative	85% , 75% and 60% FSV Base Cases[1]	100% FSV No Rural Strategy	100% FSV Alt Urban 1a 100% FSV Alt Urban 1b	100% FSV Alt Urban 2	100% FSV `Alt Urban 3	100% FSV Alt Urban 4	100% FSV Prescribed Operations
Change in the probability of overtopping[2]	Less risk	Minimal	Minimal	Marginal[2]	Marginal[2]	More risk[2]	Minimal
Change in probability of breaching fuse plugs[2]	Lower	Minimal	Minimal	Minimal[2]	Minimal[2]	Higher	Minimal

Legend	Better than Base Case operations & 100% FSV	Minimal Change from Base Case operations & 100% FSV	Worse than Base Case operations & 100% FSV

Note:

Unless noted otherwise below, changes due to variation of dam operations is for the 100% FSV scenario

(1) This specifically compares Base Case lower FSV scenarios against the Base Case 100% FSV scenario

(2) Caution is required due to limitations of modelling extreme flood events. Further investigation of dam safety risk is required (although it is a considerably greater issue for Alt. Urban 4 than Alt. Urban 3).

Results for flood mitigation are presented for average performance over many floods. It is important to recognise that flood mitigation performance in any individual flood could be worse or better. The probability of significantly worse outcomes in any single flood event compared to the average is low, but it remains possible.

- The hydrologic modelling also indicates that there are marginal differences between the operational options considered with respect to the likelihood of overtopping of the dam embankment.
- However, it must be recognised that the modelling simulations used idealised assumptions of extreme event rainfall patterns which may not adequately represent the potential change in risk. The current best science cannot define how extreme floods may occur. For example, the January 2011 flood event highlighted the possibility of an extreme rainfall burst near the end of a rainfall event which poses increased risk for dam safety.

- This increases the risk for all options, but may further increase risks for options that raise the dam safety trigger level.
- The assessed probability of initiating a fuse plug has increased from about 1 in 6,000 AEP at the time of construction of the dam in the mid-2000s to about 1 in 700 AEP currently.
- With the exception of operational alternative Urban 4, for all operational alternatives the probability of initiating a fuse plug is about 1 in 700 AEP.
- Thus the dam safety risk is higher for all operational alternatives than was originally thought due to changes to large flood predictions, and poses additional risks due to other modes of dam failure such as internal erosion through saddle dams and erosion of the fuse plug spillway.
- For operational alternative Urban 4, the probability of triggering the 1st fuse plug has increased to about 1 in 30 AEP.
- Owing to the increase in likelihood that a fuse plug in the auxiliary spillway will be breached, appropriate dam safety investigations would need to be carried-out before deciding whether or not to adopt alternative Urban 4.
- Because of the existing risks, the fuse plug and associated dam safety investigations should be completed irrespective of whether or not the Urban 4 operational alternative is considered for implementation.
- Detailed investigations of dam safety upgrade options may highlight other strategies able to deliver similar benefits to alternative Urban 4 – but with fewer risks.

S8.5 Flood warning

- Dams delay the on-set of flooding increasing the warning time for the community to take action to reduce the impact of flooding and evacuation for the safety of people.
- Wivenhoe and Somerset Dams are unique being the largest flood mitigation dams in Queensland and also being located upstream of the largest population at risk in Queensland. During major flood events, residents in close proximity to the dam require more urgent warnings than those who are further downstream and are not at immediate risk.
- Generally, BoM, BCC, ICC, SRC and Seqwater collaborate to provide robust warning and notification systems for community and stakeholder agencies during flood events.
- Following the 2011 flood event, significant improvements were made ensure that there is wide ranging and adequately managed notification and warning for populations at risk downstream of Wivenhoe and Somerset Dams during flood events.
- Seqwater has no responsibility for issuing public flood warnings but has a key role in flood forecasting and notifications to relevant organisations.

S8.6 Bridge and crossing submergence

- The main impact of bridge and crossing submergence is the disruption caused by the closure of transport routes (refer Table S5).
- Bridge and crossing submergence does not significantly impact the ability to implement flood operational options to improve flood mitigation outcomes.
- Lowering of the dam FSV, bypassing of the Rural Strategy, and stepped increases in the target flow at Moggill in the Urban Strategy tend (but not always) to reduce the frequency of submergence and increase the duration of submergence.

- Raising of the Dam Safety Strategy level will increase the flood levels upstream of the dams mainly impacting transport routes (highways).
- The costs of improving the flood immunity of the crossings are substantial and the flood impacts (annualised costs) of crossing closures through inundation are relatively small.
- The decision to improve the flood immunity of any of the crossings or other transport upgrades will need to be justified mostly on the basis of transport benefits, rather than flood mitigation as options able to be implemented in the short to medium term will have minor impacts on the duration of closures.
- Ultimately, transport improvements are a matter for the bridge or crossing owner (either the councils or DTMR).

Table S5 Flood effects on bridges and crossings - comparative summary of options (relative change of average over many floods)

Operational Option	2 to 4	5	9	17	21	25	29
Operational Alternative	85% , 75% and 60% FSV Base Cases[1]	100% FSV No Rural Strategy	100% FSV Alt Urban 1a 100% FSV Alt Urban 1b	100% FSV Alt Urban 2	100% FSV `Alt Urban 3	100% FSV Alt Urban 4	100% FSV Prescribed Operations
Duration of inundation of downstream lowest bridges [2]	1-5% increase	3% increase	5% decrease	1% decrease	5% increase	Nil	25% decrease
Duration of inundation Brisbane Valley Hwy & Mt Crosby bridge [3]	1 to 15% increase	4 % decrease	7-14% increase	4% increase	4% decrease	7% increase	32% increase
Probability of inundation Brisbane Valley Hwy & Mt Crosby bridge	Minimal	Minimal	Minor increase	Minimal	Minimal	Minimal	Significant increase
Duration of inundation of lowest level upstream bridges [4]	25-50% decrease	10% decrease	10-15% decrease	15% decrease	8% decrease	15% increase	50% decrease
Probability of inundation of lower level upstream bridges	Lower	Minimal	Minimal	Minimal	Minimal	Minimal	Lower

Legend	Better than Base Case operations & 100% FSV	Minimal Change from Base Case operations & 100% FSV	Worse than Base Case operations & 100% FSV

Notes:

Unless noted otherwise below, changes due to variation of dam operations is for the 100% FSV scenario

(1) This specifically compares Base Case lower FSV scenarios against the Base Case 100% FSV scenario

(2) Burtons Bridge used as representative bridge. Findings based on historical floods.

(3) Brisbane Valley Highway results also reasonably represent Mt Crosby Bridge. Findings based on historical floods.

(4) Mary Smokes Bridge used as representative bridge. Findings based on historical floods.

Results for flood mitigation are presented for average performance over many floods. It is important to recognise that flood mitigation performance in any individual flood could be worse or better. The probability of significantly worse outcomes in any single flood event compared to the average is low, but it remains possible

S8.7 Bank slumping and erosion

- Bank slumping and erosion are a natural process in the Brisbane River system and are not by themselves evidence of anthropogenic impact unless there is a robust baseline condition available for comparison.
- Thus river form stability comparisons should not assume a no-erosion case as the reference point as banks are dynamic zones that are continually changing in response to complex interactions between flow regimes, sediment transport, bank material and form, riparian vegetation and land-use.
- Since the building of the Wivenhoe Dam there appears to have been little change in the bed levels downstream of the reservoir. This may be a combination of the resilience of the ancient palaeo-bed, the low bed sediment yields that occur naturally in this system, and the inputs of discharge and sediment from the Lockyer Creek just downstream of the reservoir.
- Based on the available evidence, the mid-Brisbane river system appears to have been largely insensitive to changes that could be directly attributable to the 20th century construction and operation of the dams in the upper reaches. Other gradual anthropogenic influences over time, such as land clearing and sand and gravel extraction, are likely to have had the greater impact on the bank and channel stability.
- The desktop study concluded that:
  - flood releases during the Drain-Down Strategy of flood operations that maintain a constant water level for long durations are likely to have a greater impact on downstream bank erosion than a slightly varied flow level. A fixed discharge rate (above base flow and water supply release wetted channel zones) may cause notching or streambank undercutting
  - the rates of drain-down of the dam necessary in the 2011 flood event are likely to have been sufficient to contribute to large volume of mass failure erosion. Yet, these rates of were slower than the modelled estimates of the rates of discharge likely to have occurred prior to the existence of the dam
  - this indicates that pre-dam draw-down rates in the disturbed Brisbane River system will not provide appropriate reference rates for the future management of bank slumping and erosion, as the river channel margins may have altered in vegetation structure and morphology.
  - Ideally, dam release operations to reduce 'wet flow mass failures' should vary depending on the antecedent moisture condition of the river banks. Further, real time monitoring of the pore water pressure in the banks could be used to build a release strategy around the saturation of the bank material. (Given the extensiveness of such a monitoring system, further work would need to be done to determine whether a practical strategy for implementation could be developed.)
- To help establish a better baseline reference for the future management of the river system (including Lockyer Creek) a systematic long term data collection and analysis program would need to be established to better inform decision making. It is noted that the Australian Rivers Institute research program at Griffith University has been supported by Seqwater and is targeted towards this outcome.

S8.8 Flora and fauna

- Outcomes of Environmental Flows Assessment Program (EFAP) monitoring associated with the *Water Resource (Moreton) Plan 2007* (QLD) monitoring, evaluation and assessment provide a robust basis for predicting likely flow-related impacts from water management scenarios.

To date, the response of ecological assets to individual flood events has not been considered a critical component of EFAP monitoring as the approach to assessing water resource planning performance has been based on long-term measures of ecological asset viability modelled over long hydrological simulation periods (i.e. > 100 years).

- This recognises that significant flood events are rare, and alteration to the sequence of flow-related recruitment and connection opportunities provided for in the intervening periods are the largest contributors to the risk of long term population viability. Floods represent major ecosystem resetting events with a number of benefits summarised in Chapter 12.
- The general responses of aquatic ecosystems to flood events and dam operations within the current management constraints such as barriers to migration and timing and volume of releases for water supply are, in the context of population processes, transient and short lived.
- As such there are no clearly identifiable recommendations for changing the current dam operating procedures in relation to impacts on flora and fauna.

S9. Integrated assessment of operational options

Integrated assessment of the operational options to satisfy the requirements of QFCoI Final Report recommendation 17.3 requires difficult trade-off considerations between:

- the damage and impacts associated with flooding;
- the water supply costs associated with increased production of manufactured water and the need to bring forward infrastructure upgrades;
- not worsening dam safety risks while any necessary upgrades of the dam are planned and executed;
- the ability to minimise disruption to the community by reducing the cost of traffic rerouting resulting from the submergence of bridges, crossings and roads; and
- permitting increased flooding due to smaller floods so that that flooding from large floods can be reduced.

No significant new operational strategies for minimising bank slumping and erosion and flora and fauna impacts were identified in the key findings above, thus these impacts have not been considered in assessing the trade-offs.

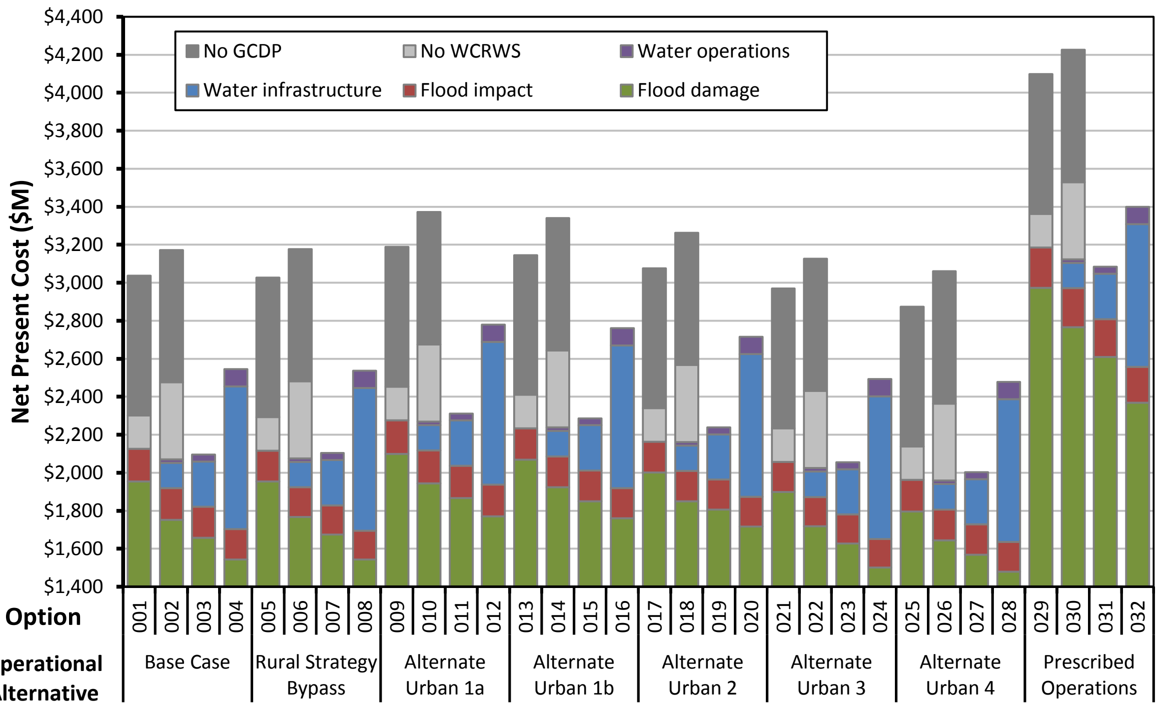
Net Present Costs (NPCs) have been estimated for tangible flood inundation damages and impacts and the brought forward costs of water infrastructure and manufactured water production. NPC estimates depend on the assumed discount rate and the accounting period. The sensitivity of the results to these parameters has been tested using the short-term, medium-term and long-term assumptions listed in Chapter 15 Table 15.8.

S9.1 Integrated assessment results

Combined NPC results based on the medium-term assumptions are provided in Figure S8 and Table S6. It can be seen that flood damage generally represents the largest component cost for all options (approximately half of which is attributed to the residential damages alone) but also that water supply costs become more dominant as the FSV is lowered. Flood impact related costs are typically less than 10% of the flood damage costs.

The cost impacts of not having the Western Corridor Recycled Water Scheme (WCRWS) (PRW - Purified Recycled Water) or both the WCRWS and Gold Coast Desalination Plant (GCDP) (MFW - Manufactured Water) available are shown for the 100% FSV and 85% FSV cases. The same extra manufactured water costs apply to all the 100% FSV and 85%FSV options. Similar but as yet unquantified extra costs in this regard will also apply to all the other FSV options.

Bulk water infrastructure and operational costs increase as the FSV is lowered and tend to equal or outweigh reductions in flood damage costs. This applies to all the operational alternatives considered.



Source: Aurecon 2014, Figure 52

Figure S8 Influence of operational option on total NPC for medium-term assumptions

A range of observations can be made based on this combined NPC assessment and the supporting hydrologic modelling:

Base Case (current operations with reduction in dam FSV) – Options 001 to 004

- Reducing FSV provides additional volume for storage attenuation of flood peaks. There appears to be limited benefit for flows less than around 4,000 m³/s, because the additional storage is not utilised/needed for such small floods.
- Reducing the FSV reduces flood damages and impacts for floods between 5,000 m³/s and 25,000 m³/s with the amount of benefit increasing with reduction in FSV.
- The flood damage NPCs are reduced by 10% and 21% for FSV reductions to 85% FSV and 60% FSV respectively.
- Estimated flood impact NPCs are reduced by 3% and 7% for FSV reductions to 85% FSV and 60% FSV respectively.
- Total NPCs (flood damage, impact costs and water supply costs) are reduced by 2.6% when the dam is lowered from 100% FSV to 85% FSV.

- Total NPCs (flood damage, impact costs and water supply costs) are increased by 20% when the dam is lowered from 100% FSV to 60% FSV.

Within the level of accuracy of the NPC assessments for all the options, permanent reductions in the FSV of Wivenhoe Dam cannot be justified. This conclusion is dependent upon several significant assumptions including:

- The availability of manufactured water to supplement the bulk water supply. The modelling of bulk water infrastructure and operational costs was based on the assumption that GCDP and WCRWS are available for immediate drought response. As illustrated in Figure 15.21, bulk water infrastructure and operational costs increase significantly if these sources are not available, which does not support a lowering of the FSV of Wivenhoe Dam.
- The assumptions about the discount rate and forecast period.
- Assumptions about rainfall / flood event probability.
- Accuracy of data available to assess flood damages and impacts (building data, damage curves, flood surfaces, etc.).

Rural Strategy Bypass – Options 005 to 008

- The Rural Strategy Bypass operational alternative generally slightly reduces the mitigation for minor and low end moderate flood events and provides a very slight benefit for high end moderate to major flood events.
- The influence on bridges varies: low level bridges, including the largest cost contributors of Colleges Crossing and Burtons Bridge, experience increased frequency but shorter overall duration of inundation.
- The NPCs for this operational alternative are comparable with (approximately the same as) the Base Case.

Alternative Urban 1a – Options 009 to 012

- Alternative Urban 1a options provide less mitigation than the Base Case for minor to moderate flood events but have some benefit for major floods.
- The NPCs for this operational alternative increase 7% to 10% above the equivalent Base Case – FSV option.

Alternative Urban 1b – Options 013 to 015

- This operational alternative is a combination of the two previous alternatives. It reduces flood mitigation in minor to moderate floods but tends to improve flood mitigation outcomes in major floods.
- The small benefit of the Rural Strategy Bypass is outweighed by increased costs of alternative Urban 1a. This alternative also has flood damage costs about 6% to 14% higher than the equivalent Base Case – FSV option.
- The NPCs for this operational alternative increase 5% to 9% above the equivalent Base Case – FSV option.

Alternative Urban 2 – Options 016 to 020

- This operational alternative provides less mitigation than the Base Case operations for minor to low end moderate flood events (even less than alternative Urban 1a) but provides more benefit for high end moderate and major floods.

- The cost of increased flooding in minor and moderate floods tends to outweigh the benefits of reduced flooding for major floods.
- As with Urban 1 operational alternatives, this alternative appears to reduce the benefits of lowering the FSV such that they have a higher net cost than the Base Case.
- The NPCs for this alternative increase 2% to 7% above the equivalent Base Case – FSV option.

Alternative Urban 3 – Options 021 to 024

- This operational alternative displays similar characteristics to the Rural Strategy Bypass for minor flood events, but provides greater mitigation for moderate and major floods.
- Damage and impact costs are generally lower than the Base Case.
- The NPCs for this alternative are 2% to 3% lower than equivalent Base Case – FSV option.

Alternative Urban 4 – Options 025 to 028

- This operational alternative matches the Base Case mitigation for minor flood events while providing greater attenuation for moderate and major events.
- Flood damage and impact costs are generally lower than the Base Case options excluding fuse plug costs. However, the fuse plug costs are only a small proportion of the total cost.
- This set of options appears to be the most cost-effective, with total flood damage costs between 4% and 8% lower than the equivalent Base Case – FSV option.
- The NPCs for this alternative are 3% to 8% lower than the Base Case options. However, it is important to note that Urban 4 costs do not include the change in risk to dam safety and this variation poses the most risk to dam safety.
- Further refinement of this operational alternative would be required before it could be considered for implementation in order to confirm the expected costs of emergency spillway repairs and associated dam safety upgrades.

Prescribed Operations – Options 029 to 032

- This operational alternative tends to reduce flood mitigation for all but very major floods.
- The NPCs for flood damages and impacts costs for this alternative are 34-51% greater than the equivalent Base Case – FSV option.

S9.2 Net present cost conclusion

The study has identified that there is no simple solution that demonstrates a marked reduction in total costs.

The integrated assessment of net present costs indicates that while lowering the full supply volume of the dam significantly reduces flood damages and impacts, when water supply costs are considered, there is likely to be no overall benefit to the community as a whole. Separate assessment of new infrastructure alternatives to increase flood storage may be warranted to determine if there is a net benefit.

These conclusions are sensitive to the availability of manufactured water and study assumptions, but are considered to be well within the accuracy of the assessment and the uncertainty and variability of natural flood and drought conditions.

Based on the above, it is difficult to support any permanent reduction in the FSV of Wivenhoe Dam.

Continued use of the seasonally[5] declared temporary FSLs for Wivenhoe Dam is a way of delivering improved flood mitigation potential while at the same time seeking to minimise water supply security risk compared to a permanent lowering of the dam.

Only operational alternatives Urban 3 and Urban 4 provide a small reduction in net present costs from the Base Case – with the reduction in costs reducing as the dam levels are lowered. It is cautioned that the NPC modelling does not consider implications of breaching the fuse plugs on issues such as dam safety, operations and mitigation of subsequent flood events. This significantly affects the perceived benefit of the operational alternative Urban 4 in an economic sense.

Operational alternatives which modify the dam safety trigger threshold would require more thorough investigation of the dam safety implications before being considered for implementation.

These conclusions are based on a widely accepted industry methodology which annualises the estimated costs of all potential floods based on their likelihood. The 'real life' effectiveness of each operational alternative depends on particular characteristics of the actual flood event – hence no single flood operations alternative can guarantee the best mitigation outcome for all events.

[5] A seasonally declared temporary FSL is generally a pre-wet season decision made by the Minister for Energy and Water Supply in accordance with the *Water Supply (Safety and Reliability) Act 2008* to lower the full supply level in the dam in response to forecasts by BoM of above average rainfall.

Table S6 Total NPC costs for medium-term assumptions

Operational Alternative/Option		FSV	Flood Damage ($M)	Flood Impact ($M)	Water Infra. ($M)	Water Ops ($M)	TOTAL ($M)	% Change from Base Case Equivalent[1]		
								Flood Damage	Flood Impact	TOTAL
001	Base Case	100%	$1,953.8	$171.5	$-	$-	$2,125	0.0%	0.0%	0.0%
002		85%	$1,752.4	$165.7	$133.55	$18.52	$2,070	-10.3%	-3.4%	-1.6%
003		75%	$1,658.5	$162.2	$238.30	$37.02	$2,096	-15.1%	-5.4%	0.5%
004		60%	$1,544.1	$158.7	$750.93	$91.25	$2,545	-21.0%	-7.5%	25.4%
005	Rural Strategy Bypass	100%	$1,954.8	$160.6	$-	$-	$2,115	0.1%	-6.4%	-0.5%
006		85%	$1,767.2	$156.3	$133.55	$18.52	$2,076	0.8%	-5.7%	0.2%
007		75%	$1,674.1	$154.3	$238.30	$37.02	$2,104	0.9%	-4.9%	0.4%
008		60%	$1,543.3	$151.4	$750.93	$91.25	$2,537	-0.1%	-4.6%	-0.3%
009	Alternate Urban 1a	100%	$2,099.7	$176.8	$-	$-	$2,276	7.5%	3.1%	7.1%
010		85%	$1,944.8	$172.5	$133.55	$18.52	$2,269	11.0%	4.1%	9.5%
011		75%	$1,866.7	$170.2	$238.30	$37.02	$2,312	12.6%	4.9%	10.1%
012		60%	$1,770.8	$167.1	$750.93	$91.25	$2,780	14.7%	5.3%	8.8%
013	Alternate Urban 1b	100%	$2,068.6	$164.9	$-	$-	$2,234	5.9%	-3.8%	5.1%
014		85%	$1,924.1	$162.2	$133.55	$18.52	$2,238	9.8%	-2.1%	8.0%
015		75%	$1,850.5	$161.1	$238.30	$37.02	$2,287	11.6%	-0.7%	8.9%
016		60%	$1,760.3	$159.4	$750.93	$91.25	$2,762	14.0%	0.4%	8.1%
017	Alternate Urban 2	100%	$2,001.1	$162.0	$-	$-	$2,163	2.4%	-5.5%	1.8%
018		85%	$1,850.3	$158.8	$133.55	$18.52	$2,161	5.6%	-4.2%	4.3%
019		75%	$1,806.1	$158.3	$238.30	$37.02	$2,240	8.9%	-2.4%	6.7%
020		60%	$1,717.3	$156.9	$750.93	$91.25	$2,716	11.2%	-1.1%	6.4%
021	Alternate Urban 3	100%	$1,898.6	$158.4	$-	$-	$2,057	-2.8%	-7.6%	-3.2%
022		85%	$1,718.0	$154.6	$133.55	$18.52	$2,025	-2.0%	-6.7%	-2.2%
023		75%	$1,627.1	$153.1	$238.30	$37.02	$2,056	-1.9%	-5.6%	-1.9%
024		60%	$1,501.0	$150.6	$750.93	$91.25	$2,494	-2.8%	-5.1%	-1.9%
025	Alternate Urban 4	100%	$1,795.4	$166.6	$-	$-	$1,962	-8.1%	-2.9%	-7.7%
026		85%	$1,644.2	$162.3	$133.55	$18.52	$1,959	-6.2%	-2.1%	-5.4%
027		75%	$1,568.3	$159.7	$238.30	$37.02	$2,003	-5.4%	-1.5%	-4.4%
028		60%	$1,478.6	$156.9	$750.93	$91.25	$2,478	-4.2%	-1.1%	-2.5%
029	Prescribed Operations	100%	$2,973.8	$212.1	$-	$-	$3,186	52.2%	23.7%	49.9%
030		85%	$2,766.0	$206.0	$133.55	$18.52	$3,124	57.8%	24.3%	50.4%
031		75%	$2,608.8	$199.8	$238.30	$37.02	$3,084	57.3%	23.2%	46.3%
032		60%	$2,368.3	$189.5	$750.93	$91.25	$3,400	53.4%	19.4%	32.1%

1. For the Base Case, the % change is the comparison between the lowered full supply volume (FSV) option and the 100% FSV option. For comparisons between the operational alternatives and the Base Case, the % change comparisons are between the full supply volume equivalents

Source: Aurecon 2014, Table 43

Table S7 NPC of increase in water supply costs attributed to Wivenhoe Dam

	No WCRWS ($M)			No WCRWS or GCDP ($M)		
FSV	Infra	Ops	Total	Infra	Ops	Total
100%	$155.40	$21.21	$176.61	$864.71	$47.47	$ 912.18
85%	$357.82	$47.82	$405.64	$1,013.78	$88.60	$1102.38

Source: Aurecon 2014, Tables 32, 40

Chapter 1 Background

The broad aim of preparing the Wivenhoe and Somerset Dams Optimisation Study (WSDOS) report is to present various operational options to enable the government to make informed decisions on the future operation of Wivenhoe and Somerset dams. The report addresses the recommendations of the Queensland Floods Commission of Inquiry to investigate alternative strategies for the flood operations for the dams.

The optimisation study extends beyond alternative flood operations of the dams for flood mitigation to also consider potential alternative water supply operations and the associated implications for dam safety, disruption to the community, bank slumping and erosion and flora and fauna.

This is the first major review of flood operations since Wivenhoe Dam was built. The work is only possible now because of the experience and learnings and the data that became available during and after the 2010 / 2011 wet season, and because of hydrologic and other techniques that are now possible with advances in computer technology.

Current circumstances are far different to when Wivenhoe Dam was built to provide flood mitigation and water supply services. The current demands for water supply and recent upgrades of infrastructure capacity and configuration in south east Queensland provides a different context to those that existed in 1977 when the original feasibility and impact assessments for Wivenhoe Dam were completed.

Optimisation of the operation of Wivenhoe and Somerset dams is particularly challenging because releases from these dams must take into account flows emanating from downstream tributaries (which cannot be controlled by the dams).

Ultimately, trade-offs must be made between the key considerations of flood mitigation, water supply security and the structural safety of the dams whilst having regard to bank slumping and erosion and impacts on flora and fauna. This is an opportunity to consider how to make best use of existing water infrastructure.

1.1 Wivenhoe and Somerset dams

Wivenhoe and Somerset dams are located in the upper reaches of the Brisbane River catchment. Both were conceived as dual water supply and flood mitigation dams. That is, the dams support growth in SEQ, whilst also providing significant flood mitigation in the downstream reaches of the Brisbane River. Wivenhoe Dam is located mid-catchment, with Somerset Dam located on the Stanley River, one of the major tributaries flowing into Wivenhoe Dam. Wivenhoe Dam receives inflows from approximately 7,000km^2, or a little more than half of the total Brisbane River catchment area.

The location of the two dams is shown in with details pertaining to each dam provided in Chapter 2.

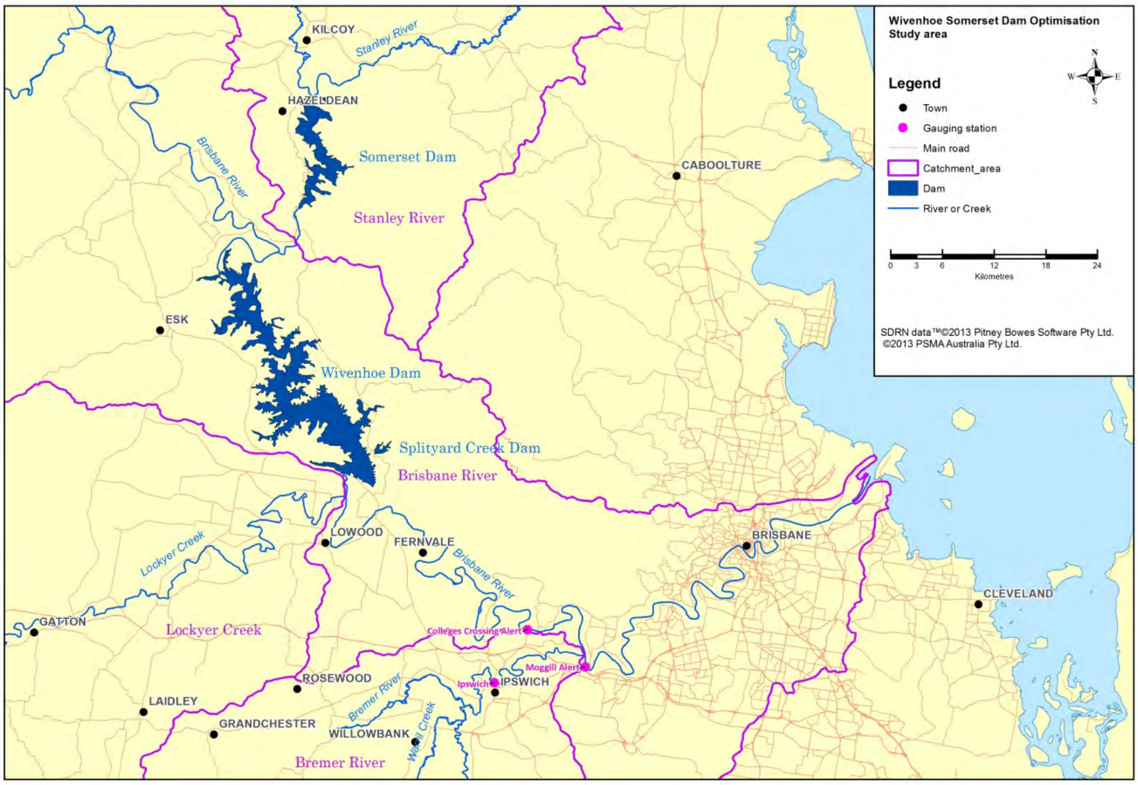


Figure 1.1 Location of Wivenhoe and Somerset dams

1.2 Lead-up to the January 2011 flood event

1.2.1 Rainfall

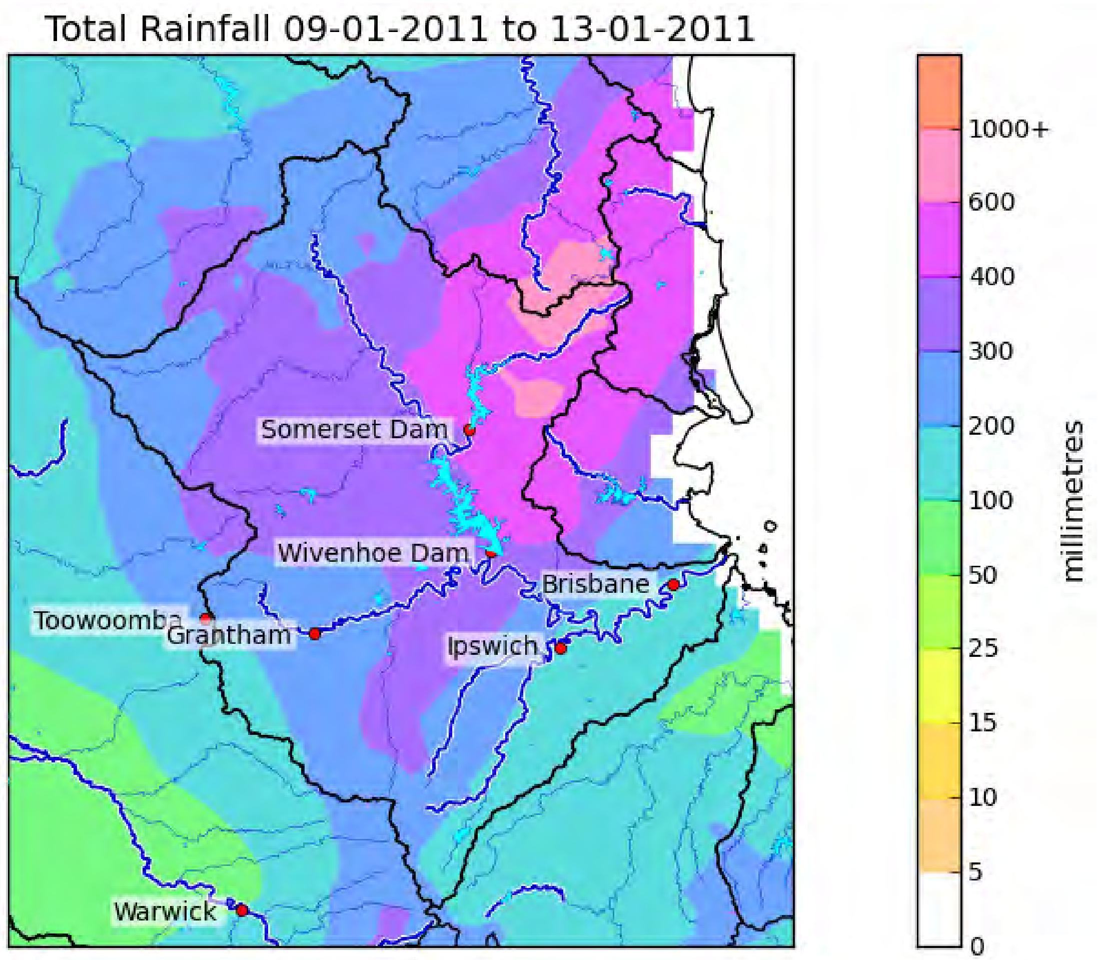
From September 2010 to January 2011, numerous rainfall records were set across not only SEQ, but much of Australia. A number of these records are described in the Special Climate Statement 24 document, issued by the Bureau of Meteorology (BoM 2011a):

> *'It was the wettest December on record for Queensland and for eastern Australia as a whole…For Australia as a whole it was the third-wettest December on record. This followed an extremely wet spring, the wettest on record for Queensland…It was Australia's wettest July to December on record.'*

The Bureau of Meteorology's Flood Summary for Brisbane River at Brisbane – December 2010 to January 2011 (BoM 2011b) indicated that:

- rainfalls of between 600 – 1,000 mm were recorded in most of the Brisbane catchment during December 2010 and January 2011.
- most of this rainfall fell between 09/01/2011 and 13/01/2011 with over 600 mm recorded in parts of the Stanley River catchment during this period.

Figure 1.2 is reproduced from the BoM report (BoM 2011b), highlighting the distribution of this extreme rainfall event.



Source: BoM 2011b, Figure 3

Figure 1.2 Rainfall map for the 96 hours to 9am on 13/01/2011 (BoM)

BoM (BoM 2012) further highlighted that, with respect to the seasonal conditions from which the January events arose:

> *'The 2010–11 La Niña event was one of the strongest on record, comparable in strength with the La Niña events of 1917–18, 1955–56 and 1975–76... In October and December 2010, and February and March 2011, the Southern Oscillation Index values (a measure of a La Niña's strength) were the highest recorded for each month since records commenced in 1876.'*

Notably, major floods were not recorded in 1917–18 and 1975–76.

1.2.2 Catchment conditions

SEQ experienced persistent, above average, rainfall over the 2010–11 spring and summer seasons. Rainfall in September 2010 was typically 55 mm above average and in October, was 250 to 400 mm above average, resulting in most catchments being at or near saturation by the end of October 2010. The catchments dried during November in response to well below average rainfall. However, this was followed by a prolonged period of heavy rainfall during December 2010 and January 2011 that yielded total rainfalls for the period up to 1,000 mm above average and resulted in widespread flooding between late December 2010 and mid-January 2011.

In the 25 days prior to the commencement of the January 2011 flood event, three separate flood events impacted on Wivenhoe and Somerset dams (Seqwater 2011a). Flood releases were made from Wivenhoe Dam on all but five of those days. The total outflow from the three additional events was around 690,000 ML and the details of these events are outlined in Table 1.1.

Table 1.1 Outflow from three separate flood events, commencing December 2010

Event	Start Date	End Date	Volume Released (ML)
1	13/12/2010	16/12/2010	70,000
2	17/12/2010	24/12/2010	150,000
3	26/12/2010	02/01/2011	470,000

Source: Seqwater 2011a, Table 3.1.1

Less than four days separated the end of the third of these events and the commencement of the January 2011 flood event. Due to the rainfall that had occurred in the dam catchments throughout December 2010, the catchment conditions were near saturation at the start of the January 2011 Flood Event resulting in high runoff.

1.3 The January 2011 flood event

1.3.1 Peak flood levels

The rainfall in January 2011 produced one of the largest floods recorded in the Brisbane River (dating back to the late 1800s) and the largest flood event that the Wivenhoe and Somerset dams have experienced since they were constructed in 1983 and 1955 respectively. The Brisbane River peaked at 4.46 mAHD at the Port Office gauge at 3am on 13th January 2011, which was the highest flood level at this location since a level of 5.45 mAHD was recorded in 1974 (refer Figure 2.10 in Chapter 2).

Further upstream, the recorded peak was the highest on record at several locations, albeit records do not always extend back to the 1800s. For those locations where records do extend back to at least 1893, the 2011 flood was the 4th or 5th highest on record, as indicated in Table 1.2. It can be seen that the highest flood on record (1893) produced levels that were up to 6 m higher than those of 2011.

Table 1.2 Selected January 2011 flood heights - Brisbane River

Location	Peak Level (m)	Status	Previous Historical Record
Cooyar Creek	9.48	Higher than previous record	9.33 m (1974)
Savages Crossing	24.42	Highest since records began (1959)	23.79 m (1974)
Mt Crosby	26.18	5th highest on record	32.00 m (1893)
Centenary Bridge	12.07	4th highest on record	17.90 m (1893)
Brisbane City (Port Office)	4.46	Highest since 1974	8.43 m (1841) 8.35 m (1893) 5.45 m (1974)

Source: Seqwater 2013b, Appendix B2

The Bremer River also experienced the highest flood levels since the 1974 event, as shown in Table 1.3.

Table 1.3 Selected January 2011 flood heights - Bremer River

Location	Peak Level (m) January 2011	Status	Historical Record
Rosewood	7.50 m	2nd highest on record	Record 7.62 m Jan 1974
Ipswich#	19.25 m	4th highest on record	24.5 m (Jan 1893) 23.6 m (Feb 1893) 20.7 m (Jan 1974)

Note: # Can be influenced by Brisbane River levels

Source: Seqwater 2014b, Appendix B2

BoM's Queensland Flood Summary for January 2011 (BoM 2011c) describes the period as follows:

> *'Southeast Queensland had experienced very much above average to highest on record rainfall for the month of December. Further rainfall then followed in the first week of January, saturating the catchment area.*
>
> *By the 7th of January a combination of weather systems centred themselves over land over the Burnett River catchment area. These systems combined to produce heavy rainfall and major flooding in the Mary River catchment and about the Sunshine Coast before moving southward into the Pine and Brisbane River catchments. Heavy to very intense rainfall from the 9th to the 12th of January resulted, causing rapid creek rises and extreme flash flooding in the Lockyer Valley and major river flooding in the Brisbane and Bremer Rivers…*
>
> *Record flood heights were recorded at various locations along Lockyer and Warrill Creeks and the Bremer and the upper Brisbane River. Peak river levels on the Bremer River at Ipswich and along the Brisbane River between Mt Crosby and Brisbane city remained below the 1974 flood level.*

1.3.2 Peak inflows and outflows of Wivenhoe and Somerset dams

A summary of the estimated total inflow and outflow volumes and flow rates from Wivenhoe and Somerset dams for the January 2011 event (Seqwater 2011a) is presented in Table 1.4. In terms of total flood volume, January 2011 was almost double the January 1974 flood and rivalled the February 1893 flood.

The event began at approximately 7:40 am on 6 January and finished at 12:00 on 13 January 2011 (note drain-down continued until 19 January). The flood was characterised by two distinct peak inflow rates to Wivenhoe Dam separated by about 30 hours – each peak was comparable to the inflow rate from the 1974 event.

Table 1.4 Summary of January 2011 inflows and outflows for Wivenhoe and Somerset dams

Item	Unit	Somerset Dam	Wivenhoe Dam
Inflow volume	ML	822,000	2,750,000*
Outflow volume	ML	820,000	2,750,000
Inflow peaks	m^3/s	4,000 (9th Jan) 3,000 (11th Jan)	9,500 (10th Jan) 10,300 (11th Jan)
Outflow peaks	m^3/s	1,700 (10th Jan) 1,400 (12th Jan)	7,460 (11th Jan)
Peak water level	mAHD	105.11	75.06

* Wivenhoe Dam inflow figures include Somerset Dam outflow and were determined by reverse routing

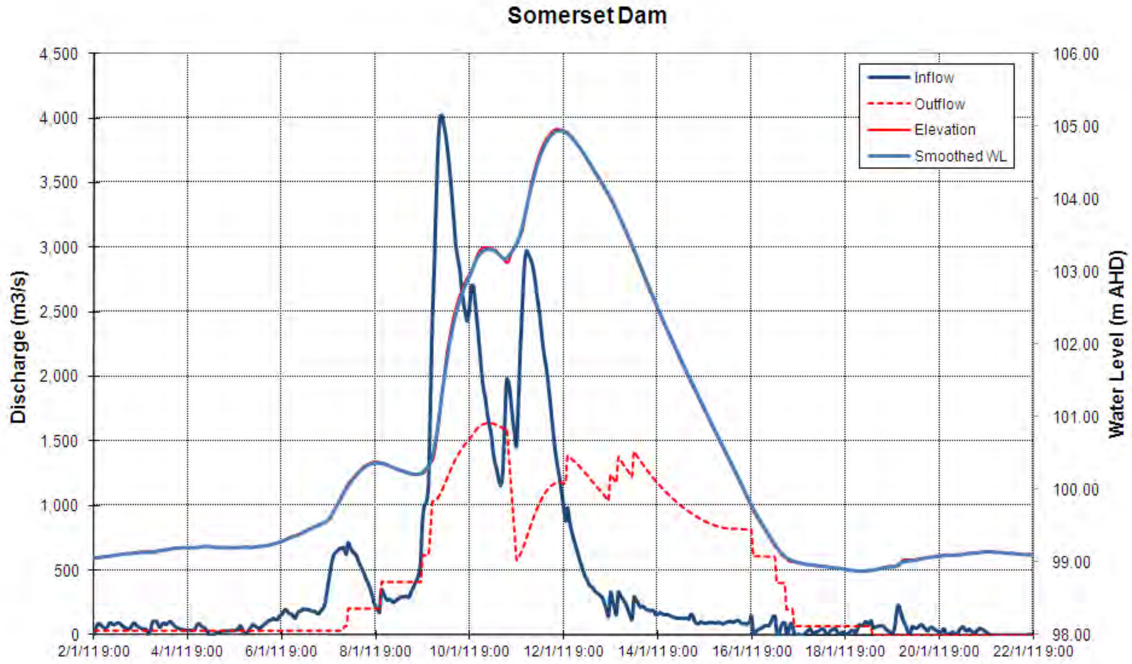
Source: Seqwater 2013b[6] Table 5-3, Table 5-4, Figure 5-24

It can be seen that the volume released from Wivenhoe (2,750,000 ML) is approximately four times that released in the three lead-up December 2012 events combined (as listed in Table 1.1). Additionally, the volumes tabulated in Table 1.4 are substantially larger than the available flood storage volume in each dam.

Figure 1.3 and Figure 1.4 show the scale of the events experienced, and the substantial attenuation provided by the two dams. For Somerset Dam, the peak inflow of approximately 4,000 m^3/s was attenuated to 1,700 m^3/s, whilst for Wivenhoe Dam, the peak inflow of almost 10,300 m^3/s was reduced to just under 7,500 m^3/s (i.e. the flood peak was mitigated by approximately 30%).

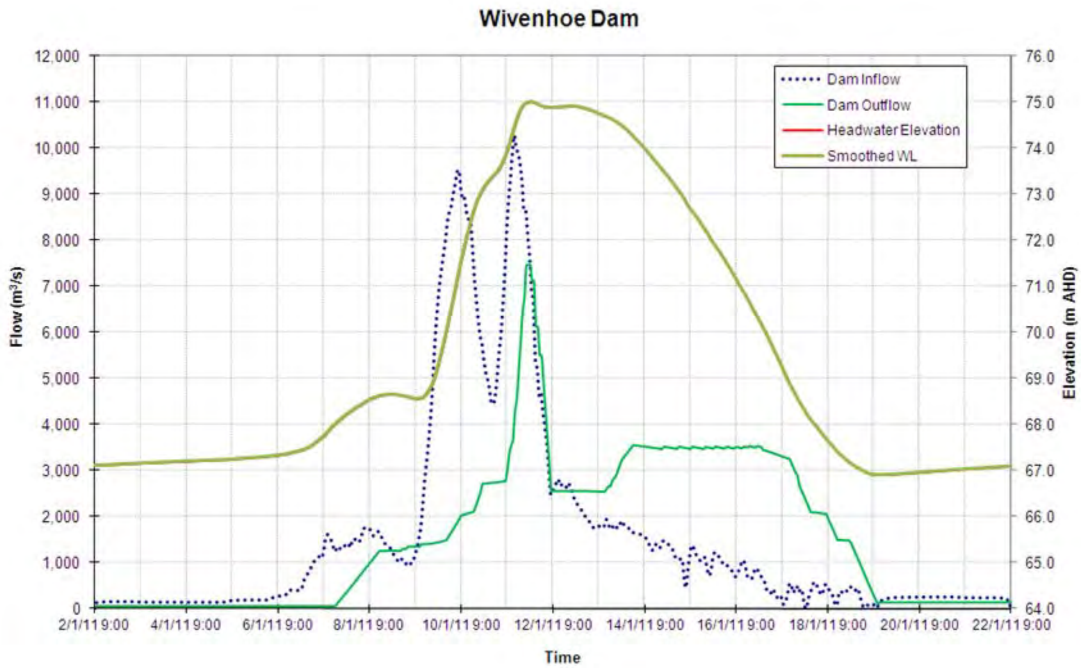
The effective operation of the dams significantly reduced the amount of flood damage that would have occurred downstream if the dams were not in place.

[6] Previous estimates of Jan 2011 event reported in the Flood Event Report (Seqwater 2011a) were prepared with only limited time and analyses in a six week period after the flood. Seqwater has since undertaken more comprehensive review of data and analyses with updated estimates in the Seqwater Flood Hydrology Model Report (Seqwater 2013b) now considered to be the most definitive estimate of this flood.



Source: Seqwater 2013b, Figure 5-24

Figure 1.3 Somerset Dam inflows, outflows and water levels, January 2011



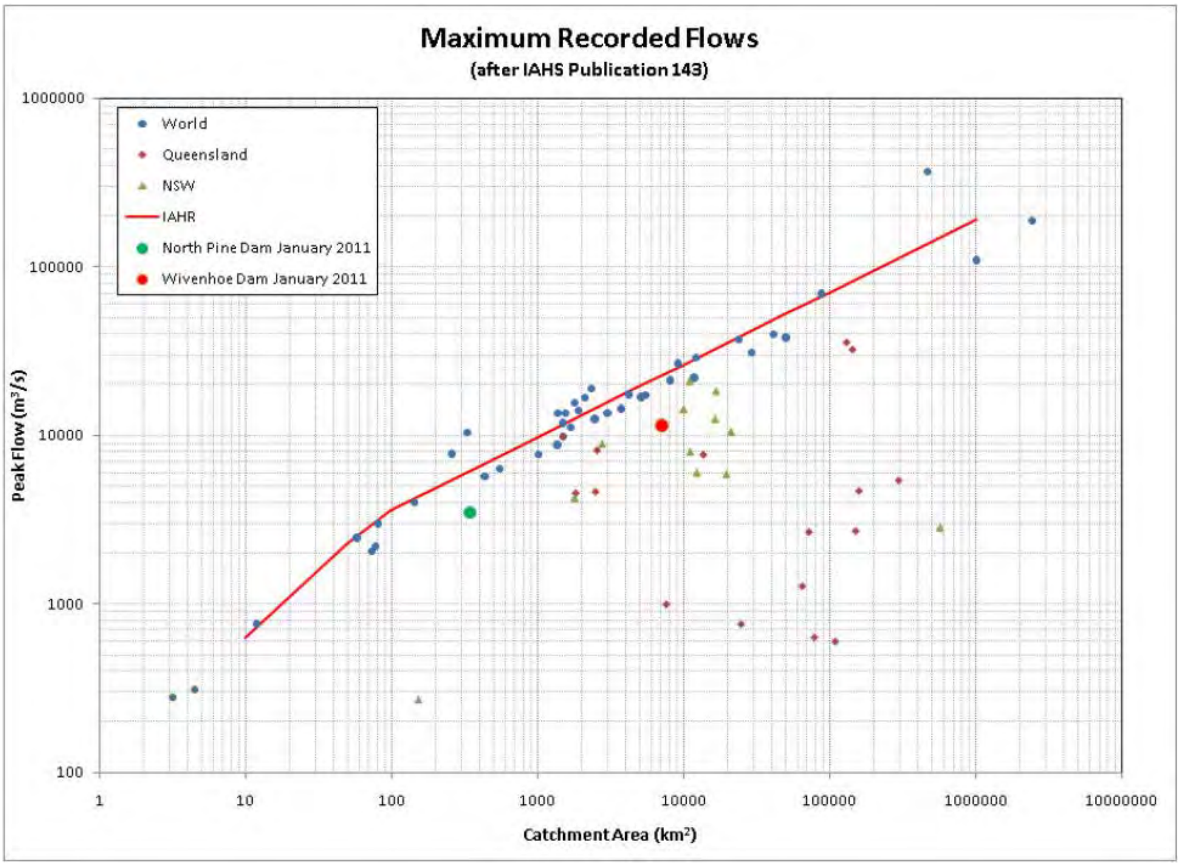
Source: Seqwater 2013b, Figure 5-24

Figure 1.4 Wivenhoe Dam inflow, outflows and water levels, January 2011

1.3.3 International context

The International Association for Hydro-Environment Engineering and Research (IAHR Publication 143) publishes a list of maximum recorded flows for Australian and international catchments. This data is plotted in Figure 1.5.

The Wivenhoe Dam January 2011 inflow peak is plotted on this graph and shows its significance when compared with maximum recorded flows for national and international catchments of similar area. The peak Wivenhoe Dam flow is approximately half the enveloped international maximum recorded flow for its catchment size. The North Pine Dam January 2011 event flow is also indicated for comparison.



Source: Seqwater 2011d, Figure 9.8.1

Figure 1.5 Maximum recorded flows for Australian and international catchments

1.4 Historical peak flows

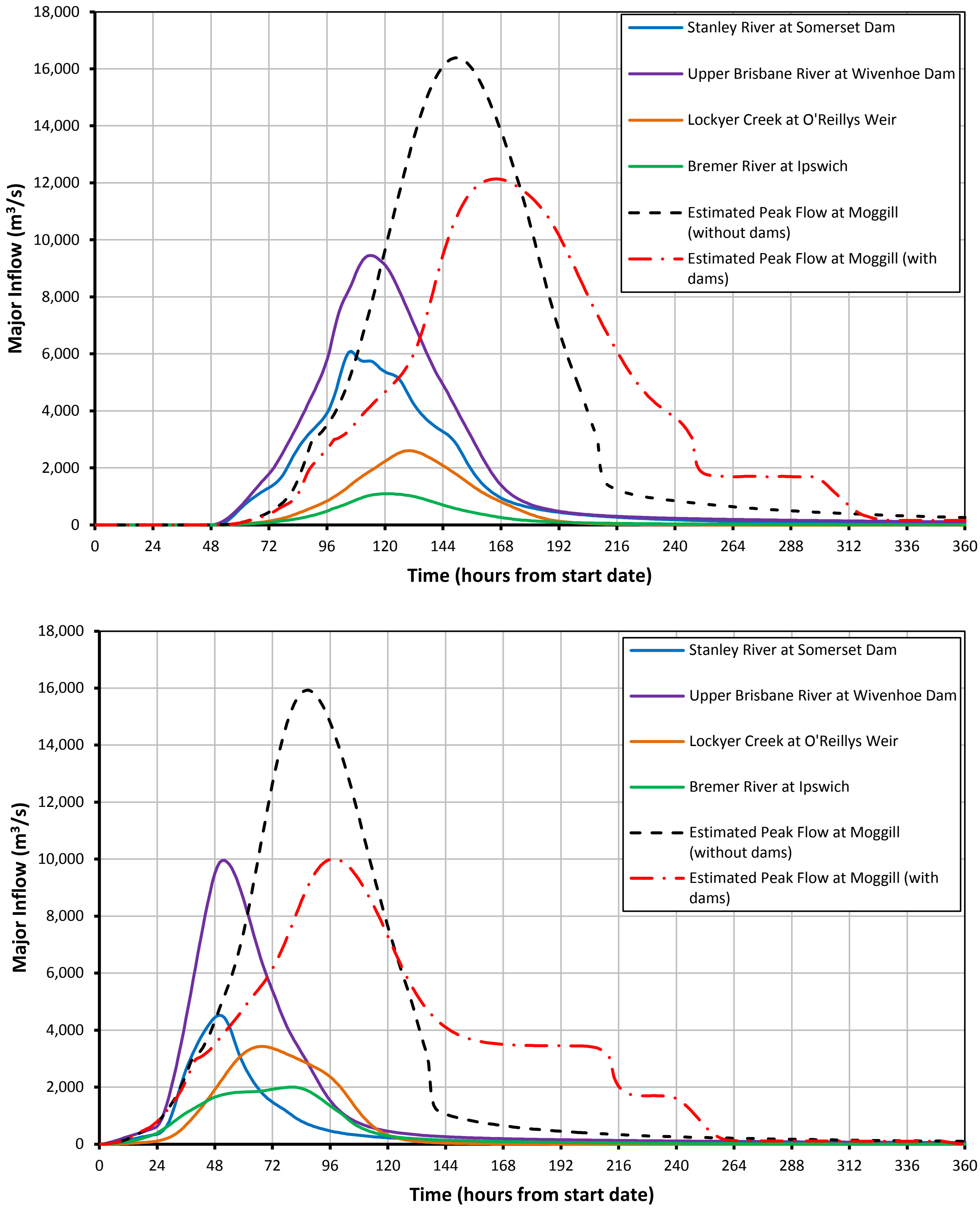
Further perspective is provided through comparison of the magnitude of historical events. SKM (2013) have considered peak flood flows at various locations along the river system. Those for the Brisbane River at the site of Wivenhoe Dam and the Brisbane Port Office are presented in Table 1.5 for selected floods.

Table 1.5 Historical no-dam peak flows at Wivenhoe Dam site

Year of Flood [1]	Estimated peak flow at Wivenhoe Site (m^3/s)	Estimated peak flow at Brisbane Port Office (m^3/s)
1841		17,300
1844		14,100
1887	6,700	
1890	6,630	10,600
1893	15,140	16,100
1898	9,000	9,300
1908	5,670	6,200
1931	6,860	7,200
1955	9,960	8,900
1974	10,910	13,700
1983	8,470	7,600
1999	11,190	8,500
2011	11,090	13,400
2013	6,100	7,600

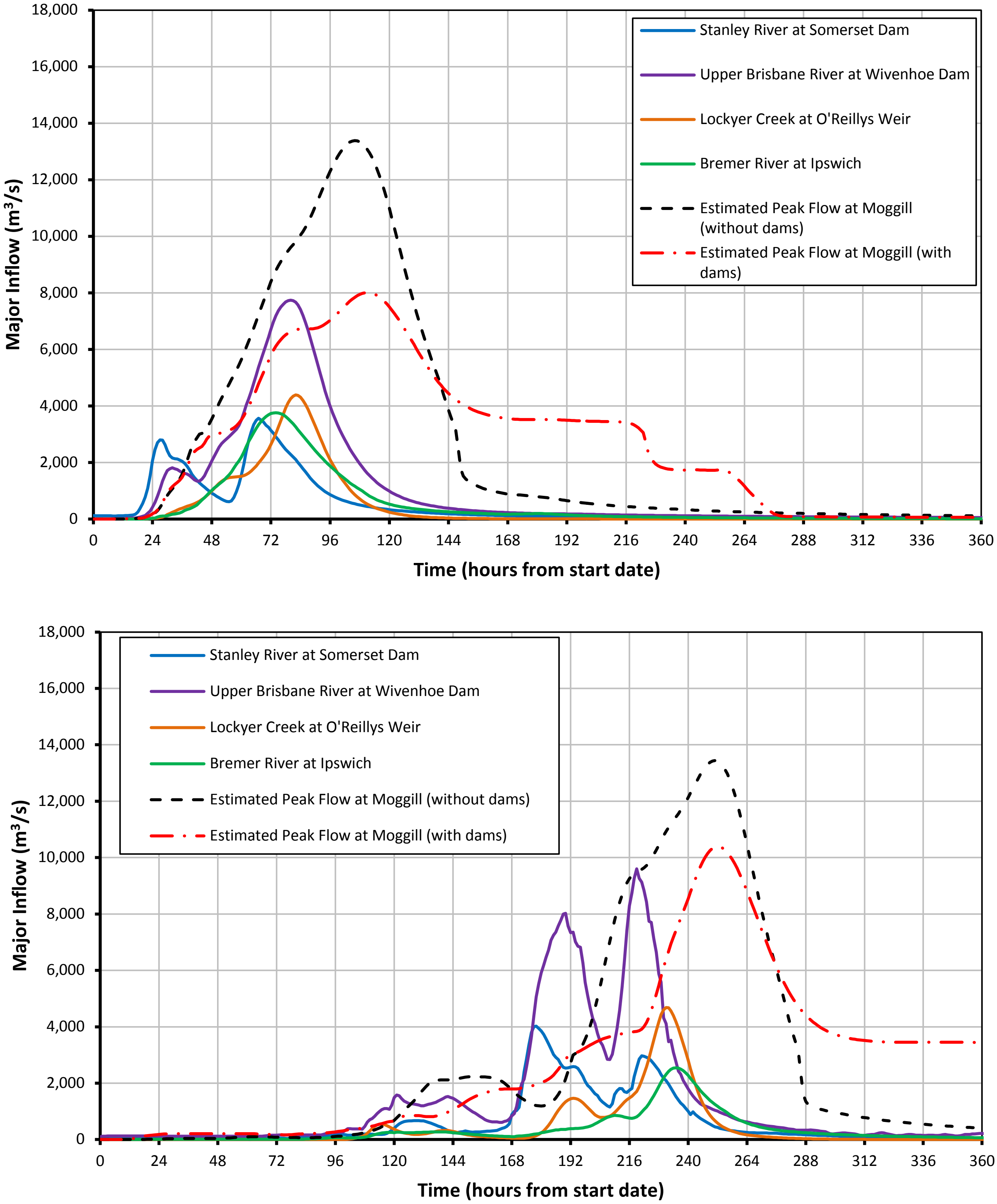
Note: 1. Where multiple floods occur in any one year, only the largest flood of that year is presented.

A graphical comparison of inflow and outflow (with and without the dams) hydrographs are presented in Figure 1.6 and Figure 1.7 for the January and February 1893 floods and the January 1974 and January 2011floods. These show the inflows (estimated or measured) at the locations of Stanley River at Somerset Dam, the Upper Brisbane River at Wivenhoe Dam, Lockyer Creek at O'Reilly's Weir and the Bremer River at Ipswich. They also show the estimated flows at Moggill with and without the dams. These provide an easy comparison of the size of the floods emanating from the different parts of the catchment for these major flood events. The double-peak from the upper Brisbane catchment in January 2011 event illustrates the highly variable rainfall patterns that can occur.



Source: Based on Seqwater 2014a

Figure 1.6 Pre-dam flood events site specific inflows: Jan 1893 (top) & Feb 1893 (bottom)



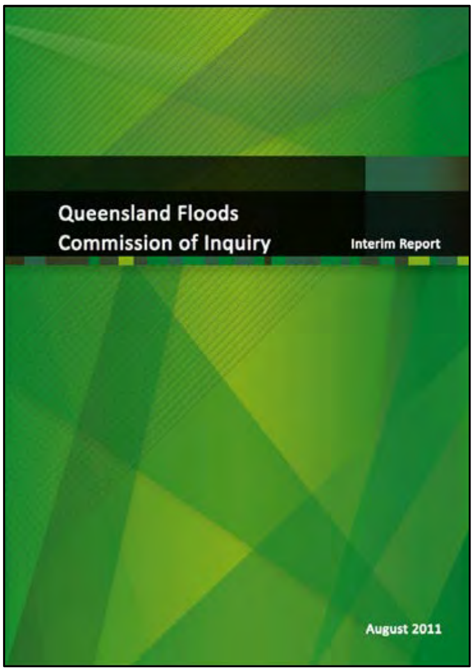
Source: Based on Seqwater 2014a

Figure 1.7 Post-dam flood events - site specific inflows: Jan 1974 (top) & Jan 2011 (bottom)

1.5 Queensland Floods Commission of Inquiry

In response to the widespread flooding that occurred in 2010 and 2011, the Queensland Floods Commission of Inquiry (QFCoI) was established to review all aspects of these flood events across Queensland. The QFCoI examined the flood operations at Wivenhoe, Somerset and North Pine dams, commissioned experts to analyse the event and offer opinion on the actions taken, and received public submissions between February 2011 and March 2012. The QFCoI issued an Interim Report in August 2011 and handed down its Final Report in March 2012.

A review of the QFCoI Interim and Final reports yields five recommendations of direct relevance from the Interim Report, and a further six recommendations from the Final Report. These are reproduced in Table 1.6 and Table 1.7.



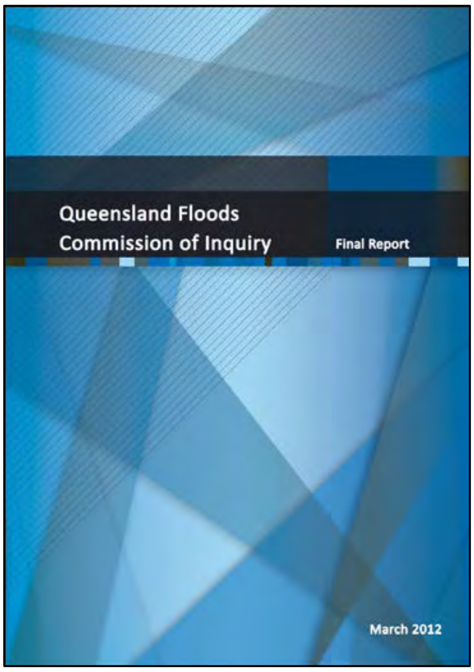


Table 1.6 QFCoI recommendations relevant to WSDOS – Interim Report

<table>
<tr><th>No</th><th>Recommendation</th></tr>
<tr><td>2.2</td><td>It should be accepted that control over temporary alteration of the full supply level of Wivenhoe, Somerset and North Pine dams is solely the function of the Queensland Government acting through the responsible Minister.</td></tr>
<tr><td>2.11</td><td>The steering committee should ensure the scientific investigations and modelling outlined in recommendation 2.12 and 2.13 are completed. It should also assess the need for any other work to be done, and instigate any other investigations or work considered necessary for a full and proper review of the Wivenhoe manual.</td></tr>
<tr><td>2.12</td><td>The following scientific investigations should be carried out prior to modelling work under the supervision of the steering committee and reviewed by the technical review committee:
1. Review of the design hydrology
a. Using a stochastic or Monte Carlo or probabilistic approach
b. Taking into account observed variability in temporal and spatial patterns of rainfall
c. Taking into account observed variability in relative timings of inflows from the dams and downstream tributaries
2. Production of a digital terrain model incorporating a bathymetric survey of all critical sections of creeks and rivers upstream and downstream of the dam relevant to flood modelling
3. Assessment of the reliability of the 24 hour, three day and the five day rainfall forecasts
4. Consideration of whether and how weather radar can be incorporated into decision making
5. Requesting information from the Bureau of Meteorology as to its willingness to provide ensemble forecasts
6. Consideration as to whether and how ensemble forecasts can be incorporated into decision making.</td></tr>
<tr><td>2.13</td><td>The following modelling work should be carried out under the supervision of the steering committee and reviewed by the technical review committee:
1. Modelling across the full range of supply levels, operating strategies and flood events (historical, design and synthetic) in each case assessing the consequences in terms of risk to life and safety and economic, social and environmental damage. In terms of operating strategies, using a full range of strategies including:
a. A stepped change from W3 to W4
b. Moving to a higher rate of release earlier in W1
c. Bypassing W1
d. Altering maximum release rates under W3
e. Operating the gates in conjunction with the initiation of any of the fuse plugs in order to achieve a lower rate of discharge
2. Simulations to test the robustness of relying on the 24 hour, the three day and the five day rainfall forecasts
3. Development of a probability distribution for the time between closely spaced flood peaks in the catchment using historical records.</td></tr>
<tr><td>4.16</td><td>Dam operators should plan to contact people identified by their emergency action plans about dam outflow in sufficient time for them to be able to respond to the information</td></tr>
<tr><td>4.18</td><td>Dam operators should assess the effectiveness of using SMS and/or email as a bulk instantaneous communication to all people on the notification list while individually contacting those whom it is essential to inform immediately</td></tr>
</table>

Table 1.7 QFCoI recommendations relevant to WSDOS – Final Report

No	Recommendation
17.3	The Queensland Government should ensure that, when it considers options for the operational strategies to be employed at Wivenhoe and Somerset dams, and North Pine Dam, it is presented with a wide range of options which prioritise differing objectives. The Queensland Government should determine the operational strategies by considering the implications of each option over a range of flood events for at least: • inundation of urban and rural areas • water supply security • dam safety • submerging of bridges • bank slumping and erosion • riparian fauna and flora.
17.4	Seqwater should, in creating the new Wivenhoe and North Pine flood mitigation manuals, comprehensively consider: • The amount of discretion that is able to be exercised by the flood engineers and the senior flood engineers, and the description of the circumstances in which such discretion may be exercised • The circumstances in which it might be appropriate to release water in advance of an impending flood on the basis of forecasts from the Bureau of Meteorology • If strategies of the form of strategy W2 and W3 in Revision 7 are included in the revised manual, or any strategy defined as a 'transition strategy', when and how those strategies should be implemented • If the concept of 'urban inundation' is relevant to the operation of the dam, how it should be defined, and if the definition involves diverse concepts, how those concepts can be related back to the strategies, so that flood engineers can reach a clear understanding of their objectives and primary considerations • If the concept of 'natural peak flow' is relevant, how it should be defined.
17.5	The conditions for the use of a particular strategy in all flood mitigation manuals should reflect objective standards
17.15	As part of the longer term review of the Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam the Queensland Government should consider whether the dam operators should be able to extend the drawdown of the lake beyond seven days in order to reduce downstream bank slumping.
17.25	The Department of Transport and Main Roads, in conjunction with Brisbane City Council and Somerset Regional Council, should investigate options for the upgrade of Brisbane River crossings between Wivenhoe Dam and Colleges Crossing and undertake a cost-benefit analysis of these to determine the outcome which best serves the public interest.
17.26	As part of the longer term review of the Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam, the Queensland Government should consider the impact of possible upgrades of bridges downstream of Wivenhoe Dam on different operating strategies for the dam.

1.6 Purpose and scope

This WSDOS report presents the findings of investigations initiated to address the key QFCoI Final Report recommendation 17.3 and encompasses a description of the dam operations modelling work undertaken by Seqwater in response to QFCoI Interim Report recommendation 2.13. In addressing these recommendations, relevant matters in other recommendations listed in Table 1.6 and Table 1.7 were also considered.

The primary purpose of WSDOS is to present the Queensland Government with a wide range of operational strategy options for the Wivenhoe / Somerset Dam system.

Wivenhoe and Somerset Dams are considered as a combined system, with the selection of options pertaining to the operation of this system. This has manifested itself in options being primarily centred on the operation of Wivenhoe (as the larger of the two storages, and in recognition that Somerset discharges to Wivenhoe) with an "operating target line[7]" (or interaction line) being used to guide the desirable lake level in Somerset Dam.

The operational alternatives considered for Wivenhoe Dam incorporate:

- A Base Case (existing operational condition)
- Lowering the FSV thus decreasing the water supply compartment.
- Bypassing the rural strategy, thereby increasing the flood compartment allocated to the urban flood compartment
- Alternative operations to increase downstream target flows thereby assisting to maintain the flood compartment airspace through potentially higher and earlier dam releases
- Changing the flood compartment by raising the dam safety flood operations threshold (which included potential initiation of fuse plugs)
- Operating the dam under a prescribed gate opening procedure.

In addressing QFCoI Final Report recommendation 17.3, investigations have been undertaken to enable consideration and presentation of the implications of each operational strategy in terms of the criteria nominated in the recommendation. Within this consideration, the modelling of options primarily informs implications for dam safety, flooding and water supply security and disruption to transport due to the submergence of bridges and crossings.

It is noted that additional information and understanding will be generated through the Brisbane River Catchment Flood Study (BRCFS). The BRCFS will initially provide a comprehensive review and update of hydrology, assigning probabilities to flows. This will then be followed by the completion of hydraulic modelling (which will produce flood levels throughout the system) and a floodplain risk management plan.

[7] The Wivenhoe/Somerset Operating Target Line is defined in Seqwater 2011a as being based on: (i) equal minimisation of flood level peaks in both Dams in relation to their associated failure levels; (ii) minimisation of flows in the Brisbane River downstream of Wivenhoe Dam; and (iii) consideration of the time needed at the onset of a flood event to properly assess the magnitude of the flood event and the likely impacts. This is to ensure the likely optimal strategy to maximise the flood mitigation benefits of the storages can be selected.

This report describes the operational options selected for analysis and discusses the outcomes of the investigations required to determine the advantages and disadvantages of each option, particularly with respect to the above considerations highlighted in QFCoI Final Report recommendation 17.3. Relevant matters relating to a future revision of the Manual are also discussed.

WSDOS does not address QFCoI recommendations that do not relate to operational options at Wivenhoe and Somerset Dams. These include floodplain planning and local infrastructure solutions for mitigating flood impacts. These are generally the responsibility of the relevant local government.

1.7 Context

The last decade has demonstrated the significant variability of climate and consequential risks for dam operations. Substantial concerns for water supply occurred in the early to mid 2000's in the millennium drought, which was followed by the major flooding of January 2011.

Wivenhoe and Somerset Dams have finite storage capacity and hence cannot eliminate flooding. The flood mitigation that can be achieved by the dam operations is variable as it depends on the unique characteristics of each flood event. The experience from the January 2011 flood event attracted questions such as to what extent can the dams mitigate different flood events and can the dam operations be optimised.

WSDOS was initiated to review the operation of Wivenhoe and Somerset Dams and inform review of the Flood Manual. The need for the study aligns to best practice for continuous improvement and risk management. In addition to the experience and learnings from the January 2011 flood event, the current demands for water supply and recent upgrades of infrastructure capacity and configuration in south east Queensland provides a different context to that which existed when assessments were undertaken in 1977 for the feasibility and impact assessment associated with the original approval of Wivenhoe Dam. The optimisation study extends beyond alternative flood operations of the dams and also considers potential alternative water supply operations for the current SEQ system configuration.

The approach and assessment methods applied in this study to assess flood mitigation were only possible from data, technology development and learnings from the 2011 flood event and more recent flood episodes. These include:

- Flow gauging measurements at the Centenary Bridge at the peak of the January 2011 flood event and gauging measurements during the January.
- Comprehensive calibration of new flood hydrology models for the Brisbane River basin incorporating the recent flood flow gauging measurements and revised rating relationships.
- An improved understanding of the Brisbane River basin flood behaviour and the influences of floodplain storage downstream of Wivenhoe Dam to Moggill (i.e. how floods move down the river).
- Rainfall radar data collected over several events from 2008 to 2012 has provided sufficient data to develop and calibrate modelling to simulate space-time patterns of rainfall using BoM technology (which has only become available since the 2011 flood event).
- The creation of a large data base of historical, design, and stochastic flood events prepared for comprehensive stress testing of dam flood operations and to develop an understanding of the potential variability of flood mitigation performance.

- A review of modelling information available to flood engineers during the January 2011 flood event has enabled a dam flood operations simulation model to be developed and applied that uses realistic representation of the likely foresight of flood conditions available to engineers to make decisions for the dam operations.
- Current hardware and software computing capabilities has enabled a flood operation simulation model to be applied that can test numerous flood events within a reasonable simulation time.

1.8 Project management

The overall responsibilities for WSDOS were assigned in the June 2012 Queensland Government's response to the QFCoI Final Report.

A project steering committee was established with representatives from DEWS (the project co-ordinator and agency responsible for the final WSDOS report to the Government), Seqwater (the owner and operator of Wivenhoe and Somerset Dams), Brisbane City Council (BCC), Ipswich City Council (ICC), Somerset Regional Council (SRC) and Lockyer Valley Regional Council (LVRC) (the local governments whose areas are affected by flooding influenced by Wivenhoe and Somerset Dams) and other stakeholder agencies including the Department of Natural Resources and Mines (DNRM), the Department of State Development, Infrastructure and Planning (DSDIP), Department of Transport and Main Roads (DTMR) and Queensland Treasury and Trade.

The original Steering Committee of WSDOS was chaired by Seqwater and that Steering Committee ceased to operate on 30 June 2012. The chair and related work was transferred to DEWS as part of the implementation of the QFCoI Final Report.

WSDOS project management arrangements are summarised in Figure 1.8.

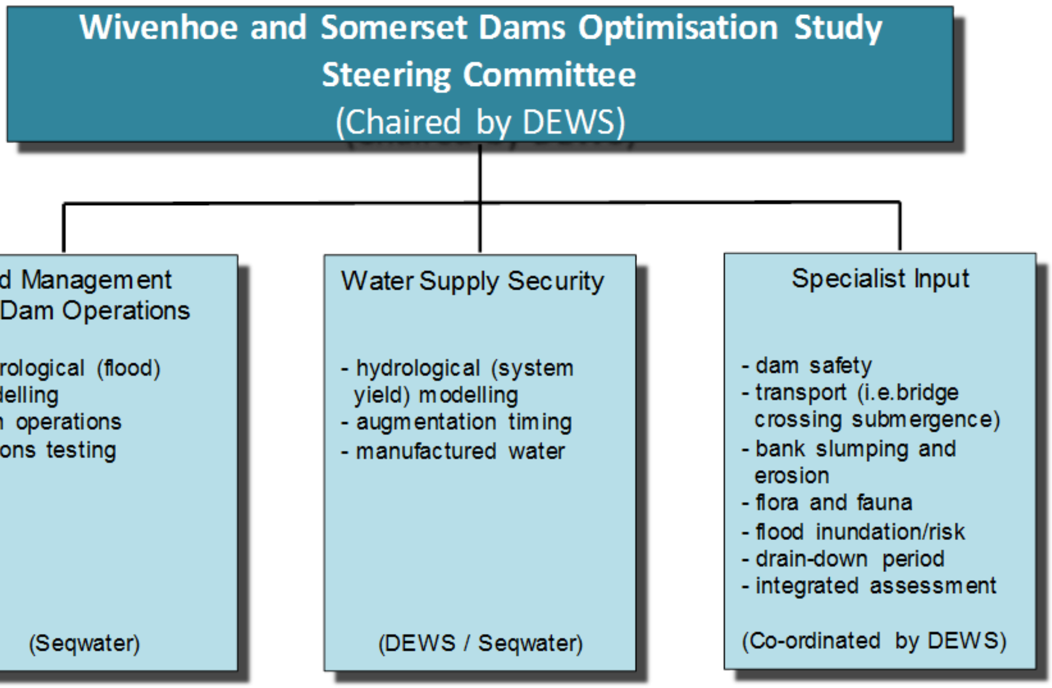


Figure 1.8 Project management arrangements

DEWS commissioned a number of specialist reports to fully address the terms of the QFCoI recommendations as follows:

- dam safety regulatory considerations were reported by DEWS
- water supply security impacts investigated jointly by DEWS and Seqwater
- bridge and crossing submergence impacts were addressed by DTMR
- bank slumping and erosion and flora and fauna was investigated by DSITIA
- analysis of the time between closely spaced flood events to inform drain-down considerations was reported by DSITIA
- an integrated assessment of the operational strategy options was undertaken by consultants (commissioned by DEWS).

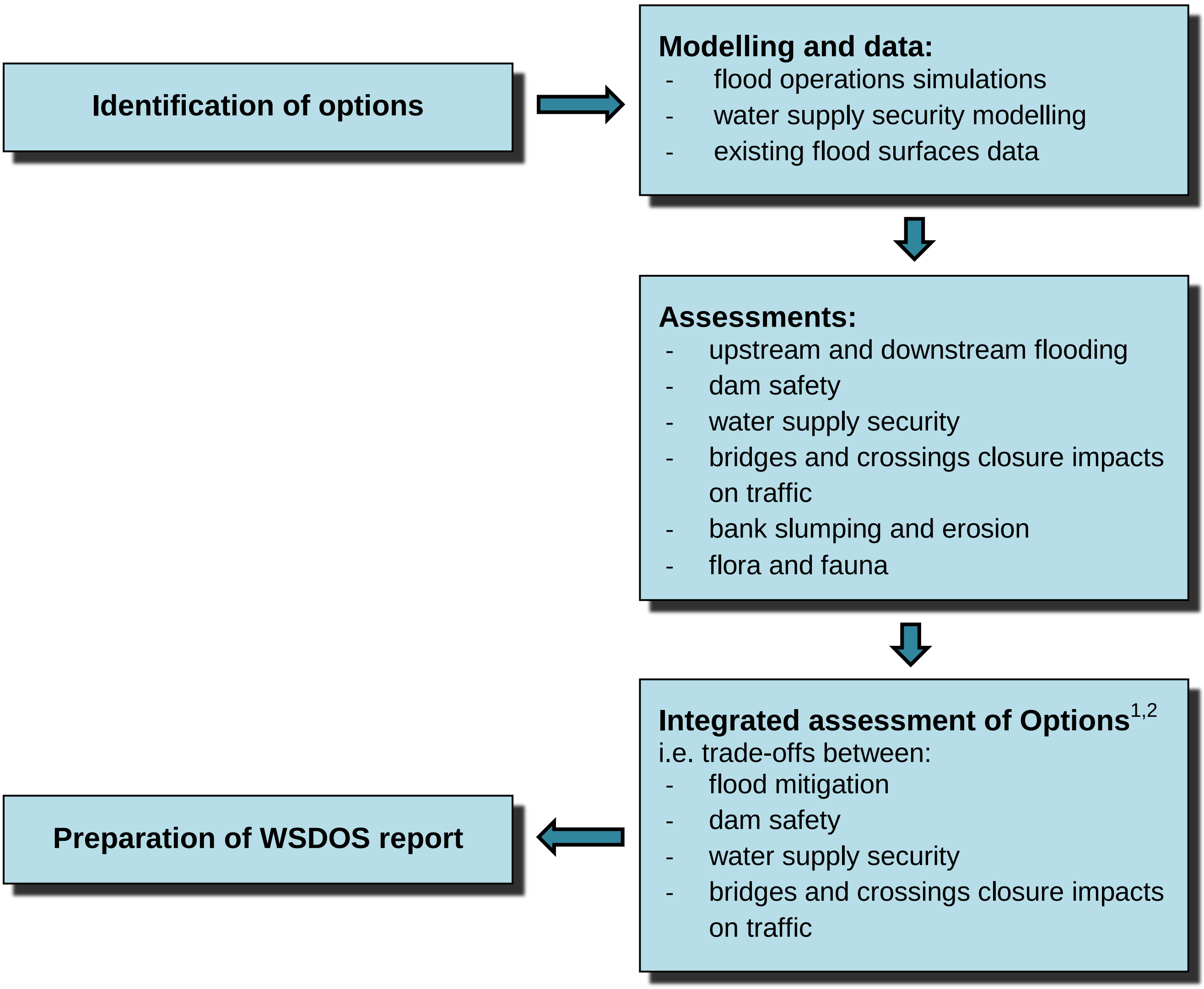
Seqwater undertook the major work involving flood hydrology and dam operations and flood management assessments and also provided the water supply modelling capability to determine impacts on water supply security for the region.

DSITIA developed the South East Queensland regional stochastic model for water supply security assessments used by Seqwater and prepared assessments on bank slumping and erosion, flora and fauna and on closely spaced flood events.

Brisbane City Council provided flood inundation extents for a range of flood events (sourced from its 2009 studies) for the study area of interest. Consultants determined the costs of flood impacts and carried out risk assessments as part of the integrated assessment of the operational strategy options.

Information from WSDOS will be available for input to the Brisbane River Catchment Flood Study, the Brisbane River Floodplain Management Study and preparation of the Brisbane River Floodplain Management Plan.

WSDOS has been a multi-disciplinary exercise requiring the integration of a range of considerations that are affected by how the dams are operated. Figure 1.9 shows the general process for preparing the study report which sought to optimise flood operations dams to provide an appropriate balance between flood mitigation, water supply security, dam safety, social and environmental impacts.



Note:

1. The integrated assessment of operational options comprised a comparison of:
    a. net present costs of tangible estimated flood damages and impacts along with brought forward water supply capital expenditure and operational costs
    b. flood mitigation benefits, dam safety impacts, water supply security impacts and disruption to the community due to bridge and crossing submergence.
2. The integrated assessment of operational options did not include a comparison of bank slumping and erosion and flora and fauna impacts as the assessments undertaken did not identify any strategies for improved operations that could be used to distinguish between the operational options being investigated.

Figure 1.9 General process for preparing the study report

1.9 Reports prepared

Figure 1.10 shows the key reports prepared resulting from investigations undertaken as part of WSDOS, in order to allow consideration of the implications of each option over a range of flood events. These include:

- hydrologic studies to develop inflows for a wide range of flood events for the assessment of the operational strategy options

- development of a flood operations simulations model (FOSM) used for the assessment of options relating to dam operations. The flood operations simulations model assessed the impact of proposed operational alternatives on dam outflows and dam safety (refer also to Figure 6.9 for additional detail as to the modelling work undertaken)
- water supply security assessments that permit trade-off considerations between the loss of water supply security and any improvements in flood mitigation
- a review of dam safety regulatory requirements
- a transport issues paper which considers the impacts of downstream bridge and crossing closures considering in particular the frequency and duration of the closures and the implications of the re-routing of traffic
- assessments relating to bank slumping and erosion, and riparian fauna and flora impacts
- a study of the probability of closely spaced events occurring. This study informed the risk of successive flood events occurring within a short period of time (e.g. 7 days), and hence, also informs the risk/benefit of taking longer than 7 days to drain-down water levels in Wivenhoe, following a flood event.

In addition, information provided by BCC has been utilised (2009 flood maps), and advice has been received from the Bureau of Meteorology in relation to the potential for use of rainfall forecasts.

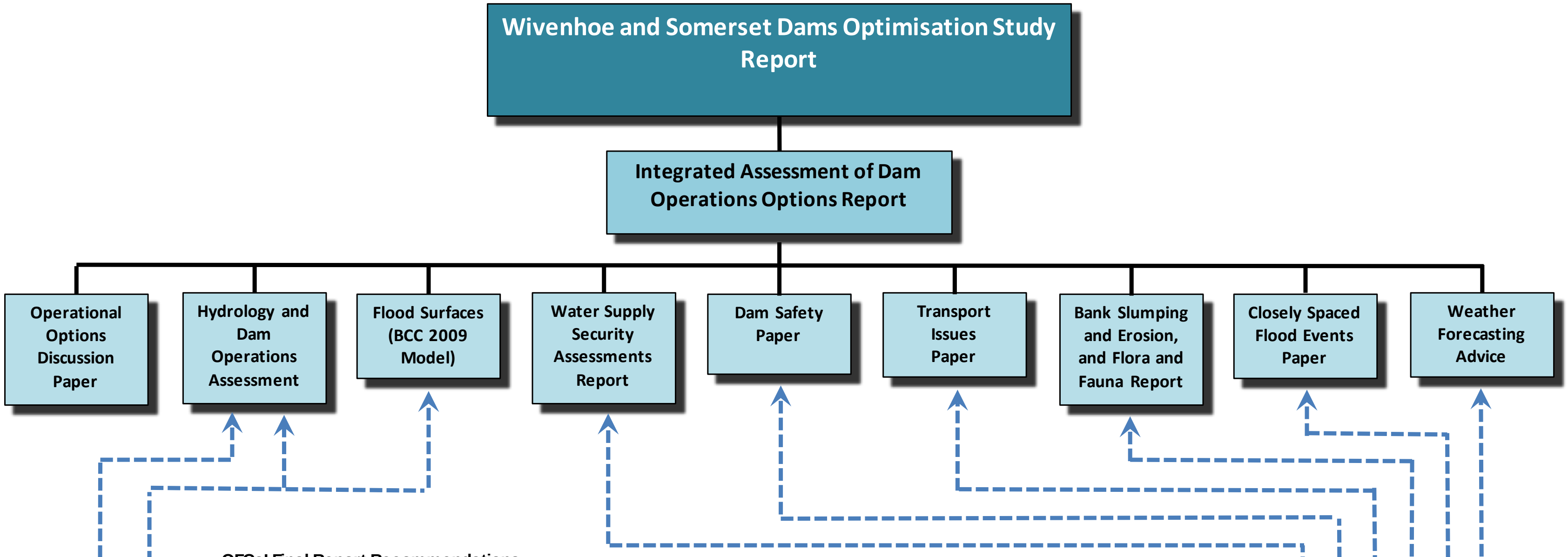
The results of these studies have been used in completing an integrated assessment of the relative costs and damages for the various options considered.

It was necessary to separately consider risks to dam safety because the risks could not be assessed using conventional economic techniques.

1.10 Planning for the optimisation study

Planning for the optimisation study recognised that every flood is different and progressed on the basis that:

- dam safety should not be reduced below current levels and should be increased if possible
- water supply security should not be adversely affected
- the mitigation benefit of the dams on major floods should be retained
- flooding and damage to property and infrastructure should be reduced
- if practicable, timeframes for residents to respond to imminent flooding to be enhanced
- dam operations during minor and moderate inflows will minimise disruption to the community in downstream areas by managing releases in a way that:
    - seeks to reduce bank slumping and erosion and flora and fauna impacts, and
    - minimises traffic impacts.
- objective standards should provide the basis for the operation of the dam. (These should aim to achieve relatively consistent flood mitigation outcomes but recognise that the dam operator must be able to exercise sufficient professional judgement to optimise flood mitigation outcomes.)



QFCol Final Report Recommendations:

17.3: The Queensland Government should ensure that, when it considers options for the operational strategies to be employed at Wivenhoe and Somerset dams, and North Pine Dam, it is presented with a wide range of options which prioritise differing objectives. The Queensland Government should determine the operational strategies by considering the implications of each option over a range of flood events for at least:

- inundation of urban and rural areas
- water supply security
- dam safety
- submerging of bridges
- bank slumping and erosion, riparian fauna and flora.

17.5: As part of the longer term review of the Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam the Queensland Government should consider whether the dam operators should be able to extend the drawdown of the lake beyond seven days in order to reduce downstream bank slumping.

QFCol Interim Report Recommendation:

2.13: The following modelling work should be carried out under the supervision of the steering committee and reviewed by the technical review committee:

1. modelling across the range of full supply levels, operating strategies and flood events (historical, design and synthetic) in each case assessing the consequences in terms of risk to life and safety and economic, social and environmental damage…
2. simulations to test the robustness of relying on the 24 hour, the three day and the five day rainfall forecasts
3. delvelopment of a probability distribution for the time between closely spaced flood peaks in the catchment using historical records.

Figure 1.10 WSDOS – key reports

Chapter 2 Wivenhoe and Somerset dams overview

The Wivenhoe and Somerset dams system is the major water supply source for SEQ and has the dual function of also providing flood mitigation for downstream communities. The dams are located on the Brisbane and Stanley Rivers respectively and together command roughly half the total Brisbane River catchment.

This chapter describes the nature of the overall Brisbane River catchment to provide the context in which the dams are operated, and includes background information about:

- the dams themselves (i.e. their design and operation);
- their catchments; and
- the downstream floodplain areas, flood exposure and flood history profiles.

2.1 Wivenhoe Dam

2.1.1 Description

Wivenhoe Dam was completed in 1984 and is a zoned earth and rock fill embankment dam located on the Brisbane River approximately 80 km from Brisbane by road but some 150 km upstream from the mouth of the river. The main earth and rock embankment is some 2.3 km in length, 50 m high and has a crest level of EL 80 mAHD with a central concrete ogee crest gated-spillway (Seqwater 2013a; URS 2013). Two earth-fill saddle dams are located in the low points of the ridge forming the eastern side of the impoundment that act to retain flood waters above the full supply level.

In 2005, Wivenhoe Dam was modified by the addition of an auxiliary (fuse plug) spillway in the main embankment of the right abutment to improve the capacity of the dam to safely pass extreme flood events (refer to Chapter 9 for further information).

At full water supply level (EL 67.0 mAHD), Wivenhoe Dam has a storage capacity of approximately 1,165,000 ML or about 2000 times the daily water supply needs of Brisbane (Seqwater 2013c). Water releases from Wivenhoe Dam supplement natural flows in the Brisbane River and supply water to the Mount Crosby Water Treatment Plants (East Bank and West Bank) at Mount Crosby Weir, approximately 60km downstream (URS 2013).

The ultimate storage capacity of the dam above full supply level (before overtopping of the embankment occurs at EL 80 mAHD) is 1,970,000 ML which includes storage for flood mitigation and for dam safety.

In addition to its water supply and flood mitigation functions, Wivenhoe Dam also facilitates hydroelectricity generation in association with the nearby much smaller Splityard Creek Dam (refer to Section 2.1.4).

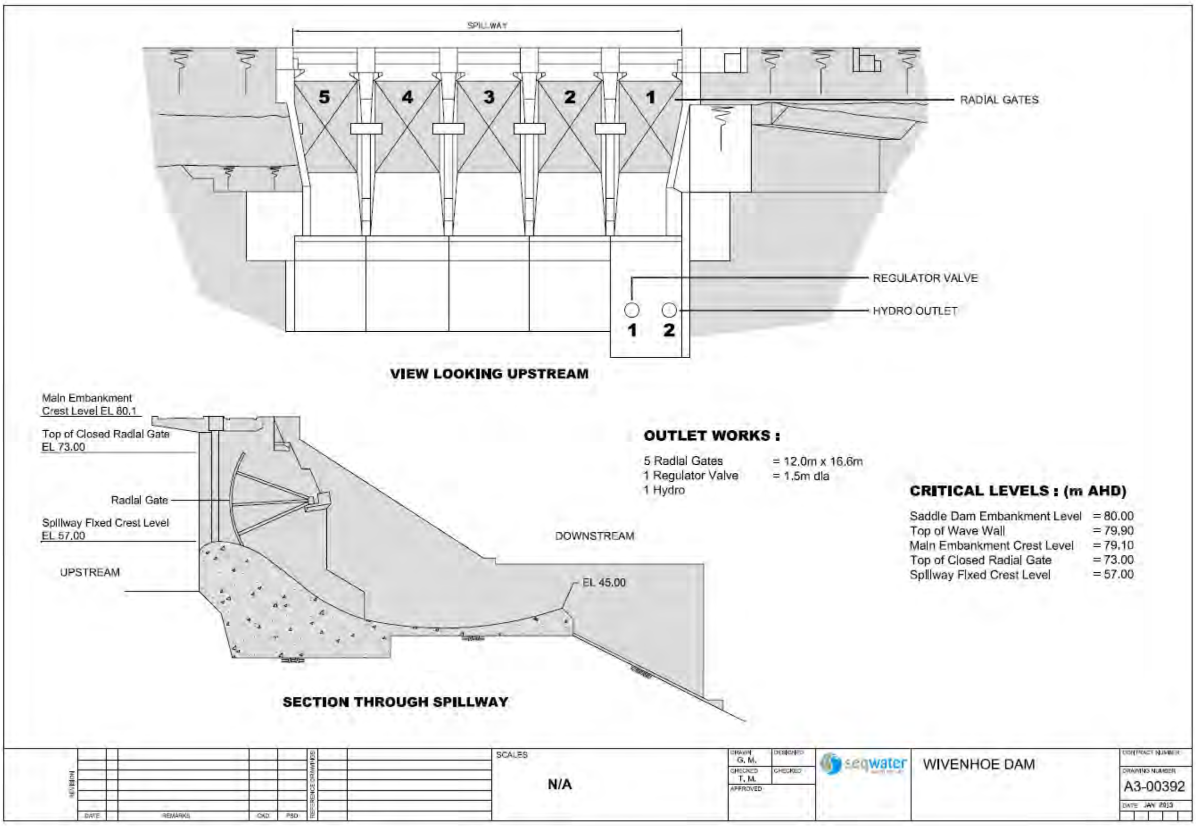
The principal characteristics of Wivenhoe Dam are summarised in Table 2.1 and shown in Figure 2.1.

Table 2.1 Characteristics of Wivenhoe Dam

Feature	Value
Catchment area	6,970 km^2
Full Supply Level (FSL)	67.0 mAHD
Storage Volume at FSL	1,165,200 ML
Flood Mitigation Volume (EL67 to EL80 mAHD)	1,970,000 ML [1]
Lake Surface area at FSL	10,750 ha
Spillway Gates	5 x 12.0 m (wide) x 16.6 m (high)
Spillway Crest Level	57.0 mAHD
Top of closed Spillway Gates	73.0 mAHD
Embankment Crest Level	80.1 mAHD
Main Spillway Maximum Discharge	12,400 m^3/s
Auxiliary Spillway Maximum Discharge	15,000 m^3/s

Note: 1. From URS 2013

Source: URS 2013; Seqwater 2013a; Seqwater 2013b



Source: Seqwater 2013a

Figure 2.1 Wivenhoe Dam main spillway cross-section

2.1.2 Main spillway

The main spillway is located in the central section of the dam embankment and comprises a concrete ogee crest controlled by five radial gates. The dam also comprises a hydro-outlet and one 1,500 mm cone dispersion regulator valve to release water outside of flood events for low-flow management purposes (Seqwater 2013a).

Each radial gate is operated by two hydraulically-driven rope winches that are located on the piers beside each gate and are powered by external mains supply electric power. Each 16 m high gate can be fully opened in 35 minutes. While the radial gates have been designed to withstand limited overtopping, this is to be avoided where possible. Once overtopped, the radial gates can become inoperable if the lifting tackle is fouled by debris; however the gates remain structurally sound until the lake level exceeds EL 77.0 mAHD. Above this level, structural damage is likely to cause the gates to become inoperable (Seqwater 2013a).

2.1.3 Auxiliary spillway (fuse plugs)

An auxiliary fuse plug spillway was added in 2005 (see Figure 2.2) to increase the spillway capacity of Wivenhoe Dam to make it less likely to experience overtopping of the main dam embankment in extreme flood events. It is located in the right abutment and comprises three bays that feature earthen embankments specially designed to automatically erode in the event of flood levels reaching their specific trigger levels. The auxiliary spillway, if fully utilised, has a peak discharge capacity that is slightly higher than the main spillway.

Note: The naming convention (e.g. Left fuse plug) is based on looking downstream

Figure 2.2 Wivenhoe Dam auxiliary spillway and fuse plug bays

Details of the auxiliary spillway design are provided below in Table 2.2.

Table 2.2 Wivenhoe Dam auxiliary spillway specifications

Fuse Plug	Spillway Crest Width (m)	Lake level at fuse plug overtopping	Peak Outflow (m^3/s)		
			Main Spillway	Total Right Abutment Spillway	Total Outflow at Initiation
Central	34.0	75.7	10,600	1,650	12,250
Right	64.5	76.7	11,200	5,400	16,600
Left	65.5	76.2	11,900	9,900	21,800

Source: Seqwater (2013a) Appendix E and Wivenhoe Alliance (2005)

Note: Spillway crest at base of all fuse plugs is RL 67 m AHD.

2.1.4 Splityard Creek Dam and Wivenhoe Power Station

Splityard Creek Dam and Wivenhoe Power Station are located on the eastern side of Wivenhoe Dam and are the two main elements of a pumped storage hydro-electric installation that has been operating since 1984 and is currently owned and operated by CS Energy (CS Energy 2014).

Splityard Creek Dam is a 76 m high and 1,120 m long earth and rock fill dam with a crest level of EL 168 mAHD and capacity of approximately 28,700 ML (at a full supply level of EL 166.5 mAHD). It has a relatively small catchment area of only 3.6 km^2 and has a spillway capacity of 420 m^3/s (QFCoI 2012).

During off-peak hours water is pumped from Lake Wivenhoe up into Splityard Creek Dam. When peak electricity demand occurs, that water is released back into Lake Wivenhoe to generate hydroelectricity. Over a 12 hour period, the maximum volume that can be extracted from, or released into, Wivenhoe Dam is about 23,000 ML (Seqwater 2013b).

This water volume can affect the level in Wivenhoe by up to 300 mm (when Wivenhoe Dam is at FSL) and hence can influence operational decisions (Seqwater 2013b). However, as the maximum volume potentially released into Wivenhoe Dam would be less than 2% of its flood mitigation capacity over 12 hours it has not been considered significant enough to include in the dam operations modelling of options for this study. Flood operations protocols have been established to minimise the impact of such transfers.

2.2 Somerset Dam

2.2.1 Description

Somerset Dam is a mass concrete dam located on the Stanley River about 53 km upstream of Wivenhoe Dam. Construction of Somerset Dam was initiated in 1935 but was delayed due to World War II. The dam was largely complete by 1955 but not finally commissioned until 1959 (Seqwater 2013a).

Somerset Dam is 305 m long and 53 m high at its deepest section (URS 2013). The dam has a central ogee spillway with eight radial crest gates and outlet works comprised of four cone dispersion valves and eight low level sluice gates.

A reinforced concrete deck above the crest of the dam carries winches and a gantry crane required to operate the sluices, crest gates and coaster gate. Nine breeze ways are located either side of the dam, under the concrete deck.

Like Wivenhoe Dam, Somerset Dam is a dual-purpose dam with dedicated compartments for water supply and flood mitigation. At the FSL of EL 99.0 mAHD, approximately 1.45 m below the spillway crest level, Somerset Dam has a water supply storage capacity of approximately 380,000 ML while an additional 721,000 ML is available for flood mitigation up to EL 109.7 mAHD which is the maximum safe level identified in the 2013 Flood Manual (Seqwater 2013a).

Transfers to Wivenhoe Dam are made by a combination of regulator valves, sluice gates and crest gates. Water from Somerset Dam is released into Wivenhoe Dam, which in turn supplements the natural flow of the Brisbane River and maintains the supply of water to the Mount Crosby pumping station located 132 km downstream (Seqwater 2013d).

The principal characteristics of Somerset Dam are summarised in Table 2.3.

Table 2.3 Characteristics of Somerset Dam

Feature	Value[1]
Catchment area	1320 km^2
Full Supply Level (FSL)	99.0 mAHD
Storage at FSL	380,000 ML
Flood Mitigation volume	721,000 ML*[2]
Lake Surface area at FSL	4,210ha
Spillway Gates	7.9 m (wide) x 7.0 m (high)
Spillway Crest Level	100.45 mAHD
Embankment Crest Level	107.45 mAHD

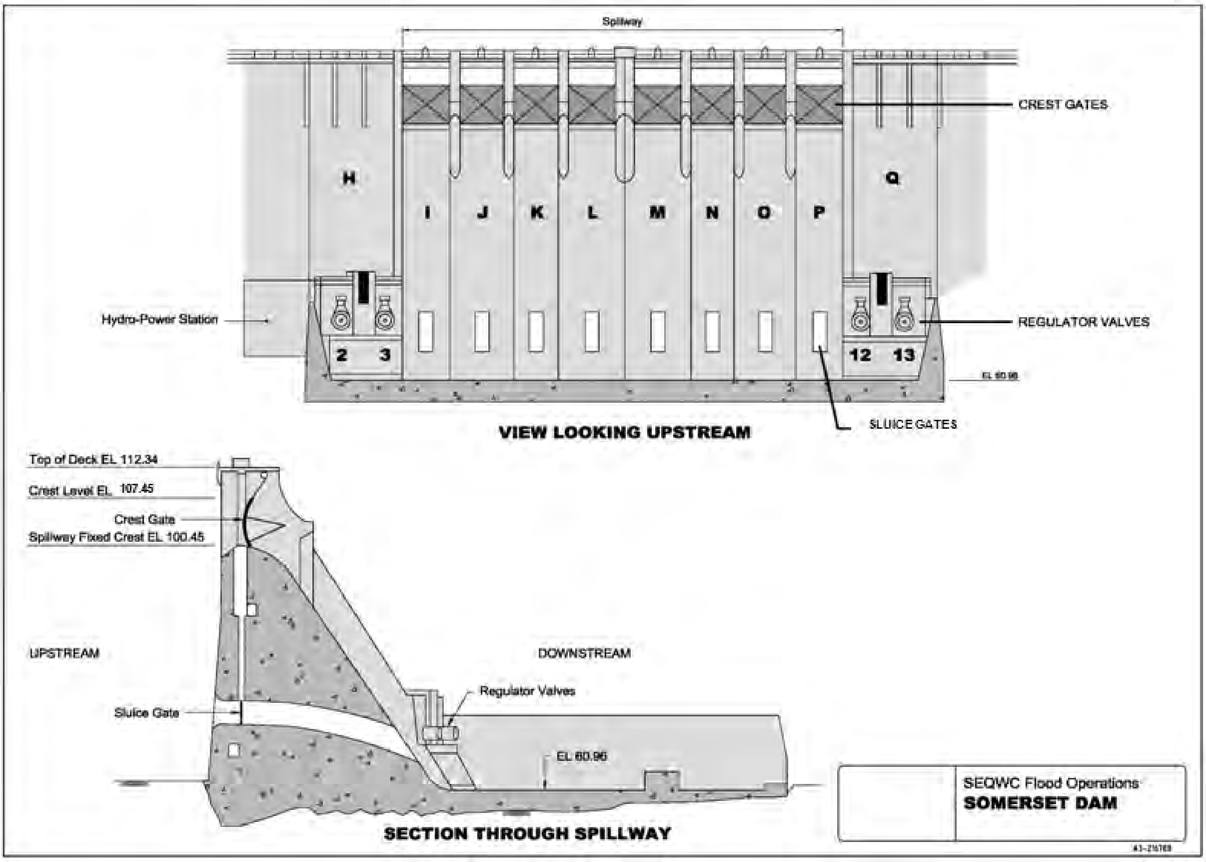
Note: * Crest gates fully open.
1. From URS 2013.
2. From Seqwater 2013a

Source: URS 2013, Seqwater 2013a

2.2.2 Spillway

The centrally-located gated overflow spillway (refer Figure 2.3) is controlled by 8 radial gates and there are 8 low level sluice gates. Each of the radial crest gates and sluice gates are typically operated either fully open or fully closed (Seqwater 2013a).

Normal operating procedure for Somerset Dam during a declared flood event requires the radial crest gates to be fully open.



Source: Seqwater 2013a, Figure 6.1.1

Figure 2.3 Section through Somerset Dam spillway

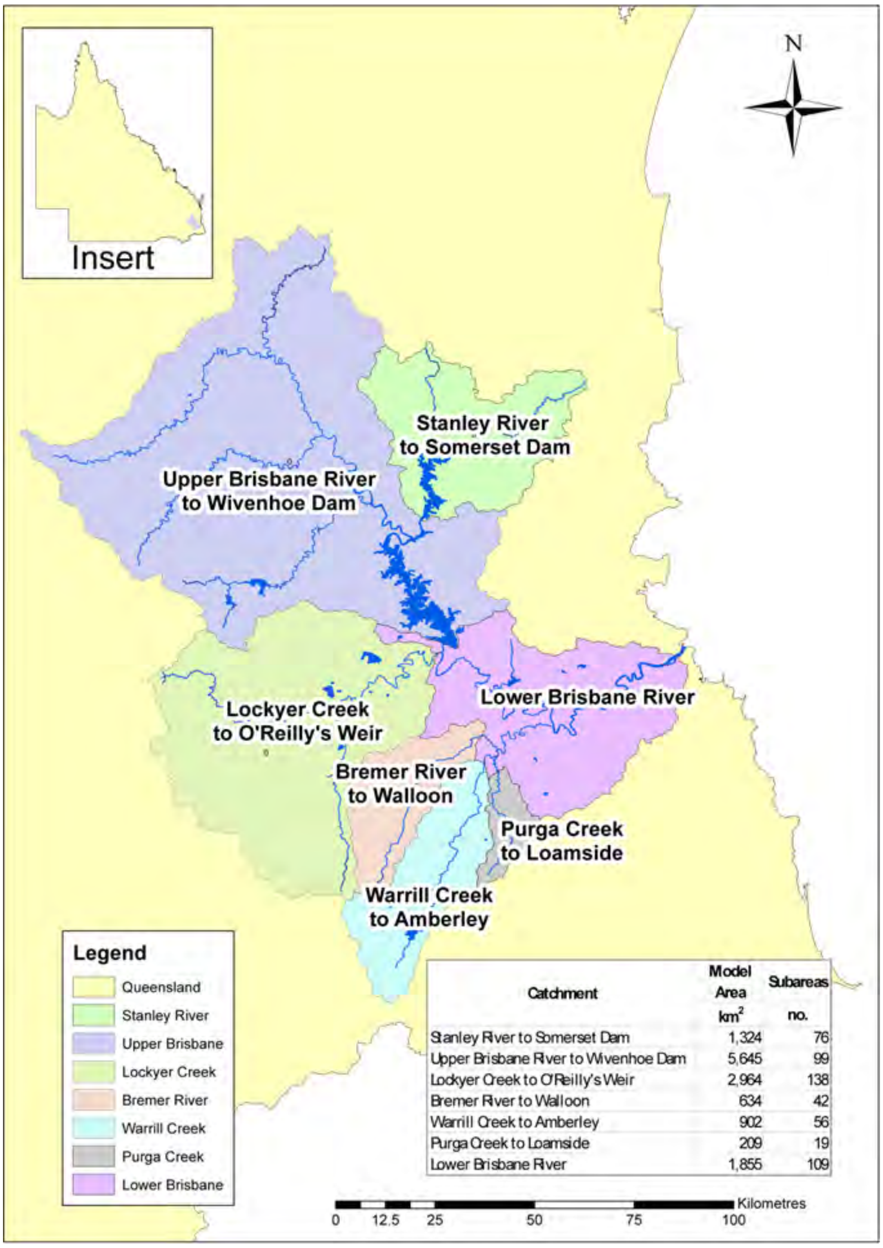
2.3 Catchment

The Brisbane River catchment (Figure 2.4) is approximately 14,000 km^2 and comprises the seven main sub-catchments of:

- Upper Brisbane River
- Stanley River
- Lockyer Creek
- Bremer River
- Warill Creek
- Purga Creek
- Lower Brisbane River.

The catchment is bounded by the Great Dividing Range to the west and a number of smaller coastal ranges to the east and the north. The headwaters are at the northern extent of the catchment, bounded by the Brisbane Range approximately 120 km north west of Brisbane City (Middelmann et al. 2001). Around half of the Brisbane River catchment is located downstream of Wivenhoe Dam.

Ongoing settlement and development within the floodplain over the past century has been responsible for significant change of the Brisbane River catchment, as is true of effectively all waterways in both rural and urban areas. In addition, channel modification, including dredging and widening in the lower reaches took place in the 1930s and 1940s to improve channel navigability and for increased flood mitigation (Babister 2011).



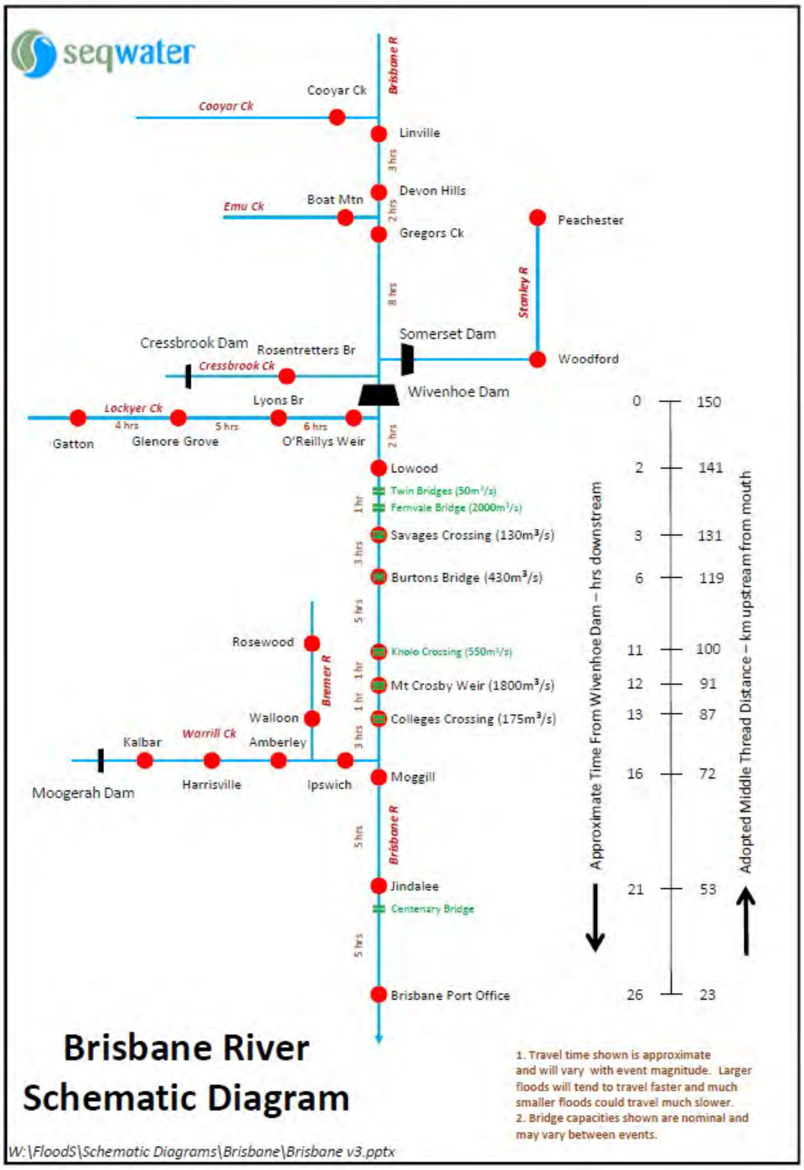
Source: Seqwater 2013b, Figure 6-1

Figure 2.4 Brisbane River sub-catchments

The behaviour of floodwaters in the catchment is complex. Rainfall within this large catchment is rarely uniform, with significant variation in the location, intensity and timing. Several major watercourses dominate the catchment, each having unique characteristics, runoff responses to rainfall, and routing behaviour that influences the timing and hydrograph shape of floods advancing downstream.

Much of the catchment is rural, predominantly forestry and grazing land, with the exception of the major metropolitan areas of Brisbane and Ipswich and a number of smaller towns (Healthy Waterways 2013).

A schematic of the Brisbane River and its tributaries is provided in Figure 2.5 showing key locations and approximate travel times for flows downstream of Wivenhoe Dam to reach the Brisbane Port Office gauge.



Source: Seqwater 2013a, Appendix M

Figure 2.5 Brisbane River schematic diagram

2.3.1 Wivenhoe Dam catchment (upper-Brisbane River)

The upper Brisbane River drains an area of approximately 7,000 km^2, including the catchment of the Stanley River and Somerset Dam, into Wivenhoe Dam. The major tributaries of the Upper Brisbane River - Cooyar, Emu and Cressbrook creeks - drain in a south-easterly direction and join the River upstream of its junction with the Stanley River and Somerset Dam (Seqwater 2013b).

The upper catchment, which has its headwaters in the Great Dividing Range and Conondale Range remains in a relatively natural state, whilst the majority of the remaining catchment has been cleared for grazing and intensive agriculture (Healthy Waterways 2013).

The Upper Brisbane River catchment encompasses the towns of Esk, Toogoolawah, Crows Nest, Cooyar, Blackbutt, Benarkin, Yarraman, Linville, Moore and Harlin and the local government areas of Somerset and Toowoomba Regional Councils. Of these, only Esk (population ~ 1,755) has the potential to be affected by large flows in the Brisbane River.

Source: Seqwater 2013a, Appendix J

Figure 2.6 Bridges potentially impacted by elevated lake levels in Wivenhoe Dam

The catchment is traversed by a number of major arterial roads, including the Wivenhoe Somerset Road, Esk - Kilcoy Road and the Brisbane Valley Highway. Bridges upstream of Wivenhoe Dam, associated with these roads, can be affected by elevated water levels within the dam and are shown in Figure 2.6 (Seqwater 2013a).

2.3.2 Somerset Dam catchment (Stanley River)

The headwaters of the Stanley River rise in the forested Conondale Ranges (Healthy Waterways 2013). Together with its tributaries, Kilcoy Creek, Sheep Station Creek and Delaney Creek, the Stanley River drains an area of approximately 1,320 km^2 to Somerset Dam (Seqwater 2013b).

Riparian vegetation remains in very good condition in the upper reaches of the Stanley River while the mid reaches have been extensively cleared for the grazing of beef and dairy cattle (Healthy Waterways 2013). The Stanley River catchment is much wetter than that of the Brisbane River, draining through one of the heaviest rainfall regions in Australia (EHA 2010).

The catchment of Somerset Dam and the Stanley River encompass parts of the Moreton Bay, Sunshine Coast, and Somerset Regional councils and the towns of Kilcoy, Woodford, Mt Mee, D'Aguilar, Neurum and Peachester. Kilcoy (population ~ 1,700) is the only centre likely affected by high flows or elevated lake levels in Somerset Dam.

The catchment is traversed by a number of major arterial roads, including the Esk - Kilcoy Road, Neurum Road, Kilcoy - Murgon Road, Mount Kilcoy Road and the D'Aguilar Highway. Bridges associated with these roads can be affected by elevated lake levels in Somerset Dam, as outlined in Table 2.4 (Seqwater 2013a).

Table 2.4 Bridges potentially impacted by elevated lake levels in Somerset Dam

Bridge Name	Road	Deck Elevation (EL mAHD)	Local Government
Mary Smokes Creek	D'Aguilar Highway	102.81	Somerset Regional Council
Kilcoy Creek	D'Aguilar Highway	104.76	Somerset Regional Council
Beam Creek	Esk Kilcoy Road	106.52	Somerset Regional Council
Scrubby Creek	D'Aguilar Highway	107.60	Somerset Regional Council
Oakey Creek	Esk Kilcoy Road	108.55	Somerset Regional Council

Source: Seqwater 2013a, Appendix J

2.3.3 Downstream catchments

In the lower catchment, Lockyer Creek forms the largest tributary of the Brisbane River in terms of catchment size, commanding an area of around 2,964 km^2 (Seqwater 2013b). Lockyer Creek catchment includes the towns of Lowood (population ~ 3,350), Minden, Laidley, Forest Hill, Gatton, Grantham, Helidon, Murphys Creek and Withcott. Lockyer Creek drains into the Brisbane River immediately downstream of Wivenhoe Dam near Lowood. Lockyer Creek has a number of major tributaries including Murphys Creek, Flagstone Creek, Sandy Creek, Gatton Creek, Laidley Creek and Buaraba Creek.

The upper parts of the Lockyer Creek Catchment to the south and west are generally steep and mainly forested while the lower floodplains are used for intensive agriculture with a number of small population centres located across the area (ICA 2011, Healthy Waterways 2013). Significant flows from the Lockyer in the 2013 flood event proved problematic due to the high sediment load and consequent impact on the water treatment facilities (Seqwater 2013e).

The second largest tributary of the Brisbane River is the Bremer River, which commands a catchment area of around 1,500 km^2 (refer to Figure 2.7) The tributaries of the Bremer River have their headwaters in the Little Liverpool range to the southwest, and drain in a north easterly direction into the Bremer River, which drains into the Brisbane River at Moggill (ICA 2011).

The Bremer River catchment is generally steep and lightly forested, except the lower north-eastern areas which drain through the City of Ipswich (ICA 2011, Healthy Waterways 2013). The Bremer River catchment comprises the local government areas of Scenic Rim Regional Council and Ipswich City Council. Local population centres include Ipswich City (population ~ 180,000), Chuwar, Walloon, Rosewood, Calvert, Grandchester, Harrisville, Warrill View, Munbilla, Kalbar and Aratula.

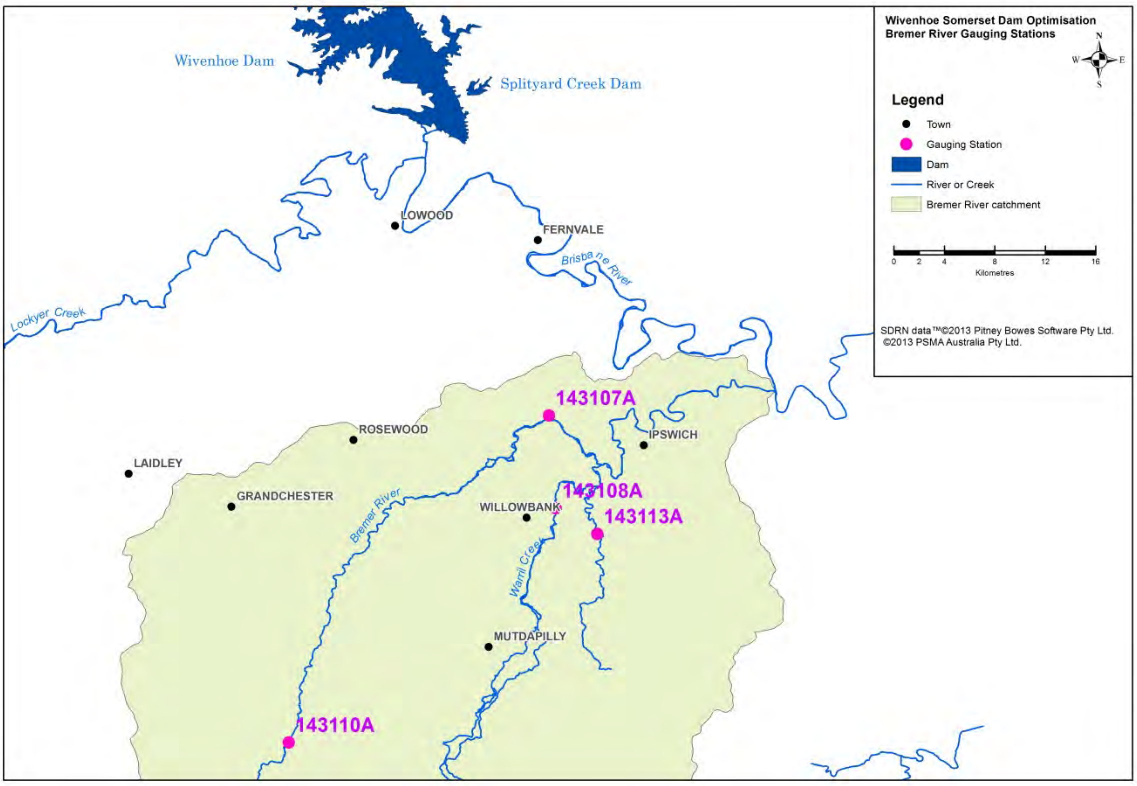


Figure 2.7 **Bremer River catchment and stream gauging stations**

The mid Brisbane River catchment extends from Wivenhoe Dam to the Bremer River junction Weir with the lower Brisbane catchment extending to the river mouth in Moreton Bay. The mid and lower Brisbane River catchment area totals around 1,900 km^2 (Seqwater 2013b). Flows in the river reach between Wivenhoe Dam and Mount Crosby Weir are regulated by releases from the dam (as well as receiving inflows from Lockyer Creek).

The northern and eastern parts of the mid-Brisbane catchment comprise areas made up of the Brisbane Forest Park, grazing land, intensive agriculture and rural residential blocks (Healthy Waterways 2013). Population centres within the mid-Brisbane catchment include Fernvale (population ~ 2,400), Glamorgan Vale and Marburg. The lower-Brisbane comprises grazing and agricultural areas as well as the highly modified urbanised areas of Brisbane City and its suburbs (population ~ 1.9 million).

In addition to Lockyer Creek and the Bremer River, the Brisbane River catchment below Wivenhoe Dam is drained by numerous tributaries, including Six Mile Creek, Kholo Creek, Goodna Creek, Woogaroo Creek, Sandy Creek, Pullen Pullen Creek, Moggill Creek, Oxley Creek, Norman Creek, Enoggera Creek, and Bulimba Creek. Flood events are recorded at various stream gauging stations, the locations of which are indicated on Figure 2.8.

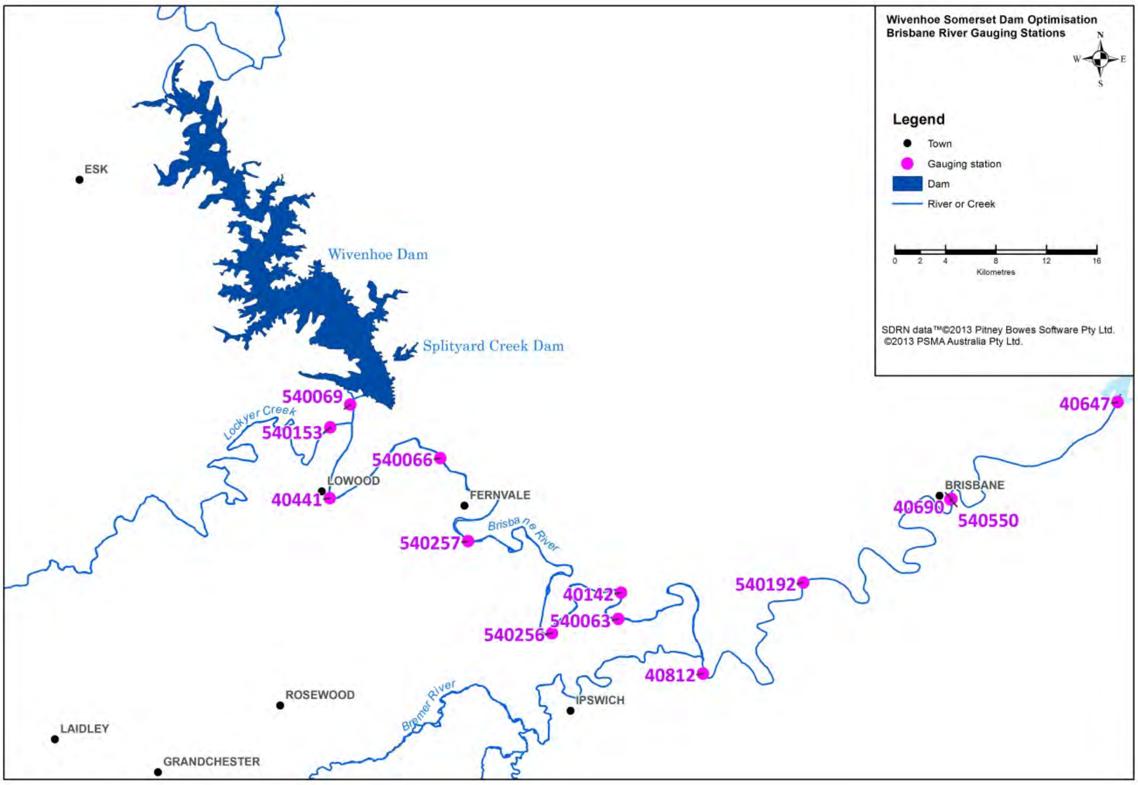


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Figure 2.8 Mid and lower-Brisbane River stream gauging stations

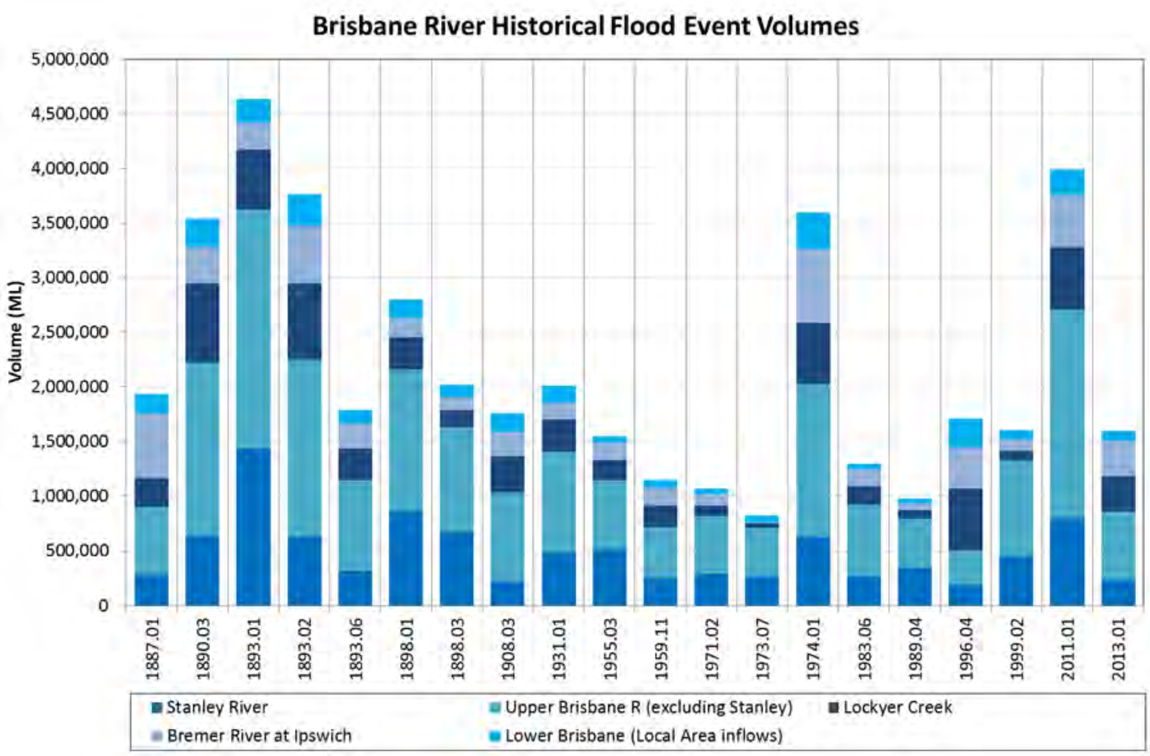
The Brisbane River catchment below Wivenhoe Dam includes the local government areas of Somerset Regional, Brisbane City and Ipswich City councils.

The catchment downstream of Wivenhoe Dam is crossed by a number of significant arterial roads, including the Brisbane Valley Highway. A number of low level bridges and crossings on these roads experience inundation as a result of releases from Wivenhoe Dam, as detailed later in Chapter 10.

2.4 Brisbane River floodplain

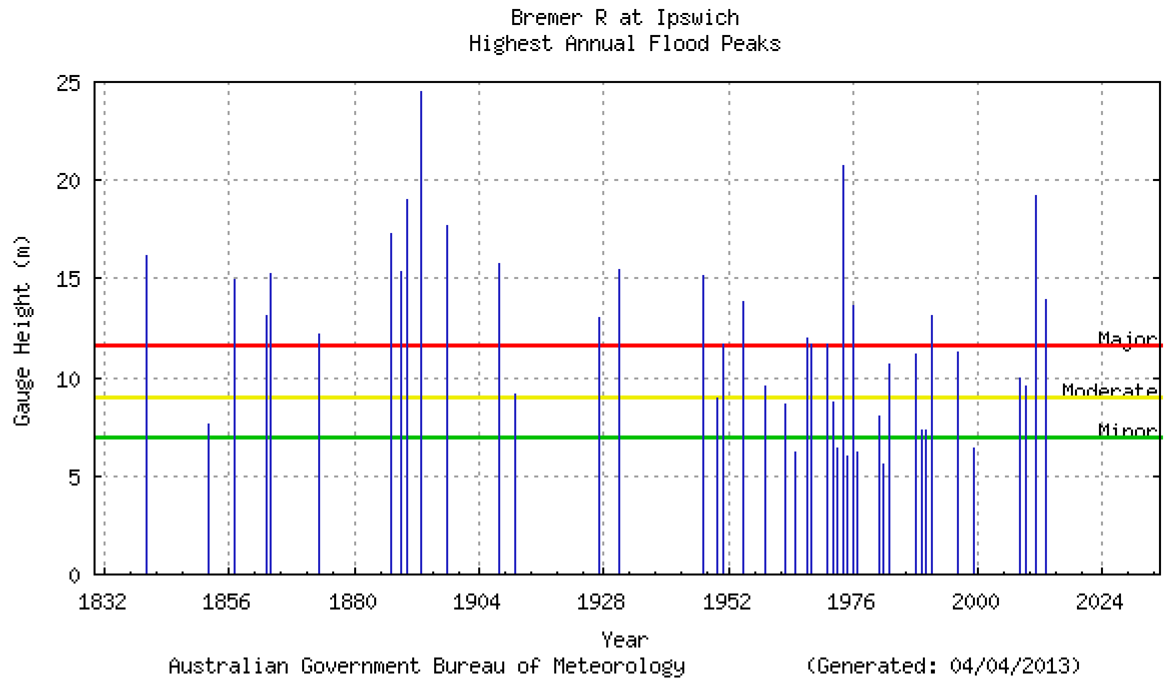
2.4.1 Historical flood events

Floods have played a significant role in the history of the cities of Brisbane and Ipswich and the catchment more broadly. Figure 2.9 and Figure 2.10 (BoM 2013) summarise the occurrence of Bremer and Brisbane River flooding since the beginning of records and shows the flood volumes and peak lake levels recorded during selected historical events. Aboriginal folklore tells of a flood which broke over the banks near the present location of the William Jolly Bridge and flowed across the area now occupied by the Brisbane CBD (Jones 1935). In 1824, the explorer John Oxley recorded the presence of debris 30 m above the water surface around Mount Crosby. Flood records for Brisbane extend as far back as 1840s (Jones 1935). Quality flood records began in earnest from the mid-1950s. It should be noted that all flood levels prior to 1983 have no mitigating benefits attributable to Wivenhoe Dam, whereas those events post 1983 have had peaks reduced through operation of the dam. Floods occurring before 1955 (by which time the construction of Somerset Dam was mostly complete) were not subject to any regulation (Seqwater 2013b).



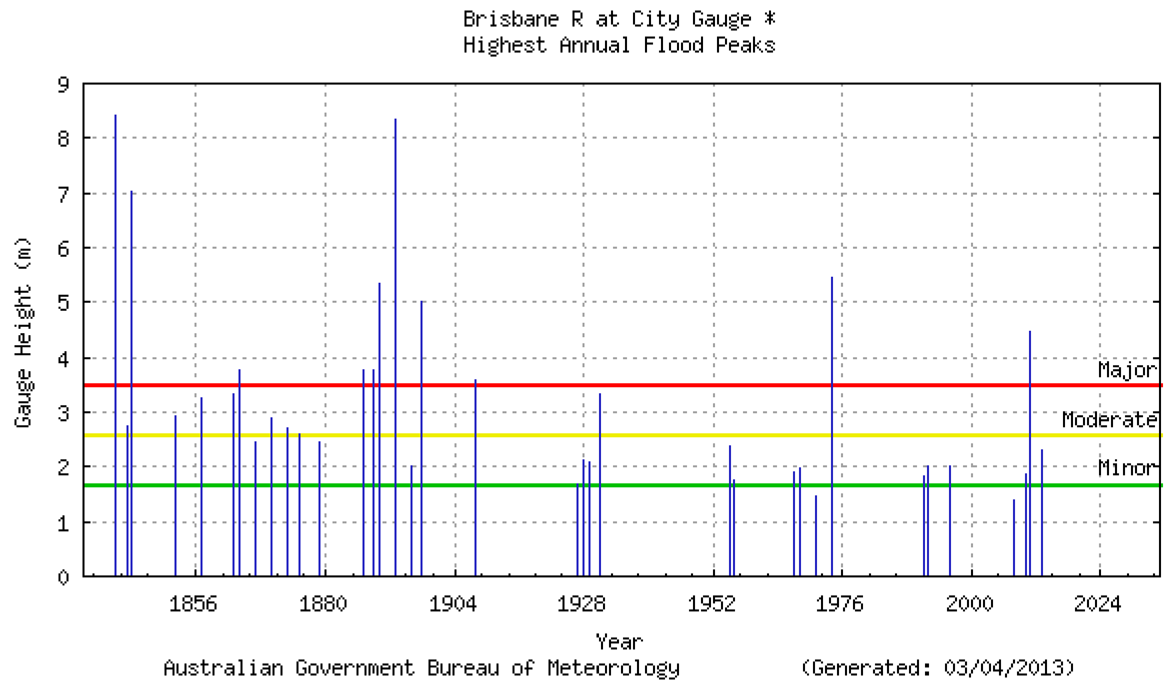
Source: Seqwater 2014a, Figure 2-4

Figure 2.9 Historical Flood Event Volumes



Source: BoM 2013

Figure 2.10 Historic floods in the Bremer River



Source: BoM 2013

Figure 2.11 Historic floods in the Brisbane River

It should be noted for both figures that the “major”, “moderate” and “minor” flood classifications are as used by BoM, and are different to those adopted by Seqwater for modeling purposes. Additionally, flows are influenced by the construction of Somerset Dam (mid 1950s) and Wivenhoe (mid 1980s).

The earliest flood records note a Bremer River flood peak of 17.35 m at Ipswich in 1840 (Seqwater 2013b). The 1841 flood event was the highest recorded in Brisbane’s history, with a height of 8.43 mAHD at the Port Office gauge (located on the left bank / city side of the river) (Seqwater 2013b).

In 1844, further heavy floods were experienced in Brisbane and Ipswich, peaking at around EL 7.03 mAHD at the Port Office gauge (BoM 2013). The year of 1893 saw three major floods, peaking on the 5th, 12th and 19th of February. The first and third peaks reached 8.35 mAHD and 8.09 mAHD respectively, washing away houses at Ipswich and Brisbane (BoM 2013).

From the early 1860s and up until 1910, peak flood heights at Brisbane Port Office were affected by dredging and other significant river improvement works (Seqwater 2013b). Initial works commenced as early as 1862 and were completed by 1867, seeking to improve navigability of the river. Some additional works were carried out in 1867 between Brisbane and Ipswich to improve navigation up to Ipswich and dredging and river improvement continued up to 1910. From this period no further works were carried until Seventeen Mile Rocks were removed in 1965 (Seqwater 2013b).

Flooding over the 25th to 29th January 1974 peaked at 5.45 mAHD at the Port Office (Seqwater 2013b), with both the Brisbane and Bremer Rivers at their highest level since 1893 (BoM 2013). The 1974 flood event was the largest recorded in the 20th century and ranks as the fifth largest flood recorded since 1841 (the 1841 flood, two 1893 floods and the 2011 flood were larger) when adjusted for the influence of dams and channel modifications (Babister 2011).

The January 2011 flood event was the largest experienced since the construction of Wivenhoe Dam. This flood peaked at 4.46 mAHD at the Brisbane City gauge (located on the right bank / Kangaroo Point) (Seqwater 2013b). The intense rainfall experienced in SEQ from the 9th to 12th January 2011 fell on a catchment already saturated by above-average to highest-on-record rainfall in December 2010 (BoM 2013).

Additional detail with respect to historical floods may be obtained from Seqwater (2013b).

2.4.2 Impacts of modern floods

The floodplain of the Brisbane River and its tributaries is highly urbanised and includes the cities of Ipswich and Brisbane. Development of Brisbane river floodplain has increased in intensity following the floods of 1974. Table 2.6 shows the changes in impacts due arguably to increased floodplain development since 1974 for the different flood levels portrayed in Figure 2.11.

Flood statistics vary and are not always comparable. Properties can be affected by flooding over ground, over building floor level or by flood waters cutting access. The estimates in Table 2.6 are for numbers of properties flooded over ground.

Table 2.5 Estimated number of properties flooded by 1974 and 2011 Floods

Properties Type	1974	2011[1]
Brisbane Residential	6,700	10,000 – 12,500
Brisbane Non-residential		2,500 – 4,000
Ipswich Residential	1,800[2]	1,200 – 3,000
Ipswich Non-residential		200 – 1,700

Note : 1. This is the number of properties impacted by flooding rather than number of properties impacted by flooding above habitable floor level in Chapter 15.

2. Number of properties includes residential and commercial properties.

Source: BoM 1974, Aurecon 2014

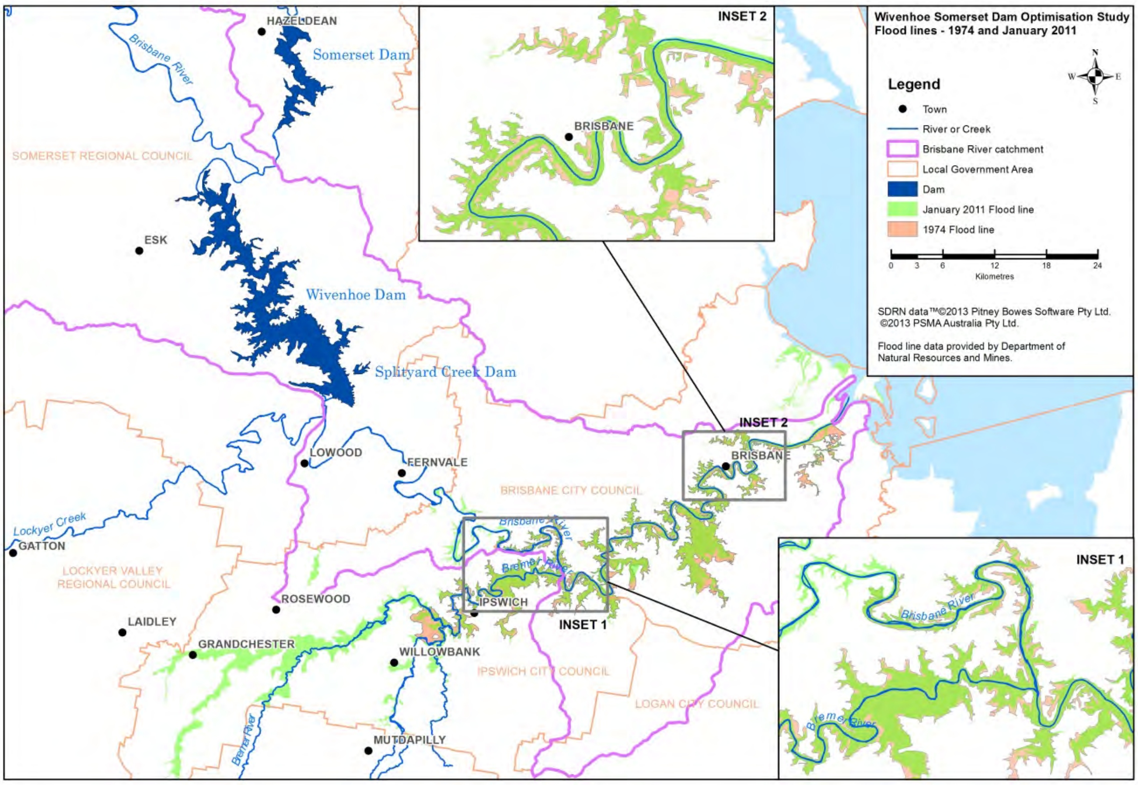


Figure 2.12 Extent of 1974 and 2011 floods

The January 1974 flood which rose to 5.45 mAHD at the Brisbane Port Office gauge, caused widespread damage in Brisbane and Ipswich. It was estimated that the 1974 flood damage cost (both direct and indirect costs) was approximately $178 million (direct costs $142 million) in 1974 dollars (SMEC 1975). This estimate was based on Brisbane River flooding only (i.e. backwater flooding of tributaries including the Bremer River, as caused by Brisbane River levels). The actual total damage for both Brisbane and Ipswich would have been much greater given the severe flooding from metropolitan tributaries in both cities and the damage resulting from flooding from the Bremer River in Ipswich.

It was estimated that for the extent of floodplain development in 1974, damage estimates in 1974 dollars would range from $10 million for a flood of 2 mAHD to $531 million for a 10 mAHD flood in Brisbane (SMEC 1975).

Aurecon (2014) estimated 10,000 to 12,000 residential properties, and 3,000 to 4,000 commercial properties were inundated by floodwaters in Brisbane during the 2011 flood with damages estimated at approximately $3 billion. Between 1,200 and 3,000 residential and 200 to1,700 non-residential properties were inundated in Ipswich by Bremer River flows and/or Brisbane River backwater.

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Chapter 3 Flood Manual

Given the potential significant impact on downstream populations, it is imperative that Wivenhoe Dam and Somerset Dam be operated during flood events in accordance with clearly defined operational procedures to protect the structural safety of the dams and minimise impacts to life and property.

The purpose of the Flood Manual is to provide sufficient information and guidance to suitably qualified and experienced professional engineers to allow those engineers to make appropriate decisions on how best to release floodwater from the dams during Flood Events.

This chapter outlines:

- the legislative requirements relating to the preparation of a flood mitigation manual
- the changes to the Flood Manual since the 2011 Flood Event, and
- summarises the key aspects of 2013 Flood Manual (Revision 11) operational procedures.

3.1 Legislative requirements

Wivenhoe Dam and Somerset Dam are subject to regulation under the *Water Supply (Safety and Reliability) Act 2008* (QLD) (the Act). Accordingly, as the owner/operator of both dams, Seqwater is required to produce a flood mitigation manual (the Flood Manual), which under Section 371D of the Act must:

- State objectives for flood mitigation and their relative importance to each other
- State operational strategies required to achieve, and appropriately balance, the objectives for flood mitigation
- State operational procedures required to achieve the operational strategies for flood mitigation, including for releasing water during flood events, a declaration of a temporary full supply level or variations to procedures to deal with urgent circumstances
- State roles and responsibilities, qualifications, experience and training of all persons responsible for the operation of the dams
- Provide for a system (the forecast system) to forecast the amount of rainfall in or affecting the dam catchment, inflow to the dam, outflow from the dam and the water levels of the dams required by the Flood Manual, and
- State any other relevant matter prescribed under a regulation.

The Minister may approve a flood mitigation manual only if satisfied that it meets the following criteria, prescribed under Section 371F of the Act:

a) the manual complies with the requirements under Section 371D as outlined above, and

b) the carrying out of the operational strategies and operational procedures under the manual would minimise risk to human life and safety, and

c) the manual achieves an appropriate balance in relation to each of the following:
   i. preventing failure of the dam, including, for example, by protecting the structural integrity of the dam
   ii. minimising risk to property
   iii. minimising disruption to transport
   iv. maintaining the full supply level for the dam after a flood event
   v. minimising environmental impacts on the stability of banks of watercourses and on riparian flora and fauna.

3.2 Changes to the Flood Manual since the 2011 flood event

Following the 2011 flood event the Flood Manual (Version 7, Nov 2009) has been revised on four occasions. These revisions sought to incorporate specific recommendations arising from the QFCoI (QFCoI 2011, QFCoI 2012), subsequent changes to the Act, the independent review of Seqwater's flood event report (USBR et al. 2012) and Seqwater's own post-event recommendations (Seqwater 2011a). This has resulted in a significant re-structuring of and re-naming of the earlier dam operating strategies and relaxation of some bridge submergence rules. However, the fundamental operational philosophy of the Flood Manual is not significantly different from what it was in 2011. Further changes may be made following WSDOS.

3.2.1 Revision 8 (September 2011)

QFCoI Interim Report recommendation 2.8 was that, in relation to the Flood Manual, Seqwater should:

1. *conduct an interim review of the existing manual*
2. *have the draft manual assessed by independent expert peer reviewers*
3. *consider the expert peer reviews*
4. *submit the draft manual for approval under the Act so that it can be approved before 1 October 2011.*

QFCoI Interim Report recommendation 2.9 further detailed specific matters requiring particular attention during the interim review:

- *definition of what 'best forecast rainfall' means*
- *prescription about how forecast rainfall information is to be used by the flood engineers*
- *definition of 'predicted lake level' and the use of consistent language throughout the Wivenhoe manual about predicted lake levels*
- *clarification of options for transition to strategies W2 or W3 from strategy W1*
- *clarification of the rules for drawdowns of the dams following flood events*
- *removal of the term 'non-damaging flows' (and similar terms) to describe flows below 4,000 m^3/s at Moggill*
- *clarification of whether W3 allows the flood engineers to release water which would create a flow at Moggill of over 4,000 m^3/s*
- *precise definition of the maximum mechanical capability of the gate opening mechanism*
- *clarification of how part 8.6 should be followed in strategy W4, including clarifying the use of the word 'generally'.*

The QFCoI recommendations have been implemented to the extent practical.

Version 8 of the Flood Manual focused on clarification of terminology and strategy decision making, mainly to improve public understanding but made no changes to the previous operating practices. In addition the Flood Manual included allowance for the possibility of a 'temporary full supply level' being declared to provide an increased flood storage compartment to assist in urban flood mitigation. This required a number of related changes to be made for operational consistency.

3.2.2 Revision 9 (November 2011)

Revision 9 consisted of the inclusion of a new chapter in the Flood Manual that specifically describes the procedures required to be followed when a Temporary Full Supply Level is enacted.

3.2.3 Revision 10 (October 2012)

Revision 10 followed QFCoI Final Report (QFCoI 2012), which made further comment and recommendations into the style of language and descriptions used in the revised Flood Manual at this time.

As a result a number of generally minor changes were made to the Flood Manual that did not alter the objectives, strategies or operating practices of Revision 9. For example, changes included the addition of a Preamble providing a brief overview of the Wivenhoe and Somerset Dam infrastructure and storage volumes, some clarification of roles and responsibilities, changes in BoM forecast terminology, clarification on the use of discretion and minor edits to various descriptions and notes. The emergency procedures for gate operations in the event of loss of communication were also revised.

3.2.4 Revision 11 (November 2013)

The Minister of Energy and Water Supply established a Ministerial Advisory Council for Flood Mitigation Manuals (Advisory Council) in 2012 to provide advice to the Minister before deciding whether or not to approve a submitted Flood Manual. This process commenced in the lead-up to the 2013/14 wet season. The main issues that were addressed in preparation of the Revision 11 Flood Manual were:

- amendments made to the Act in late 2012
- consideration of bridges
- merger of Strategies W2 and W3 and improved clarity of strategies and procedures
- improvements to draw-down procedures, and
- releases for the Mt Crosby Water Treatment Plant (WTP).

Changes were made to the Flood Manual in relation to:

1) Amendments made to the Act in late 2012[8], which included:
   a) introduction of mandatory requirements for the content of flood manuals
   b) introduction of mandatory requirements in respect of:
      i) the review and amendment of flood manuals
      ii) annual preparedness reports

[8] See *Water Legislation (Dam Safety and Water Supply Enhancement) and Other Legislation Amendment Bill 2012*

iii) qualifications, experience and training of flood engineers
iv) flood reporting.

c) introduction of a statutory procedure for the manner in which dam owners can seek authorisation to operate outside of the procedures set out in the flood manual (Alternative Procedures)
d) the Minister's approval to a flood manual must be for a period of no more than 5 years.

These changes required removal from the Flood Manual of those matters that were contained in the revised Act, other than the provision relating to Alternative Procedures. It was considered necessary to keep this provision within the Flood Manual to assist operational decision making during a flood event. The provisions in the Act relating to Alternative Procedures were copied into the Flood Manual (with necessary adjustments).

2) Consideration of bridges

When the Flood Manual was originally developed, priorities for maintaining bridges free of flood water were determined using input from local government stakeholders and updated advice was sought in this regard through the WSDOS process. The only change resulting from this was that Somerset Regional Council advised considerations for Twin Bridges and Savages Crossing could be removed.

3) Merger of Strategies W2 and W3 and improved clarity of strategies and procedures

This addressed some of the specific recommendations from the QFCoI in regard to simplifying the description of the various strategies and DEWS' suggestion to consider the merging of Strategies W2 and W3, with the aim of simplifying flowcharts and making it easier for stakeholders to understand the Flood Manual.

In response, Seqwater made significant changes to the operational procedures in the Flood Manual, relating mainly to Sections 5 and 6, which are summarised below:

a) Strategy W2 and Strategy W3 were combined into a single strategy and Strategies S1, S2 and S3 were also combined into a single strategy
b) Significant clarification of operational practice was added, including a guidance table in the new Strategy WU that largely reflects historic practice
c) All strategies were renamed to limit confusion with the old numbered strategies
d) Drain-down was drafted as a strategy in a similar manner to the other strategies
e) The new procedures strongly focused on the iterative nature of flood operations
f) Where predicted conditions are used in Operational Procedures, the “judged likely” or “judged very likely” terminology was used to emphasize that professional judgement is involved in assessing likely conditions
g) No time limits were provided for predicted conditions, which allow professional judgement to be applied without arbitrary time limits being imposed.

4) Improvements to Draw-Down Procedures

Constraints on the rate of draw-down relating to Burtons Bridge closure were relaxed to allow for greater volumes of flood storage to be made available to mitigate an approaching flood event, without exceeding the urban damage threshold below Moggill and without affecting the major crossings at Mt Crosby and Fernvale.

5) Releases for the Mt Crosby Water Treatment Plant (WTP)

The January 2013 flood event demonstrated the potential need to make releases from Wivenhoe Dam during flood events to maintain water quality levels for the Mt Crosby WTP for the purposes of ensuring a secure urban water supply to Brisbane. Previously the Flood Manual did not explicitly account for such an objective and the Manual was amended to recognise this issue.

3.3 Overview of the current manual of dam operations

The current Revision 11 Flood Manual (Seqwater 2013a) describes the approved rationale to address the objectives under the Act. In decreasing order of importance and in simple terms, the stated Seqwater objectives are to:

- ensure the structural safety of the dams
- provide optimum protection of urbanised areas from inundation
- minimise disruption to rural life in the valleys of the Brisbane and Stanley Rivers
- retain the dams at near FSL at the conclusion of a flood event, and
- minimise impacts to riparian flora and fauna during the drain-down phase of the flood event.

In meeting these five objectives the Flood Manual states that the dams must be operated to account for the potential effects of successive, closely spaced flood events.

3.3.1 Operational strategies

Figure 3.1 shows the current allocation of Wivenhoe storage capacity to water supply, rural flood mitigation, urban flood mitigation and dam safety purposes.

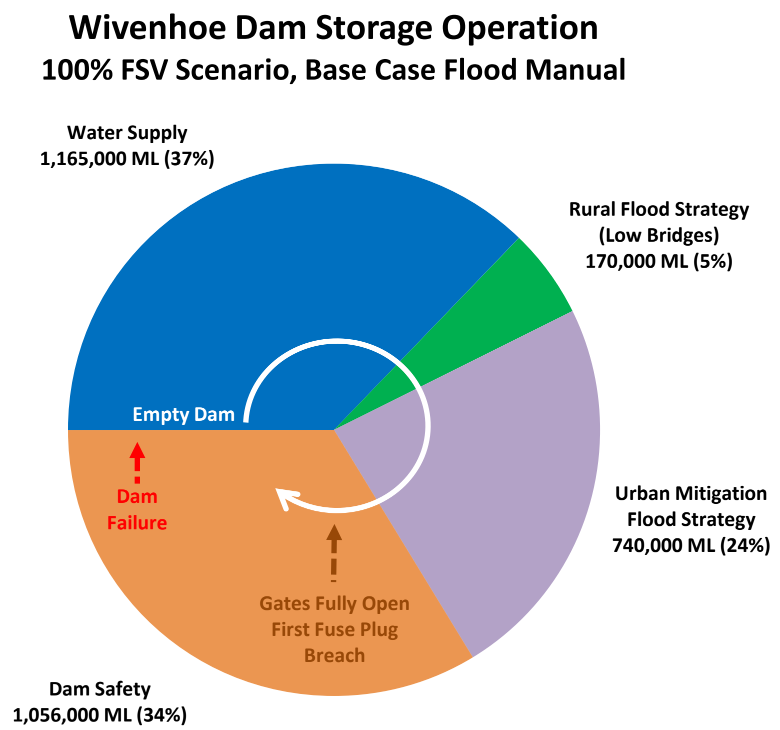


Figure 3.1 Apportionment of Wivenhoe Dam storage to water supply and flood operations

The operational strategies devised by Seqwater to achieve the flood mitigation objectives are summarised below and schematically as Figure 3.2 in the context of a typical timeline of likely responses to a developing, escalating and finally receding flood event:

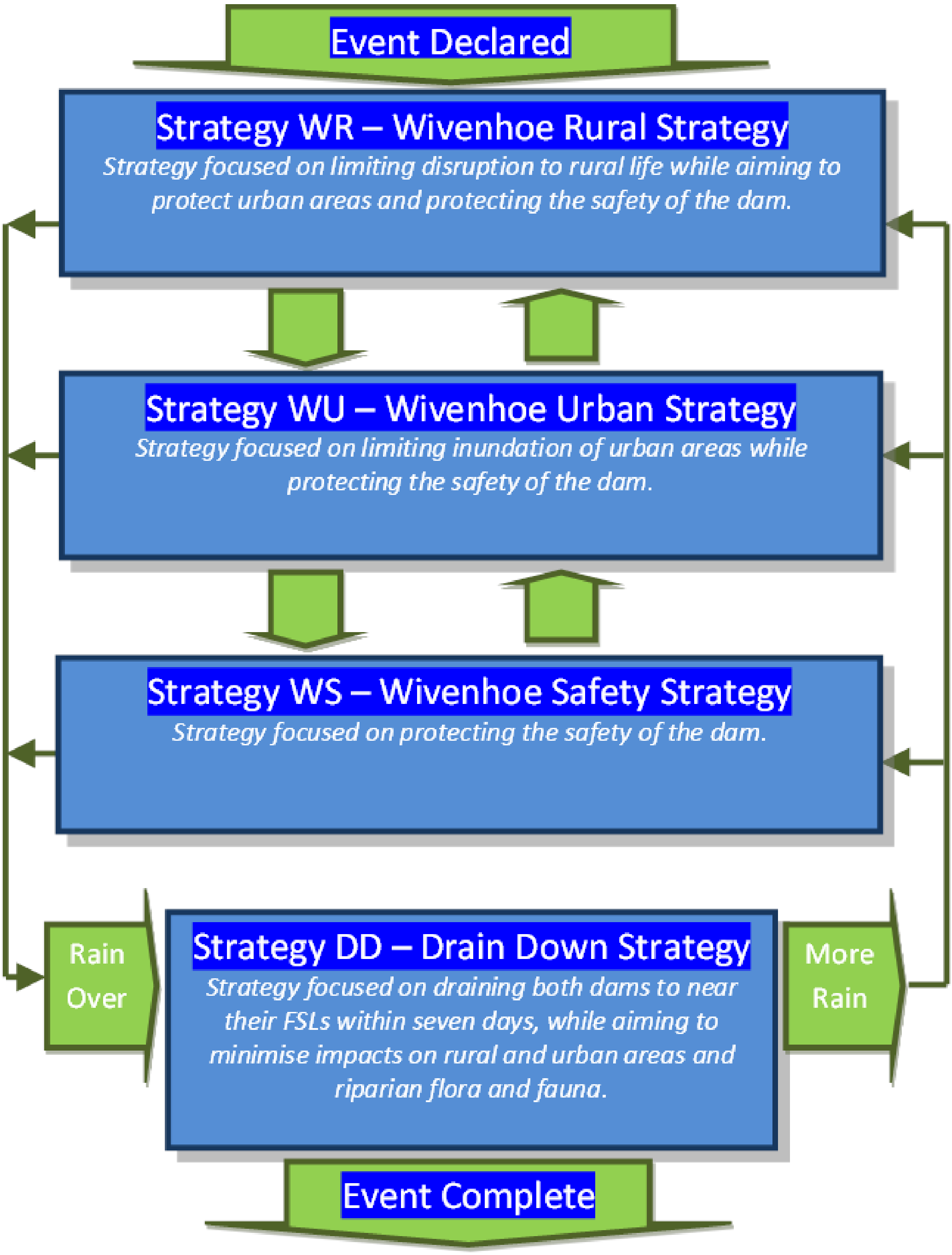
- Strategy **WR** focuses on minimising disruption to rural life while limiting inundation of urban areas and protecting the safety of the dams – the 'Rural Strategy'
- Strategy **WU** focuses on limiting inundation of urban areas while protecting the safety of the dams – the 'Urban Strategy'
- Strategy **WS** focuses on protecting the structural safety of the dams – the 'Dam Safety Strategy'
- Strategy **DD** focuses on draining both dams to near their FSLs within seven days of completion of the flood event, whilst minimising impacts on rural and urban areas and riparian flora and fauna – the 'Drain-Down Strategy'.

Dam flood operations[9] will often start with selection of the Rural Strategy. Other strategies are selected when the 'exit criteria' for the previously selected strategy is triggered. While each strategy has its primary objective, lower level objectives can be considered. This depends on the availability of information on the likelihood of the flood event either escalating or receding, along with consideration of the component of downstream flooding that does not originate from dam releases but from other sources.

If the flood inflows are still rising or the rainfall event is judged likely to continue, the exit criteria for the Rural Strategy and Urban Strategy are selected with reference to the Wivenhoe Dam level. The flood engineer uses the Seqwater flood forecasting system (described in Appendix L of the Flood Manual) and applies professional judgement of the circumstances of the event and uncertainty in the predictions to make decisions based on predicted dam levels.

The Drain-Down Strategy is typically selected shortly after the flood peak has occurred. The exit criteria from other strategies to enter the Drain-Down Strategy are that the rainfall event is judged very likely to be complete or nearly complete and the combined dam storage has started to fall. Professional judgement is deemed important in determining when to select the Drain-Down Strategy.

[9] The commentary in these sections is derived from Seqwater 2014a, Section 2.2.



Source: Seqwater 2013a, Figure 5.4.1

Figure 3.2 Overview of the Wivenhoe Dam operating strategies

The predicted dam level can influence strategy selection and how the subsequent Operational Procedures for a strategy are applied. This in turn can partially influence the predicted dam level, i.e. there is an acknowledged circular relationship between strategy selection and operational procedures that must be managed.

3.3.2 Operational procedures

Flood operations control the release rate (outflow) from Wivenhoe and Somerset dams. Release rates are determined using Operational Procedures.

The strategy selection is in response to the flood event rainfall and catchment response (i.e. inflows) and releases are only a partial influence on strategy selection.

After initial identification of a specific strategy, the decision process considers application of the operational procedures for that strategy by performing predictions of dam levels and downstream flows, and then checks to confirm that the original strategy selection remains appropriate. If not, variations of the operational procedure are tested within the scope permitted by the Flood Manual, or another strategy is selected and the process is repeated until a strategy is deemed suitable to meet the relevant criteria.

The common procedure that applies to all strategies is to prepare a Release Plan, which will vary for each strategy. This is the planned sequence of dam releases over the following hours and days developed in accordance with the guiding intent and criteria in the Flood Manual. The Release Plan will often regularly change during flood events in response to changing rainfall and stream flow conditions even if the selected strategy does not change. Hence strategy selection and the development of the release plan are undertaken at regular intervals in an iterative manner, as illustrated Figure 3.3.

Source: Seqwater 2013a, Figure 5.3.1

Figure 3.3 Strategy selection and dam release plan process

The concepts of developing forward looking release plans and using predicted future dam levels to guide strategy selection enables the dam operations to be responsive to predictions and possibilities in the hours and days ahead. This makes the flood operations decision making process complex, but has the stated aim of achieving more beneficial flood mitigation outcomes compared with more simplistic prescriptive approaches. The key limitations to the success of these decisions are then the quality of information available to estimate the predicted flood hydrographs and the uncertainty of forecast model inputs and outputs.

3.4 Wivenhoe Dam operations

This section summarises the main objectives, procedures and considerations that apply to operating strategies for Wivenhoe Dam. As noted later, Wivenhoe and Somerset dams are in the main operated as a single storage, but with Wivenhoe Dam being the downstream control, it becomes the focus of operations.

3.4.1 Rural and urban strategies - general

Under both the Rural and Urban strategies, the intent of dam operations is always to determine dam release rates in order to achieve a downstream target flow in the river at selected locations, whilst still considering the available flood capacity remaining in Wivenhoe Dam. In this regard the dam release plan also has to consider the actual and predicted flood flows emanating from downstream of the dam catchment areas, such as Lockyer Creek and the Bremer River, which do not pass through the dam and therefore cannot be controlled.

The relative flow contributions from the downstream and upstream catchments can vary markedly between and within each flood event. Therefore the timing and magnitude of dam releases is also expected to be varied to respond to the circumstances. For example, provided there is adequate flood capacity remaining in the dam, the procedures allow for gates to be adjusted to reduce releases if necessary to prevent increasing flow beyond the downstream target (i.e. in response to the estimate of flows emanating from the downstream catchments). This can occur even if the dam levels are still rising because the Flood Manual has criteria for managing the flood capacity in the dam. If the dam flood level continues to rise (and the remaining flood capacity decreases to the next pre-determined trigger level), the procedures in the Rural and Urban Strategies will then guide the flood engineer to ultimately select a higher downstream flow target, or where levels are predicted to exceed the dam safety trigger, the Dam Safety strategy (WS) may need to be invoked.

3.4.2 Operations in the Rural Strategy

Under the Rural Strategy, the dam operations focus on minimising rural disruption and achieving the requirements for the Urban Objective by developing release plans to:

- limit potential inundation of the various vulnerable low-lying downstream bridges; and
- limit the predicted (combined) peak flow at Moggill to below 2000 m^3/s if possible.

The vulnerability of the bridges to inundation varies considerably and the release plan would be expected to initially limit predicted combined downstream flows to be slightly less than the flow capacity of the most vulnerable bridge (to allow for uncertainties). If the flood escalates and inundation of the currently most vulnerable bridge cannot be avoided, the target release rate is increased to a level that would not inundate the next most vulnerable bridge.

Procedurally, these changes occur when one of the following criteria applies:

- Wivenhoe Dam (actual or predicted) level is likely to exceed a pre-specified level for each bridge (refer Seqwater 2013a, Table 5.5.1). This criteria ensures that the flood capacity in the dams is always managed;
- it is predicted that flow emanating from the downstream catchments will inundate the bridge anyway
- the bridge has already been inundated during the event; or
- it is predicted that the releases required to achieve the requirements of the Drain-Down Strategy would result in inundation of the bridge.

The Flood Manual procedures also distinguish between events on the basis of the contribution from the Bremer River catchment, such that when these are large, the criteria for flow limits at Moggill (to meet the Urban Objective) may govern the release rate.

Two higher level bridges downstream of Wivenhoe Dam have significance beyond disruption to rural life when they become inundated. These are:

- Brisbane Valley Highway (Geoff Fisher Bridge), vulnerable at approximately 2,000 m^3/s flow, and

- Mount Crosby Weir Bridge, vulnerable at approximately 1,800 m^3/s flow.

When these higher bridges are inundated there are regional scale impacts to transport routes and lack of access to broad areas of communities. Accordingly, the procedures are designed to try and avoid their inundation in Rural Strategy operations but they are sacrificed[10], within the Urban Strategy, whenever the Wivenhoe Dam level is predicted to exceed FSL + 3 m.

The exit from the Rural Strategy and the trigger to apply the Urban Strategy occurs at a Wivenhoe Dam level corresponding to FSL + 1.5 m. The Flood Manual states that if the actual Wivenhoe Dam level exceeds this trigger value, the Urban Strategy must be selected unless in the Duty Flood Operations Engineer's professional judgement, a change to the Drain-Down Strategy is anticipated in the near future. However, if the predicted Wivenhoe Dam level exceeds this trigger value, the Urban Strategy may be selected before the actual dam level exceeds FSL +1.5 m, again on the basis of the Duty Flood Operations Engineer's professional judgement.

3.4.3 Operations in the Urban Strategy

In the Urban Strategy, the requirements to achieve the Dam Safety Objective are also met by criteria that explicitly manage the remaining flood capacity in the dams. The Urban Strategy dam operations focus on minimising inundation of the majority of downstream urban areas by developing release plans to achieve a target flow at Moggill. This reference location is chosen because inundation of urban areas and damage to urban infrastructure is known to commence when the flow at Moggill exceeds approximately 2000 m^3/s, becoming significant once the flow at Moggill exceeds 4000 m^3/s.

When it is not possible to limit the flow to 2000 m^3/s at Moggill, the Urban Strategy operations incrementally increase the target flow (through a combination of predicted downstream inflows and releases from Wivenhoe) until, based on the Duty Flood Operations Engineer's professional judgement, a suitable balance is achieved between minimising the flow at Moggill and managing the remaining flood capacity in the dams. The Flood Manual includes parameters to guide this judgement in the form of a target relationship between flow at Moggill and allowable predicted peak Wivenhoe dam level. In large events that may potentially trigger the Dam Safety Strategy, the Urban Strategy target guide ensures that the highest tolerable flow at Moggill is achieved (and hence highest possible dam releases) before entering the Dam Safety Strategy.

[10] Downstream bridge structures have been shown capable of withstanding quite considerable inundation without structural damage and are able to be reinstated without incurring major maintenance costs after the flood recedes, though damage can still occur.

There are several factors that can result in unintentionally exceeding the adopted target flow at Moggill, which are explained below:

- Rainfall that occurs in the downstream catchments can increase the flow at Moggill to beyond the target that was intended at the time of the dam release owing to the long travel time of releases (12hr to 24hr) downstream of Wivenhoe Dam to Moggill.
- Related to the above, the variability in flow travel time to Moggill is a function of floodplain storage at different water levels and allowance for this requires professional judgement.
- Similarly, there is often considerable uncertainty in estimates of the flow emanating from Lockyer Creek due to its extensive floodplain areas and uncertainty in flood gauge ratings.
- Ultimately, in order to prevent possible dam crest gate overtopping, dam releases may exceed the desired target downstream river flow.

The Flood Manual requires exit from the Urban Strategy and the application of the Dam Safety Strategy when the predicted Wivenhoe Dam level is judged very likely to exceed EL 74 mAHD.

3.4.4 Operations in the Dam Safety Strategy

In the Dam Safety Strategy, the Flood Manual procedure meets the Dam Safety Objective by increasing dam releases up to the maximum rate required as necessary to limit the peak Wivenhoe Dam level. This is to try and prevent uncontrolled overtopping of the dam and associated embankments, which will likely lead to loss of integrity and failure of the dam (refer Chapter 9).There are no operating rule limits in the Dam Safety Strategy for the maximum rate of gate operations; however, there are physical limits to the rate of gate operations and limits to personnel capabilities for safe gate operations in extreme weather.

Importantly then, when faced with an increasing inflow situation with dam levels already above EL 74 mAHD, the primary requirement in the Dam Safety Strategy is to ensure the release plan has all crest gates fully open, prior to breaching the first fuse-plug(EL 75.7 mAHD). If water levels continue to rise, the second and third fuse-plugs will automatically initiate in a staged manner, which together should ultimately result in a doubling of the controlled spillway discharge.

In the Dam Safety Strategy the primary input to the release plan is the actual and predicted upstream catchment flood inflows. Flows emanating from the downstream catchments are typically not able to be considered in this situation. However, professional judgement may be used to develop a release plan aiming to minimise peak flow at Moggill while protecting the safety of the dam. Provided the above principles are applied, it is permissible for releases to exceed the predicted inflows into Wivenhoe Dam. Overall, protecting the safety of the dam is the primary aim.

The Flood Manual notes that the exit criteria from the Dam Safety Strategy would comprise selection of the Urban Strategy if the lake level is judged unlikely to reach EL 74 mAHD. Otherwise, once the rainfall event is considered to be complete, or nearly complete, and the combined dam storage volume has started to fall, the Drain-Down Strategy would be selected.

3.4.5 Operations in the Drain-Down Strategy

In the Drain-Down Strategy the Dam Safety Objective is met with a criterion to collectively drain the dams to FSL within seven days. This criterion is based on the analysis of historical flood records (refer Chapter 6) that show a significant probability of two or more flood producing rain systems occurring in the Brisbane River basin within a short time of each other. If there is a favourable fair weather outlook, the Flood Manual allows the drain-down time criterion to be extended to 14 days if certain operational procedures are followed.

In the Drain-Down Strategy, the Urban Objective is achieved according to the following order of priority:

- avoid exceeding the peak target flow at Moggill.
- reduce the flow at Moggill to less than 4,000 m^3/s.
- reduce the flow at Moggill to between 2,000 – 4,000 m^3/s.
- reduce the flow at Moggill to less than 2,000 m^3/s.

The Rural Objective is achieved according to the following priority:

- reduce the flow to allow the Geoff Fisher Bridge and Mount Crosby Weir Bridge to be opened.
- reduce the flow to allow Burtons Bridge to be opened.
- reduce the flow to allow Colleges Crossing to be opened.

The Flood Manual addresses the objective to minimise impacts to riparian flora and fauna by applying qualitative interpretation of the likely controlling physical factors. The guidance includes:

- planning to cease dam releases during daylight hours to allow a safe and adequate fish recovery operation; and
- minimise potential for bank slumping by avoiding rapid drawdown of downstream river levels. Commonly this consideration is applied by attempting to replicate natural flow recession rates.

In the Drain-Down Strategy, the Flood Manual also gives consideration to:

- developing a release plan that can minimise adverse water quality and other impacts on urban water supplies below Wivenhoe Dam;
- achieving a relatively constant downstream flow at Moggill (or an alternative location) to avoid renewed rises in downstream river levels, which may other otherwise hamper community flood recovery activities; and
- draining the floodwater in the dams as quickly as possible while still meeting multiple criteria to accommodate potential further rainfall and increases in stream flows,

The Flood Manual notes that the exit criterion from the Drain-Down Strategy is normally when the dams have collectively been drained to FSL or near FSL but, renewed potential for a rise in the lake level would result in the need to move back into another flood operation strategy.

3.5 Somerset Dam operations

Seqwater operates Somerset Dam in conjunction with Wivenhoe Dam to maximise the downstream flood mitigation benefits. In general terms, the Flood Manual procedures aim to balance the combined flood storage compartments of both dams. As Somerset Dam is the upstream dam, decisions on its releases must take into account the Wivenhoe Dam level.

While Somerset Dam is considered as “an extension” of the storage of Wivenhoe Dam there are two specific strategies that Seqwater applies to its operations:

- “Somerset Flood” Strategy (SS) aims to protect the safety of both dams while maximising the use of the combined dam flood storage volume. This strategy applies in the rising phase of the flood until Wivenhoe Dam Drain-Down Strategy is selected; and
- “Drain-Down” Strategy (DD), which aims to drain Somerset Dam in conjunction with application of the Wivenhoe Dam Drain-Down Strategy.

The Somerset Flood Strategy operation generally applies from the start of a flood until the Wivenhoe Drain-Down Strategy is selected. However, as noted in Chapter 9, the operation of Somerset Dam is currently constrained due to concerns over its ultimate safety at high flood levels. Principally these concerns manifest in the radial crest gates having to remain open during a flood event to avoid potential structural overloading. As a result of this operational decision, there is an additional 2.7 m (107.0 m to 109.7 m) of lake level available (i.e. the critical dam safety water level rises).

The dam’s low level sluice gates (not a feature available at Wivenhoe Dam) are used to regulate releases when flood levels are below the spillway crest level. The maximum rate of opening and closing the sluices also represents a constraint to operations that is noted in the Flood Manual.

A failure of Somerset Dam in an extreme flood could risk consequential ‘cascade’ failure of Wivenhoe Dam with catastrophic downstream consequences. To achieve a safety-focused “balance” of the use of the flood storage in Somerset Dam and Wivenhoe Dam, the Flood Manual provides guidance in the form of a so-called ‘Interaction Line’. This relates a target water level in Somerset Dam to a corresponding target water level in Wivenhoe Dam. The limit of the interaction line is set to the respective critical dam safety levels for each dam so that the use of the combined storage of both dams is always in a ‘balanced’ state that approximately minimises the probability of failure of both dams.

The aim of the Somerset Flood Strategy operations is to always adjust releases to move the separate dam levels towards the interaction line, and to match it at the peak of the flood event. The Flood Manual notes that it is not always possible to match the interaction line for several reasons including:

- When the spillway commences overflowing, the outflow from Somerset Dam may sometimes be higher than the interaction line guidance.
- The inflow hydrographs (timing and volumes) into both dams can vary significantly within a flood event depending on the relative contributions from the upper Brisbane catchment into Wivenhoe Dam and the Stanley River catchment inflows into Somerset Dam.

In the Somerset Drain-Down Strategy, the aim of operations is to generally follow the interaction line as both dams are progressively drained together.

3.6 Dam operations with temporary full supply level

The Flood Manual allows operations to be varied to adapt to a temporary full supply level (TFSL) declaration (below the Wivenhoe Dam 67 m AHD level) that may be made by the State Government under provisions of the Act.

The procedures aim to have any water stored above the temporary full supply level released as soon as practicable, giving consideration to the following matters:

i. the rainfall forecasts over the period of the release;
ii. the volume of water needing to be released;
iii. the timing of the inundation of bridges downstream of Wivenhoe Dam to limit disruption to impacted communities;
iv. the release rate to aim for a maximum flow of 400 m^3/s at Burton's Bridge, unless an increase in the release rate is judged likely to reduce the potential for the flow at Moggill to exceed 4,000 m^3/s from an impending rainfall event; and
v. the impacts to riparian flora and fauna are to be minimised where practicable.

The Flood Manual also allows for declaration of a flood event if, during the release of water to achieve a TFSL, there is significant rainfall run-off or inflows. In this circumstance, the operational procedures revert to the standard procedures, except that the FSL becomes the temporary full supply level and there is a transition plan to the standard procedures.

Chapter 4 Issues and challenges

This chapter summarises the key issues that have been identified relating to:

- relevant recommendations from the QFCoI
- other matters identified relating to the operation of the dams, and
- relevant matters that may inform the future upgrade of the dams, flood studies and floodplain management.

Addressing these issues presents a range of analytical and trade-off challenges.

4.1 Flood Commission of Inquiry recommendations

A summary of the key recommendations of relevance to WSDOS was provided in Chapter 1 of this report. Two of these recommendations are of particular importance. These are QFCoI Interim Report recommendation 2.13 and QFCoI Final Report recommendation 17.3, with QFCoI Final Report recommendations 17.4 and 17.5 also of direct relevance.

Issues considered in this report are summarised in Table 4.1, along with an indication of where in the report the issue has been dealt with.

Table 4.1 Key issues identified in QFCoI

QFCoI Recommendation	Chapter / Section in WSDOS Report
Recommendation 2.13 – Interim Report	
• modelling across a range of full supply levels, operating strategies and flood events (historical, design and synthetic)	Section 4.1.4 Chapter 6 and Chapter 7
• bypassing the Rural Strategy in the Flood Manual	Results presented in Chapter 7
• consideration of the release rates in the Rural and Urban Strategies	
• stepped change in the downstream target flow in the Urban Strategy in the Flood Manual including	
• operation of the dam gates in conjunction with the initiation of any of the fuse plugs	Dam Safety results and discussion presented in Chapter 9
• raising the Dam Safety Strategy trigger level in combination with increasing the maximum target flow in the Urban Strategy	
• raising the Dam Safety Strategy trigger level to a high level that would allow operation in the Urban Strategy while allowing the lowest fuse plug to breach	
• simulations to test the robustness of relying on rainfall forecasts, and	Section 4.1.5
• the probability of closely spaced flood peaks.	Section 6.5
Recommendation 17.3 – Final Report:	
• a requirement for a wide range of operational strategy options to be presented	Chapter 4 and Chapter 5
• the need for options to *prioritise differing objectives*	Chapter 5
• *considering the implications of each option over a range of flood events for at least:*	Chapter 6 and Chapter 7
o *inundation of urban and rural areas*	Chapter 7, 14 & 15.2
o *water supply security*	Chapter 8, 15.4 &15.5
o *dam safety*	Chapter 9
o *submerging of bridges*	Chapter 10 & 15.3
o *bank slumping and erosion*	Chapter 11
o *riparian fauna and flora.*	Chapter 12
Recommendation 17.4 – Final Report	
• the consideration of the degree of discretion able to be exercised by the flood engineers	Section 4.1.3
• the release of water in anticipation of an impending flood event	Section 4.1.5.1
Recommendation 17.5 – Final Report	
• the need to reflect objective standards in the implementation of Flood Manual	Sections 1.10 & 4.1.3

strategies.	

4.1.1 Wide range of options to inform operational strategy

Implementing Final Report recommendation 17.3 requires the consideration of a wide range of operational strategy options which prioritise differing objectives. This is addressed in Chapter 5 which outlines the range of options for managing the various water supply and flood compartments within the storage, whilst assessing the impacts on flows (and hence flooding) downstream of the dam.

These are operational options that require no new infrastructure to be constructed (i.e. options seeking to make better use of existing infrastructure).

Strategies that are not covered in this study include:

- infrastructure related options to enable flood storage to be increased (e.g. raising of either Wivenhoe or Somerset Dam, or constructing new storages) and
- planning by local authorities and other initiatives to mitigate flood impacts on the floodplain.

The idea of assessing the operational options is to determine whether the existing infrastructure can be operated better without causing unnecessary expense or risk to the community. Further investigation of regional infrastructure options to mitigate flooding may occur where an appropriate business case exists.

4.1.2 Prioritising differing objectives

Final Report recommendation 17.3 requires consideration of the implications of each operational option with respect to at least urban and rural flood inundation, water supply security, dam safety, submerging of bridges, bank slumping and erosion, and riparian fauna and flora. Managing the dam to optimise the outcomes for each of these objectives cannot be achieved through any one option; i.e. a focus on one priority can be to the detriment of one or more of the other four priorities.

The Flood Manual lists the primary objectives of the operational strategies in descending order of importance, as follows:

- ensure the structural safety of the dams
- provide optimum protection of urbanised areas from inundation
- minimise disruption to rural life in the valleys of the Brisbane and Stanley Rivers
- retain the dams at near FSL at the conclusion of a flood event and
- minimise impacts to riparian flora and fauna during the drain down phase of the flood event.

The dams must also be operated to account for the potential effects (risks) of closely spaced flood events.

In keeping with the above priorities, the Flood Manual states that dam safety is of paramount importance during all phases of flood operations owing to the risk to downstream life and property.

Assessments have been undertaken giving consideration to the relative proportions of the total water supply and flood storage. These consider the volumes allocated to the provision of water supply and to the rural, urban, dam safety and drain down strategies identified in the

Flood Manual. Effectively, this provides a means to review the prioritisation of the use of the total storage volume of Wivenhoe Dam.

Additionally, a common key issue for all those affected by flooding is warning time, which can be utilised to reduce damages, and to minimise the risk of harm to individuals.

4.1.3 Exercising discretion

Final Report recommendation 17.4 states Seqwater should, in creating new flood mitigation manuals, comprehensively consider 'the amount of discretion that is able to be exercised by the flood engineers and the senior flood engineers, and the description of the circumstances in which such discretion may be exercised'.

This aspect of recommendation 17.4 related to the use of professional judgement in making Flood Manual operational decisions. Such decisions include, among other matters:

- the use of rainfall and stream flow data
- forecasts or predictions about likely rainfall, dam levels and potential flooding
- responding to incidents or events such as unexpected inflows, dam safety risks, issues with the operation of the gates and
- engagement with appropriate authorities on matters such as bridge submergence and other impacts.

Such judgements and associated requirements are outlined in the 2013 Flood Manual.

The main issue is that professional judgement should be based on some reference to objective criteria or evidence leading to a conclusion.

The Flood Manual now includes a section outlining the process that must be adopted and authorisations required on the rare occasions when it may be necessary to implement alternative procedures to achieve flood mitigation objectives.

The Queensland Government in its response to Final Report recommendation 17.4 recognised that it would be necessary to consider the outcomes of WSDOS in order to implement this recommendation in full.

The main areas within the Flood Manual that require application of professional judgement by the dam operator relate to advance releases in response to seasonal forecasts or an imminent flood event.

In relation to the release of water stored above the temporary FSL, Section 8.4 of the Flood Manual indicates that consideration be given to rainfall forecasts by BoM (for the period of release), the volume of water to be released, and any program with respect to the timing of the inundation of bridges downstream of Wivenhoe.

During a flood event, Chapter 8 of the Flood Manual relating to temporary FSLs does not apply, and dam release rates will be in response to actual and forecast inflows to the dam during a flood event or predicted flows at nominated critical downstream locations.

4.1.4 Trade-off implications of reducing full supply volume

Wivenhoe and Somerset dams contribute about 60% of the system yield and 70% of the total water supply storage available from the SEQ water supply system comprising some 12 dams and other storages. Any reduction to the full supply volume of these dams will impact on the supply.

By lowering the dam levels, either temporarily, semi-permanently or permanently, there will be potential consequential impacts that may increase the need to supply desalinated water from the Gold Coast Desalination Plant (required when the storage in the water grid reduces to 60%), or require the imposition of restrictions when the storage in the water grid reduces to 40% or potentially introduce the need for other supplementary supplies.

Hydrologic modelling has been undertaken to allow an assessment of the potential costs and impacts of a lower FSL, with these being offset by the potential benefit of maintaining a larger flood storage compartment. The modelling focuses on varying reductions in the FSV of Wivenhoe Dam in order to assess implications on:

- the performance of the bulk water supply system in the medium term (i.e. 5-10 years)
- the need for and duration of drought contingency measures to be implemented and
- long-term implications for SEQ water security, through the consideration of the corresponding reduction in system yield.

In simple terms, the key issue to be addressed is the trade-off between the provision of storage for flood mitigation and water supply storage. The greater the reduction of the FSV in Wivenhoe Dam, the greater the impact on both medium and long-term water security for SEQ.

The assessment of these trade-offs has been based the assumption of permanent reductions in FSVs. The outcomes associated with temporary reductions in the Wivenhoe Dam storage will lie somewhere between the outcomes associated with existing operations and permanent reductions in FSVs and would depend on the frequency and duration of temporary reductions in the FSVs.

Any reduction in the FSV of Wivenhoe Dam will increase the probability of drought contingency measures being required. This in turn could bring forward the timeframe for supplementing water supplies with manufactured water (e.g. the Gold Coast Desalination Plant and the Western Corridor Recycled Water Scheme) and the augmentation or construction of new water supply infrastructure.

4.1.5 Forecasting and early releases

Final Report recommendation 17.4 addresses items that should be considered in creating new flood mitigation manuals for dam operation, with one of these items being '…the circumstances in which it might be appropriate to release water in advance of an impending flood on the basis of forecasts from the Bureau of Meteorology'.

Seqwater receives forecast rainfall from the Bureau of Meteorology (BoM) for consideration in estimating the potential timing and magnitude of flood flows in various catchments. These forecasts are used in the Flood Forecasting Model runs to assist in managing flood events generally and providing extended flood flow projections. The uncertainty of forecast rainfall in terms of spatial and temporal distributions is however especially recognised (BoM 2013 pers. comm., 30 August), as discussed further below, and hence flood operations are based on recorded rainfall and stream flows as well as giving consideration to rainfall forecasts during real-time dam operations.

4.1.5.1 Pre-emptive / advance releases

Under Part 3 of Chapter 4 of the Act, the Minister for Energy and Water Supply may declare temporary FSLs in order to mitigate flood or drought on a case by case basis. Such decisions are made in the public interest having regard to the impact on water supply security of the dam, dam safety, and possible other public safety, environmental, social and economic impacts.

Declaring a temporary FSL is a pre-season (or early in the season) decision based on climatological forecasts and advice obtained as to the extent to which the proposed temporary FSL is likely to mitigate the impacts of a potential flood or ongoing drought condition. The issue of advanced releases is linked to that of forecasting accuracy, and further research is required. It is not intended that the declaration of a temporary FSL be used in response to an imminent flood event.

The multi-agency process relating to the declaration of a temporary FSL is now well established and it is not proposed that it be reviewed.

4.1.5.2 Use of forecasts in real-time dam operations

BoM had previously advised Seqwater circa 2006 (QFCoI 2011) and reiterated in 2010 (via email), that their short to medium term (0 to 48hr) prediction of rainfall for the objective use in flood forecasting models had at times considerable error or uncertainty in the prediction of the location, amount and timing of rainfall events at the scale of the Wivenhoe catchment.

Nevertheless, forecasting the development and movement of broadscale synoptic features likely to produce heavy rainfall has been improving over time (BoM 2013, pers. comm., 30 August). This includes the forecasting of decaying tropical cyclones, east coast low pressure systems and significant upper level trough systems. However forecast models still cannot be relied upon to capture the development of rainfall events at extended timescales. In particular, the forecast models will have less skill (or accuracy) at the catchment scale relevant to dam operations for higher rainfall intensities.

While forecasts may indicate that a heavy rainfall event is possible, forecasts should only be taken as a guide and cannot be relied upon with any significant certainty. Very heavy rainfall concentrations are ultimately dependent on finer scale (mesoscale) and convective features that interact with the regional topography and it remains difficult (if not impossible) to currently predict the actual location, timing and intensity of rain within a catchment like the Brisbane River basin, where operation of dams in the catchment needs to consider both upstream and downstream rainfall and inflows.

4.1.5.3 Future rainfall forecast investigations

In correspondence received from BoM on 30 August 2013, BoM advised that it was '…clear that further work is required to fully explore the use of rainfall information for dam management' and stated that 'on some occasions, the 7 day rainfall forecast may provide some indication of the flood-producing potential of systems but models cannot be relied upon to capture the development of every rainfall event at that timescale.'

The risk is that a decision based on uncertain rainfall forecast information may produce a worse outcome than one based on actual rainfall observations.

There may be scope in the future for the more direct use by Seqwater of BoM forecasts in the operation of the dams but this requires targeted research. This would include simulations to test the robustness of relying on rainfall forecasts as suggested in the QFCoI Interim Report recommendation 2.13.2.

This process would need to be progressed subsequent to WSDOS, owing to the complexity and timelines required to develop processes that would be accepted and supported by experts.

4.2 Operation of the dams

4.2.1 Flood behavior

The flood behaviour in the Brisbane River catchment is complex. There are several major waterways within the basin with each tributary possessing individual catchment characteristics, runoff response from rainfall, and routing behaviour which influences the timing and hydrograph shape of floods moving down the waterways. Further, rain does not fall evenly across the catchments, and rainfall patterns are not predictable in real time on a catchment scale.

All of these factors result can result in unique flood characteristics for any flood event. Operation of the dams needs to be sufficiently flexible to account for the fact that every flood will be different.

4.2.2 Ability of the dams to mitigate flooding

Wivenhoe Dam sits at the mid-point of the Brisbane River catchment, with a catchment area of (approximately 7,000 km^2 inclusive of Somerset Dam). The dam therefore generally exerts a mitigating influence on runoff from only the upper half of the total Brisbane River catchment area (approximately 14,000 km^2).

4.2.3 Complexity of dam operations to mitigate flooding

Whilst any flood mitigation (reducing dam outflows to below dam inflows) achieved by the dam can exert a positive (reducing) influence on downstream flows, this is subject to the relative timing of flow peaks emanating from Wivenhoe and those derived from downstream tributaries such as the Bremer River or Lockyer Creek and lower Brisbane River inflows. The contributing sub-catchments are shown in Figure 2.4.

The timing of releases from Wivenhoe Dam and warning times available are critical to the minimisation of flood damages and impacts at key locations such as Savages Crossing (Fernvale), the David Trumpy Bridge (Ipswich) and Moggill (Brisbane). The travel time for releases to reach Moggill depends on the magnitude of the flood and the contributions of tributary inflows, and can vary between 12 and 24 hours (Seqwater 2014a).

This illustrates the operational and modelling challenge faced, as the dam operators can never know with certainty the exact inflows from areas downstream of Wivenhoe Dam (such as the Bremer River or lower Brisbane River) that will be occurring at particular locations at any given future time.

4.2.4 Interaction of the dams

The operation of the two dams is based on recorded rainfall, actual and predicted water levels, and the predicted flow at downstream locations (refer also Chapter 3 which discusses the Flood Manual in greater detail).

A further relevant factor is the relative volume and level contained in the lakes formed by Wivenhoe and Somerset dams. The Flood Manual includes an interaction diagram (reproduced in Chapter 9), which portrays the “operating target line” for managing the relative volume and levels contained in the lakes formed by Wivenhoe and Somerset Dams.

The aim is that at the peak of an event, levels in the lakes for both dams sit on the interaction line. Use of the interaction diagram aims to ensure that the maximum safe levels in Wivenhoe and Somerset dams are reached at the same time (i.e. maximise the use of the two storages; see previous sections).

4.2.5 Wivenhoe Dam fuse plugs

The potential consequences of a failure of the main dam wall are catastrophic and would mean loss of a major portion of the SEQ water supply. Reconstruction of the dam wall would be a lengthy and costly process.

For this reason, three fuse-plugs were constructed as part of an auxiliary spillway, which was built in 2005. The purpose of these “plugs” is to reduce the risk of overtopping (and resultant potential failure) of the dam. The plugs are designed to erode should they be overtopped, leading to the release of water through the fuse-plug bays at flow rates dependent on the depth of flow through the spillway.

The existence of the fuse-plugs poses some additional challenges. These centre on the following issues:

- the relative rarity of having a dam with both gates and fuse-plugs
- the fuse-plugs being designed for dam safety purposes, rather than for flood mitigation and the timeframe required for their replacement if triggered and
- uncertainty around potential downstream erosion associated with operation of the fuse-plugs.

The triggering of fuse plugs has dam safety implications, and has been addressed further in Chapter 9.

4.3 Uncertainty of modelling

The science of flood hydrology is the conversion of observed and/or forecast rainfall into runoff to provide estimates of flood hydrographs throughout a catchment. This multi-faceted process is an essential precursor to simulating dam operations. Hydrologic modelling, especially in real time, is a complex process which may involve considerable uncertainty in many facets of the process. As such professional judgement is required to be applied at several points in the process.

Several key factors are addressed below:

- **Estimation of observed catchment rainfall:** The first step in determining flood behaviour in a catchment is the estimation of rainfall in terms of depth, timing and spatial distribution. The Brisbane River basin has one of the most comprehensive real time monitoring rainfall networks in Australia. Even so, during the January 2011 event, gauges did not always provide an accurate estimate of catchment rainfall as evidenced by the Lockyer Creek flash flood on the afternoon of Monday 10th January and the high rainfall on the immediate area around Wivenhoe Dam on the morning of Tuesday 11th January. Whilst additional gauges would be of benefit, the uniqueness of every rainfall event will not ensure that a more comprehensive network of rainfall gauges will provide more accurate estimates of catchment rainfall for all events.

- **Estimation of runoff:** Catchment rainfall is typically converted into excess rainfall or runoff by a simple initial loss - continuing loss model where initial loss is the depth of rainfall which is lost before runoff commences and a simple lumped continuing loss rate accounts for the complexity of the other processes in the runoff processes such as infiltration, interception, evapo-transpiration, and depression storage. Typically, the initial loss and continuing loss rates are assumed to be uniform over a catchment and do not take into account the variability of soil type and vegetation cover. Initial loss will necessarily vary depending on the state of the catchment (wetness or dryness) at the start of the event and the continuing loss rate can similarly vary. A hydrologist adjusts loss parameters to best match the observed response at river gauges.

- **Runoff routing:** Once an estimate of excess rainfall or runoff has been made it is necessary to route catchment runoff in order to estimate the shape, timing and magnitude of the flood peak at a particular point of interest. As catchment and channel conditions vary over time, it is not possible to derive a unique set of routing parameters to define this process and professional judgement is required to fine tune the parameters to best match the observed response.

- **Conversion of water level to flow:** Hydrological models generate estimates of flow throughout a catchment whereas the observed response is measured water level at a particular point. In calibrating flood models, the simulated or modelled flow is compared with an estimated or rated flow at a stream gauging station. To enable this comparison, a rating table or curve, a relationship between height and flow unique to that location, is required at the gauging station. Ratings are typically derived by measuring flow (gauging) at a location and plotting these flows against recorded water levels and deriving a line of best fit. However, this process is subject to considerable uncertainty as the measured flows are usually much smaller than the estimated peak flood flows at the site. In addition changes in the channel geometry and roughness due to sediment transport and vegetation mean that ratings may not be stationary with time, especially at low stages. Hysteresis (different flow rates on the rising and falling limbs of the hydrograph for the same water level) also add to the uncertainty of the rating relationship. Ratings may be exceeded in large events and at some sites, such as in the Lockyer Creek catchment where the water courses breaks out to wide floodplains at high stages, are extremely sensitive to small variations in water level which may arise in response to changes in local land uses prior to or during the event.

During a flood event, the uncertainties and complexities described above are compounded by:

- **Gauge failure:** There are no guarantees that the rainfall and water level monitoring network will be 100% reliable during a flood event. Equipment malfunction is expected and professionals making use of the data must be able to identify gauges which are reporting spurious data and take appropriate action to identify, correct or omit. Given that there are over 350 rain gauges and 250 water level gauges available in SEQ, data checking in real time can be a time consuming task made difficult by the sheer volume of data. The inbuilt redundancy in the system ensures that models produce reasonable results even if some gauges fail.

- **Model performance:** It cannot be assumed that calibrated flood hydrology models perform similarly in the next real time event. Modelling of actual and forecasted catchment flows requires professional judgement to: (i) identify which models are not performing satisfactorily, and (ii) to identify the reasons why before the forecast flows (model) can be used for dam operations with any confidence. Professional judgement is critical when the observed catchment response during an event is beyond the model calibration set.

- **Forecast rainfall:** For accurate hydrologic modelling of flood flows in the Brisbane River, the best estimate of rainfall depth, timing and spatial distribution down to a 5 km grid is required. As indicated above, this can be problematic using observed rainfall data but the uncertainty is magnified when applying forecast rainfall. Numerical weather prediction models operate on much coarser grids and do not provide the resolution of depth, timing and spatial distribution required for accurate estimates of future flows. It is this area of flood operations that requires the highest degree of professional judgement. Engineers and hydrologists typically liaise with meteorologists from BoM but ultimately, it is the task of the engineer / hydrologist to judge the suitability to apply meteorological forecast rainfalls to the hydrologic models.

4.4 Planning linkages

The outcomes of this study and future operation of Wivenhoe and Somerset dams has close linkage to:

- future upgrades of the Flood Manual to accommodate the operational strategy option preferred by the Queensland Government.
- the Brisbane River Catchment Flood Study, with the preferred operational strategy option impacting flood releases from the dams and consequently the downstream hydrologic and hydraulic assessments.
- research into the use of rainfall forecasts to improve flood operations.
- investigations needed to confirm the viability or otherwise of operational strategy options that involve initiation of the first fuse plug (including potential erosion of the downstream spillway and other consequential impacts).
- investigations into dam spillway and safety upgrades required to meet DEWS dam safety requirements (DEWS 2013b) which may impact the choice and implementation of operational strategy options and the preparation of the Brisbane River Floodplain Management Plan and development decisions.
- the review of the SEQ level of service by DEWS due in the latter half of 2014 and the corresponding water security program to be formulated by Seqwater and anticipated in 2015 and
- the North Pine Dam Optimisation Study from a water supply perspective.

Chapter 5 Operational options

This chapter provides an overview of the operational options investigated by Seqwater. The options are designed to address relevant QFCoI recommended modelling of strategies aimed at mitigating downstream flooding.

5.1 Options identification

The process that led to the identification of options is described in the *Wivenhoe and Somerset Dams Optimisation Study – Options Discussion Paper Revision 5* (DEWS 2013a). The options identified evolved from:

- an understanding of the QFCoI recommendations;
- conceptualisation of alternatives in the allocation of the total storage between water supply, rural and urban flood mitigation, and dam safety strategies for flood operations (refer 2013 Flood Manual);
- consideration of downstream flood behaviour and critical flow and location thresholds; and
- an understanding of dam safety operational requirements.

QFCoI Interim Report recommendation 2.13 has been addressed by completing modelling of 32 operational options across a range of supply levels, operating strategies and for historical, design and stochastic flood events, with Table 5.1 providing a summary of the details. Other flood mitigation and management options, including new infrastructure, planning controls and local solutions to mitigate the impacts of flooding have not been assessed in detail under WSDOS. Analysis of the options identified has required appropriate variation of the operating rules outlined in the 2013 Flood Manual (Seqwater 2013a).

5.2 Option definition

The 32 operational options comprised:

- four water supply FSV scenarios for Wivenhoe Dam (current or 100%; 85%; 75% and 60%)
- eight alternatives of flood operations for Wivenhoe and Somerset dams, including:
  - the Base Case (existing operations)
  - six variations of parameters in Flood Manual, and
  - one case of prescribed operations for Wivenhoe Dam which is different to the concepts in the Flood Manual and does not have regard for downstream catchment flows.

The eight operational alternatives are summarised in detail in Table 5.1. Because of the intricacies of the flood operations variations, especially in the Urban Strategy phase, Table 5.2 was prepared to allow ‘at a glance’ identification of some of the main differences.

Table 5.1 Operational alternatives considered

Operational Alternative	Strategies 2013 Flood Manual	Variation from 2013 Flood Manual (WR –Rural Strategy, WU – Urban Strategy, WS – Dam Safety Strategy, DD – Drain Down Strategy)	Option Number [11]
Base Case (Flood Manual)	WR, WU, WS and DD	As per flood manual	1 to 4
Bypass Rural	WR	No stepped flow targets when flow below 2,000 m^3/s at Moggill or dam level below FSL+3 m	5 to 8
	WU	No change	
	WS	No change	
	DD	No change	
Alternative Urban 1a	WR	No change	9 to 12
	WU	Once FSL+3 m exceeded, target flow at Moggill lifted to 4,000 m^3/s. Target remains until WS trigger EL 74 m	
	WS	No change	
	DD	No change	
Alternative Urban 1b	WR	Bypassed. No stepped flow targets when flow below 2,000 m^3/s at Moggill or level below FSL+3 m	13 to 16
	WU	As for Urban 1a	
	WS	No change	
	DD	No change	
Alternative Urban 2	WR	Bypassed	17 to 20
	WU	• Once FSL+3 m exceeded, target flow at Moggill immediately lifted to 3,300 m^3/s • Once predicted flow reaches 3,300 m^3/s, target then transitions to 4,000 m^3/s at EL 74 m • Increase in WU compartment size (dam safety trigger raised to EL 74.5 m) • Gradual increase in downstream target flows from 4,000 m^3/s at EL 74 m to 6000 m^3/s at EL 74.5 m	
	WS	• Dam safety trigger raised to RL 74.5. Flow to be 6,000 m^3/s at EL 74.5 m • Decrease in volume of dam safety owing to 0.5 m increase in WS trigger	
	DD	No change	
Alternative Urban 3	WR	Bypassed	21 to 24
	WU	• Same as Base Case (100% FSV) up to EL 74 m • For other FSVs, flow targets based on maintaining same WR and WU volumes as for 100% FSV case • Increase in WU compartment size, owing to raising of dam safety trigger to EL 75 m • Downstream target flows increase from 4,000 m^3/s at EL 74 m to 6,000 m^3/s at EL 75 m	
	WS	Decrease in WS compartment size (matches increase in WU compartment size)	
	DD	No change	
Alternative Urban 4	WR	No change	25 to 28
	WU	• Same as Base Case to 74 m • Increase in WU compartment size by raising dam safety trigger to Fuse Plug 2 initiation (EL 76.2 m) • Flow set at 4000 m^3/s from EL 74 m to EL 76.2 m	
	WS	• Dam safety trigger raised to EL 76.2 m • Decrease in WS compartment size (matches increase in WU compartment)	
	DD	No change	
Prescribed Option	WR, WU, WS & DD	Strategies replaced by prescribed gate openings, which do not consider downstream flows	29 to 32

[11] In each case, the four options are based on 100%, 85%, 75% and 60% FSV

Table 5.2 Summary of flood operations variations

Operational Alternative	*Rural Strategy* FSL[1] + 1.5 m	*Urban Strategy* FSL + 1.5 m to *Dam Safety Strategy* Level		*Dam Safety Strategy* Level (EL mAHD[2])
		Target Flow at Moggill (m^3/s)	Max Target Flow at Moggill (m^3/s)	
Base Case	Yes	Flood Manual	4,000	74.0
Bypass Rural	No	Flood Manual	4,000	74.0
Alt Urban 1a	Yes	Stepped change to 4,000	4,000	74.0
Alt Urban 1b	No	Stepped change to 4,000	4,000	74.0
Alt Urban 2	No	Stepped change to 3,300	6,000	74.5
Alt Urban 3	No	Gradual increases to 6,000	6,000	75.0
Alt Urban 4	Yes	Same as Base Case up to EL 74 mAHD	4,000	76.2
Prescribed Operations	Simple rules to maximise available storage in dams (Refer Table S1). Responds to Wivenhoe Level & does not consider downstream flows.			NA

Notes:
1. FSL – full supply level
2. EL mAHD – elevation metres Australian Height Datum (AHD)

Table 5.3 relates each operational alternative to the element(s) of QFCoI Interim Report recommendation 2.13 (QFCoI 2011).

Table 5.3 Operational alternatives and relevance to QFCoI Interim Report recommendation 2.13

Alternative	Relevance to QFCoI Interim recommendation 2.13
Base case	Establishes a "reference position" for the relative comparison of options based on different FSVs (100%, 85%, 75% and 60%).
Bypassing the Rural Strategy	Addresses QFCoI Interim Report recommendation 2.13 (1) b. & c. for a higher rate of release earlier in the Flood Manual Rural Strategy and also bypassing the rural strategy.
Alternative Urban 1a	Addresses QFCoI Interim Report recommendation 2.13 (1) d. altering the maximum release rate in the Flood Manual Urban Strategy.
Alternative Urban 1b	Addresses QFCoI Interim Report recommendation 2.13 (1) b. , c. and d. as described above
Alternative Urban 2	Compromise between Base Case and Alternative Urban 1a. .Addresses QFCoI Interim Report recommendation 2.13 (1) a., b., c., and d. as described above but additionally providing for a stepped (transitioning) from the *Urban Strategy* to the *Dam Safety Strategy*
Alternative Urban 3	Addresses QFCoI Interim Report recommendation 2.13 (1) a., b., c., and d.
Alternative Urban 4	Addresses QFCoI Interim Report recommendation 2.13 (1) e. a., b., c., and d. as described above but additionally considering the operation of the dam gates in conjunction with the initiation of any of the fuse plugs in order to achieve a lower rate of discharge.
Prescribed Operations	Addresses the requirement to consider a wide range of operating strategies [Recommendation 2.13(1)]

Note: The Rural Strategy, Urban Strategy and Dam Safety Strategy are as described in Chapter 3 and in the 2013 Flood Manual.

Details of the four FSV scenarios are shown in Table 5.4.

Table 5.4 Wivenhoe Dam full supply volume (FSV) scenarios

Full Supply Volume (FSV) (%)[1]	Corresponding Full Supply Level (mAHD)	Level below existing FSL (m)	Resultant Full Supply Volume [2] (ML)	Additional flood storage volume created [3] (ML)
100	67.00	0	1,165,000	0
85	65.25	1.75	990,000	175,000
75	64.00	3.00	874,000	291,000
60	61.75	5.25	700,000	465,000

Notes:

(1) Percentage compared to the existing FSV. Addresses QFCoI Interim Report recommendation 2.13 (1) by modeling across a range of full supply levels.
(2) Source: Seqwater 2014a, Table 5.1.
(3) Additional flood storage volume is the storage volume difference between the lowered FSL and the existing FSL of EL 67 mAHD. The quoted volumes do not allow for any increase in volume associated with raising of the dam safety trigger.

The eight operational alternatives combined with the four nominated FSV scenarios yields 32 options for analysis.

Figure 5.1 is presented below to illustrate the effect of lowering the dam to enable more of the storage capacity in the dam to be allocated to flood mitigation. Figure 5.1 illustrates the changed volume allocations to water supply storage and urban flood mitigation that would occur if the dam is lowered to 85% FSV. Refer to Figure 3.1 (100% FSV) for comparison. The primary change is the reallocation of 175,000 ML from the water supply compartment to the urban flood mitigation compartment.

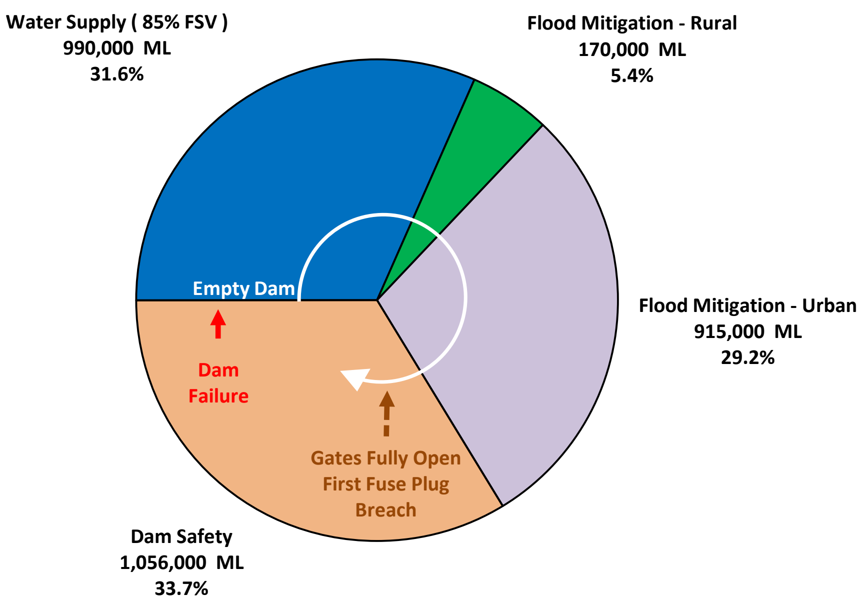


Figure 5.1 Storage allocation for 85% FSV and Base Case operations

5.3 Operational alternatives

Further details of the eight operational alternatives listed in Table 5.1 are provided in the following sections, with more information available in Seqwater (2014a).

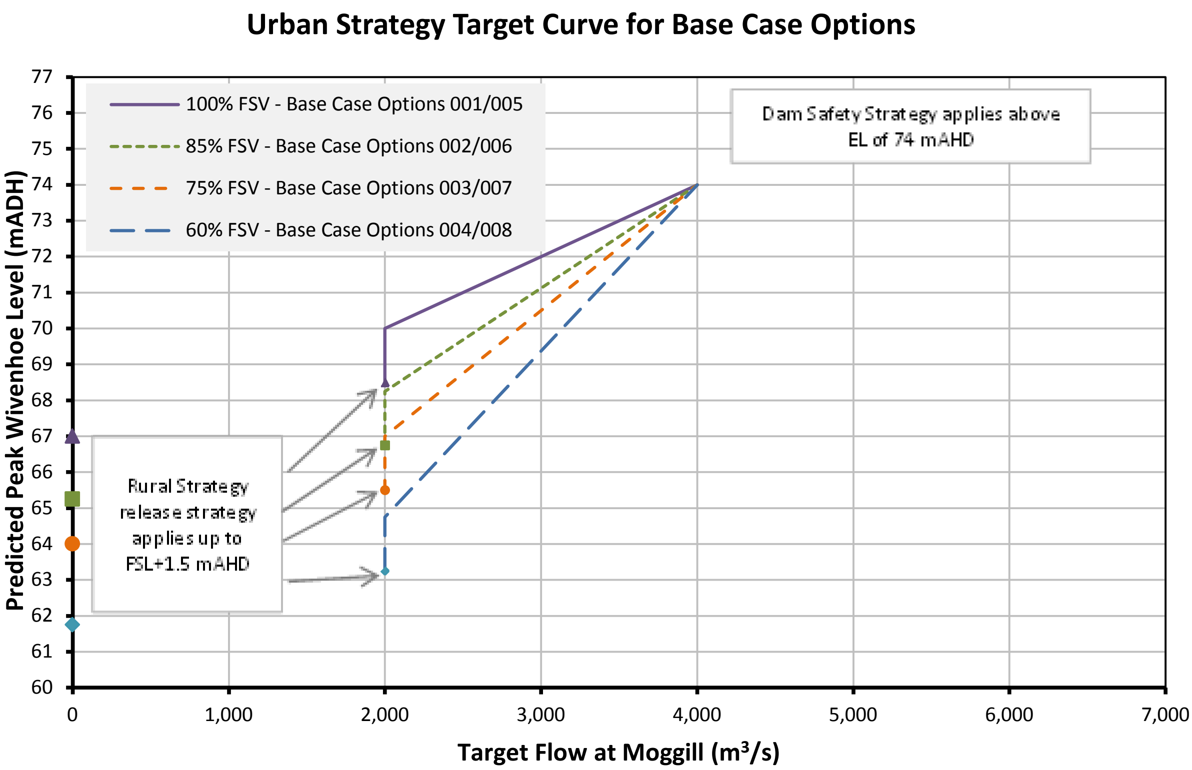
5.3.1 Base Case operations

In Seqwater (2014a), the Base Case (2013 Flood Manual operational procedures) were simulated for each of the four FSV scenarios in order to:

- test the performance of the lowered FSVs alone; and
- provide a point of reference for comparison with all other results.

Under the Base Case operational alternative:

- reductions in the FSV of Wivenhoe Dam are added to the flood mitigation (Urban Strategy) compartment (as illustrated for the 85% FSV scenario in Figure 5.1).
- the Rural Strategy in the 2013 Flood Manual is not adjusted and
- adjustments to the Urban Strategy to accommodate the lowered full supply level have been made.



Source: Based on Seqwater 2014a

Figure 5.2 Urban Strategy release target guide curve for Base Case options

Figure 5.2 shows the target flow at Moggill applied within the current Urban Strategy for a given predicted water level in Wivenhoe. A line (curve) is presented for each of the four FSV scenarios. The urban strategy target guide curve for the 100% FSV Base Case option is that from the Revision 11 Flood Manual.

5.3.2 Bypassing the Rural Strategy

This alternative was identified to assess the effect of excluding (bypassing) the Rural Strategy. Under this alternative, consideration is not given to low level downstream bridges and dam flood operations start in the Urban Strategy. Operations typically start matching outflows to inflows until a target flow of 2000 m^3/s at Moggill is reached. This target flow aims to limit potential inundation of Brisbane Valley Highway and Mount Crosby Weir Bridge, as both are significant regional transport routes. This objective applies to the releases made from the dams until the Wivenhoe Dam level is predicted to exceed FSL + 3 m.

In defining this alternative, Seqwater noted that exclusion of the Rural Strategy resulted in a need to consider how to define the required gradual increase in dam releases at the start of the flood event. This is reflective of the current Flood Manual, in which the Rural Strategy provides a means to commence flood releases gradually as flood flows upstream (and downstream) of the dams start to increase early in each flood event. Gradually increasing release rates at the beginning of a flood event is desirable as it:

- supports meeting of the objective to have the dams near FSL at the end of the event (i.e. ensures Wivenhoe Dam's water supply function is not unnecessarily impacted as a result of the dam being drawn-down below FSV through excessive releases should the flood not eventuate).
- avoids downstream floods exceeding 'natural flooding' (no dams flows) in small flood events.
- provides greater warning times for areas directly downstream.

The flood operations simulation model (FOSM) addresses this by setting rules for a maximum release, whereby the maximum release rate is determined using existing flood storage and an estimate of the total inflow volume over the next 24 hours. The maximum release rate only applies when the flow at Moggill is less than 2000 m^3/s, and the predicted level in Wivenhoe is less than FSL + 3 m.

Figure 5.3 illustrates the effect of bypassing the Rural Strategy with the proportion of Wivenhoe storage for urban flood mitigation increasing from 24% to 29%.

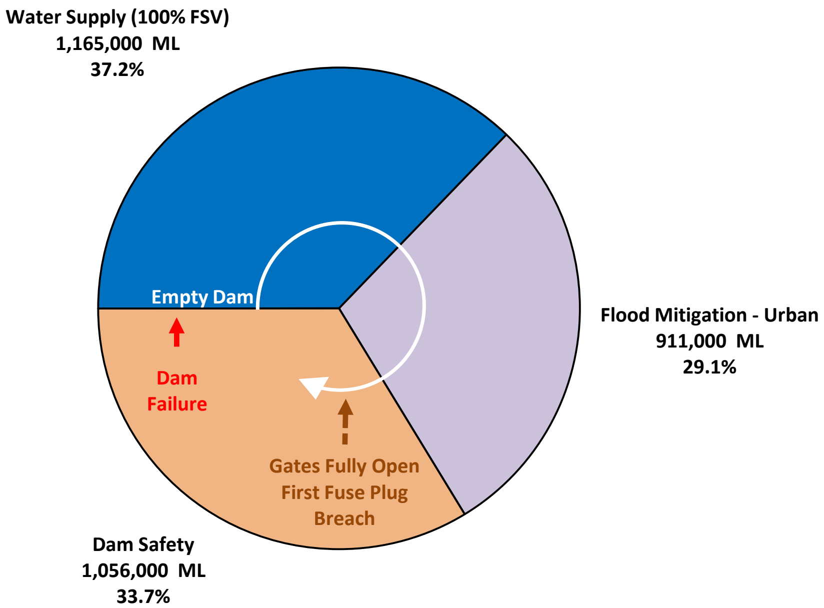
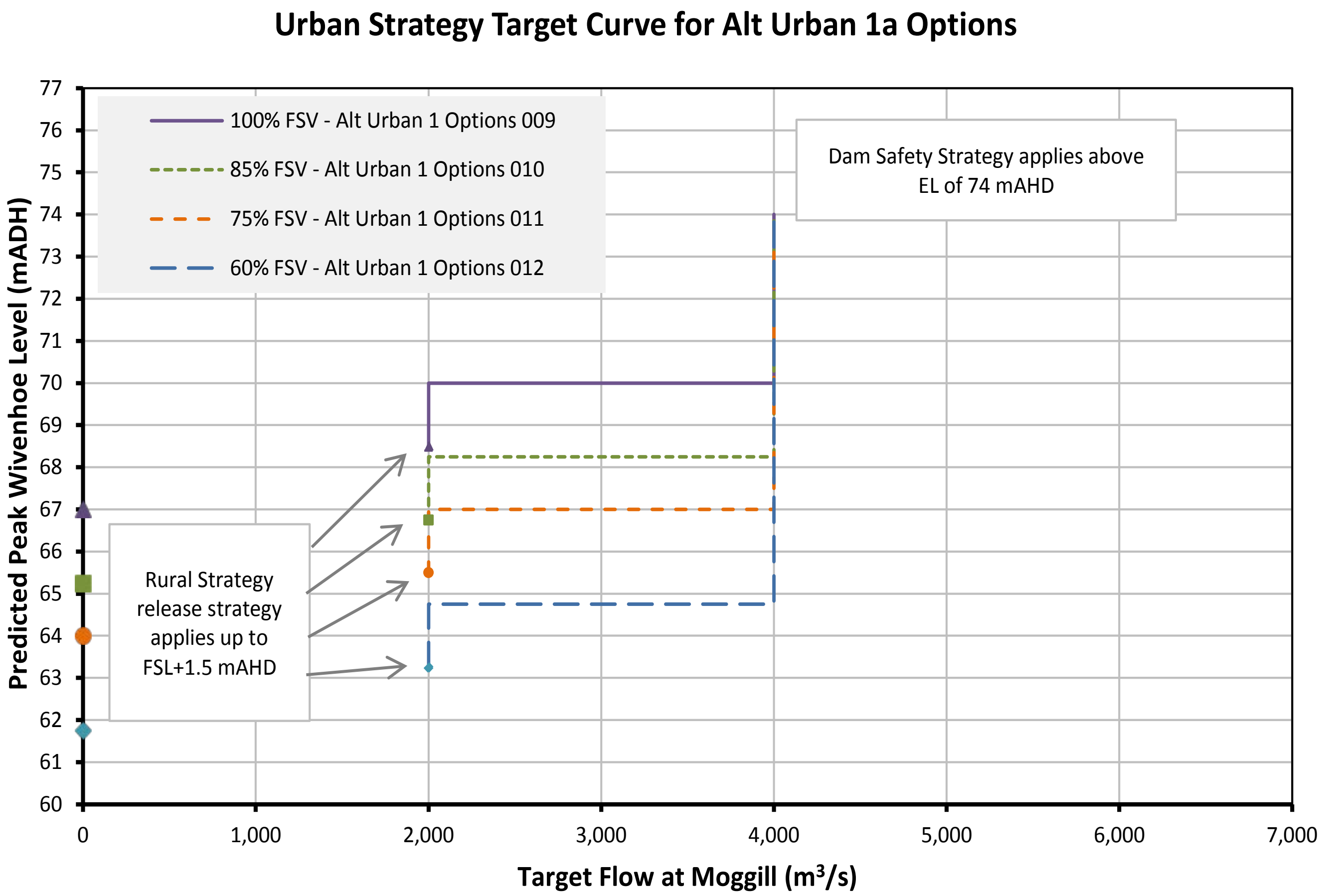


Figure 5.3 Storage allocation with bypass of Rural Strategy

5.3.3 Alternative Urban 1a

This alternative represents Base Case dam operations (including use of the Rural Strategy) but with a single step change from the maximum target flow at Moggill in the Rural Strategy (2,000 m^3/s) to the maximum target flow at Moggill in the Urban Strategy (4,000 m^3/s), and hence produces higher releases earlier in flood events (see Figure 5.4). The maximum target flow of 4,000 m^3/s at Moggill (when Wivenhoe Dam level is predicted to exceed FSL + 3 m) is maintained until the Dam Safety Strategy trigger of EL 74 mAHD is reached. All other parameters of the flood operations were the same as the Base Case.

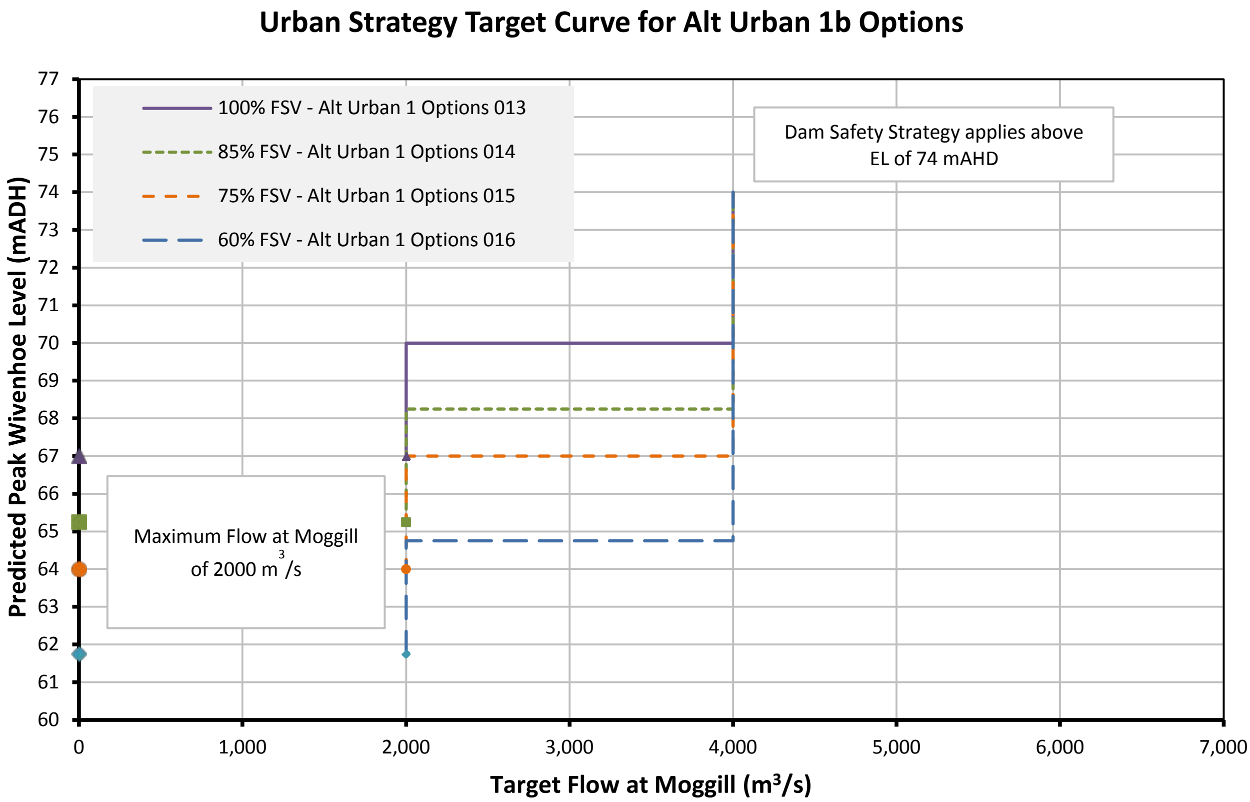


Source: Based on Seqwater 2014a

Figure 5.4 Urban Strategy release target guide curves for alternative Urban 1a options

5.3.4 Alternative Urban 1b

Under the Urban 1b alternative, dam operations are similar to those for Urban 1a, but exclude (bypass) the Rural Strategy (refer Figure 5.5).



Source: Based on Seqwater 2014a

Figure 5.5 Urban Strategy release target guide curves for alternative Urban 1b options

Figure 5.4 and Figure 5.5 show how the releases from Wivenhoe in the Urban Strategy would be managed under alternatives Urban 1a and 1b and also show that as soon as the water level in Wivenhoe is predicted to reach FSL + 3 m, releases would be adjusted to target 4,000 m^3/s at Moggill. The same philosophy applies, irrespective of the starting FSL. For example, the FSL for the 100% FSV is EL 67 mAHD (refer Table 5.4), hence targeting of a flow of 4,000 m^3/s occurs when the lake level reaches EL 70 mAHD. If the dam were to be at an FSV of 85%, the corresponding FSL would be EL 65.25 mAHD, and the trigger to move to 4,000 m^3/s would occur at the lower level of EL 68.25 mAHD (FSL + 3 m for 85% FSV).

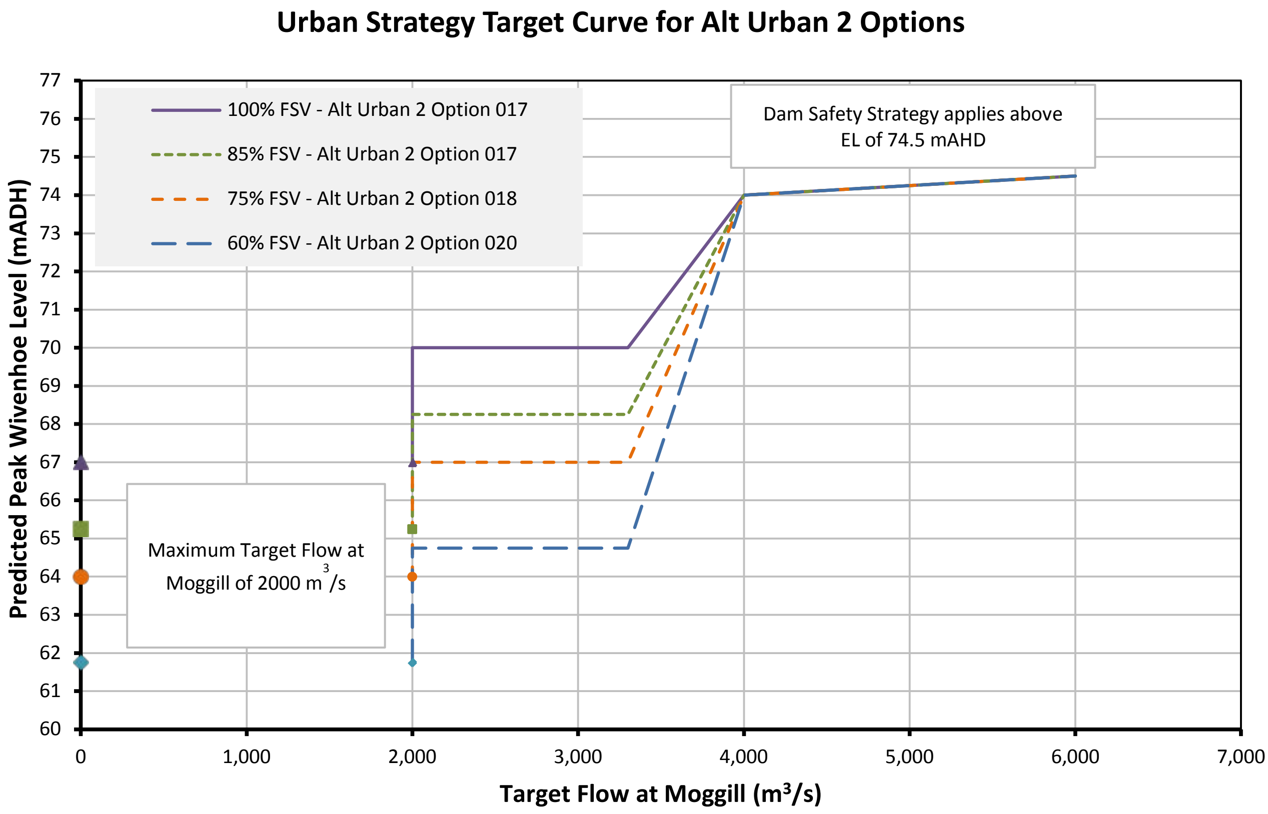
5.3.5 Alternative Urban 2

Urban 2 was investigated to consider a possible compromise between the Urban 1a operations and those for the Base Case. Releases would involve a stepped change to a target flow of 3,300 m^3/s at Moggill when the Wivenhoe Dam level is predicted to exceed FSL + 3 m, followed by a linear increase in the target flow at Moggill to 4,000 m^3/s for a predicted Wivenhoe Dam level at EL 74 mAHD, increasing to 6,000 m^3/s for EL 74.5 mAHD predicted Wivenhoe Dam level. Raising the Dam Safety Strategy trigger level by 0.5 m (to EL 74.5 mAHD) increases the flood storage by 77,000 ML.

Urban 2 allows higher releases in the Urban Strategy and a greater allocation of flood storage to the Urban Strategy. This combination can delay or reduce the probability that dam operations will need to escalate to the Dam Safety Strategy in large flood events.

A comparison between the Urban 1 alternatives (Figure 5.4 and Figure 5.5), and that for the Urban 2 alternative (Figure 5.6) highlights the change in operational strategy. The key differences evident for the Urban 2 curve are:

- targets of 3,300 m^3/s (rather than 4,000 m^3/s) at Moggill once the first trigger level of FSL + 3 m is reached;
- transitions linearly from 3,300 m^3/s to 4,000 m^3/s target flows at Moggill between predicted levels of FSL + 3 m and 74 m; and
- the guide curve transitions linearly again from 4,000 m^3/s to 6,000 m^3/s target flows at Moggill for predicted lake levels from 74 m to 74.5 m.

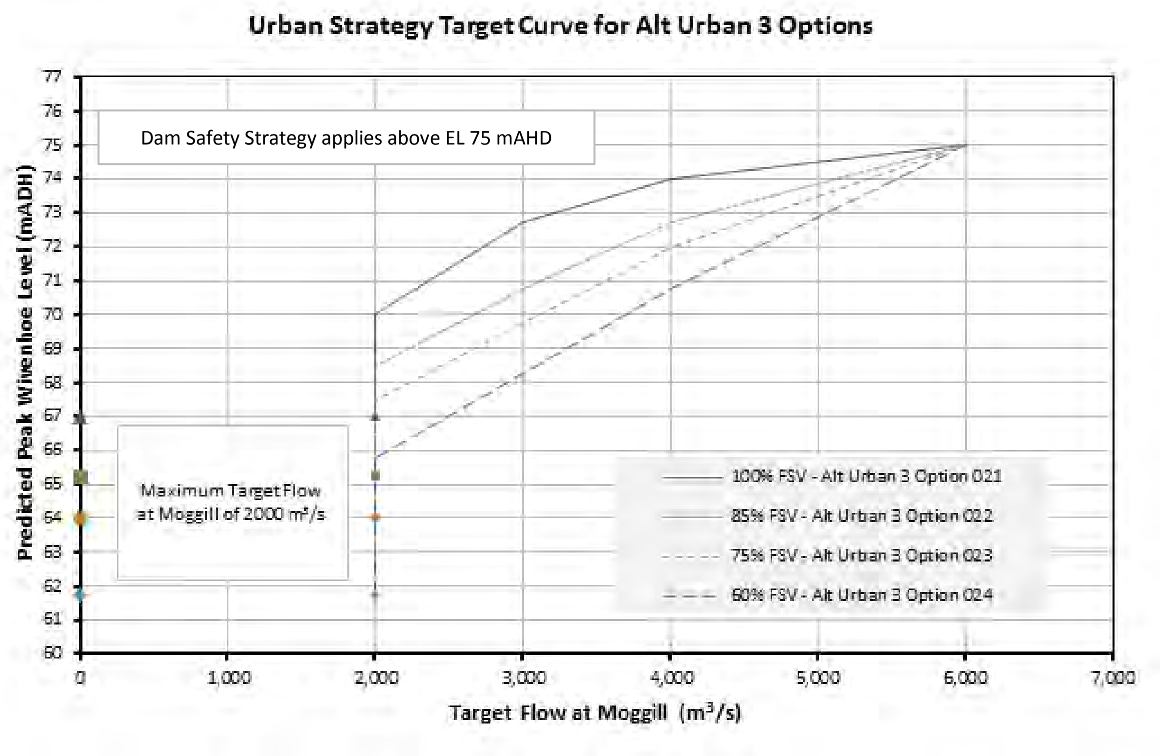


Source Based on Seqwater 2014a

Figure 5.6 Urban Strategy release target guide curve for alternative Urban 2 options

5.3.6 Alternative Urban 3

The alternative Urban 3 investigates the potential to improve the mitigation of infrequent major floods whilst aiming to achieve similar performance to the Base Case options for frequent minor and moderate flood events (Seqwater 2014a). The Urban Strategy target guide curve for the alternative is provided as Figure 5.7.



Source: Based on Seqwater 2014a

Figure 5.7 Urban Strategy release target guide curve for alternative Urban 3 options

Urban 3 encompasses the following changes:

- bypassing the Rural Strategy;
- increasing the maximum target flow at Moggill to 6000 m^3/s in the Urban Strategy;
- using a different approach (i.e. volumetric) to adapt the Urban Strategy target guide curve to lower FSV scenarios; and
- a further raising (above Urban 2) of the Dam Safety trigger level to EL 75.0 mAHD together with raising the Dam Safety Strategy transition level to EL 75.5 mAHD[12].

For the 100% FSV scenario, the Urban Strategy target guide curve for Urban 3 is defined the same as the 100% FSV Base Case up to EL 74.0 m AHD predicted Wivenhoe Dam level. The target flow at Moggill then increases linearly from 4,000 m^3/s for a predicted Wivenhoe Dam level of EL 74.0 mAHD to 6,000 m^3/s for a predicted level of EL 75.0 mAHD. With this approach, additional urban flood mitigation storage is gained by raising the Dam Safety Strategy trigger level and assigned to targeting higher flows at Moggill during major flood events.

[12] The Dam Safety trigger curve is presented as Figure 6.4 (Section 6.2.1)

A notable difference under Urban 3 is in the way that the Urban Strategy target guide curve is adapted for lower FSV scenarios. An 'equal flood storage' approach is used to adapt the Urban Strategy target guide curve to lower FSVs. Using this approach for the 85%, 75%, and 60% FSV scenarios, the target flows at Moggill occur at the same flood storage volumes above FSL in each case. In the current Flood Manual (100% FSV), the levels defining the Urban Strategy target guide curve can be equated to storage volume above FSV as follows:

- 352,000 ML flood storage (3 m) above FSL can be used for a target flow of 2,000 m^3/s
- 618,000 ML flood storage (5 m) above FSL can be used for a target flow of 3,000 m^3/s, and
- 911,000 ML flood storage (7 m) above FSL can be used for a target flow of 4,000 m^3/s.

The same volumes were applied in all four FSV scenarios.

5.3.7 Alternative Urban 4

Alternative Urban 4 variation aims to hold water in the dams (Seqwater 2014a) and retains a maximum target flow at Moggill of 4,000 m^3/s up to EL 76.2 mAHD. This contrasts with the Urban 2 and 3 which increase the target flow at Moggill to above 4,000 m^3/s at lower levels in Wivenhoe Dam (e.g. EL 74 mAHD for Urban 2 and the 100% FSV Urban 3 option). Unlike the Urban 2 and 3 options, the Urban 4 variation also includes the Rural Strategy.

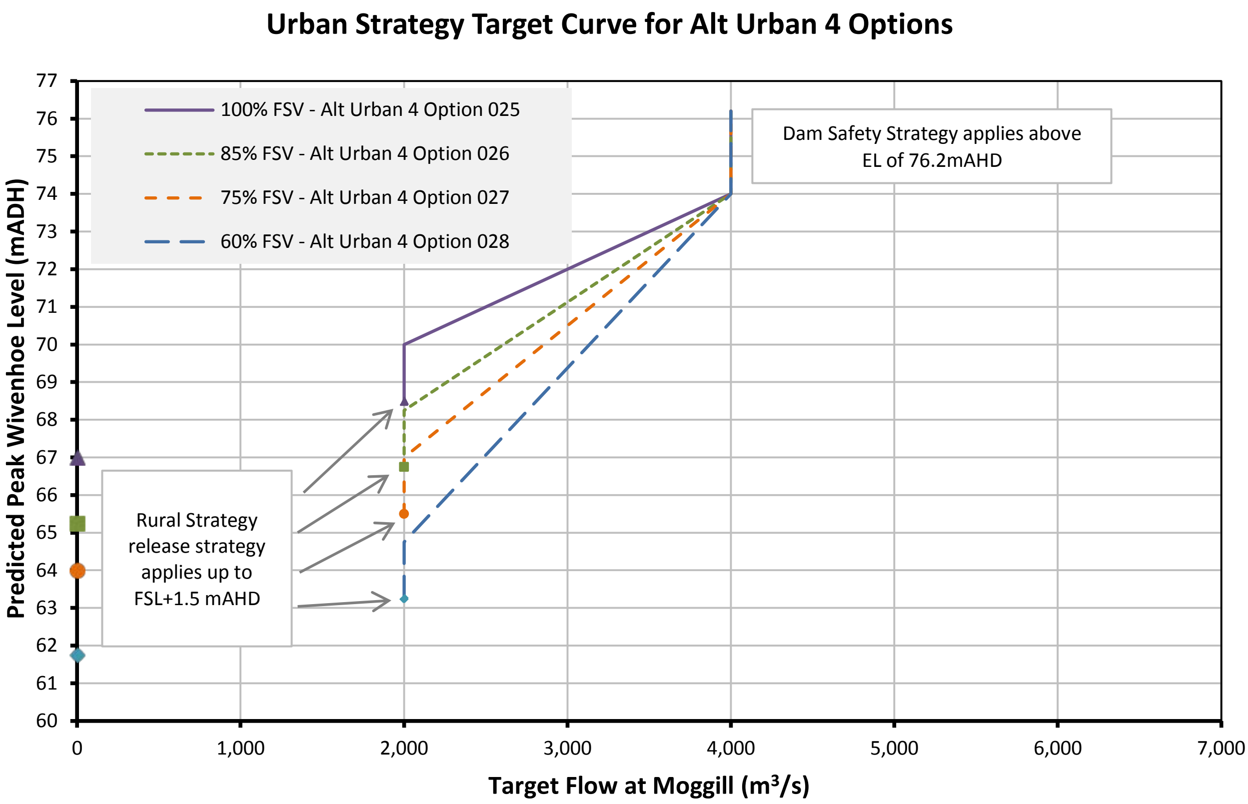
Urban 4 also raises the Dam Safety Strategy trigger level to a predicted Wivenhoe Dam level of EL 76.2 mAHD which allows the Urban Strategy to operate in conjunction with breaching of the lowest (centre) fuse-plug embankment (EL 75.7 mAHD). This option was recommended to be analysed by the QFCoI (Interim Report recommendation 2.13).

The Urban 4 target guide curve (refer Figure 5.8) is as for the Base Case (refer Figure 5.2) with the exception of the raising of the Dam Safety Strategy trigger level (and consequent extension of the Urban Strategy target guide curve) to EL 76.2 mAHD. This reduces the storage capacity for dam safety.

In major flood events, this variation has a higher probability of breaching the fuse plug spillway. If the lowest fuse-plug spillway breaches, the main spillway gates settings would attempt to compensate for the flow through the fuse-plug spillway, so that total flow released from the dam is the release required to achieve the downstream target flow. In reality, this could be difficult to achieve in real time operations, particularly when the fuse-plug initially breaches, because the time required for the fuse-plug to fully breach may be faster or slower than expected.

When attempting to apply Urban 4 at the higher levels in Wivenhoe Dam, the constraint of preventing overtopping of the spillway gates will apply more frequently. Thus, it can be inferred that it would be more difficult (for larger floods) to manage Wivenhoe Dam releases to achieve downstream target flows.

Because this alternative would likely increase the potential for breaching a fuse-plug, it would require further comprehensive risk assessment and analysis before it could be implemented.



Source: Based on Seqwater 2014a

Figure 5.8 Urban strategy release target guide curve for alternative Urban 4 options

Figure 5.9 shows that for the 100% FSV scenario under alternative Urban 4, with the trigger raised to EL 76.2 mAHD, the portion of Wivenhoe storage for rural and urban flood mitigation combined has increased from 29% for Base Case operations(refer Figure 3.1) to 40%, whilst that for dam safety has reduced from 34% to 22%.

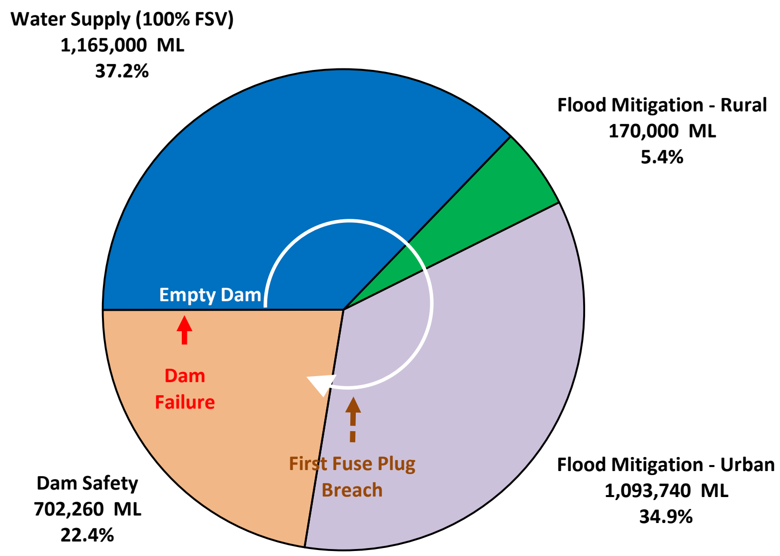


Figure 5.9 Storage allocation for Urban 4

5.3.8 Prescribed operations

The prescribed mode of operations was based upon a submission from a member of the community to the State Government that was subsequently included in DEWS (2013a).

This variation would not apply the operating philosophy and concepts in the current Flood Manual; i.e. managing releases considering downstream inflows to minimise downstream impacts up until dam safety requirements become the priority.

The prescribed operations represent a simplified set of operating rules that primarily respond to the level in Wivenhoe Dam. The operating rules are focused on maintaining maximum possible air space (available storage) in the dam on the basis that it may be required should the event worsen. This option does not consider the downstream catchment contribution to flooding conditions when making decisions for dam releases.

In simple terms, the variation is based on having gates open sooner and for longer than other options, with no consideration of downstream inflows.

As described in Seqwater (2014a), the prescribed operations rules consider when the water level initially exceeds FSL, and whether levels in Wivenhoe are rising or falling, but do not consider downstream flows. The prescribed rules mostly relate to the rates of gate opening and closing in response to Wivenhoe water levels – although a maximum outflow of 4,000 m^3/s up to EL 74.0 mAHD is specified

The prescribed operations were not varied for lower FSV scenarios in Seqwater's modelling.

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Chapter 6 Dam flood operations assessment

6.1 Operational options

This chapter provides a summary of Seqwater's assessment of the options outlined in Chapter 5. Full details of establishment of the model, and of the results of modelling are contained in the *Wivenhoe-Somerset Dam Optimisation Study - Simulation of Alternative Flood Operations Options* (Seqwater 2014a), whilst the presentation and discussion of results is presented in the following chapter.

Thirty-two operational options were defined on the basis of four starting full supply volumes (FSV) and eight operational alternatives. These are detailed in Table 6.1.

Table 6.1 Operational alternatives and options

Operational Alternative	Option	FSV	Rural	Max Urban Target Flow (m^3/s)	Dam Safety trigger (mAHD)
Base Case	001	100%	Yes	4,000	74.0
	002	85%			
	003	75%			
	004	60%			
Bypass Rural	005	100%	No	4,000	74.0
	006	85%			
	007	75%			
	008	60%			
Alt Urban 1a	009	100%	Yes	4,000	74.0
	010	85%			
	011	75%			
	012	60%			
Alt Urban 1b	013	100%	No	4,000	74.0
	014	85%			
	015	75%			
	016	60%			
Alt Urban 2	017	100%	No	6,000	74.5
	018	85%			
	019	75%			
	020	60%			
Alt Urban 3	021	100%	No	6,000	75.0
	022	85%			
	023	75%			
	024	60%			
Alt Urban 4	025	100%	Yes	4,000	76.2
	026	85%			
	027	75%			
	028	60%			
Prescribed Operations	029	100%	No	n/a	n/a
	030	85%			
	031	75%			
	032	60%			

Figure 6.1 illustrates the 32 options modelled in terms of the proportions of:

- the storage in Wivenhoe Dam allocated to various Flood Manual strategies and
- how the storage for the Urban Strategy is used relative to target flow at Moggill.

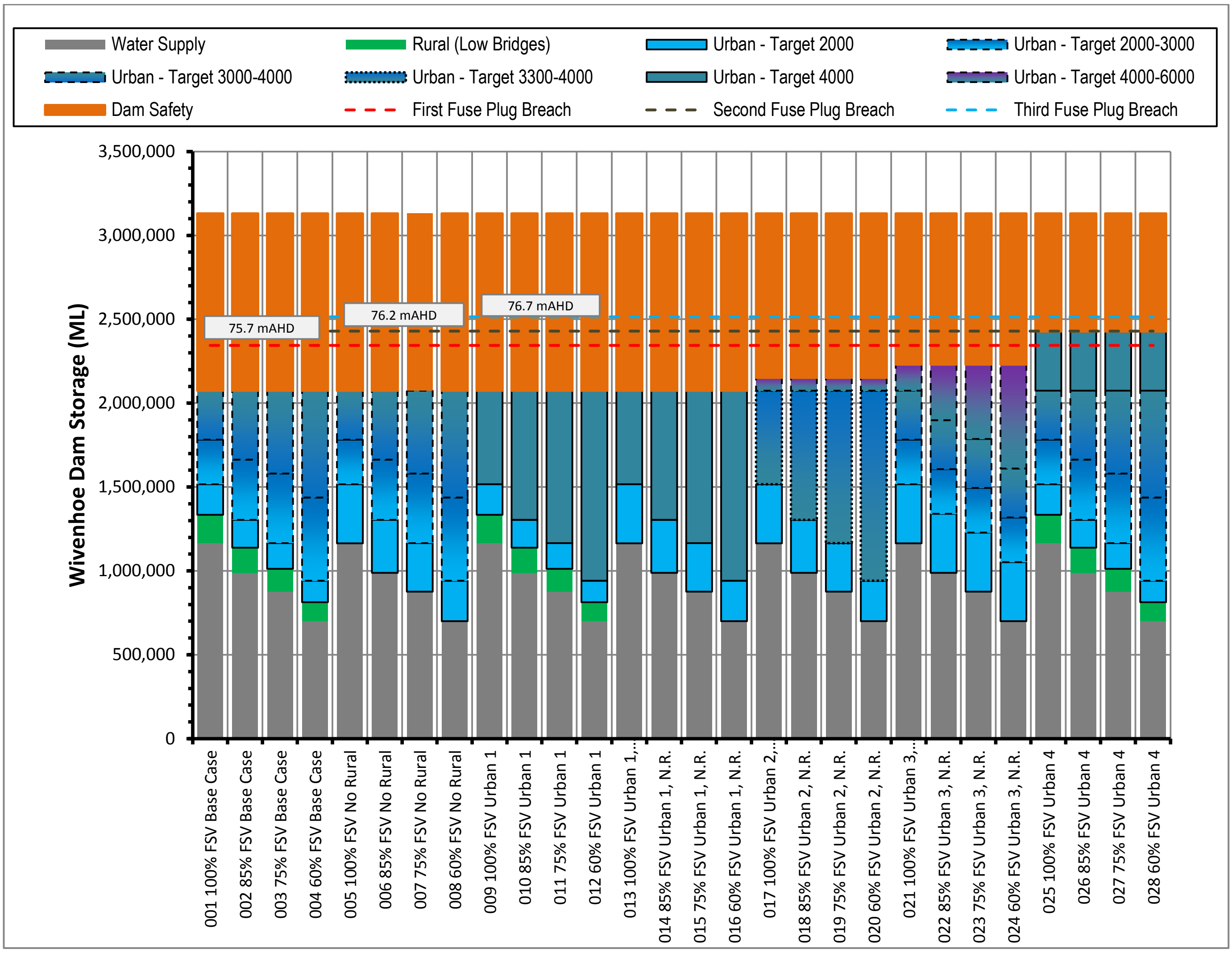


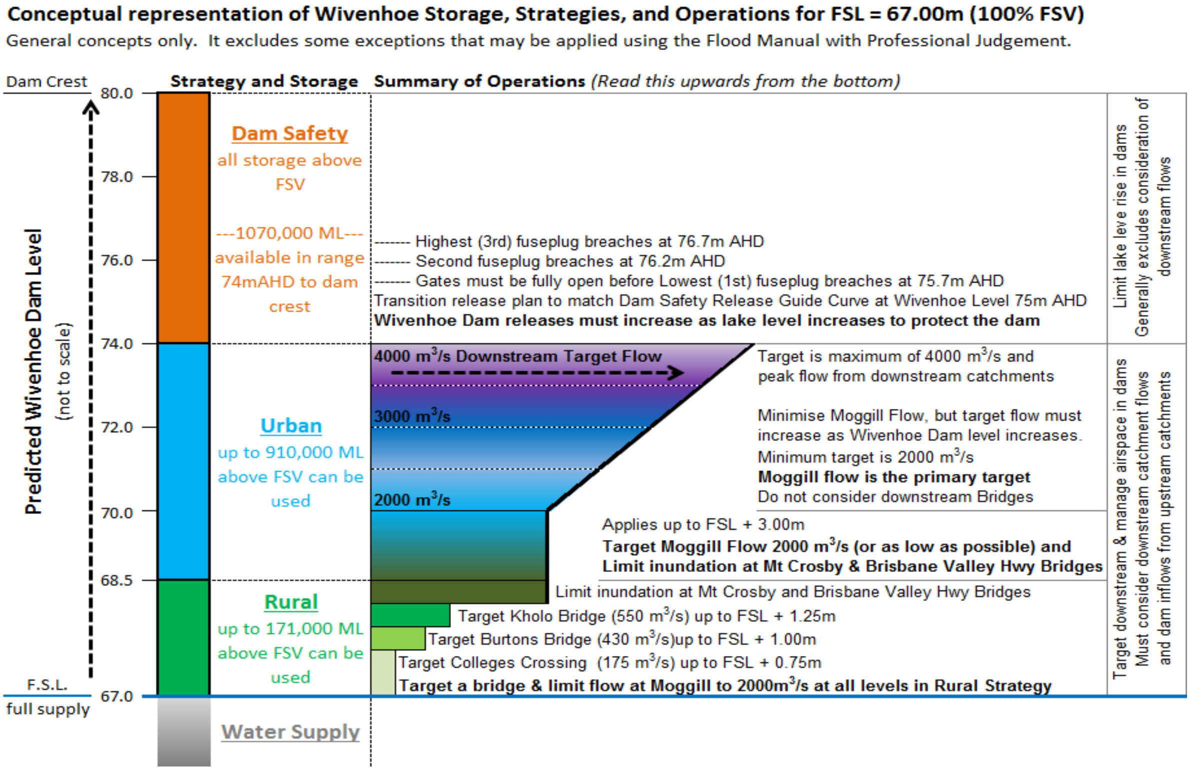
Figure 6.1 Operational Options

6.2 Flood operation strategies

6.2.1 Wivenhoe flood operations

The operational strategies (Rural, Urban, Dam Safety, and Drain-down) to achieve the flood mitigation objectives listed in the Flood Manual were detailed in Chapter 3. The strategies link water levels in Wivenhoe with target flow rates (i.e. releases from Wivenhoe are based on a target flow at various locations (primarily Moggill or bridges upstream of Moggill), recognising that downstream catchments could be contributing anything from zero to more than the target in their own right). Implementation of release strategies is therefore based on releasing only that portion of the target flow not being delivered from downstream catchments. For example, if the target flow is 2,000 m^3/s at Moggill, and the Bremer River is predicted to be contributing 500 m^3/s by the time Wivenhoe releases reach Moggill, then the release from Wivenhoe would be 1500 m^3/s, subject to whether the predicted water level within Wivenhoe was acceptable (i.e. in accordance with the target operating curve).

A range of flows is associated with each operational strategy in the Flood Manual, as described in the remainder of this section and shown in Figure 6.2. The figure has particular relevance when considering the alternatives and options modelled by Seqwater.



Source: Seqwater 2014a, Figure 2-14

Figure 6.2 Wivenhoe Dam operational strategies and procedures

Within the Rural Strategy, target flows are linked to bridge submergence, with key flow targets for each bridge as shown in Figure 6.3. The maximum flow under Rural Strategy is 2,000 m^3/s at Moggill.

The Urban Strategy applies within a range of target Moggill flows up to 4,000 m^3/s. This recognises an historical understanding that at 2,000 m^3/s, both the Brisbane Valley Highway and Mount Crosby Weir bridges are being affected, and that urban impacts are starting to be realised. At 4,000 m^3/s, overfloor flooding in houses becomes more significant, though there is some evidence that a slightly lower flow (say 3,500 m^3/s) might be of consequence. At all times, the target is to minimise the flow at Moggill, whilst recognising levels in Wivenhoe Dam. For the most part, the Urban Strategy applies for a Wivenhoe Lake level from 1.5 m above full supply level to 7 m above (i.e. EL 74 mAHD).

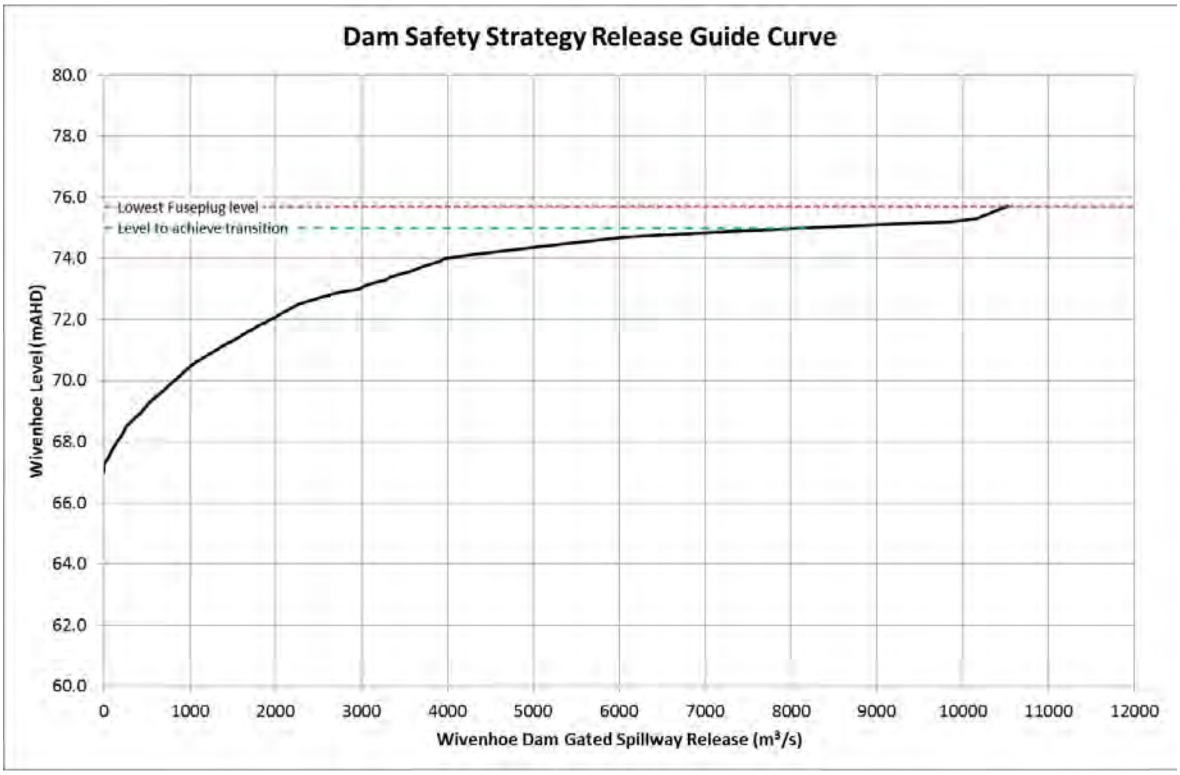
The Dam Safety Strategy applies as soon as the level in Wivenhoe is predicted to exceed EL 74 mAHD. At this stage, the primary consideration is protection of the dam from the potential to fail. At this time, the operators set a release plan that will achieve the required release by the time the lake level reaches EL 75 mAHD.

As the level rises, the release must rise accordingly, with the link between predicted level and target release as illustrated in Figure 6.4.

The Drain-down Strategy seeks to drain both Wivenhoe and Somerset dams within a seven day period.

Source: Based on DTMR 2013, Figure 1

Figure 6.3 Submergence flows for bridges and crossings



Source Seqwater 2014a, Figure 2-6

Figure 6.4 Dam Safety Strategy release guide curve

6.2.2 Somerset flood operations

Only two operational strategies apply to Somerset Dam. These are the:

- Somerset Flood Strategy aimed at protecting the safety of the dam while making best use of the flood storage to mitigate flooding downstream of Wivenhoe Dam and
- Drain-down Strategy focussed on draining both Wivenhoe and Somerset dams within seven days whilst minimising impacts on rural and urban areas and riparian flora and fauna.

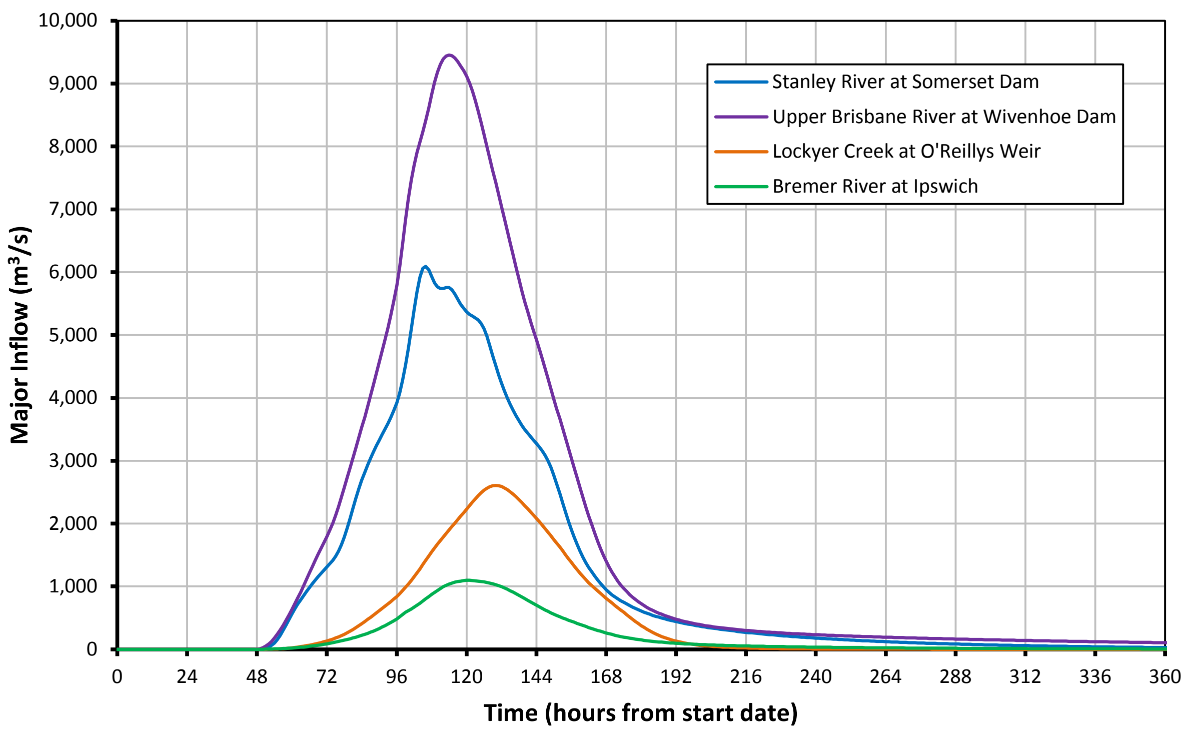
6.3 Flood operations simulation model (FOSM)

6.3.1 Overview

A FOSM was developed by Seqwater in order to test the full range of identified options (Seqwater 2014a). The FOSM is driven by flood event hydrographs at key locations, with parameters representing the dam flood operation rules.

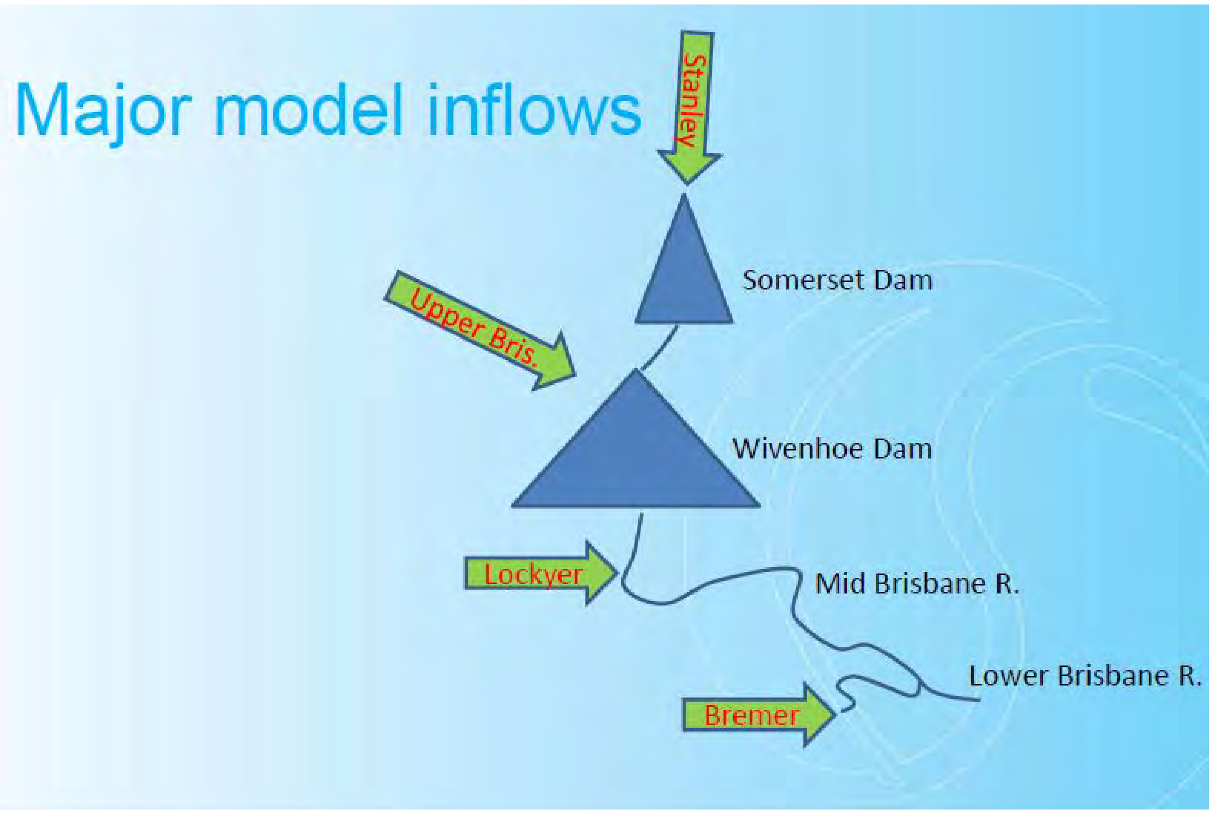
The model accepts inputs in terms of event inflows for Somerset, Wivenhoe and locations downstream of Wivenhoe (refer Figure 6.5 and Figure 6.6) predicts lake levels in Wivenhoe, and applies operating rules for the gates at Wivenhoe and the sluices at Somerset, in accordance with the nominated strategy. A schematic of the FOSM is provided as Figure 6.7.

It should be noted that the FOSM model is not suited to the assessment of very small floods (which are generally not going to affect residences), and that the downstream results from the FOSM are less reliable for floods producing flows greater than 16,000 m^3/s (i.e. those greater than the largest historical flood experienced).



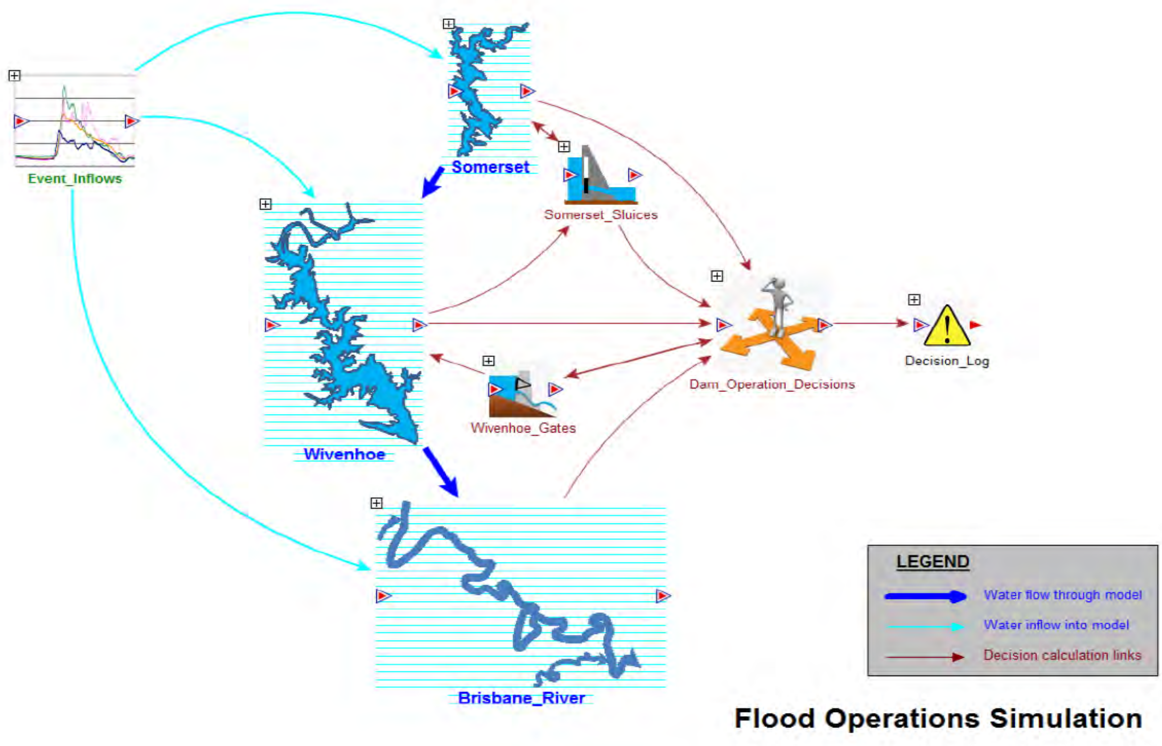
Source: Seqwater 2014a, Appendix A

Figure 6.5 Example of inflow hydrographs (Jan 1893 event)



Source: Seqwater

Figure 6.6 Major model inflows (Seqwater)



Source: Seqwater

Figure 6.7 Schematic of Seqwater Flood Operation Simulation Model (FOSM)

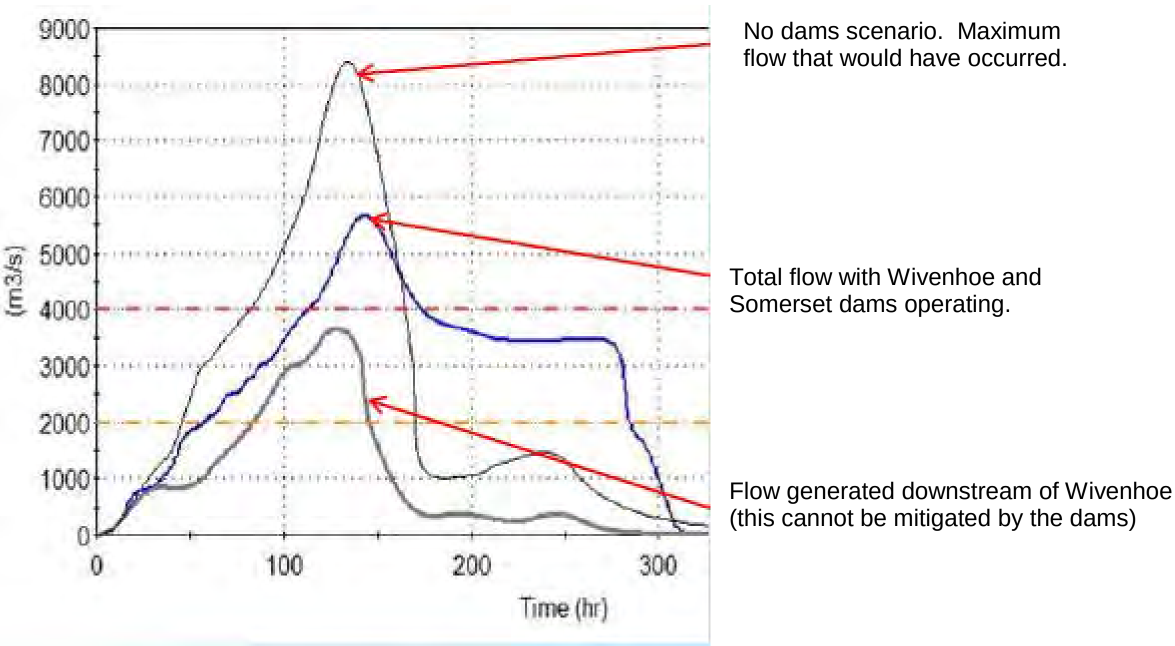
Seqwater note that the model:

- was constructed to enable numerous flood events to be simulated within a reasonable simulation time;
- mimicked realistic limits of foresight for reliable flood hydrograph information that would be available to make decisions for the operations of the dams;
- simulated the decision procedures to apply the operating rules for the dams and determine releases to be made from the dams;
- simulated the routing of floods through Somerset and Wivenhoe Dam;
- simulated the routing of downstream catchment flows combined with dam releases to assess total Brisbane River flows downstream to (at) Moggill; and
- estimated the flood level at Ipswich taking account of flow in the Bremer River and backwater influence from the Brisbane River.

The model produces three 'scenario' estimates that enable the flood mitigation performance of each flood event to be evaluated. These comprise:

- the flood that would occur as a result of downstream flows and dam releases;
- the flood that would occur if the dams did not exist ('no dams' scenario); and
- the flood that would occur from flow emanating from downstream catchments only.

An example providing definition of the three estimates is provided in Figure 6.8.



Source: Seqwater

Figure 6.8 Estimates of flood hydrographs

6.3.2 Model Limitations

While the FOSM has been developed to provide a reasonable representation of real time flood operations there are important assumptions and limitations (Seqwater 2014a):

- The model was developed as a planning tool specifically for WSDOS and it is not the model that is used in real time flood operations.
- The results obtained from this model may not be same as the dam operations decisions (and consequently actual downstream flood flows) that may occur from real time operations for any individual flood.
- The model has been developed with parameters applied in an attempt to be relatively neutral, that is, neither overly conservative, nor overly optimistic.
- The model validation indicates the differences relative to real time operations are probably relatively neutral. The modelling is therefore deemed suitable for the purposes required for WSDOS.

There are also a number of assumptions and limitations of the differences between the FOSM and real time flood operations that have opposite effects on the neutrality of the simulation results compared to what may occur in real time flood operations. The significance of these are detailed in Seqwater (2014a).

One of the most important differences is the uncertainty of forecast catchment flows which is not represented in the FOSM.

6.4 Flood events modelled

The Flood Operations Simulation Model has assessed 32 different options, as described earlier in Table 5.1. Each of these options has been run for a broad range of floods, comprising:

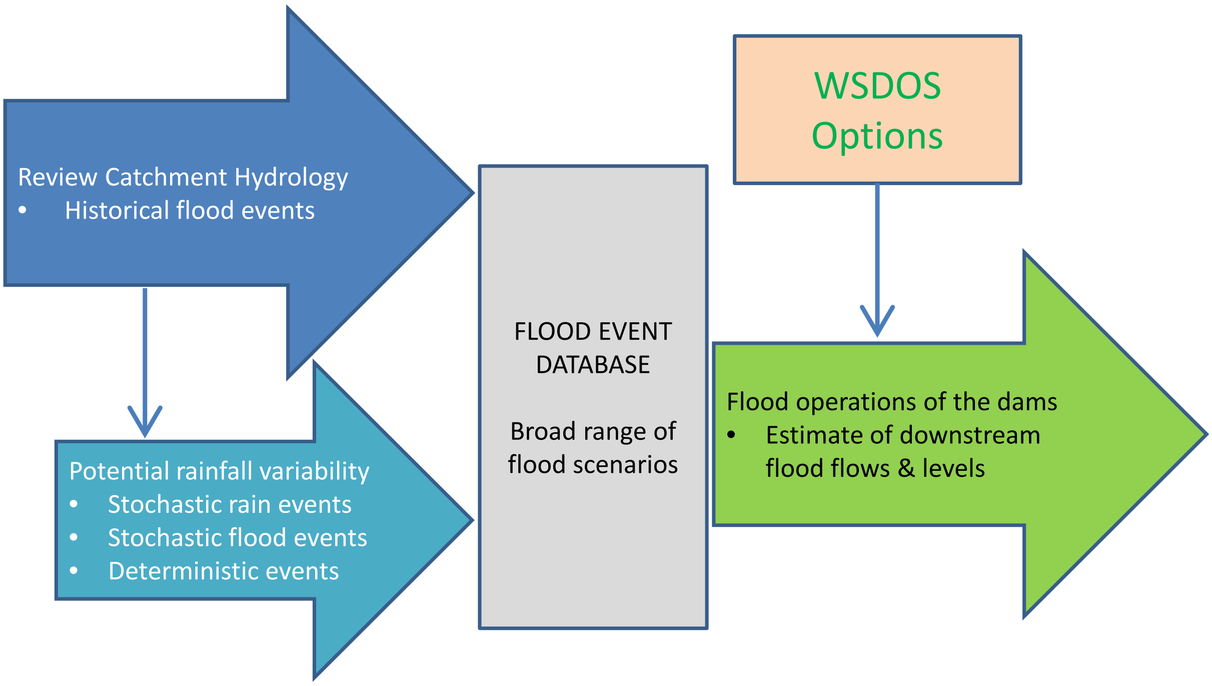
- 19 of the 20 largest historical flood events for the Brisbane River from the last 125 years (comprising 1887, 1890, three floods from 1893, two floods from 1898, 1908, 1931, 1955 (excluded from analysis), 1959, 1971, 1973, 1974, 1983, 1989, 1996, 1999, 2011 and 2013). It should be noted that this does not equate to the 20 largest floods in Ipswich, though the majority of these are included e.g. the 1947 and 1976 Ipswich floods are not included.
- 3,840 stochastically generated events (selected from over 5,000 events) with the smallest floods, and those exceeding 16,000 m^3/s (beyond 1 in 1,000 AEP).
- Over 100 extreme events, addressing dam safety and estimation of the probable maximum flood (PMF).

Several key points need to be made in relation to these flood events:

- For historical events, the modelling assumes some drawdown at the start of the event reflective of prior inflows and hence the dams will not always be at FSL at the start of the event, whereas for the stochastic floods, dams are always assumed to be full. This will translate into slightly better performance being evident when considering the historic floods.
- The largest of the historical floods typically received an average of 400 mm of rainfall across the catchment. For the stochastic floods, the range of rainfall depths is approximately 150 to 600 mm (on average).

The flood hydrographs for each of the above events have been combined into a flood database, which is then used to inform the FOSM, as illustrated in Figure 6.9

Whilst results have been presented for each historic flood, an averaging of results has been required for the stochastic floods.



Source: Seqwater 2014a, Figure1-1

Figure 6.9 Overview of dam operations modeling process and generation of flood hydrographs

6.5 Modification to the drain-down period

The potential to modify the drain-down period to more or less than seven days potentially sets up some conflicts between benefits and impacts, as summarised below.

The advantages and disadvantages of changing the drain-down period are not clear cut, as some forms of damage are exacerbated by the duration of flood flows (i.e. if the period of drain-down is increased), whilst others can be exacerbated by the rate of change in water level (i.e. if the period of drain-down were to be decreased). Key impacts can include:

- Submergence of low bridges (preference is normally for a faster rate of drain-down)
- Submergence of bridges closer to the drain-down threshold (i.e. a longer drain-down period will result in a lower peak flow, which may allow a bridge close to this threshold to not be affected)
- Bank slumping (could be affected positively or negatively by a change in drain-down rate, depending on the primary mechanism of failure). Relevant factors include soil type, saturation, extent of vegetation remaining, and bank height.
- Risk of worsening a closely following subsequent flood.

Of the above points, the increased risk of exacerbating flooding is considered the item of greatest importance.

Recommendation 2.13(3) from the Interim Report of the Queensland Flood Commission of Inquiry recommended the ‘development of a probability distribution for the time between closely spaced flood peaks in the catchment using historical records’.

A paper was commissioned to examine the climatic influences that cause major flooding in SEQ. It demonstrated that a flood event can be closely followed by another flood event. A long-term sequence of flows into Wivenhoe Dam was also examined to construct a probability distribution of the time between flood events to provide input to the optimum operation of the flood storages. Daily inflows to Wivenhoe Dam were estimated for the period from 1889 to 2011 using the Integrated Quantity-Quality Model (IQQM) of the Brisbane catchment.

The review of the period between larger flow events into Wivenhoe Dam showed that there is an 8 to 11% chance that two significant flow events could be separated by 7 days or less. This finding supports maintenance of the existing drain-down operational procedure, as detailed in the Flood Manual, and hence no further modelling of this was required.

Chapter 7 Dam operations – flood mitigation assessment

7.1 Introduction

7.1.1 Purpose and structure of the chapter

Seqwater (2014a) assessed 32 options to enable assessment of the potential flood mitigation performance of a broad range of alternative flood operations strategies. The investigated options address the requirements of the QFCoI Interim Report recommendation 2.13 (QFCoI 2011).

As described in the previous chapters, the 32 options cover four different water supply operation FSV scenarios ranging from 60% to 100% of the original design FSV. For each FSV scenario, eight operational alternatives were investigated. Seven of these variations applied the operating philosophy and concepts defined in the Flood Manual, whilst the eighth variation considered the application of simple prescribed operations as an alternative to the Flood Manual concepts.

The chapter has been arranged as detailed in Table 7.1.

Table 7.1 Presentation of results

Section	Title	Contents
7.1	Introduction	Overview of chapter content and structure, detailing location and format of results. Explanations are provided as to how to interpret the result figures.
7.2	Result Summary	This section contains a summary of key Seqwater findings from the modelling completed for WSDOS. Placing this section at the front of the chapter allows the reader the opportunity to understand key findings, with following sections providing supporting detail.
7.3	Flood mitigation provided by reducing the full supply volume	Provides commentary on the impacts (both positive and negative) of varying the full supply volume in Wivenhoe Dam. Results are discussed in terms of both stochastic and historical floods, and for flows at both Moggill and Ipswich.
7.4	Flood mitigation provided by varying operations	A comparison of results, and discussion of the relative implications of the eight dam operation alternatives. As above, results are presented for stochastic and historical floods, and for flows at both Moggill and Ipswich. All results are for the 100% FSV scenario.
7.5	Relative change plots	Statement about plots comparing operational alternatives with the Base Case to assist analysis of results.
7.6	Results analysis and discussion	This section provides an overview of findings for each of the eight dam operational alternatives in isolation, building on the two preceding sections.
7.7	Performance of the existing Wivenhoe-Somerset system	An analysis of the performance of the dams in mitigating floods.
7.8	Conclusions	This section captures key conclusions made throughout the chapter.

7.1.2 Result locations

Seqwater have generated and presented results for several key locations. These comprise:

- Wivenhoe Dam and Somerset Dam (inflows, outflows/releases and levels)
- Savages Crossing (peak flows)
- Moggill (peak flows), and
- Ipswich (peak levels).

This chapter summarises the results of analysis with full details available in Seqwater (2014a).

For the purposes of this report, the presentation of results mostly focusses on two locations (Moggill and Ipswich), as these provide a strong appreciation of the relative performance of the modelled options. Results for levels and flows at Wivenhoe and flows at Savages Crossing are available in Seqwater (2014a) however:

- Flows at Wivenhoe Dam are not indicative of the implications for flooding of downstream areas as there can be significant inflows downstream of the dam.
- In general, the impacts on flows at Savages Crossing display similar trends to those at Moggill. To avoid repetition of large sections of text, discussions have been based on the flows at Moggill.

Peak levels at Ipswich are presented as Ipswich is influenced by flood flows in the Bremer River and backwater effects from the Brisbane River.

Flood severity classifications for the Brisbane River used in this study (refer Figure 7.8) were:

- minor flood - peak flow at Moggill < 3,000 m^3/s i.e. more frequent than about a 1 in 10 AEP - inundation in the order of hundreds of properties
- moderate flood - peak flow at Moggill 3,000 m^3/s to 6,000 m^3/s i.e. about a 1 in 10 AEP to about 1 in 50 AEP flood –inundation in the order of hundreds to thousands of properties
- major flood - peak flow at Moggill > 6,000 m^3/s i.e. less frequent than about a 1 in 50 AEP flood –inundation in the order of 1,000s to 10,000s of properties.

(Note: These are different to those adopted by BoM.)

The onset of significant over-floor urban dwelling flooding has been assumed to occur at about 4,000 m^3/s at Moggill, however urban inundation and other impacts occur for flows above 2,000 m^3/s. Submergence of the Mt Crosby and Brisbane Valley Highway bridges occurs at between 1,800 m^3/s and 2,000 m^3/s. The flood threshold and flood severity classification provided the basis for the selection of the target flows at Moggill shown in Table 5.1.

For Ipswich the flood severity classifications used in this study (refer Figure 7.9) are as per BoM's classifications:

- minor flood – flood level at David Trumpy Bridge between 7–9 m . Minor flooding causes inconvenience. Low-lying areas next to watercourses are inundated which may require the removal of stock and equipment. Minor roads may be closed and low-level bridges submerged (BoM n.d.).
- moderate flood - flood level at David Trumpy Bridge between 9–11.7 m. Moderate flooding may require the evacuation of some houses. Main traffic routes may be

covered. The area of inundation is substantial in rural areas requiring the removal of stock (BoM n.d.).

- major flood - flood level at David Trumpy Bridge > 11.7 m. Major flooding results in the inundation of extensive rural areas and/or urban areas. Properties and towns are likely to be isolated and major traffic routes likely to be closed. Evacuation of people from flood affected areas may be required (BoM n.d.).

7.1.3 Results presentation and interpretation

Given the number of simulations conducted (around 4,000 simulations across historic events, stochastically generated events, and extreme floods) combined with 32 operational options, and reporting at up to 4 different locations, it can be seen that there are of the order of half a million results to be considered.

Clearly it is not possible to comment on the outcomes of each simulation individually. For this reason, results have been grouped, with several different forms of plots used to convey findings. The different forms of presentation are discussed below.

Historic events

Figure 7.1 illustrates how historical results have been presented in Seqwater (2014a). In this example, the figure provides predicted flows at Savages Crossing for the Base Case operations, for each of the 19 modelled historical events. Four bars are evident for each event, with a different colour used for each of the four FSV scenarios.

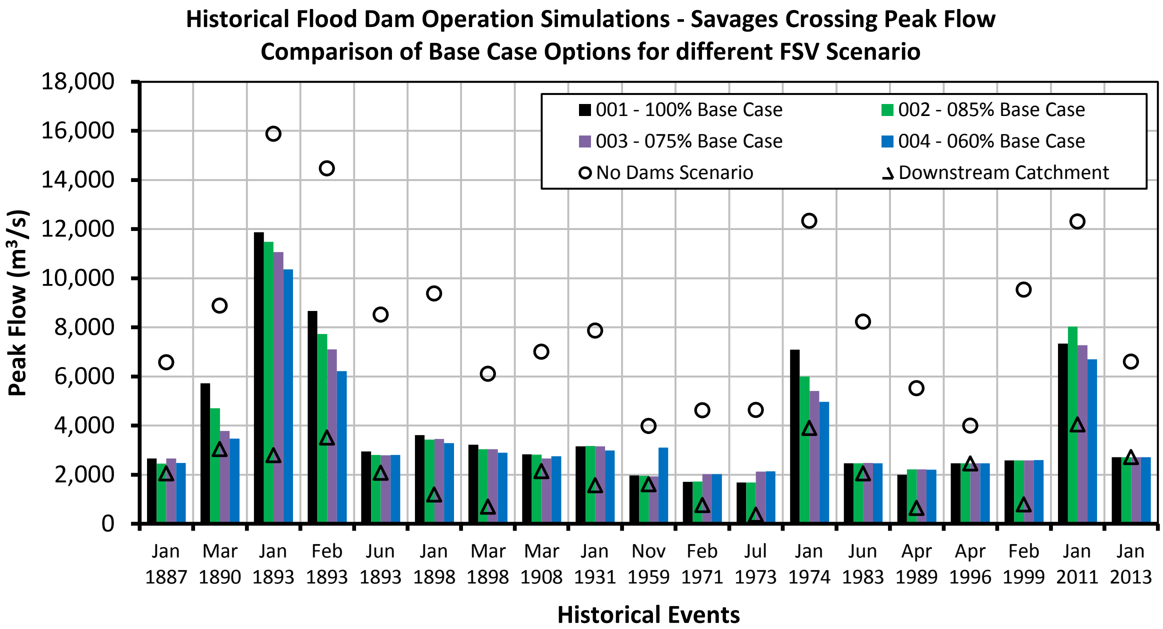


Figure 7.1 Example plot – impact of changing FSV under Base Case operating conditions - historical

The first four bars relate to the January 1887 event, with black representing 100%FSV, green (85% FSV); purple (75% FSV) and blue (60% FSV). The next group of four bars represents the March 1890 event, then the January 1893 event and so on.

Interpretation of the plot requires the reader to observe whether the green, purple and blue bars indicate lower flows than those for the 100% FSV scenario (i.e. the black bar). For the third grouping of bars (i.e. the January 1893 event), it is clear that reducing the FSV has a benefit in reducing the flow at Savages Crossing.

However, for some events (e.g. the January 2013 event, which is the grouping furthest to the right), there is no change in predicted peak flows (all 4 bars are the same height), and hence the reduction in FSV is seen to offer no benefit.

The other items to note on this plot are the circle and triangle symbols. The circle shows the modelled peak flow at this location with no dams in place. In this plot, the circle for January 2013 sits at a flow of just over 6,600 m^3/s, which would represent a major flood. However, all four bars are much lower (less than 3,000 m^3/s), demonstrating that for this particular flood, the dams have provided a major reduction in flow. In simple terms, the greater the distance the circle sits above the bars, the greater the reduction in peak flow that was or would have been achieved through operation of the dams.

The triangle symbol represents the contribution of the downstream catchment to the predicted flow and the height above the triangle to the circle represents the maximum extent of flood mitigation achievable. In two cases, the downstream contribution (e.g. in 1996 and 2013) provides 100% of the flow at this location – that is, Wivenhoe Dam has had sufficient storage such that releases have not contributed to the peak flow.

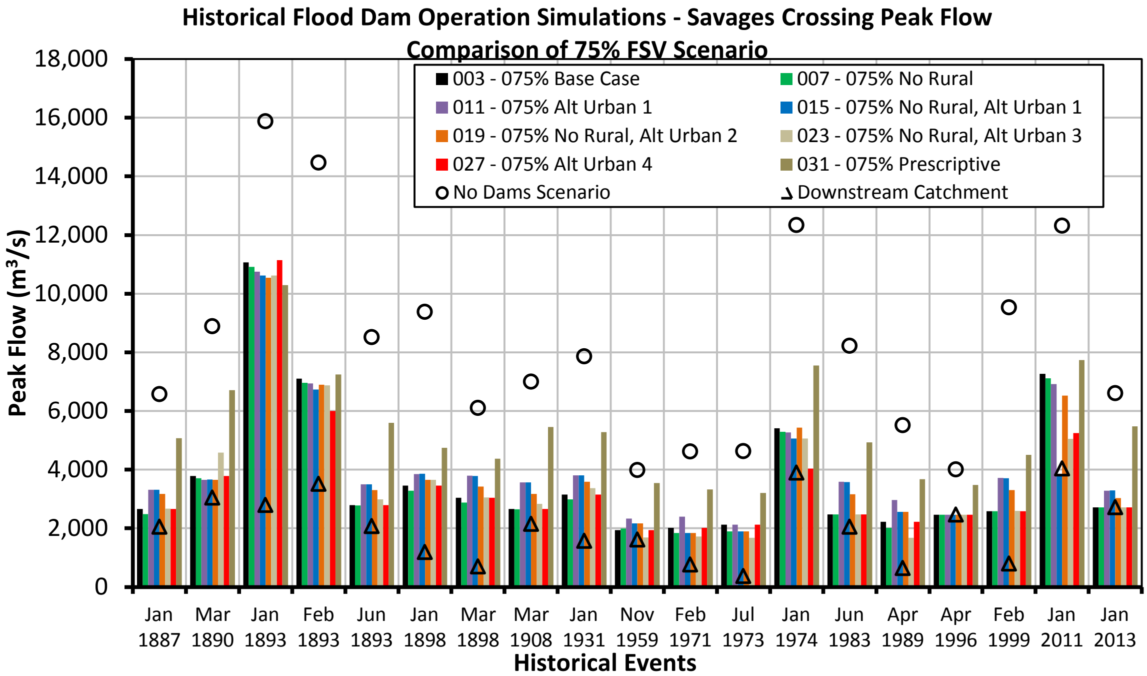


Figure 7.2 Example plot –comparison of operational alternatives for 75% FSV scenario - historical

Figure 7.2 provides a similar form of plot, with the difference being that instead of the bars representing the four different FSV scenarios, there are now eight bars per event representing the different operational alternatives being tested.

In this case, the location is again Savages Crossing, whilst the scenario being represented is the 75% FSV case.

The figure should be interpreted by comparing the height of each bar (for a given historic event) to that for the Base Case operations (the black line). The lower any given colour bar in comparison to that for the Base Case, the better that operational alternative has performed in mitigating peak flows.

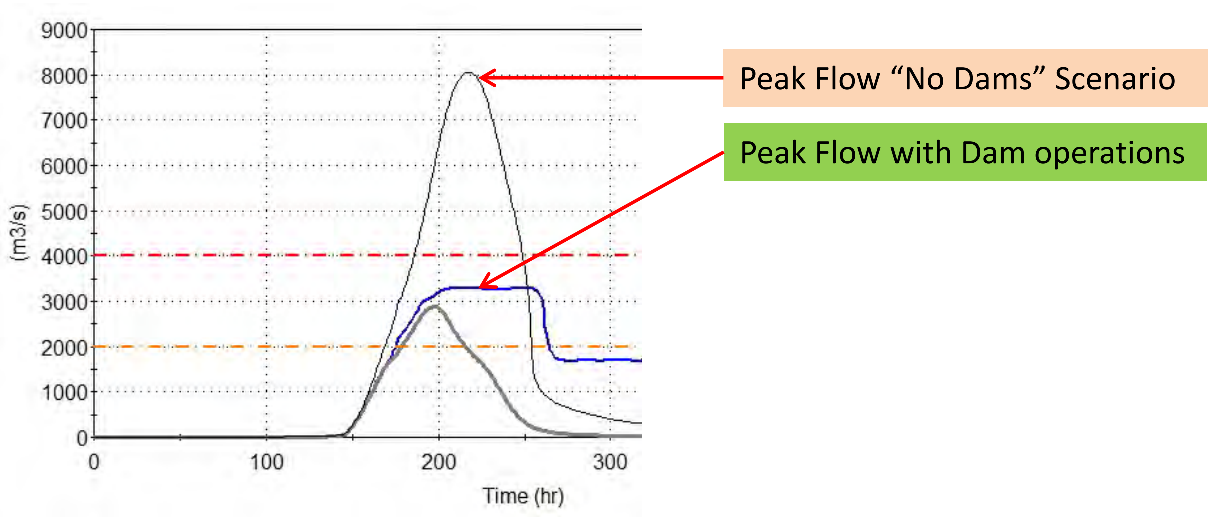
It can be seen that some colour bars sit below the black bar (showing an improvement), whilst others stretch above the black bar, representing an increase in the peak flow at this location. That is, for some of the historic floods, the operational alternative under consideration would make the flood worse.

This phenomenon must be kept in mind when considering the relative merit of one operational alternative over another. More importantly, it highlights that any given operating rules may work well for some events, but not for others. Hence, the reader should be interested in which operational alternatives tend to provide the best benefits across the range of floods (rather than focussing on a single flood).

Stochastic events

As with all of the WSDOS flood simulations, stochastic flood events (statistically generated synthetic events), the key interest is the degree of flood mitigation that can be realised for any given flood event, under the defined operational alternative.

Figure 7.3 provides an example of a stochastic event, indicating hydrographs with and without dams.



Source: Seqwater

Figure 7.3 Converting predicted flows to a point on the scatter diagram

The peaks of the grey and blue lines (in this example, close to 8,000 m^3/s and approximately 3,300 m^3/s respectively) can be plotted on a scatter diagram. If the same process is followed for each of the 3,840 stochastic events, then a diagram showing the results of simulations of the stochastic events such as that reproduced as Figure 7.4 can be produced.

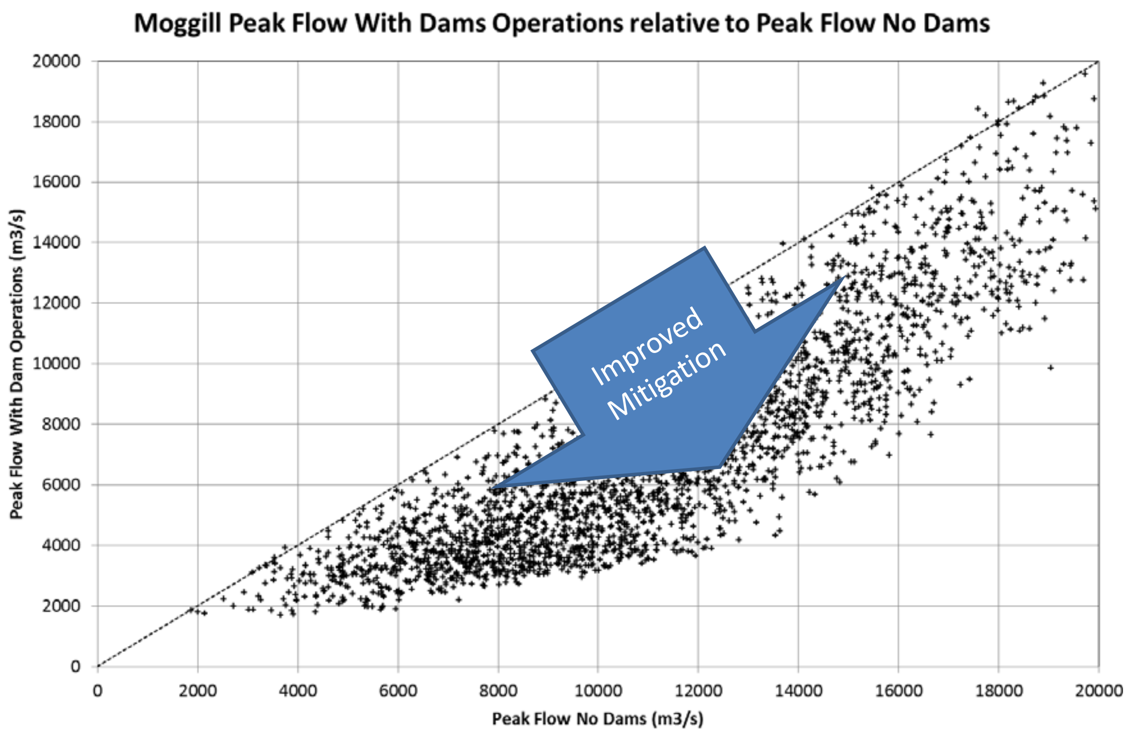
Each dot in the figure is representative of a single flood. The location of the dot is based on the predicted peak flow if there were no dams (the x-axis) and that with the dams in place (the y-axis) for the given operational alternative, which in this case is the Base Case with 100% FSV.

It is important to note that the dotted diagonal line represents the “no mitigation” line. Any dot sitting below the line (which is the majority of dots) indicates a flood event which has been mitigated through operation of the two dams. Those dots (floods) furthest below the line are being mitigated the most.

A scatter plot has been prepared for each of the 32 options. In order to allow comparison between the various operational alternatives, it is necessary to provide a simpler representation than the scatter plot. This has been achieved by statistically determining a median (50^{th} percentile) line through around 4000 points, as illustrated in Figure 7.5.

The blue line in Figure 7.5 represents the median (50^{th} percentile) value of all points for a given “no dams” flow (x-axis value), whilst the red line is the 90^{th} percentile, and the green line the 10^{th} percentile. These lines highlight the significant variability that can occur, with some floods experiencing a high degree of flood mitigation (those plotting close to or below the green line) and others for which only a low degree of flood mitigation will be achieved (e.g. points plotting closer to or above the red line).

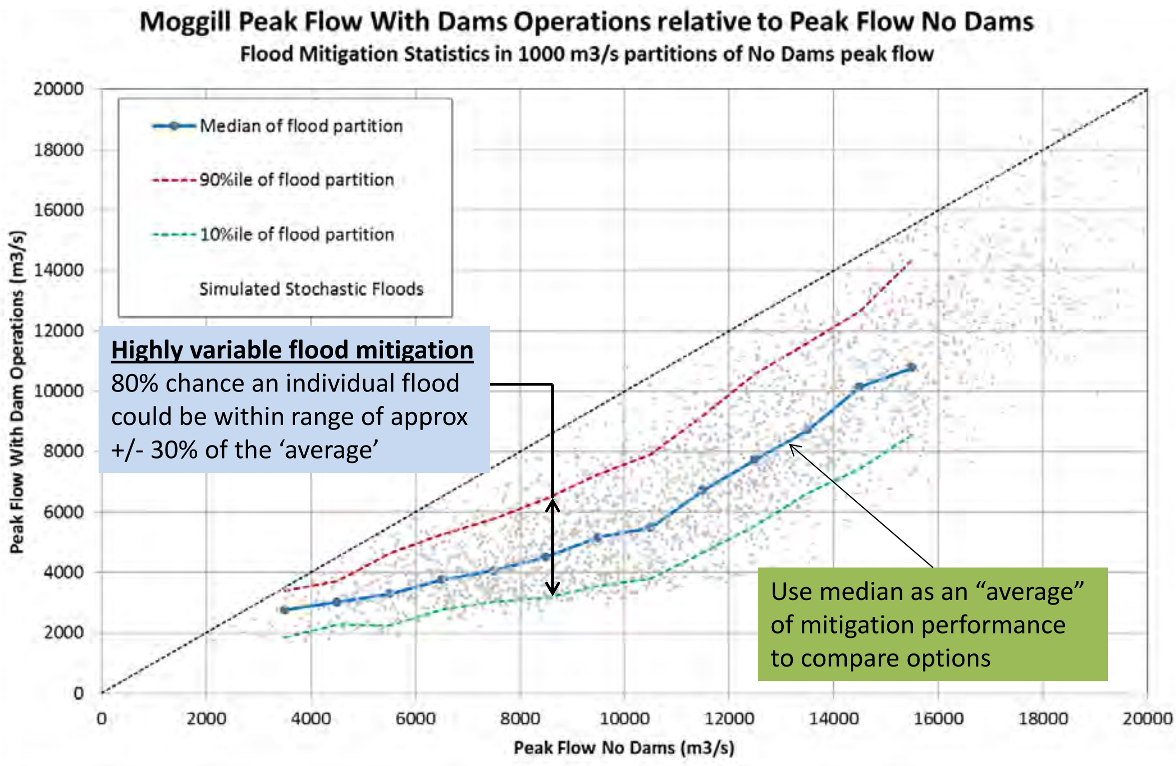
In some cases (in the 8,000 to 20,000 m^3/s peak flow range), the flood peak is shown to increase.



Source: Seqwater

Figure 7.4 Summary of stochastic simulations of peak flow reductions at Moggill

For an individual event, it can be inferred that there is 80% probability that the peak flow at Moggill could be within a range of -30% to +30% of the ‘average’ peak flow of many flood events over a long period (for similar order of magnitude of catchment flood flows).



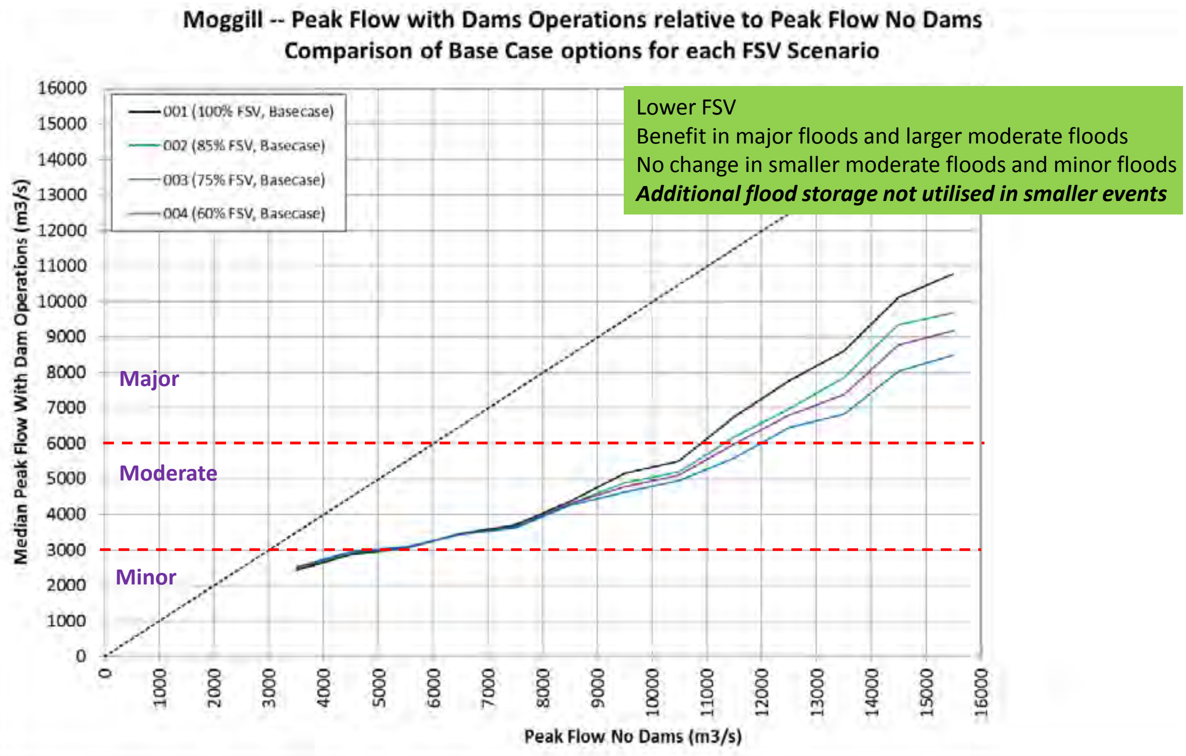
Source: Based on Seqwater 2014a

Figure 7.5 Example– predicted flow mitigation for stochastic events (Base Case 100% FSV)

The final step in the process was to plot all of the relevant median lines onto a single plot, as shown in Figure 7.6. In this example, the blue line from Figure 7.5 is reproduced on Figure 7.6 (the black line), representing the Base Case (100% FSV). Similarly, lines for each of 85% FSV, 75% FSV and 60% FSV are added. The final figure allows the relative performance of the four scenarios to be compared (in this example, for Base Case operations).

Where the four lines are coincident, in this case for a no-dams flow below around 8,500 m^3/s, there is no benefit attributable to having a lower FSV. This is expected as smaller sized floods can be accommodated within the flood storage compartment of the dam. As the flood magnitude increases, the lines begin to separate demonstrating improved median flood mitigation performance associated with lower FSV scenarios.

The high degree of variability in performance outcomes (some better, some worse and some similar) of the operational alternatives for the range of stochastic flood events analysed is discussed in Section 7.6. In this section, there is a comparison of the stochastic results for each operational alternative with the Base Case equivalent to highlight the variability in performance.



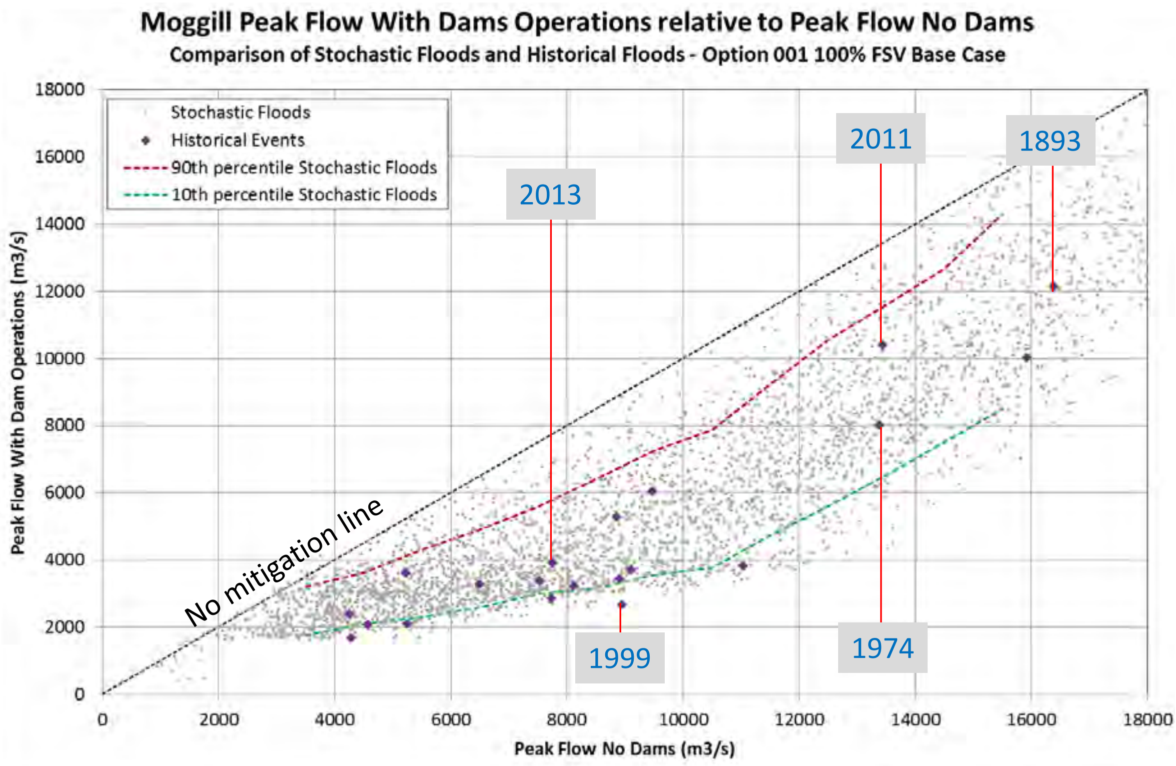
Source: Based on Seqwater 2014a

Figure 7.6 Example – average impact of lowering FSV on flow mitigation (Base Case)

7.1.4 Linking historic and stochastic results

Prior to presenting and discussing key modelling results, it is important to provide an understanding as to how stochastic and historic results might be compared. This has been achieved through plotting (by way of example) several historic events on the stochastic plots.

Figure 7.7 indicates where the modelled historical floods sit on the scatter plot for stochastic peak flows at Moggill. Each historic flood event has been plotted on the basis that Wivenhoe and Somerset were operated in accordance with the 2013 Flood Manual. The plot includes an overlay of the modelled dam performance for historical events on top of the stochastic results comparing peak flows at Moggill with and without the dams.



Source: Based on Seqwater 2014a

Figure 7.7 Comparison of historical and stochastic events

Some points of note are:

- For the 1999 event, a peak flow (no dams) of almost 9,000 m^3/s is mitigated to less than 3,000 m^3/s.
- For stochastic events the dams were assumed to be full at the start of the event, whereas historical flood events include some floods where the dam was below full supply level at the start, which can improve the level of mitigation achieved.
- The January 2013 event was substantially mitigated (despite inflows downstream of Wivenhoe being almost 4,000 m^3/s)
- The dams would have reduced the 1974 flow at Moggill by close to 40%
- The two floods where volumes were particularly large (1893 and 2011) indicate mitigation of the flood peak in the order of 25% at Moggill.
- The majority of peak flows at Moggill are mitigated well below the flow predicted with no dams present. That is, operation of the dams in accordance with the 2013 Flood Manual would mitigate the largest historical floods, and most of these would be reduced by at least 30% at Moggill, with ten of the events mitigated to closer to 50%.
- As noted in relation to Figure 7.5, points that plot above the 'no-mitigation' line, demonstrate a small number of cases where floods may be slightly larger than with the no-dams scenario. That is, whilst the dams demonstrate mitigation for almost all events, there are some that show no mitigation, or are marginally worsened. This confirms that no one set of operating rules can guarantee mitigation in all cases.
- Once cause for floods being worsened by the presence of the dams could be coincidental flows resulting from fuse plug breaches with downstream inflows.

7.2 Results summary

All of the findings and observations in this chapter have been made from a hydrologic perspective. Some options producing the lowest flood flows or levels may have other adverse impacts identified through the integrated assessment that may outweigh the positives.

Table 7.2 provides a comparative summary of the findings and observations arising from Seqwater's operational simulations. Whilst a significant degree of assessment has been undertaken, none of the options (comprising different FSVs and operational alternatives) have been fully optimised. The summary is presented at the beginning of this chapter in order to facilitate a high level understanding of key findings prior to the provision of detail in subsequent sections.

Results for flood mitigation are presented for average performance over many floods. It is important to recognise that flood mitigation performance in any individual flood could be worse or better. The probability of significantly worse outcomes in any single flood event compared to the average is low, but it remains possible.

Several high level observations are offered below, with relevant discussion provided in the following sections. Comments relate to flooding only, with no consideration of costs. Observations of the impact of the operational alternatives have been made with respect to:

- flood mitigation in the mid and lower Brisbane River
- flood mitigation in the Bremer River at Ipswich.
- inundation of bridges (duration) both upstream and downstream of Wivenhoe Dam.

It can be seen that:

- reducing the FSV provides largely positive or neutral flood mitigation outcomes.
- a similar observation may be made in relation to alternatives Urban 3 and Urban 4 (though the latter has fuse plug spillway risks that would need to be investigated and resolved before it could be considered for implementation – refer Chapter 9).
- the Rural Bypass strategy is largely neutral.
- as presented, the Urban1, Urban 2 and the Prescribed Operations alternatives tend to have a higher proportion of negative outcomes.

Results pertaining to the impact of reducing the FSV are discussed in Section 7.3, with emphasis on flows at Moggill and levels at Ipswich. The performance of the various operational alternatives under the 100% FSV scenario is then compared in Section 7.4. Further detail is available in Seqwater (2014a).

Table 7.2 Flood mitigation comparative summary – relative change of average over many floods

Operational Option	2 to 4	5	9	17	21	25	29
Operational Alternative (Results for flood mitigation are presented for average performance over many floods.)	85% , 75% and 60% FSV Base Cases[(1)]	100% FSV No Rural Strategy	100% FSV Alt Urban 1a 100% FSV Alt Urban 1b	100% FSV Alt Urban 2	100% FSV `Alt Urban 3	100% FSV Alt Urban 4	100% FSV Prescribed Operations
Flood Mitigation – Mid and Lower Brisbane River							
Major flood, peak flow at Moggill [(2)] Refer note 1 for reduced FSV and note 2 for other alternatives	5-20% lower	up to 2% lower	up to 5% lower	up to 5% lower	up to 10% lower	up to 20% lower	up to 20% higher
Moderate flood, peak flow at Moggill (refer notes 1 and 2)	0-10% lower	0-2% lower	0-10% higher	0-5% higher	0-5% lower	0-10% lower	up to 50% higher
Minor flood, peak flow at Moggill (refer notes 1 and 2)	nil	nil	0-20% higher	0-10% higher	nil	nil	up to 80% higher [(7)]
Probability exceed 4,000 m³/s flow at Moggill	lower	minimal	higher	higher	nil	nil	much higher
Delay time[(3)] to the onset of 4,000 m³/s flow at Moggill	0-4 hours later	minimal	8 hours earlier	4 hours earlier	minimal	minimal	15 hours earlier
Flood Mitigation – Bremer River at Ipswich							
Peak level at Ipswich 10 to 15 m	nil	nil	+1 m	+0.5 m	minimal	minimal	+2 to 3 m
Peak level at Ipswich above 15 m	nil	nil	minimal	minimal	minimal	minimal	+1 to 2 m
Probability exceed 11.7 m flood level at Ipswich	nil	minimal	higher	higher	minimal	minimal	much higher
Delay time[(3)] to the onset of 11.7 m flood level at Ipswich	minimal	minimal	3 hours earlier	2 hours earlier	minimal	minimal	7 hours earlier
Flood Effect on Bridges							
Duration of inundation of downstream lowest bridges [(4)]	1-5% increase	3% increase	5% decrease	1% decrease	5% increase	nil	25% decrease
Duration of inundation Brisbane Valley Hwy & Mt Crosby bridge [(5)]	1 to 15% increase	4 % decrease	7-14% increase	4% increase	4% decrease	7% increase	32% increase
Probability of inundation Brisbane Valley Hwy & Mt Crosby bridge	minimal	minimal	minor increase	minimal	minimal	minimal	significant increase
Duration of inundation of lowest level upstream bridges [(6)]	25-50% decrease	10% decrease	10-15% decrease	15% decrease	8% decrease	15% increase	50% decrease
Probability of inundation of lower level upstream bridges	lower	minimal	minimal	minimal	minimal	minimal	lower

Legend	Better than Base Case operations & 100% FSV	Minimal Change from Base Case operations & 100% FSV	Worse than Base Case operations & 100% FSV

Unless noted otherwise below, changes due to variation of dam operations are based on the 100% FSV scenario

(1) This specifically compares Base Case lower FSV scenarios against the Base Case 100% FSV scenario

(2) Range represents potential change due to combined variation of dam operations for 100% FSV.

(3) Reduced delay (earlier) represents an adverse impact whilst an increase in the delay (later) is a positive benefit. Findings are based on historical floods.

(4) Burtons Bridge used as representative bridge. Findings based on historical floods.

(5) Brisbane Valley Highway results also reasonably represent Mt Crosby Weir Bridge. Findings based on historical floods.

(6) Mary Smokes Bridge used as representative bridge. Findings based on historical floods.

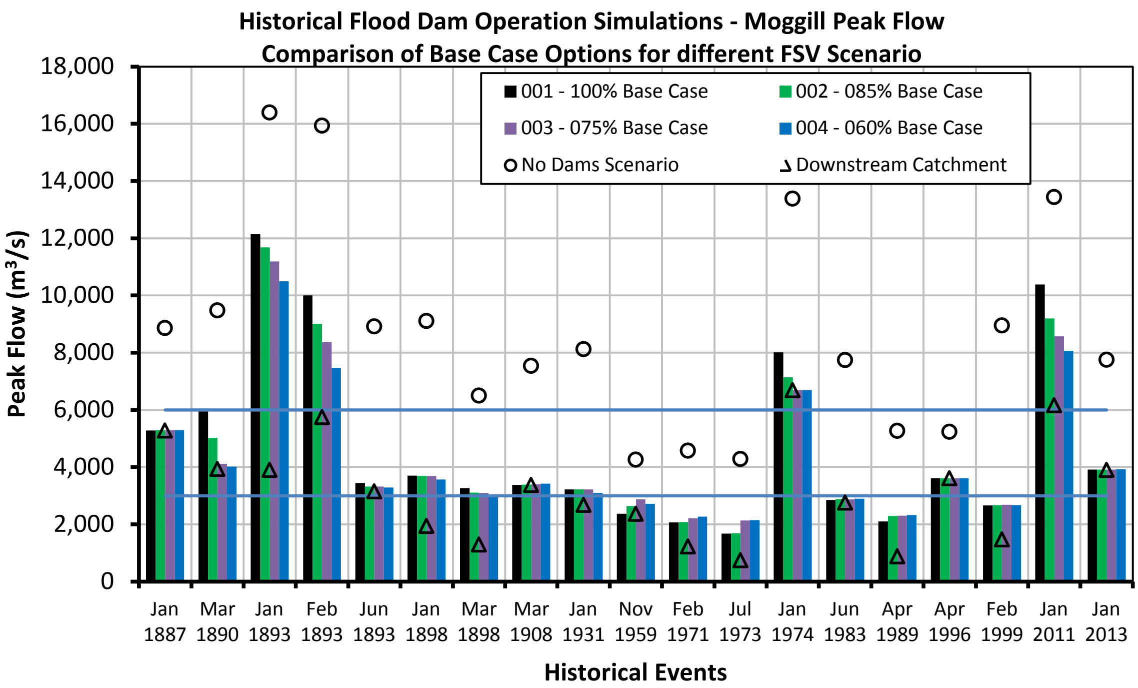
(7) Prescribed operations can amplify minor floods (i.e. peak flow higher than 'no dams' scenario).

Source Seqwater 2014a

7.3 Flood mitigation provided by reducing the full supply volume

7.3.1 Historical events

The section discusses the relative performance for the modelled largest historic events based on operations under the 2013 Flood Manual with reduced FSV.



Note: The two blue horizontal lines indicate the flood classification thresholds of 3,000 m^3/s and 6,000 m^3/s.

Source: Based on Seqwater 2014a, App C1)

Figure 7.8 Historical peak flow at Moggill – impact of varying FSV (Base Case options)

Moggill

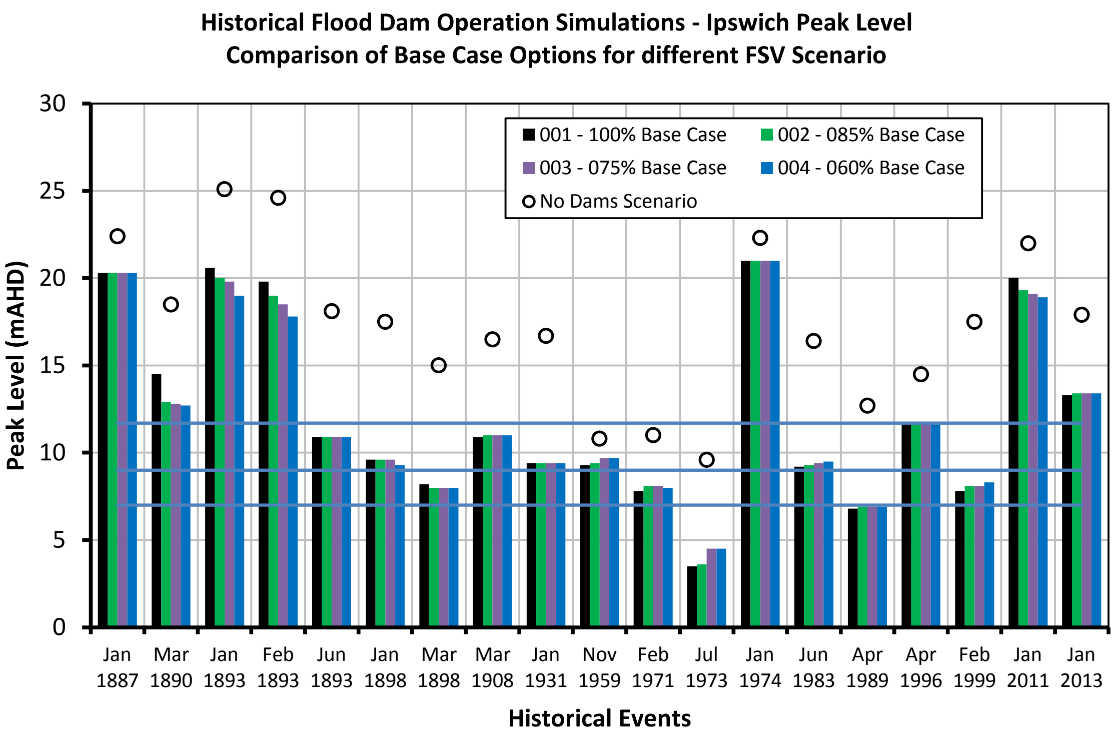
The performance of varying the FSV for historic events is illustrated in Figure 7.8. It shows that:

- Reducing the FSV provides a variable benefit. For several events (e.g. the 1887, 1996 and 2013 floods), there is no indication of any performance benefit associated with lowering the full supply volume. This is largely true for all the minor to moderate floods, and is consistent with the finding for stochastic floods reported later.
- Benefits are generally only evident for the five largest historical floods, these being the March 1890, January and February 1893 floods, January 1974 and January 2011, with the reduction in peak flows generally increasing as the FSV is reduced 100% FSV down to 60% FSV.
- No benefits occur by lowering the FSV for smaller floods owing to the adequacy of the existing flood storage volume.
- peak flow reductions at Moggill achieved by lowering the dam to 85% FSV are of the order of 5 to 10%. (i.e. peak flows are predicted to be between 5% (for 1893) and 10% (for 1974, 2011) lower than for the 100% FSV scenario.)

- the dams (under existing operations 100% FSV Base Case) already significantly reduce peak flood flows. It can be seen that:
  - o Mitigation of peak flows is achieved for each of the historical events. (For the 1974 event, the dams provide a 40% mitigation (reducing the peak flow at Moggill from approximately13,400 m^3/s to 8,000 m^3/s. For an 85% FSV scenario, the flow is then reduced a further 10% to around 7,100 m^3/s.)
  - o The extent of mitigation varies across a wide range, from a predicted 45% mitigation (1959 flood) to over two thirds (70%) of the peak flow being mitigated for the1999 flood.

Ipswich

A similar comparison has been made in Figure 7.9 for the peak levels predicted at Ipswich.



Note: The three blue horizontal lines indicate the BoM flood classification levels for minor, moderate and major flooding.

Source : Based on Seqwater 2014a, App C1

Figure 7.9 Historical peak level at Ipswich – impact of varying FSV (Base Case options)

Wivenhoe and Somerset dams provide flood mitigation benefits that are similar at Ipswich and Moggill. However flood mitigation performance at Ipswich is dependent on the relative dominance of the Bremer River and Brisbane River flows (which comprise releases from Wivenhoe Dam).

When the Bremer River is the dominant influence on flooding in Ipswich, optimising the operation of Wivenhoe Dam offers a reduced potential for improved mitigation in Ipswich. This was illustrated in the modelling undertaken by Seqwater for those flood events where changing the FSV has no impact on flood levels at Ipswich (including 1887, 1974 and 2013 among others). However, the modelling has shown that a reduction in the FSV does appear to offer some noticeable reduction in flood levels at Ipswich in the major floods of 1890, 1893 (January and February), and 2011.

7.3.2 Stochastic events

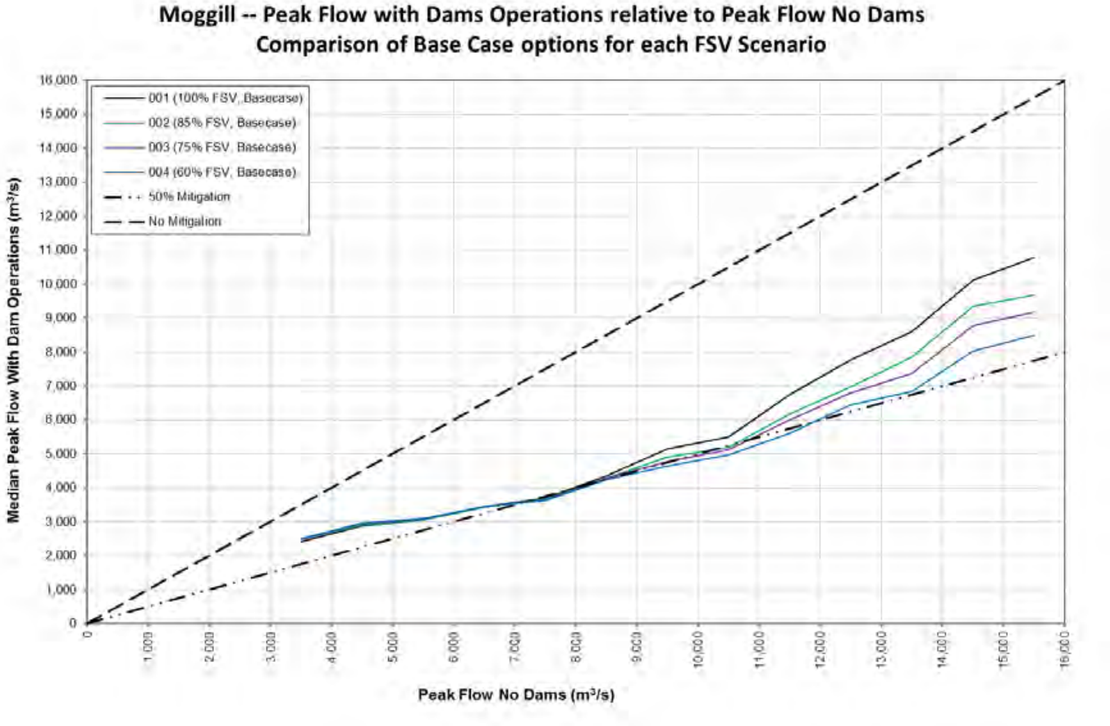
Moggill

The impact of reducing full supply volume on the simulated stochastic flood events is illustrated for flows at Moggill (Figure 7.10) and levels at Ipswich (Figure 7.11).

In Figure 7.10, it can be seen that:

- There is effectively no median performance benefit in reducing the FSV for “no-dams” flows up to 8,500 m^3/s, with mitigation performance the same for all of the FSV scenarios.
- Above this flow, some mitigation benefits become evident in the median performance simulation results. For the largest “no-dam” flows of close to 16,000 m^3/s (similar in magnitude to the January and February 1893 events), the 100% FSV case yields a mitigated flow of just under 11,000 m^3/s, whilst those for the 60 to 85% FSV scenarios suggest mitigated flows ranging from 8,500 m^3/s to less than 10,000 m^3/s.
- A further comparison can be made by looking at mitigation performance for a “with-dam” flow of 6,000 m^3/s at Moggill. Under the 100% FSV scenario, a “no-dams” flow of 11,000 m^3/s can be mitigated to 6,000 m^3/s (median results). For the 60% FSV scenario, a 12,000 m^3/s “no-dams” flow experiences median mitigation to 6,000 m^3/s.
- The median mitigation achieved is as much as 50% for most flows between 6,000–9,000 m^3/s.
- The lower FSV scenarios do not improve the performance in the range between 3,500–8,500 m^3/s. Lowering the FSV is seen to provide relative benefits for larger flows.

In viewing the figure, it is important to note that only median lines are plotted, and that a ± 30% variation is possible for any given flood event.



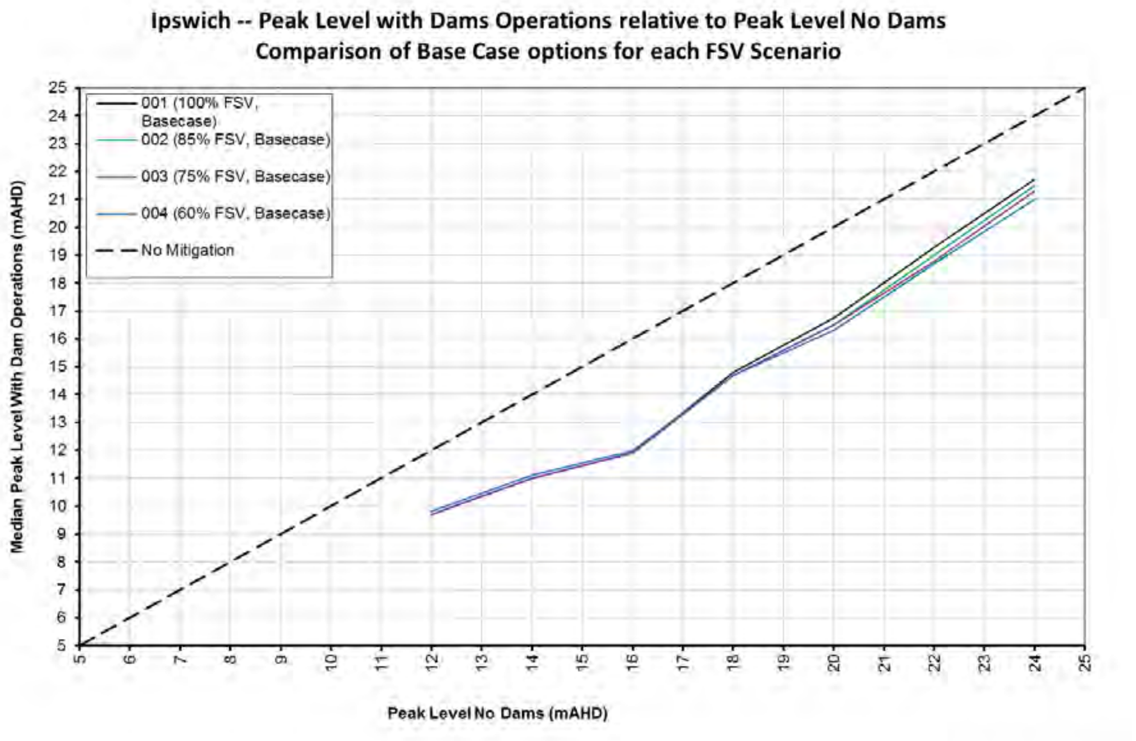
Source: Based on Seqwater 2014a, Figure E2

Figure 7.10 Peak flow at Moggill – impact of varying FSV (Base Case options)

Ipswich

The results for Ipswich (Figure 7.11) at the David Trumpy Bridge appear somewhat different, given that this plot is presented in terms of height rather than flows. It can be seen that:

- Median results are similar for all four FSV scenarios, being effectively the same as the Base Case up to a level of EL 18 mAHD (no dams).
- The dams (for the Base Case) are predicted to provide a median benefit ranging from a 2 m decrease in flood height for smaller floods (EL 12 mAHD reducing to just under EL 10 mAHD), up to an maximum benefit of 4 m (EL 16 mAHD reducing to EL 12 m AHD). As indicated above, this performance is maintained for all four FSV scenarios (i.e. no worsening). Flood levels of 16 m or higher would have occurred at least ten times between 1887 and 1974.
- Above the EL 18 mAHD level, where a median reduction in level of approximately 3 m is predicted, the four curves exhibit some slight differences in predicted performance (i.e. improvement compared to the Base Case). For a no-dams level of EL 24 mAHD (just below the January and February 1893 event peaks), the median flood level mitigation ranges from just over 2 m (100% FSV scenario) to 3 m (60% FSV scenario), with the latter exhibiting a 1 m improvement.



Source: Based on Seqwater 2014a, Figure E3

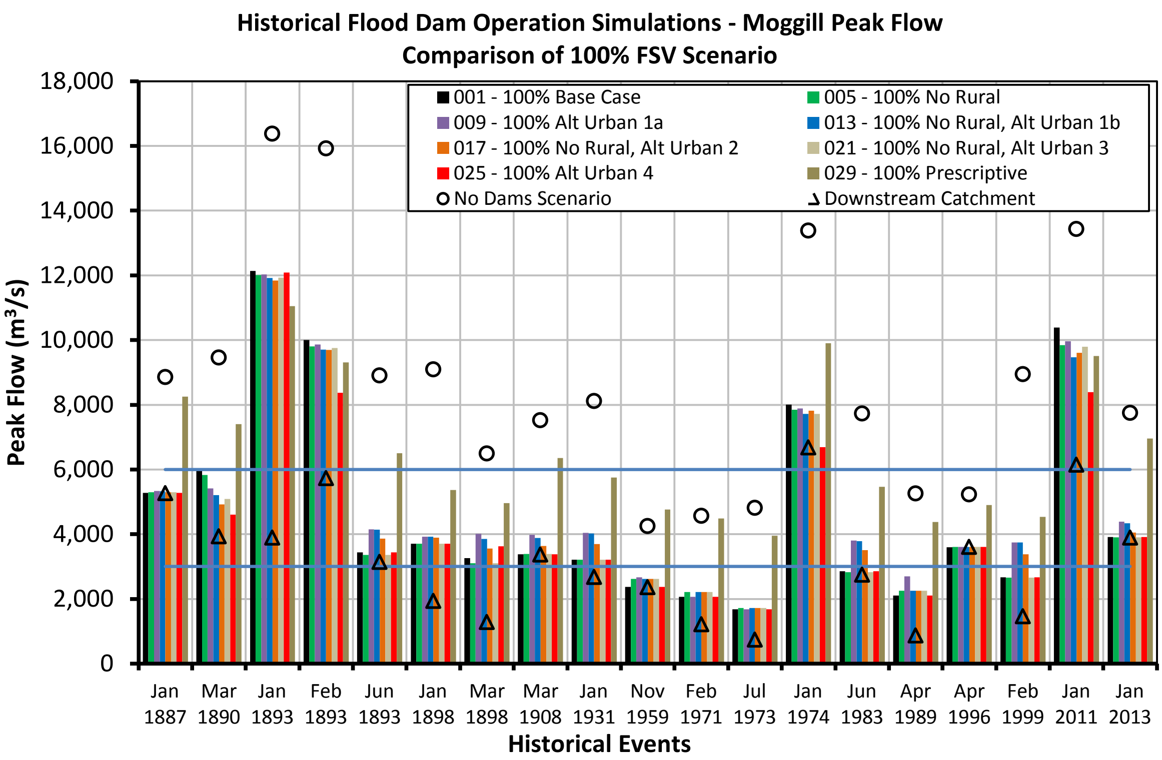
Figure 7.11 Peak level at Ipswich – impact of varying FSV (Base Case options)

7.4 Flood mitigation provided by varying operations

7.4.1 Historical events

Moggill

Figure 7.12 provides an indication of the relative performance of the operational alternatives at Moggill for the largest historical flood events. In this case, all operational alternatives shown are for the 100% FSV scenario only. The results indicated in the figure provide a number of clear findings, and trends associated with different sized floods are once again evident.



Note: The two blue horizontal lines indicate the flood classification thresholds of 3,000 m^3/s and 6,000 m^3/s.

Source : Based on Seqwater 2014a App C1

Figure 7.12 Historical peak flow at Moggill – impact of varying operations for 100% FSV

The key observations are:

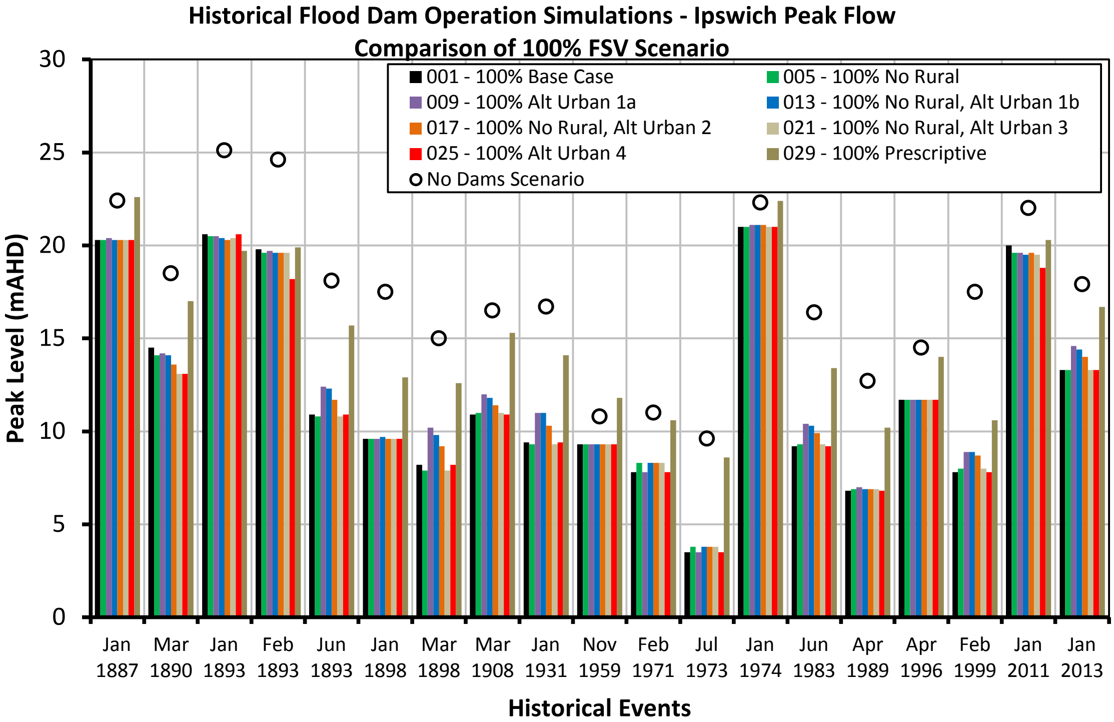
- For most flood events (and especially minor and moderate floods), there is little or no reduction in flood flows at Moggill associated with the operational alternatives. This is a consequence of the existing dams having sufficient flood storage to mitigate the floods or the flood being dominated by inflows downstream of Wivenhoe Dam.
- The Prescribed Operations alternative exhibits the least mitigating benefit on peak flows at Moggill for most of the historical events, generally resulting in higher peak flows than the Base Case. The only exceptions to this finding are for the January 1893 event, the February 1893 event, and the January 2011 event. The Prescribed Operations alternative (as defined for this study) reduces peak flows for the largest floods when they are generated mainly from upstream of the dams. However, mitigated peak flows for floods emanating primarily from downstream of the dams (1887, 1908, 1974 and 2013) are generally worse than for the Base Case.

- In general, alternative Urban 1 (with or without the Rural Strategy being bypassed) provides less mitigation for floods below 6,000 m^3/s (minor to moderate floods) than the Rural Bypass, Urban 2, Urban 3 and Urban 4 alternatives. This is particularly noticeable for those events around the 4,000 m^3/s flow magnitude.
- The Urban 2 alternative results are largely similar to those for Urban 1, though slightly better performing for half of the historical events.
- The Rural Bypass operational alternative often provides the best performance (though limited mitigation when compared to the Base Case), and is regularly matched by the operational alternative Urban 3 (lowest flows are shared for nine of the events). These tend to be for the smaller of the historic floods.
- Similarly, the operational alternative Urban 4 provides the lowest predicted peak flow for 11 events, though of these, peak flows for seven of the events are the same as those predicted for the Base Case (noting that Urban 4 is targeted towards providing benefit for larger floods).
- Under alternative Urban 4, a substantial improvement to the Base Case is evident for four flood events. These are March 1890, February 1893, January 1974 and January 2011. That is, for three of the largest four historical events, Urban 4 demonstrates the potential to provide a significant benefit.
- The overall conclusion is that the considered alternatives offer little benefit for smaller magnitude floods but larger potential benefits for larger floods. This supports the conclusions evident from consideration of the stochastic floods (refer Figure 7.12), where the Base Case, Rural Bypass, Urban 3 and Urban 4 lines coincide up to a flow of approximately 8,500 m^3/s (peak flow no dams).

Ipswich

Figure 7.13 contains a summary of the relative performance at Ipswich of the eight operational alternatives for the 100% FSV scenario. Whilst some trends are similar to those for flows at Moggill, it is clear that several of the historic floods are more significant at Ipswich than they were at Moggill. For example, the 1887 peak flood level rivals that for 1893, whereas the peak flows are substantially different. The key points to note are:

- Overall, there is potentially less benefit from lowering FSVs and improving Wivenhoe Dam flood operations to be realised at Ipswich than Moggill, owing to the influence of the Bremer River
- There are some six events for which no benefit is evident across the operational alternatives, as evidenced by all alternatives producing the same peak level (i.e. 1887, Jan 1898, 1959, 1974, 1989, and 1996)
- Adverse impacts to levels at Ipswich occur under the Urban 1 and Urban 2 alternatives for the June 1893, March 1898, March 1908, January 1931, June 1989 and January 2013 events
- The Prescribed Operations alternative generates higher levels for all events except January 1893, where a reduction of 0.9 m was estimated.
- Alternative Urban 4 appears to offer the best overall flood performance for the larger floods (other than January 1893 and 1974). A distinct benefit is evident for the March 1890, February 1893 and January 2011 flood events, though for all other historic floods, the peak level generated under this operational alternative is similar to the Base Case and/or the Rural Bypass strategy (i.e. no additional benefit offered).



Source: Based on Seqwater 2014a, App C1

Figure 7.13 Historical peak level at Ipswich – impact of varying operations for 100% FSV

7.4.2 Stochastic events

Moggill

A comparison of the impact on peak flows at Moggill, of varying flood operations of the dams is shown Figure 7.14. The plot indicates some significant variability in performance, but consistent trends. With regard to the median peak flows at Moggill, seven of the eight variations are grouped relatively tightly, with a mitigation of peak flow between 30 and 50% in nearly all cases. The eighth operational alternative (prescribed management of gates) provides a lesser performance, only matching the other variations for the highest “no-dams” peak flows (15,000 to 16,000 m^3/s). However, at the lower end of the flow scale, the Prescribed Operations indicates a potential worsening of flows, increasing above the no-mitigation line.

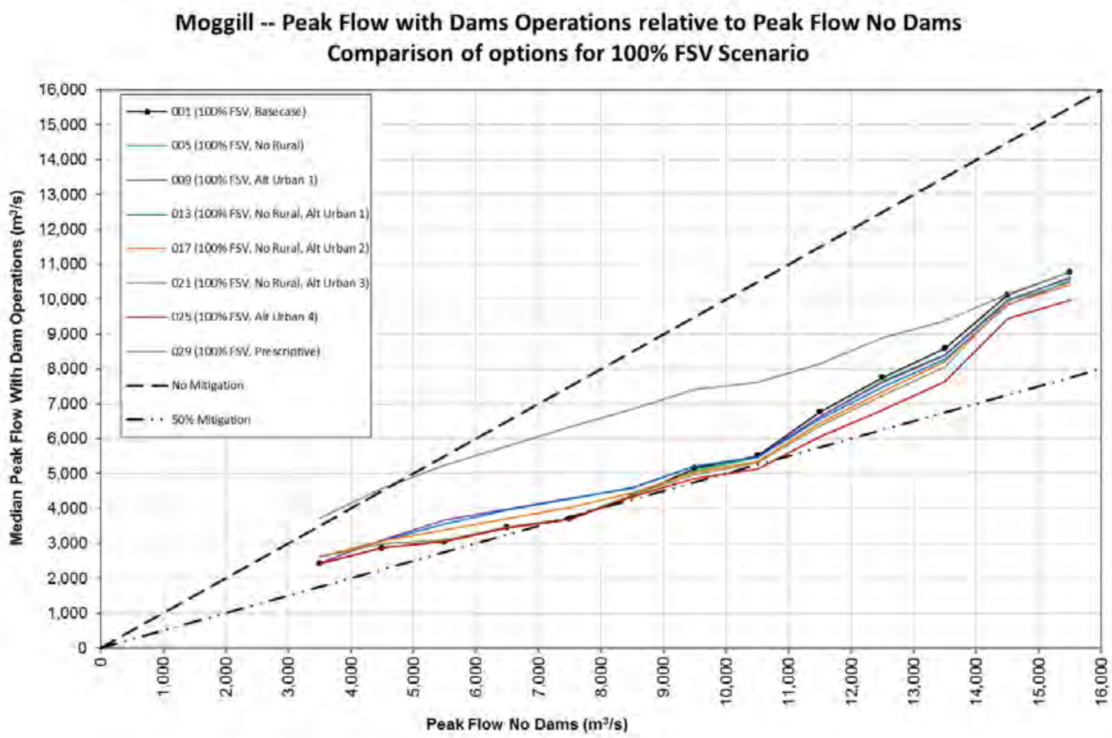
Other observations that can be made are:

- The operational alternatives are most tightly grouped (i.e. perform in a similar manner) for the 9,000 to 10,000 m^3/s no dams peak flow range, with no more than 300 m^3/s appearing to separate the lines within this range.
- None of the alternatives offer any benefit across the lower flow range when compared to the Base Case. Alternatives Urban 3 and Urban 4 perform better than the other alternatives, but only match the Base Case between the 5,000 and 8,000 m^3/s ‘no-dams’ peak flows.
- For ‘no-dam’ peak flows greater than approximately 10,000 m^3/s, alternative Urban 4 is clearly the best performing operational alternative from the perspective of reducing peak flows at Moggill.

- At the lower end of the scale, the lines for alternatives Urban 1 and Urban 2 sit slightly above that for the Base Case – that is, these alternatives are predicted to generate worse outcomes (an increase in flows) for smaller floods than for the Base Case.

For higher flows, a comparison between the benefits of lowering the FSV (Figure 7.10) and those for varying dam operations (Figure 7.14) demonstrates that varying the FSV offers a greater reduction in peak flows. It is seen in Figure 7.10 that varying the FSV can reduce a 15,000 m^3/s flow by up to 45% to approximately 8,200 m^3/s for a 60% FSV (as compared to around 30% or approximately 10,500 m^3/s for the100% FSV scenario); whilst all alternative Urban Strategies (other than Urban 4 - refer Figure 7.14) can only achieve about 30% reductions; i.e. from 15,000 to approximately 10,200 m^3/s.

Urban 4 achieves similar reductions in peak flood flows to the 60% FSV scenario. This is because Urban 4 provides similar increases to the urban flood mitigation compartment through raising the dam safety trigger level.



Source : Based on Seqwater 2014a, Figure E5

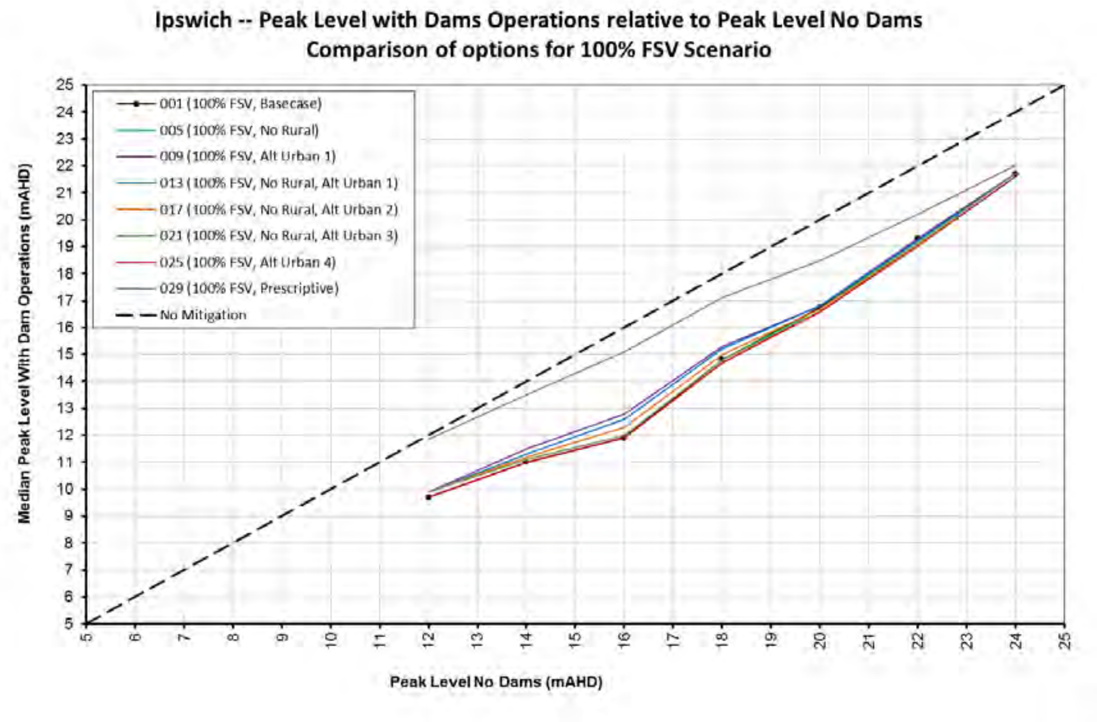
Figure 7.14 Peak flow at Moggill – impact of varying operations for 100% FSV

Ipswich

Figure 7.15 illustrates the relative performance of operational alternatives on predicted median peak flood levels at Ipswich. Lines are slightly more tightly grouped than for the plot showing flows at Moggill (generated from Figure 7.14), but do exhibit similar trends. These can be summarised as follows:

- There is little performance differentiation evident between the operational alternatives for ‘no dam’ levels above EL 20 mAHD.
- The greatest variation occurs around EL 16 mAHD, where alternatives Urban 1 and Urban 2 sit above the Base Case (i.e. predicted levels are up to 1 m worse than for the Base Case under these operational alternatives).

- All other alternatives (excluding Prescribed Operations) tend to perform to the same standard, as shown by their common alignment in the figure.
- The Prescribed Operations alternative sits well above the Base Case, indicating that under this operational alternative, peak levels at Ipswich would be of the order of 2 m higher for much of the modelled range.



Source: Based on Seqwater 2014a, Figure E6

Figure 7.15 Peak level at Ipswich – impact of varying operations for 100% FSV

7.5 Relative change plots

In addition to the plots discussed in the preceding sections, Seqwater (2014a) have also produced a series of 'relative change plots' enabling comparison of the effects of varying operations with the 100% FSV Base Case. These plots differ in that rather than illustrate the relative benefit of various alternatives by comparing to the 'no dams' flow or level, results have been plotted against the Base Case (option 001). Seven plots (one for each operational alternative) have been produced for each of three locations (Savages Crossing, Moggill and Ipswich). As with previous plots, the Moggill and Savages Crossing plots contain flows, whilst those at Ipswich are presented as levels. Whilst all plots may be viewed in Seqwater (2014a), the following subset of results (refer Table 7.3) are presented in the following sections of the report as part of the discussion.

Table 7.3 Relative change plots

Alternative	Flow at Moggill	Flow at Savages Crossing	Level at Ipswich
Rural bypass	Fig 7.16	#	#
Urban 1a	Fig 7.17	#	#
Urban 1b	Fig 7.18	#	#
Urban 2	Fig 7.19	#	#
Urban 3	Fig 7.20	Fig 7.23	Fig 7.25
Urban 4	Fig 7.21	Fig 7.24	Fig 7.26
Prescribed	Fig 7.22	#	#

Refer Seqwater (2014a)

The primary purpose of these plots is to augment understanding of the potential implications (both positive and negative) for each of the considered alternatives relative to the Base Case. Descriptions are therefore brief, building on the findings generated from review of the historic and stochastic plots previously described.

7.6 Results analysis and discussion

7.6.1 Bypass of the Rural Strategy

Table 7.2 provided a clear indication that bypassing the Rural Strategy offers a relatively neutral outcome, in that impacts for both upstream and downstream areas will largely remain similar to those now experienced (or forecast to be experienced under the 2013 Flood Manual). A minor benefit is indicated for moderate to major floods (no more than a 2% average reduction in peak flow), whilst it appears that there will be a slightly detrimental effect on smaller floods (refer Figure 7.16). It was demonstrated that mitigation for the Rural Bypass operational alternative was often similar to the Urban 3 alternative, and that for some events, both are also similar to the Base Case.

With reference to Table 7.2, little impact (positive or negative) is evidenced for flood levels at Ipswich. In terms of the inundation of bridges, there will be a slight increase in the duration of submergence for the lower downstream bridges, offset by a 4% decrease in inundation time for the Brisbane Valley Highway and Mt Crosby bridges. The average duration of submergence of bridges upstream of Wivenhoe will also decrease in a minor way. Overall, the inclusion or exclusion of the Rural Strategy appears to make little difference to road closure impacts.

Seqwater (2014a) note that the simulation results presented in their study are for a limited number of small flood events (typically minor floods events greater than 2,000 m^3/s) which nearly all trigger the Urban Strategy and therefore result in downstream river flows significantly larger than the hydraulic capacity of the lower level bridges. Hence, their results may not be fully representative of the potential effects of bypassing the Rural Strategy in relation to smaller flood events. None-the-less, Figure 7.16 does demonstrate that for the higher end of smaller floods (i.e. around the 2,000 m^3/s to 3,000 m^3/s range), the strategy tends to cause higher flow rates at Moggill than those generated for the Base Case.

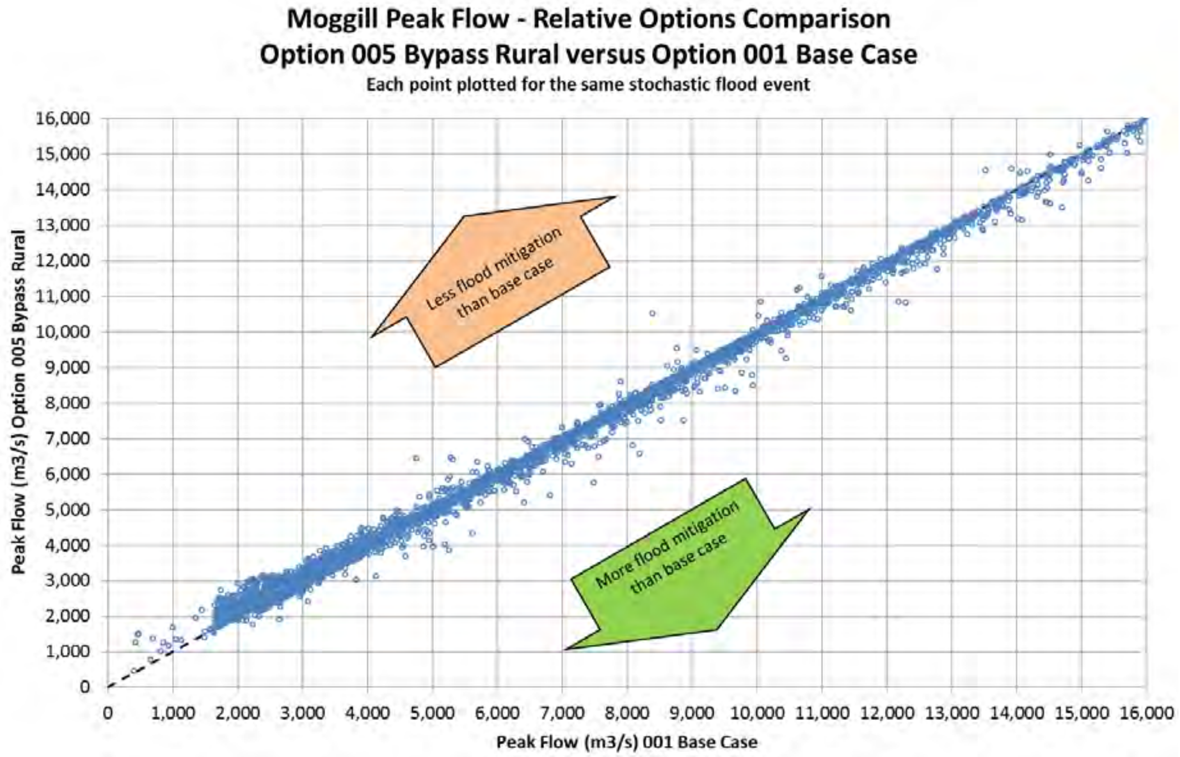


Figure 7.16 **Rural Bypass vs Base Case – Peak Flow at Moggill**

7.6.2 Alternative Urban 1

Under the Urban 1 Strategy alternatives, a higher minimum Moggill target flow of 4,000 m^3/s is adopted when the Wivenhoe Dam level is predicted to exceed FSL + 3 m. The alternative is subdivided into Urban 1a (with the Rural Strategy) and Urban 1b (bypassing the Rural Strategy).

The historical flood event and stochastic flood event simulation results for the alternative Urban 1 dam operations with this stepped change in the target flow at Moggill (Seqwater 2014a) indicates:

- Minor to marginal decrease in the magnitude of peak Brisbane River flows at Moggill for moderate and major events (typically less than 5% average reduction in peak flow)
- More frequent occurrence of moderate floods with peak flows exceeding 4,000 m^3/s at Moggill
- No benefit in Ipswich, and in some cases an adverse impact, producing higher peak flood levels of up to 1 m or more higher than the Base Case, and
- The onset of critical flooding at Ipswich and Moggill could occur typically between 3 to 8 hours earlier than the Base Case which would make less time available to evacuate and prepare for flooding.

The Urban 1 dam operations alternative would increase the probability of moderate floods exceeding 4,000 m^3/s flow at Moggill. Similarly, this variation of dam operations produces adverse impacts on peak flood level at Ipswich in some flood events as the higher releases earlier in the flood event increase the probability that the Brisbane River levels at Moggill will be higher when the Bremer River peak flow occurs.

Seqwater (2014a) noted that whilst this alternative is likely to provide a slight benefit with respect to the duration of flooding for the lower level bridges (refer Table 7.2), the impacts for the higher bridges are worse, with a 7% to 14% increase in the time of inundation.

Figure 7.17 and Figure 7.18 reinforce the point that whilst the Urban 1a and Urban 1b alternatives may decrease the magnitude of peak Brisbane River flows (i.e. above 6,000 m^3/s), there is a noticeable increase in flows for the smaller events (approximately 2,000 m^3/s to 5,000 m^3/s range) for most of the events modelled. It can be seen that peak flows can be increased by up to 1,000 m^3/s for a substantial number of scenarios in the 3,000 m^3/s to 4,000 m^3/s base flow range.

The results appear similar for Urban 1a and Urban 1b, despite the latter having no Rural Strategy.

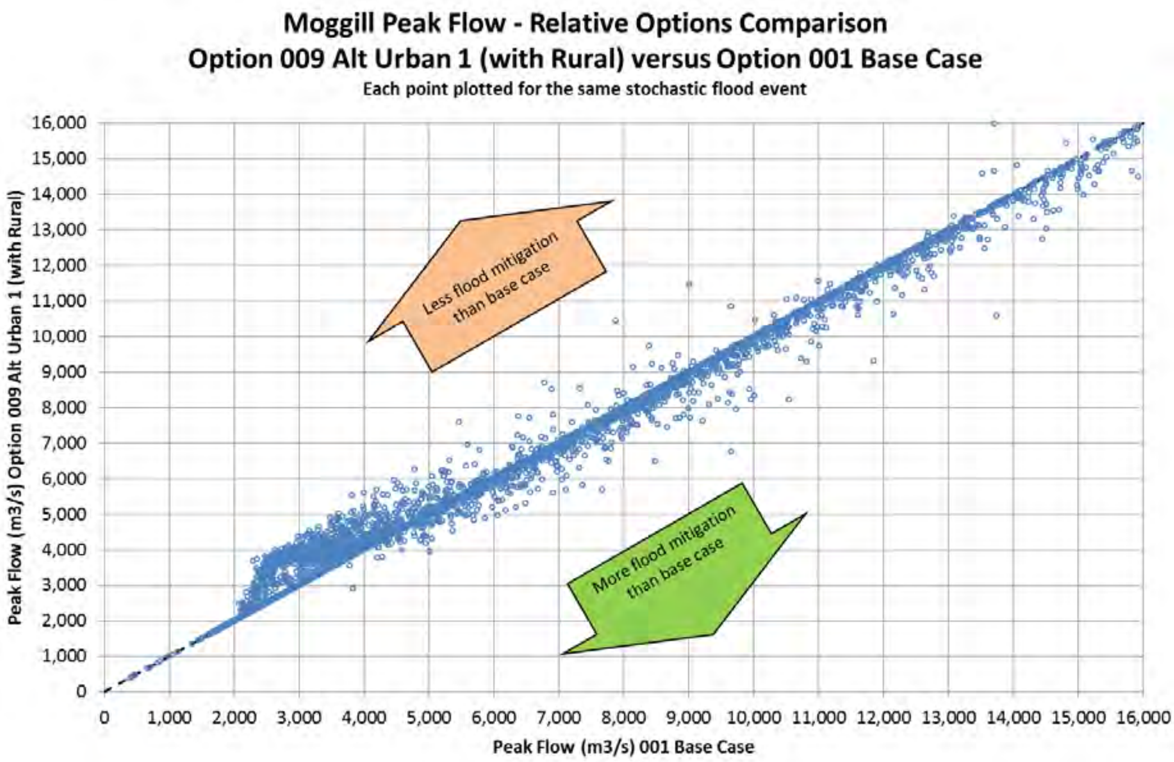


Figure 7.17 Urban 1a vs Base Case – Peak Flow at Moggill

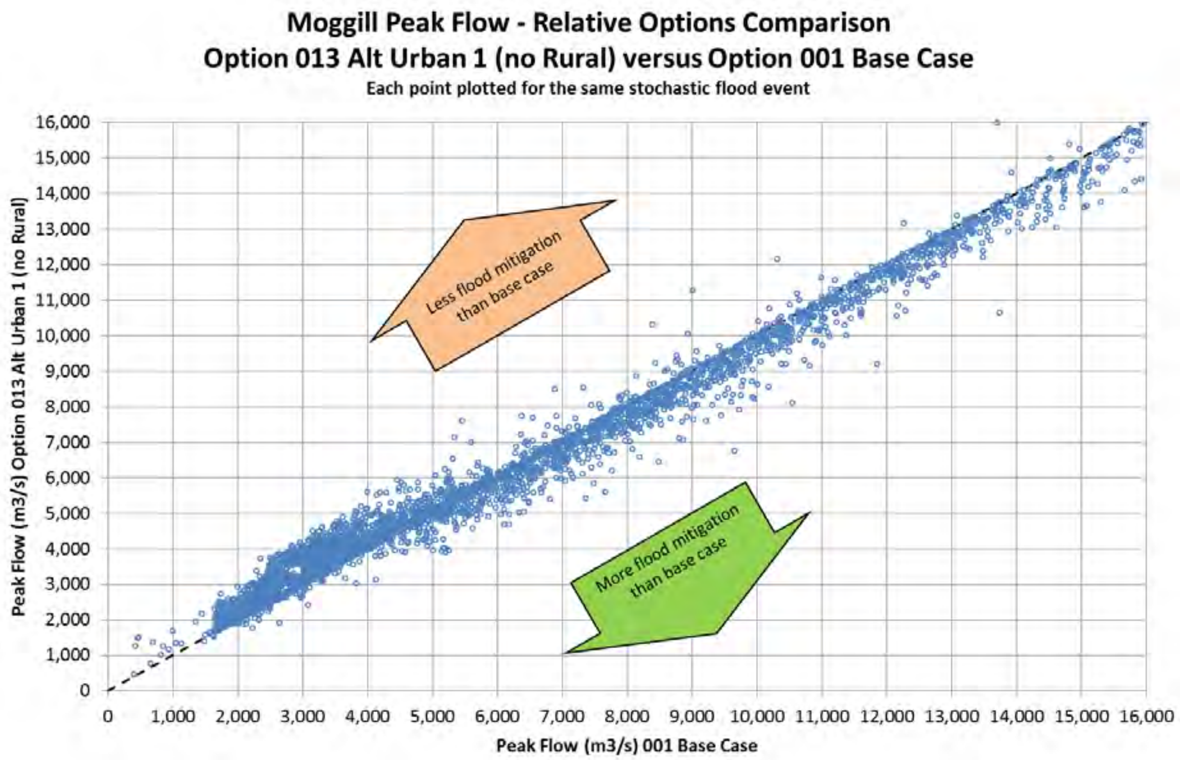


Figure 7.18 **Urban 1b vs Base Case – Peak Flow at Moggill**

7.6.3 Alternative Urban 2

The Urban 2 variation of dam operations represents a ‘softer’ (smaller) stepped change to higher releases earlier in flood events in combination with increasing the maximum target flow at Moggill and raising the Dam Safety Strategy trigger from EL 74 m to EL 74.5 m.

The Urban 2 dam operations allow higher releases in the Urban Strategy, whilst also allocating more flood storage to the Urban Strategy. This combination can delay or reduce the probability that dam operations will need to elevate to the Dam Safety Strategy in larger flood events.

The historical flood event and stochastic (reference to Figure 7.19) flood event simulation results for the alternative Urban 2 dam operations indicate:

- There are increased flood mitigation benefits (compared to the Base Case and alternative Urban 1) in terms of decreasing the magnitude of Brisbane River peak flows (averaging up to 5% lower) in major flood events, and
- A compromise that moderates the adverse impacts of the alternative Urban 1 dam operations and the more desirable features of the Base Case for moderate flood events would be achieved. The adverse impacts of a stepped change in the target flow are still evident, though less severe than the alternative Urban 1 dam operations.

The simulation results of the Urban 2 dam operations indicate that raising the maximum target flow at Moggill in the Urban Strategy in combination with raising the Dam Safety Strategy trigger level improves flood mitigation performance in major flood events.

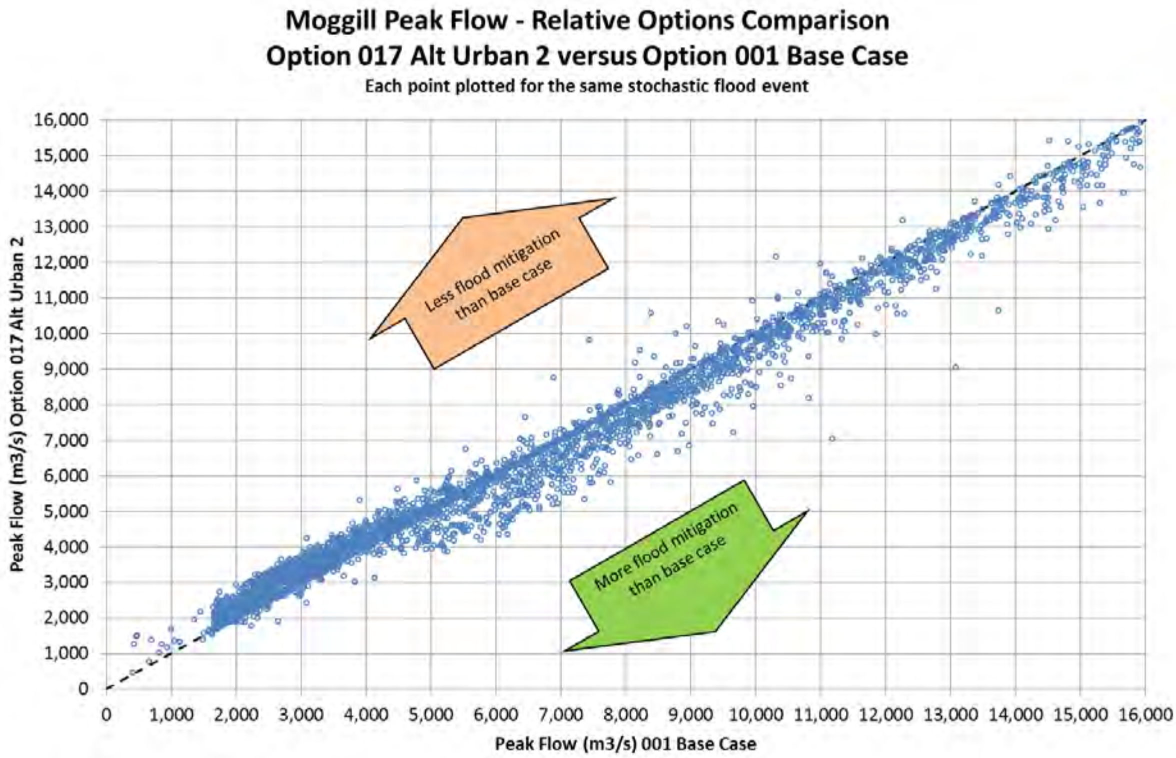


Figure 7.19 **Urban 2 vs Base Case – Peak Flow at Moggill**

Other conclusions that can be drawn with reference to Table 7.2 are:

- The peak flows for both minor and moderate events will tend to increase slightly (on average)
- Flooding at Moggill will tend to occur slightly earlier (typically 4 hours) than for the Base Case
- Similarly, a slightly earlier start to flooding at Ipswich is predicted
- There will be negligible to minor decreases in the duration of flooding of bridges
- Upstream bridges will benefit slightly (15% decrease in duration of inundation).

7.6.4 Alternative Urban 3

Alternative Urban 3 was designed to increase the benefits for the mitigation of major floods whilst still achieving a similar performance to the Base Case for minor and moderate flood events. It incorporates higher downstream target flows and allocates more flood storage to the Urban Strategy, along with raising of the dam safety trigger to EL 75 m.

The historical flood event and stochastic (refer Figure 7.20) flood event simulation results for the alternative Urban 3 dam operations indicate:

- Increased flood mitigation benefits in major flood events with a predicted average 10% reduction of Brisbane River peak flows (compared to the Base Case), though improvements at Ipswich were evident for only three of the historic events (1890, 1898 and 2011).
- The performance of alternative Urban 3 matches that of bypassing the Rural Strategy for smaller events (i.e. no real benefit in comparison to the Rural Bypass variation)
- The alternative Urban 3 dam operations may better utilise the additional storage gained if the FSV is lowered, and

- Similar flood mitigation performance (i.e. no improvements) as the Base Case for more frequent moderate and minor flood events would be achieved at all locations.

The alternative Urban 3 dam operations provide superior flood mitigation performance compared to alternatives Urban 1 and Urban 2 dam operations.

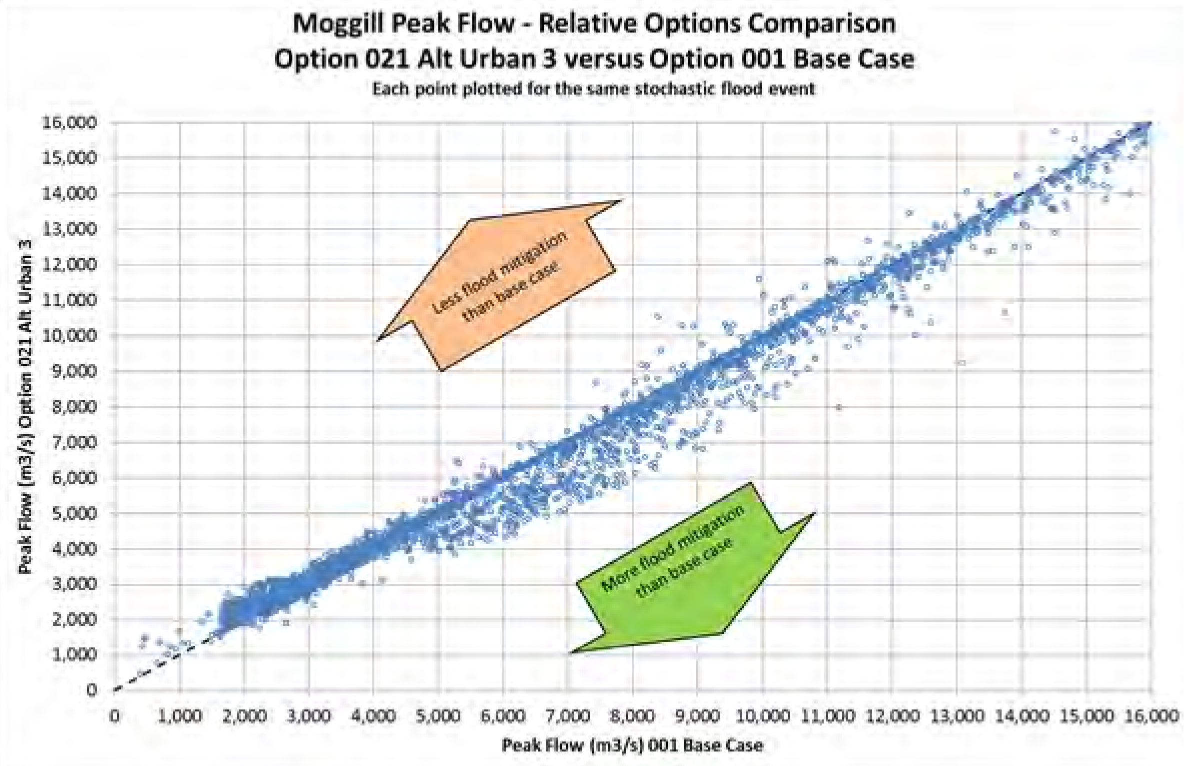


Figure 7.20 **Urban 3 vs Base Case – Peak Flow at Moggill**

7.6.5 Alternative Urban 4

The alternative Urban 4 dam operations applied an approach of holding more water back in the dams. This contrasted against the other Urban alternatives which tend to release more water. This alternative was investigated to address QFCoI Interim Report recommendation 2.13(1)e, as detailed in Table 1.6.

The alternative Urban 4 dam operations raise the Dam Safety Strategy trigger level to 76.2 mAHD (predicted Wivenhoe Dam level) which allows the Urban Strategy to operate in conjunction with breaching of the lowest (centre) fuse plug.

The historical flood event and stochastic (refer Figure 7.21) flood event simulation results for the alternative Urban 4 dam operations indicate:

- There could be significant flood mitigation benefits for a selection of major floods (particularly in terms of flow at Moggill) compared with Base Case operations, though as with several variations, flood mitigation performance varies between events. Examples include:
  - o In a number major flood events (such as the 2nd 1893 flood, 1974 flood, and 2011 flood) up to a 20% reduction of Brisbane River peak flows may be achieved

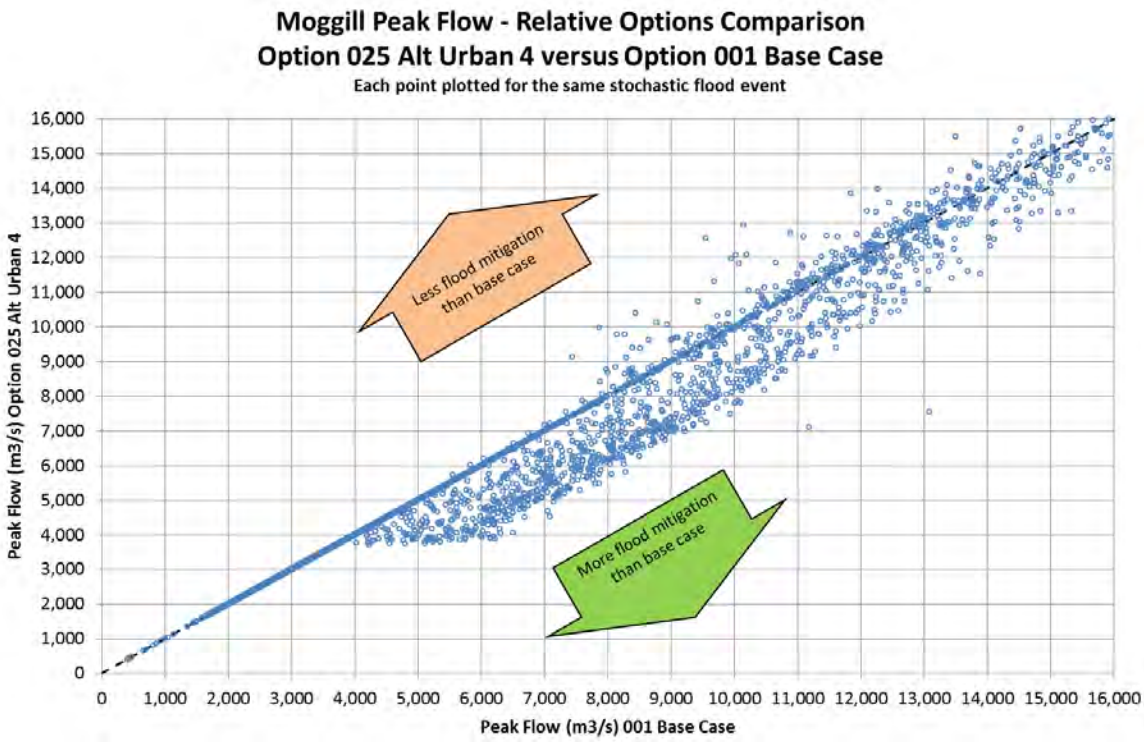


Figure 7.21 Urban 4 vs Base Case – Peak Flow at Moggill

- o A reduction (compared to the Base Case) of 1.4 m (Mar 1890), 1.6 m (Feb 1893) and 1.2 m (Jan 2011) for peak levels at Ipswich
- o In some major flood events (e.g. 1st 1893 flood) there would be no benefit (e.g. no reduction in Brisbane River peak flow for the 100% FSV scenario) or possibly an adverse impact (in the form of an increase in the Brisbane River peak flow for the 75% FSV scenario)

- For some flood events, a variation in flood mitigation performance might occur in response to:
    - o Breaching of the fuse plug, which may lead to coincident timing of the Wivenhoe release with that of peak flows occurring in the downstream catchments. There is further variability in this aspect with lower FSV scenarios, as the lower FSV scenarios tend to delay the breaching of the fuse-plug.
    - o Gate overtopping constraints, which may limit the potential to restrict the total release to the minimum necessary to achieve the downstream target flow.
- Over an average of many floods, there is no predicted significant reduction in peak flood levels in Ipswich. The best potential for reductions will occur in those flood events where the flood level is dominated by backwater influence from the Brisbane River (with only a minor contribution from the Bremer River catchment).
- The flood mitigation performance is the same as the Base Case for moderate and the lower end of the major flood events.
- There is increased duration of submergence of bridges upstream and downstream of the dams. The influences on duration of submergence include:
    - o As more water is stored in the dams and higher peak flood levels occur in the dams, this increases the probability and duration of submergence of upstream bridges; and
    - o For downstream bridges, the storage of more water results in the need for a higher release flow for the drain-down phase after the flood peak, leading to an increased duration of inundation.

- There is no significant change to the onset of critical flooding in Brisbane and Ipswich.
- For a limited number of major historic floods (e.g. the 2nd 1893 flood and 2011 flood events) there may be some benefits in the form of an increase time before the onset of critical flooding at Fernvale, or even the prevention of critical flooding at Fernvale.

Figure 7.21 highlights the performance of Alternative Urban 4 in comparison to the Base Case, clearly demonstrating both benefit and risk. Given the number of floods for which a significant benefit is indicated, it would appear prudent to consider the cost and dam safety risk issues associated with the option in conjunction with a review of those events where a worse outcome is predicted, to assess whether it is possible to reduce the adverse effects.

7.6.6 Prescribed Operations alternative

The Prescribed Operations alternative does not apply the operating philosophy and concepts in the 2013 Flood Manual (described in Chapter 3). Instead, a series of rules relating to gate opening and closing rates have been applied.

The historical flood event and stochastic (refer Figure 7.22 flood event simulation results for the prescribed operational alternative indicates generally inferior flood mitigation performance to all the other alternatives considered as it does not take account of flow occurring in the catchments downstream of Wivenhoe Dam. In some cases the Prescribed Operations could amplify the flood which contradicts the intention to operate Wivenhoe Dam as a flood mitigation dam.

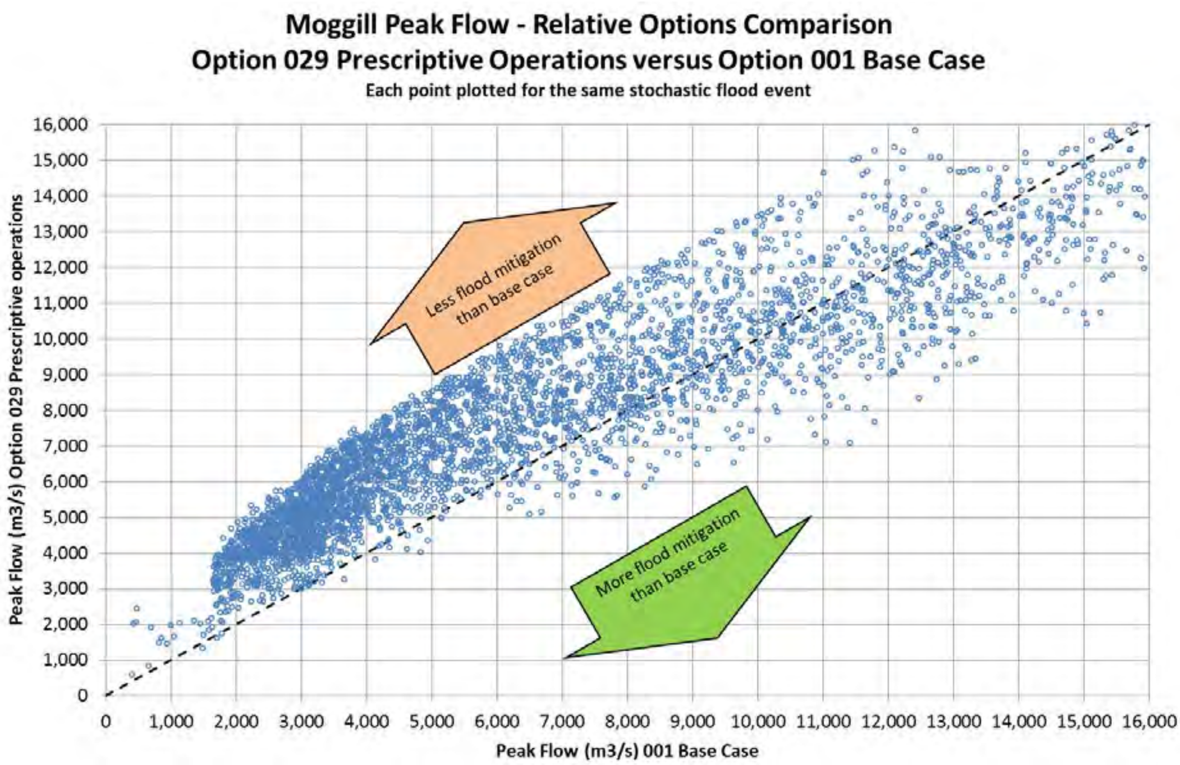


Figure 7.22 Prescribed operations vs Base Case – Peak Flow at Moggill

7.6.7 Locational impacts

The results of Seqwater modelling (flood operation simulations) have been generated for locations at Savages Crossing, Moggill and Ipswich. Results were also generated for Wivenhoe, but are largely similar to those at Savages Crossing, and offer little relevance to the discussion of downstream flooding.

The impacts of the various operational alternatives on flows at Moggill have formed the basis for discussion when comparing the relative performance of each alternative against the performance of the Base Case (i.e. existing operating procedures). It is important to also consider the implications for other locations, especially when considering further the Urban 3 and Urban 4 alternatives which appear to be the alternatives other than the Base Case which could be further optimised. In this section, additional results are presented for flows at Savages Crossing, and levels at Ipswich.

Savages Crossing

Figure 7.23 presents the results for Savages Crossing for Urban 3 alternative in comparison to those for the Base Case. The performance is comparable to Figure 7.20 for the Moggill location indicating slightly reduced flood mitigation for small floods and generally improved outcomes for major floods.

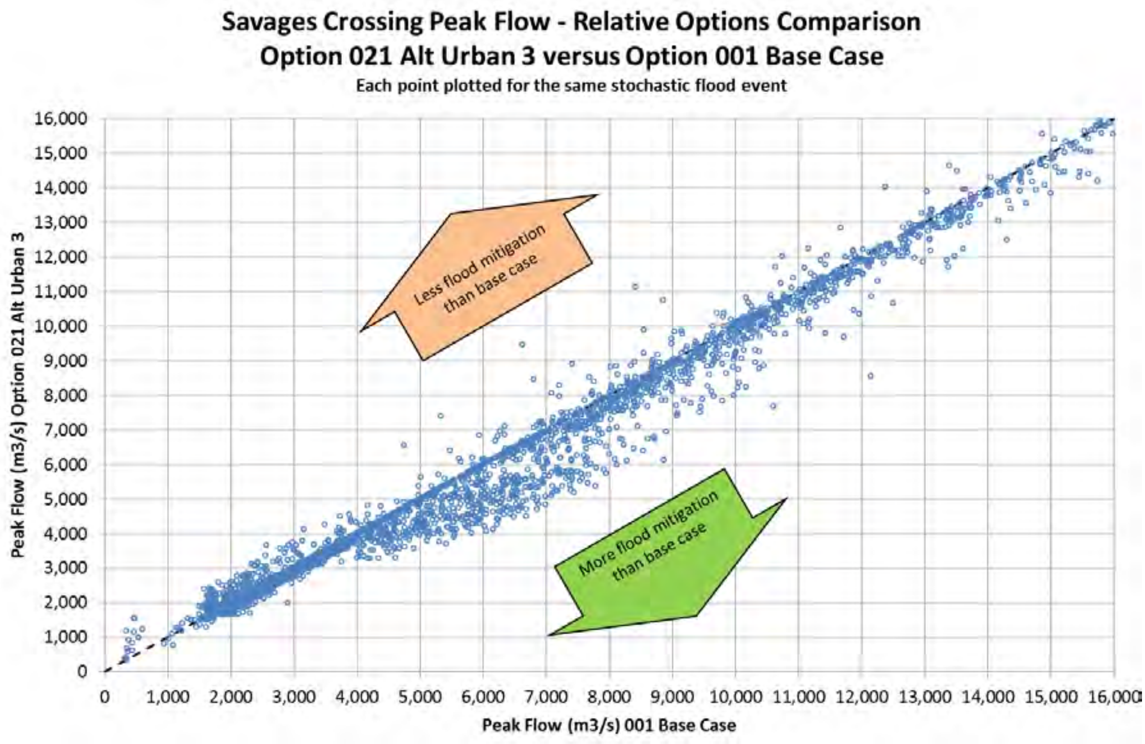


Figure 7.23 Urban 3 vs Base Case – Peak Flow at Savages

Similar observations can be made for Alternative Urban 4 when comparing Figure 7.24 below (Savages Crossing) with Figure 7.21 (Moggill).

The performance of the Urban 4 alternative at Savages Crossing, as for Urban 3, is slightly more variable than it is at Moggill. The conclusion is that whilst performance is generally better across the board, and may benefit Moggill, there is the risk of a slight increase to the Fernvale area, especially for the larger events.

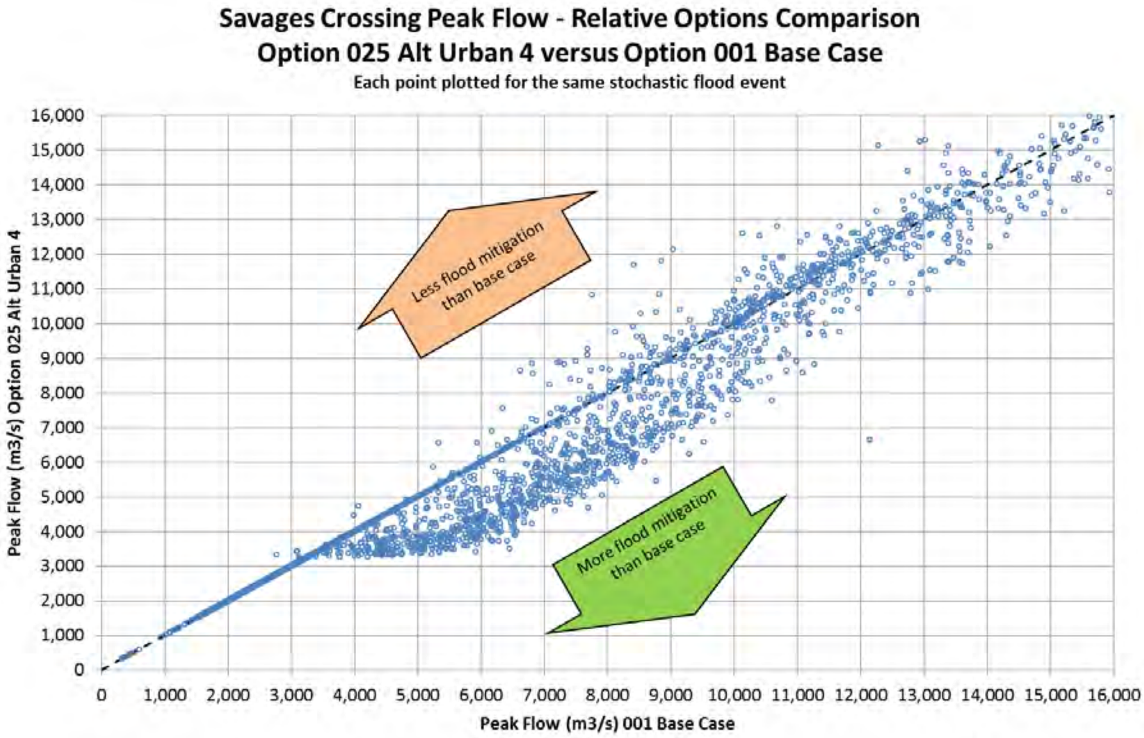


Figure 7.24 Urban 4 vs Base Case – Peak Flow at Savages

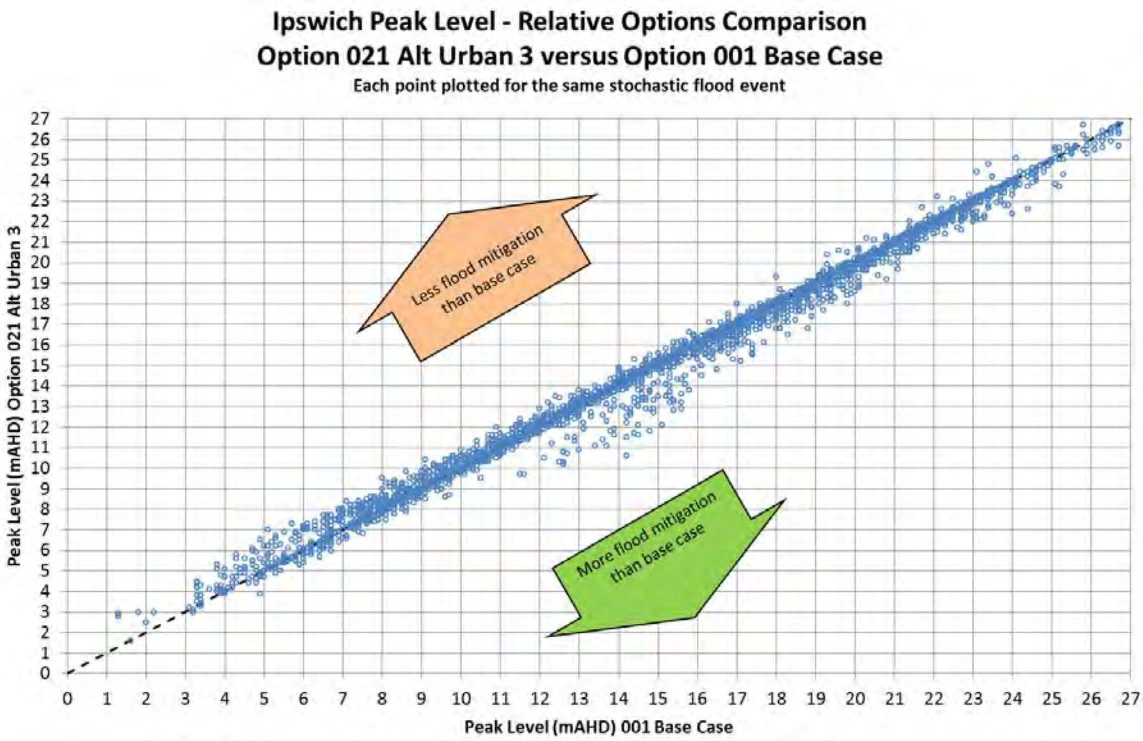


Figure 7.25 Urban 3 vs Base Case – Peak Level at Ipswich

Ipswich

Figure 7.25 provides a comparison between the performance of Alternative Urban 3 at Ipswich, and that for the Base Case.

The figure demonstrates a relatively tight grouping of points at several locations, with Urban 3 levels generally within 1 m of those generated for the Base Case with some exceptions for minor and moderate floods. Overall however, the alternative generates more benefits than dis-benefits.

Figure 7.26 provides a similar comparison for the Urban 4 alternative.

Figure 7.26 Urban 4 vs Base Case – Peak Level at Ipswich

Figure 7.26 needs to be considered in conjunction with Figure 7.15 which indicates overall minimal change in overall results from the Base Case. Nevertheless, Figure 7.26 indicates a strong beneficial trend for some floods and that there are relatively few negative outcomes until an elevation of the order of 22 m is reached.

7.7 Performance of the existing Wivenhoe-Somerset system

The Seqwater results, whilst geared towards the assessment of operational alternatives, also provide some strong evidence as to the performance of the dam under the operating procedures specified in the 2013 Flood Manual.

The impacts of operational alternatives at Moggill and Ipswich have been presented in this report as the two primary indicators of performance, whilst the complete set of results is presented in Seqwater (2014a). The impact of operational alternatives on levels upstream of Wivenhoe has also been considered with the overall impacts of changed operations relatively minor when compared to the potential downstream benefits.

For historical events, the peak flood flows at Moggill are mitigated by up to 70% compared with the 'no dams' peak flows estimated. The extent of mitigation varies across a wide range, which the greatest mitigation of 70% occurring in the 1999 flood following a drought which had depleted the dam supplies. Wivenhoe and Somerset Dams also provide a benefit (lowering of flood levels) of 2 m to 4 m on average at Ipswich. This applies across a broad range of 'no dams' case estimated flood levels (12 m to 24 m).

7.7.1 Varying Full Supply Volume

With reference to peak flows at Moggill:

- The reduction of the FSV does indicate a benefit, though primarily for major floods only, with results showing minimal benefit below a 'no dams' flow of 8500 m^3/s.
- Consideration of performance for the historical events indicates that for smaller floods, little benefit is evident as the existing flood storage is adequate.
- The review of stochastic results suggests that the benefits of reducing the FSV only become apparent (meaningful) for flows above 10,000 m^3/s. This benefit remains evident up to a flow of 15,500 m^3/s, which is the upper extent of simulations. Benefits could continue for higher flows, though eventually an upper limit to benefits would be reached, as the magnitude of extreme floods dwarfs the storage capacity of the dam.
- The decreases in peak flow at Moggill attributable to reducing the FSV are substantially smaller in magnitude than those offered by the presence of the dams.

The review of peak Ipswich flood levels indicates that:

- Reducing FSVs provides only marginal benefit beyond that already provided by the existing dams. As indicated above, the dams provide benefits of 2 to 4 m (reduction in height). Reducing the FSV to 85% would provide a further decrease of less than 0.5 m, whilst a 60% FSV scenario would provide less than 1 m benefit compared to the existing dams.
- With reference to historic floods, reducing the FSV indicates benefits (of the order of 1 to 1.5 m) are evident for only three of the largest five floods analysed, and also for the March 1890 flood. Interestingly, no benefits are indicated for the January 1887 or January 1974 floods which were dominated by Bremer River flows.
- For smaller floods, peak levels can be worsened (e.g. 1959, 1973, 1983, and 1999).

7.7.2 Relative performance of operational alternatives

The relative performance of the eight operational alternatives (including the Base Case) has been conducted. This reveals that:

- None of the alternatives offer any particular benefit, compared to the Base Case, across the lower flow range. The Urban 3 and Urban 4 alternatives perform better than the other variations, but only match the Base Case between the 5,000 m^3/s and 8,000 m^3/s 'no-dams' flows.
- For 'no-dam' flows greater than approximately 10,000 m^3/s, Urban 4 is clearly the best performing alternative from the perspective of reducing peak flows at Moggill, and levels at Ipswich.

- The above conclusions are supported with reference to historical events, with all variations (with the exception of the prescribed operation variation) generating some reduction in flow at Moggill for major flood events, but little benefit showing for smaller events. Indeed, each of the Urban 1, Urban 2 and Prescribed Operations alternatives can worsen flood performance, leading to an increase in flows at Moggill.
- Under the Urban 4 variation, a substantial improvement to the Base Case is evident for only four events. These are March 1890, February 1893, January 1974 and January 2011. That is, for three of the largest four historical events, alternative Urban 4 demonstrates the potential to provide a significant benefit.
- The overall conclusion is that the considered variations offer little benefit for smaller magnitude floods.
- The performance at Ipswich generally demonstrates less potential benefit, with reductions effectively only evident under alternative Urban 4, and even then, only for three of the historical events (Mar 1890, Feb 1893 and Jan 2011).
- The Prescribed Operations alternative could worsen (increase) flood levels at Ipswich by up to 2 m for flood levels (no dams) between 12 and 20 m AHD, and by up to 5 m when compared to the Base Case.

7.8 Conclusions

In considering the results presented in this chapter, it is important to note that the potential benefits to flood mitigation cannot be considered in isolation. Changes to strategies and operational procedures may have implications for risk to dam safety and/or water supply security. Results are largely presented in terms of 'average benefits' may not occur for every flood. It is possible that various individual floods will experience either substantially better or substantially worse performance than the average.

The analysis by Seqwater has yielded a number of key findings. These are summarized below, and are prefaced by the comment that findings should be viewed from a relative perspective, rather than absolute one. That is, the findings allow for a relative comparison between alternative operations, but do not represent the best outcome that could be achieved for any one event. Similarly, whilst significant effort has gone into the assessments undertaken for WSDOS, future refinements are to be expected, which may lead to minor changes in results and findings.

A review of the historical and stochastic simulation results for alternatives Urban 3 and Urban 4 demonstrates:

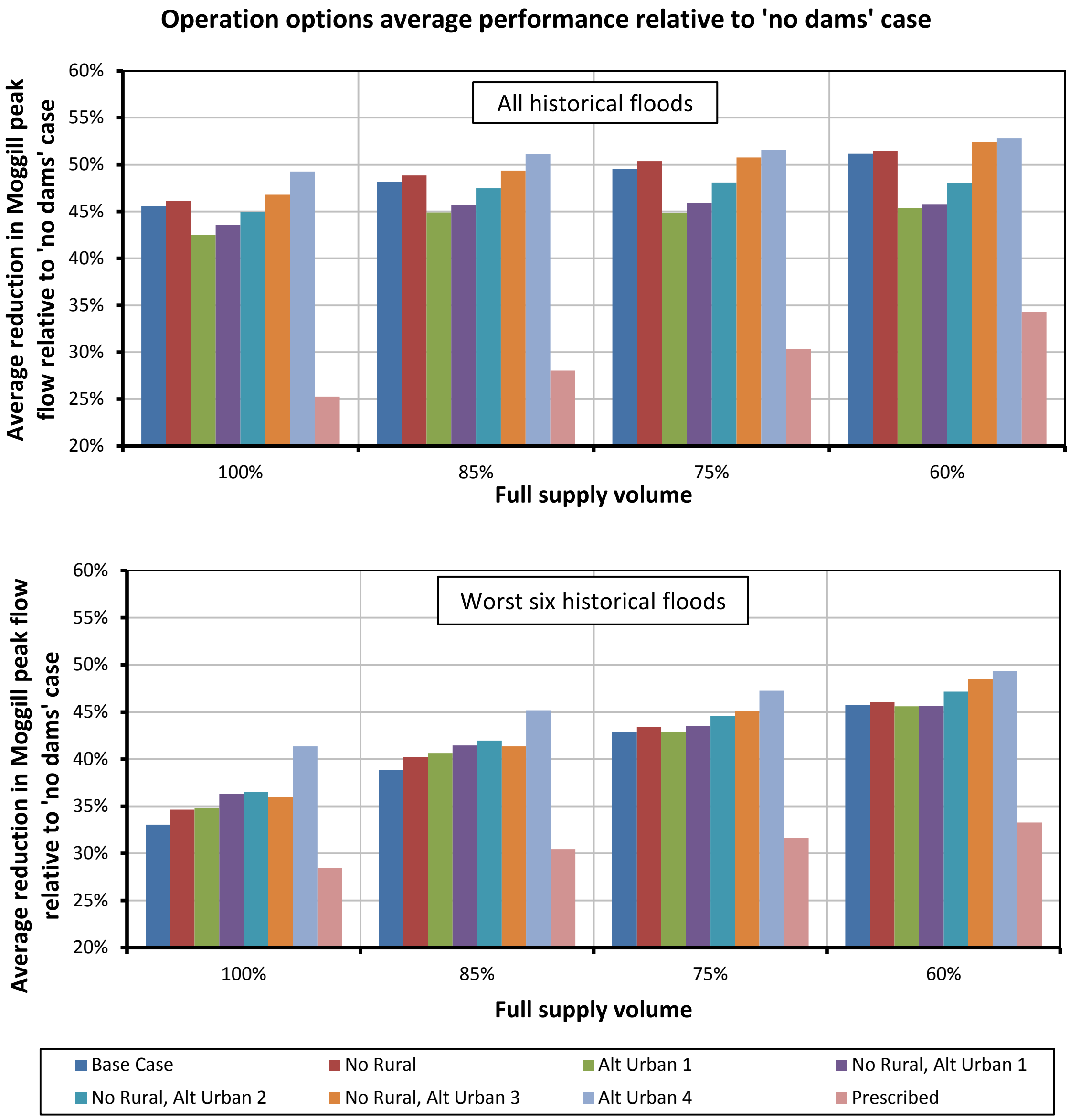
- clear benefits at Moggill, and in particular for the larger events
- similar benefits for flows at Savages Crossing (and hence Wivenhoe), although there is a small risk of increased flows at Savages Crossing under Alternative Urban 4
- lesser benefits at Ipswich for the majority of alternatives, owing to the influence of the Bremer River (i.e. the operation of Wivenhoe is only one of the influences on flooding at Ipswich).

Figure 7.27 summarises the effects of the 32 operational options investigated on the full set of selected historical flood events and on a subset of the 6 largest historical flood event on flows at Moggill relative to the 'no dams' scenario by averaging the reductions in peak flows across all events. The patterns for the two sets of data are markedly different.

Consideration of all the historical flood events shows that the operational alternatives provide:

- a modest increase in the average reduction of peak flood flows over the no dams case (around 5%) by reducing the FSV from 100% to 60%, and
- a small to modest increase (maximum 3%) in the average reduction in peak flood flows for operational alternatives (i.e. no reduction in FSV) – except for the Prescribed Releases alternative which generally results in worse outcomes (i.e. peak flow reductions diminish by around 25%).

Only the Rural Bypass and Urban 3 and 4 operational alternatives provide increased reductions in average peak flood flows (i.e. additional to that achieved by lowering the FSV).



Note: Top plot represents the performance assessed against 20 historical floods since 1887.
Bottom plot represents the performance assessed against the six worst recorded floods since 1887.

Figure 7.27 Average reduction in peak flow at Moggill relative to 'no dams' case for operational alternatives and different FSVs

A key objective of seeking to vary the flood operations of the dams is to investigate the potential to reduce the potential for damaging flows at Moggill (of the order of 4,000 m^3/s to 6,000 m^3/s and beyond) while at the same time not worsening smaller floods, or compromising dam safety.

Hence the average performance of the operational alternatives for the six worst historical floods (above 4,000 m^3/s at Moggill) is plotted separately in Figure 15.6. Some significant contrasts become evident when compared to the average of all floods:

- as the operational alternatives become more aggressive by increasing target flows at Moggill and raising the Dam Safety Strategy trigger level, the average reductions in the peak flows at Moggill increase – with the exception of the Prescribed Operations alternative, and
- reductions in peak flood flows by reducing the FSV from 100% to 60% are more pronounced being about 12%.

The modelling (Figure 7.27) indicates that the greatest flood mitigation benefits are achieved by increasing the flood storage either by lowering the FSL of Wivenhoe Dam or by increasing the Dam Safety Strategy trigger level. Strategies that only modify target flows at Moggill provide lesser flood mitigation improvements.

Clearly, the dams already provide significant flood mitigation and increases in the urban flood storage tend to improve flood mitigation outcomes for the major historical floods. Lesser flood mitigation improvements are likely to be achieved through flood operations which increase target flows at downstream locations and hence increase releases from Wivenhoe Dam.

Chapter 8 Water supply security

Wivenhoe and Somerset dams were originally designed and constructed for the provision of a reliable urban water supply for the greater Brisbane region, as well as providing flood mitigation for the downstream floodplain (refer to Chapter 2 for an overview).

This chapter summarises the results of water supply security investigations undertaken for WSDOS (and the North Pine Dam Optimisation Study) based on modelling input from Seqwater (2014b, 2014c). These investigations entailed assessments of system yield and demand modelling to determine the water security implications of lowered FSVs at both Wivenhoe and North Pine Dams, as part of the SEQ water supply system.

Additional discussion is also provided regarding the water supply implications of variations to the availability of manufactured water production.

8.1 General

Regional water supply is delivered by the SEQ water supply system, shown in Figure 8.1. This complex network of water storages, treatment, pipelines and pumps is operated by Seqwater. Seqwater optimises the use of available water by moving it when and where it is needed.

Water supplies to the SEQ region, under the *Water Act 2000* (QLD), are operated and managed by Seqwater in accordance with the SEQ System Operating Plan (SOP, QWC 2012). The SOP sets out the desired Level of Service (LOS) objectives and operating rules for the SEQ water supply system. It requires Seqwater to prepare an annual operations plan, a manufactured water readiness plan, future water demand plans and a water supply asset plan.

DEWS is currently leading a review of the desired LOS objectives, which will include consideration of the impacts of reduced water demand in recent years as a result of increased rainfall and community awareness initiatives.

Following the LOS review, the revised objectives will be prescribed in regulation and Seqwater will within 12 months develop an updated detailed water security program (anticipated in late 2015). The water security program will detail how future water supply needs will be addressed including new infrastructure, demand management and drought response measures. The water security program will also detail how water security will be maintained for those SEQ communities that are not directly connected to the bulk water supply system (such as Boonah and Beaudesert).

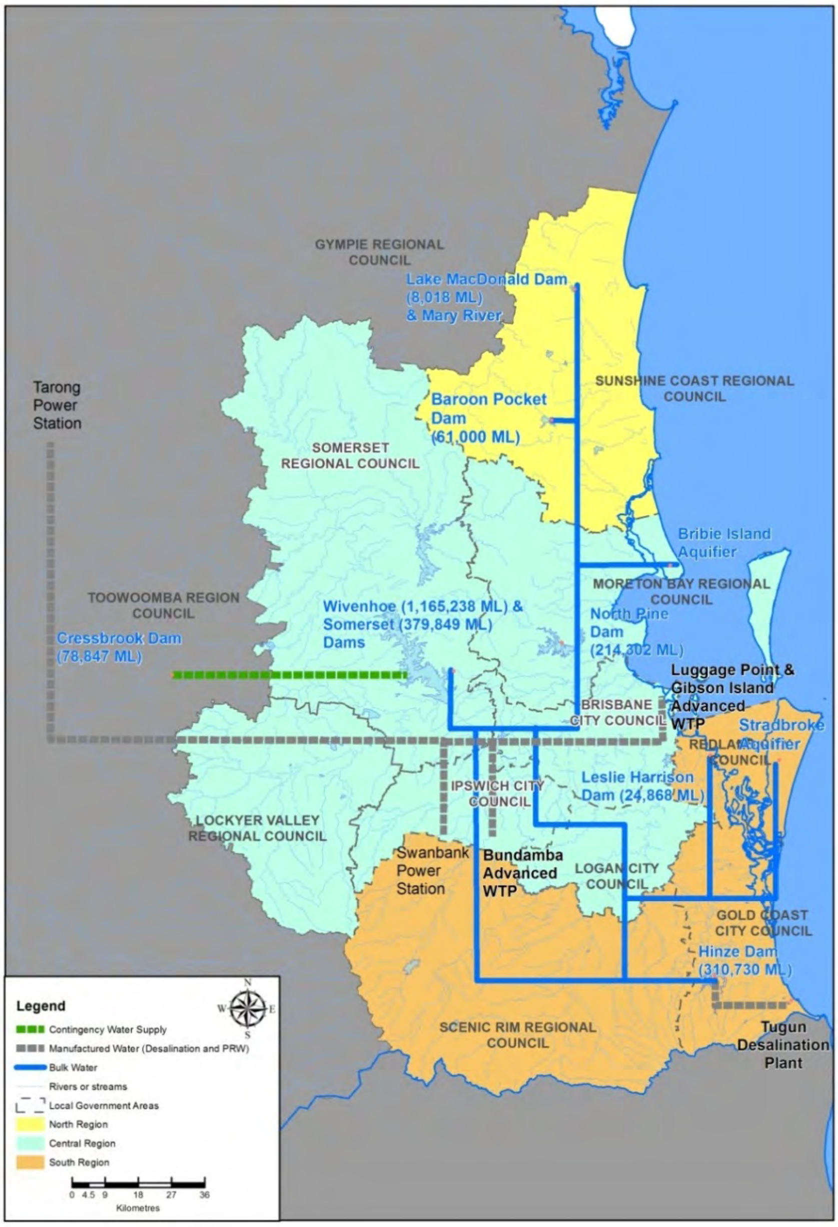


Figure 8.1 SEQ water supply system

8.2 Water storages and drought response strategy

Water to the SEQ region is sourced from 12 water storages within three sub-systems:

- Northern System – Ewen Maddock Dam, Cooloolabin Dam, Wappa Dam, Baroon Pocket Dam and Lake Macdonald
- Central System – Leslie Harrison Dam, Somerset Dam, Wivenhoe Dam, North Pine Dam and Lake Kurwongbah, and
- Southern System – Hinze Dam and Little Nerang Dam.

At current full supply levels, Wivenhoe and Somerset dams have a combined water supply storage capacity of approximately 1,600,000 ML, which is equivalent to approximately 60% of the total water stored in the SEQ water storages. The allocation of water from the Central Brisbane River Water Supply Scheme including Wivenhoe and Somerset dams is around 279,000 ML/a.

The SEQ water supply system sources include two manufactured water assets:

- Gold Coast Desalination Plant (GCDP), and
- Western Corridor Recycled Water Scheme (WCRWS).

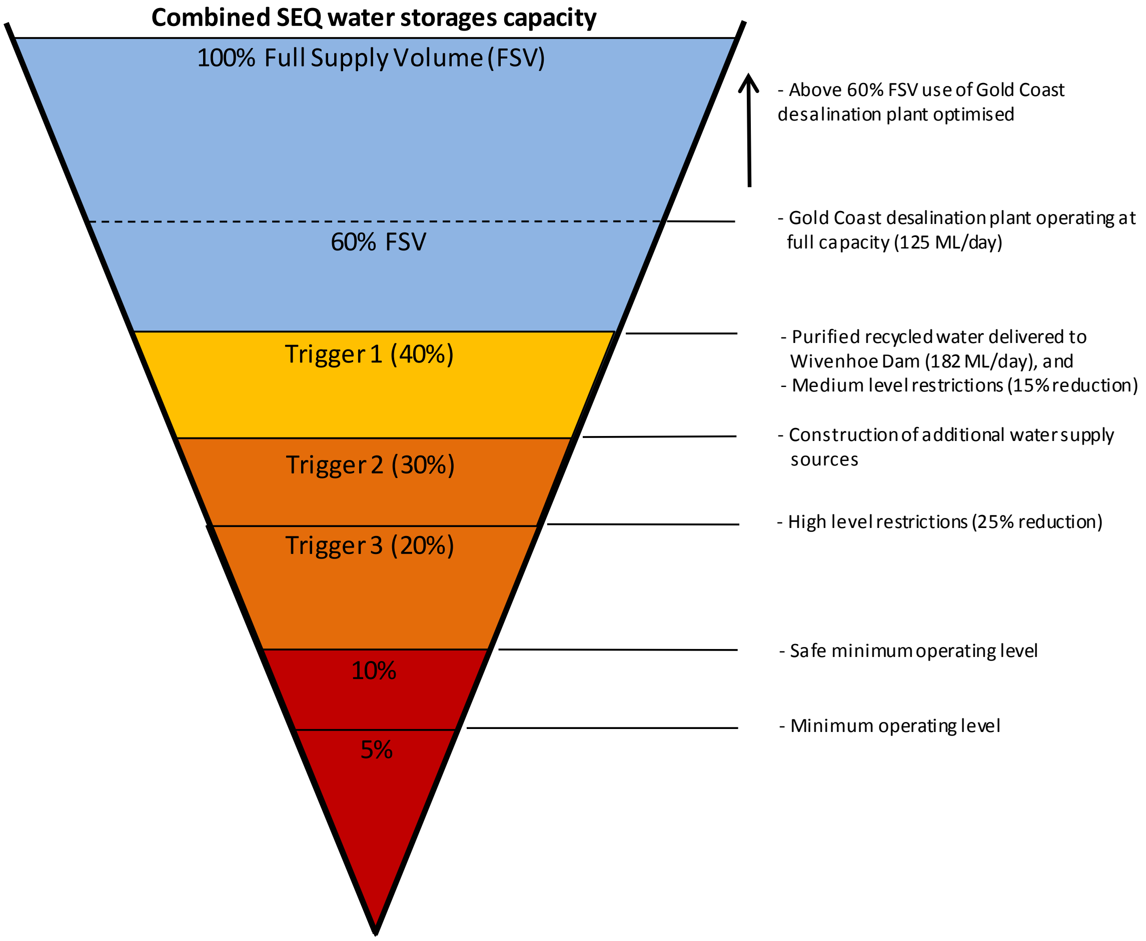
At full production, the GCDP at Tugun has the ability to provide 125 ML/day or 45,625 ML/a of desalinated water. Currently, the GCDP is operated in standby mode due to the availability of (lower cost) surface water. However, should the combined capacity of the SEQ water storages reduce to 60% or should a water supply emergency eventuate, the GCDP could be brought into full production.

During the 2013 flood event turbidity levels in the Brisbane River at Mt Crosby Weir were four times the level experienced during the January 2011 flood event. Supply from the desalination plant was ramped-up to 100% to assist in meeting demands whilst the Mt Crosby water treatment plants were off-line for around 24 hours (Seqwater 2012/13 Annual Report)

The WCRWS consists of advanced water treatment plants (AWTPs) at Luggage Point, Gibson Island and Bundamba that can supply purified recycled water (PRW). Under the SOP, the WCRWS is brought into full operations when the capacity of the SEQ water storages drops to 40%. Water supply restrictions are also introduced at this point. Currently the WCRWS is being placed into a care and maintenance mode with the ability to be recommissioned and operated at full capacity should the 40% SEQ water storages trigger be reached.

At water supply levels lower than 40%, augmentation of supply and more severe restrictions can be triggered as summarised in Figure 8.2.

The SEQ system storages supplied around 282,000 ML to SEQ in the 2012–13 financial year.



Source: Adapted from QWC 2010, Figure 3.1

Figure 8.2 Current FSV triggers for changes to water supply operations and usage restrictions

8.3 Water security modelling

To inform WSDOS, Seqwater has undertaken numerical systems modelling to assess the implications of options for lowering the FSV of Wivenhoe and North Pine dams on the water supply security for SEQ. The modelling scenarios included options to lower the FSV in Wivenhoe Dam independent of, as well as in combination with, lowering the FSV in North Pine Dam. Additional modelling was undertaken by Seqwater to assess scenarios where no manufactured water (GCDP and/or WCRWS) was available.

The modelling provided two types of output. Firstly, modelling of the effect of reduced FSV and changes to manufactured water operation on the system yield provided an understanding of the effect of changes on the timing of future supply augmentation. Secondly, changes to the cumulative probability of reaching defined triggers of 60%, 40% and 30% combined capacity provided insight into the potential effects on the timing and duration of operation of drought contingency measures, including manufactured water production.

8.4 The Regional Stochastic Model (RSM)

Modelling was undertaken using the RSM tool, an implementation of the Water Headworks Network (WATHNET) water balance model (Kuczera et al. 2009). The RSM model has been designed to simulate the complex operation of water supply systems serving urban, industrial, irrigation and in-stream demands. The RSM tool contains data describing the SEQ water supply system infrastructure (storage and pipeline capacities plus manufactured water), climatology (rainfall inflow to storage and evaporation), estimated water demands and the agreed SOP rules for allocating water across the region. The model data and assumptions are reviewed annually in line with the relevant SOP and any network changes.

The RSM tool simulates the behaviour of system storages and water transport needs within the SEQ water supply system. It does this by statistically generating synthetic potential stream inflow sequences that have equivalent statistical characteristics to the available reliable historical record to assess the potential impacts of climate variability on water supply security beyond that which has been experienced historically.

For the present study, the RSM model assessed 10,000 potential synthetic stream inflow sequences, each 117 years in length to match the period of the historical record, nominally from July 1890 to June 2007. Each of these replica time histories can be regarded as equally possible climate sequences for any period of 117 years. It also considers the actual historical record of inflows for the 117 year period as a reference and for comparison (Seqwater 2014b).

Uncertainties in using stochastic modelling techniques impact the reliability of yield assessments which are dependent on the representativeness of the historical record for predicting future rainfalls and stream flows. For example, estimated water supply yields for SEQ are significantly lower when the historical data set (used as the basis for generating the stochastic inflow sequences) includes, rather than excludes, the 2001 to 2007 drought.

8.5 Modelled scenarios and assumptions

The RSM (VD4i) has been used to assess the specific FSV operating scenarios listed below in Table 8.1. These possible scenarios were developed to provide a range of likely practical approaches suitable for assessing the water supply system response to changes in the operating rules for these dams.

Table 8.1 Modelled water security scenarios

North Pine Dam	Wivenhoe Dam (% FSV)			
(% FSV)	100	85	75	60
100	X	X	X	
85	X	X		X
75			X	
42[1]	X			X

Note: 1. The 42% level for North Pine corresponds to the dam spillway fixed crest level, which forms a practical limit.

The stochastic modelling has been based on the infrastructure that existed in 2013. The assumed water demand projections are based on the 'most likely' scenario from the Seqwater Waterhub System Demand Forecasting Module involving demand rebound to

185L/p/d residential and 100 L/p/d non-residential demand, including Power Station Demands (~97L/p/d exclusive of power station demands) by 2017/18.

This includes the 10,000 ML/a contracted supply to Toowoomba. Because the projected demand due to expected growth is estimated to exceed the available system yield within the next 20 years, the simulations have been undertaken for a nominal planning horizon of 20 years out to 2033.

Water restrictions were assumed to be applied to all SEQ regions during the simulations, as follows:

- 15% reduction to average regional total urban use when the SEQ water storages fall to 40% and applied until the storage level returns to 50%, and
- 25% reduction to average regional total urban use when the SEQ water storages fall to 20% but revert to 15% when the storage level reaches 30%.

The following manufactured water availability was modelled (Seqwater 2014c):

- WCRWS and GCDP available
- only GCDP available
- only WCRWS available
- WCRWS and GCDP unavailable

All modelling has been based on a permanent lowering of FSVs over the full period of the simulations. Temporary lowering of the FSV from time to time would have less impact on water supply security while potentially higher demand will have a greater impact.

8.6 System yield assessments

The modelling indicates that the yield of the bulk water supply system to deliver the currently specified level of service for SEQ generally remains constant at around 430,000 ML/a when varying the FSVs in both Wivenhoe Dam and North Pine Dam from 100% down to 75%.

This outcome is the result of complex interactions in the regionally networked model reflecting:

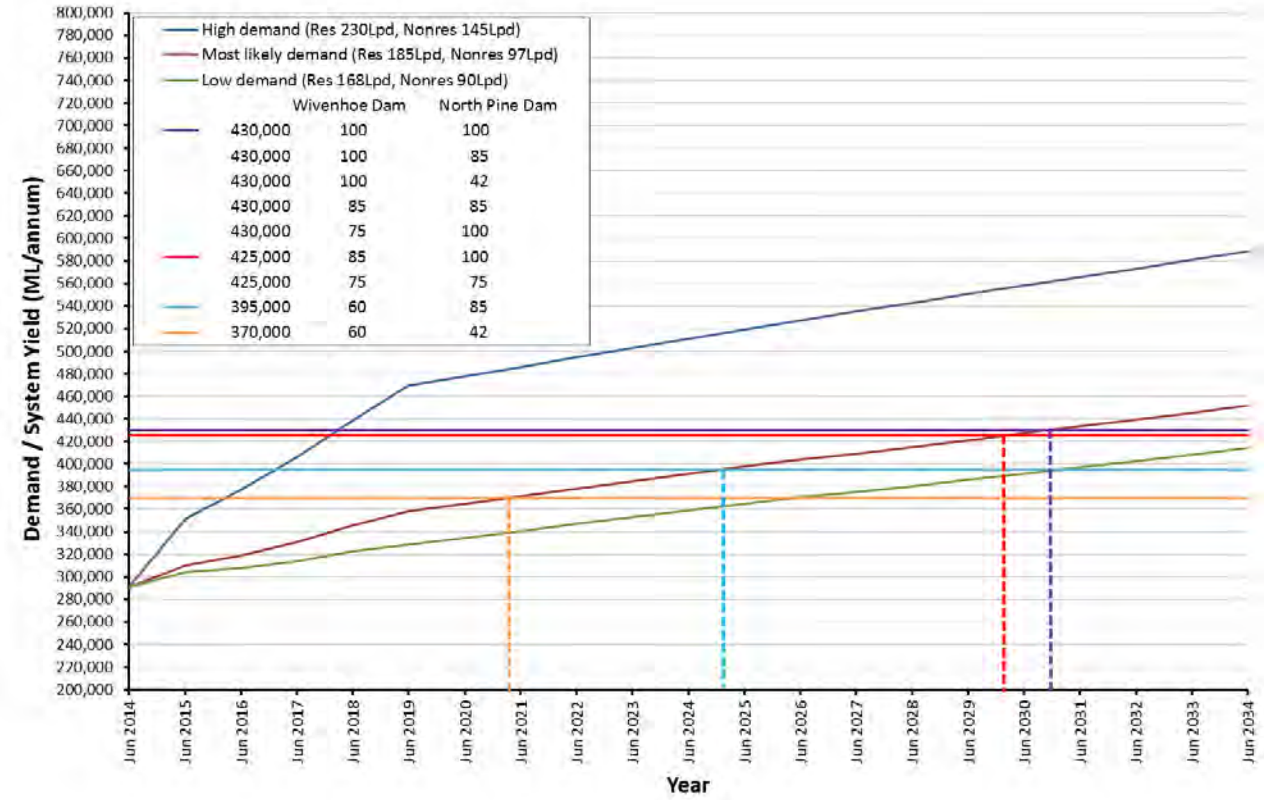
- The flexibility provided under the current level of service (LOS) specification defined in subordinate legislation in the System Operating Plan
- Earlier production of desalinated water and introduction of water restrictions as the dam levels lower
- Consequential adjustments to water transfers between the northern system (Sunshine Coast areas), the central system (Brisbane, Ipswich, Logan and western areas), and the southern system (Gold Coast areas)
- That the northern and southern systems are more likely to run out of water in an extreme drought, and
- The current LOS yield is governed by the first objective to fail (which is currently the Baroon Pocket Dam dead storage criterion).

Table 8.2 summarises the results of system yield assessments of the SEQ water supply system as it currently operates with existing infrastructure. It indicates that the northern SEQ sub-region is the constraining sub-region, with it being subject to more frequent local supply shortfalls than the other SEQ sub-regions. This means that the north is the first sub-region to require additional water supplies or extensive demand management. Furthermore, analysis of population growth in the northern SEQ sub-region indicates that additional water supplies will be required around the early 2030s.The implications of variable FSVs for Wivenhoe and North Pine dams on system yield and therefore the timing of supply augmentations is shown in Figure 8.3.

Table 8.2 Comparison of system yields and limiting factors

Wivenhoe Dam %FSV	North Pine Dam % FSV	LOS yield (ML/a)	Change in LOS yield	Limiting factor	Supply shortfalls	Frequency of reaching 40%	Comment
100%	100 %	430,000		Baroon Pocket Dam reaching dead storage	Potential for small local supply shortfalls on Sunshine Coast	1:55 years on average	The frequency that Baroon Pocket Dam reaches dead storage level (leading to potential water supply shortfalls on the Sunshine Coast) is the constraint on the system
100%	85%	430,000	No decrease	Baroon Pocket Dam reaching dead storage	Small local supply shortfalls on Sunshine Coast	1:51 years on average	Lowering North Pine Dam by only 15% doesn't affect Baroon Pocket Dam so there is no change in the system yield
100%	42%	430,000	No decrease	Baroon Pocket Dam reaching dead storage	Small local supply shortfalls on Sunshine Coast	1: 40 years on average	The larger reduction in North Pine Dam FSV leads to a slightly higher risk of supply shortfalls on the Sunshine Coast (represented by Baroon Pocket Dam reaching dead storage level more frequently)
85%	100 %	425,000[1]	No effective decrease	Baroon Pocket Dam reaching dead storage	Small local supply shortfalls on Sunshine Coast	1:35 years on average	Water restrictions occur more frequently, leading to less pressure being placed on Baroon Pocket Dam.
85%	85%	430,000	No decrease	Baroon Pocket Dam reaching dead storage	Small local supply shortfalls on Sunshine Coast	1:34 years on average	Reduction in FSV of both Wivenhoe and North Pine Dams increase the risk of supply shortfalls on the Sunshine Coast (represented by Baroon Pocket Dam reaching dead storage level more frequently)
75%	100 %	430,000	No decrease	Baroon Pocket Dam reaching dead storage	Small local supply shortfalls on Sunshine Coast	1:25 years on average	Water restrictions occur more frequently, leading to less pressure being placed on Baroon Pocket Dam.
75%	75%	425,000[1]	No effective decrease	SEQ water storages reaching 40% combined capacity	Small local supply shortfalls on Sunshine Coast	1:25 years on average	Frequency of reaching 40% increases enough for this criteria to fail before the demand is reached when BPD fails. The decrease in LOS yield is not significant.
60%	85%	395,000	- 35,000 ML/a	SEQ water storages reaching 40% combined capacity	-	1:26 years on average	40% combined capacity is reached significantly more frequently, leading to the central sub-region requiring additional supplies to provide water security through low inflow conditions.
60%	42%	370,000	- 60,000 ML/a	SEQ water storages reaching 40% combined capacity	-	1:26 years on average	40% combined capacity is reached significantly more frequently, leading to the central sub-region requiring additional supplies to provide water security through low inflow conditions.

1. Within the level of accuracy of analysis, these should be regarded as a no decrease result.
Source: DEWS 2014



Source: DEWS 2014

Figure 8.3 Supply demand balance - full supply volume scenarios

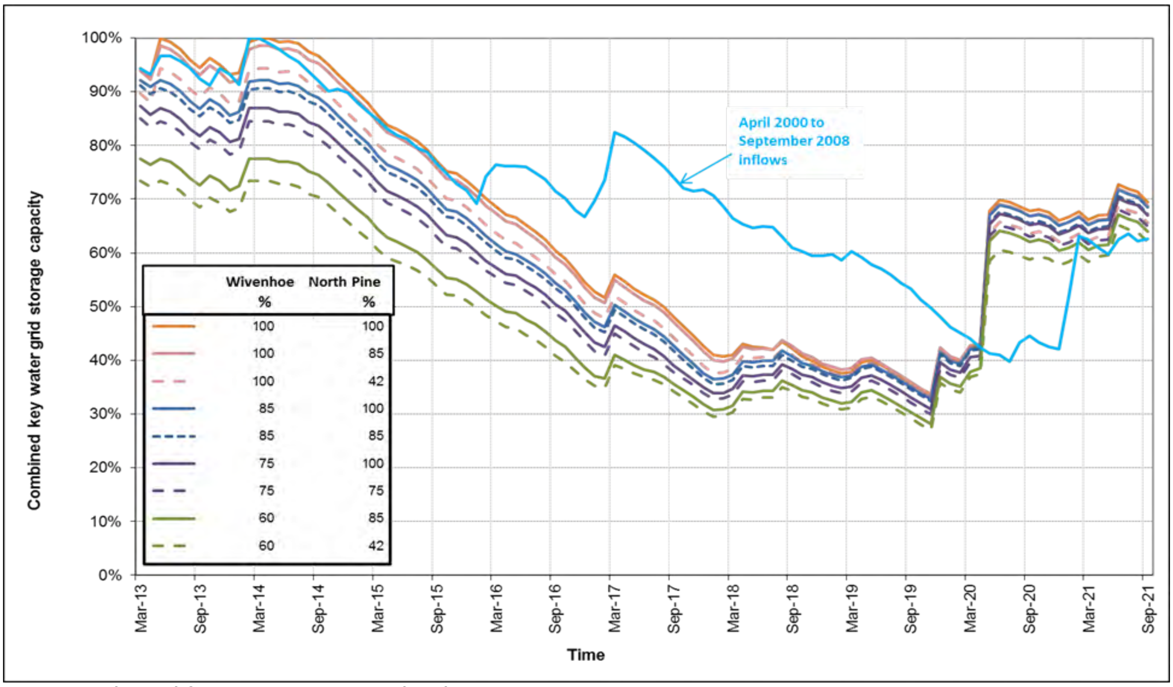
Uncertainties in using stochastic modelling techniques impact the reliability of yield assessments which are dependent on the representativeness of the historical record for predicting future rainfalls and stream flows. The estimated water supply yields for the SEQ water supply system is significantly lower when the historical data set used for generating synthetic climate sequences includes, rather than excludes, the 2001 to 2007 'Millennium Drought' (Pollard et al. 2008). The effect of the Millennium Drought was to significantly downgrade the estimated historical no-failure yield of the Wivenhoe-Somerset dam system, from around 380,000 ML/a to approximately 260,000 ML/a.

Figure 8.4 compares the SEQ water storages capacity behaviour during the 2001 to 2007 drought with a severe drought selected from the stochastically generated sequences and also illustrates the effects of lowering the FSVs in Wivenhoe and North Pine dams. It shows that, as expected, there is a graduation in the water supply available on an annual basis from the Base Case 100/100 (North Pine FSV / Wivenhoe FSV) scenario down to the 85/60 scenario. However it also illustrates that when the combined FSVs of the dams are reduced, manufactured water tends to be triggered earlier under current operating rules thus diminishing the impact of lowering the FSVs of Wivenhoe and North Pine Dams.

Historical timescale modelling[13] (Figure 8.5) was undertaken to highlight the longer term impacts of lowering the FSVs including the Federation Drought (1895–1902) and the recent Millennium Drought (1997–2009). In both droughts, if Wivenhoe FSV were set below 85%, then the SEQ water storages would have fallen below 40% on two occasions. Only the Millennium Drought results in the SEQ water storages falling below 40% (but not below 30%) when normal operations of the dams is 100% FSV. Lowering the FSV of Wivenhoe Dam to

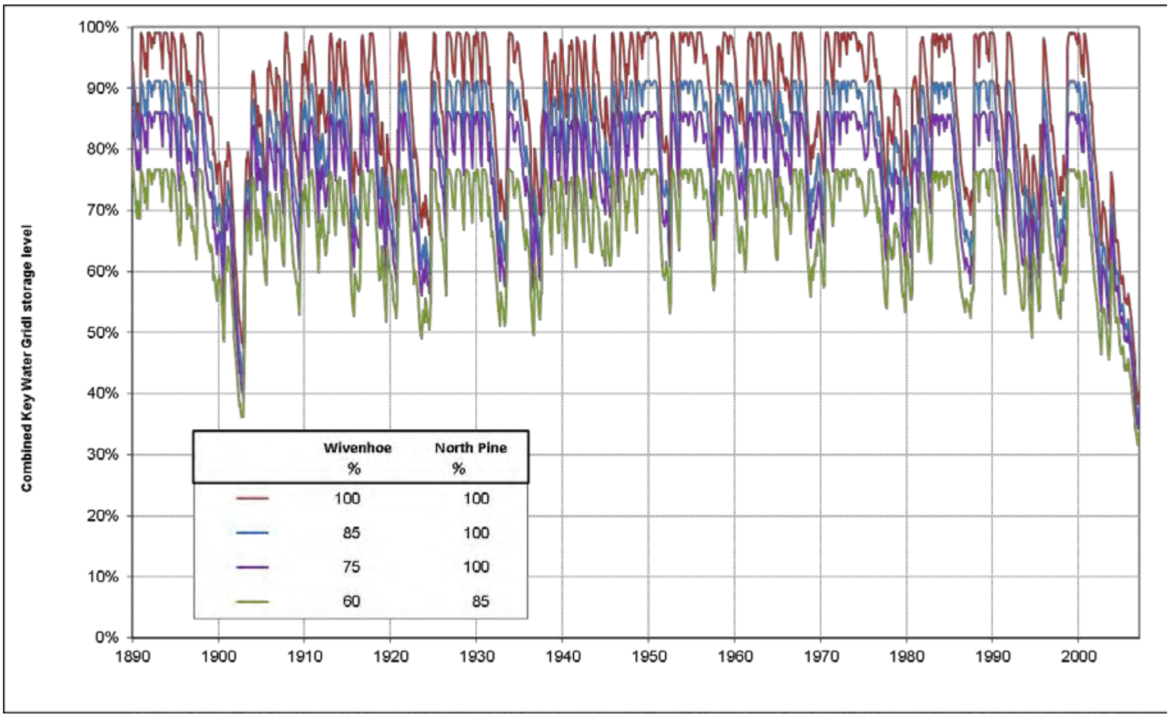
[13] For the historical simulation the demand was fixed at 375,000 ML/a, which is expected to be reached by 2021 under the present 'most likely' demand projections.

60% increases the frequency of reaching 60% of the combined SEQ water storages capacity and hence triggering of GCDP production.



Source: adapted from Seqwater 2014b, Figure 3.15

Figure 8.4 Simulation showing SEQ water storages performance for the historical millennium drought and a stochastically generated sequence applying nine FSV scenarios



Source: Seqwater 2014b, Figure 3.20

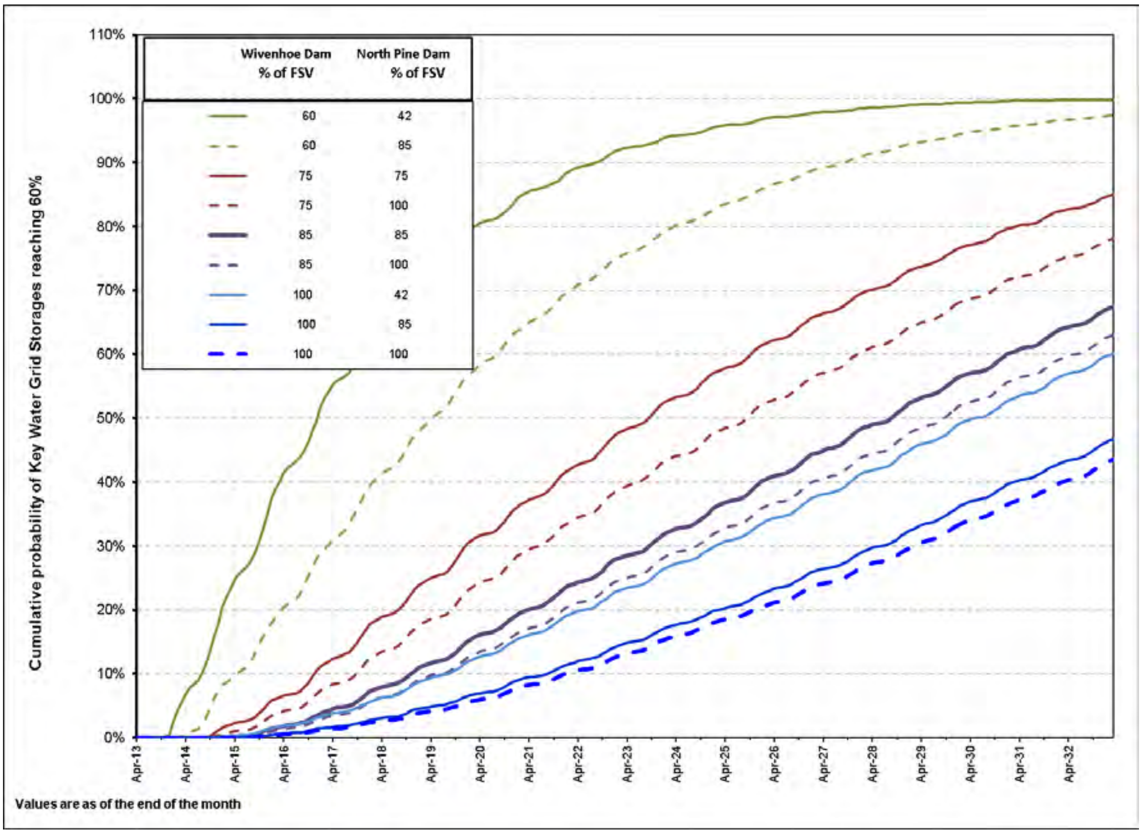
Figure 8.5 Simulated historical performance of the SEQ water storages applying four FSV scenarios

8.7 Cumulative probability assessments

8.7.1 Lowered FSVs

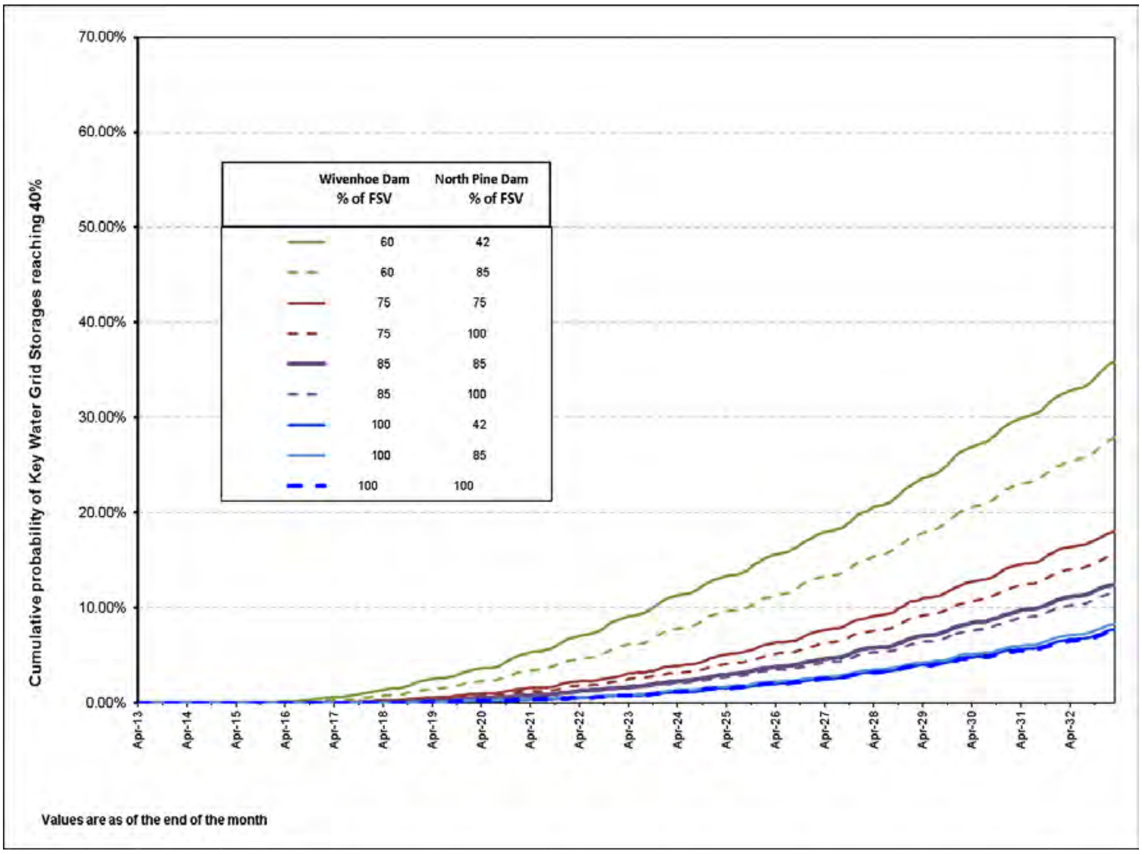
The cumulative probability modelling results for the 60%, 40% and 30% SEQ water storages trigger levels and for each FSV strategy are summarised in Table 8.3 for 2018, 2023 and 2033. The Base Case for comparative purposes was 100% FSV in both Wivenhoe and North Pine dams. Various scenarios considering the lowering of the FSV in Wivenhoe Dam alone and in combination with a lowering of the FSV in North Pine Dam were analysed, assuming manufactured water was available.

Figure 8.65 and Figure 8.76 show the cumulative probability of the SEQ water storages falling to 60% and 40% respectively over the next 20 for various scenarios of lowering the FSVs in Wivenhoe and North Pine dams.



Source: Seqwater 2014b, Figure 3.1

Figure 8.6 SEQ water storages – modelled cumulative probability of reaching 60% over time



Source: Seqwater 2014b, Figure 3.5

Figure 8.7 SEQ water storages – modelled average probability of reaching 40% over time

Table 8.3 Cumulative probability of SEQ water storages reaching 60%, 40% and 30% trigger levels – North Pine and Wivenhoe dams FSV lowered (with manufactured water available)

Combined Capacity Trigger Levels Response Strategy	Year	Modelling Cases (Wivenhoe FSV / North Pine FSV)								
		100/100	85/100	75/100	85/85	75/75	100/85	60/85	100/42	60/42
60%	2018	2.6%	6.2%	13.1%	7.7%	18.5%	3.0%	40.7%	6.1%	65.1%
GCDP (125 ML/d)	2023	13.00%	24.2%	39.1%	28.4%	48.1%	14.7%	75.6%	23.3%	92.2%
	2033	43.5%	63.1%	78.1%	67.4%	84.9%	46.7%	97.4%	60.1%	99.8%
40%	2018	0.01%	0.08%	0.1%	0.1%	0.2%	0.04%	0.7%	0.02%	1.3%
WCRWS (182 ML/d) [1]	2023	0.8%	1.5%	2.4%	1.6%	3.00%	0.8%	6.1%	0.8%	8.9%
	2033	7.6%	11.5%	15.6%	12.4%	18.03%	8.3%	27.9%	7.7%	35.2%
30%	2018	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.02%
Construction of Additional Supplies[2]	2023	0.06%	0.2%	0.2%	0.2%	0.3%	0.1%	0.4%	0.1%	0.5%
	2033	1.4%	2.1%	2.6%	2.2%	3.00%	1.4%	4.1%	1.2%	5.4%

Notes:

1. WCRWS brought on line in addition to GCDP
2. Additional supplies assumed to be 125 ML/d desalination plants

Source: Seqwater

Reducing the FSV of Wivenhoe Dam increases the probability of triggering drought contingency measures. For example:

- reducing the FSV of Wivenhoe Dam to 85% (indicated by the purple dotted line):
  - increases the cumulative probability of the SEQ water storages reaching 60% of combined capacity within the next 10 years by over 10% (i.e. from 13% to about 25%)
  - nearly doubles the cumulative probability of reaching 40% of combined capacity of SEQ water storages within 10 years (i.e. from about 0.8% to 1.5%)
- reducing the FSV of Wivenhoe Dam to 75% (indicated by the red dotted line) triples the cumulative probability of reaching:
  - 60% of combined capacity of SEQ water storages within the next 10 years (i.e. from 13% to 39%).
  - 40% of combined capacity of SEQ water storages within the next 10 years (i.e. from about 0.8% to 2.5%).

Reducing the FSV of Wivenhoe Dam can therefore bring forward the timeframe for supplementing water supplies with manufactured water (i.e. desalinated water and purified recycled water). Furthermore, reducing the FSV of Wivenhoe Dam extends the time below the trigger points, increasing the time that manufactured water supplies are required. For example during drought, in Figure 8.4, the Western Corridor Recycled Water Scheme is operating an additional 12 months when the FSV of Wivenhoe Dam is reduced to 85%.

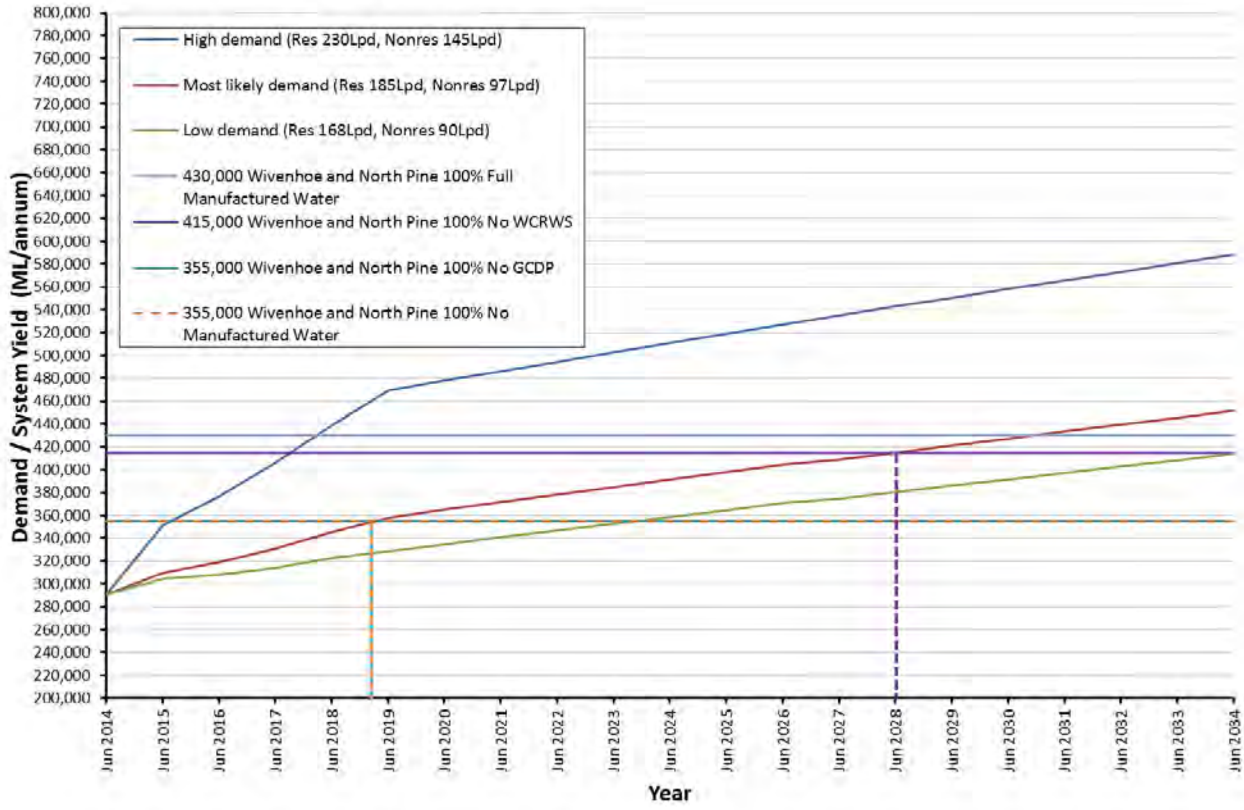
8.7.2 Availability of manufactured water

The implications of variable availability of manufactured water for addressing shortfalls were only assessed for scenarios where both dams were maintained at either 100% FSV or 85% FSV. These results are summarised in Table 8.4.

Table 8.4 Cumulative probability of SEQ water storages reaching 60%, 40% and 30% trigger levels – various North Pine and Wivenhoe dams FSVs versus manufactured water availability

Manufactured Water Production	Year	Probability of reaching 60% combined capacity		Probability of reaching 40% combined capacity		Probability of reaching 30% combined capacity	
		100/100	85/85	100/100	85/85	100/100	85/85
Full Manufactured Water available	2018	2.6%	7.7%	0.01%	0.1%	0.00%	0.00%
	2023	13%	28.4%	0.8%	1.6%	0.06%	0.2%
	2033	43.5%	67.4%	7.6%	12.4%	1.4%	2.2%
Without GCDP (i.e. WCRWS is the only manufactured water available)	2018	2.3%	8.2%	0.1%	0.2%	0.00%	0.01%
	2023	13.2%	29.2%	1.3%	2.9%	0.2%	0.4%
	2033	44.2%	68.3%	10.6%	17.7%	2.8%	4.5%
Without WCRWS (i.e. GCDP is the only manufactured water available)	2018	2.6%	9.2%	0.02%	0.1%	0.00%	0.01%
	2023	14.2%	30.6%	1.0%	2.0%	0.2%	0.4%
	2033	45.8%	69.7%	8.6%	13.9%	2.5%	3.7%
Without GCDP and WCRWS (i.e. no manufactured water is available)	2018	2.7%	9.5%	0.1%	0.3%	0.01%	0.01%
	2023	14.8%	31.6%	1.6%	3.6%	0.4%	0.7%
	2033	46.8%	70.6%	11.9%	19.5%	4.2%	7.0%

Source: Seqwater



Source: DEWS 2014

Figure 8.8 Supply demand balance – changed availability of manufactured water

The implications of variable availability of manufactured water for system yield and therefore supply augmentation timing were assessed for scenarios where both dams were maintained at either 100% FSV or 85% FSV as shown in Figure 8.8.

If the WCRWS was not available to be fully operational at the 40% trigger, the timeline for augmentation of supply in SEQ would be brought forward from 2031 to 2028 and the likelihood of reaching the 30% trigger would be increased. Modelling indicated that the cumulative probability of reaching 30% within the next 20 years would approximately double (but be less than 5%) if Wivenhoe and North Pine dams are lowered to 85% FSV. Having neither the WCRWS nor the GCDP would roughly triple the cumulative probability of reaching the 30% trigger by 2033 (but the probability is less than 7%).

Increases in the frequency of use of manufactured water supplies are an increase in bulk water supply costs. These additional costs are described in Chapter 15 and included in the options assessment.

There are only small changes in the cumulative probabilities in Table 8.4 between manufactured water being available and not available. This is due to several factors such as:

- the cumulative probabilities for reaching the thresholds for initiating manufactured water production and construction of new sources of supply assuming the current high levels in the dams.
- the current demands being well below the SEQ water supply system yield, and to a lesser extent
- the system operating rules incorporating triggers for restrictions and manufactured water production.

Figure 8.8 indicates that without the WCRWS and the GCDP, supplies in SEQ would need to be augmented around 2019. A future decision to actually augment supply would be based on consideration of the SEQ water supply system yield as in Figure 8.8 and the levels in the dams at the time. If the SEQ water storages are relatively full, typically, it can take between eight to ten years to deplete them. Obviously, the least cost solution will be to defer capital expenditure until it is needed.

8.8 Conclusions

The Seqwater RSM modelling indicates that the yield of the SEQ water supply system to deliver the currently specified level of service for SEQ generally remains constant at around 430,000 ML/a when varying the FSVs in both Wivenhoe Dam and North Pine Dam from 100% down to 75%.

Under the assumed most likely projected demands, augmentation of the supply yield of the SEQ water supply system would need to commence around 2031.

Without Purified Recycled Water from the Western Corridor Recycled Water Scheme, the system yield reduces to 415,000 ML/a and at this demand, the SEQ water storages drop below 20% much more frequently while there is the risk that the Brisbane storages could reach minimum operating level.

Without both purified recycled water (PRW) and desalinated water from the Gold Coast Desalination Plant the system yield drops to about 355,000 ML/a.

The corresponding timelines (Figure 8.8) for augmentation of supply would be brought forward to 2028 (no PRW) and 2019 (no PRW and no desalination) allowing for construction and commissioning. As indicated above, a future decision to actually augment supply would be based on consideration of the SEQ water supply system yield as in Figure 8.8 and the levels in the dams at the time.

The probabilities of reaching manufactured water production triggers (60% and 40% of the SEQ water storage) in the next 10 to 20 years increase if there is a lowering of the levels in Wivenhoe Dam. The probabilities of reaching these trigger levels increase further if one or both of the manufactured water sources (PRW and desalination) are not available. This increased triggering would translate into increased bulk water supply costs.

The Wivenhoe and Somerset dams system is central to and provides approximately 60% of SEQ's water supply. The effect of the 2001 to 2007 drought was to significantly downgrade its yield. This experience cautions against any significant lowering of Wivenhoe Dam especially on a permanent basis. Uncertainties in using stochastic modelling techniques impact the reliability of yield assessments which are dependent on the representativeness of the historical record for predicting future rainfalls and stream flows.

Given that current water usage for the 2012-13 financial year for all of SEQ was 282,000 ML, the modelling indicates that the FSV of Wivenhoe Dam could be lowered at least on the basis of a declared temporary full supply level having regard to weather forecasts and dam levels at the time.

The modelling results indicate that altering the full supply volume (FSV) of Wivenhoe Dam has implications for the water security for SEQ. The modelling suggests that reducing the FSV of Wivenhoe Dam to 85% can have implications on the performance of the bulk water supply system in the medium term (i.e. 5-15 years), increasing the risk that drought contingency measures would need to be implemented. The greater the reduction in the FSV of Wivenhoe Dam, then the greater is the impact on both medium and long-term water security.

DEWS is currently reviewing the desired Level of Service objectives for SEQ and subsequently it is proposed that Seqwater establish a new water security program for the SEQ water supply system in late 2015.

The formulation of the water security program should further consider the risks of lowering the water supply levels in Wivenhoe Dam based on a stronger understanding of changes in water usage and dam levels during severe droughts.

Chapter 9 Dam Safety

The structural safety of the dams is the paramount objective of dam flood operations. Assessment of the safety of Wivenhoe (and Somerset) dam for a range of operational options and over a range of flood events was a key consideration required under QFCoI Final Report recommendation 17.3.

Analysis of options under in this study was on the basis that the current level of safety of the existing dams will not be reduced.

This chapter:

- outlines the minimum dam safety requirements that must be met by the operator of Wivenhoe and Somerset dams
- describes the current dam safety status of each of the dams, and
- discusses the implications for dam safety of operational options outlined in Chapter 4.

9.1 General

Major dams are usually constructed and sized to provide reliable water supplies. They may also provide flood mitigation or hydroelectric power generation. Dams generally require many years for planning and construction and are costly to establish. Dams have very long useful lives and generally provide water economically when compared to other source of supply options.

The potential sudden loss of a major dam through its physical failure can have catastrophic consequences for any downstream communities (in terms of casualties and property damage from flooding) as well as an ongoing water supply crisis for the wider population served.

Because of the potentially extreme consequences of dam failure for major dams, their design has long embodied the concept of relatively conservative risk assessments with well-established national and international guidelines and standards that aim to ensure that the likelihood of dam failures is extremely rare (ANCOLD 2000, DEWS 2013b).

9.2 Legislation

There is no Federal legislation covering the safety of dams, but Queensland is one of four Australian states where the development and surveillance of dams is controlled. Under the provisions of the *Water Supply (Safety and Reliability Act) 2008* (QLD) (the Act), both Wivenhoe and Somerset dams are Category 2 referable dams. A Category 2 dam is one where the population at risk is greater than 100 people.

DEWS administers the Act and is the dam safety regulator in Queensland. DEWS also applies various safety conditions to referable dams and publishes the following guidelines with which owners of referable dams must comply:

- Queensland Dam Safety Management Guidelines February 2002 – (DNRM 2002)
- Guidelines for Failure Impact Assessment of Water Dams - .(DEWS 2012)
- Guidelines on Acceptable Flood Capacity for Water Dams January 2013 – (DEWS 2013b).

The Act (Part 2, Chapter 4) also requires the owner of Wivenhoe and Somerset dams (Seqwater) to prepare and maintain a flood mitigation manual (FMM) for the dams, which must meet the requirements set-out in the Act.

The purpose of a FMM is to provide sufficient information and guidance to support appropriate decisions on how best to release flood waters from a dam during flood events (i.e. in line with the flood mitigation objectives).

In particular, a FMM needs to document:

- flood mitigation objectives for dam operations and their importance relative to each other
- operational strategies required to achieve the objectives, and
- operational procedures to be followed under each strategy.

9.3 Dam failure and Acceptable Flood Capacity

All dams have some risk of failure. Dam failure mechanisms vary depending on the event that leads to failure, the individual dam configuration, its foundations and the structural materials used. As this study is focused on dam flood operations, it also tends to focus on dam failure as a result of hydraulic conditions e.g. overtopping of the embankment by a very large flood or increased risk of piping or erosive failure in large floods.

The critical failure mode will depend on the individual circumstances for each dam. In order to minimise the risk of failure, the critical failure modes have to be adequately protected. As a general rule, assuming the foundations are sound, mass concrete dams will tend to have greater resistance to failure due to overtopping than dams constructed of earth and/or rock-fill.

Earth and/or rock fill embankments (e.g. Wivenhoe Dam) can be subject to embankment erosion as a result of overtopping by floodwaters, or by piping (seepage or leaking) where there is localised weakening and flow through the embankment leading to failure by the formation and growth of erosion pipes through the embankment.

Mass concrete dams (Somerset Dam) tend to fail due to hydraulic causes through an overloading failure of the structure itself, stability failure of the concrete monoliths (sliding or toppling) or erosion or structural failure of foundations or abutments. The Portfolio Risk Assessment (URS, 2013) identified that the critical failure modes for Somerset Dam are limitations on the load that can be placed on the upper structure of the monoliths and potential significant damage to downstream foundations during large flows.

The possible ‘sunny day’ failure scenario of earthquakes is currently identified as a critical failure mode for Somerset Dam only (URS 2013).

An important dam safety concept is Acceptable Flood Capacity (AFC). The AFC is the overall flood discharge capacity required of a dam to enable it to safely pass a design flood of a given magnitude without causing failure of the dam. The magnitude of the design flood required is based on the hazard that the dam presents to downstream communities if it were to fail. The higher the hazard or the consequences of failure, the higher the required AFC.

The maximum probability of flood event that needs to be safety passed (i.e. the probability of the AFC) can be selected as a function of the *assessed hazard category* for the dam or by undertaking a *full risk assessment* for the dam. Both methods produce required AFC flood magnitudes which are a function of the consequences of dam failure.

In addition to the AFC considerations, a full risk assessment should incorporate the risks of Wivenhoe and Somerset dams operating in tandem. Because they are linked storages, a failure of Somerset Dam could precipitate a cascade failure of the downstream Wivenhoe Dam during large to extreme flood events across the whole basin.

9.3.1 Wivenhoe Dam

Wivenhoe Dam is located upstream of a number of communities including the cities of Brisbane and Ipswich and large areas of each are expected to be inundated with catastrophic impacts to life and property if it were to fail.

The potential consequences of failure of Wivenhoe Dam have been estimated (URS 2013) and include:

- up to around 270,000 people put at risk (depending on the failure scenario)
- loss of life of the order of 400 (there are significant uncertainties in estimating loss of life)
- total direct damage costs to the community of over $100 billion (a significant fraction of the gross domestic product of Australia)
- total indirect costs of a similar magnitude, and
- the loss of the most significant water supply source for SEQ.

As a result, Wivenhoe Dam is classified as an 'extreme' hazard category dam (i.e. the population at risk is greater than 1,000) and therefore in accordance with relevant guidelines (DEWS 2013b) should be able to safely pass the largest possible flood that is estimated to be able to occur in its catchment (the Probable Maximum Flood (PMF)) without failure i.e. the AFC for Wivenhoe Dam is the PMF.

Since the required spillway capacity for Wivenhoe Dam was first determined in 1977 and construction of the dam in 1983, there have been several revisions of the Probable Maximum Precipitation (PMP) and hence the PMF. These factors gave rise the construction of a wave wall along the crest of the dam, and in 2005 the construction (Wivenhoe Alliance 2005) of an auxiliary spillway located in the embankment wall to the right of the central spillway (looking downstream) and the strengthening of the wave wall, The original design frequency for the auxiliary spillway was 1 in 6,000 AEP.

The auxiliary spillway comprises three bays sealed by fuse plug earth and rock embankments which are designed to erode when overtopped and allow additional releases.

Overtopping of the first fuse-plug begins at EL 75.7 mAHD with the second and third plugs following at EL 76.2 mAHD and EL 76.7 mAHD respectively. Once all fuse plugs are fully eroded, the auxiliary spillway discharges a flow approximately equal to the flow passing through the five central spillway gates (fully open).

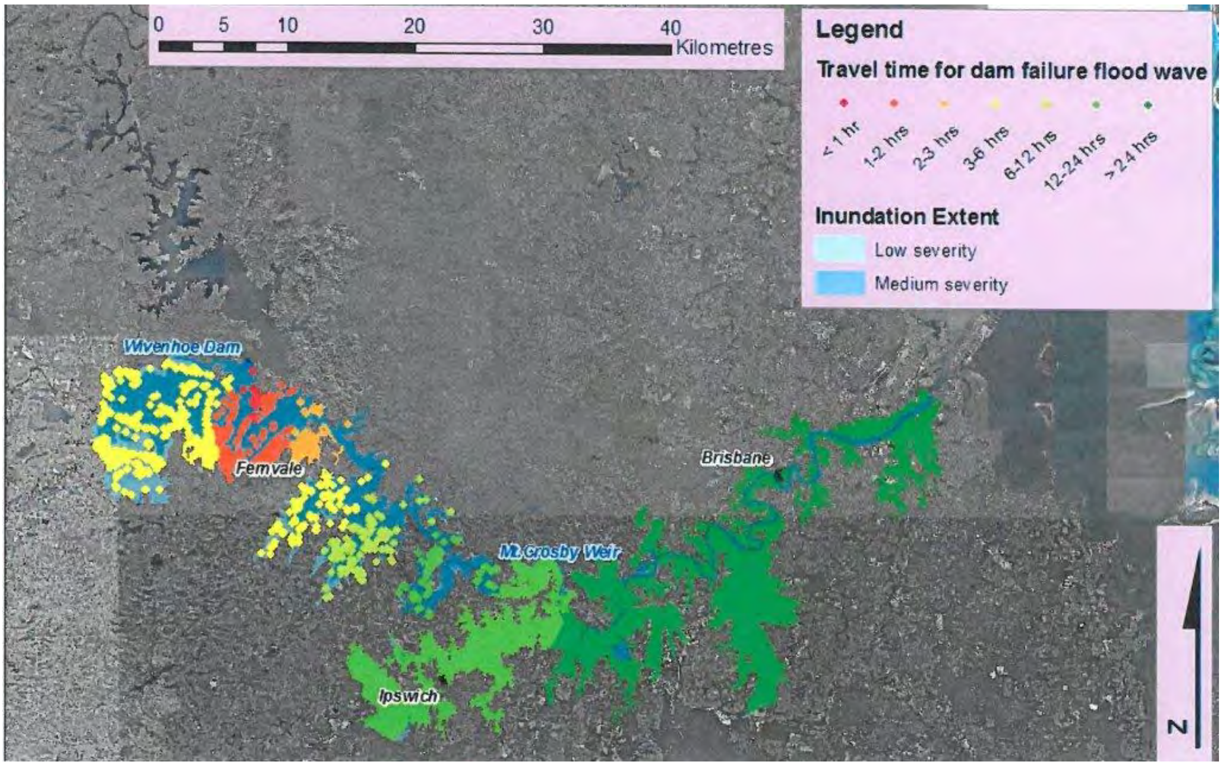
The recent Seqwater Portfolio Risk Assessment (PRA) for Wivenhoe Dam (URS 2013) identifies three critical failure modes that contribute about 98% of the risk of failure of Wivenhoe Dam:

- two are possible piping (internal erosion) failure through the foundations[14] of Saddle Dams 1 and 2, which provide the impoundment for the flood compartment (estimated likelihood of approximately 1 in 120,000 to 1 in 180,000 AEP), and
- the third is overtopping failure of the main dam embankment, (estimated likelihood in the order of 1 in 500,000 AEP).

The risks associated with the critical failure modes are aggravated by elevated lake levels with greater risks occurring whenever the lake level rises above about 76 mAHD (Seqwater 2014a) and require the dam to be operated in accordance with specific flood operation rules in order to manage the risk.

The PRA (URS 2013) also evaluated the current societal risk profile for Wivenhoe Dam as being slightly higher than the ANCOLD (and Queensland) recommended maximum tolerable risk profile.

Estimated dam failure flood wave travel times have been published in the PRA (URS 2013). Due to their distance downstream, the larger population centres are expected to receive many hours of warning prior to the arrival of dam failure flooding (12 to 24 hours, or greater) however, there are smaller communities closer to the dam (e.g. Fernvale) where warning times would be much shorter. Figure 9.1 (URS 2013) below indicates the relative dam failure flood wave travel times for areas downstream of Wivenhoe Dam.



Source: (URS 2013)

Figure 9.1 Estimated warning time for overtopping failure of Wivenhoe Dam

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[14] The PRA also identified piping failure through the embankments of Saddle Dams 1 and 2 as potential flood initiated failure mode, however these were assessed as having much lower probabilities (approximately 1 in 19,600,000 and 1 in 23,300,000 respectively) than piping through the foundations

9.3.2 Somerset Dam

Somerset Dam is immediately upstream of Lake Wivenhoe on the Stanley River. The PRA (URS 2013) indicates the consequences of a Somerset Dam failure, which may lead to a cascade failure of Wivenhoe Dam, are also catastrophic. As a result, Somerset Dam is also classified as an 'extreme' Hazard Category dam (i.e. the population at risk is greater than 1,000) and should therefore also be able to safely pass the PMF for its catchment without failure. Hence, Somerset Dam's AFC is also the PMF.

Somerset Dam comprises a 58 m high mass concrete gravity wall with eight low level sluice gates, four regulator valves and eight spillway crest gates.

The dam was completed in 1959 and extensive cracking was subsequently identified in parts of the upper gallery walls (upper parts of the dam wall). This cracking has been extensively investigated in recent years to determine what role it might have in critical failure scenarios. It is currently estimated this dam can withstand limited overtopping of the main monolith crest without damage.

A critical failure mode for Somerset Dam is considered to be a failure of the upper portion of the dam wall above the change of section in the monoliths due to loading from high lake levels during major floods. Another potential critical failure mode is via erosion of the abutment and downstream foundation material in larger overtopping events. This aspect is currently being investigated as follow-up work from the PRA (URS 2013).

Flood releases from Somerset Dam are regulated through the sluice gates only with minor adjustments via the cone valves. The crest gates are held fully open for the duration of a flood, with flows passing over the spillway crest.

Uncertainty currently exists about the operational reliability and the structural adequacy of the spillway crest radial gates and their supporting structures in a large event. The spillway crest gates on Somerset Dam were originally provided to regulate flood outflows. However, this function is now largely performed by Wivenhoe Dam with Somerset Dam operated in an assisting and less critical flood mitigation role.

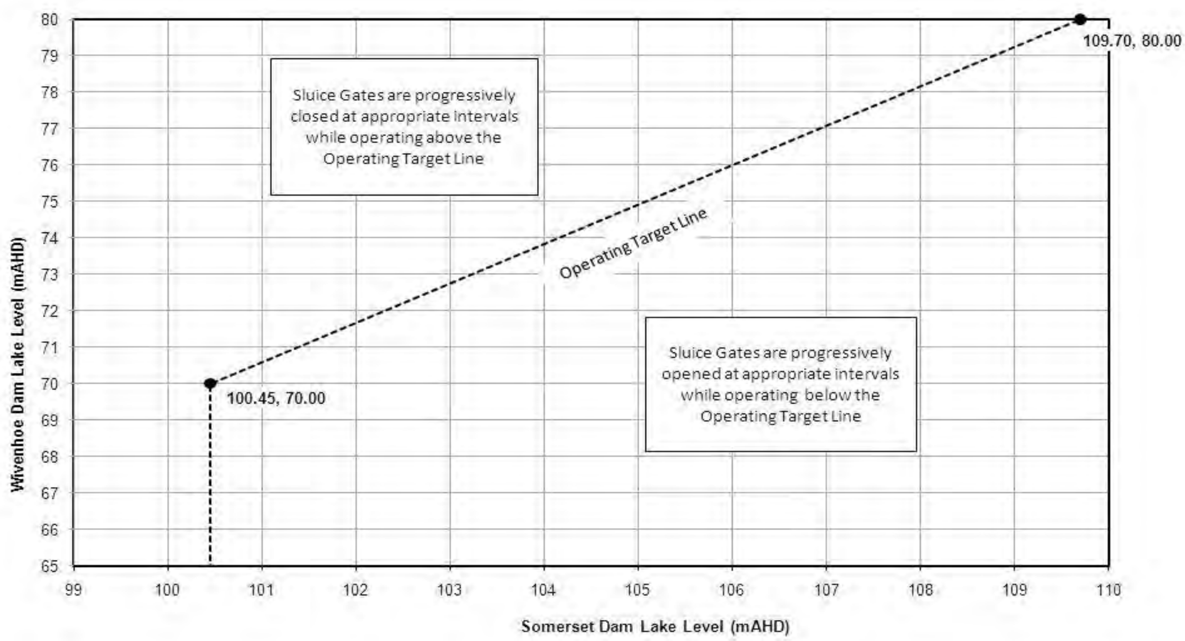
Resolving the uncertainties around the spillway gates has not been a priority as this does not significantly affect the overall flood mitigation response of the dams across the range of flood events. However, high lake levels due to extreme floods (or lesser floods in combination with inappropriate operation of the crest gates or the sluices) could increase the risk of dam failure.

9.3.3 Relationship between lake levels in Somerset Dam and Wivenhoe Dam

The management of the Somerset Dam releases into Wivenhoe Dam and the effect on the Somerset lake level is critical to its overall safety. As Somerset feeds directly into Wivenhoe Dam downstream, it is also conceivable during larger flood events over the whole basin that a failure of Somerset dam could precipitate a cascade failure of Wivenhoe Dam. This places a premium on understanding the limitations of both dams.

The safety of Somerset Dam relative to that of Wivenhoe Dam is controlled by flood operation rules, which currently aim to keep the relative risks of failure as similar as possible throughout each flood event. This is achieved by ensuring the respective lake levels are kept as close as practicable to the specified 'interaction line' in the Flood Manual - refer Figure 9.2 below (Seqwater 2013a).

As many major floods tend to begin with inflows from the wetter Stanley River catchment upstream of Somerset Dam, flood operations often tend to commence with the storage levels plotting below the interaction line on the Somerset Dam "side" of the line.



Source: Seqwater 2013a

Figure 9.2 Wivenhoe Somerset dams Interaction Line

The appropriateness of the current strategy (i.e. using the flood storage in each dam at a similar rate up to maximum safe levels) should be re-evaluated. Because of the potential for cascade failure, a more clearly defined policy position on the appropriate order of dam failure may be required in order to avoid the complete loss of the capacity to subsequently provide an adequate water supply.

9.4 Dam safety impacts of operational alternatives

All Seqwater dams have been subject to a portfolio risk assessment (URS 2013). The PRA provides the basis for necessary future dam upgrades. The following assessment of impacts of the operational alternatives is based on consideration of the dam overtopping assessments, the AFC described earlier, the likelihood of the fuse plugs and associate spillway being initiated and the risks to the saddle dams.

9.4.1 Assessment of options for dam overtopping

The likelihood of dam overtopping for each of the operational options was investigated by Seqwater and are reported in Seqwater (2014a). The principal findings from that investigation are presented below.

Simulations were performed to assess the relative capacity of alternative operations to pass extreme events and identify any dam safety implications. Three different methods to develop extreme floods for capacity simulation were assessment:

- Probable Maximum Flood (PMF) events to determine the portion of PMF (scaled PMF) that can safely pass through Wivenhoe Dam assuming that 1 spillway gate has failed.

- Deterministic design extreme floods derived in accordance with Australian Rainfall and Runoff guidelines. This method allowed an approximate estimate of the AEP of the dam crest flood which would overtop Wivenhoe Dam to be identified.
- Hypothetical extreme floods derived by scaling up a major historical flood event (in this case scaling up of the January 2011 flood event).

The simulation results were used to identify the magnitude of extreme flood that safely pass through Wivenhoe Dam without overtopping the dam embankment (80 m AHD peak water level) and safely pass through Somerset Dam without exceeding the maximum safe level (109.7 mAHD peak water level) and are shown in Figure 9.3..

For all dam operations options including raising the dam safety strategy trigger level, the results indicate minimal change in the spillway adequacy of Wivenhoe Dam to pass large extreme flows expressed as a percentage of the probable maximum flood (PMF).

The possibility of cascade failure, i.e. a failure of Somerset Dam causing the subsequent failure of Wivenhoe Dam was also reviewed.

The simulation results indicate that:

- Wivenhoe Dam can pass approximately 68% of the probable maximum flood (PMF) with one gate failed. Somerset Dam can pass 71% of the PMF with all gates operational and one gate failed at Wivenhoe.
- All operational alternatives based on concepts in the Flood Manual, including those that raise the Dam Safety Strategy trigger level, did not significantly change the current capacity to pass the PMF event.
- Lower FSVs for Wivenhoe Dam only marginally increase the capacity to pass the PMF.
- The effects of lowering FSV under Base Case operations are as follows:
- The capacity of Wivenhoe Dam to pass extreme floods increases to between 70% and 71% of the critical PMF event (with one gate failed)
- The capacity of Somerset Dam to pass extreme floods increases marginally to 72% of the critical PMF event for the 85%, 75% and 60% FSV scenarios.
- The probability of flood levels reaching the Wivenhoe Dam crest level decreases marginally from approximately 1 in 65,000 to approximately 1 in 70,000 AEP
- The probability of flood levels reaching the maximum safe level in Somerset Dam does not change (1 in 25,000 AEP).
- Both the design AEP floods and stochastic flood simulation results identify appreciable probability of cascade failure. Mitigation of cascade failure risk will need to be an important consideration for the prioritisation of planning and upgrade works to Somerset Dam to achieve acceptable flood capacity.

Seqwater (Sewater 2014a) have cautioned against relying solely on the modelling results to fully understand the impact of the operational options on dam safety because the probable maximum flood (PMF) and design (AEP) events *“have idealised assumptions of rainfall used as inputs to generate these floods………that uses uniform rainfall probability and temporal pattern on the entire catchment…..without pre-burst rainfall”* which Seqwater believe *“is not well suited to define the hydrological risk to the safety of Wivenhoe and Somerset Dams”*.

In addition, Seqwater note that the January 2011 flood highlighted the possibility of an extreme rainfall burst late in a flood event which poses increased risk for dam safety generally, and particularly for options that raise the dam safety trigger level.

9.4.2 AFC estimates under current operations

The assessment shows neither Wivenhoe Dam nor Somerset Dam can currently pass 100% of their respective required AFC and therefore both require future upgrades. This is not through any specific deficiencies in the original design of the dams but rather has resulted from large increases in the estimates of the floods (due to a better understanding of potential extreme rainfall) which these dams might be subjected.

Furthermore, the consequences of a potential failure have increased with population and development and increased knowledge of the details of those consequences.

This is not an uncommon situation for many existing large dams in Australia and worldwide. It is one that dam safety regulators have to deal with in a practical manner and Queensland has a specified program for dam spillway upgrades based on risk.

DEWS (2013c) has established a maximum allowable timeline for owners to upgrade dams which do not meet 100% AFC. These timeframes were decided as a maximum timeframe for realising necessary upgrades, based on the low probabilities typically estimated for dam failure events and recognising the likely time needed to plan, investigate and implement potentially major construction works. The schedule from the guideline is reproduced in Table 9.1.

Table 9.1 Prescribed schedule for dam safety upgrades

Tranche	Required minimum flood discharge capacity	Date by which the required minimum flood capacity is to be in place for existing dams
1	25% AFC [1]	1 October 2015 [2]
2	65% AFC	1 October 2025 [2,3,4]
3	100% AFC	1 October 2035 [2,3,4]

Source: DEWS 2013b, Section 4

Notes:

1. Or with at least 1:2,000 AEP for erodible dam embankments (whichever is the bigger flood)
2. As a guide, it is expected that up to about five years may be required to complete a flood discharge capacity upgrade for dams greater than 10 metres in height, and two years will be required to complete a spillway upgrade for smaller dams. However, each case will be considered on its merits.
3. In each case the required discharge capacity will need to be reassessed just prior to the undertaking of final spillway upgrade works to ensure that the required acceptable flood capacity has not changed and that the planned spillway capacity is still consistent with the specified upgrade program
4. The timing of the tranches will be confirmed once the acceptable flood capacity, and related assessments have been completed for all or most of the known referable dams

Based on analysis undertaken as part of this study (Seqwater 2014a) and outlined in 9.4.1 above, the estimates of the present extreme flood capacity (as a proportion of the required AFC) of each dam are summarised in Table 9.2, together with the prescribed DEWS timeline to meet the AFC.

Table 9.2 Current estimates of Wivenhoe and Somerset Dams Acceptable Flood Capacity

Dam	Required AFC	Current proportion of AFC dams can pass[1]	AEP of Critical Flood[2]	Year upgrade required to be completed
Wivenhoe	100% PMF	≈68% PMF	≈ 1:65,000	2035
Somerset	100% PMF	≈71% PMF	≈ 1:25,000	2035

Notes:

1 Using Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam Revision 11 - Nov 2013)

2 PMFs are with one gate failed at Wivenhoe

The AEPs of the floods just overtopping Wivenhoe Dam and reaching the maximum safe level for Somerset Dam are estimated to be approximately 1 in 65,000 and 1 in 25,000 respectively (Seqwater 2014a). As required by the *Guidelines on Acceptable Flood Capacity for Water Dams January 2013 – DEWS 2012*, these extreme flood capacity assessments assume one gate closed on the Wivenhoe Dam central spillway, however all sluices on Somerset are assumed operable.

Consequently, both Wivenhoe and Somerset dams need future upgrades to meet the requirement to safely pass 100% of their respective PMFs.

Although Wivenhoe and Somerset dams do not meet the required AFCs, as both exceed 65% of the current estimates of AFC, dam safety upgrades for both dams are currently required by 2035. Because of the magnitude of consequences of failure for these dams, the timing of these upgrades may need to be periodically reviewed. Plans for both dams are subject to further studies

9.4.3 Fuse-plugs and auxiliary spillway

Under the Base Case (100% FSV) scenario:

- The lowest fuse plug overtops at approximately 1 in 700 AEP
- The second fuse plug overtops at approximately 1 in 2,000 AEP
- The highest fuse plug overtops at approximately 1 in 5,000 AEP

The probability of a flood overtopping the lowest fuse plug decreases to approximately 1 in 1,000 AEP for the 60% FSV Base Case.

Most of the simulated alternative dam operations do not significantly change the AEP of overtopping the lowest fuse plug. However, for alternative Urban 4 operations which include allowing the breaching of a fuse plug as a flood mitigation (rather than a dam safety) measure (i.e. setting the dam safety trigger at EL 76.2 mAHD) there would be approximately 20 times greater probability of overtopping the lowest fuse plug i.e. AEP approximately 1 in 30 at 100%FSV, reducing to 1 in 200 AEP at 60%FSV. Seqwater have indicated that this would not meet Queensland guidelines and other recognised dam safety guidelines[15].

[15] The relevant guidelines on the operation of fuse plug spillways are the Queensland Guidelines on Acceptable Flood Capacity (DEWS 2013c) and the US Department of the Interior Guidelines for Using Fuse–plug

Whilst the auxiliary spillway fuse plugs are designed to erode quickly when overtopped, the fuse plug embankments are constructed of natural earth-fill and gravel materials and there is no certainty about exactly how their erosion will progress when overtopped. Furthermore, the consequences of breaching the fuse plugs are not limited to replacing the fuse plug embankment(s) as this will typically take up to six months and mean that the dam will not have the same control of any subsequent events in the same wet season.

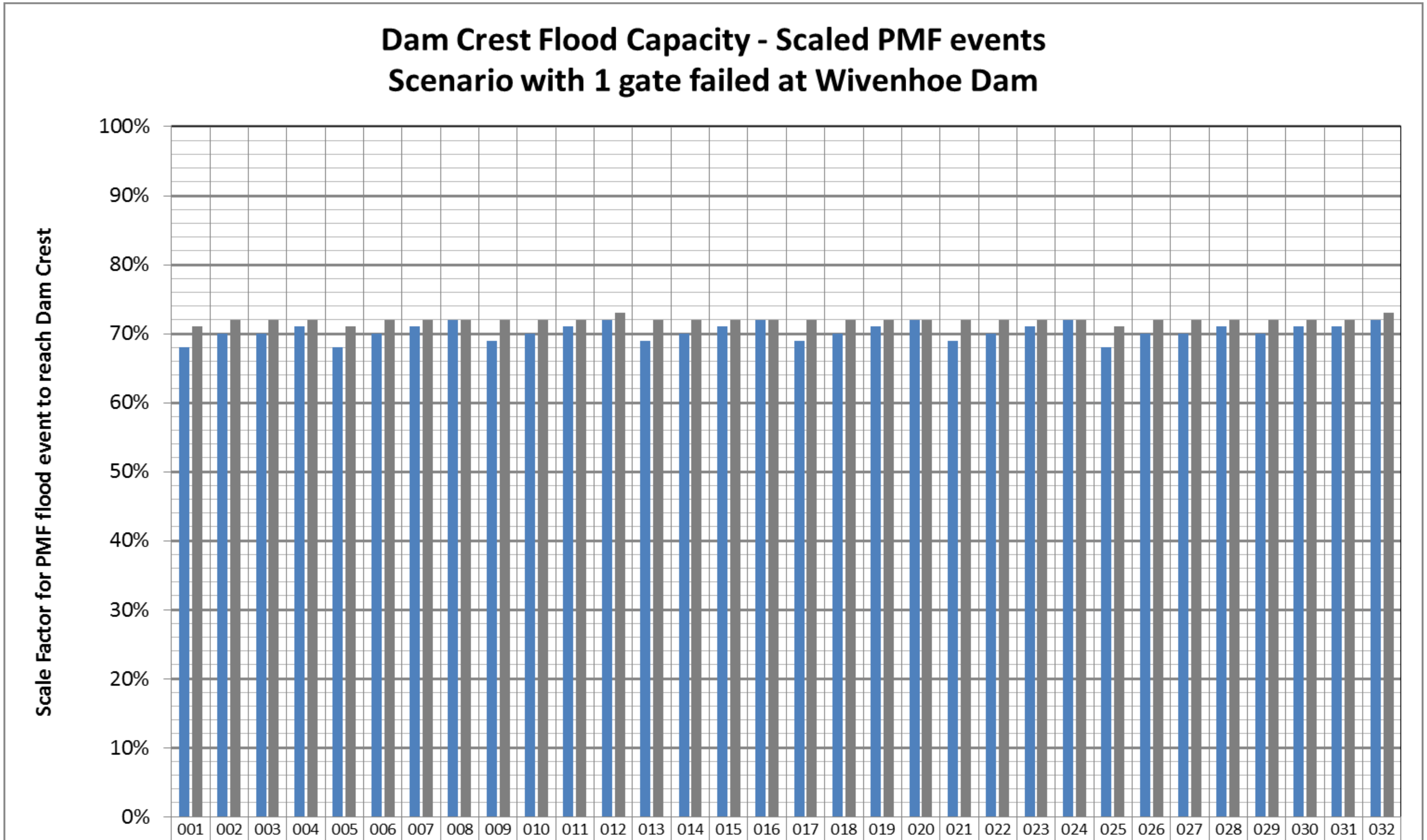
The auxiliary spillway was also originally intended to function only as an emergency spillway which would trigger for flood events having an AEP of the order of 1 in 6,000. As such, an unlined downstream spillway chute was considered acceptable on the basis that there was a low probability of it operating and that tail water levels would be high when it did trigger – helping limit erosion downstream of the auxiliary spillway. Alternative Urban 4 operations are estimated to substantially increase the probability of the auxiliary spillway activation in conjunction with lower downstream tail water levels, exacerbating the spillway chute scour and downstream damage.

9.4.4 Saddle dam piping (internal erosion)

The flood simulation results show that the probability of Wivenhoe Dam level reaching EL 76 mAHD is relatively low at about 1 in 1,000 AEP (for 100% FSV Base Case). Most of the alternative dam operations considered do not adversely increase the probability of reaching or exceeding EL 76 mAHD flood level in Wivenhoe Dam. However, the alternative Urban 4 operations indicate that the probability of reaching or exceeding EL 76 mAHD would increase by a factor of five to approximately 1 in 200 AEP and result in more frequent wetting of the saddle dam foundations which would make the saddle dams more susceptible to failure.

The risk is the increased potential for piping failure. The Portfolio Risk Assessment (URS, 2013) discussed the potential failure mode for piping failure at Wivenhoe Dam saddle dam embankments when flood levels in Wivenhoe Dam reach approximately EL 75–76 mAHD. URS note that "*This does not mean that Wivenhoe Dam will fail at these levels, but rather that there is increased probability of failure if these flood levels occur frequently*".

Embankments in Auxiliary Spillway (USBR 1987). Under these guidelines, the AEP of triggering an auxiliary spillway of this type would not normally be more frequent than 1 in 500.



	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	026	027	028	029	030	031	032
Wivenhoe Dam	68%	70%	70%	71%	68%	70%	71%	72%	69%	70%	71%	72%	69%	70%	71%	72%	69%	70%	71%	72%	69%	70%	71%	72%	68%	70%	70%	71%	70%	71%	71%	72%
Somerset Dam	71%	72%	72%	72%	71%	72%	72%	72%	72%	72%	72%	73%	72%	72%	72%	72%	72%	72%	72%	72%	72%	72%	72%	72%	71%	72%	72%	72%	72%	72%	72%	73%

Source: Seqwater 2014a

Figure 9.3 Modelled % AFC results for all WSDOS operational options

9.4.5 Comparison of peak dam levels under alternatives urban 3 and 4

Seqwater determined that the 36 hour inflow volume was the most suitable for assessing extreme flood levels to compare urban 3 and 4. This is consistent with the finding of the PMF and design AEP flood event simulations which also indicated a 36 hour critical duration for rainfall bursts.

Alternatives urban 3 and 4 are the only alternatives that raise the dam safety trigger level and show some change in overtopping and fuse-plug breaching risks – relative to Base Case operations. This can be shown by plotting the peak level reached in Wivenhoe Dam for the same flood event for alternatives Urban 3 and Urban 4 against that for the Base Case (see Figures 9.4 and 9.5).

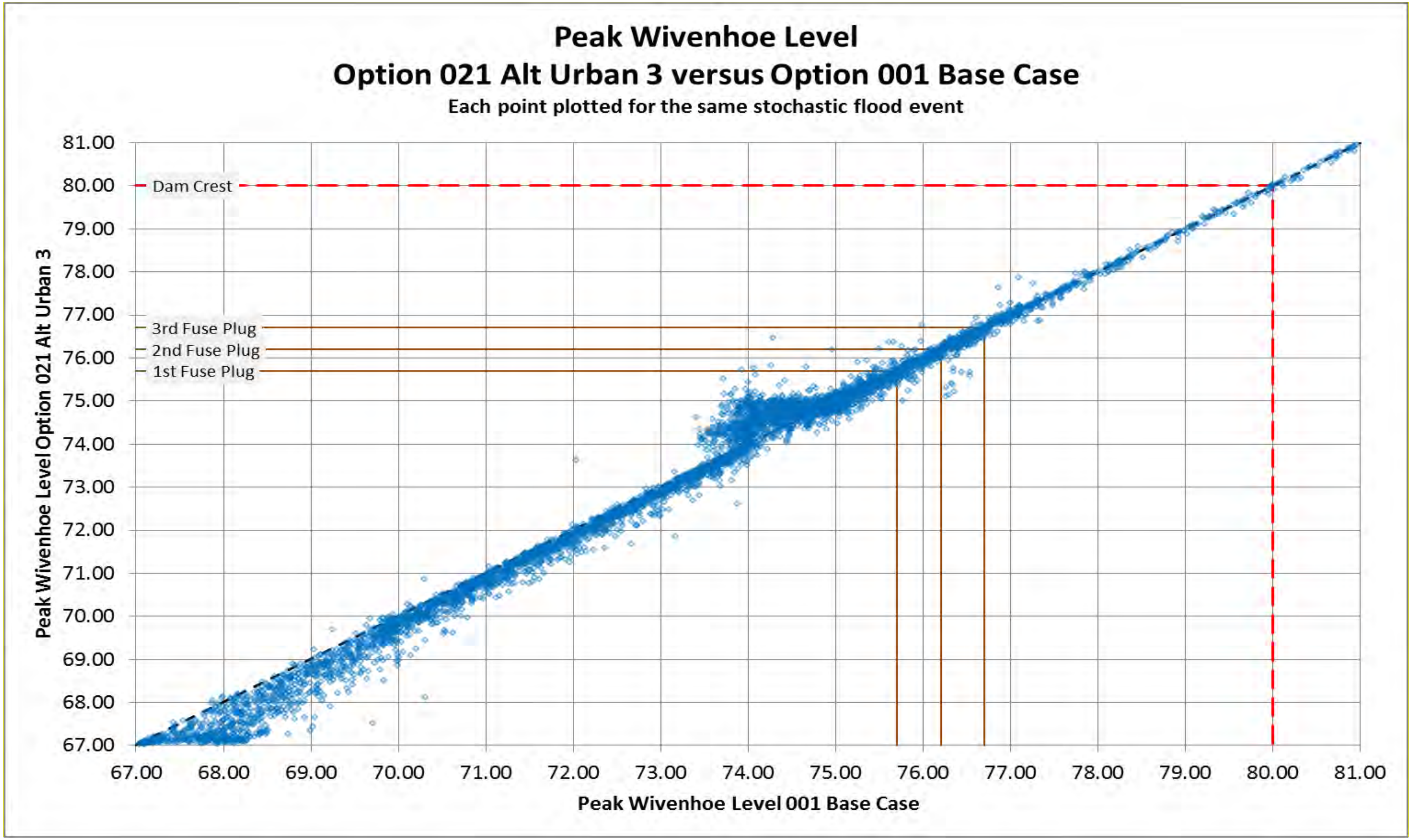
It is important to note there are only a relatively limited number (a few hundred extreme flood events) in the sample, so the results are not definitive. Nonetheless, the flood simulation results available indicate the following:

Figure 9.4 - alternative Urban 3 option comparison shows:

- A notable increase in the probability of Wivenhoe Dam flood levels between 74 mAHD to 75 mAHD.
- Above 75 mAHD the Urban 3 probable flood levels converge closer to the Base Case.
- There are a few potential flood scenarios (low probability, but nonetheless a possibility) that indicates Urban 3 could in some floods result in breaching of one or more of the fuse plugs, that would not breach for the same flood in the Base Case.
- There does not appear to be any detectable increase in the probability of flood levels reaching the dam crest for the Urban 3 option.

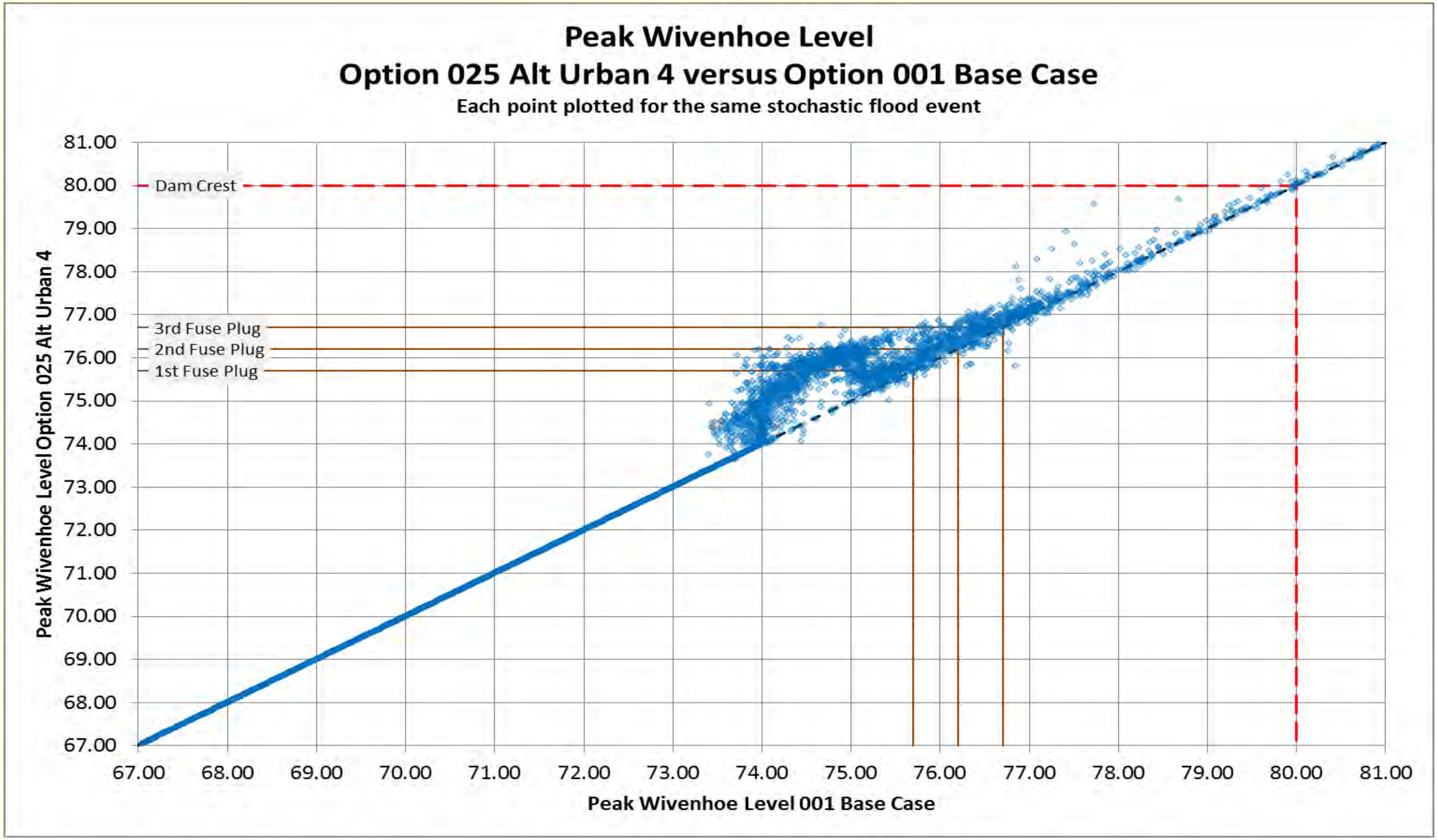
Figure 9.5 - alternative Urban 4 option comparison shows:

- A notable increase in the probability of Wivenhoe Dam flood levels between 74 mAHD up to about 77 mAHD.
- Higher probability of breaching all three fuse plugs.
- A few potential extreme flood scenarios (low probability, but nonetheless a possibility) that indicate the Urban 4 option could increase the peak Wivenhoe Dam levels in some floods up to 1 to 2 m higher than the Base Case and reach close to the dam crest level.
- There is a small detectable increase in the probability of flood levels reaching the dam crest for the Urban 4 option.



Source: Seqwater 2014a

Figure 9.4 Wivenhoe Dam Peak Level – Relative Comparison Urban 3 and Base Case



Source: Seqwater 2014a

Figure 9.5 Wivenhoe Dam Peak Level – Relative Comparison Urban 4 and Base Case

9.4.6 Comparative summary of dam safety impacts

Table 9.2 summarises the assessment of the dam safety impacts. Only alternative Urban 4 has unacceptable outcomes in the immediate future. However fuse plug spillway assessments and dam safety upgrade assessments should be completed in the shorter term. Additional investigations should be completed to better understand the risks prior to implementation of any option that raises the Dam Safety Strategy trigger level such as alternative Urban 3 and alternative Urban 4.

Table 9.6 Dam safety impacts - comparative summary of options (relative change to the Base Case over many floods)

Operational Option	2 to 4	5	9	17	21	25	29
Operational Alternative	85% , 75% and 60% FSV Base Cases(1)	100% FSV No Rural Strategy	100% FSV Alt Urban 1a 100% FSV Alt Urban 1b	100% FSV Alt Urban 2	100% FSV `Alt Urban 3	100% FSV Alt Urban 4	100% FSV Prescribed Operations
Change in dam safety risk due to overtopping failure of Wivenhoe dam in a maximum extreme flood (2)	Less risk	Minimal	Minimal	Marginal (2)	Marginal (2)	More risk (2)	Minimal
Change in probability of breaching fuse plugs (2)	Lower	Minimal	Minimal	Minimal (2)	Minimal (2)	Higher	Minimal

Legend	Better than Base Case operations & 100% FSV	Minimal Change from Base Case operations & 100% FSV	Worse than Base Case operations & 100% FSV

Note:

Unless noted otherwise below, changes due to variation of dam operations is for the 100% FSV scenario

(1) This specifically compares Base Case lower FSV scenarios against the Base Case 100% FSV scenario

(2) Caution is required due to limitations of modelling extreme flood events. Further investigation of dam safety risk is required (although it is a considerably greater issue for Alt. Urban 4 than Alt. Urban 3).

Results for flood mitigation are presented for average performance over many floods. It is important to recognise that flood mitigation performance in any individual flood could be worse or better. The probability of significantly worse outcomes in any single flood event compared to the average is low, but it remains possible.

9.5 Upgrade options

For Wivenhoe Dam, it was originally proposed that a second auxiliary (fuse plug) spillway be constructed on the left abutment at Saddle Dam 2, which would trigger at EL 78.3 mAHD providing the additional capacity required to meet the AFC. However the engineering feasibility of this option remains to be proven, along with a need to properly understand its implications for areas downstream. Hence other options may need to be investigated.

Somerset Dam has uncertainties around the issues raised earlier, i.e.:

- resistance of abutment and downstream foundations to impact erosion by dam overtopping flows
- stability of the upper parts of the dam under dam crest flood loads
- structural adequacy and reliability of the spillway gates and supports – also under flood loads.

Therefore, further detailed investigations are required to determine the most appropriate dam safety upgrade measures and timeframes for Somerset Dam.

The Portfolio Risk Assessment (URS 2013) makes no specific recommendations for upgrading either Wivenhoe or Somerset Dams although necessary investigations and approximate timeframes are indicated. The issues at each dam are complex and upgrade options will involve significant capital expenditures.

Recommended future investigations are as follows:

Wivenhoe Dam:

- Fuse plug and saddle dam assessments
- investigation of the existing saddle dam stability and foundations.
- Develop options for upgrades to meet 100% AFC

Somerset Dam:

- Detailed surveys and analysis of structural and foundation issues.
- More detailed assessment of risk of cascade failure of Wivenhoe in major events.
- Develop options for upgrades to meet 100% AFC

It is important that these investigations be undertaken as a priority as they will likely have implications for downstream development and flood risk management options – as well as potentially highlight other flood mitigation strategies that are able to deliver similar benefits to alternative Urban 4 – but with less uncertainty over issues such as the consequences of fuse-plug operation.

9.6 Conclusions

Current status of dams

- Wivenhoe and Somerset Dams are classified as extreme hazard dams using established risk assessment metrics. Based on the current standards-based methodology outlined in the Queensland dam regulation guidelines (DEWS 2013b) on Acceptable Flood Capacity for dams, both require augmentation to ensure that they can safely pass their respective PMFs.
- Current estimates of the extreme flood capacity of both dams under existing operations are significantly less than 100% of their respective PMFs (i.e. Wivenhoe-68%PMF and Somerset-71%PMF). However, they do meet the minimum AFCs required within the current timeframes set in Queensland's dam spillway upgrade program.
- The probability of the maximum flood event that Wivenhoe Dam can safely pass (with all gates operational) has been estimated (Seqwater 2014a) as approximately 1 in 65,000 AEP; while the probability of the maximum flood event that Somerset Dam can currently pass (with all sluice gates operational and all spillway crest gates open) has been estimated as approximately 1 in 25,000 AEP. Exceeding these flood events may lead to catastrophic failures of one or both of these dams.

- A policy position needs to be established on whether the probability of failure of Somerset Dam should be further reduced such that failure of Wivenhoe Dam becomes more likely to occur before the failure of Somerset Dam. Such a preferential order is likely to reduce the risk of cascade failure of both dams and preserve any residual water supply. This would need to be reflected in both the operating target line (Interaction line – Figure 9.2) for the joint operation of Wivenhoe and Somerset Dams and also in the design of the dam upgrades.

Impacts of operational options

- The simulations undertaken for this study indicate that none of the operational options considered for improving the flood mitigation performance of the Wivenhoe and Somerset Dams significantly change the current level of risk to dam safety as a result of exceeding the maximum safe levels of the dams.
- However, Seqwater (Sewater 2014a) have cautioned against relying solely on the simulation results to fully understand the impact of the operational options (particularly those that raise the Dam Safety Strategy trigger level) on dam safety because the modelling uses idealised assumptions of extreme event rainfall patterns and may not adequately represent the potential change in risk. Recent events such as January 2011, highlighted the possibility of an extreme rainfall burst near the end of a rainfall event which poses increased risk for dam safety.
- This increases the risk for all options, but may further increase risks for options that raise the dam safety trigger level. Raising the Dam Safety Strategy trigger level to above the fuse plug levels will increase the risk of other modes of dam failure such as piping through saddle dams. Hence variations which modify the dam safety trigger threshold would require more thorough investigation of these dam safety implications before being considered for implementation.
- Because of its potential to increase the likelihood that a fuse plug in the auxiliary spillway will be breached, the investigations indicated in Section 9.5 would need to be carried-out before deciding whether to adopt alternative Urban 4. For alternative Urban 4, the probability of triggering the 1st fuse plug increases from about 1 in 700 AEP (the AEP for all operational alternatives except Alt 4) to about 1 in 30 AEP.
- Because the assessed probability of initiating the a fuse plug has increased from about 1 in 6,000 AEP at the time of construction in the mid-2000s to about 1 in 700 AEP currently, the fuse plug and associated dam safety investigations should be completed irrespective of whether or not alternative operations are implemented, as the issues are relevant to all operational options.

Dam upgrade considerations

- Options for upgrading the dams to be able to pass 100% of the PMF require further detailed investigations to understand both the engineering feasibility and whether they have implications for developments (e.g. facilities, infrastructure and property), and flood risk management downstream.
- Detailed investigations of dam safety upgrade options may also highlight other flood mitigation strategies that are able to deliver similar benefits to alternative Urban 4 – but with fewer risks.
- Upgrades to the flood capacity of these two dams are likely to present additional options to improve flood mitigation for more frequent events.

- Notwithstanding that Wivenhoe and Somerset dams at the current FSLs are “tranche 3” augmentations not required until 2035, the likely lead times for determining and implementing the most suitable options; along with the fuse plug operational issues and the potential of the dam failure and operation to influence work currently underway to develop a Brisbane River Catchment Floodplain Management Plan mean that relevant investigations towards dam upgrades should be initiated as soon as practicable.

Chapter 10 Bridge and crossing submergence

During the operation of the Wivenhoe Dam and Somerset Dam for flood mitigation purposes, when the flood storage is being utilised, bridges and areas upstream may become temporarily inundated (Seqwater 2013a).

There are five bridges or crossings upstream of Somerset Dam and thirteen upstream of Wivenhoe Dam that are potentially impacted. Few of these are likely to be severely impacted other than for the most extreme floods. Hence, transport impacts upstream of the dams are not normally required to be a primary consideration when operating Wivenhoe and Somerset dams.

Downstream of Wivenhoe Dam, up to eight bridges and adjacent low level floodplains can be affected and may become fully submerged in even relatively minor floods or during water releases as part of pre-flood preparations. This includes inundation of the Brisbane Valley Highway at Fernvale (Geoff Fisher) Bridge and the Mount Crosby Weir, which are the two most flood resilient crossings. Inundation of these bridges and others in the Brisbane Valley can cause isolation and inconvenience to residents in the Brisbane Valley and the Western Suburbs of Brisbane. Impacts to higher-level bridges downstream of the Moggill Ferry would occur only in rare floods (larger than experienced historically), and although disruption to navigation in the lower Brisbane River associated with high flood debris loads is also a consideration in dam operations, it is secondary to issues associated with inundation of upstream bridges.

When bridges are likely to become inundated, either through dam operations or independent downstream flooding impacts, there are emergency procedures in place to alert the responsible authorities (e.g. DTMR, BCC, SRC or ICC) of the need to respond (in accordance with their Disaster Management procedures). The affected routes are then closed in an orderly manner, supported by appropriate diversion signage, and post-event safety inspections are undertaken prior to re-opening any of the crossings.

10.1 Transport impacts due to flooding below Wivenhoe Dam

DTMR (2013) summarises investigations undertaken to specifically address QFCoI Final Report recommendation 17.25:

> *The Department of Transport and Main Roads, in conjunction with Brisbane City Council and Somerset Regional Council, should investigate options for the upgrade of Brisbane River crossings between Wivenhoe Dam and Colleges Crossing and undertake a cost-benefit analysis of these to determine the outcome which best serves the public interest.*

These investigations focused on three areas downstream of (Wivenhoe):

- Mount Crosby – including Colleges Crossing and Mount Crosby Weir
- Brisbane Valley Highway – Geoff Fisher Bridge at Fernvale and
- Somerset Region – including Savages Crossing, Burtons Bridge and England Creek

The flood-affected bridges and crossings below Wivenhoe Dam are indicated in Figure 10.1, together with the estimated river flow typically capable of closing each route.

Source: DTMR 2013, Figure 1

Figure 10.1 Impacted bridges and crossings downstream of Wivenhoe Dam and the river discharges indicative of their closure

Table 10.1 lists various relevant characteristics of each route, listed in their downstream sequence. Consultation was undertaken between DTMR and each of the impacted Local Government Authorities in regard to the transport-related issues of bridge closures in their areas of responsibility. In addition, correspondence occurred between DEWS and the local governments in connection with this study.

It is clear that the locations first affected in any dam release scenario are in the Somerset Regional Council (SRC) area, these being Twin Bridges upstream of Fernvale, the England Creek crossing and Savages Crossing downstream. These routes serve rural areas and their potential inundation has been considered in previous dam operations. Following consultation, SRC has agreed that due to their low level of immunity to flooding and the small population affected, that consideration of these locations need not be included in the present dam operational strategy (Seqwater 2013a).

The next low level bridge affected is Colleges Crossing, which is the furthest downstream and is also frequently closed (e.g. throughout 2010, 2011 and 2012) by managed releases from Wivenhoe Dam. This is followed next by submergence of Burtons Bridge and Kholo Bridge respectively. A significant flood event is generally needed to impact Geoff Fisher (Brisbane Valley Highway) Bridge at Fernvale and the Mount Crosby Weir crossing.

During the January 2011 floods, Mt Crosby Road and surrounds (Pullen Pullen and Kholo Creeks) the Moggill Ferry, Colleges Crossing and the Mt Crosby Weir were all closed. Moggill Road was also closed at several low-lying locations.

Table 10.1 Flood-impacted bridges and crossings downstream of Wivenhoe Dam

Crossing	Road	Deck Elevation (m AHD)	Flow Capacity[1] (m^3/s)	DTMR Avg. Daily Traffic[3] (vpd)	No. of Residents Affected[4]	Typical Duration of Closure[5] (days)
Twin Bridges	Wivenhoe Pocket Road	20	50	500	-	n/a
Geoff Fisher Bridge	Brisbane Valley Hwy, Fernvale.	33.8	2,000	3,400	-	0.5 to 6
England Creek	England Creek Rd	n/a	n/a	79	19	n/a
Savages Crossing	Banks Creek Road	20.6	130	119	8	8 to 12
Burtons Bridge	Summerville Road East	19.6	430	112	15	6 to 10
Kholo Bridge	Kholo Road	11.9	550	680	400	6 to 10
Mt Crosby Weir	Allawah Road	12.4	1800	280	5,400	1 to 6
Colleges Crossing	Mt Crosby Road	-	175[2]	10,520	5,400	8 to 12
Moggill Ferry	Moggill Road	-	-	1,000	10,000	-

1. It is noted that the flow capacity of the bridges are estimates as the actual capacity will vary depending on the catchment condition, the amount of erosion/deposition at the location and the amount of vegetation in the channel.
2. Affected by tidal flows.
3. Daily traffic outputs from DTMR traffic modelling and local councils
4.. Indicative only, figures based on information from DTMR 2013.
5. Ranges indicative of historical flood event modelling (Seqwater 2014a)

DSITIA provided daily time step flow modelling results for downstream of Wivenhoe Dam at three locations (directly downstream of Wivenhoe Dam, Savages Crossing gauge, and downstream of Mt Crosby Weir) to allow assessment of the frequency and duration of inundation of river crossings. This allowed assessment of the impact of high frequency inundation of river crossings to be incorporated into Net Present Cost (NPC) estimates (refer Chapter 15) as the probabilistic assessment of floods used was geared towards the assessment of lower frequency events.

Simulation modelling of flood events was undertaken to determine the inundation impacts of the four lower FSV scenarios and eight operational alternatives that form the 32 options being analysed. The results of the modelling for the Fernvale Bridge (Brisbane Valley Highway) downstream of Wivenhoe Dam and Mary Smokes Creek Bridge on the D'Aguilar Highway upstream of Somerset Dam are presented below (Figure 10.2 to Figure 10.5).

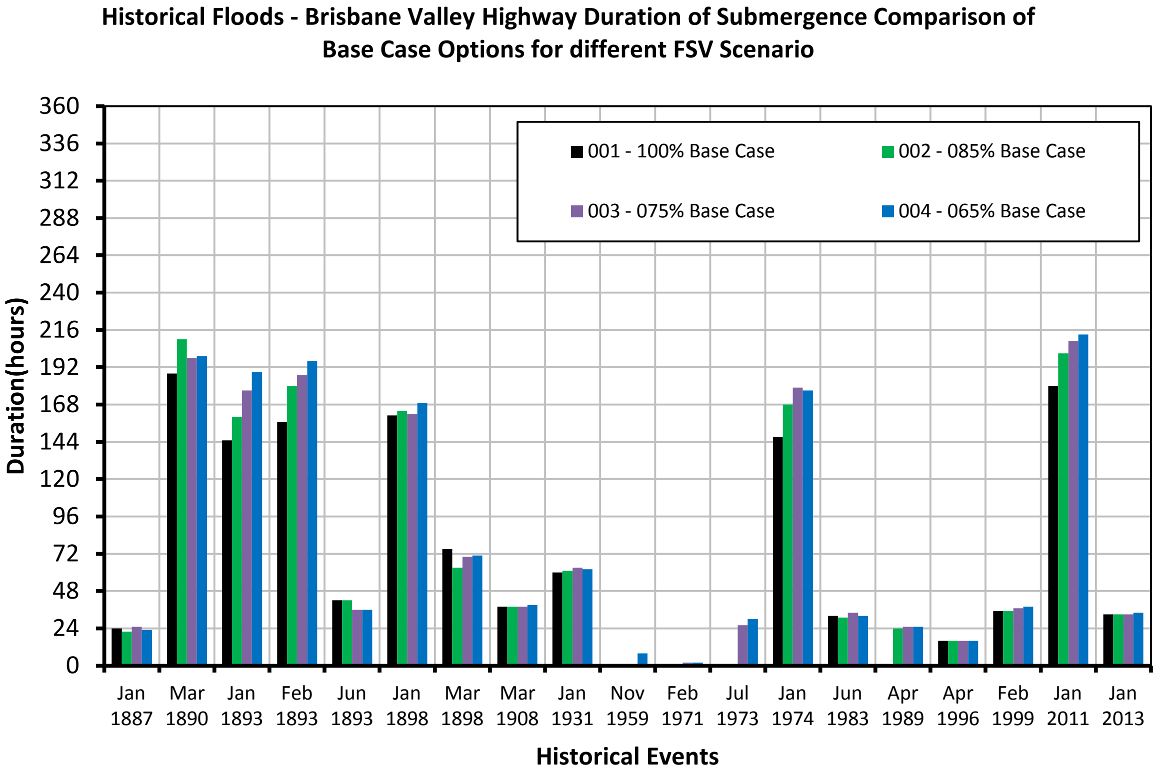


Figure 10.2 **Flood duration impacts at Brisbane Valley Highway (Geoff Fisher Bridge) for different FSVs**

The modelling summarised in Figure 10.2 indicates that lowering the FSV would increase the duration of downstream bridge closures in major floods and some moderate floods. Increased flood storage capacity requires higher drain-down flows in larger flood events.

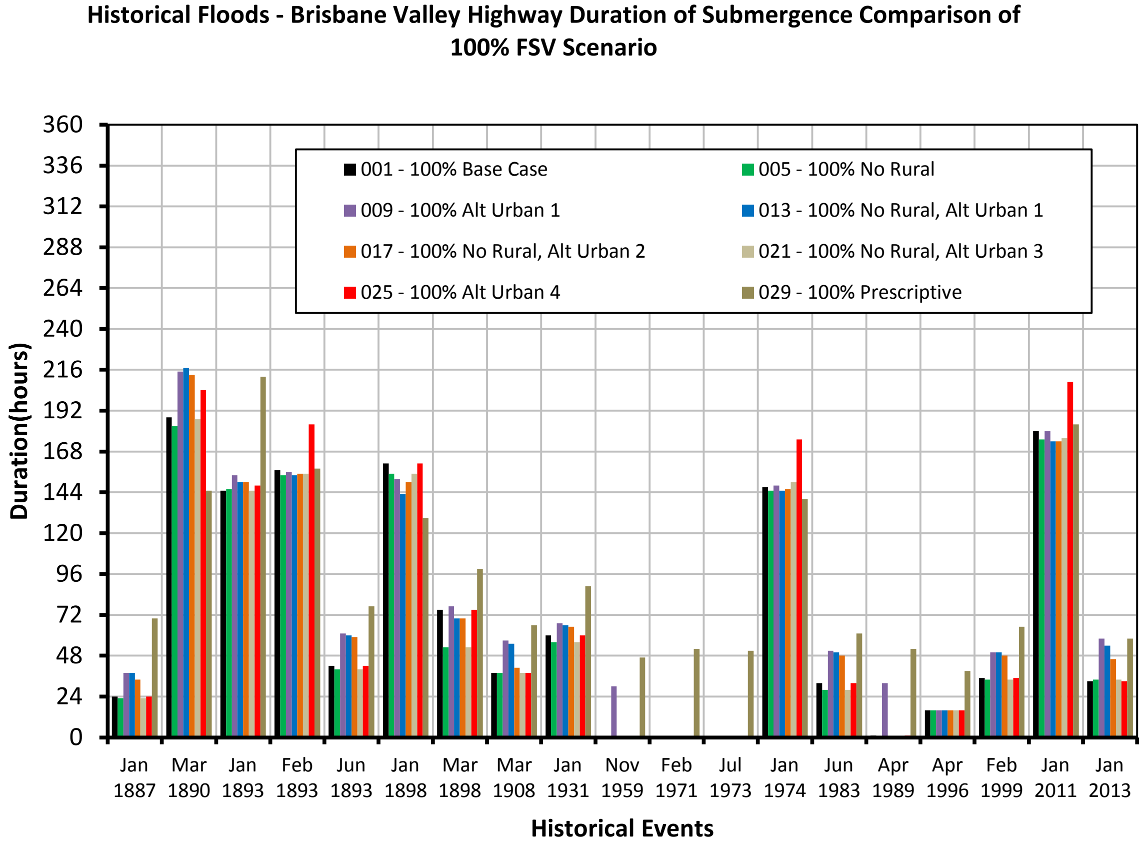


Figure 10.3 Flood duration impacts at Brisbane Valley Highway (Geoff Fisher Bridge) for different operations and 100%FSV

Figure 10.3 summarises the flood duration impacts at Brisbane Valley Highway (Geoff Fisher Bridge) for different operational alternatives and 100%FSV. Operational alternatives Urban 1 and 2 could increase duration of inundation of downstream bridges due to large floods emanating from upstream of the dams. Higher early releases results in earlier inundation of the Brisbane Valley Highway (Geoff Fisher Bridge). The operational alternative Urban 4 variation could increase the duration of downstream bridge closures in major floods and some moderate floods. Prescribed operations could increase the frequency and duration of downstream bridge closures.

Figure 10.4 indicates that lowering the FSV of Wivenhoe Dam tends to reduce the duration of flooding upstream of Somerset Dam. Likewise flooding upstream of Wivenhoe Dam would be reduced.

Figure 10.5 indicates that operational alternatives Urban 1 and 2 could reduce the duration of upstream bridge closures in moderate floods and some major floods. Operational alternative Urban 4 could increase the duration of upstream bridge closures as more flood water would be stored in the dams due to the raising of the *Dam Safety Strategy* trigger level in Wivenhoe Dam.

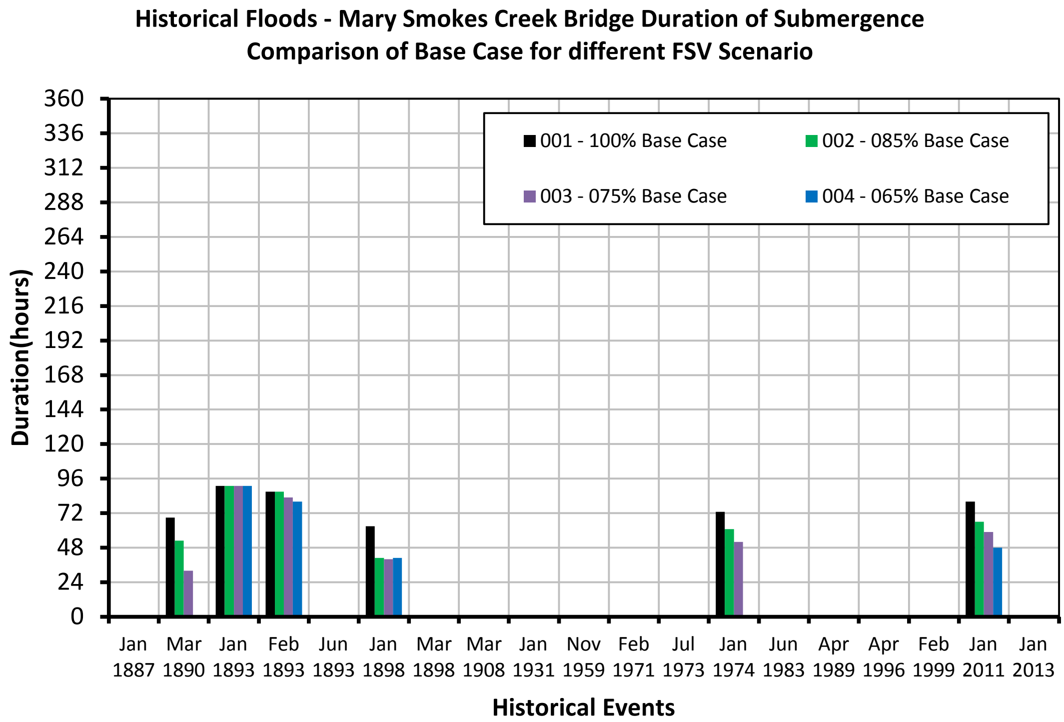


Figure 10.4 Flood duration impacts at Mary Smokes Creek Bridge for different FSVs

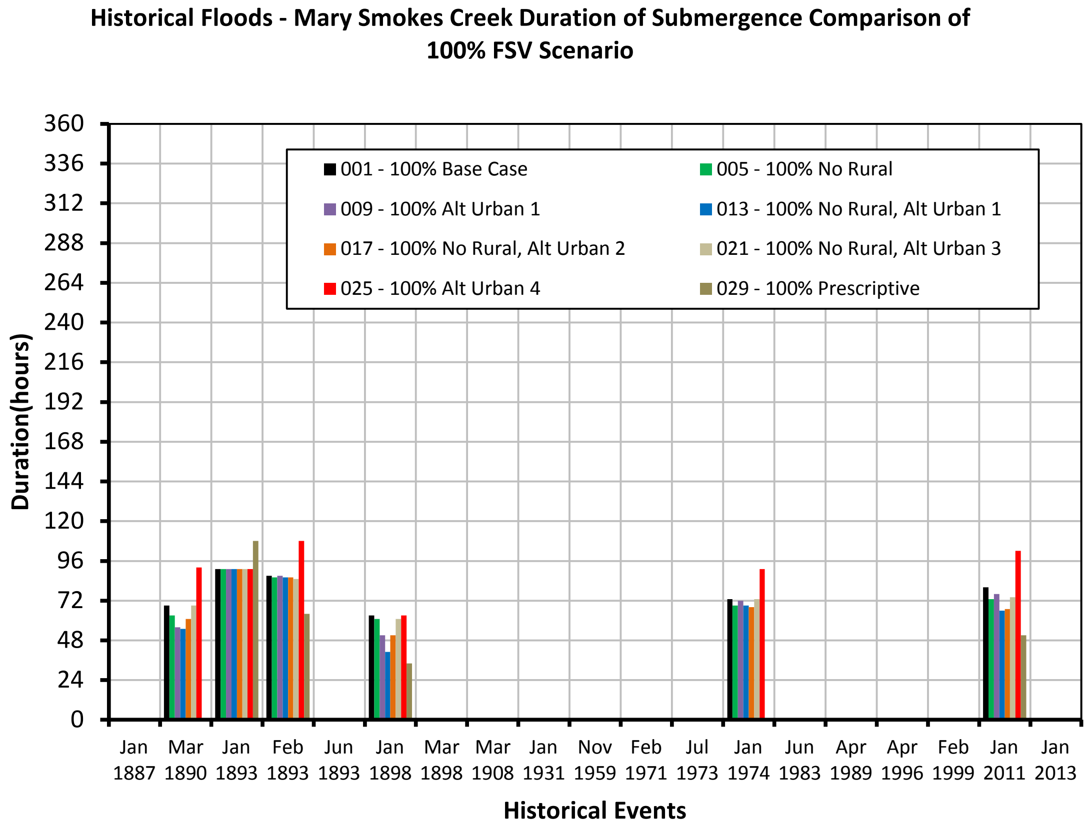


Figure 10.5 Flood duration impacts at Mary Smokes Creek Bridge for different operations and 100%FSV

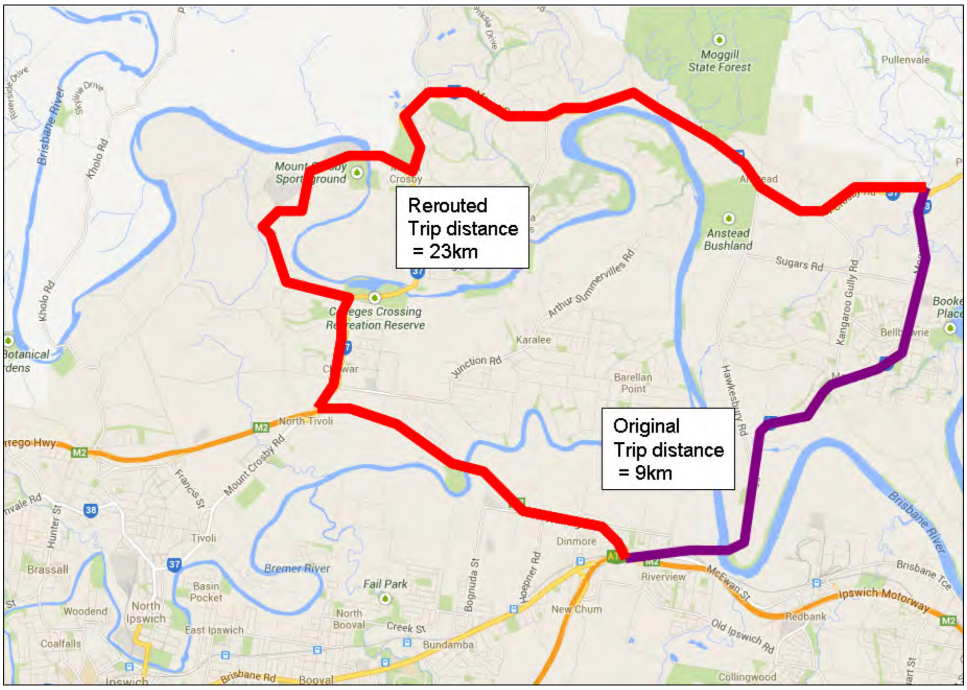
10.2 Outcome of assessment of transport options

10.2.1 Mount Crosby region

The Mount Crosby Flood Immunity Study investigated strategic options to improve the flood immunity of the road network in the Mount Crosby area. This considered engineering design, flood impacts, traffic issues, geotechnical issues and cost assessments. The effect of traffic redistribution due to the closure of river crossings around the region has also been considered, including the Mount Crosby Weir, Colleges Crossing and Moggill Ferry.

Diversion routes were identified and strategic modelling was used to derive approximate traffic assignment (in terms of number of vehicles) for each route. It was found, for example, that if Colleges Crossing was closed, traffic would reroute west across Mount Crosby Weir, meaning an increase of over 7,000 vehicles per day along this route and an increase in trip distance of 2.1 km. There would also be an increase of around 650 vehicles per day using the Moggill Ferry. However, if the Moggill Ferry was also closed, then all traffic would need to reroute through Mount Crosby Weir, which could mean an increase in trip distance of 14km for some vehicles, as shown in Figure 10.6.

A range of flood mitigation options were investigated, consisting of combinations of location and level of flood immunity. Based on the option review and evaluation undertaken, the study indicated constructing a new crossing along the preserved Moggill Pocket Arterial Road (the Karalee Crossing) is the preferred option to provide flood immunity for major connecting roads to the 2011 flood level. Not only does this option have the benefit of providing a good fit into the long-term strategic intent of the regional State-controlled network, but the State-controlled corridor is already cleared and declared in published street directories. However, in order to improve the immunity of the surrounding road network additional improvement works would be needed. A bridge at the Moggill Ferry location was deemed impractical.



Source: DTMR 2013, Appendix B Figure 2

Figure 10.6 Example of traffic rerouting from Moggill ferry to Mount Crosby Weir

DTMR have also investigated smaller raisings of the existing bridge at Colleges Crossing to cope with the operational / routine releases from Wivenhoe Dam at 430 m^3/s, 1,000 m^3/s and 2,000 m^3/s. The estimated cost of these raisings range from around $70M to $150M.

The preferred DTMR option in the Mount Crosby area that would provide flood immunity for major connecting roads up to the 2011 flood level, which is estimated to have less than 1 in 100 AEP, is a new Karalee river crossing along the preserved Moggill Pocket Arterial Road corridor. The indicative capital cost is $174M.

In addition to a new Karalee crossing, in order to provide similar flood immunity to connected service areas, road improvements would also be required at Pullen Pullen Creek ($30M), Kholo Creek ($83M) and Junction Road ($23M).

Less desirable options from an overall traffic management perspective to meet the 2011 level would be to raise Colleges Crossing ($272M) and Mount Crosby Weir ($158M). Lower levels of service improvement are commensurately less expensive, with a 1 in 50 AEP immunity achievable at Colleges Crossing with a low level bridge for approximately $191M and 1 in 20 AEP immunity achievable at Mount Crosby with additional road surfacing for less than $1M[16].

10.2.2 Brisbane Valley Highway

The Brisbane Valley Highway Flood Immunity Study was undertaken to investigate the feasibility of a new or upgraded highway crossing over the Brisbane River at Fernvale, with particular focus on the Geoff Fisher Bridge. This bridge was overtopped in the 2011 flood event and the approach roads were again overtopped in 2013. The purpose of this study was to assess the costs and implications of providing flood immunity for this section of the highway for flows of up to 3500 m^3/s and 4,000 m^3/s.

Investigations included:

- construction of a new bridge 30 m downstream of the existing bridge and upgrade of approaches – capacity 3,500 - 4,000 m^3/s (approximate cost $170M);
- a new bridge west of Fernvale (upstream of the existing bridge) and connections with the existing highway corridor – capacity 3,500 - 4,000 m^3/s (approximate cost $97M); and
- a wider network solution involving the Gatton - Esk Road (uncosted).

The first option ($170M) would provide a new highway connected bridge immediately downstream of the existing Geoff Fisher Bridge (this would also require the existing highway to be raised above the design flood level for a number of kilometres), with an immunity of approximately 1 in 20 AEP. The second option ($97M) to provide a new bridge upstream of Fernvale connected to existing local roads, with a similar level of immunity, but an increase travel distance of some 25 km.

A wider network solution involving the Gatton Esk Road is another potential option. Whilst it has not been costed, it is considered likely to be much more expensive as several bridges and crossings would need to be studied/upgraded in addition to the Lockyer Creek Bridge.

[16] Allawah Road (BCC controlled) already provides an approximately 1 in 20 AEP flood immunity crossing of the Brisbane River across Mt Crosby Weir however Allawah Road is currently unsurfaced along approximately 1.2km of its 5km length. Sealing the pavement would provide a durable all weather access to the area at times when Colleges Crossing is closed due to dam releases. This cost does not include any upgrade of Mt Crosby Weir Bridge which may also be required to ensure its structural integrity – noting its current load and speed restrictions

10.2.3 Somerset region

England Creek, Savages Crossing and Burtons Bridge, were all designed for overtopping and could be raised by some amount. However, the existing substructures may not be able to be strengthened sufficiently to resist the increased flow forces and particularly in the case of Burton’s Bridge, additional roadworks may be required (dependant of the level of raising) to account for river break-outs.

Any improvement in flood immunity for access to affected rural communities would require new bridges to be constructed at England Creek ($8M), Savages Crossing ($25M) and Burtons Bridge ($25M). Note, these costs do not allow for associated works to raise the existing roads to the new bridge heights.

10.3 Conclusions

DTMR (2013) advises that the results of the above investigations provide indicative costs for the various bridge upgrade concepts and that further detailed investigations would be required to develop firm costs. However the investigations indicate that the costs to upgrade the Brisbane River crossings downstream of Wivenhoe to achieve significant improvements in flood immunity are likely to be substantial.

The investigations have also provided estimates of the potential benefit of raising the bridges to the levels indicated and these have been used to estimate Average Annual Damage and NPC of traffic impacts presented in Chapter 15 as part of the integrated assessment of the proposed dam operational alternatives.

Given that the costs of improving the flood immunity of the crossings are substantial and the flood impacts (annualised costs) of crossing closures through inundation are relatively small the decision to improve the flood immunity of any of the crossings will need to be justified mostly on the basis of transport benefits, rather than flood mitigation.

Chapter 11 Bank slumping and erosion

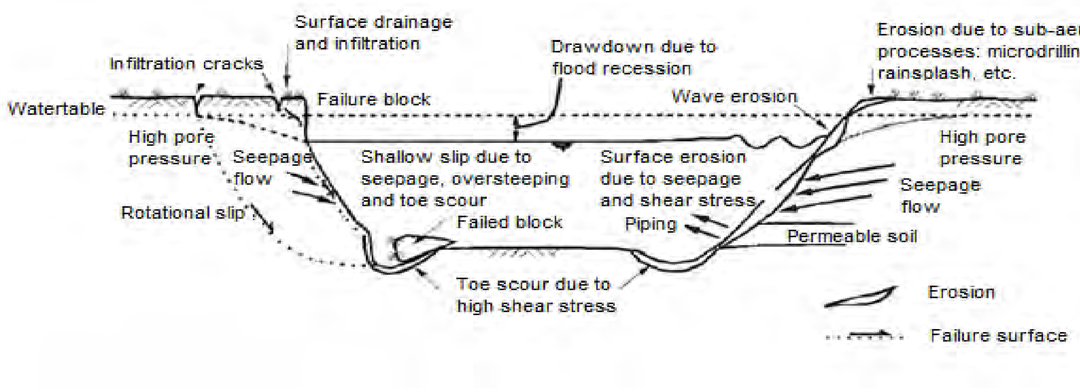
A river is a very complex natural system. Rivers in their natural state are in a continual process of adjustment of their channel forms in response to flow (whether natural or imposed), the nature of the river bed and bank materials and riparian vegetation that act to stabilise erodible sediments. The degree and rate of adjustment will vary over time and in space for different river reaches as they traverse the geologic landscape. These processes also interact with the sediment transported from upstream reaches that occurs gradually but persistently under average flow conditions and also episodically due to rarer flood events.

Over long timescales, the form of river channels can be considered to have reached a dynamic equilibrium condition with their landscape. This implies that at any point in time there will always be deviations evident from what might be regarded as the longer term equilibrium position and, given a sufficiently large flood event, a significant localised shift in the equilibrium state (e.g. realignment etc.) may be triggered. When assessing the current state of stability of any river system it is therefore necessary to consider the immediate and recent past rainfall and flooding events and their likely relationship to the estimated equilibrium (or reference) condition.

When a river is subjected to anthropogenic impacts (such as the building of a dam or the dredging of its bed) and the catchment landscape is altered due to farming or urban encroachment, separating natural and anthropogenic influences presents a complex puzzle. Accordingly, in Australia, the condition prior to European settlement is often taken to be the most representative of the equilibrium state, though it is not always possible to accurately assess this due to a lack of historical data.

11.1 Erosion processes below Wivenhoe Dam

There are many and varied mechanisms by which erosion of river banks can occur, with Figure 11.1 illustrating the typically identified modes of failure and their causative mechanisms. The two key forms of bank erosion found to occur in the mid-Brisbane during the 2011 and 2013 floods were fluvial entrainment and wet failures. Fluvial entrainment is the removal of sediment by the direct action of flow. This removal is the result of the shear stress (force) of the water exceeding the shear strength (resistance) of the bank material. Fluvial entrainment is therefore influenced by both the flow hydraulics (e.g. stream power) and the geotechnical characteristics of the river bank (e.g. sediment cohesiveness, clay and organic matter content). The exact mechanism causing wet flow mass failures in this situation are not well understood.



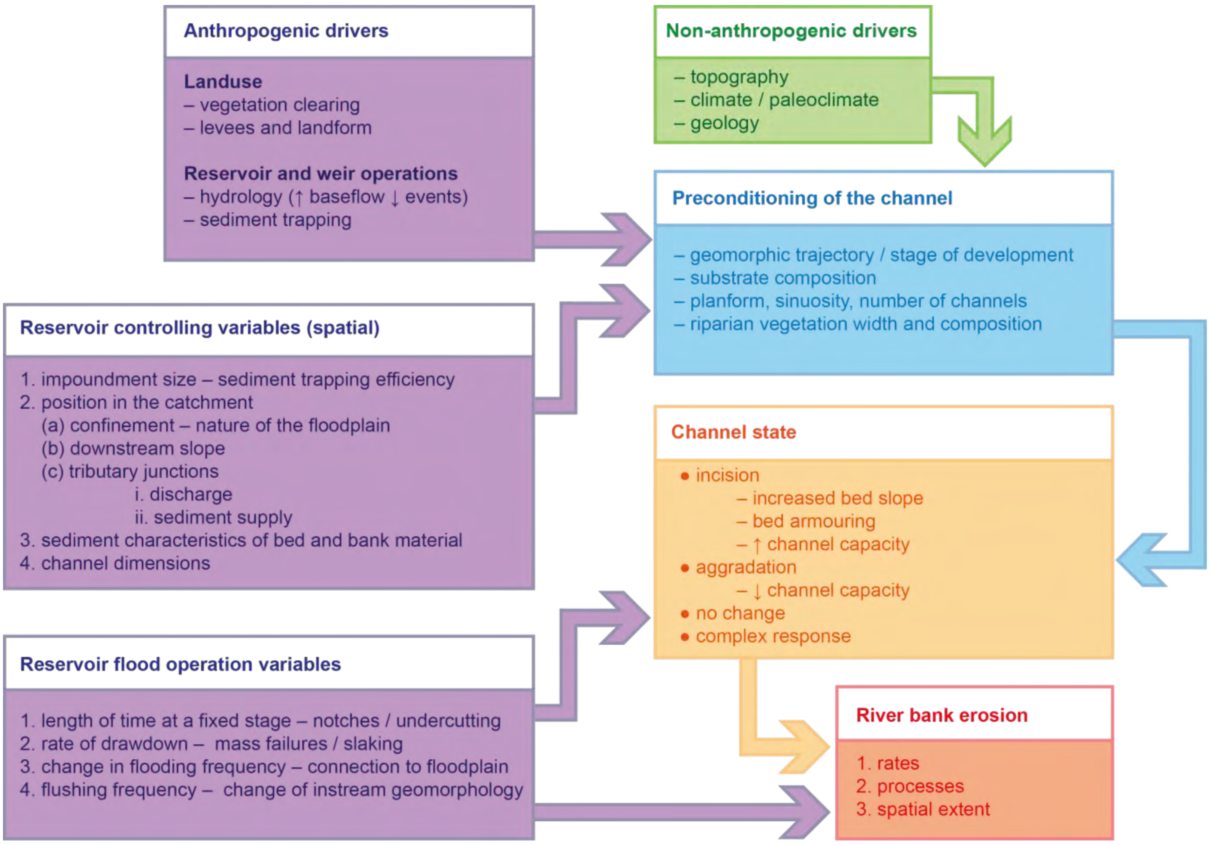
Source: Abernethy and Rutherfurd 2000

Figure 11.1 Processes of bank erosion

In response to QFCoI Final Report recommendation 17.3, DSITIA (2014) has addressed the question of the degree to which the presence and operation of Wivenhoe Dam may impact the erosion processes downstream of the dam, concentrating on the Mid-Brisbane section above Mt Crosby weir.

The DSITIA report drew upon a wide range of pre and post 2011 flood event studies to:

- identify relevant degradation processes and associated flood event impacts for bank slumping and erosion, recognising that such effects are affected by the historical sequence (including frequency) of flood events, other natural process and the impact of human activities;
- outline potential flow release strategies that would mitigate impacts on bank slumping, and erosion having regard to the rising and falling stages (including magnitude and duration) of a flood event;
- identify recommendations that can be made relating to the releases from Wivenhoe Dam; and
- outline possible future sampling, survey and monitoring activities that could be undertaken to help further refine the flood mitigation manuals for Wivenhoe and Somerset dams beyond the current stage of the WSDOS process.



Source: DSITIA 2014, Figure 5

Figure 11.2 Framework for investigating the effects of reservoirs on downstream river bank erosion

To aid the analysis of dam regulation impacts on bank erosion, a conceptual model (Figure 11.2) and a four step approach for analysing the impact of dam water release strategies on downstream bank erosion processes was developed:

Step 1 evaluated the initial trajectory of the stream pre-dam.

> This considered how both anthropogenic and non-anthropogenic drivers may have pre-conditioned the channel. Factors that influence the sediment yield and hydrology of the channel and measures of land clearance, sand and gravel extraction, catchment topography, geology and climate were assessed.

Step 2 assessed the change in the stream trajectory caused by the imposition of the dam.

> The position of the dam reservoir in the catchment, its size, mode of operation and trapping efficiency all influence the already likely modified channel downstream. This can (i) amplify or reduce sediment volumes propagating down the channel; (ii) reverse these processes; (iii) stall channel change; or (iv) result in a complex response of all of these. In addition, non-flood related releases such as daily and pre wet season dam releases (associated with temporary fully supply levels) can predispose the channel banks for later mass failure during flood events.

Step 3 identified the existing bank erosion processes operating in the channel.

> The processes already identified operating within the stream provide an indication of how the channel is responding to its current condition, and provides a baseline for estimation of future impacts.

Step 4 assessed the consequences of various dam release strategies on the stream system.

> This was in terms of the rate, spatial extent or process of erosion, or a combination of all of these.

11.2 Outcome of the erosion assessment

Prior to Wivenhoe Dam, it is estimated that the Mid-Brisbane river system was an irregularly meandering river confined in a wider macrochannel, with coarse grained bed sediment. The macrochannel is a remnant that was formed from an historical flow regime that occurred thousands of years ago in response to much higher runoff conditions than are presently experienced. The anthropogenic modifications of the catchment up to 1985 have included large scale land clearance, and instream gravel and sand extraction. The land clearance is likely to have increased the sediment supplied to the channel, and also the runoff rate and volume, resulting also in consequential increased flows in the channel. Photographs of the channel show that erosion within the macrochannel was occurring pre-regulation by the dams (Figure 11.3 and Figure 11.4). These would have trapped sediment and created more complex channel diversity.

Erosion within the macrochannel, occurring as mass failures, was identifiable by historic photographs of such failures on the upper parts of the macrochannel banks (Figure 11.3 and Figure 11.4). There were also signs that various other erosion processes were active.

Post dam development, the base flow in the Mid-Brisbane is estimated (DSITIA 2013b) to have increased from around 20% of the total annual flow to around 40%. Likewise the mean daily base flow has nearly doubled from 500 ML/day to almost 900 ML/day as a result of daily drinking water releases to Mt Crosby Weir. These estimates are based on hydrologic modelling simulations of the period 1889 to 2011. This modelling also indicates that the frequency of small and moderate floods has decreased post-Wivenhoe (e.g. the flow that had an estimated pre-development frequency of 1 in 2 AEP is now estimated as having a frequency of 1 in 2.6 AEP.

Source: Queensland State Archives in Kemp et al. 2013

Figure 11.3 Severely eroded banks of the Brisbane River near Ipswich in 1898, probably resulting from the 1893, 1896 and 1898 floods

Source: John Oxley Library in Kemp et al. 2013

Figure 11.4 Bank retreat on the Brisbane River downstream from Northbrook Homestead in 1916 [17]

[17] The site is presently submerged by Wivenhoe Dam.

Despite the combination of changes to the Mid-Brisbane there has been little modification to the large macro channel environment, but there has been internal modification of the low flow channel. From descriptions of variability in the bed profile and land-use change it appears that there has generally been a sediment build-up of the river bed, which would be expected with an increased sediment supply following land-use change. It is suggested that historically there have been long periods of gradual deposition of sediment between major flood events, followed then by episodic mobilisation of the accumulated material downstream. These episodes of sediment flushing appear to have been generally confined and do not appear to have penetrated below what is a much more ancient armoured bed sediment layer.

Since the building of the Wivenhoe Dam there appears to have been little change in the bed levels downstream of the reservoir. This may be a combination of the resilience of the ancient palaeo-bed, the low bed sediment yields that occur naturally in this system, and the inputs of discharge and sediment from the Lockyer Creek just downstream of the reservoir.

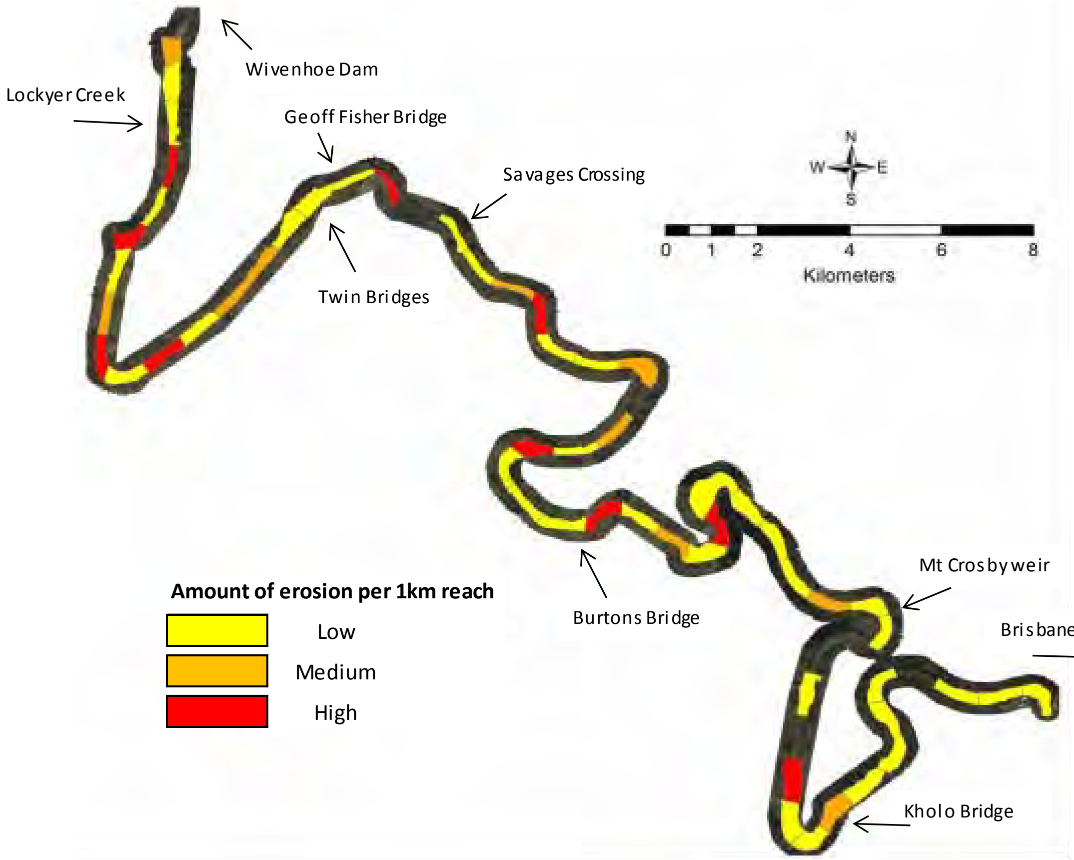
Investigation of the impacts of the 2011 and 2013 flood events (such as those portrayed in Figure 11.5 and Figure 11.6) shows that there has been significant bank erosion in the form of wet flow mass failures and fluvial entrainment (Olley et al. 2012; Stewart et al. 2013). Following the 2011 events Olley et al. (2012) divided the Mid-Brisbane into 56 reaches, measuring approximately 1 km each, in order to assess the extent of erosion downstream. Depending on estimated eroding volumes, the reaches were classified in high (11,000 - 90,000 m^3), medium (5,500 - 11,000 m^3) and low (0 - 5,500 m^3) erosion classes (). Repeat LiDAR analyses showed that the total sediment eroded from Mid Brisbane River channel banks during the 2011 floods was estimated to be 430,000 m^3. The dominant erosion processes that were identified were fluvial entrainment and wet-flow failures, which accounted for approximately 40% and 60% of the sediment eroded, respectively (Olley et al. 2012).The mechanisms of wet flows in this situation are not well understood, making it difficult to assess if their rates are being altered by anthropogenic activity.

Source : Olley et al. 2012

Figure 11.5 Example of mid-Brisbane bank erosion

Source : Based on SEQ Catchments 2011, Figure 17

Figure 11.6 Example of slump failure in the upper-Brisbane River showing the typical 'horseshoe' shape



Source: Olley et al. 2012

Figure 11.7 Total volume of erosion in each Mid-Brisbane River reach estimated from analyses of repeat LiDAR captured in 2001 and 2011

There is no long term baseline study of erosion rates and extent of bank failures for the Mid-Brisbane River, so while the contribution of anthropogenic activity cannot be discounted, it is difficult to assess the exact contribution to the alteration of erosion rates. It has been postulated that an increase in the rate of bank erosion due to wet flow failures and fluvial entrainment could be a response to a longer flattened flood hydrograph, and increased base flow, respectively.. It is thought that conventional models of channel incision, as a result of sediment trapping in the reservoir, followed by channel widening are not applicable in this system due to availability of significant inputs of sediment from the Lockyer Creek.

11.3 Conclusions

Episodes of bank slumping and erosion during high flow events are to be expected in any natural river system and are not by themselves evidence of anthropogenic impact unless there is a robust baseline condition available for comparison. Thus river form stability comparisons should not assume a no-erosion case as the reference point as banks are dynamic zones that are continually changing in response to complex interactions between flow regimes, sediment transport, bank material and form, riparian vegetation and land-use.

Based on the available evidence, the Mid-Brisbane river system appears to have been largely insensitive to changes likely directly attributable to the 20th century construction and operation of the dams in the upper reaches. Other gradual anthropogenic influences over time, such as land clearing and sand and gravel extraction, are likely to have had the greater impact on the bank and channel stability.

Release strategies that maintain a constant water level for long durations are likely to have a greater impact on downstream bank erosion than a slightly varied flow level. A fixed release discharge may cause notching or undercutting at low levels, or completely saturate the bank at higher levels.

The rates of recession in the 2011 flood event were sufficient to result in a large volume of mass failure erosion. These rates of drawdown were slower than the draw down rates prior to the existence of the dam (estimated from modelling but not accounting for all land-use changes). This indicates that pre-dam drawdown rates in the disturbed Brisbane River system will not produce appropriate reference rates for the management of bank slumping and erosion, as the channel margins may have altered in vegetation structure and morphology.

Ideally, dam release operations to reduce ‘wet flow mass’ failures should vary depending on the antecedent moisture condition of the river banks. If the flood occurs when the river banks are already wet but not yet totally saturated) the strategy would be to control the release so that there is a fast drawdown to try to avoid bank saturation being reached. In the case that the river banks are relatively dry, there is less likelihood of banks suffering wet failures and a longer and flatter drawdown to allow controlled drainage/exfiltration of the river banks could reduce bank erosion. Ideally, real time monitoring of the pore water pressure in the banks could be used to build a release strategy around the saturation of the bank material. However, given the extensiveness of such a monitoring system, further work would need to be done to determine whether a practical strategy for implementation could be developed

Further work is needed to develop such a strategy (particularly considering the extent of monitoring likely to be required) and associated implementation guidelines. To help establish a better baseline reference for the future management of the river system it is recommended that a systematic long term data collection and analysis program be established to better inform decision making. It would be important to include the Lockyer Creek in this program of work as the sediments delivered to the mid-Brisbane from the Lockyer influence the processes occurring in the mid-Brisbane River. It is noted that the Australian Rivers Institute research program at Griffith University has been supported by Seqwater and is targeted towards this outcome.

Chapter 12 Riparian flora and fauna

A diverse and functional riparian zone that evolves through compatibility of the physical and biological environmental processes is universally recognised as a key attribute of a healthy instream ecosystem (DSITIA 2014). Such environments are established and persist in expectation of natural flooding events.

Dams that support regional lifestyles, growth and prosperity unavoidably change the natural flow regime and modify the physical properties of upstream and downstream habitats. Flow patterns directly impact water quality and habitat conditions, and mediate ecological processes, such as spawning and the dispersal of water-dependent biota.

The general hydrologic effect of a dam is to reduce flow variability – lowering the peak of naturally occurring flood flow hydrographs and tapering flows down to a lower level of water release from the dam until the floodwaters have been discharged to the desired level.

The ecological consequences of this relate to the reduction or elimination of the more frequent small flood events (e.g. magnitudes less than a 1 in 10 AEP flood) and the attenuation of mid-range floods (e.g. magnitudes up to a 1 in 100 AEP flood). Dams also alter baseflow – either reducing it, or maintaining it at relatively constant rates where there are deliberate releases for water supply purposes. They can also introduce artificially long high-flow flow releases following flood peaks. These anthropogenic changes to flow characteristics within the riverine system can have significant ecological consequences by way of modifying the habitat, its benefactors and stressors. Loss of these events may result in:

- the reduction of flow-cues associated with critical life history events (i.e. spawning and recruitment) of some species;
- reduction of downstream freshwater influence and subsequent loss of brackish water habitat for estuarine species; and
- reduction of sediment and nutrient export to estuaries.

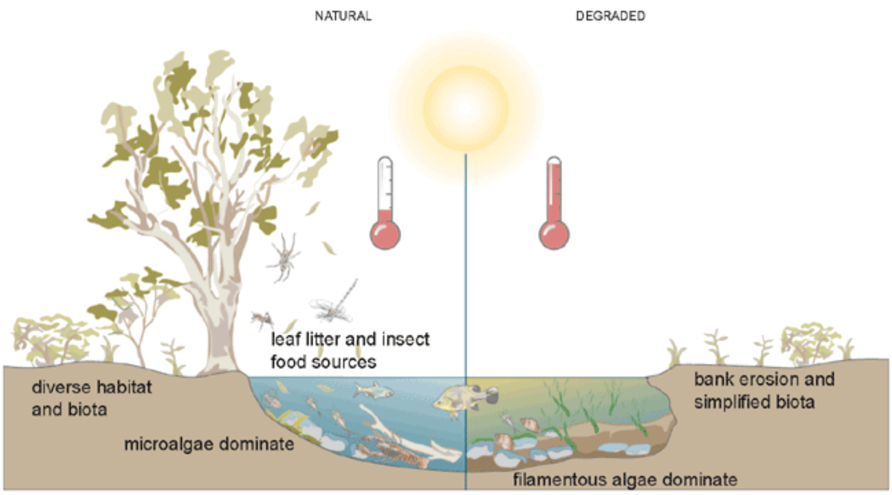
More extreme large floods (e.g. magnitudes greater than a 1 in 100 year AEP flood) will tend to impact the river at their natural frequency.

Land use and vegetation management activities that alter either the quantity of vegetated groundcover, or the composition of the riparian communities are likely to have a negative impact on those attributes that are often important in influencing the rate of erosional processes (refer Chapter 11).

Riparian vegetation also provides a number of beneficial roles in aquatic ecosystems, including shading of channels and temperature regulation, primary production, carbon and nutrient cycling, and the direct provision of habitat via the input of woody debris (Figure 12.1). Additionally, deep rooted vegetation can limit the erosion of (and therefore stabilise) stream banks.

This chapter summaries the findings of a desktop study of the potential impacts of Wivenhoe/Somerset dams flood operations on Brisbane River flora and fauna undertaken by DSITIA to support the Wivenhoe and Somerset Dams Optimisation Study (DSITIA 2014). DSITIA's study has drawn on monitoring and research of flow dependent aspects of the Brisbane River ecosystem conducted as part of the Environmental Flows Assessment Program (EFAP) used by DNRM to assesses the effectiveness of the *Water Resource (Moreton) Plan 2007* and Moreton Resource Operations Plan (2009) in achieving their environmental outcomes

However, to date, the response of ecological assets to individual flood events has not been considered a critical component of EFAP monitoring as the approach to assessing water resource planning performance has been based on long-term measures of ecological asset viability modelled over long hydrological simulation periods (i.e. > 100 years). Significant floods in this context are relatively rare events.

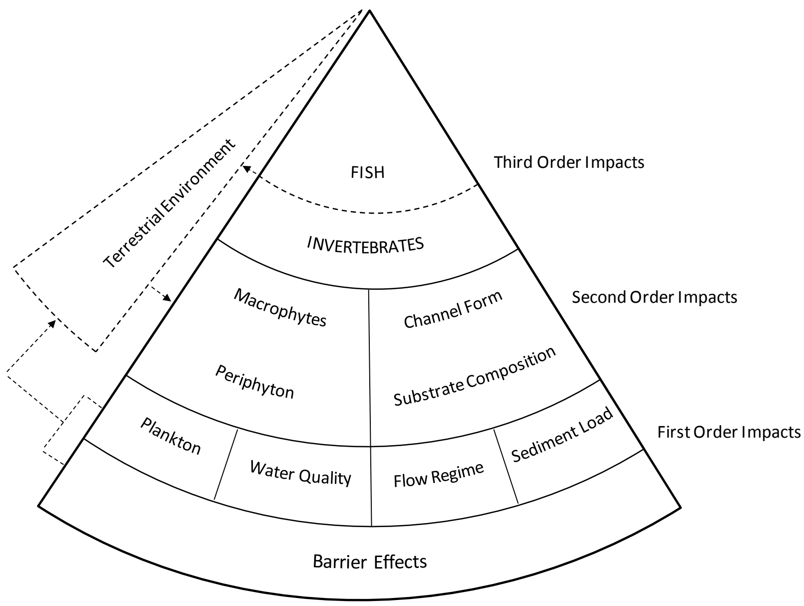


Source NLWRA 2002, Figure 3.4

Figure 12.1 Effects of loss of riparian vegetation and catchment degradation on rivers

12.1 Ecological impacts downstream of Wivenhoe Dam

The two main fluvial geomorphic alterations from a dam are (i) a change in the hydrology and (ii) the sediment regime. These so-called first order effects (Figure 12.2) can lead to second-order impacts of changes in channel form and substrate composition and even third-order impacts on fauna.



Source: Petts 1984

Figure 12.2 Framework for the examination of impounded rivers

DSITIA (2013a, 2014) notes that there has been significant alteration to the natural flow regime in the Brisbane River due to a range of anthropogenic impacts and management interventions over time. For example, the mean annual flow (MAF) at the river mouth is estimated to be only ~64% of pre-development (pre-European) levels and more frequent flood flows (up to 1 in 20 AEP) are all less than 66% of pre-development values of all catchment inflows. The impacts of water resource development and river extractions increase at sites further upstream of the tidal limit, Savages Crossing and immediately downstream of Wivenhoe Dam. Although increased base flows (up to ~900 ML/d) in the mid-Brisbane reaches have provided increased habitat for aquatic vegetation growth and subsequently Australian lungfish spawning, other impacts are negative. For example, the modified hydrology has substantially altered timing of spawning cues, connectivity cues and opportunities for migratory species, and reduced the frequency of intermediate disturbance events that play an important role in supporting habitat diversity.

The following range of potential and actual impacts on flora and fauna resulting from the Wivenhoe-Somerset dam operations have been identified (DSITIA 2014).

12.1.1 Flood events

Floods represent major ecosystem resetting events with a number of benefits. This was summarised for south-east Queensland catchments by DSITIA (2013c), which examined the impact of the January 2011 floods on aquatic ecosystems. It summarised the positive benefits as:

- scouring of sediments deposited under increased rates of sedimentation due to anthropogenic disturbance of catchments and waterways;
- removal of dense overgrowths of instream vegetation, including growths of exotic species such as water hyacinth, salvinia and paragrass;
- increase in the abundance of native fish species following floodplain inundation; and
- general increase in the ecological condition of rivers and streams.

The negative effects were summarised as:

- inundation of sewage treatment plants and consequent contamination of waterways with up to 51,000 CFU/ml (compared to a human health guideline of < 40 CFU/ml for recreational contact), probably with associated increased nutrient loading
- temporary reduction in the food supply of threatened freshwater turtle species, loss of established turtle nesting areas, physical damage to turtles passing over instream structures, and mortality of turtles stranded by receding floodwaters
- increase in the abundance of exotic European carp within some western parts of the catchment, and
- some dispersal of exotic fish species, e.g. gambusia, into habitats previously only inhabited by native fish species.

Flood flows resulting in rapid increases in river height can have a large immediate impact if coinciding with periods of spawning/nesting of aquatic animals; including fish, turtles, water rats and platypus, especially if such rapid increases are naturally very rare. Scouring of the river substrate may also impact spawning/nesting of aquatic animals through loss of food sources at a critical time. However, flow modelling (DSITIA 2013b) indicates rapid changes in flows would only have occurred in about 2% of years under the ‘pre-development’ scenario, and less frequently under the ‘existing development’ scenario.

12.1.2 Estuarine and marine areas

During and after dam releases, the increased volumes of freshwater shift the salinity gradient downstream towards the bay. Accordingly the zone where suspended sediments begin to flocculate and where maximum turbidity occurs, temporally shifts downstream as well. During relatively wet years, the Brisbane River is near-fresh upstream from Goodna whereas during drought years saline waters intrude above Karana Downs towards the Mount Crosby weir.

Depending on the size of the flood, salinity in parts Moreton Bay can be reduced for periods up to 1 month. The main areas affected may include the north-east of the Brisbane River mouth including Bramble Bay and the central and eastern parts of Moreton Bay. Short term reduction in salinity of this nature is unlikely to have a significant impact on the biota.

It is unlikely that the Wivenhoe-Somerset dam flood operations significantly alter the flood impacts on the estuarine and marine environments.

12.1.3 Riverine ecosystems–riparian vegetation

Flood drain-down discharges from the dams under current operations may provide some benefit to riparian vegetation as they provide seed dispersal onto higher levels as well as causing scouring in the main river channel, which inhibits regrowth of seedlings in the low flow channel. This may provide a function of minimising the impact of vegetation encroachment downstream of Wivenhoe Dam.

12.1.4 Aquatic habitat (macrophytes, riffles, pools)

Discharges of ~4,000 m^3/s are deemed sufficient to cause scouring of erodible riffles (shallow stream transitions) and movement of sediment in pools. When flows of sufficient magnitude occur during the peak growth period for aquatic macrophytes (water-based vegetation), scouring can cause significant loss of density and abundance. For example, the January 2011 floods caused significant changes to the instream channel at Savages Crossing.

Prior to the flood a single channel existed, but afterwards a large gravel bar split the channel into two with one being narrower, deeper and faster flowing, prior to the flood there were extensive beds of paragrass on the banks and floating aquatic weeds such as water hyacinth and salvinia. All these have been washed away and a site visit in September 2011 suggested that they had not re-established.

12.1.5 Fish

Increased discharges can allow connectivity between freshwater and estuarine habitat across the Mount Crosby Weir, which is beneficial to migratory fish species. Additionally these levels of discharge provide periods of extended brackish habitat in the upper Brisbane River estuary and increase the productivity potential. The aquatic advantages of these releases are very short-lived (~10 days) and therefore the benefit is limited to a short time period after this, particularly in an otherwise dry year. There are potential negative impacts for the Australian lungfish if displaced and trapped downstream of the weir.

12.1.6 Turtles

There are four species of freshwater turtles native to the Brisbane River catchment within the Wivenhoe Dam impoundment and downstream from it. All four have wide distribution across multiple catchments including the Brisbane River Catchment. None are listed as threatened species under either State legislation, and / or Federal legislation.

Peak discharges of ~4,000 m^3/s are thought sufficient to inundate a significant number of nests (e.g. this creates ~5.8 m river rise at Savages Crossing).

During flood releases and releases associated with a temporary full supply level declaration, turtle fatalities can occur if they are drawn through the outlet works or impacted against hard surfaces. Scouring of the river substrate associated with the water release can cause a significant reduction in instream macrophytes, algae and associated invertebrates (molluscs, insects, crustaceans) which are food species for turtles.

Turtle nesting (expected during the period October to January) occurs above water level. If the water level is raised during this period, turtle nests may be flooded and eggs drowned.

Associated with rapid drawdown of water levels within impoundments, there may be loss of shallow water vegetation along the margins of the reservoir which may also impact the food source and refuge of young turtles.

12.2 Conclusions

Outcomes of Environmental Flows Assessment Program (EFAP) monitoring associated with the *Water Resource (Moreton) Plan 2007* (QLD) monitoring and evaluation and assessment provide a robust basis for predicting likely flow-related impacts from water management scenarios. However, as significant flood events are relatively rare, alteration to the sequence of flow-related recruitment and connection opportunities provided for in the intervening periods are the largest contributors to the risk of long term population viability.

Brisbane River floods do however represent major ecosystem resetting events with a number of benefits such as: scouring of sediments; removal of overgrowths of in stream vegetation; increased native fish stocks; and general increase in the ecological condition of rivers.

Potential negative effects include pollution from inundated infrastructure (e.g. sewage treatment plants); threats to some threatened freshwater turtle species (i.e. loss food supply and nesting areas, stranding, and physical injury); and spread of exotic pest species.

The general responses of aquatic ecosystems to flood events and dam operations within the constraints of the current management impositions, such as barriers to migration and timing and volume of releases for water supply are, in the context of population processes, transient and short lived.

As such the DSITIA study made no recommendations for changing the current dams operations in relation to impacts on flora and fauna.

Chapter 13 Flood notifications and warnings

This Chapter discusses the existing flood warning systems and arrangements for residents located downstream of Wivenhoe Dam and Somerset Dam and whether these systems allow residents to take timely action to minimise the potential impacts of flood releases.

Generally, BCC, ICC, SRC, BoM and Seqwater have robust warning and notification systems in place to warn community and stakeholder agencies of the potential negative impacts of flooding in all its forms. These are aligned within the Queensland Disaster Management Arrangements (QDMA) structure.

The Queensland Government has recently introduced new legislation which sets statutory criteria for preparing Dam Safety Emergency Action Plans (EAPs) in Queensland. The legislative standards and regulator's guidelines aim to ensure that dam owners place a premium on notification processes that are negotiated with stakeholders, the community and Local and District Disaster Management Groups. Queensland's legislation builds upon and is consistent with the Australian Emergency Management Guidelines and Manuals for providing warning and notification for floods affected by dams (AG 2009).

Accordingly, responsible government agencies and entities aim to provide timely and appropriately detailed warning messages and notifications to those potentially impacted.

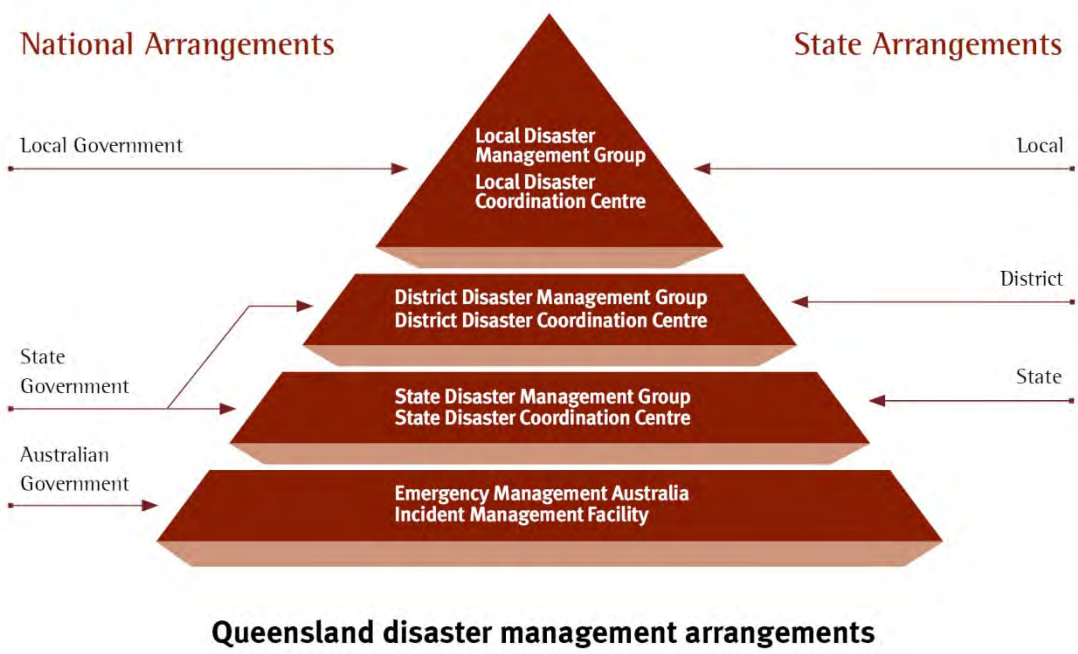
13.1 Queensland's disaster management arrangements (QDMA)

The Queensland Disaster Management system is a multi-tiered system of committee and coordination centres at state, district and local levels. Within this system the whole-of government disaster management arrangements are based on partnerships between government, government–owned corporations, non-government organisations, the commerce and industry sector and local community.

The QDMA are made up of several key management and co-ordination structures through which the functions of disaster management for Queensland are achieved (See Figure 13.1).

The principal structures that make up the QDMA are:

- disaster management groups operating at local, district and state levels which are responsible for the planning, organisation, co-ordination and implementation of all measures to mitigate/prevent, prepare for, respond to and recover from disasters;
- co-ordination centres at local, district and state levels that support disaster management groups in co-ordinating information, resources and services necessary for disaster operations;
- state government functional agencies through which the functions and responsibilities of the state government in relation to disaster management are managed and coordinated; and
- state government threat-specific agencies responsible for the management and coordination of combating threats.



Source: EMQ 2013

Figure 13.1 Queensland disaster management structure

The QDMA are activated using an escalation model from 'Alert' to 'Lean Forward' to 'Stand Up' and to "Stand Down". The levels of activation are as follows:

- 'Alert' – A heightened level of vigilance due to the possibility of an event in the area of responsibility. No action is required however the situation should be monitored by someone capable of assessing the potential of the threat.
- 'Lean Forward' – An operational state prior to 'Stand Up' characterised by a heightened level of situational awareness of a disaster event (either current or impending) and a state of operational readiness. Disaster co-ordination centres are prepared but not activated.
- 'Stand Up' – The operational state following 'Lean Forward' whereby resources are mobilised, personnel are activated and operational activities commenced. Disaster co-ordination centres are activated.
- 'Stand Down' – Transition from responding to an event back to normal core business and/or recovery operations. There is no longer a requirement to respond to the event and the threat is no longer present.

The movement of disaster management groups through this escalation phase is not necessarily sequential; rather it is based on flexibility and adaptability to the location and event.

Activation of the response arrangements may occur when there is a need to:

- monitor potential threats or disaster operations
- support or co-ordinate disaster operations being conducted by a designated primary agency
- co-ordinate resources in support of disaster operations and recovery operations at local or district level, and
- co-ordinate State-wide disaster response and recovery activities.

Activation does not necessarily mean the convening of disaster management groups; rather the provision of information to disaster management group members regarding the risks associated with a pending hazard impact.

13.2 Regulatory standards for notifications and warnings

The Queensland Government has established statutory criteria and standards under the *Water Supply (Safety and Reliability) Act 2008* (QLD) (the Act) for emergency situations at referable dams. A referable dam is a large dam that would put lives at risk if it were to fail and the regulatory criteria and standards are required to be formalised in the form of an EAP for that referable dam.

The primary reason for an EAP is to minimise risk posed by a dam failure or downstream release hazards. Such risks can arise from a number of scenarios which can include failure of elements of the dam, failure of the complete dam structure or risks to people or property as a result of water releases from an uncontrolled or controlled spillway. In order to maximise preparedness for such events, provision is also made for taking into account circumstances which may develop into the failure of a dam. Although emergency action planning provides for all potential risks, for the purposes of this report the focus will be placed on notifications and warnings during flood events.

Prior to the statutory requirements under the Act, EAPs were non-statutory and required as part of dam safety conditions on the development permit for the dam. Recommendation 17.31 of the final report of the QFCoI (QFCoI 2012) included that the Queensland Government should legislate to oblige each owner of referable dam to have an EAP approved by the appropriate Queensland Government agency. The Act has now been amended to contain the requirement for all referable dams to have an EAP approved by the chief executive of DEWS

Recommendation 4.16 of the Interim Report of the QFCoI (QFCoI 2011) was that dam operators should plan to contact people identified by their EAPs about dam outflow in sufficient time for them to be able to respond to the information. In cases where there may be insufficient time to notify affected people through existing emergency management systems, due to the close proximity of these people to the dam, the dam owner may need to notify them directly.

The Act requires that EAPs state when and how the owner of the dam must notify the relevant entities of an emergency condition. Relevant entities include persons whose safety or property may be threatened by the emergency condition. An emergency condition includes a downstream release hazard in relation to a dam. A downstream release hazard is a reasonably foreseeable hazard to persons or property downstream of a dam that could potentially be caused or aggravated by a flow event over a dam's spillway or by a controlled release of water from a dam.

To assist dam owners in the development of EAPs, DEWS released a Provisional Guideline (DEWS 2013c). This guideline also assists Local and District Disaster Management Groups to understand their role in the preparation of EAPs.

13.3 Roles of responsible organisations in flood warning

The QFCoI found in its Interim Report (QFCoI 2011) that flood warning is the responsibility of BoM, local governments and dam owners.

BoM provides the forecasting of flood levels and the conditions likely to give rise to floods. Local governments provide the warning of the likely impacts of floods on local communities such as inundation extents and location, while dam operators have a responsibility for providing notifications and warnings about the dam release or spill events to those communities immediately downstream of the infrastructure.

13.3.1 Bureau of Meteorology

The BoM, in association with Seqwater, BCC and ICC, operate a flood warning system for the Brisbane River basin. Data from the rainfall and river height network, which is made up of manual rainfall and river height observers as well as automated telemetry equipment, is collected, processed and used to determine forecast flood levels.

The flood warning system has been upgraded in recent years by the BoM, Seqwater, BCC and ICC with the installation of additional Automated Local Evaluation in Real Time (ALERT) flood warning stations. These provide early warning of heavy rainfalls and river rises throughout the catchment and enable more accurate and timely response to impending river and creek flooding throughout the Brisbane Valley.

In consultation with Seqwater, BCC and ICC, the BoM's Flood Warning Centre issues Flood Warnings and River Height Bulletins for the Brisbane River basin regularly during floods. Warnings are sent to radio stations for broadcast, and to the councils, emergency services and a large number of other agencies involved in managing flood response activities.

BoM does not:

- issue flash flood warnings (described as situations where the rain-to-flood time is less than 6 hours) for specific locations or individual creeks
- predict the extent to which the increased river height levels will cause an inundation of floodplains
- interpret the impact of any predicted flood levels or expected flooding on people or infrastructure, or
- disseminate targeted information to individuals or communities who are likely to be affected by any expected flooding.

13.3.2 Seqwater

Seqwater has a role in providing notifications and advice about Wivenhoe Dam and Somerset Dam releases to the community and stakeholder agencies. This role has been expanded since the January 2011 flood event in response to the recommendations of the QFCoI Interim Report (QFCoI 2011) Chapter 4 and Final Report (QFCoI 2012) Chapter 17 recommendations.

Seqwater has five key documents which establish the procedures and processes for providing warning to State agencies, Stakeholders and the community during flood events in the Brisbane River, Bremer River and Lockyer Creek:

- the Wivenhoe Dam EAP (Seqwater 2013g)
- the Somerset Dam EAP (Seqwater 2013h)
- Communications Protocol for Releases from Seqwater's Gated Dams (Wivenhoe Dam, Somerset Dam, North Pine Dam and Leslie Harrison Dam) (Seqwater 2013i)
- the Wivenhoe Dam and Somerset Dam Flood Mitigation Manual (Seqwater 2013h), and
- Bulk Authority Emergency Response Plan, Whole of Supply Chain Response, 2013 (Seqwater 2013j).

In general and for Wivenhoe Dam and Somerset Dam, Seqwater is aligned within the QDMA Structure to provide advice and information to the Brisbane Region Local Disaster Management Group (LDMG), Ipswich Region LDMG, Somerset Region LDMG and Lockyer Valley LDMG as well as the relevant SEQ service providers and SEQ water supply system emergency stakeholders.

The Wivenhoe Dam and Somerset Dam Flood Mitigation Manual (Section 1.3 Role of Seqwater) states that Seqwater does not have responsibility for:

- forecasting flood levels along the Brisbane River, Bremer River or Lockyer Creek during Flood Events (this being the responsibility of the BoM), or
- interpreting forecast flood levels to provide local information on areas likely to be inundated or providing local flood warnings to residents (this being the responsibility of the local government and the LDMG in consultation with the BoM).

The Wivenhoe Dam EAP, Somerset Dam EAP and the Communications Protocol for Releases from Seqwater's Gated Dams (Communications Protocol) are the three documents that provide the procedures and processes for notifications and external communications about releases from the Dams. Both the Flood Mitigation Manual and the Emergency Response Plan provide some guidance for notification and external communications but are not the definitive documents.

13.3.3 Notification and warnings – Seqwater, local, state and federal governments

Seqwater Mechanisms

Under the current standards and guidelines for EAPs, Seqwater is only expected to provide information as to timing and volume of dam outflows during a flood event. Predictions as to river heights or inundation areas are the responsibility of others within the disaster management framework. It is the responsibility of residents close to the dam to be aware of how flood flows will affect their property and have in place appropriate plans or courses of actions in the event of floods.

Seqwater's established Communications Protocol (Seqwater 2013i) defines the communication arrangements in the event of a dam release from one of Seqwater's gated dams, to assist in the effective, coherent and timely coordination of information to stakeholder agencies and the public. A stakeholder agency in this instance includes federal, state and local governments. The Communications Protocol is implemented when the conditions for a potential dam release eventuate. Seqwater will send a message to stakeholder agencies advising of such conditions existing. The EAP identifies the various conditions that lead to a dam release occurring.

To maintain the consistency with the QDMA, Seqwater has established levels of activation for when the Communications Protocol is implemented. Different floods call for different frequency of communication. A slow rising flood may require less frequent provision of information, while a rapidly rising flood may require very regular communication.

Under the Communications Protocol Seqwater rely on various communications mediums to provide information to the public and stakeholder agencies. Formal notifications are made using the Dam Release Situation Reports. These situation reports are generally issued as soon as practical after the mobilisation of the Flood Operations Centre and then on an ongoing basis at 7:00am and 7:00pm. Should an unexpected escalation in a flood event occur the situations reports will be issued at other times.

Seqwater provides projected Wivenhoe Dam outflow hydrographs to stakeholder agencies operating flood modelling systems. Updated hydrographs are emailed when a significant change is made to the Wivenhoe Dam Release Plan. Agencies currently receiving this information are: BoM, BCC, ICC and SRC. This allows those agencies to undertake assessments of projected inundation extents and heights during a flood event.

In accordance with the QFCoI recommendations Seqwater also provide information to subscribers using the Dam Release Notifications via email, SMS or recorded messages. These notifications are made if a dam release is occurring, about to occur or there has been a significant change to releases. Information about releases can be accessed through a dam release hotline as well as using Seqwater's web and social media updates. The dam release notification network, hotline and web and social media updates are mediums by which the general public can maintain situational awareness during a flood event.

Local, state and federal government mechanisms

The local government areas downstream of Wivenhoe Dam that are directly affected by flood releases from the dam include SRC, BCC and ICC. Each of these local governments have a LDMG established under the QDMA which has the role of coordinating the management of the wider community consequences as a direct or indirect result of severe weather.

In accordance with the *Disaster Management Act 2003* (QLD) and the Queensland Local Disaster Management Guidelines (EMQ 2012), it is a role of the LDMG to provide the public with hazard awareness, household preparedness and emergency planning information about events and recommended actions. Broadcast radio is the primary vehicle for public information in most events, however emergency service agencies are now increasingly also using more contemporary mass communication mediums such as social networking sites, subscription services or emergency alert notifications.

The further downstream the population is from the dam, the more appropriate it is that they are warned through other less direct means than by the dam owner. Wivenhoe Dam does have a large population at risk downstream of the dam however very few of the population live immediately downstream of the dam i.e. within one hour flow travel time of the dam.

An added level of complexity to consider when dealing with flood events downstream of Wivenhoe Dam are inflows into the Brisbane River from Lockyer Creek and Bremer River. If a flood is originating only from the Lockyer Creek or Bremer River then communities will be notified by the LDMG and the BoM as there are unlikely to be releases from Wivenhoe Dam.

The notification and warning of communities further downstream such as those in Ipswich and Brisbane Cities is considered to be adequately provided by the local governments in consultation with the BoM. Should there be a major escalation in a flood event then notification and warning would be escalated to the responsibility of the Queensland Government through the QDMA.

Another consideration during the practical implementation of the notifications and warning during a flood is that the large flood mitigation storage in Wivenhoe Dam allows downstream residents to be notified in advance of a release. What this means is that should a flood event become major there should already exists a heightened sense of awareness within the at risk communities. The heightened awareness would come from the notifications made by Seqwater and the LDMGs while minor and moderate flood releases are being made from Wivenhoe Dam.

In the context of providing warnings for those residents who live immediately downstream of Wivenhoe Dam the Somerset Region LDMG is the key LDMG that Seqwater liaises with during a flood emergency. To provide warnings and notifications to affected residents the Somerset Region LDMG may use any appropriate form of communication to get messages to the community.

Since the January 2011 flood event SRC has implemented initiatives to improve the way in which monitoring, management and notification and warning of a flood event is undertaken as follows:

- Improved management and coordination systems:
    - Employment of a Disaster Management Officer and a Communications Coordinator
    - Establishment of an Incident Management Team
    - Purchase and installation of Incident Management Software
    - Embedment of the Local Government Association of Queensland's Disaster Hub within SRC's website for public access.
- Advanced Flood Early Warning Systems:
    - Installation of computer server redundancies
    - Installation of dedicated Ultra High Frequency radio network
    - Installation of new rainfall and river gauges at a number of key sites
    - Upgrading of existing river gauges for radio and mobile telephone communications
    - Adoption of an advanced computer based system to control SRC's Flood Early Warning Systems and network
    - Installation of the BoM's Enviromon system for monitoring BoM flood ALERT Stream Gauging Stations.
- New notification and warning mediums:
    - An early warning network for subscribers which provides the community and stakeholders to with notifications
    - Automated issuing of alerts to SRC staff by SMS and email through internal SRC systems
    - Installation of warning sirens at Lowood and Fernvale
    - Installation of eight video streaming cameras at commonly inundated crossings
    - Installation of a number of fixed electronic road closed signs
    - Purchase of 2 x trailer mounted VMS units
    - Installation of fixed LED signage at Fernvale and Kilcoy to display public notices

- o 15 minute interval updates of flood cameras on SRC's website
- o Use of social media to provide information to the community.

Seqwater and Somerset Regional Council interactions

During a flood event it is the agreed position of both Seqwater and SRC that the Somerset Region LDMG be the primary source of detailed information about the flood event. Detailed information includes notification of such things as projected flood levels and inundation extents, evacuation procedures, evacuation centres and other relevant notifications for community.

For the majority of residents living downstream of Wivenhoe Dam and Somerset Dam, the timing of notifications and the level of detail is appropriate for residents to take action. This assumption considers that residents are receiving notifications from Seqwater and their relevant local government LDMG as well as being proactive in maintaining individual situational awareness.

In the context of Wivenhoe Dam there is a clear distinction of notification and warning for populations at risk during minor and moderate flood events and the kinds of notifications and warnings that might be required during an emergent situation as a result of a major flood event. This kind of emergent situation arises when the dam owner is required to escalate releases rapidly to maintain the structural integrity of the dam.

The population at risk located within one hour flow travel flow from Wivenhoe Dam may be notified very quickly by Seqwater's voluntary Flood Release Notification Service; however the messages may not be sufficiently detailed for action to be taken. This would rely on the LDMG to provide a more detailed message which should include evacuation information. Timing is crucial in this instance to ensure the safety of close proximity populations downstream.

The final option open to both Seqwater and the Somerset Region LDMG is the use of the National Emergency Alert System which issues warnings to telephones linked to the addresses (properties and houses) within a geographical area affected by an emergency. Warnings can also be sent to mobile telephones based on the last known location of the handset at the time of an emergency.

Seqwater and SRC have established protocols with the National Emergency Alert System and will use that system during an emergency situation to provide notifications to those at risk. In preparation for the use of the National Emergency Alert System SRC have created a number of pre-formatted emergency alert messages to deal with common flooding scenarios. Similarly, Council have created maps that can be used to identify areas that these messages will be sent by the National Emergency Alert System. This dramatically speeds up the distribution of these emergency alerts during major events.

13.4 Conclusions

Generally, Seqwater, BoM, BCC, ICC, and SRC do have robust warning and notification systems in place to warn community and stakeholder agencies during minor, moderate and major flood events.

The legislative standards in the Act and the regulator's Provisional Guideline for Emergency Action Planning for Referable Dams aim to ensure that dam owners place a premium on notification processes that are negotiated with stakeholders, the community and Local and District Disaster Management Groups.

Under the QDMA, Seqwater has no responsibility for issuing public flood warnings but has a key role in flood forecasting and notifications to relevant organisations.

Wivenhoe and Somerset Dams are unique being the largest flood mitigation dams in Queensland and also being located upstream of the largest population at risk in Queensland. During major flood events, residents in close proximity to the dam require more urgent warnings than those who are further downstream and are not at immediate risk.

The significant improvements made by both the Local, State and Federal Governments and Seqwater following on from the 2011 flood events ensure that there is wide ranging and adequately managed notification and warning for populations at risk downstream of Wivenhoe and Somerset Dams during flood events.

Chapter 14 Floodplain risk data

Assessment of the implications of urban and rural inundation was one of the considerations required under QFCoI Final Report recommendation 17.3 for a range of operational options over a range of flood events.

The currently underway Brisbane River catchment studies[18] will provide a comprehensive floodplain risk assessment of the Brisbane River catchment, including an up-to-date fit for purpose hydraulic model of the entire floodplain. These studies are not due for completion until after 2015; outside the WSDOS timeframe.

The assessment of the implications of urban and rural inundation for the various operational options considered under WSDOS has been limited to an estimate of the cost of flood damages and impacts, and qualitative consideration of other factors, including environmental factors, where this was not practical.

This Chapter outlines the basis of information used to estimate the flood damages and impacts presented in Chapter 15 (‘Integrated assessment of options’) i.e.

- Inundation extents for a range of flood events.
- Building and property data for the local government areas of Brisbane City, Ipswich City, Somerset Region and Lockyer Valley Region.

Estimation of flood damages to roads and bridges and other infrastructure (water, electricity, telecommunications, etc.) is described in Chapter 15.

14.1 Inundation extents

DSDIP (with the agreement of the BRCFS Steering Committee) is currently reviewing and updating a BCC study completed in 2009 (BCC 2009) to deliver interim flood maps for disaster management by SRC, ICC and BCC for the 2013/2014 wet season. However this update had not been completed in time to be utilised for WSDOS.

Consequently WSDOS has relied on existing available flood inundation information from the BCC study completed in 2009 (BCC 2009) for the purposes of estimating the relative costs of flooding associated with each Wivenhoe Dam operational option. This information was originally prepared by Brisbane City Council for disaster management purposes and therefore was not specifically focused on other local; government areas (i.e. Ipswich City, Lockyer Valley and Somerset Regional Councils). However, it was considered to be the best information available within the WSDOS timeframe.

The BCC two dimensional hydraulic model (BCC 2009) covers the Brisbane River catchment downstream of Wivenhoe Dam to Moreton Bay encompassing the major urban areas. The model covers an area of 4,500 km^2 or about one third of the Brisbane River catchment and includes the downstream sections of the tributaries of Bremer River and Lockyer, Warrill and Purga creeks that are impacted by backwater flooding effects from Brisbane River flooding.

Inundation extents were produced for ten flood flows at the Port Office (BCC 2009) covering small to large floods from 3,000 – 38,000 m^3/s. The smallest discharge of 3,000 m^3/s represented a minor flood (flows mostly contained within the River) with limited impacts to

[18] QFCoI recommendation 2.2 required that a single comprehensive flood model (both hydrologic and hydraulic) be developed for the Brisbane River catchment. DNRM are currently leading the Brisbane River Catchment Flood Study (BRCFS) which is scheduled for completion by late 2015. The Brisbane River Floodplain Management Study will follow the completion of the BRCFS.

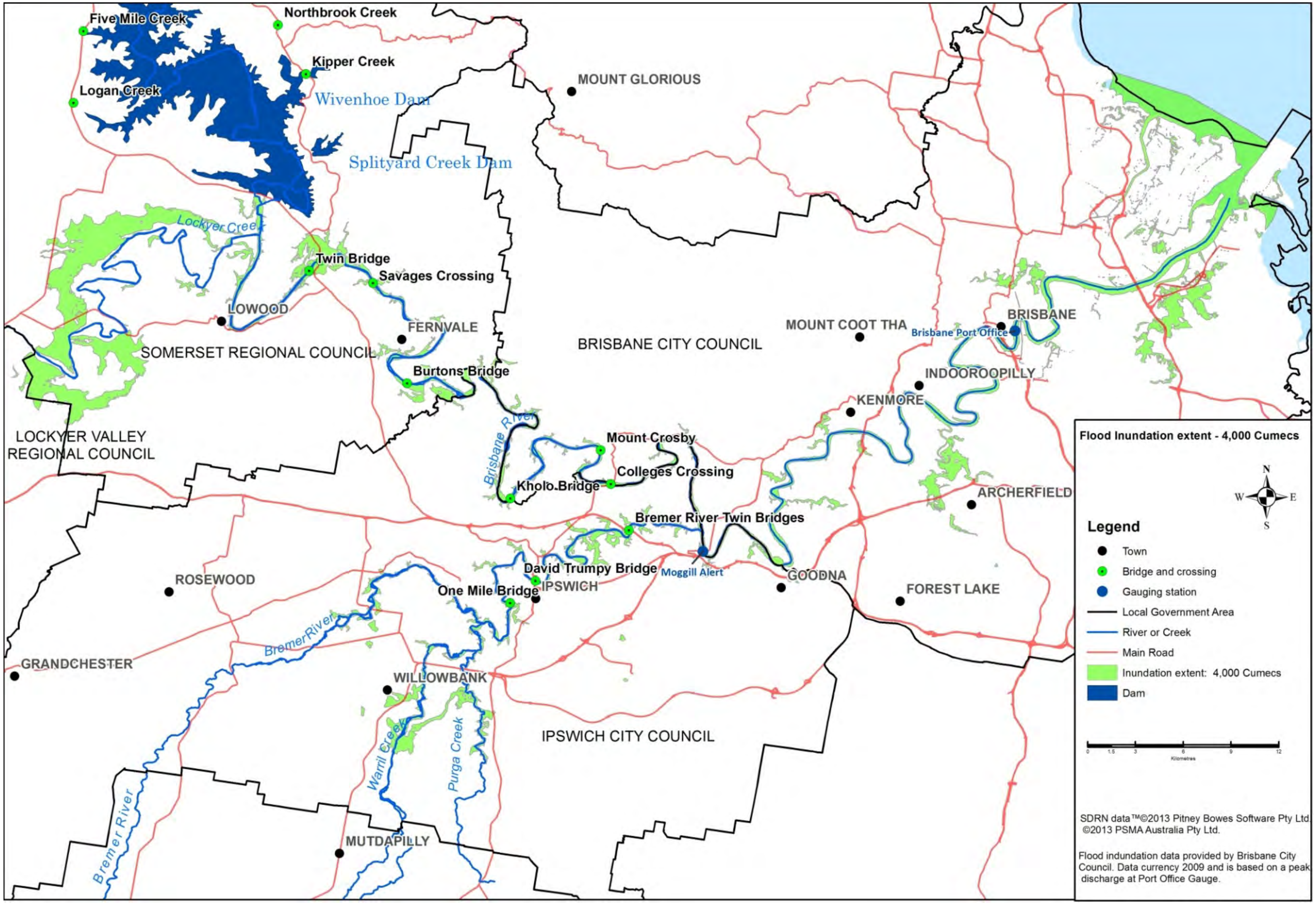
buildings whilst the largest discharge of 38,000 m^3/s represented the then estimated catchment PMF which defines the maximum extent of the floodplain (i.e. the maximum area that is subject to flooding). Inundation extents are depicted in

Figure 14.1 and Figure 14.2 for flood flows of 4,000 m^3/s and 12,000 m^3/s respectively at the Port Office (note: flows between the Port Office and Moggill do not differ appreciably).

Inundation extents were used to establish damage rating curves and to correlate modelled flows from Seqwater's FOSM with an impacted area for each option. To facilitate this, the Brisbane River floodplain was sub-divided into sixteen zones based on regions of hydraulic influence and Local Government Authority.

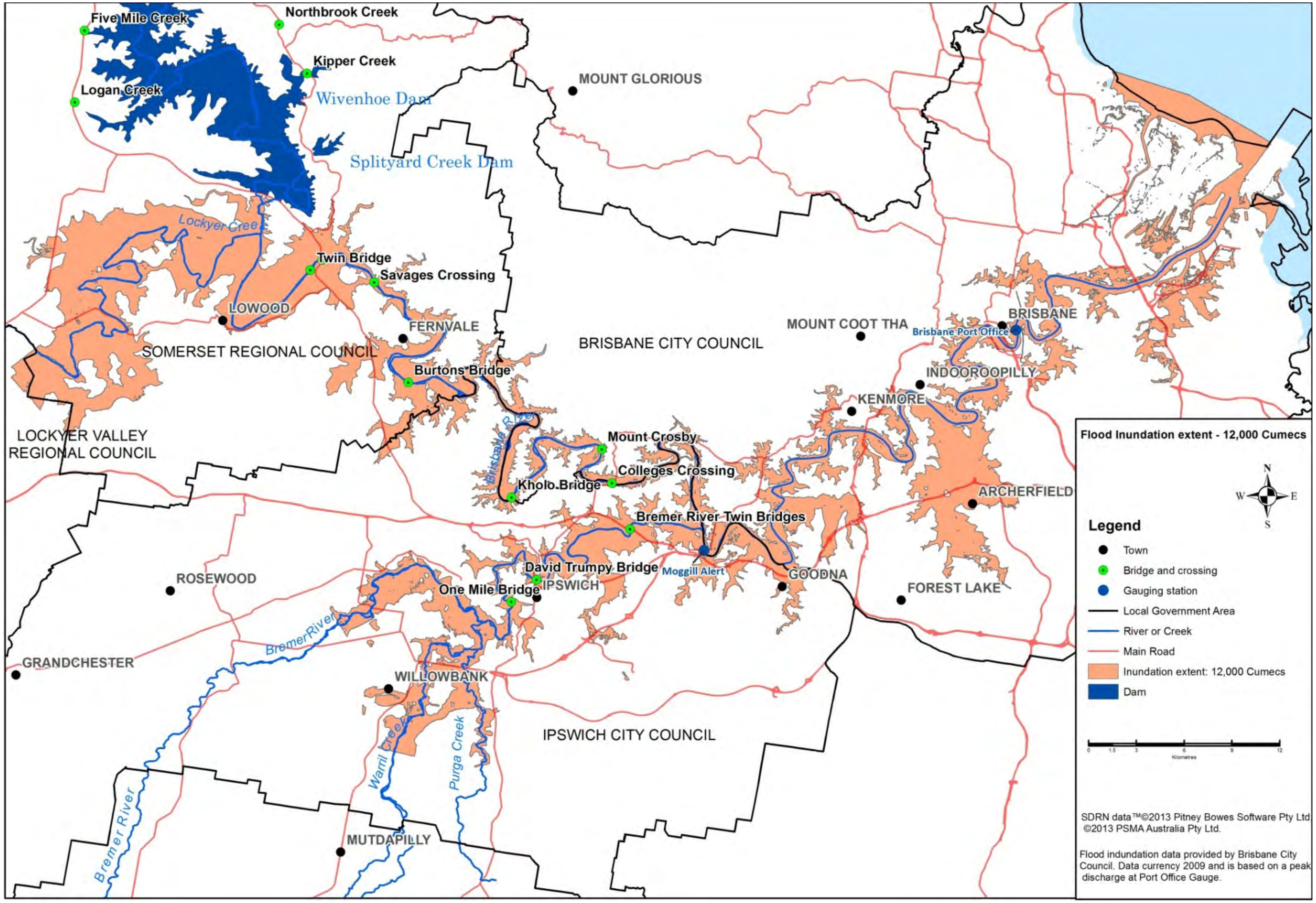
Inundation in each zone for each operational option assessed was determined as follows:

- Inundation in zones between the junction of Lockyer Creek and the junction of the Bremer River was based on a BCC flood inundation extent that correlated with the levels at Savages Crossing and Mount Crosby Weir gauging stations for the Seqwater estimated flows.
- Inundation in zones at and downstream of the junction of the Bremer River was based on a BCC flood inundation extent that correlated with the levels at Moggill for the Seqwater estimated flows."



Note: Inundation extent refers to areas downstream of Wivenhoe Dam. The inundation of areas upstream of Wivenhoe Dam is not shown.

Figure 14.1 Flood inundation extent - 4,000 m^3/s at the Brisbane Port Office (City gauge)



Note: Inundation extent refers to areas downstream of Wivenhoe Dam. The inundation of areas upstream of Wivenhoe Dam is not shown.

Figure 14.2 Flood inundation extent – 12,000 m^3/s at the Brisbane Port Office (City gauge)

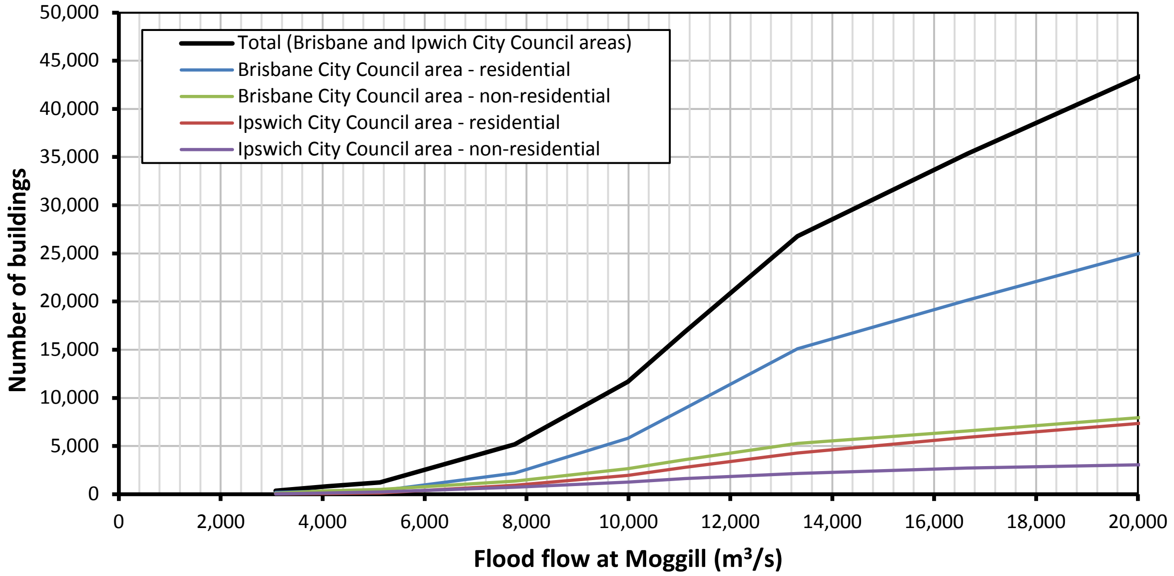
14.2 Building and property data

Property information and details on residential and non-residential buildings (i.e. commercial, industrial and community infrastructure) were obtained from the various local governments for the purposes of flood damage assessment. The data obtained included building footprints, building type data (in term of fire codes), land use information (e.g. residential, commercial etc.) and heights (eave and ground levels).

Site specific surveys and/or eave heights and ground level information captured using LiDAR helped to differentiate between low set houses, double storey buildings and multi-level unit buildings. Approximate habitable floor levels and the number of storeys of buildings were determined based on the eave height and the ground level. Together with the fire code and land-use information this then enabled the categorisation of residential building type for subsequent estimation of flood damages described in Chapter 15.

No data on buildings and properties in the SRC areas upstream of Wivenhoe and Somerset dams (e.g. Esk, Kilcoy) was included, as flooding impacts in these areas from the operation of Wivenhoe Dam is not significant in the overall context.

Based on the methodology in Section 14.1 and for various flood flows at Moggill/Port Office Figure 14.3 depicts the number of residential, non-residential and total number of buildings impacted in Brisbane City Council and Ipswich City Council areas. The buildings impacted in Somerset Regional Council and Lockyer Valley Regional Council areas are not indicated in Figure 14.3 as the number is relatively low.



Note: Assessment of the number of buildings impacted is based on flooding above habitable floor level for residential buildings and above floor level for non-residential (i.e. commercial and industrial) buildings.

Figure 14.3 Buildings impacted in Brisbane City Council and Ipswich City Council areas

14.3 Limitations

The 2009 BCC study (BCC 2009) flood profiles were produced for disaster management purposes and were based on flood flows at the Port Office gauge which themselves were generated by scaling the outputs from the Brisbane River Extreme Flood Estimation Study 2007 (WRM 2007) conducted by WRM on behalf of Brisbane City Council. The hydrology was based on only one type of storm i.e. one centred over the Brisbane River catchment. Any number of different storms could occur within the catchment with variations relating to:

- rainfall spatial patterns;
- rainfall temporal patterns;
- rainfall intensity and peak storm bursts; and
- antecedent catchment conditions.

Therefore, it is acknowledged that the actual inundation extents may be significantly different at locations upstream of Moggill depending on the relative contributions from dam releases and lower tributary (i.e. Bremer River and Lockyer, Warrill and Purga creeks) inflows.

The building and property data available was based mostly on remote sensed information with inherent inaccuracies in its interpretation (i.e. building size and floor levels) and minimal ground truthing. It is anticipated that the Brisbane River catchment studies will be generating more accurate building and property data.

The results of the integrated assessments conducted for this study will be reviewed as part of the Brisbane River catchment studies.

Chapter 15 Integrated assessment of options

This chapter presents the integrated assessment undertaken as part of WSDOS to evaluate the relative benefits and costs of the wide range of options identified in Chapter 5. It describes the adopted methodology, its assumptions and limitations, and the results of the economic assessments undertaken to provide indicative net present costs of the identified options into the future.

Integrated assessment of the operational options to satisfy the requirements of QFCoI Final Report recommendation 17.3 requires difficult trade-off considerations between:

- the damage and impacts associated with flooding
- the water supply costs associated with increased production of manufactured water and the need to bring forward infrastructure upgrades
- not worsening dam safety risks while any necessary upgrades of the dam are planned and executed
- the ability to minimise disruption to the community by reducing the cost of traffic rerouting resulting from the submergence of bridges, crossings and roads, and
- permitting increased flooding due to smaller floods so that that flooding from large floods can be reduced.

No significant new operational strategies for minimising bank slumping and erosion and flora and fauna impacts were identified, thus these impacts have not been considered in assessing the trade-offs.

The integrated assessment of operational options presented here proceeds as follows:

1. An overview of the basic methodology applied to costing each class of flood impact
2. Development of relationships describing flood-induced costs for each impact class
3. Incorporation of the probability of flood-induced impacts occurring that enables estimation of an Average Annual Damage (AAD) cost for each option
4. Calculation of the Net Present Costs (NPCs) for each operational option going forward in time (i.e. costs of flooding incurred together with required water supply augmentation investments), and
5. An integrated assessment of the NPCs of the operational options in the context of QFCoI Final Report recommendation 17.3.

Net Present Costs (NPCs) have been estimated for tangible flood inundation damages and impacts and brought-forward costs of water infrastructure and manufactured water production. Intangibles aspects that are not easily valued such as environmental and social harm were not considered in detail. Any assessment of intangible costs would require even more assumptions than for estimation of tangible costs some of which have been outlined in Section 15.1.4.

As shown in Figure 15.1 this chapter brings together the results of work outlined in:

- Chapter 7 – Dam operations – flood mitigation assessment
- Chapter 8 – Water supply security
- Chapter 9 – Dam safety (breached fuse plug costs only)
- Chapter 10 – Bridge and crossing submergence

15.1 NPC assessment methodology

The adopted methodology has been designed to allow assessment and comparison of the relative costs of the operational options being investigated under WSDOS. The primary focus of the analysis was the trade-off between flood mitigation and water supply security.

To allow a direct comparison between the operational options, the estimated costs were quantified using a consistent and comparable framework of analysis. This involved estimating the monetary value of the potential benefits (e.g. avoided flood damage costs together with the likelihood of damaging events occurring) and the likely costs (e.g. bulk water supply cots) into the future. These separate elements were all combined in a NPC analysis to provide an objective comparison of the identified options.

The total NPC is the accumulation of costs that can be directly attributed to, or modified by the operational option. For this study, the integrated assessment incorporated:

- flood damages – spatially distributed property damage directly related to inundation during a flood event
- flood impacts – impacts associated with loss or disruption of a service (eg. transport) due to a flood event
- water supply impacts – costs directly or indirectly resulting from changes to a flood mitigation or water supply strategy, and
- direct infrastructure and other capital costs associated with implementation of an option.

15.1.1 NPC Methodology overview

Cost impacts of an operational option are considered to be the difference between the NPC of the modified scenario and the Base Case (Option 001). Figure 15.1 outlines the five main phases in estimating the NPC of tangible flood damage and impact costs, plus water supply infrastructure and operational costs, associated with each operational option:

Phase 1	Average annual flood damage to buildings and infrastructure (residential and non-residential buildings, transport infrastructure excluding bridges)
Phase 2	Average annual impact costs of traffic delays due to bridge and crossing submergence and bridge damage
Phase 3	Additional infrastructure capital costs due to the possible bringing forward of water supply augmentation timing as a result of lowering the FSV of the dams
Phase 4	Additional bulk water operational costs due to lowering the FSV of the dams, and
Phase 5	Economic assessments to calculate the NPC.

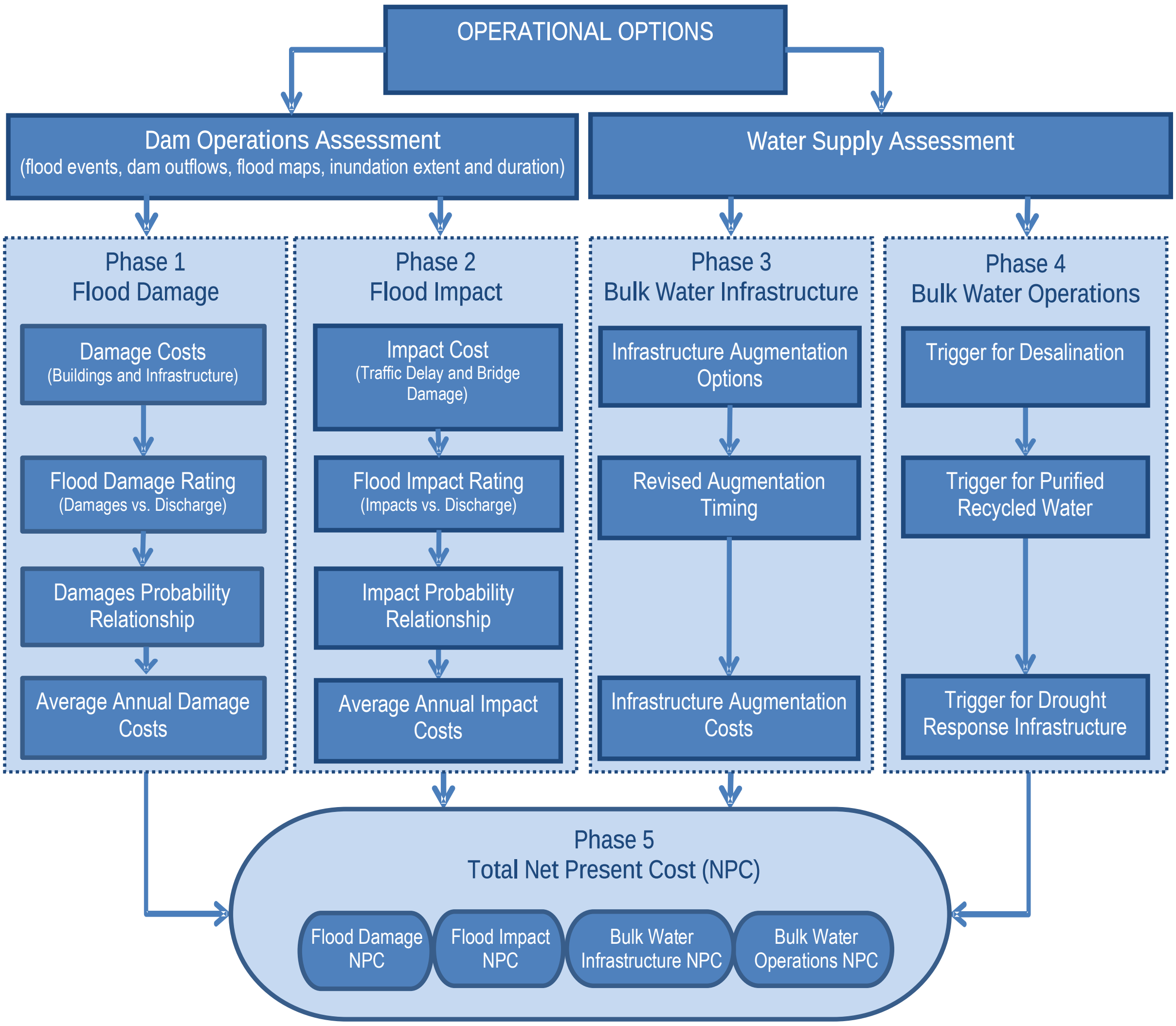


Figure 15.1 Methodology for assessing the NPCs of options

15.1.2 Flood damage and impacts

The impacts and costs of flooding vary with location within a floodplain (including depth and velocity of water as well as duration of flooding) and the susceptibility to damage by flood water of the type of property or infrastructure (houses, roads, bridges, commercial properties, etc).

Flood damages and impacts are typically described either as tangible (i.e. those that can be assigned a monetary value) and intangible (i.e. those that cannot be expressed in monetary terms). Tangible costs are further classified as direct damages (such as to houses and property) and indirect impacts (such as traffic delays associated with flooding of crossings and bridges) – see Figure 15.2. Other potential indirect costs (e.g. loss of production and loss of personal income) have not been included in this assessment. Potential intangible costs also have not been quantified in this assessment.

Potential for loss of life has not been considered in the integrated assessment. While this is always a possibility in any flood event, the present aim is to compare the impacts of a range of dam operational options that all have a likely similar potential to be associated with loss of life. However, when considering the possibility of dam failure (Chapter 9) loss of life is of paramount importance. Options that tend to reduce dam safety will therefore likely need further investigation.

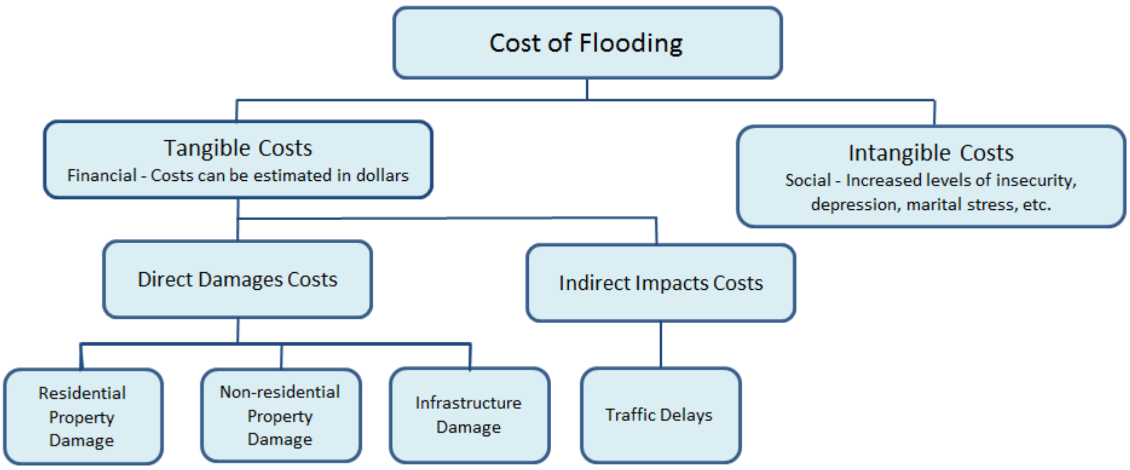


Figure 15.2 Traditional cost breakdown in assessing flood damage and impacts

Flood damage and impacts costs are dependent upon the severity of a particular flood event. Damaging floods are relatively rare events and the severity and occurrence of future flood events can only be described statistically. The procedure for producing a NPC associated with flooding therefore involves estimating the damage and impact costs resulting from a range of flood events – from very likely/minor damage to very unlikely/major damage. Assigning expected probabilities of exceedance to each of these event magnitudes allows assessment of estimated average annual costs of damages (AAD) and impacts into the future.

Empirical damage relationships for cost versus river flow were developed based on a range of previous Australian studies examining real flood outcomes. This enabled assessment of the differential effects of each operational option downstream of the dam. The hydrologic and dam operations assessments (outlined in Chapter 7) and the BCC (2009) flood surfaces information discussed in Chapter 14 provide the basis for calculating flood damages and impacts, which relate mainly to the potential depth (damages and impacts) and duration (impacts) of inundation.

The effect of each operational option is then ideally to lessen the probability of experiencing downstream flows of a given magnitude and hence to lessen the damage costs. Thus, for each operational option, a damage-probability and impact-probability relationship was established that enables an estimate of the AAD.

The flood damages assessed included:

- residential and non-residential buildings
- transport infrastructure
- other infrastructure such parks and gardens
- utilities (electricity, water and telecommunications), and
- flood cleanup and rehabilitation.

The flood impacts assessed included:

- bridge inundation
- weirs
- ferry services, and
- fuse plugs.

Potential dam failure impacts such as damage to the fuse plug spillway and erosion of saddle dams were not included though these are potential issues for operational alternative Urban 4 in particular and are also relevant to the other alternatives. The basic assumption is that the dams will not fail and that if there are dam safety issues they will be investigated and addressed via Seqwater's dams portfolio risk assessment.

15.1.3 Water supply assessment

As noted in Chapter 8, reducing the water supply storage capacity of Wivenhoe and Somerset Dam to provide greater flood mitigation capacity has the potential to affect the planning and delivery (and therefore cost) of water supplies across the SEQ water supply system.

Two water supply aspects have been investigated in the integrated assessment:

1. bulk water infrastructure augmentation bring-forward costs, including those contingency measures that are triggered when the total volume stored within SEQ water storages reduces to 30% combined capacity, and
2. operational costs mainly associated with the potential need for increased production of manufactured water as a response to a critical shortage of supply.

The assessment seeks to identify the differential costs associated with changes to water supply infrastructure augmentation timeframes and operational costs under each operational option when compared with the current Base Case (Option 001). The assessment did not include dam spillway upgrade costs, though an upgrade is required by 2035. It is recognised that this considerable expenditure may be a precursor to implementing some alternatives (in particular operational alternative Urban 4).

Future planned infrastructure and operational costs have been based on information supplied by Seqwater on bulk water costs related to possible future upgrades of supply sources within the SEQ water supply system, which are assumed to be predominantly new desalination plants.

There are also operational costs that relate to water manufacture or augmentation works undertaken in response to the combined capacity of the SEQ water storages reaching defined trigger levels during drought periods. Operational costs associated with manufactured water production have been calculated and weighted based on the estimated probability of occurrence of reaching the various trigger levels.

The infrastructure impact cost of the different operational options involving lowered FSVs of the dams was calculated as the difference between the NPC of:

- the adjusted timelines for the construction of infrastructure due to changes in the capacity of the water supply storages under each operational option, and
- the currently anticipated augmentation timelines for Option 001.

Some significant challenges exist in estimating the differential costs of options, including:

- the uncertainty of any assessments given that the LOS objectives for the region are presently under review and will inform the preparation of a new water security program by Seqwater
- the need to consider the potential lowering of the FSVs of both Wivenhoe Dam and North Pine Dam conjointly
- deriving a methodology for the apportionment of differential capital and operating cost associated with the potential lowering of the FSVs of the dams
- the estimates of capital costs beyond the first augmentation of supply currently anticipated in 2031 under Option 001
- the estimates of differential operational costs based on probability of triggering manufactured water production (that is, when the total water storage in the SEQ water supply system falls to 60% (GCDP), 40% (WCRWS) and 30% (new augmented supply) of the total SEQ water storages), and
- determining an appropriate accounting period to capture relevant costs.

In respect to the capital costs, the first augmentation occurs by 2031 and the second augmentation by the mid-2040s. Hence, it was considered appropriate to evaluate options over 20 years and 40 years to account for the shorter and medium term effects, plus a longer term of 60 years.

15.1.4 Limitations and assumptions

The results of the assessment remain indicative-only as, although the integrated assessment has been conducted based on best currently available data, there are significant uncertainties in the damage and impact estimates due to approximations and assumptions in the methodology and limitations associated with the available data (Aurecon 2013).

Specifically acknowledged limitations and assumptions of the assessment include:

- Assessment of flood impacts is limited to directly assessable tangible costs (e.g. direct flood damage; and repair and traffic impacts of bridge closure). No allowance has been made for intangible impacts (hardship, stress and the like) on communities due to flooding or long-term closure of bridges; nor for ill-defined costs such as loss of income.

- A simplified flood damage rating methodology has been used, assuming that flood damage can be directly related to peak flow in various parts of the Brisbane River. (e.g. peak flow and/or peak level at a particular reference location was deemed representative of that entire segment of the floodplain). The impacts in each segment are then summed to provide the total impact.
- The residential and non-residential damage is calculated based on adopted relationships between damage and inundation depth only and the possible effects of duration and flow velocity have not been considered. Specific flood events or impacts have not been analysed to test the veracity of these assumptions. Potential for loss of life has not been considered.
- Flood inundation mapping from earlier BCC 2009 hydraulic model studies was used to define the extent and depth of flooding; these were then necessarily linked to the recent Seqwater stochastic hydrology modelling (Seqwater 2014a) rather than to the original hydrology assumptions used to generated the flood surfaces.
- Flood levels have been based on available BCC (2009) flood mapping linked to a characteristic Brisbane River flow only (i.e. a peak discharge at the Port Office gauge). Inputs from Wivenhoe, Lockyer Creek and the Bremer River systems are included in the model but are for a single flood event directly related to a Brisbane River flow. The currently available flood mapping therefore does not allow for independent variability in the magnitude or timing of the river and tributary flows and resultant range of coincident floods.
- Flooding in Ipswich can arise from either the Brisbane or Bremer Rivers (or a combination of both) and therefore determining an accurate estimate of the NPC of future floods in Ipswich is complex. Simplifying assumptions regarding the relationship between Brisbane River flows and flood levels in Ipswich have been adopted (principally acceptance of the relationship between Brisbane River flows and flood levels in Ipswich assumed in the BCC 2009 flood inundation mapping) to allow the NPC assessment of options to be undertaken.
- Flood damages have been estimated using a GIS-based algorithm. Alternative methodologies involving more detailed site-specific assessments may provide different results.
- The estimation of AAD is dependent upon the damage cut-off threshold (flow rate below which no damage occurs). Damages outside the range of the available flood maps have been interpolated / extrapolated based on available data.
- The Seqwater (2014a) supplied dam modelling used in the stochastic assessment assumes that the dams are always at the nominated FSV at the commencement of every flood event. This neglects the potential positive and negative influences of different real reservoir levels and also the possibility of multiple flood events that could occur after breaching of a fuse plug.
- A number of low-level bridges have low immunity and time of closure has been separately calculated from DSITIA-supplied IQQM water balance modelling with a resolution of average daily flow;
- The assessment of costs of disruption to BCC ferry services and infrastructure has been based on 2011 and 2013 experience and may not be representative of future impacts.
- Modelling undertaken by Seqwater (2014b, 2014c) has assumed that the WCRWS is active and operating at sufficient capacity to supply power station demands. However, from 2014 the WCRWS will be decommissioned and placed under care and maintenance, with the ability to be re-commissioned at the 40% trigger.
- Bulk water infrastructure costs are based on estimated likely dates of required augmentation which are subject to further analysis. Dates have been rounded to the nearest year, and may over or underestimate the actual date and impact.

- Bulk water supply infrastructure and water security issues affect and are dependent on the combined SEQ water network. Costs have been distributed to the Wivenhoe Dam options based on a ratio of contributory volume reduction or storage volume rather than contribution to system yield, which may not be appropriate in all circumstances.
- Costs related to dam operations and maintenance that may be affected by changes to the operational dam FSV have not been considered.
- The assumption that the WCRWS is active, however noting that the WCRWS will be decommissioned and placed under care and maintenance with the ability to be recommissioned at the 40% trigger.

Because of these limitations, results of the integrated assessment should not be considered to be precise. They are intended to provide an indicative estimate of the magnitude of the effects of different classes of flood damage and water supply implications under the proposed range of options. The assessment merely allows these options to be compared in a consistent manner. Future Brisbane River floodplain studies will likely provide a better basis to inform long-term planning decisions.

15.2 Phase 1 - Flood damages

15.2.1 Identification and quantification

In identifying flood damages, the depth and extent of flood inundation (flood surfaces) from a previous Brisbane City Council hydraulic modelling study (BCC 2009) which modelled Brisbane River peak flows from 3,000 to 38,000 m^3/s (at the Brisbane Port Office gauge) have been used. These flood surfaces have been combined with information obtained from property databases (including estimates of habitable floor levels), transport and access information and flood damages cost data for the assessment of flood impacts.

The BCC study used a two-dimensional numerical hydrodynamic model to develop the flood surfaces but has limitations that potentially affect the integrated assessment. The BCC study and its hydrologic data (rainfall and flows) predate the present Seqwater stochastic dataset. However the main issue is that in the WSDOS assessment it has not been possible to develop flood surfaces that are specific to each flood event analysed. Inundation in each zone for each operational option assessed used flood surfaces from the BCC 2009 modelling correlated with the levels at critical locations determined from stream gauging station rating curves and estimated flows derived from Seqwater's hydrologic assessments.

This methodology was adopted to allow integrated assessment and to develop an understanding of the relativities of each option.

A review of the modelling is currently underway as part of the Brisbane River Catchment Flood Study which will result in updated hydraulic modelling for the Brisbane River.

15.2.2 Residential (building and property) flood damage

The methodology adopted to estimate residential flood damages is consistent with that used in recent similar SEQ and national studies. This methodology utilises damage versus flood depth relationships for five different building types:

- fully detached, single storey (FDSS) buildings
- fully detached, double (and more) storey (FDDS) buildings

- fully detached, high set (FDHS) buildings
- multi-unit, single storey (MUSS) buildings, and
- multi-unit, double (and more) storey (MUDS) buildings.

For each building type, damages are estimated in terms of:

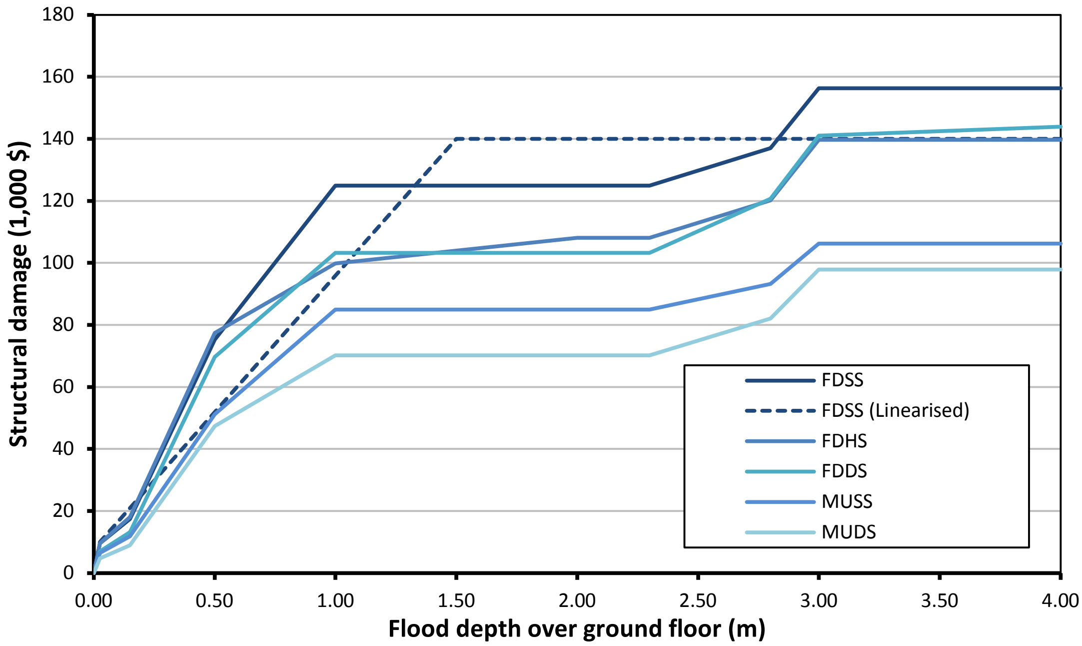
- structural damages to the building
- internal damages to the furniture and other equipment, and
- external damages, around the building for all properties.

The estimated structural damage versus flood depth relationship for the five building types above is shown in Figure 15.3. Figure 15.3 also shows the adopted FDSS simplified relationship (dashed) for assessment purposes.

For each building type, based on the local flood situation, four different cases can be distinguished:

- Flood level < ground level: no damages
- Flood level > ground level and flood level < floor level: external damage (based on flood depth over ground)
- Flood level > floor level and flood level < eave level: external damage (based on flood depth over ground) and internal + structural damage (based on flood depth over floor), and
- Flood level > eave level: maximum damage.

No allowance was made for changes to damages through changes in warning time.



Source: Based on Aurecon 2013, Figure 7

Figure 15.3 Adopted residential stage damage curves for structural damage

15.2.3 Non-residential (building) flood damage

The methodology for non-residential building damage is based on a simplified classification by floor area and a 'value class'.

Floor areas were readily estimated from the building footprint using spatial information alone, while the value class was estimated by considering its primary use classified into one of five value categories (very low, low, medium, high and very high value). Further details of the non-residential building damage methodology are available in Aurecon (2013).

15.2.4 Flood damage to road infrastructure

Damage to roads caused by inundation is generally considered to comprise an initial repair cost, followed by additional costs for the subsequent accelerated deterioration of the road. Costs estimates figures are applied as a unit cost per kilometre of road inundated for different road types based on DTMR figures.

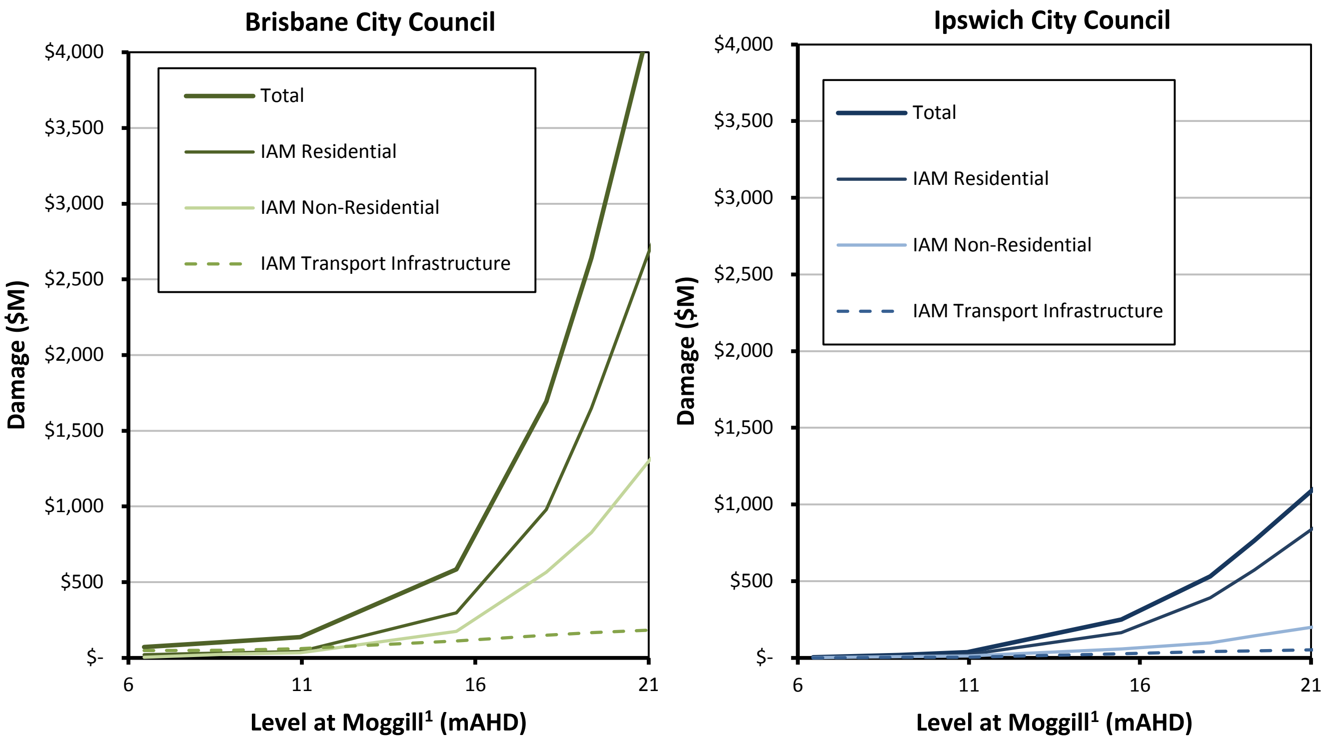
The spatial extent of road transport infrastructure in the downstream floodplain potentially affected has been determined by identifying all road assets located within each flood extent and calculating their total length. The unit costs method described above were then applied to estimate direct damage values.

15.2.5 Flood damage ratings

As discussed above, the flood damage assessment has been conducted using damage rating curves (damage as a function of peak flow rate) derived from BCC (2009) flood surfaces and GIS property information provided by the local Councils. The Brisbane River floodplain was sub-divided into sixteen zones according to regions of hydraulic influence and local government areas. Individual damage ratings were developed for each of the zones to allow estimation of damage from the peak flood flow occurring for any particular event (Aurecon 2014).

Brisbane River flows from Seqwater's hydrological modelling were converted to levels at appropriate stream gauging stations using the rating curve (flow versus level) for the stream gauging station. The level at each gauge for a particular flood event was then related to a flood level surface profile from the BCC 2009 hydraulic modelling. This flood surface profile was then applied to the zones best represented by the gauging station.

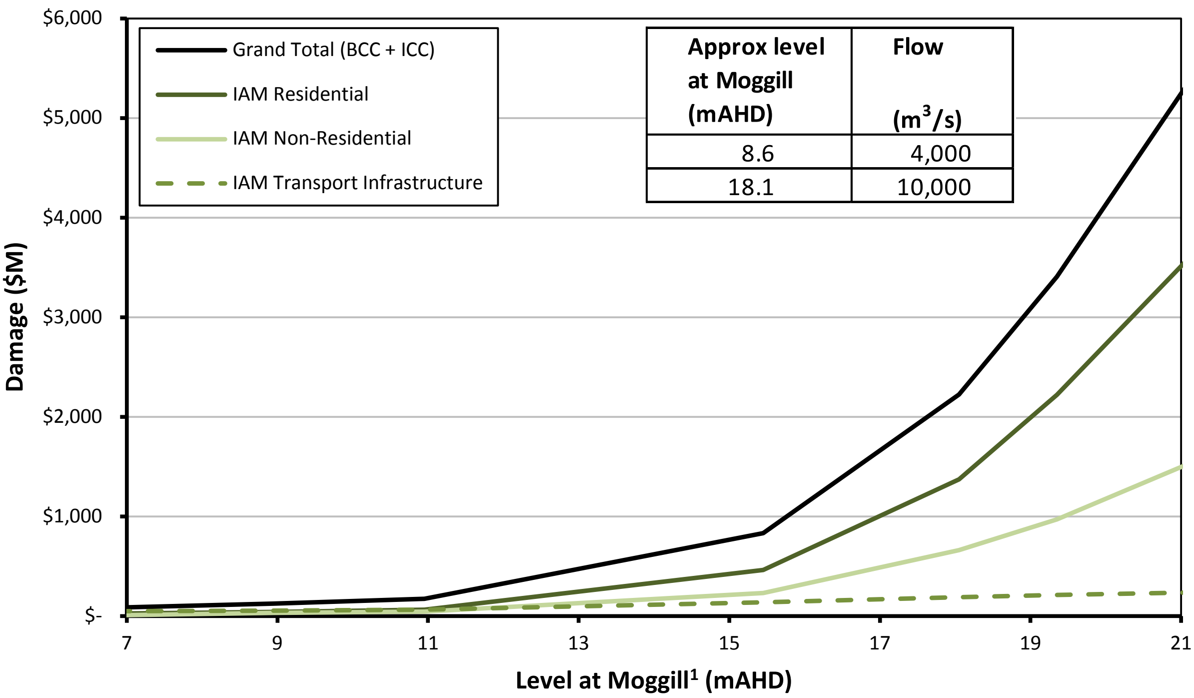
Damage ratings calculated using the aforementioned methodologies are shown in Figure 15.4 for the Brisbane City Council and Ipswich City Council areas and in Figure 15.5 for the total combined Brisbane City Council and Ipswich City Council areas.



Notes: 1. Flood damage related to the stream gauging station location at Moggill for comparative purposes.

Source: Aurecon 2014

Figure 15.4 Flood damage ratings curves for Brisbane City Council and Ipswich City Council areas



Source: Aurecon 2014

Figure 15.5 Flood damage ratings curves for combined Ipswich City Council areas

15.2.6 Other flood damage costs

Review of damages related to the 2011 Brisbane River floods identified a number of other damage costs deemed significant enough for inclusion. These consist of damages suffered by utility providers (electricity, water, and telecommunications) and local governments (transport infrastructure, parks and gardens, clean-up etc.). In the absence of any other comparable data from previous floods, these costs have been related to, for example, the residential costs incurred in the 2011 flood and this has been used for the assessment.

15.2.7 Probabilistic flood damages for existing conditions

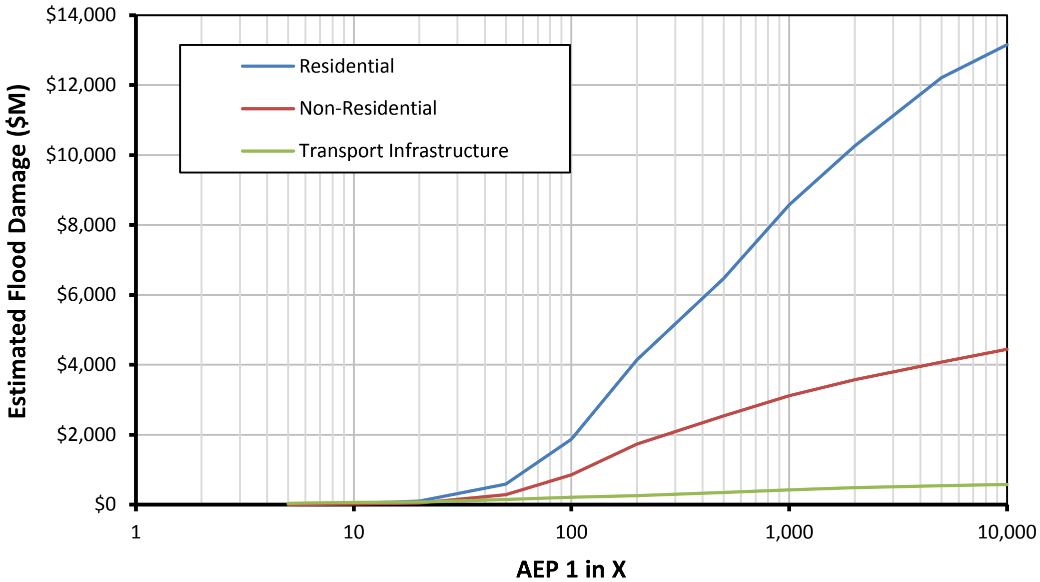
Damage probability relationships (damage versus AEP) for all local government areas combined are shown in Figure 15.6 separated into residential, non-residential and transport infrastructure.

Assigning a reliable AEP to peak river flows and hence damage is necessary for calculation of the average annual damages (AADs).

The Integrated Assessment Methodology has been designed to use the stochastic data extracted from the WSDOS Dam Optimisation Model developed by Seqwater (Seqwater 2014a) to represent the natural variability inherent in the Brisbane River catchment and, separately, the influence of the dam operations.

Therefore the probability of the peak flows generated from the stochastic assessment of the rainfall events had to be adjusted to align with the latest flood frequency analysis values (SKM 2013).

Only minor damage is predicted for small flood events (i.e. magnitudes less than the 1 in 20 AEP flood), with the main contribution coming from transport infrastructure damage. However residential damages increase rapidly as the flood magnitude increases.



Source: Derived from Aurecon 2014, Figure 12

Figure 15.6 Brisbane River flood damage probability for 100% FSV Base Case (Option 001)

The distribution of estimated combined flood damage for each local government area as well as the resulting AAD is given in Table 15.1. This shows that the majority of damage costs are expected in the Brisbane City Council and Ipswich City Council regions. Low damage is indicated for Lockyer Valley Regional Council. This may be partly due to lack of available information (i.e. the 2009 Brisbane River flood maps only partially cover this area) but also the likely limit of backwater effects from Brisbane River floods.

Table 15.1 AADs for each local government area (for 100% FSV Base Case (Option 001))

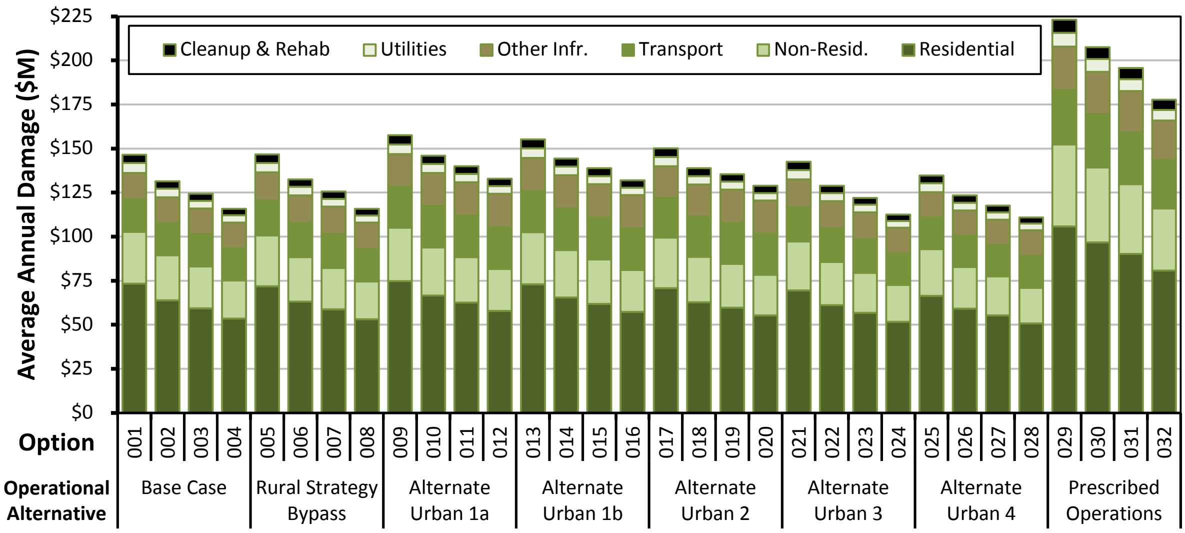
AEP (1 in X)	Combined res., non res. and transport damages for each local government area for 100% FSV Base Case (Option 001) ($M)				
	BCC	ICC	SRC	LVRC	TOTAL
5	57	2	1	~0	60
10	98	11	2	~0	112
20	185	36	4	~0	225
50	732	275	9	~0	1,016
100	2,241	632	17	~0	2,930
200	4,861	1242	27	~0	6,130
500	7,404	1898	42	0.1	9,344
1,000	9,651	2414	49	0.3	12,115
2,000	11,437	2826	55	0.3	14,318
5,000	13,534	3242	61	0.3	16,837
10,000	14,580	3531	64	0.4	18,175
AAD	97	24	1	~0	121

Note: Damage estimates for events less frequent than 1 in 1,000 AEP have higher uncertainty but less influence on AAD

Source: Aurecon 2014, Table 8

15.2.8 Influence of operational alternatives on flood damage costs

Average annual flood damage costs for residential, non-residential properties and transport infrastructure are provided for each of the operational options from Chapter 5 in Figure 15.7 and Table 15.2, together with details of other damage costs. For the current dam operations (Base Case - Option 001), residential damages comprise around 50% of the total damages and non-residential damages around 20%.



Source: Aurecon 2014, Figure 14

Figure 15.7 AAD (stochastic) for each operational option

Table 15.2 AAD for each of the operational options

Operational Option		FSV	Residential ($M)	Non-Resid. ($M)	Transport ($M)	TOTAL[1, 2,] ($M)
001	Base Case Flood Manual	100%	$73.21	$29.59	$18.56	$146.55
002		85%	$63.77	$25.64	$18.31	$131.45
003		75%	$59.33	$23.68	$18.27	$124.40
004		60%	$53.54	$21.48	$18.36	$115.82
005	Rural Strategy Bypass	100%	$71.78	$28.94	$19.84	$146.63
006		85%	$63.16	$25.27	$19.48	$132.56
007		75%	$58.73	$23.48	$19.38	$125.57
008		60%	$53.20	$21.29	$18.64	$115.76
009	Alternative Urban 1a	100%	$74.66	$30.44	$23.15	$157.50
010		85%	$66.57	$27.30	$23.52	$145.88
011		75%	$62.61	$25.71	$23.63	$140.02
012		60%	$57.79	$23.89	$23.66	$132.82
013	Alternate Urban 1b	100%	$72.85	$29.68	$23.41	$155.16
014		85%	$65.50	$26.81	$23.59	$144.33
015		75%	$61.79	$25.38	$23.65	$138.80
016		60%	$57.34	$23.72	$23.60	$132.04
017	Alternative Urban 2	100%	$70.70	$28.72	$22.50	$150.10
018		85%	$62.82	$25.70	$22.83	$138.79
019		75%	$59.73	$24.75	$23.44	$135.47
020		60%	$55.35	$23.11	$23.40	$128.81
021	Alternative Urban 3	100%	$69.42	$27.86	$19.58	$142.41
022		85%	$61.16	$24.41	$19.18	$128.87
023		75%	$56.68	$22.77	$19.11	$122.05
024		60%	$51.70	$20.80	$18.11	$112.59
025	Alternative Urban 4	100%	$66.36	$26.63	$17.93	$134.67
026		85%	$59.05	$23.71	$17.84	$123.33
027		75%	$55.34	$22.11	$17.90	$117.64
028		60%	$50.72	$20.21	$18.12	$110.90
029	Prescribed Operations	100%	$105.87	$46.40	$30.85	$223.06
030		85%	$96.69	$42.59	$30.09	$207.48
031		75%	$90.27	$39.55	$29.29	$195.68
032		60%	$80.75	$35.19	$27.72	$177.64

Notes:

1: Total Cost includes:

Other Infrastructure Damage Estimate (Section 15.2.6)	=	80% of Transport Infrastructure Cost
Utilities Damage Estimate	=	7.5% of Residential Damage Cost
Cleanup & Rehabilitation Estimate	=	4% of Total Damage Cost

2: The level of precision (significant figures) quoted in the table should not be taken to imply accuracy and has been retained only to allow differentiation between option results. Refer to Section 15.1.4 regards the limitations of this assessment

Source: Aurecon 2014, Table 11

As expected, within the range of FSVs (100% to 60%) examined, estimated residential and non-residential flood AAD reduces approximately linearly by up to 25% at 60% FSV. However, there is little change in transport infrastructure costs. Transport infrastructure damage tends to initiate at lower flows and increases much less rapidly than other damage. Hence the flood mitigation benefit as a result of attenuating larger flood events by lowering FSV is offset by increased traffic cost due to increased frequency and duration of minor flood events. This is due to the increased number of releases when the dam levels are lowered.

The Rural Bypass, alternatives Urban 1a and Urban 1b and alternative Urban 2 modify target flows at downstream locations with a view to enabling higher early releases from the dam in the Rural Strategy and Urban Strategy. Such operations generally provide less mitigation for frequent events, which have lower damage outcomes, and increased mitigation for rarer events that produce more damage. The effectiveness of these strategies in reducing AADs is therefore a balance. The analysis indicates that:

- For all FSVs assessed, the Rural Bypass operational alternative generally results in slightly lower residential and non-residential costs but increases transport damages by up to 7%. Overall, there is less than ± 1.0% difference in total cost between the Rural Bypass alternative and the equivalent Base Case FSV option.
- Alternative Urban 1a provides greater urban flood mitigation for larger flood events but this benefit is outweighed by the decreased mitigation for smaller events and damage costs are increased for all damage types, most significantly transport costs by over 30%. Total costs are typically 7.5% to 15% higher than the equivalent Base Case FSV option.
- Alternative Urban 1b (combined Rural Bypass and Urban 1a) generally increases residential, non-residential and transport costs. Total costs are typically 6% to 14% higher than the equivalent Base Case FSV option.
- Alternative Urban 2 tends to increase residential, non-residential damage costs and transport costs as the FSVs are lowered. Overall, alternative Urban 2 increases damage costs by 2% to 11% above the equivalent Base Case FSV option.

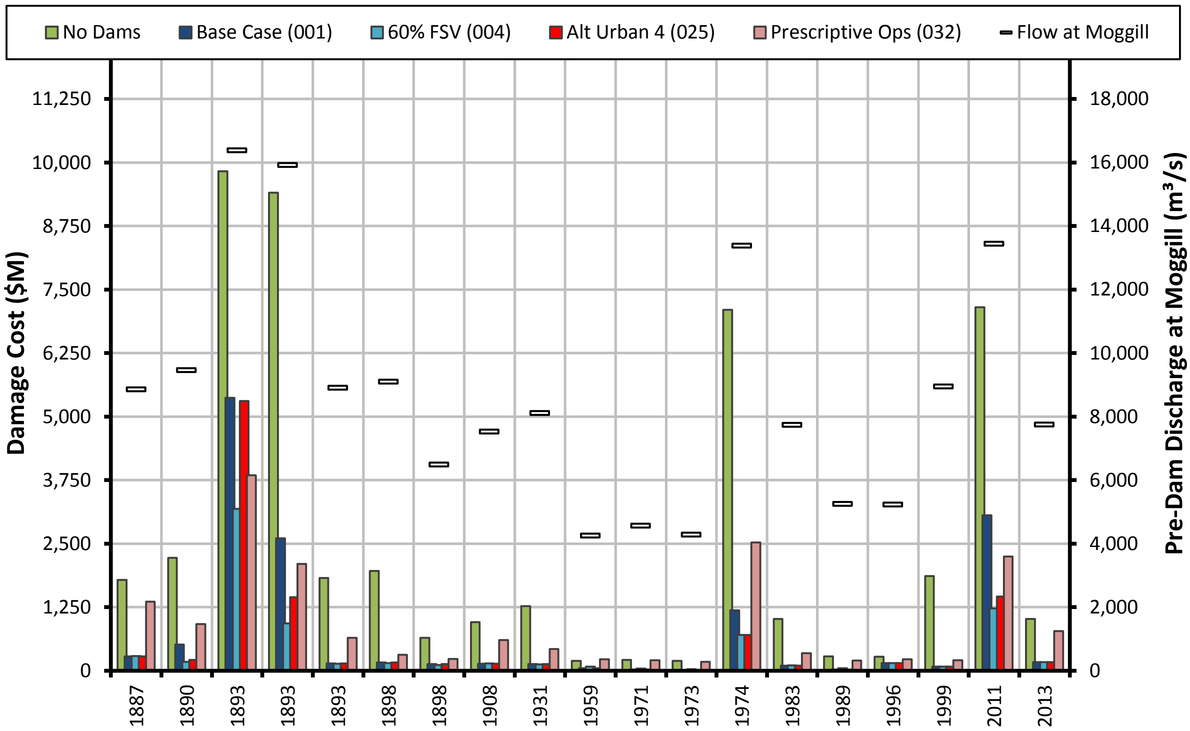
The Urban 3 and 4 operational alternatives combine increases to the flood storage for urban flood mitigation with modified flood operations which increase downstream target flows with a view to providing increased attenuation for larger flood events.

- Alternative Urban 3 reduces residential and non-residential damage costs, but increases transport costs. Total costs are typically 2% to 3% lower than the equivalent Base Case FSV option
- Alternative Urban 4 produces similar performance to the Base Case for smaller floods but improves flood mitigation for larger floods. This operational alternative results in consistently lower damage costs than the Base Case, being 8% less for 100% FSV and 4% less for 60% FSV.

The Prescribed Operations alternative focusses on maximising freeboard in the dams rather than strategically mitigating flood effects. This operational alternative provides greater mitigation for some major floods but worse flood mitigation outcomes when considered across all floods. Consequently the Prescribed Operations alternative produces AADs between 50 to 60% greater than the equivalent Base Case.

15.2.9 Historical flood event damages comparison

The methodology was also applied to historical flood events supplied by Seqwater to provide an estimate of damage costs that might result if the same flood event were to occur with current floodplain development for each operational option. Figure 15.8 shows the estimated flood damage costs from the historical events for a selected sub-set of dam operational options. Pre-dam flows at Moggill (based on the Dam Operations Model results) are shown as a reference (right hand vertical axis) of the flood magnitude. Comparing the 1974 and 2011 floods (two large floods of nearly equal peak flow at Moggill), the results highlight the variability of flood impacts and the limits of dam operations in mitigating peak flows and hence flood damage. This shows that, as expected, reducing the FSV (Option 004) generally increases mitigation as does raising the dam safety trigger level (Option 025). The Prescribed Operations option (Option 029) performs better than the Base Case for only the three largest flood events (the two floods in 1893 and the 2011 floods) and is better than Alternative Option 4 for only one event, while performing significantly worse for all smaller events.



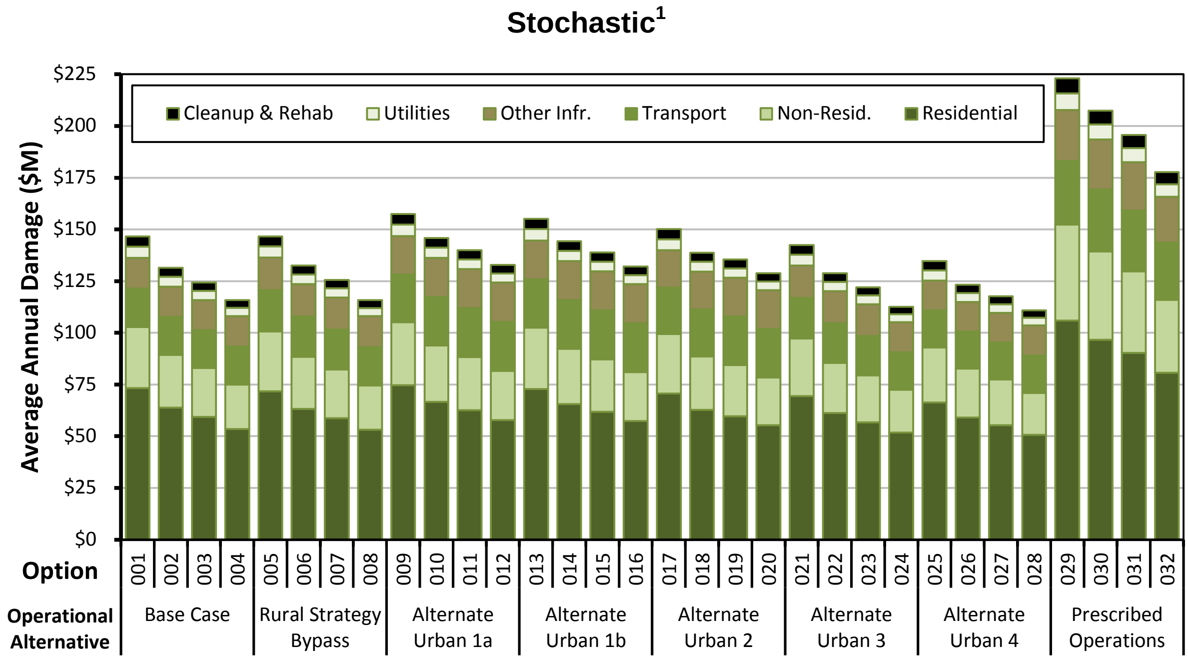
Source: Aurecon 2014, Figure 15

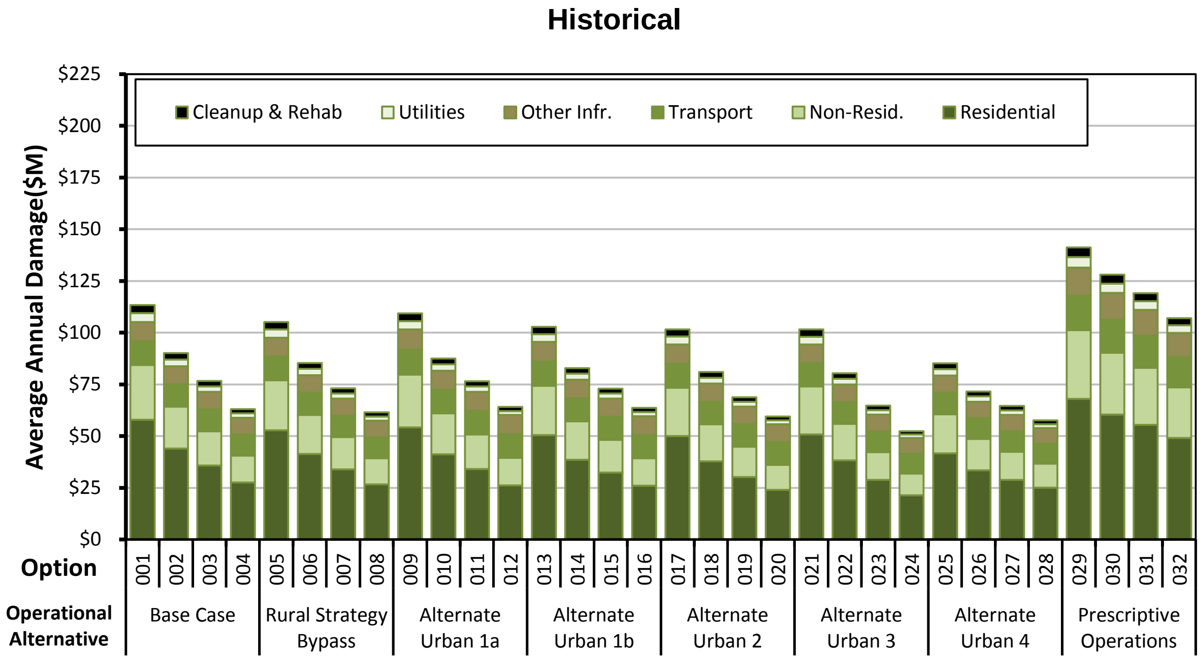
Figure 15.8 Effect of dam operational options on estimated historical flood event damages

The historical events span 126 years of records and have been used to provide an estimate of AAD resulting from this sequence of floods, as shown in Figure 15.9. The average annual damage estimates for historic floods can be seen to be significantly lower (up to 50%) than the much longer term stochastic analysis shown in Figure 15.7 (repeated in Figure 15.9 for comparative purposes). In addition, it can be seen that in percentage reduction terms, lowering the FSV has a larger benefit for the historic events than was evident for the stochastic floods simulated.

Overall the comparison provides confirmation of the order-of-magnitude of the stochastic frequency analysis of damages. Consistent with the stochastic assessment, reducing the FSV is more effective in reducing damage than is modifying the dam operating rules.

However, the historical analysis shows a slight reduction in AAD for the alternative Urban 1 and 2 strategies rather than the slight increase observed in the stochastic assessment, and enhances the reductions for the Urban 3 and 4 alternatives. The logical explanation is that the historical flood sample has a statistically low proportion of minor events, which have a low damage but high frequency. This highlights the risk of basing dam operating strategies on a limited sample set or focussing on a particular range of flows.





Note: 1. Refer Figure 15.7

Source: Aurecon 2014, Figure 14 (stochastic, top); Aurecon 2014, Figure 16 (historical, bottom)

Figure 15.9 Comparative AAD (stochastic vs historical) for each operational option

15.3 Phase 2 - Flood impact costs

As detailed in Chapter 10, numerous low level bridges cross the Brisbane River downstream of Wivenhoe Dam and when they are inundated this impacts access to both rural and suburban communities. Specific flood impacts have been assessed for seven road bridge crossings, in increasing order of flood immunity:

- Twin Bridges
- Savages Crossing
- Colleges Crossing
- Burtons Bridge
- Kholo Bridge
- Mt Crosby Weir
- Geoff Fisher Bridge (Brisbane Valley Highway at Fernvale)

Details of the assessment methodology are provided in Aurecon (2013). Potential flood impacts related to other major high-level downstream bridges (in the Brisbane metropolitan area) have been omitted from the study, but this is considered to have minimal impact on the conclusions.

Likewise, due to limited data, the upstream bridges have not been assessed. However, the different options (with exception of Urban 4) have been assessed as having negligible impact on the frequency of closure of upstream bridges due to inundation – although the duration of closure may be modified (Aurecon 2014).

In addition, impacts of flooding on disruption to Brisbane’s ferry services, related infrastructure damage and potential repair costs for Wivenhoe’s fuse plug spillways have also been assessed.

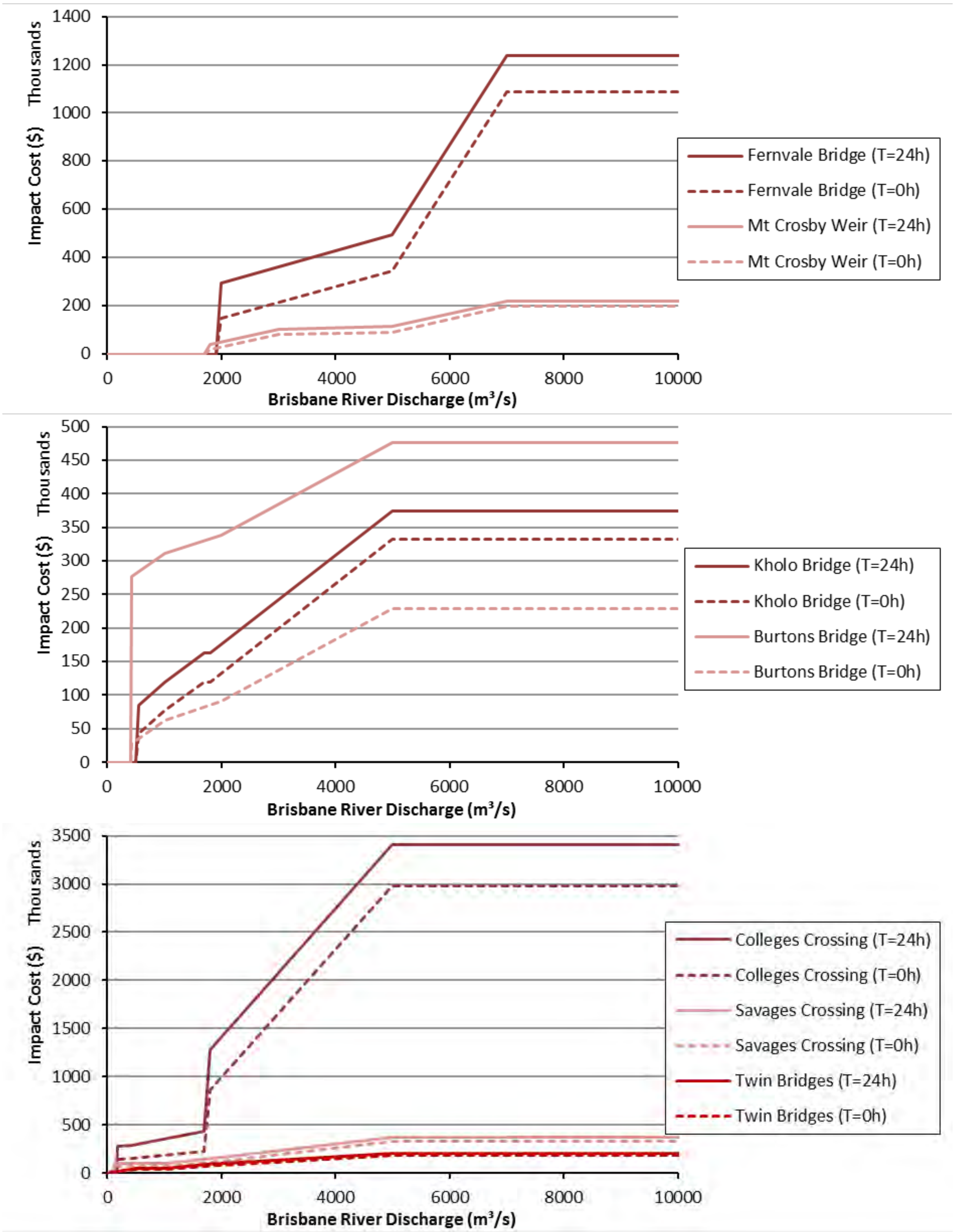
15.3.1 Assessment of bridge closure impact costs

With the exception of Burton’s Bridge, flood impacts due to closure of road bridges have been assessed by estimating the number of vehicles impacted by the closure, the average lost time per vehicle due to diversion via alternative routes, and the cost per vehicle hour of delay. Closure times are a function of the flood duration above the bridge deck level, and the time required to close, clean, repair and reopen the bridge prior to and after the flood. Values adopted for the assessment have been based on information provided by DTMR (2013).

The low-level bridges are now considered largely immune from major structural damage as a result of having been upgraded over many years and their being frequently inundated. Minor damage is however to be expected and bridge repair costs have been based on reinstatement costs incurred during the 2011 flood and allowing 1 to 7 days clean-up and repair time depending on the severity of the flood.

Burtons Bridge is unique in that there is no alternative diversion route when this bridge is closed. Assessment of impacts for Burtons Bridge has been based on an estimate of economic cost based on average lost salaries and economic impact multipliers.

The impact data has been used to derive a staged impact model that assumes closure to traffic but minimal structural damage when the flood level reaches the bridge deck, and increasing minor to moderate damage up to an upper threshold river flow rate. The resulting impact ratings shown in
Figure 15.10 for each bridge (grouped by vulnerability) include traffic diversion delay or isolation, bridge reinstatement costs and the effect of duration of closure.



Note:

T is the closure time during the flood event. T=0 and T=24h curves were used to extrapolate to different durations of flood closure

Source: Aurecon 2014, Figures 20, 21, 22

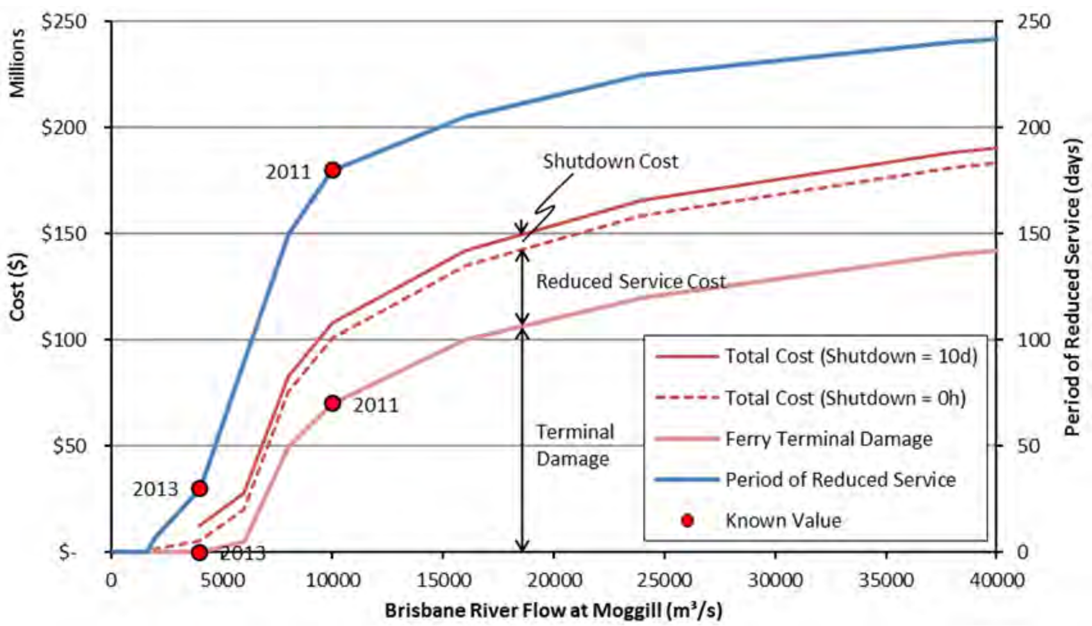
Figure 15.10 Impact ratings for low-level bridge closures

15.3.2 Flood impacts on ferry services

Floods are known to disrupt Brisbane City Council ferry services, which have been suspended during large flood events and operated at reduced speeds due to safety considerations of floating debris for periods afterwards. Flood-related disruption to the services has been assessed in terms of possible physical damage to the ferries and terminal infrastructure, direct loss of revenue and loss of productivity as passengers are delayed or forced to find alternative transport. Due to a lack of more comprehensive data the 2011 and 2013 flood events have been used to provide two points of reference and passenger delay costs have been estimated using a similar methodology to road bridges. The adopted flood impact rating curve is shown in Figure 15.11.

It is acknowledged that these flood damage costs may tend to overestimate impacts in regard to lost revenue for Translink due to commuters simply changing modes of transport and will likely overestimate infrastructure damage for future floods given that post-2011 replacement terminals have been designed to a significantly higher structural standard.

The assessment did not include costs associated with the closure of the Moggill ferry.



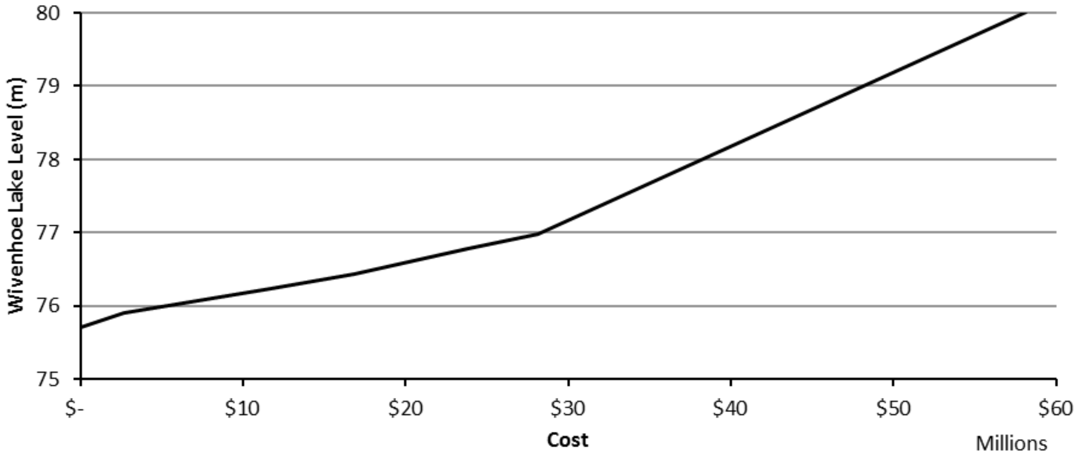
Source: Aurecon 2014, Figure 23

Figure 15.11 Impact ratings for disruption to Brisbane City Council ferry services

15.3.3 Wivenhoe fuse plug spillway repair costs

In the event of the fuse plugs being triggered, the emergency fuse plug spillways must subsequently be repaired. Estimated repair costs were provided by Seqwater and these have been converted into damage rating as a function of dam level as shown in Figure 15.12.

It can be noted that repairs are estimated to take in excess of 9 months to complete but this aspect has not been able to be included because the Seqwater stochastic event set does not consider the probability or possibility of multiple events during the same season. Until the fuse plugs are repaired, Wivenhoe Dam would operate as an uncontrolled spillway above 67 m AHD (the concrete crest of the breached auxiliary spillway) and there would be some loss of ability to effectively control major floods until fuse plug repairs are completed.

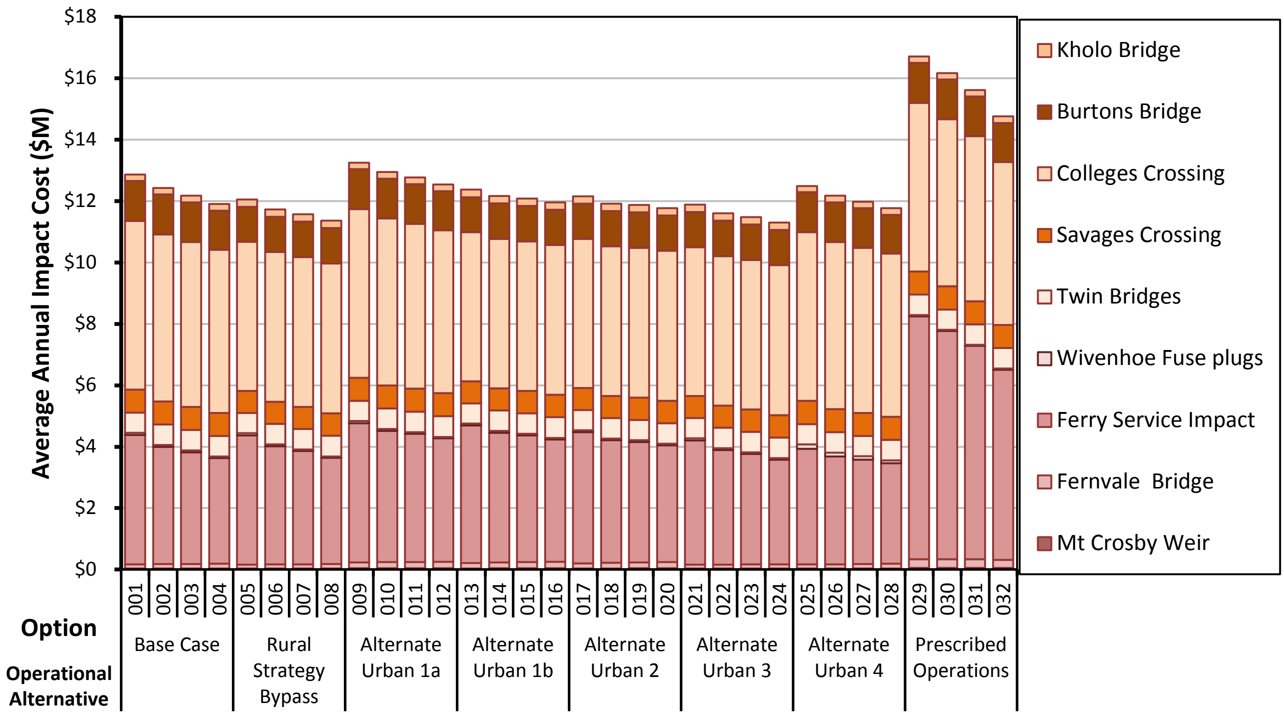


Source: Aurecon 2014, Figure 24

Figure 15.12 Impact rating for repair of the Wivenhoe Dam auxiliary spillway fuse plugs

15.3.4 Influence of operational alternatives on flood impact costs

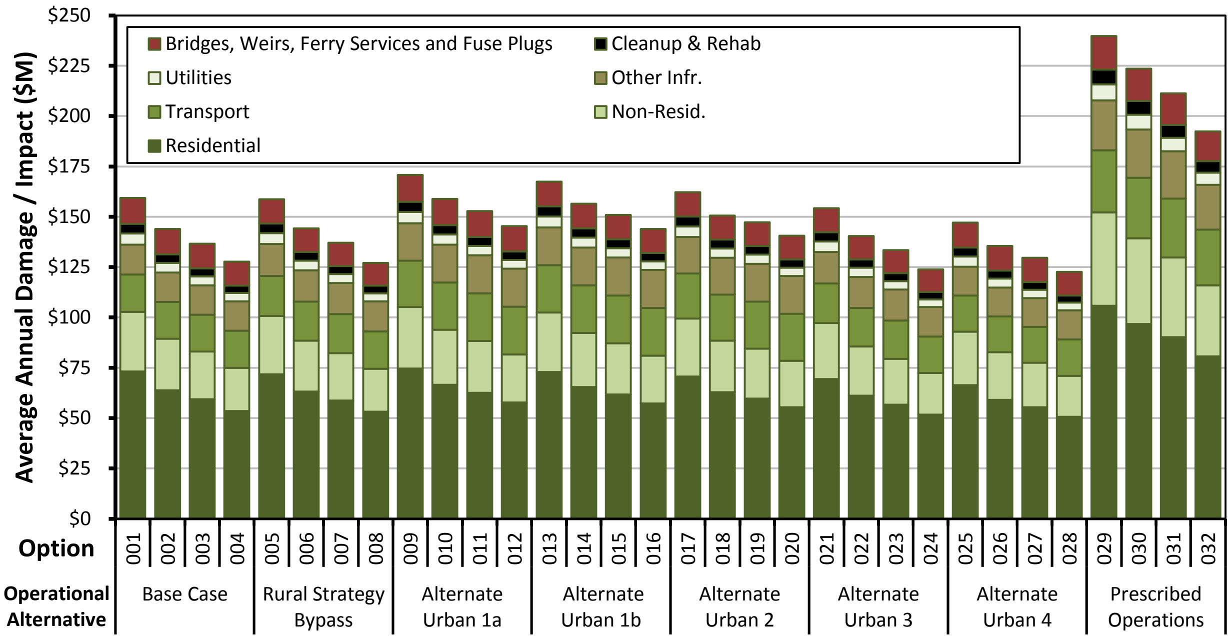
Bridge and traffic impact costs are calculated based on peak flows and time of closure. This data is available from the Seqwater modelling, however five of the bridges have a capacity less than 550 m³/s before being inundated and the stochastic model is not considered reliable for such low flow rates. For the five low-level bridges an alternative assessment was performed using the DSITIA-supplied IQQM model results for the Brisbane River catchment (refer Chapter 10) that provides a series of daily stochastic river flows based on analysis of historical records. This model is considered to have better resolution of the low flow conditions impacting these bridges.



Source: Aurecon 2014, Figures 26 and 27 combined

Figure 15.13 Flood impact AAI for mid-Brisbane bridges, Brisbane ferries and fuse plugs

Results of using the Seqwater stochastic event assessment for the higher-level bridges, ferry services and fuse plug impacts and the impacts based on the IQQM model for the low-level bridges (noting these were only calculated for Options 001 to 008) are presented in Figure 15.13. The results show that none of these impacts are significantly altered by the choice of FSV and in any case the average annual impact (AAI) values are relatively low and represent about 10% of the flood damage assessment AAD (refer Figure 15.14).



Source: Aurecon 2014, Figures 14, 26 and 27 combined

Figure 15.14 Average annual damages and impacts

Although not overly significant, the model results show that the Rural Bypass alternative actually tends to reduce AAI on the low level bridges. While the frequency of inundation is increased, this is compensated by a reduction in duration of inundation according to the cost impact relationships that have been developed. It has been assumed that low-level bridge impacts for alternatives Urban 1a, Urban 4 and Prescribed Operations are similar to the Base Case while alternatives Urban 1b (i.e. with Rural Bypass), alternative Urban 2 and alternative Urban 3 strategies are similar to the Rural Bypass alternative.

Closure of Colleges Crossing is the largest single contributor to flood impact costs of typically 40% of the total for all bridges and ferry services. It has low flood immunity as well as the highest traffic volume of the mid-Brisbane bridges. Burtons Bridge, which has limited volume but isolates the rural community of Borallon for the duration of the flood event, is the second largest contributor at around 10%. The remaining five bridges combined account for only 15%.

Disruption to ferry services represent the second largest single impact cost due to the significant infrastructure damage and long period of reduced service for large flood events, although these may be overstated as noted previously. Average impact costs of the repair of the Wivenhoe Dam fuse plugs are generally minor although it is cautioned that the assessment does not consider the associated dam safety issues.

Overall the influence of the operational alternatives on flood impact costs appear as follows:

- Reducing FSV while maintaining the current operating strategies reduces impact costs by up to 7.5% at 60% FSV.

- The Rural Bypass alternative reduces impact costs by 4% to 7% compared to the Base Case.

- Urban 1a is the only alternative that consistently increases flood impact costs by 3% to 6% compared to the Base Case.

- Alternative Urban 2 reduces costs by 1% to 6% compared to the Base Case, which is slightly worse than the Rural Bypass alone, while alternative Urban 3 reduces costs by 5% to 8%.

- Alternative Urban 4 reduces costs by 1% to 3% which is less than alternative Urban 3. Although fuse plug repair costs are double the Base Case, this is only a minor component with the impact of the Rural Strategy being the primary contributor.

The Prescribed Operations alternative increases impact costs by 25% to 32%.

15.4 Phase 3 - Bulk water supply infrastructure costs

As outlined in Chapter 8 the current bulk water supply strategy[19] is based on a staged augmentation of existing water supply infrastructure with desalination plants to accommodate both future projected demand and to ensure water supply security. Costs associated with each augmentation stage include initial construction of supply infrastructure as well as ongoing costs of operation. Under the current strategy for SEQ, the next supply source augmentation is anticipated to be a desalination plant located in the Northern SEQ sub-region (i.e. Sunshine Coast) followed by another desalination plant located in the Central SEQ sub-region (i.e. close to Brisbane).

15.4.1 Infrastructure timing for 100% FSV operations

Estimated construction and operating costs and currently anticipated implementation dates for augmentation (assuming current 100% FSV dam policy) have been based on information supplied by Seqwater for use in the analysis, as shown in Table 15.3.

Table 15.3 Assumed bulk water supply augmentation timing and costs

Item	Capital Cost ($M)	Time to Build (Years)	Date of Implementation	Operation Cost ($M/a)
Augmentation Stage 1			2031	
• Desalination Plant	1100	3		61.9
• Network Connection	166.8	1		13.9
• Associated pipe upgrades	21.5	1		0.5
Augmentation Stage 2			2044	
• Desalination Plant	1100	3		61.9
• Network Connection	145.8	1		4.1
• Associated pipe upgrades	174.2	1		0.7

Source: Aurecon 2014, Table 24

[19] The next water supply source for south east Queensland will be identified through the Water Security Program to be prepared by Seqwater.

15.4.2 Infrastructure timing for FSV lowering options

Changes to bulk water supply source infrastructure affect the water supply capacity of the SEQ water supply system and influence the timing of supply augmentations. The adopted timings of augmentations of water supply for the purposes of this assessment are shown in Table 15.4.

Table 15.4 Assumed water supply augmentation timing for different FSVs

		Wivenhoe Dam FSV							
		100%		85%		75%		60%	
		First Stage	Second Stage	First Stage	Second Stage	First Stage	Second Stage	First Stage	Second Stage
North Pine Dam FSV	100%	2031	2044	2031	2039	2031	2036		
	85%	2031	2044* (2043)	2031	2039* (2038)			2025	2031*
	75%					2030	2036* (2035)		
	42%	2031	2044* (2041)					2021	2027*

Notes:
1. *Modelling has not been undertaken for these options to determine the yield. Consequently, the dates have been inferred and could be earlier than stated. The bracketed year is the timing adopted for analytical purposes (refer Aurecon 2014, Figure 31)
2. First and second stage augmentation advice was provided by Seqwater except where inferred.

Source: Aurecon 2014, Tables 25 and 26)

Seqwater (2014c) also investigated the likely changes to the bulk water supply infrastructure augmentation schedule resulting from alteration to current manufactured water asset operations. Revised augmentation timings are listed in Table 15.5. Augmentation schedule changes have been provided for the first augmentation only. Timing of the second augmentation has been assumed to be unchanged from the current manufactured water timings.

Table 15.5 Assumed supply augmentation timing with change to manufactured water availability

Wivenhoe – North Pine Dam FSVs (%)	No WCRWS		No Desalination		No Manufactured Water	
	First Stage	Second Stage	First Stage	Second Stage	First Stage	Second Stage
100 / 100	2028	2044*	2019	2044*	2019	2044*
85 / 85	2027	2038*	2019	2038*	2019	2038*

Notes:
* Timing of second augmentation has not been determined for these cases – assumed to be unaffected by manufactured water availability but this may result in an underestimate of the NPC of the water supply augmentation costs.

Source: Aurecon 2014, Table 27

15.5 Phase 4 Bulk water operational costs

Operational costs consist of the costs of manufactured water production and any infrastructure constructed in response to drought conditions. It is noted that these costs are likely to be an underestimation of the actual costs of operation, as the costs associated with manufactured water delivery and redistribution of other water supplies in the SEQ water supply system have not been included.

15.5.1 Water security strategy

To ensure reliability of water supply to SEQ, a number of water supply thresholds have been identified which trigger augmentation of supply (refer Chapter 8). Currently, these SEQ water storages thresholds and strategies are as follows:

- at 60% combined capacity, operation of the GCDP is increased to full capacity while the level remains below the trigger threshold
- at 40% combined capacity, the GCDP continues to operate at full capacity and operation of the WCRWS is increased to full capacity while the level remains below the trigger threshold
- at 30% combined capacity, the GCDP and WCRWS continue to operate at full capacity and immediate construction commences on drought response/contingency infrastructure (assumed to be a new desalination plant).

Availability of the GCDP and WCRWS for immediate drought response will depend on the policy adopted regarding the use of manufactured water. Modelling undertaken by Seqwater (2014b, 2014c) has assumed that the WCRWS is active and operating at sufficient capacity to supply power station demands. However, from 2014 the WCRWS will be decommissioned and placed under care and maintenance, with the ability to be re-commissioned at the 40% trigger. Consequently, Swanbank Power Station demands will need to be met from other supplies.

15.5.2 Water restriction costs

The cost impacts of water restrictions or the implications that these may have on the general community are difficult to address due to a lack of information. The Productivity Commission (2011) notes that the costs associated with water restrictions (many of which are hidden and potentially intangible) are borne by households, business, the community and government. These costs may include those associated with decreased production, inconvenience and loss of amenity, compliance and enforcement. For the SEQ water supply system, restrictions are currently applied at the 40% combined capacity trigger.

Given the lack of current data, a simplified approach to the assessment of water restrictions was adopted. Studies indicate that water consumers are willing to pay relatively little to avoid low-level restrictions, but much greater amounts to ensure high-level restrictions are not imposed or are imposed very rarely. The range of estimated tolerable household costs is listed in Table 15.6.

Table 15.6 Water restrictions cost estimates for households

Restrictions	Annual Cost / household	Total Annual Cost
Low-level (10% reduction)	≈ $15	$9M
Medium to High level	$160 – $280	$95M – $165M

Note: The available data on the cost of water restrictions is limited with the above figures being used for preliminary assessment.

Source: Aurecon 2014, Table 36

It is important to note that willingness-to-pay values are based on public perception of cost and probabilities rather than an actual cost or probabilistic assessment, and it is therefore not necessarily appropriate to correlate these values to an actual impact cost.

For the purposes of this study, a cost of $130M/a has been assumed. This relates to medium-level restrictions imposed to achieve a targeted reduction of 15%, initiated at the 40% trigger.

15.5.3 Manufactured water costs

Manufactured water costs comprise the production costs for drought response and capital costs when new infrastructure is required. For the options not specifically investigating alteration of manufactured water availability, the existing manufactured water sources (GCDP and WCRWS) have been assumed to be in operational readiness and would incur no significant infrastructure cost to increase to full production capacity. Re-commissioning costs have been based on information supplied by Seqwater and have been applied to options where the asset has been de-commissioned. For simplicity these costs have been calculated based on the average time between modelled Seqwater (2014b, 2014c) supply threshold trigger events. Production costs have been based on Seqwater annual operating costs for the infrastructure and assume that the asset remains active for two months longer than the average duration that the water level remains below the threshold.

Construction of new drought response infrastructure is planned to commence when combined SEQ water storages capacity falls to 30%. The cost of bringing forward the next planned augmentation in response to drought is the difference in NPC resulting from the different construction timeframes of drought-response construction as opposed to the planned construction. This cost was assumed to not be incurred if the planned augmentation was already under construction (due to growth in demand) or in the 5 years following construction where the plant was operating at less than full capacity. Production costs have also been applied, although it is noted that drought response infrastructure may not enter production as the average duration below the threshold (from the RSM (Seqwater 2014b, 2014c) is less than the time of construction. This is considered to have negligible impact on the estimates of NPCs as reaching the 30% trigger has a low probability and production costs are significantly outweighed by the infrastructure costs.

Table 15.7 Manufactured water operating costs

Threshold	Infrastructure	Operating Cost	Average Duration	Infrastructure Cost
60%	GCDP	$44.80M/a	9 to 10 months	$18M to $28.5M [1]
40%	WCRWS	$66.80M/a	7 to 8 months	$10.2M to $33M [1]
30%	New Desalination Plant	$64.48M/a	5 to 6 months	0 to $1,000M+ [2]

Notes:
1. Re-commissioning cost calculated based on average time between trigger events and applied only to Manufactured Water
2. Bring-forward construction costs dependent on time between trigger and the next planned augmentation

Source: Aurecon 2014, Table 35

Adopted manufactured water operational costs are summarised in Table 15.7. These costs are cumulative, as higher threshold infrastructure will already be in operation when lower threshold triggers are reached.

15.6 Phase 5 – Part 1–Net present costs summary

The Integrated Assessment methodology has been developed to allow consistent assessment and comparison of costs and benefits across multiple criteria. The approach has identified potential flood-incurred costs related to spatially distributed residential and non-residential flood damage, site-specific flood impacts, bulk water supply infrastructure and water supply operations.

These potential future impacts have then been assessed and compiled in the form of an average or expected Net Present Cost (NPC). The NPC of a time series of costs is the sum of the present values of those costs. The present value is determined by discounting the future costs to reflect their current monetary value. Therefore, the NPC is dependent on the assumed discount rate (time-value of money) and the accounting period over which the costs are accrued. Sensitivity to the assumed discount rate and the accounting period parameters has been tested using the combinations for short-term, medium-term and long-term horizons listed in Table 15.8.

Dam safety implications are not suitable for conventional economic assessment as they are very high consequence and very low probability and need to be considered separately.

Table 15.8 Adopted Net Present Cost parameters

NPC Horizon	Discount Rate (%)	Accounting Period (Years)	NPC Multiplier
Short-term	9%	20	9.13
Medium-term	7%	40	13.33
Long-term	5%	60	18.93

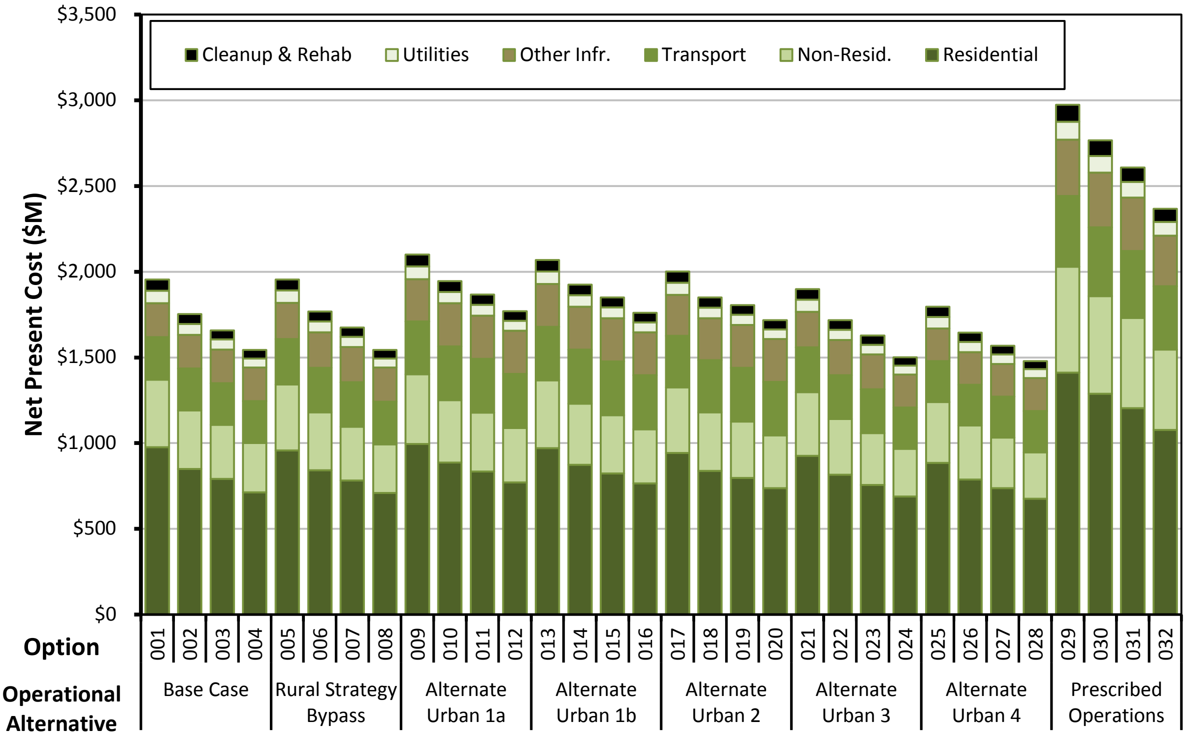
Source: Aurecon 2014, Table 1

15.6.1 Flood damage NPC

Potential future flood damage costs must be converted to an NPC to allow comparison with water supply augmentation and other future costs. To achieve this, the AAD has been equally distributed across the accounting period and beyond, hence NPC is directly proportional to the NPC multiplier and is calculated simply by multiplying the AAD by the NPC multiplier in Table 15.8. Therefore while the overall magnitude of the costs changes with NPC conditions, the relative change between options is the same regardless of the NPC assumptions. Detailed results of the flood damage NPC are presented in Table 15.9 and Figure 15.15 only for the "medium-term" parameter assumption (referred in Aurecon (2014) as median conditions).

NPC assessments were also carried out for the short-term and long-term cases (Aurecon 2014). The cost relativity for these assessments is largely described by the ratios of the NPC multipliers (refer Table 15.8).

It can be noted that the magnitude of those costs in present day values, excepting the more costly Prescribed Operations alternative, is generally approximately $2,000 million or less.



Source: Aurecon 2014, Figure 17

Figure 15.15 Flood damages NPC of operational options using medium-term parameters

Table 15.9 Flood damages NPC of operational options using medium-term parameters

Operational Option		FSV	Residential ($M)	Non-Resid. ($M)	Transport ($M)	TOTAL[1, 2] ($M)
001	Base Case Flood Manual	100%	$976.1	$394.5	$247.4	$1,953.8
002		85%	$850.1	$341.8	$244.0	$1,752.4
003		75%	$791.0	$315.8	$243.6	$1,658.5
004		60%	$713.8	$286.4	$244.8	$1,544.1
005	Rural Strategy Bypass	100%	$956.9	$385.8	$264.4	$1,954.8
006		85%	$842.1	$336.9	$259.7	$1,767.2
007		75%	$783.0	$313.1	$258.4	$1,674.1
008		60%	$709.3	$283.9	$248.5	$1,543.3
009	Alternate Urban 1a	100%	$995.4	$405.8	$308.6	$2,099.7
010		85%	$887.4	$363.9	$313.5	$1,944.8
011		75%	$834.7	$342.7	$315.0	$1,866.7
012		60%	$770.5	$318.5	$315.4	$1,770.8
013	Alternate Urban 1b	100%	$971.3	$395.6	$312.1	$2,068.6
014	(Alternate Urban 1a + Rural Strategy Bypass)	85%	$873.3	$357.5	$314.5	$1,924.1
015		75%	$823.7	$338.4	$315.3	$1,850.5
016		60%	$764.5	$316.3	$314.7	$1,760.3
017	Alternate Urban 2	100%	$942.6	$382.9	$300.0	$2,001.1
018		85%	$837.5	$342.7	$304.4	$1,850.3
019		75%	$796.3	$330.0	$312.5	$1,806.1
020		60%	$738.0	$308.1	$312.0	$1,717.3
021	Alternate Urban 3	100%	$925.5	$371.5	$261.0	$1,898.6
022		85%	$815.4	$325.5	$255.7	$1,718.0
023		75%	$755.6	$303.6	$254.8	$1,627.1
024		60%	$689.2	$277.3	$241.4	$1,501.0
025	Alternate Urban 4	100%	$884.7	$355.0	$239.0	$1,795.4
026		85%	$787.2	$316.1	$237.9	$1,644.2
027		75%	$737.8	$294.7	$238.7	$1,568.3
028		60%	$676.1	$269.5	$241.5	$1,478.6
029	Prescribed Operations	100%	$1,411.4	$618.5	$411.3	$2,973.8
030		85%	$1,289.0	$567.9	$401.2	$2,766.0
031		75%	$1,203.4	$527.2	$390.5	$2,608.8
032		60%	$1,076.5	$469.1	$369.6	$2,368.3

Note 1: Total Cost includes: Other Infrastructure Damage Cost = 75% of Transport Infrastructure Cost
Utilities Damage Cost = 5% of Residential Damage Cost
Cleanup & Rehabilitation Cost = 3% of Total Damage Cost

2: The level of precision (significant figures) quoted in the table should not be taken to imply accuracy and has been retained only to allow differentiation between option results.

Source: Aurecon 2014, Table 12

Table 15.10 Flood impacts NPC of operational options using medium-term parameters

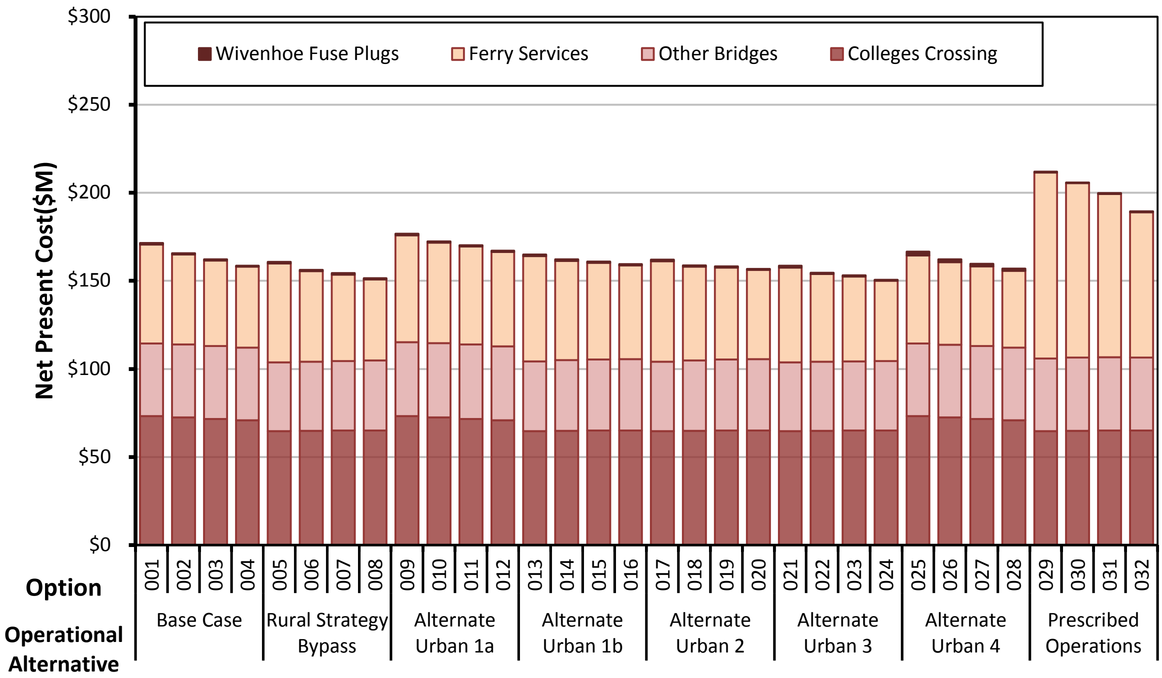
Operational Option		FSV	Colleges Crossing ($M)	Other Bridges ($M)	Ferry Services ($M)	Wivenhoe Fuse plugs ($M)	TOTAL[1] ($M)
001	Base Case Flood Manual	100%	$73.2	$41.3	$56.1	$0.94	$171.5
002		85%	$72.5	$41.4	$51.0	$0.82	$165.7
003		75%	$71.6	$41.4	$48.5	$0.75	$162.2
004		60%	$70.8	$41.3	$45.9	$0.69	$158.7
005	Rural Strategy Bypass	100%	$64.7	$39.0	$56.1	$0.92	$160.6
006		85%	$64.9	$39.3	$51.3	$0.81	$156.3
007		75%	$65.0	$39.5	$49.1	$0.75	$154.3
008		60%	$65.1	$39.7	$46.0	$0.68	$151.4
009	Alternate Urban 1a	100%	$73.2	$42.0	$60.6	$0.92	$176.8
010		85%	$72.5	$42.2	$57.0	$0.79	$172.5
011		75%	$71.6	$42.3	$55.6	$0.72	$170.2
012		60%	$70.8	$42.1	$53.6	$0.66	$167.1
013	Alternate Urban 1b	100%	$64.7	$39.6	$59.7	$0.89	$164.9
014	(Alternate Urban 1a + Rural Strategy Bypass)	85%	$64.9	$40.1	$56.4	$0.78	$162.2
015		75%	$65.0	$40.3	$55.0	$0.71	$161.1
016		60%	$65.1	$40.5	$53.2	$0.65	$159.4
017	Alternative Urban 2	100%	$64.7	$39.5	$57.0	$0.90	$162.0
018		85%	$64.9	$40.0	$53.1	$0.80	$158.8
019		75%	$65.0	$40.3	$52.3	$0.72	$158.3
020		60%	$65.1	$40.5	$50.6	$0.67	$156.9
021	Alternative Urban 3	100%	$64.7	$39.0	$53.9	$0.92	$158.4
022		85%	$64.9	$39.2	$49.7	$0.78	$154.6
023		75%	$65.0	$39.3	$48.1	$0.72	$153.1
024		60%	$65.1	$39.4	$45.5	$0.65	$150.6
025	Alternative Urban 4	100%	$73.2	$41.2	$50.1	$2.03	$166.6
026		85%	$72.5	$41.3	$46.8	$1.63	$162.3
027		75%	$71.6	$41.4	$45.3	$1.46	$159.7
028		60%	$70.8	$41.3	$43.6	$1.23	$156.9
029	Prescribed Operations	100%	$64.7	$41.3	$105.5	$0.57	$212.1
030		85%	$64.9	$41.5	$99.0	$0.52	$206.0
031		75%	$65.0	$41.6	$92.7	$0.51	$199.8
032		60%	$65.1	$41.4	$82.5	$0.50	$189.5

Note 1: The level of precision (significant figures) quoted in the table should not be taken to imply accuracy and has been retained only to allow differentiation between option results.

Source: Aurecon 2014, Table 21

15.6.2 Flood impacts NPC

The NPC outcomes for flood impacts are summarised in Figure 15.16 and Table 15.10, noting that commentary on the relativity of the various operational alternatives remains the same as for the AAD comparisons in Section 15.3.4 and are not repeated here. Colleges Crossing has the highest flood impacts NPC of all the low-level bridges at around $70M, and noting from Chapter 10 that the estimated upgrade cost to accommodate even a modest 4,000 m^3/s flow of over $300M (DTMR 2013), would appear not to be a viable investment on a cost-benefit basis.

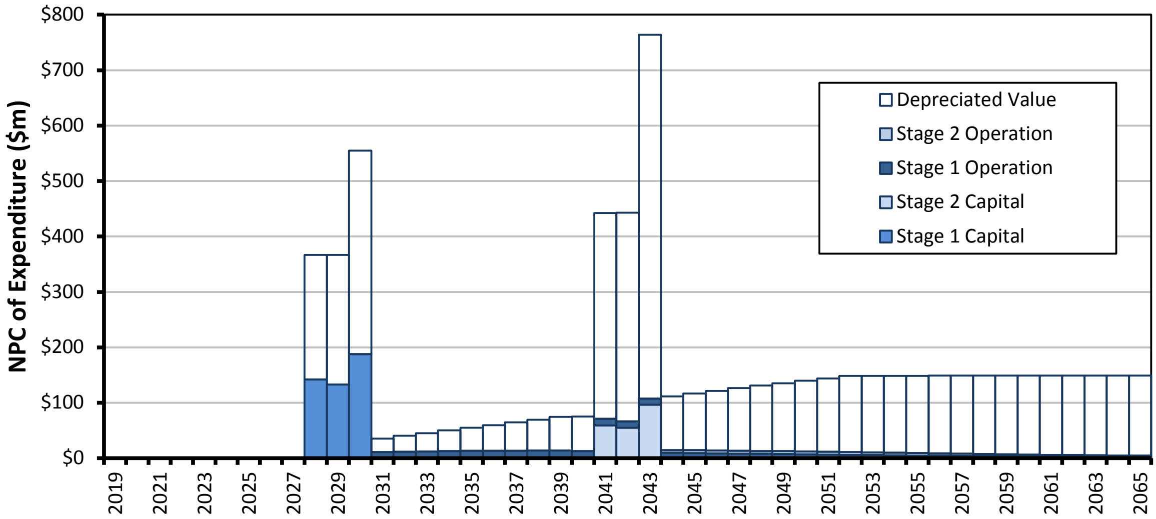


Source: Aurecon 2014, Figure 28

Figure 15.16 Flood impacts NPC of operational options using medium term parameters

15.6.3 Bulk water supply infrastructure NPC

Regional bulk water supply infrastructure costs have been assumed to consist of the NPC of anticipated first and second stage augmentation infrastructure, including construction and operating costs for the duration of the NPC accounting period. Figure 15.17 illustrates the yearly distributions of discounted costs based on current estimates of augmentation timing assuming current manufactured water infrastructure availability.



Source: Aurecon 2014, Figure 32

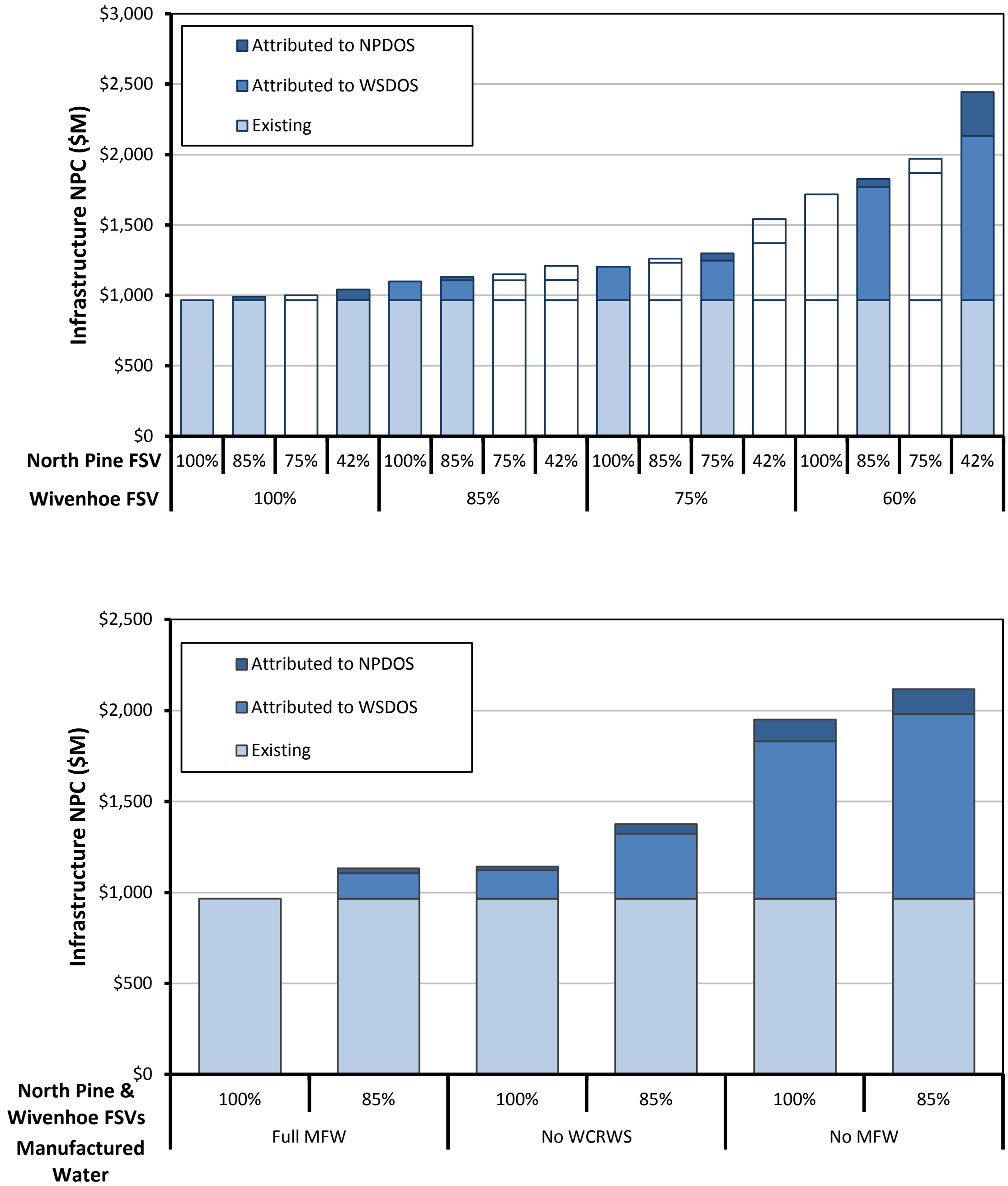
Figure 15.17 NPC of projected capital and operational costs based on medium term assumptions

This highlights the decreased influence of deferred capital costs. Bringing forward an augmentation date increases the NPC of that augmentation. Examination of the relationship between net present infrastructure costs and bulk storage volume in the water supply system modelling reveals a two-stage relationship. When the total storage volume is above about 1,020 GL, only the timing of the second augmentation is affected. However for lower storage volumes (say Wivenhoe Dam at 60% FSV) the timing of the first augmentation is also brought forward and the rate of cost increase becomes greater.

Estimated total NPC for bulk water infrastructure are presented in Figure 15.18 and

Table 15.11 for the medium-term assumption, noting that Seqwater has only analysed the effects of varying availability of manufactured water infrastructure for a select number of combinations of Wivenhoe Dam and North Pine Dam FSVs. Values in italics have been interpolated based on total storage volume and are provided as an order-of-magnitude for information only.

Sensitivity to the NPC parameters (Aurecon 2014) is such that adoption of a high discount rate and short forecast period reduces predicted bulk water infrastructure costs, most notably for cases where Wivenhoe Dam is above 85% FSV and no increase in water infrastructure costs are incurred. It is cautioned that this is because the bring-forward of augmentation costs do not occur within the short-term accounting period, not because they will not be needed in future. Conversely, adoption of a low discount rate and long accounting period increases the predicted bulk water infrastructure NPC.



Source: Aurecon 2014, Figures 34, 37

Figure 15.18 Effect of anticipated regional dam FSV scenarios on bulk water infrastructure NPC using medium-term assumptions compared to the existing FSV (Top: augmentation; Bottom: manufactured)

Table 15.11 NPC of regional bulk water infrastructure using medium-term assumptions

Wivenhoe / North Pine	FSV 100% ($M)	FSV 85% ($M)	FSV 75% ($M)	FSV 60% ($M)
FSV 100%	$1,136.36	$1,290.02	$1,410.53	*$2,001*
FSV 85%	$1,163.06	$1,327.50	*$1,476*	$2,128.55
FSV 75%	*$1,177*	*$1,349*	$1,519.91	*$2,293*
FSV 42%	$1,222.24	*$1,418*	*$1,800*	$2,837.35
MFW / Wivenhoe & North Pine dams		**No WCRWS ($M)**		**No WCRWS or GCDP ($M)**
FSV 100%		$1,340.37		$2,271.55
FSV 85%		$1,609.26		$2,462.70

Note: Values in italics are interpolated only.
Source: Aurecon 2014, Table 28

15.6.4 Apportionment of bulk water supply infrastructure NPC

To investigate the impacts of WSDOS operational alternatives independently requires bulk water NPC to be apportioned to the impacts of the operational changes to Wivenhoe and North Pine dams. Two methods were used depending on the particular situation (Aurecon 2014), with both based on a ratio of storage volume between Wivenhoe-Somerset and North Pine Dam.

The impacts of changes to the bulk water infrastructure NPC attributed to Wivenhoe Dam options are illustrated graphically in Figure 15.18 and in Table 15.12 for the medium-term investment assumption.

Table 15.12 WSDOS increase in bulk water infrastructure NPC for medium-term assumptions

Wivenhoe / North Pine	FSV 100% ($M)	FSV 85% ($M)	FSV 75% ($M)	FSV 60% ($M)
FSV 100%	$-	$133.55	$238.30	*$751*
FSV 85%	$-	$140.35	*$266*	$805.99
FSV 75%	$-	*$141*	$281.53	*$901*
FSV 42%	$-	*$143*	*$404*	$1,166.15
MFW / Wivenhoe & North Pine dams		**No WCRWS ($M)**		**No WCRWS or GCDP ($M)**
FSV 100%		$155.40		$864.71
FSV 85%		$357.82		$1,013.78

Note: Values in italics are interpolated only. The increase in bulk water infrastructure NPC is the apportionment of costs to Wivenhoe Dam only (refer Aurecon 2014).
Source: Aurecon 2014, Table 32

Reductions in the water supply storage volume, tend to bring forward of the second augmentation stage. Reducing the Wivenhoe Dam FSV initially results in an near-linear increase in infrastructure cost that is independent of North Pine Dam while the FSV of all dams is at 75% or greater. The timing of the first water supply augmentation is impacted when the total storage volume of the two dams is reduced below approximately 1,020 GL and results in higher overall costs that are attributable to both the Wivenhoe and North Pine Dam options.

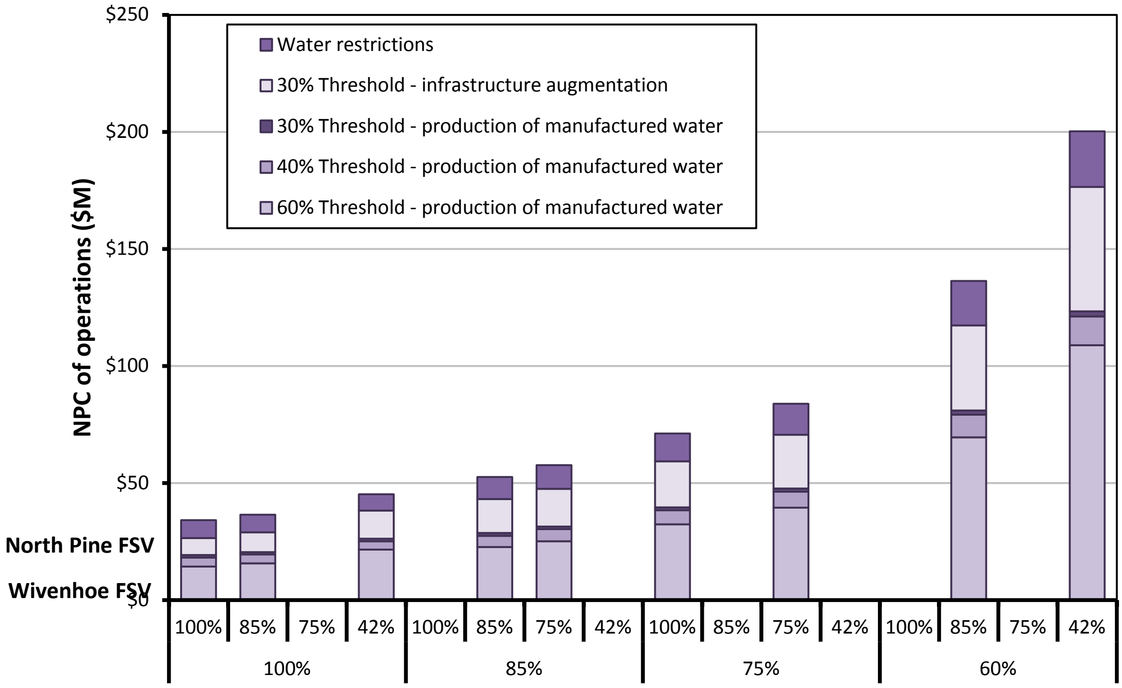
Reduced availability of manufactured water brings forward the timing of the first augmentation stage, increasing the infrastructure NPC. With reduced manufactured water, a reduction in the FSV of the dams to 85% has no further impact on the timing of the first augmentation. The timing of the second augmentation without manufactured water has been assumed to be unchanged from the case with manufactured water. Cost impacts will have been underestimated if the second stage must also be brought forward.

15.6.5 NPC of operations

Net present cost of operations attributable to implementing the water security strategy can be calculated as the sum of the present cost of the consequences of reaching a water supply threshold in each year multiplied by the probability of the threshold being reached in each year. Seqwater (2014b, 2014c) has assessed the cumulative probability of reaching (falling below) each threshold level, but this does not include the probability of multiple subsequent occurrences. To include this, a stochastic simulation was performed assuming that the probability of subsequent thresholds being reached has the same probability distribution as the first. The influence of repeat triggers depends on the NPC assumptions (i.e. the weighting given to long-term costs), but can be significant when reaching the threshold has a high probability of recurrence.

Changes to the water supply infrastructure modify the probabilities of reaching each water supply security threshold. Reducing the full supply level from 100% down to the minimum examined (Wivenhoe Dam at 60% FSV and North Pine Dam at 42% FSV) reduces the mean time to reach the 60% supply threshold from over 25 years to less than 5 years. For the same scenarios, the mean time to reach the 40% threshold, which triggers imposition of water restrictions, is reduced from approximately 50 years to less than 30 years.

The modelling performed by Seqwater suggests that the average durations below each of the trigger thresholds tend to reduce slightly as the storage volume decreases, however this is outweighed by the probability of reaching the threshold. Figure 15.19 shows the breakdown of NPC attributed to reaching each of the thresholds. The major contributions are from production of manufactured water at the 60% threshold, which has the lowest cost but highest probability of occurrence, and bring-forward of augmentation infrastructure, which has low probability but very high cost. These two components also experience the greatest increase as the water supply volume decreases.



Source: Aurecon 2014, Figure 44

Figure 15.19 Water supply operations NPC at each threshold assuming medium-term assumptions

Costs associated with medium-level water restrictions (based on community perception and willingness-to-pay, as discussed in section 15.5.2) comprise approximately 20% of current costs of water operations. Although the cost increases as the storage volume is reduced, the percentage contribution decreases to 11% of total costs for the minimum supply volumes examined. As with the manufactured water costs, the significantly lower probability of triggering increased water restrictions means that they should have a small contribution to overall costs. Given the uncertainty regarding the water restriction cost estimates, it is considered reasonable to neglect the community costs of higher-level water restrictions.

Estimated total NPC of operations are presented in Table 15.13 and Figure 15.20, for a select number of combinations of Wivenhoe and North Pine dam FSVs. Water supply security (operational) costs are sensitive to the NPC assumptions (refer Aurecon 2014) and starting levels in the dams.

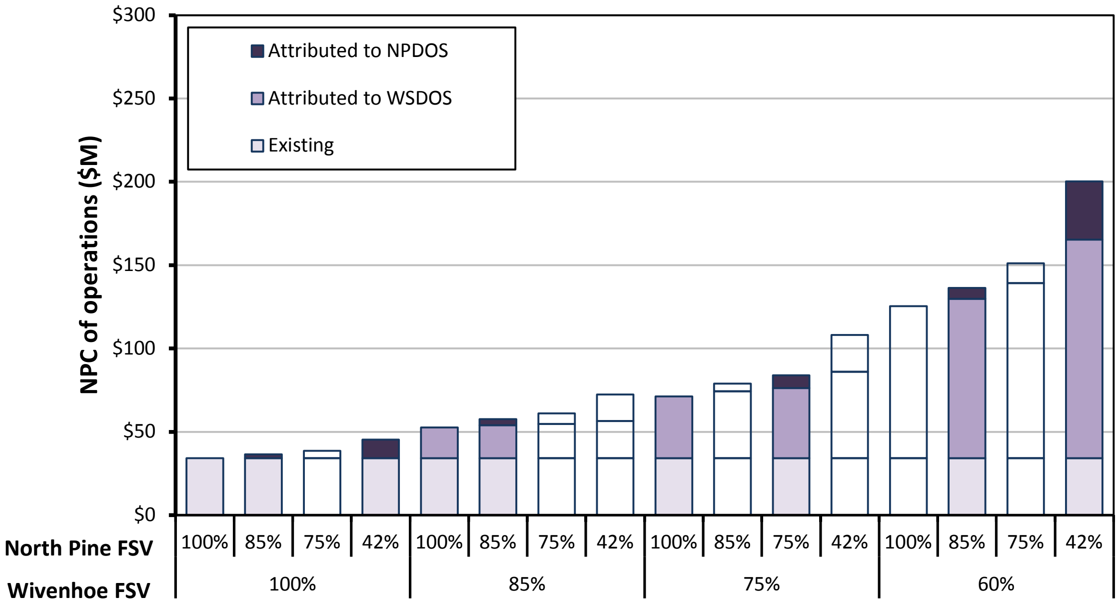
Table 15.13 NPC of operational costs for medium-term assumptions

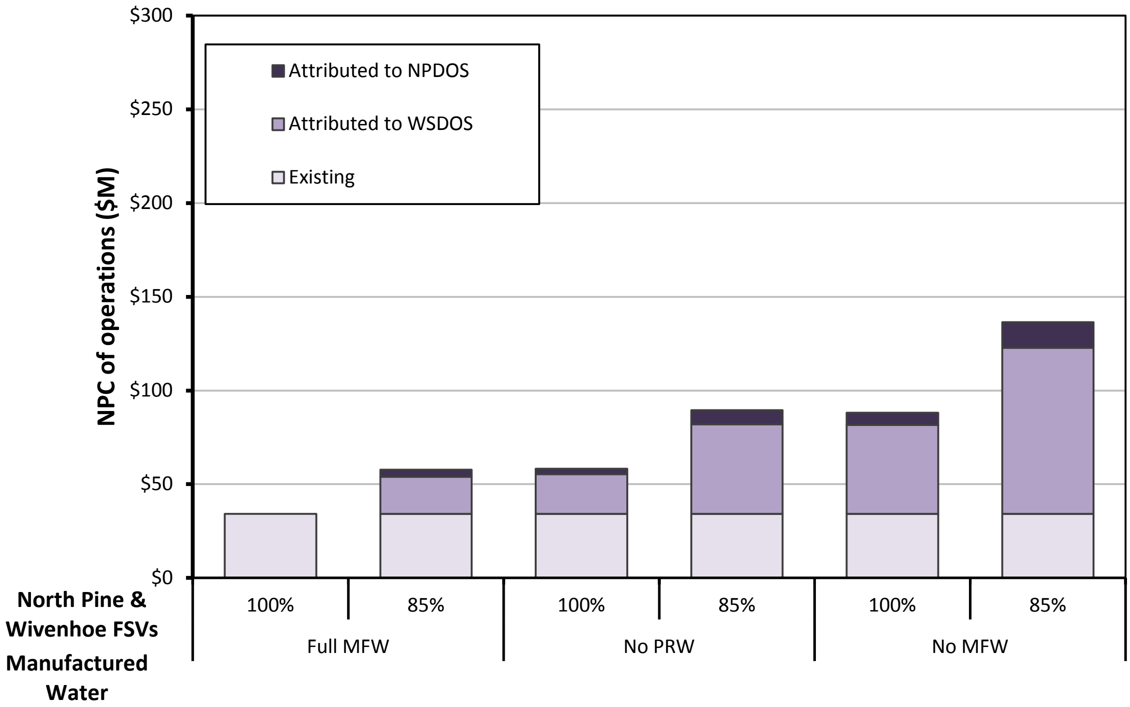
Wivenhoe / North Pine	FSV 100% ($M)	FSV 85% ($M)	FSV 75% ($M)	FSV 60% ($M)
FSV 100%	$34.12	$52.63	$71.14	*$125.4*
FSV 85%	$36.44	$57.67	*$78.8*	$136.34
FSV 75%	*$38.5*	*$61.1*	$83.95	*$151.2*
FSV 42%	$45.22	*$72.4*	*$108.1*	$200.23

MFW / Wivenhoe & North Pine dams	No WCRWS ($M)	No WCRWS or GCDP ($M)
FSV 100%	$58.26	$88.16
FSV 85%	$89.46	$136.38

Notes:
Values in italics are interpolated only. The increase in the NPC of operational costs is the apportionment of costs to Wivenhoe Dam only (refer Aurecon 2014).

Source: Aurecon 2014, Table 37





Note: Unshaded bars are interpolated only.
Source: Aurecon 2014, Figure 45, 48

Figure 15.20 Effect on NPC of dam FSV scenarios (top) and manufactured water strategies (bottom)

15.6.6 Apportionment of NPC of operational cost increases

Cost impacts of the different water supply scenarios are considered to be the difference between the NPC of the modified scenario and the current water supply scheme. As with the bulk water infrastructure costs, the impacts of changes to the water security cost attributed to the Wivenhoe Dam options are apportioned on the basis of their storage volume relative to North Pine Dam. This is illustrated graphically in Figure 15.20 and summarised in Table 15.14 for the medium-term assumption.

It should be noted that the values are approximate because bring-forward times have been rounded to the nearest year and distribution of costs between NPDOS and WSDOS has been estimated as above. As discussed earlier, reductions in the water supply storage volume, whether in Wivenhoe Dam or North Pine Dam, results in increased frequency of triggering supplementation of the water storage with manufactured water. The relationship between volume reduction and cost is not linear, but rather increases more quickly as the volume is reduced in either Wivenhoe or North Pine Dams.

Table 15.14 WSDOS increase in NPC of operational costs for medium-term assumptions

Wivenhoe / North Pine	FSV 100% ($M)	FSV 85% ($M)	FSV 75% ($M)	FSV 60% ($M)
FSV 100%	$-	$18.52	$37.02	*$91.3*
FSV 85%	$-	$19.90	*$40.3*	$95.63
FSV 75%	$-	*$20.6*	$42.10	*$105.0*
FSV 42%	$-	*$22.4*	*$51.9*	$131.18

MFW / Wivenhoe & North Pine dams	No WCRWS ($M)	No WCRWS or GCDP ($M)
FSV 100%	$21.21	$47.47
FSV 85%	$47.82	$88.60

Note: The italicised values should be treated with caution as they are interpolated values (refer Aurecon 2014).
Source: Aurecon 2014, Table 40

15.7 Phase 5 – Part 2– Integrated assessment of NPC's of options

This section brings together the individually assessed Net Present Cost estimates from the preceding analyses into a final summary form that enables consideration of the relative economic merits of the operational alternatives. NPC estimates depend on the assumed discount rate and the accounting period. The sensitivity of the results to these parameters has been tested using the short-term, medium-term and long-term assumptions listed in Table 15.8.

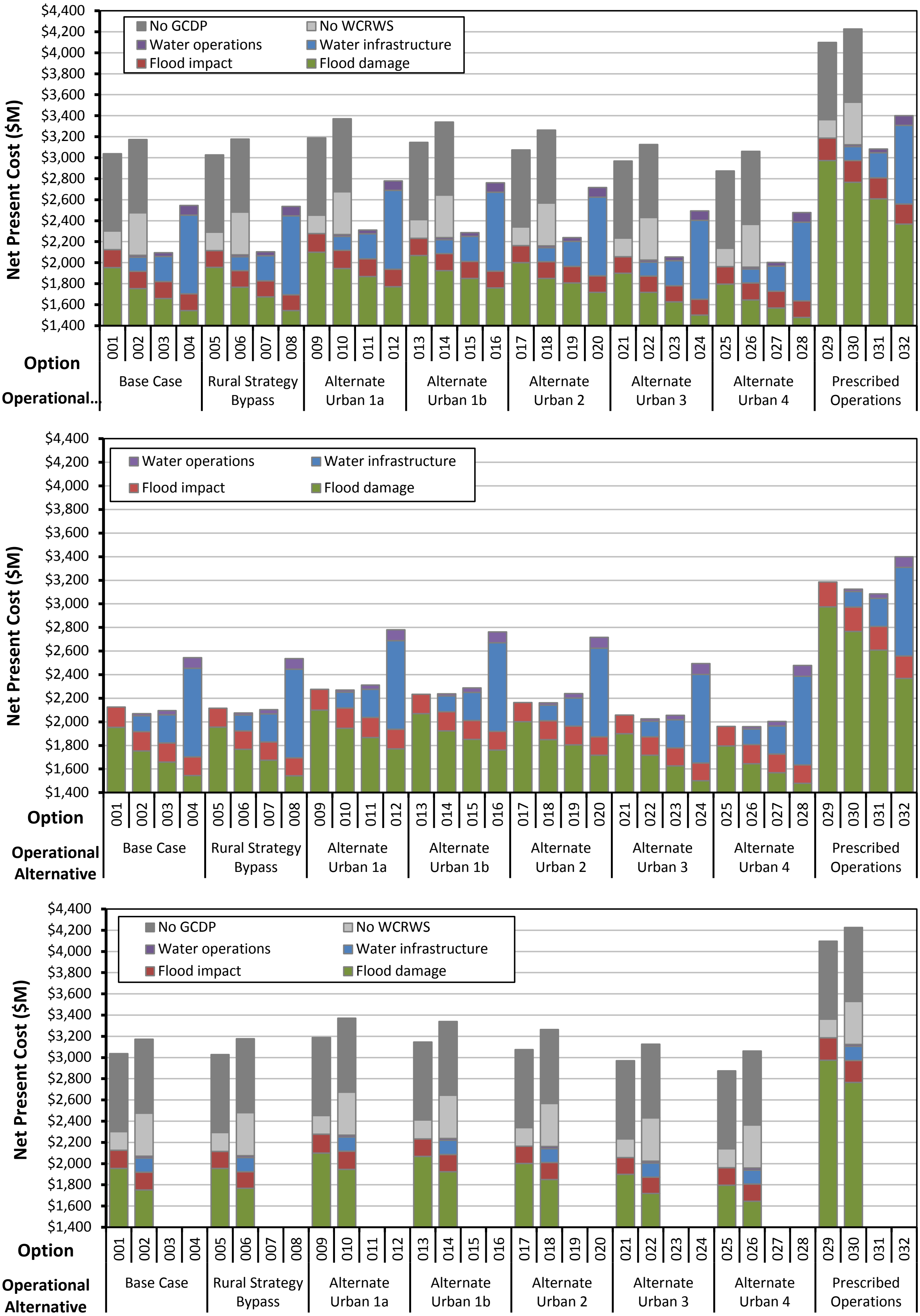
15.7.1 NPC of operational alternatives

Combined NPC results based on the medium-term assumptions are provided in Figure 15.21 and Table 15.15. It can be seen that flood damage generally represents the largest component cost for all options (approximately half of which is attributed to the residential damages alone) but also that water supply costs become more dominant as the FSV is lowered.

Flood impact related costs are typically less than 10% of the flood damage costs.

The cost impacts of not having the WCRWS or both the WCRWS and GCDP available are shown in Table 15.16 and Figure 15.21 for the 100% FSV and 85% FSV cases. The same extra manufactured water costs apply to all the 100% FSV and 85%FSV options. Similar but as yet unquantified extra costs in this regard will also apply to all the other FSV options.

Bulk water infrastructure and operational costs increase as the FSV is lowered and tend to equal or outweigh reductions in flood damage costs. This applies to all the operational alternatives considered.



Source: Aurecon 2014, Figure 52

Figure 15.21 Influence of dam operational options on total NPC for medium-term assumptions

Table 15.15 Total NPC costs for medium-term assumptions (median conditions)

Operational Alternative/Option		FSV	Flood Damage ($M)	Flood Impact ($M)	Water Infra. ($M)	Water Ops ($M)	TOTAL ($M)	% Change from Base Case Equivalent[1]		
								Flood Damage	Flood Impact	TOTAL
001	Base Case	100%	$1,953.8	$171.5	$-	$-	$2,125	0.0%	0.0%	0.0%
002		85%	$1,752.4	$165.7	$133.55	$18.52	$2,070	-10.3%	-3.4%	-2.6%
003		75%	$1,658.5	$162.2	$238.30	$37.02	$2,096	-15.1%	-5.4%	-1.4%
004		60%	$1,544.1	$158.7	$750.93	$91.25	$2,545	-21.0%	-7.5%	19.7%
005	Rural Strategy Bypass	100%	$1,954.8	$160.6	$-	$-	$2,115	0.1%	-6.4%	-0.5%
006		85%	$1,767.2	$156.3	$133.55	$18.52	$2,076	0.8%	-5.7%	0.3%
007		75%	$1,674.1	$154.3	$238.30	$37.02	$2,104	0.9%	-4.9%	0.4%
008		60%	$1,543.3	$151.4	$750.93	$91.25	$2,537	-0.1%	-4.6%	-0.3%
009	Alternate Urban 1a	100%	$2,099.7	$176.8	$-	$-	$2,276	7.5%	3.1%	7.1%
010		85%	$1,944.8	$172.5	$133.55	$18.52	$2,269	11.0%	4.1%	9.6%
011		75%	$1,866.7	$170.2	$238.30	$37.02	$2,312	12.6%	4.9%	10.3%
012		60%	$1,770.8	$167.1	$750.93	$91.25	$2,780	14.7%	5.3%	9.2%
013	Alternate Urban 1b	100%	$2,068.6	$164.9	$-	$-	$2,234	5.9%	-3.8%	5.1%
014		85%	$1,924.1	$162.2	$133.55	$18.52	$2,238	9.8%	-2.1%	8.1%
015		75%	$1,850.5	$161.1	$238.30	$37.02	$2,287	11.6%	-0.7%	9.1%
016		60%	$1,760.3	$159.4	$750.93	$91.25	$2,762	14.0%	0.4%	8.5%
017	Alternate Urban 2	100%	$2,001.1	$162.0	$-	$-	$2,163	2.4%	-5.5%	1.8%
018		85%	$1,850.3	$158.8	$133.55	$18.52	$2,161	5.6%	-4.2%	4.4%
019		75%	$1,806.1	$158.3	$238.30	$37.02	$2,240	8.9%	-2.4%	6.9%
020		60%	$1,717.3	$156.9	$750.93	$91.25	$2,716	11.2%	-1.1%	6.7%
021	Alternate Urban 3	100%	$1,898.6	$158.4	$-	$-	$2,057	-2.8%	-7.6%	-3.2%
022		85%	$1,718.0	$154.6	$133.55	$18.52	$2,025	-2.0%	-6.7%	-2.2%
023		75%	$1,627.1	$153.1	$238.30	$37.02	$2,056	-1.9%	-5.6%	-1.9%
024		60%	$1,501.0	$150.6	$750.93	$91.25	$2,494	-2.8%	-5.1%	-2.0%
025	Alternate Urban 4	100%	$1,795.4	$166.6	$-	$-	$1,962	-8.1%	-2.9%	-7.7%
026		85%	$1,644.2	$162.3	$133.55	$18.52	$1,959	-6.2%	-2.1%	-5.4%
027		75%	$1,568.3	$159.7	$238.30	$37.02	$2,003	-5.4%	-1.5%	-4.4%
028		60%	$1,478.6	$156.9	$750.93	$91.25	$2,478	-4.2%	-1.1%	-2.6%
029	Prescribed Operations	100%	$2,973.8	$212.1	$-	$-	$3,186	52.2%	23.7%	49.9%
030		85%	$2,766.0	$206.0	$133.55	$18.52	$3,124	57.8%	24.3%	50.9%
031		75%	$2,608.8	$199.8	$238.30	$37.02	$3,084	57.3%	23.2%	47.1%
032		60%	$2,368.3	$189.5	$750.93	$91.25	$3,400	53.4%	19.4%	33.6%

Notes:

1. For the Base Case, the % change is the comparison between the lowered full supply volume (FSV) option and the 100% FSV option. For comparisons between the operational alternatives and the Base Case, the % change comparisons are between the full supply volume equivalents
2. Operational alternatives are defined in Table 5.1.

Source: Aurecon 2014, Table 43

Table 15.16 NPC of increase in water supply costs attributed to Wivenhoe Dam

	No WCRWS ($M)			No WCRWS or GCDP ($M)		
FSV	Infrastructure	Operations	Total	Infrastructure	Operations	Total
100%	$155.40	$21.21	$176.61	$864.71	$47.47	$912.18
85%	$357.82	$47.82	$405.64	$1,013.78	$88.60	$1102.38

Source: Derived from Aurecon 2014, Tables 32, 40

A range of observations can be made based on this combined NPC assessment and the supporting hydrologic modelling:

Base Case (current operations with reduction in dam FSV) – Options 001 to 004

- Reducing FSV provides additional volume for storage attenuation of flood peaks. There appears to be limited benefit for flows less than around 4,000 m^3/s, because the additional storage is not utilised/needed for such small floods.
- Reducing the FSV reduces flood damages and impacts for floods between 5,000 m^3/s and 25,000 m^3/s with the amount of benefit increasing with reduction in FSV.
- The flood damage NPCs are reduced by 10% and 21% for FSV reductions to 85% FSV and 60% FSV respectively.
- Estimated flood impact NPCs are reduced by 3% and 7% for FSV reductions to 85% FSV and 60% FSV respectively.
- Total NPCs (flood damage, impact costs and water supply costs) are reduced by 2.6% when the dam is lowered from 100% FSV to 85% FSV.
- Total NPCs (flood damage, impact costs and water supply costs) are increased by 20% when the dam is lowered from 100% FSV to 60% FSV.

Within the level of accuracy of the NPC assessments for all the options, permanent reductions in the FSV of Wivenhoe Dam cannot be justified. This conclusion is dependent upon several significant assumptions including:

- The availability of manufactured water to supplement the bulk water supply. The modelling of bulk water infrastructure and operational costs was based on the assumption that GCDP and WCRWS are available for immediate drought response. As illustrated in Figure 15.21, bulk water infrastructure and operational costs increase significantly if these sources are not available, which does not support a lowering of the FSV of Wivenhoe Dam.
- The assumptions about the discount rate and forecast period.
- Assumptions about rainfall / flood event probability.
- Accuracy of data available to assess flood damages and impacts (building data, damage curves, flood surfaces, etc.).

Rural Strategy Bypass – Options 005 to 008

- The Rural Strategy Bypass operational alternative generally slightly reduces the mitigation for minor and low end moderate flood events and provides a very slight benefit for high end moderate to major flood events.
- The influence on bridges varies: low level bridges, including the largest cost contributors of Colleges Crossing and Burtons Bridge, experience increased frequency but shorter overall duration of inundation.
- The NPCs for this operational alternative are comparable with (approximately the same as) the Base Case.

Alternative Urban 1a – Options 009 to 012

- Alternative Urban 1a options provide less mitigation than the Base Case for minor to moderate flood events but have some benefit for major floods.
- The NPCs for this operational alternative increase 7% to 10% above the equivalent Base Case – FSV option.

Alternative Urban 1b – Options 013 to 015

- This operational alternative is a combination of the two previous alternatives. It reduces flood mitigation in minor to moderate floods but tends to improve flood mitigation outcomes in major floods.
- The small benefit of the Rural Strategy Bypass is outweighed by increased costs of alternative Urban 1a. This alternative also has flood damage costs about 6% to 14% higher than the equivalent Base Case – FSV option.
- The NPCs for this operational alternative increase 5% to 9% above the equivalent Base Case – FSV option.

Alternative Urban 2 – Options 016 to 020

- This operational alternative provides less mitigation than the Base Case operations for minor to low end moderate flood events (even less than alternative Urban 1a) but provides more benefit for high end moderate and major floods.
- The cost of increased flooding in minor and moderate floods tends to outweigh the benefits of reduced flooding for major floods.
- As with Urban 1 operational alternatives, this alternative appears to reduce the benefits of lowering the FSV such that they have a higher net cost than the Base Case.
- The NPCs for this alternative increase 2% to 7% above the equivalent Base Case – FSV option.

Alternative Urban 3 – Options 021 to 024

- This operational alternative displays similar characteristics to the Rural Strategy Bypass for minor flood events, but provides greater mitigation for moderate and major floods.
- Damage and impact costs are generally lower than the Base Case.
- The NPCs for this alternative are 2% to 3% lower than equivalent Base Case – FSV option.

Alternative Urban 4 – Options 025 to 028

- This operational alternative matches the Base Case mitigation for minor flood events while providing greater attenuation for moderate and major events.
- Flood damage and impact costs are generally lower than the Base Case options excluding fuse plug costs. However, the fuse plug costs are only a small proportion of the total cost.
- This set of options appears to be the most cost-effective, with total flood damage costs between 4% and 8% lower than the equivalent Base Case – FSV option.
- The NPCs for this alternative are 3% to 8% lower than the Base Case options. However, it is important to note that Urban 4 costs do not include the change in risk to dam safety and this variation poses the most risk to dam safety.

- Further refinement of this operational alternative would be required before it could be considered for implementation in order to confirm the expected costs of emergency spillway repairs and associated dam safety upgrades.

Prescribed Operations – Options 029 to 032

- This operational alternative tends to reduce flood mitigation for all but very major floods.
- The NPCs for flood damages and impacts costs for this alternative are 34-51% greater than the equivalent Base Case – FSV option.

15.7.2 Net present cost conclusion

The study has identified that there is no simple solution that demonstrates a marked reduction in total costs.

The integrated assessment of net present costs indicates that while lowering the full supply volume of the dam significantly reduces flood damages and impacts, when water supply costs are considered, there is likely to be no overall benefit to the community as a whole. Separate assessment of new infrastructure alternatives to increase flood storage may be warranted to determine if there is a net benefit.

These conclusions are sensitive to the availability of manufactured water and study assumptions, but are considered to be well within the accuracy of the assessment and the uncertainty and variability of natural flood and drought conditions.

Based on the above, it is difficult to support any permanent reduction in the FSV of Wivenhoe Dam.

Continued use of the seasonally[20] declared temporary FSLs for Wivenhoe Dam is a way of delivering improved flood mitigation potential while at the same time seeking to minimise water supply security risk compared to a permanent lowering of the dam.

Only operational alternatives Urban 3 and Urban 4 provide a small reduction in net present costs from the Base Case – with the reduction in costs reducing as the dam levels are lowered. It is cautioned that the NPC modelling does not consider implications of breaching the fuse plugs on issues such as dam safety, operations and mitigation of subsequent flood events. This significantly affects the perceived benefit of the operational alternative Urban 4 in an economic sense.

Operational alternatives which modify the dam safety trigger threshold would require more thorough investigation of the dam safety implications before being considered for implementation.

These conclusions are based on a widely accepted industry methodology which annualises the estimated costs of all potential floods based on their likelihood. The 'real life' effectiveness of each operational alternative depends on particular characteristics of the actual flood event – hence no single flood operations alternative can guarantee the best mitigation outcome for all events.

[20] A seasonally declared temporary FSL is generally a pre-wet season decision made by the Minister for Energy and Water Supply in accordance with the *Water Supply (Safety and Reliability) Act 2008* to lower the full supply level in the dam in response to forecasts by BoM of above average rainfall.

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