Wivenhoe Somerset Dam Optimisation Study – Simulating Dam Operations for Numerous Floods

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Wivenhoe Dam and Somerset Dam are located in the Brisbane River Basin. The combined maximum water storage capacity of both dams is over 4.2 Gigalitres. Current operations use 1.5 Gigalitres of storage capacity to provide urban water supply to South East Queensland and the remaining 2.7 Gigalitres of storage capacity is used for flood mitigation. A study to investigate alternative operations of the dams was initiated following major flooding in the Brisbane River in 2011 and in response to recommendations from the Queensland Floods Commission of Inquiry. The investigations considered different scenarios for water supply operations combined with different operational rules for flood mitigation.

The flood operations involve decisions based on flood flows from catchments upstream and downstream of the dams together with criteria for the effect of planned releases on predicted dam levels. The operations require continual review of decisions for dam releases as knowledge of the catchment flood flows changes as actual rainfall and river gauge data become available. It was important that the flood operations simulations could conceptually represent decisions that would be made in real time operations with continually changing knowledge of the flood.

Every flood is different and it is not sensible to optimise dam operations for one flood or a few select floods. Changed operational rules can worsen flood mitigations outcomes for some flood events and improve outcomes for other flood events. To optimise storage volumes and operational rules, the range of potential benefits and adverse impacts needs to be identified. Thousands of flood events were generated stochastically using world leading technology to simulate variable spatial and temporal patterns of rainfall. This provided a comprehensive basis to 'stress test' the flood mitigation operations.

This paper presents the methods used to apply a Flood Operation Simulation Model, and the methods used to present results of thousands of flood simulations in a way that different operational options could be compared. The approach was found to be valuable to understand the capacity of the dams to mitigate floods. The study identified shortcomings for the conventional design event approach to flood estimation. A broader range of stochastic floods was an advantage to assess flood mitigation performance and extreme floods of interest to dam safety.

Key Words: ***Multi-purpose Dams, Operations, Flood Mitigation, Dam Safety, Stochastic Floods***

Introduction

Wivenhoe Dam and Somerset Dam (the dams) are located in the Brisbane River Basin and are the primary sources of urban water for South East Queensland. The dams are also operated to mitigate floods in the Brisbane River downstream of Wivenhoe Dam. Flood operations are undertaken in accordance with the *Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam* (Flood Manual).

The flood mitigation functions of the dams are facilitated with:

- storage capacity in the dams above the dedicated water supply full supply volume (FSV) that can be used to temporarily store a limited quantity of flood water; and,
- spillway gates or sluices that can regulate the outflow from dams subject to constraints of the physical arrangements of the spillways, capacity of the gates, and dam water levels.

The last decade has demonstrated the variability of climate and risks for dam operations and safety. Significant concerns for urban water supplies occurred from the early 2000s to 2008 during the millennium drought.

Significant flooding occurred in the Brisbane River Basin in January 2011 which produced extensive flooding consequences in urban and rural areas including areas not affected, and areas affected, by the operation of the dams.

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 January 2011 flood attracted questions such as to what extents can the dams mitigate different flood events.

The Wivenhoe Somerset Dam Optimisation Study (WSDOS) was initiated to review the operation of the dams and inform long term review of the Flood Manual.

The requirements for the study were outlined in the recommendations from the Queensland Floods Commission of Inquiry (CoI). The need for the study aligns to best practice for continuous improvement and risk management. A specific recommendation from the CoI[1] was that scientific investigations should consider a review of design hydrology using a stochastic or Monte Carlo approach, taking into account observed variability in temporal and spatial patterns of rainfall, and taking into account observed variability in relative timings of inflows from the dams and downstream tributaries.

[1] Interim Report, Recommendation 2.12

Background

The capacity of the dams, catchment context, complexity of flooding in the Brisbane River Basin, and concepts of the dam operations were all important factors for the approach used for the study. A summary is provided herein and further detail is available in the study reports (DEWS 2014, Seqwater 2014).

Details of the Dams

Somerset Dam was commissioned in 1955. Wivenhoe Dam was later commissioned in 1983. In 2005, Wivenhoe Dam was upgraded with an auxiliary fuse plug spillway as an interim stage of upgrade towards meeting Acceptable Flood Capacity. Key details for the dams are summarised in Table 1.

Table 1 – Summary details of the dams

Basic Details	Somerset Dam	Wivenhoe Dam
Approx. max. height (m)	58	50
Structure type	Concrete gravity dam	Zoned earthfill (# 1)
Full Supply Level (m AHD)	99.0	67.0
Storage capacity at Full Supply Level (ML)	379,000	1,165,000
Maximum allowable reservoir level (m AHD)	109.7 (# 2)	80.0 (# 3)
Maximum storage at maximum level (ML)	1,100,000	3,132,000
Main spillway details, dimensions, and maximum flow capacity	63.4 m wide crest level 100.45 mAHD	60 m wide crest level 57.0 mAHD
	8 gates (# 4) 7.9m x 7.0m	5 gates 12m x 16.6m
	4,000 m^3/s	13,500 m^3/s
Additional flood release outlets or auxiliary spillway details	8 low level sluices (# 5) with gates	3 x fuse plug 164 m total
		breach levels 75.7, 76.2, 76.7 mAHD
	2,000 m^3/s	15,000 m^3/s
Catchment area	1,320	6,980 (# 6)

Table Notes:

#1 Wivenhoe Dam has main embankment and two saddle dams
#2 Somerset Dam level with flow overtopping concrete dam
#3 Wivenhoe Dam embankment crest level
#4 Somerset Dam crest gates are not used to regulate outflow
#5 Somerset Dam sluices are used to regulated outflow
#6 Wivenhoe Dam catchment with Somerset Dam catchment

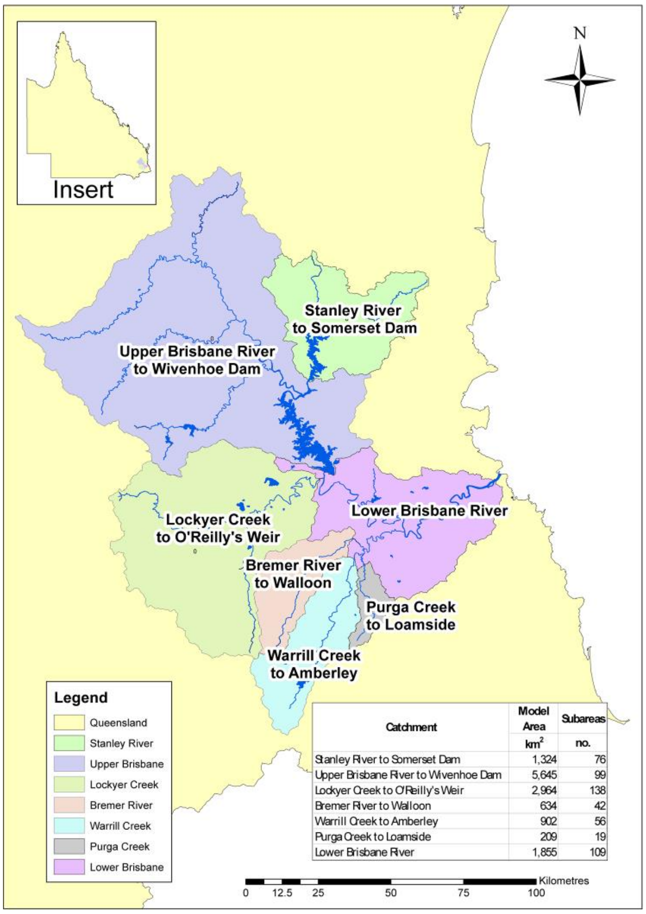
Wivenhoe Dam is located downstream of Somerset Dam and when it was commissioned it became the main structure for flood operations to mitigate floods in downstream reaches of the Brisbane River. Somerset Dam is now operated in conjunction with Wivenhoe Dam with a main focus to balance the storage of flood water in the respective dams.

The remainder of this paper focuses mainly on the operating rules for Wivenhoe Dam.

Catchment Context

The Brisbane River main stream and tributaries collect runoff from a total basin area of 13,500 km^2. A map of the Brisbane River Basin is presented in Figure 1. It is important to note that approximately half of the total basin area lies downstream of Wivenhoe Dam and the dam operations do not regulate the flow from the downstream catchments.

Figure 1 – Map of Brisbane River Basin



Major downstream tributaries include Lockyer Creek and Bremer River. Lockyer Creek has a catchment area of 2960 km^2. The Bremer River catchment area to Ipswich[2] is 1870 km^2 and this catchment has tributary catchments of Bremer River, Warrill Creek, and Purga Creek.

A detail map of key locations downstream of Wivenhoe Dam is presented in Figure 2. Moggill is 77 km downstream of Wivenhoe Dam and is a key location of interest for the Wivenhoe Dam flood operations. The downstream river reach from the Lockyer Creek – Brisbane River junction to Moggill is referred to as the Mid-Brisbane River. The river reach downstream of Moggill is referred to as the Lower-Brisbane River. The Bremer River joins the Brisbane River at Moggill. In large floods, the levels in the Brisbane River at Moggill can influence the Bremer River flood levels at Ipswich.

[2] Refer detail map on Figure 2 for key downstream locations.

Figure 2 – Detail Map of Brisbane River downstream of Wivenhoe Dam

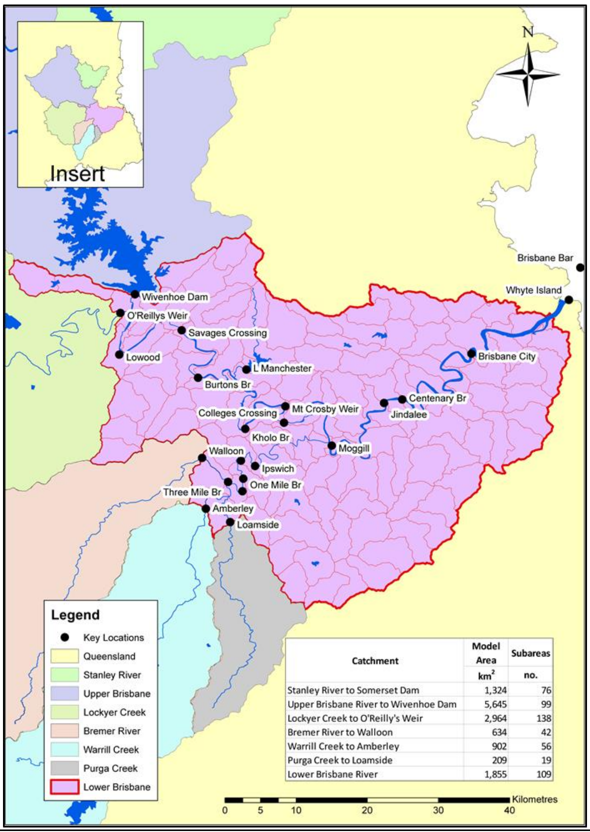
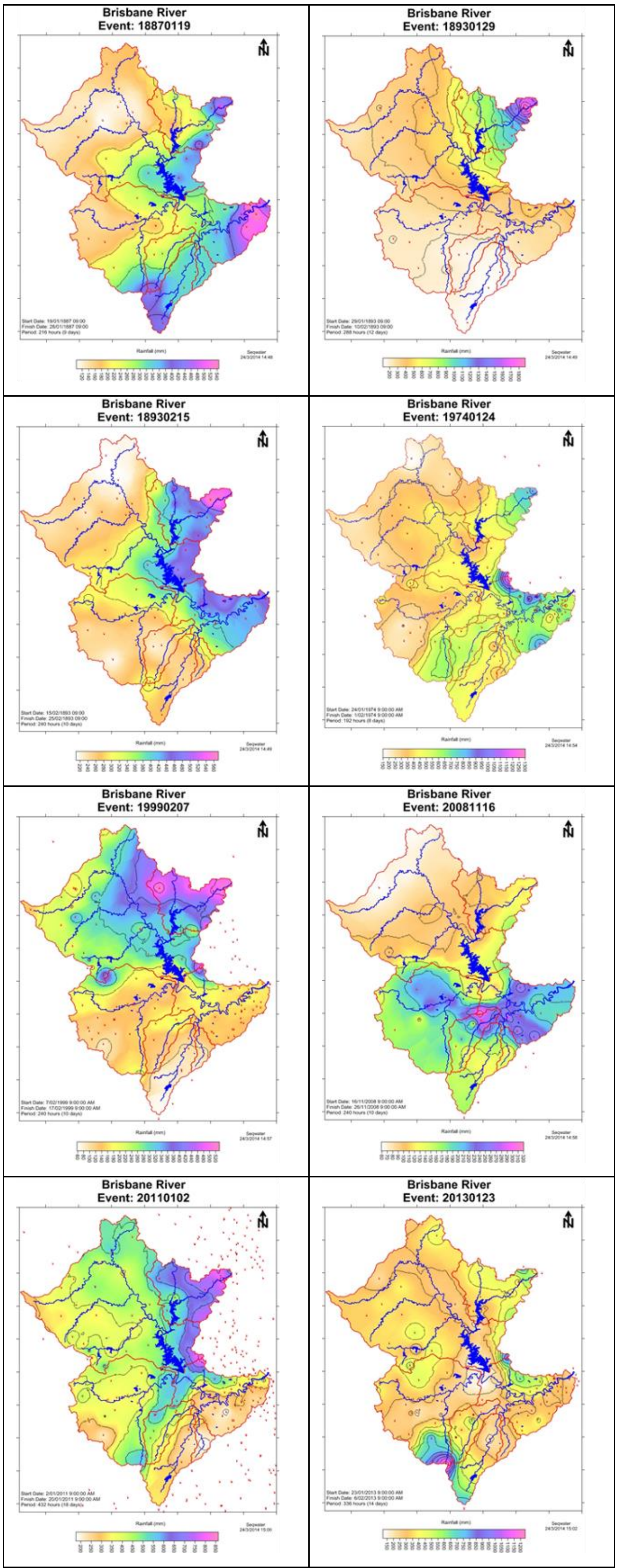


Figure 3 – Examples of different spatial patterns of rainfall in historical floods



Note: Colour scales for each event are not equal. The colour range is set to highlight variation across the catchment.

Complexity of Brisbane River Flooding

A comprehensive review of the Brisbane River Basin flood hydrology was undertaken to support the study. Recent floods had produced valuable data which appeared inconsistent with previous estimates of historical floods. The review reassessed all previous historical rainfall and flood data with the benefit of flow gauging data, improved estimates of river gauging station rating curves supplemented with calibration of flood hydrology models.

The review identified significant variability of rainfall patterns in terms of event rainfall totals, temporal patterns, and spatial patterns. The combined influence of variability of rainfall patterns, rainfall loss rates, channel and floodplain routing was identified to be a significant influence on complex flood behaviour in the Brisbane River even without the influence of major dams. Some examples of different spatial patterns for the event total rainfall are presented in Figure 3.

The complex flood behaviour of the Brisbane River becomes even more complex with the operations of the major flood mitigation dams. The dams are operated with highly developed operating rules which take account of flows occurring upstream of the dams and downstream of the dams when operating in strategies with objectives for flood mitigation in rural and urban areas. This meant that the potential variability of rainfall patterns, particularly relative differences between upstream of the dams and downstream of the dams, and the effect on relative magnitude and timing of flood flows was an important consideration to realistically assess the implications of alternative flood operations rules.

Concepts of Flood Operations at Wivenhoe Dam

A detailed description of the flood operations of Wivenhoe and Somerset Dam is presented in the WSDOS report (DEWS, 2014) and the Flood Manual (Seqwater, 2013). A summary of the operations is described below.

The flood operations at Wivenhoe Dam are defined in the Flood Manual to achieve specific objectives, which include in order or priority:

- protect the structural safety of the dams;
- protect urban areas from inundation;
- minimise disruption to rural life;
- retain the dams at Full Supply Level at the end of the flood event; and
- minimise impacts to riparian flora and fauna.

Operational Strategies are defined in the Flood Manual to achieve these objectives.

The operational strategies include a Rural and Urban Strategy which are linked to a permissible quantity of flood storage (specifically level in Wivenhoe Dam) that can be used for these strategies. The Dam Safety Strategy applies at higher levels in Wivenhoe Dam during floods which exceed the capacity of available storage that can be used in the Urban Strategy. A Drain Down Strategy applies after the flood peak to drain the dams back to Full Supply Level.

Within each strategy, operational procedures provide specific details of targets, criteria, and some considerations for professional judgment. A common aspect of the operational procedures is a requirement to prepare a release plan which defines the planned dam releases in the hours and days ahead.

Operating Concept for Rural and Urban Strategies

In the Rural and Urban Strategies, the primary intent of dam operations is to achieve a target flow at one or more key locations in the downstream river, whilst managing the available flood storage in the dams.

In the Rural Strategy the target locations are bridges along the mid Brisbane River that are important for rural areas. In the Urban Strategy the target location is Moggill which is at the junction of the Brisbane and Bremer River. The intent to achieve a target flow at Moggill mitigates peak flows along the lower Brisbane River through urban areas of Brisbane and parts of Ipswich.

With the approach to aim for a downstream target flow, the dam operations must always consider the predicted flows from rainfall over catchments downstream of the dams. When the downstream catchment flows are increasing, it is common that Wivenhoe Dam releases may decrease to achieve the selected target flow. The downstream target flow is increased as necessary to achieve a suitable balance between flood mitigation and managing the available flood storage in the dams.

A maximum target flow at Moggill and maximum allowable predicted level in Wivenhoe Dam defines the upper limit of potential dam operations in the Urban Strategy. When it is not possible to meet these criteria in large floods, the Dam Safety Strategy is selected.

Operating Concept for Dam Safety Strategy

In the Dam Safety Strategy the primary intent is to protect the safety of the dam by limiting the rise of lake level. The dam releases must increase as the lake level increases. A guide curve (which is also used for emergency operations when communications are lost) provides a relationship between lake level and dam release. The current operating rules require that the main spillway gates at Wivenhoe Dam are all fully open before overtopping of the lowest fuse plug embankment.

A key difference between the flood mitigation strategies for Rural and Urban objectives and the Dam Safety Strategy is that the Dam Safety Strategy generally does not consider downstream catchment flows[3]. This means that flood mitigation for downstream communities may diminish in the Dam Safety Strategy, although the dams still have a mitigating effect.

Operating Concept for Drain Down Strategy

In the Drain Down Strategy the primary intent is to drain the dams back to Full Supply Level within seven days. This is important for both Dam Safety and flood mitigation to empty the flood storage to be ready for another potential flood. Historical data for South East Queensland indicates a probability in the order of 10% that potential consecutive floods could occur within a seven day period (DEWS, 2014).

The release plan for the Drain Down strategy can be developed to account for many of the objectives such as reducing river flows in flooded urban areas, allowing bridges to become clear of inundation, and the rate of closure of releases to minimise potential bank slumping.

Operating Concept for Somerset Dam

Somerset Dam is operated in conjunction with Wivenhoe Dam to achieve the overall objectives. The aim is generally to balance the flood storage between the dams to minimise the risk of premature failure of either dam. The primary guide is an interaction line which defines corresponding target levels in each dam. As Somerset Dam is located upstream of Wivenhoe Dam, Somerset Dam responds to the Wivenhoe Dam levels and Wivenhoe Dam operations are the main influence for downstream flood mitigation.

Dam Operations Respond to Predictions

The exit criteria to change from the Rural Strategy to the Urban Strategy or, from the Urban Strategy to the Dam Safety Strategy are defined by the predicted Wivenhoe Dam lake level. Using predicted future dam levels to guide the Strategy selection makes the dam operations responsive to predictions beyond the current point in time. This means that decisions are not just reactive to current conditions but also respond to estimated flood behaviour in the hours and days ahead. This makes the dam operations complex, yet it is also this aspect that achieves beneficial flood mitigation outcomes. A key limitation is the estimates of predicted catchment flow hydrographs that have uncertainty in model inputs and outputs.

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[3] Exceptions are permissible to consider downstream catchment flows with careful professional judgement.

Optimisation Study Approach

The approach adopted to assess alternative flood operations of Wivenhoe and Somerset Dams was to develop a framework that could:

- simulate the operations of the dams with reasonable representation of real time flood operations;
- simulate the flood flows (or levels) downstream of the dams, and lake levels in the dams that would occur as result of the dam operations;
- perform simulations of numerous flood events with reasonable total simulation time; and
- produce outputs that could enable numerous flood simulation results to be compared.

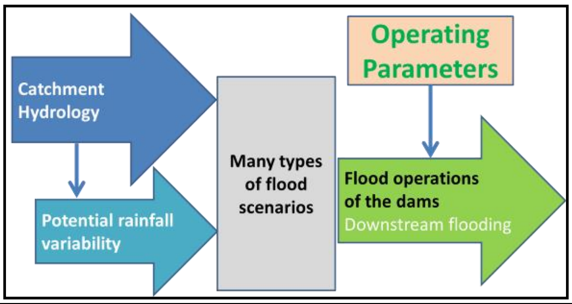
It was considered preferable to be able to assess a large number of flood events and also be able to assess a broad range of dam operations options. This approach provided a good opportunity to comprehensively "stress test" the dam operations rules. Conceptual hydrological routing methods were deemed suitable for this providing adequate calibration and validation could be performed.

Three key steps to establish the framework were:

- Review of the Brisbane River Basin flood hydrology and calibration of new rainfall-runoff routing models. This produced estimates of flood flow hydrographs for a range of historical floods and established suitably calibrated hydrological routing methods.
- Generation of a broad range of rainfall events to apply to the hydrological models to generate a large database of flood event flow hydrographs at key locations.
- Development of a model to simulate the flood operations of the dams and downstream flood flows, using flood event inputs (flow hydrographs) and parameters defining the operating rules.

A summary of the key components of the study is presented in Figure 4.

Figure 4 – Key Study Components



It was identified that as every flood is different due to variable rainfall patterns and, with the highly developed operating rules for the dams that take account of downstream catchment flows, there would be a significant possibility that changing the flood operations rules could result in better outcomes for some floods and worse outcomes for other floods.

The step taken to generate many rainfall events with variable space-time patterns of rainfall was considered very important to understand the implications of alternative flood operations. Seqwater commissioned consultants SKM (together with Bureau of Meteorology) to generate a large number of stochastic floods that could be used to stress test the dam operations. The methods used to generate the stochastic floods are presented in a separate accompanying paper (Jordan et al, 2014).

The scope of the study work undertaken by Seqwater was for flood operations modelling to produce estimates of flood flow (or level) hydrographs at key locations in the downstream river and at the dams. A separate study commissioned by DEWS prepared the follow-on integrated assessment of consequences, flood damage cost estimates, and economic implications for alternative water supply operations. The integrated assessment approach is presented in a separate paper (Toombes et al, 2014).

Flood Operations Simulation Model

A Flood Operations Simulation Model was developed using GoldSim software. GoldSim was selected for the following reasons:

- Suitable for modelling of non-linear dynamic systems, particularly for flow routing;
- Capacity to configure complex decision logic;
- Dynamic time-step capability;
- Proven use for Monte Carlo simulation which suited the interest to simulate numerous flood events;
- Good features for model version control and documentation; and
- Reasonably common use in the water industry in Queensland such that there would be capacity to have the model reviewed by a local expert.

The model was developed using conceptual 'top-down' modelling methods. This means that complex or non-linear system behaviour (such as flood routing along a river) can be simplified to conceptual mathematical methods providing that adequate validation of the model is undertaken.

Level-pool routing methods were used for flood routing through the dams. For flow routing in the river downstream of Wivenhoe Dam, the model applied linear Muskingum channel routing combined with storage-discharge relationships for conceptual representation of floodplain storage areas.

The model required a method to simulate realistic limits of foresight for catchment flood flow hydrograph information that would be available to make decisions for the operations of the dams in real time. Specifically what this means is that at the start of flood events, the full event hydrograph is not known. As the flood event progresses more knowledge of the flood flow hydrographs from the catchments becomes available as actual rainfall occurs.

The model was able to simulate quantifiable aspects of decision making for the flood operations, but was not able to simulate some aspects of professional judgment such as confidence in catchment flood hydrographs.

The model was validated by comparison of simulated dam operations and actual dam operations for four previous flood events which covered the range of operations using the Rural, Urban, and Dam Safety strategies.

Alternative Dam Operation Options

The study assessed 32 alternative dam operating options which comprised four scenarios for water supply operations (defined by full supply volume) combined with eight sets of variations of the flood operations.

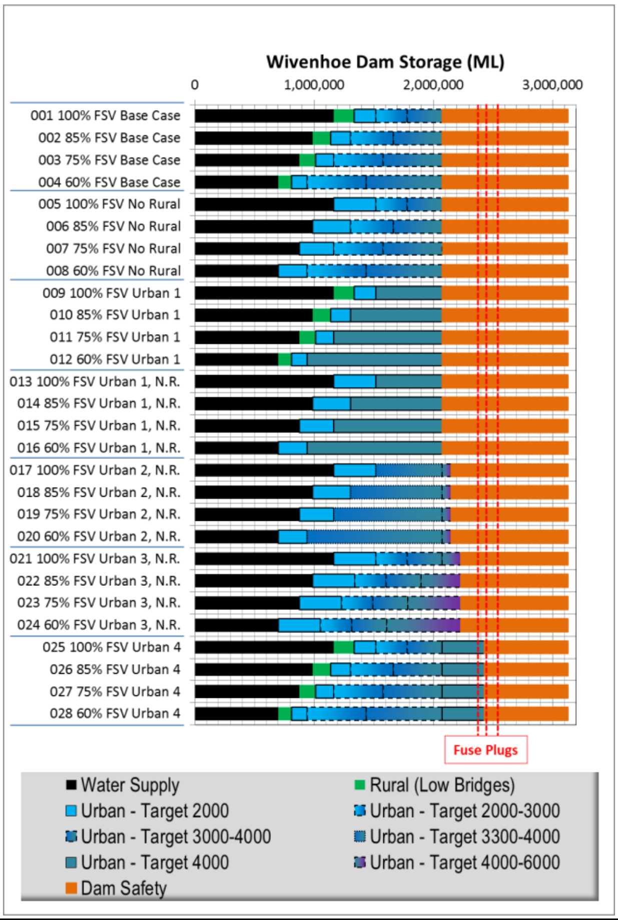
The first set of flood operations rules was based on the current Flood Manual to define a 'base case' to compare the alternative flood operations.

Six variations of the flood operations applied the operating philosophy in the current Flood Manual with different operating parameters. These variations included the option to exclude the Rural Strategy, and change the flood storage allocated to different strategies. The variations also considered changing the parameters used in the Urban Strategy for the downstream target flows. The variations generally tended towards potential to release more water from Wivenhoe Dam, however one option was considered that would tend to store more floodwater and allow the lowest and smallest fuse plug to breach while operating in the Urban Strategy.

Another variation of the operations considered simple (prescriptive) operating rules that do not consider the downstream catchment flows and aim to maximise available flood storage (i.e. store as little as possible).

To enable stakeholders to understand the differences between the alternative options a graphical representation of the storage allocated to different strategies and the way that the storage is used in the Urban Strategy was prepared as shown in Figure 5.

Figure 5 – Graphical Representation of Options



Simulations to Assess Flood Mitigation

Flood simulations were undertaken using historical floods and stochastic floods to assess the flood mitigation performance of the dams with alternative operations.

The historical flood simulations included estimates of the largest 20 floods that have occurred in the last 125 years. This provided a reasonable sample of different rainfall patterns that have been observed. The historical flood simulations were undertaken using a simulated drawdown of the initial dam level that was derived from water supply simulations using historical inflows.

The stochastic flood simulations were performed for nearly 4000 different flood events with variable patterns of rainfall. The stochastic flood simulations were valuable to stress test dam operations to assess the potential variability of flood mitigation beyond the variability evident in historical flood event simulations. The stochastic flood simulations assumed the dams were full at the start of each flood.

Flood Mitigation Results for Historical Floods

The simulation results for the historical floods were particularly valuable for non-technical stakeholders.

The historical flood results were presented in the form of bar charts showing different colour bars for each operating option and each group of bars represented a different flood event. The charts also showed the peak flow that would occur for each flood if the dams did not exist to demonstrate the flood mitigation that would be achieved. An example is presented in Figure 6.

Although the historical flood simulations were a relatively limited sample of 20 floods, it was sufficient to identify several important observations.

The results showed that the dams provide substantial flood mitigation in many events. For major floods that exceed the flood storage available for the Urban Strategy, some flood mitigation benefit is still achieved when the dam operations need to apply the Dam Safety Strategy. In major floods (approximately four events in the last 125 years), significant urban inundation (peak flows above 4000 m^3/s) would still occur as the dams have limited capacity for temporary storage of flood water.

Importantly, the historical flood simulations were also able to demonstrate that variation of the flood operations could provide benefit for some floods and yet also produce adverse impacts (less mitigation) for other floods.

Flood Mitigation Results for Stochastic Floods

It was not practical to present the stochastic flood simulation results in a similar format to the historical flood results.

A 'flood mitigation' scatter plot was prepared to plot each flood with a point defined by the peak flow that would occur if the dams did not exist (no dams) and the peak flow that would occur with a specific dam operating option. An example is presented in Figure 7. The 1:1 line represents no flood mitigation. Points that plot well below the 1:1 line are floods where significant flood mitigation would be achieved.

Figure 6 – Example Presentation of Historical Flood Simulation Results

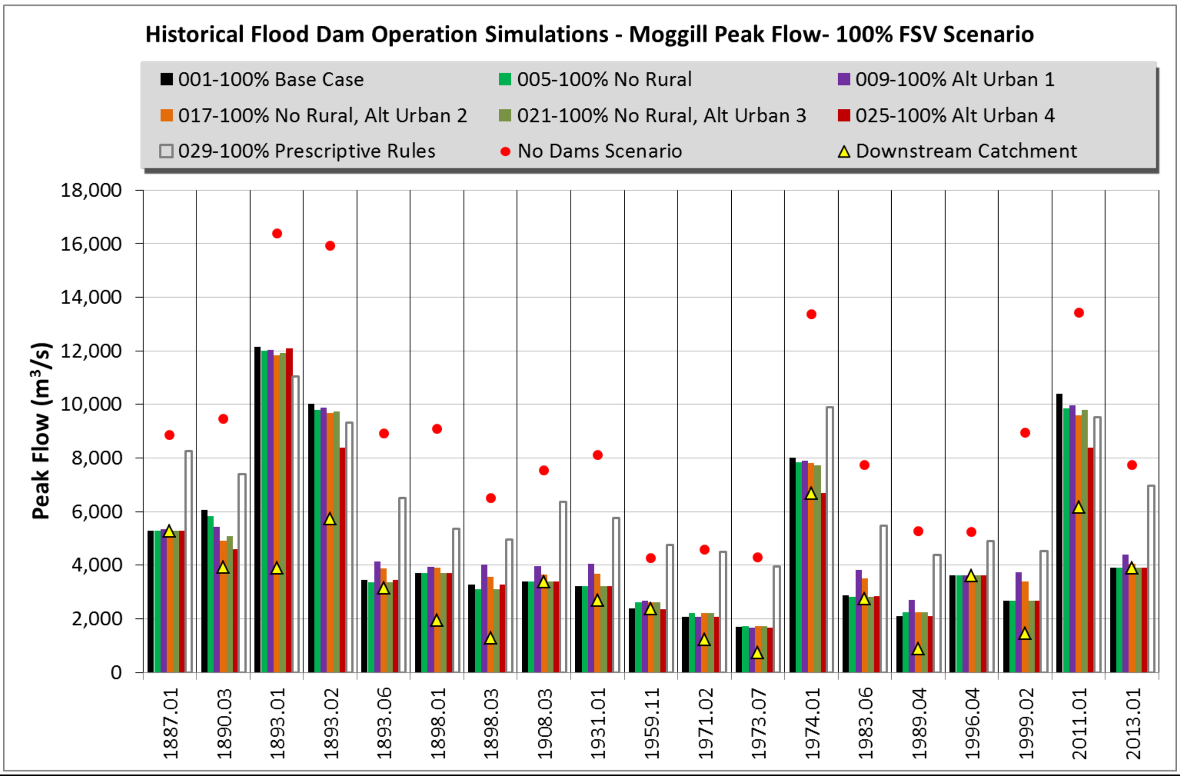
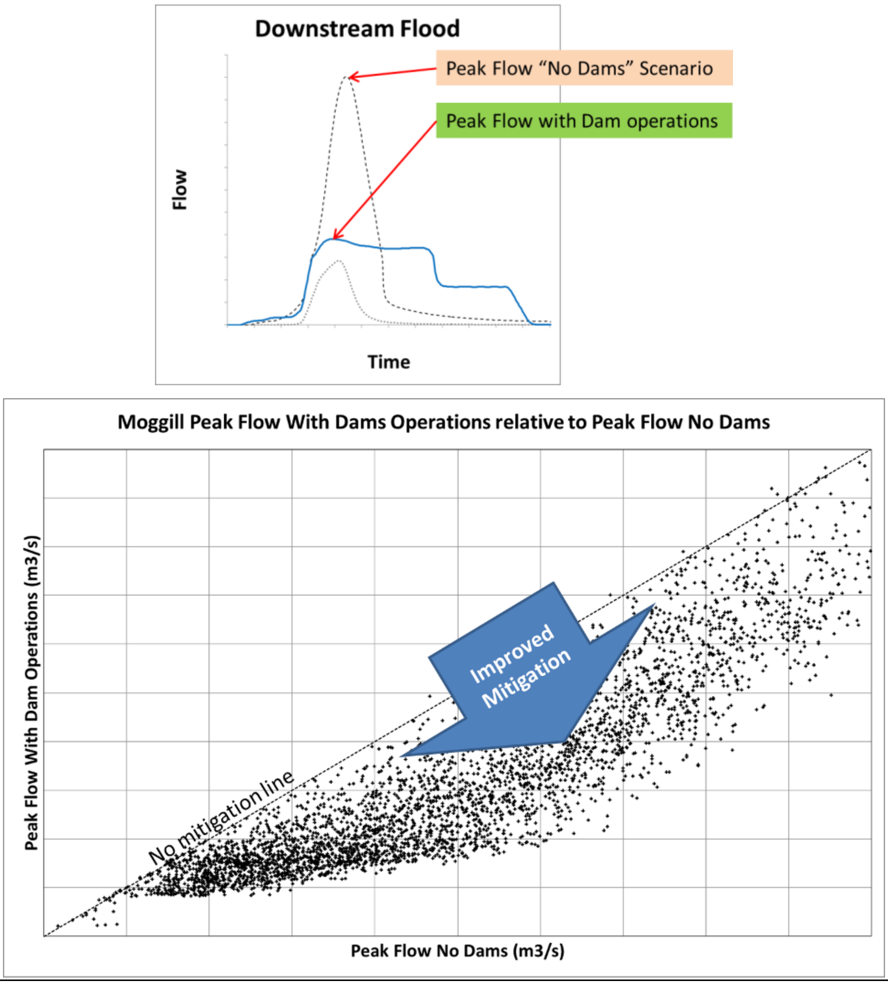


Figure 7 – Example Concept of Flood Mitigation Scatter Plot for Stochastic Flood Simulation Results



The flood mitigation scatter plots for each operating option were then further analysed by fitting a line of median flood mitigation performance and the potential variability of flood mitigation defined by 10^{th} and 90^{th} percentiles. These statistics were calculated by analysis of partitions of the peak flow for the no-dams scenario (i.e the x-axis plotting position).

An example showing the Base Case (current Flood Manual) is presented in Figure 8. In this example, the historical flood simulation results are also shown and were found to align well with the flood mitigation performance identified from the stochastic flood simulation results. Some of the historical floods plotted below the range of flood mitigation identified from the stochastic floods because for some of the historical flood simulations the initial start level in the dams were significantly below FSL (such as the 1999 flood).

The plots of flood mitigation performance from stochastic flood simulations identified an important observation for the variability of flood mitigation. It was identified that up to +/- 30% variation in peak flow with dam operations could be expected due to the variability of rainfall patterns across the catchments upstream and downstream of the dams.

The lines defining the median flood mitigation for each operating option were then overlaid to enable comparison of alternative operations of the dams. An example is presented in Figure 9.

From these options comparisons plots it was possible to identify that some alternative operation options could produce a minor benefit for a limited range of flood magnitude but could also produce adverse impacts (less flood mitigation) for smaller more frequent floods. These types of observations are important to inform the trade-offs that may be necessary between adverse impacts and potential benefits for changing the flood operations.

Using the Results to Understand Relative Change

It was identified that changes to the operations rules do not produce uniform impacts and benefits for specific magnitude of flood events.

If the operating rules are changed, the individual points in a specific region on the flood mitigation scatter plot (Figure 7) do not all move down (improvement) or up (worsening) to follow the trend of the median flood mitigation. This means that the options comparison using median flood mitigation line plotted in the form shown on Figure 9 can be misleading.

An alternative form of results plot was prepared to more specifically understand the potential for better or worse outcomes due to change in the flood operations. The relative change plot shown on Figure 10 plots the peak flow for each flood for the Base Case dam operations on the x-axis and the peak flow for the same floods with an alternative flood operation on the y-axis. The 1:1 line represents no change from the base case. Points plotting below the 1:1 line are floods where improved outcomes would occur for the alternative operation option, and above the 1:1 line are worse mitigation results.

The example shown in Figure 10 shows that for this option consistently worse flood mitigation would occur for floods up to approximately 4000 m^3/s peak flow. For floods larger than 4000 m^3/s peak flow there would be general minor improvement in flood mitigation, but it is also evident that some flood scenarios are possible where worse outcomes would occur from a change to the flood operations.

The relative change plots were particularly useful to demonstrate that any change to the flood operations could result in some worse outcomes in some floods. The disadvantage of these plots is that the degree of flood mitigation that would be achieved is not identifiable.

The best appreciation of the implications of changing the flood operations was gained by reviewing the flood mitigation plots (to understand degree of mitigation) in conjunction with the relative change plots (to understand the possibility of better and worse individual flood outcomes).

Other key performance indicators

The results described so far have focused on the peak flow in the downstream river as a measure of flooding. Changing the flood operations would also produce other impacts on flooding. The same approach used to plot the historical floods or stochastic floods can be useful to assess other impacts on flooding such as:

- The duration of inundation of downstream bridges;
- The duration of inundation of upstream bridges;
- Peak flood levels in the dams; and
- Delay to the onset of critical urban flooding.

It was identified that the current dam operations provide a benefit to delay the onset of critical urban flooding. An example is presented in Figure 11.

The delay of critical urban flooding is an important benefit for safety and damage reduction because it can increase the warning time for downstream communities to prepare for flooding and evacuate flood prone areas. If the lead time is used wisely flood damage can also be reduced.

It was important to consider the benefit of delaying critical urban flooding because some of the alternative flood operation options that would tend towards higher early releases would diminish this benefit.

Impacts and Benefits Vary at Different Locations

Results plots were prepared at several locations of interest and for different parameters of interest. It was identified that changing the flood operations would not only produce a mix of worse and better outcomes across different flood events, but also worse and better outcomes at different locations for the same flood event.

The results demonstrated that the overall implications for changing flood operations for flood mitigation can be quite diverse. Gaining an understanding of the scope of consequential impacts and benefits is important to inform trade-offs that may be necessary to select optimal operation rules.

Figure 8 – Comparison of Stochastic and Historical Floods and Variability of Flood Mitigation

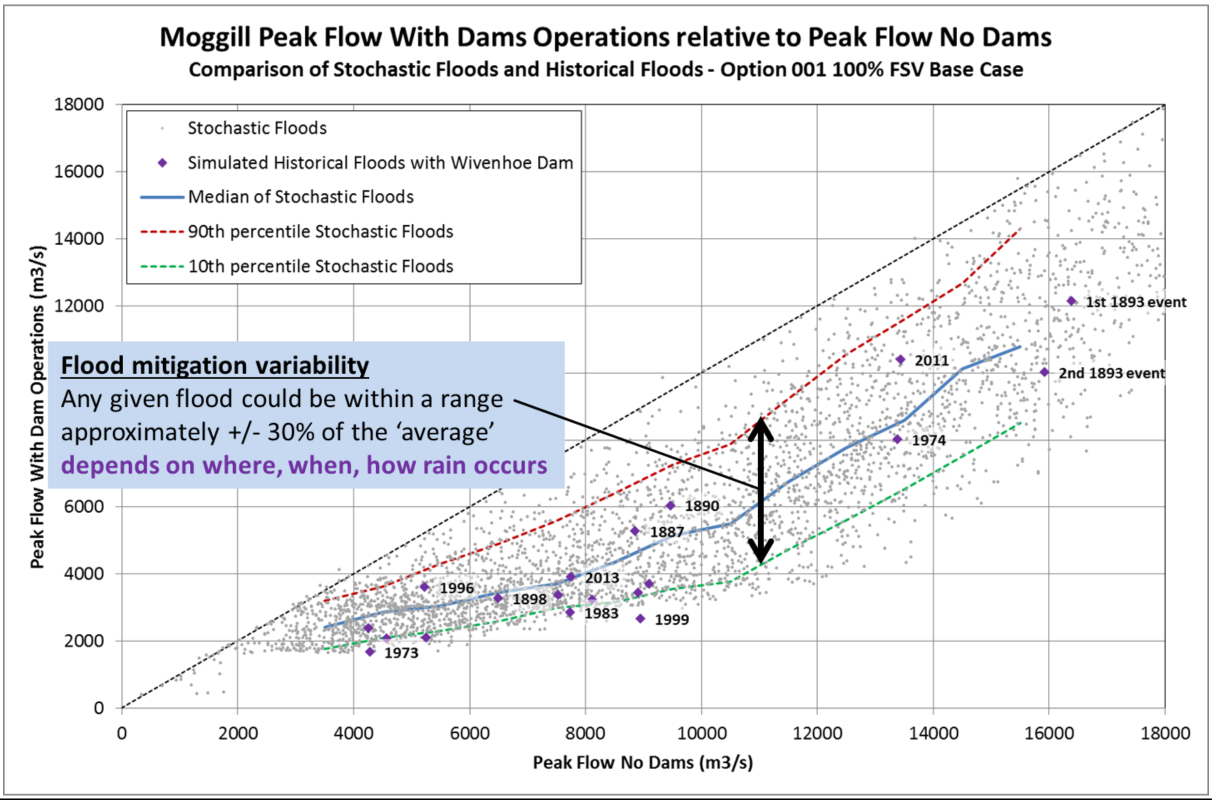


Figure 9 – Comparison of Options Using Lines Defining Median Flood Mitigation Performance

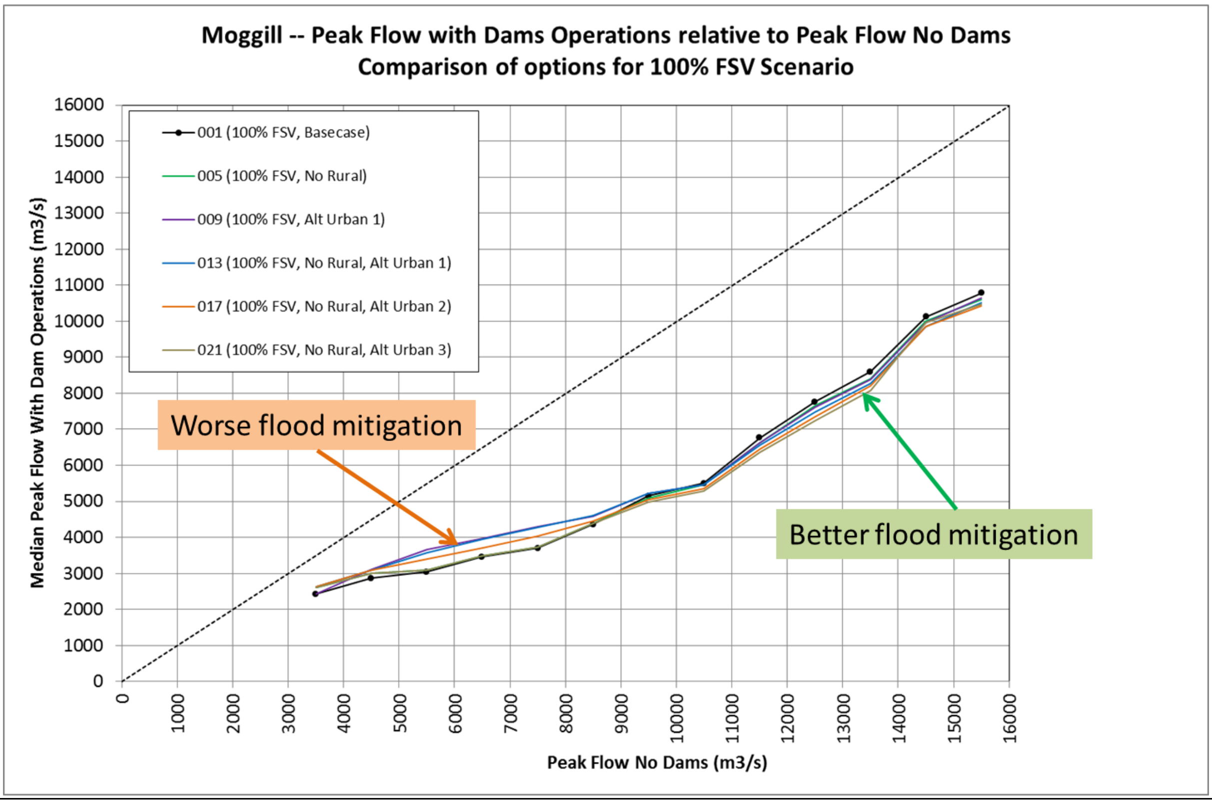


Figure 10 – Example of Relative Change Plot to Compare an Option against a Base Case

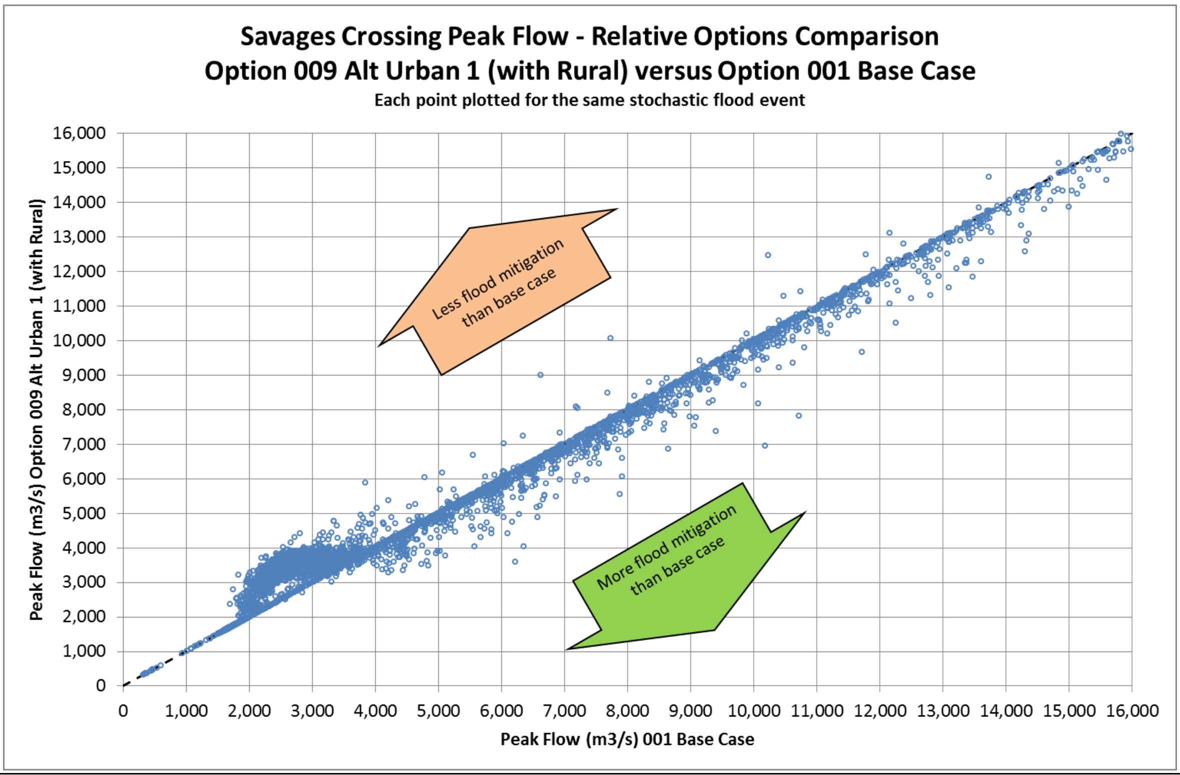
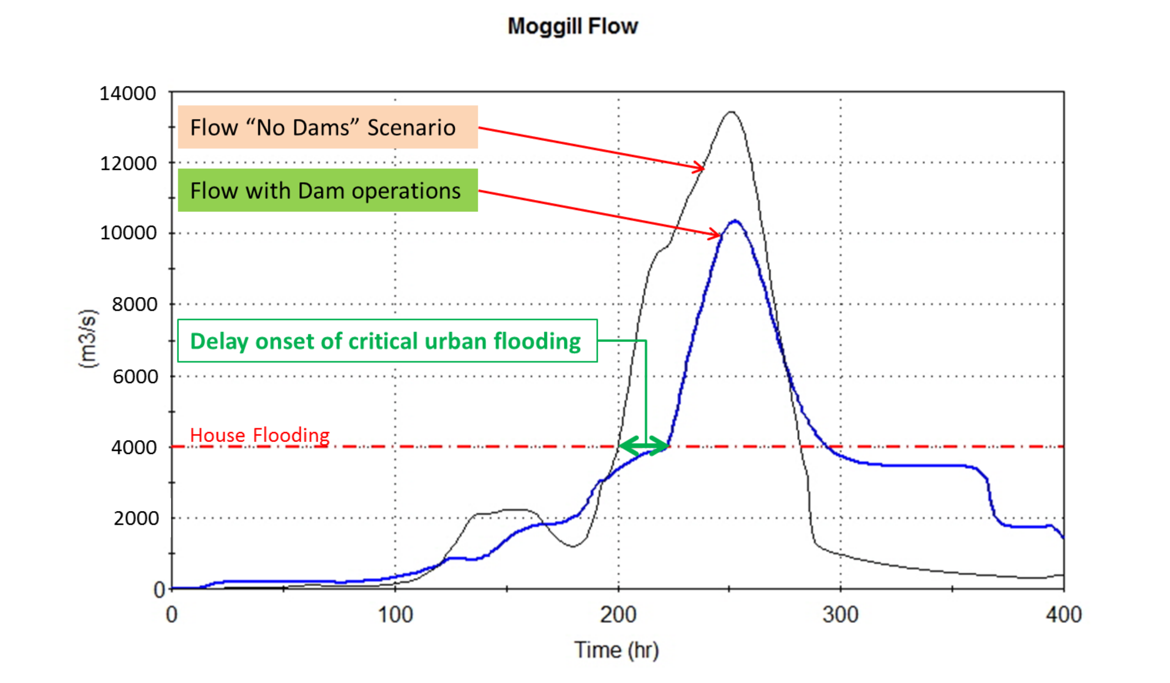


Figure 11 – Benefit of Dam Operations to Delay the Onset of Critical Flooding



Dam Safety Interests – Extreme Floods

Changing the flood operations of the dams will affect the way extreme floods pass through the dams. The interest for dam safety was to understand the potential impacts on extreme flood levels in the dams which may be of concern for potential risk of overtopping and catastrophic dam failure. Impacts on flood levels below the dam crest were also of interest for other potential failure modes.

Initial Extreme Flood Simulations

The initial approach to assess extreme floods was to simulate conventional deterministic PMF flood events and design AEP flood events. This initial approach was chosen to align to established methods for dam safety such as Queensland Acceptable Flood Capacity guidelines and ANCOLD guidelines for risk assessment.

It became evident after the initial extreme flood simulations that there appeared to be no detectable change in the probability of overtopping the dam for conventional design floods. This finding was not expected as a good understanding of the operations suggests that adverse impacts would occur for options that tend to store more flood water or decrease the storage reserved for the Dam Safety Strategy. The misleading finding was identified to be due to limitations of the idealised assumptions of conventional design floods. Specifically the extreme design floods all had rapidly increasing inflow at the start of the flood event and this caused early implementation of the Dam Safety Strategy in many of the flood simulations.

It was concluded that conventional design flood event hydrographs with uniform rainfall probability and temporal pattern on the entire catchment and without pre-burst rainfall are not well suited to define the hydrological risk to the safety of Wivenhoe Dam and Somerset Dam.

Stochastic Extreme Flood Simulations

To overcome the limitation of the conventional deterministic design floods, simulations were undertaken using the full suite of stochastic floods. The challenge was that the Annual Exceedance Probability of the stochastic floods was not easily definable.

Relative change plots for the Wivenhoe Dam peak level were useful to identify the effects of alternative flood operations. An example shown in Figure 12 for the operating option that would tend to store more floodwater was useful to identify that this option would have detrimental impact on the probability of breaching the fuse plug spillways and detectable adverse impact on the probability of overtopping the dam. Specifically for this option it was also identified that increased probability of peak flood levels at about 76 mAHD would be of concern for increased potential for piping failure of the Wivenhoe Saddle Dams.

The stochastic flood simulation results were also useful to gain a better understanding of the potential for failure of Somerset Dam to cause cascade failure of Wivenhoe Dam. The conventional design floods provide some indication of the possibility of cascade failure however the stochastic flood simulation results shown in Figure 13 provided a much clearer understanding of the potential for cascade failure.

Conclusions

There can be significant challenge to understand the full scope of adverse impacts and positive benefits for modifying flood operations of a gated flood mitigation dam. The task is more challenging with operating rules that consider downstream catchment flows and with realistic understanding that every flood is different due to variability of rainfall patterns. The comprehensive approach adopted for the Wivenhoe Somerset Dam Optimisation Study was found to be very useful to provide evidence based information to stakeholders to understand the implications of alternative flood operations.

The following conclusions were drawn from the study:

- As every flood is different, changing the flood operations will produce benefits for some floods and adverse impacts for other floods.
- Changing the flood operations would also produce better and worse outcomes at different locations for the same flood event.
- The dams with current operating rules provide substantial flood mitigation in many events.
- The dams have limited capacity for temporary storage of flood water, and significant urban inundation in major flood events will be inevitable.
- Flood mitigation performance is highly variable and depends on the unique characteristics of the flood event being mitigated. Different rainfall patterns are a significant influence on flood mitigation outcomes.
- Changing the flood operation rules would only produce minor improvements and these improvements are less significant than the variability of flood mitigation due to variability of rainfall patterns.
- The dams provide an important benefit to delay the onset of critical urban flooding. Changing the flood operations to apply higher early dam releases could diminish this benefit.
- Conventional design flood event hydrographs using uniform rainfall probability and temporal pattern on the entire catchment and without pre-burst rainfall are not well suited to define the hydrological risk to the safety of the flood mitigation dams.
- Numerous flood hydrographs generated from stochastically derived rainfall events with variable space-time patterns of rainfall were more useful to detect potential change in extreme flood levels. This was the only method that was able to differentiate the implications of different flood operations on the interests for dam safety.
- Stochastic flood simulations were particularly useful to gain a clearer understanding of the potential for cascade failure of the dams.

A more complete list of study conclusions is available in the overarching report prepared by the Department of Energy and Water Supply for the Wivenhoe Somerset Dam Optimisation Study (DEWS, 2014).

Figure 12 – Relative change plot for Wivenhoe Dam Peak Level

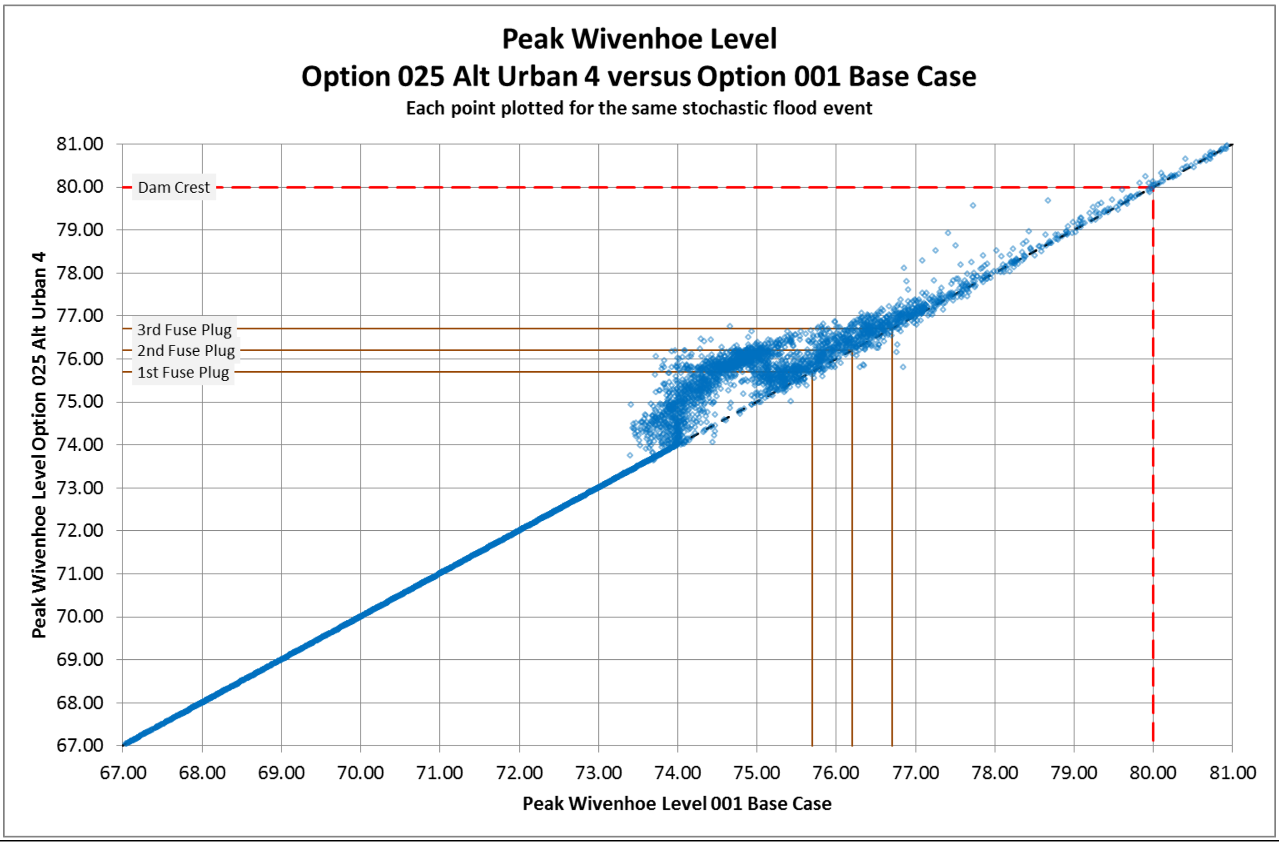
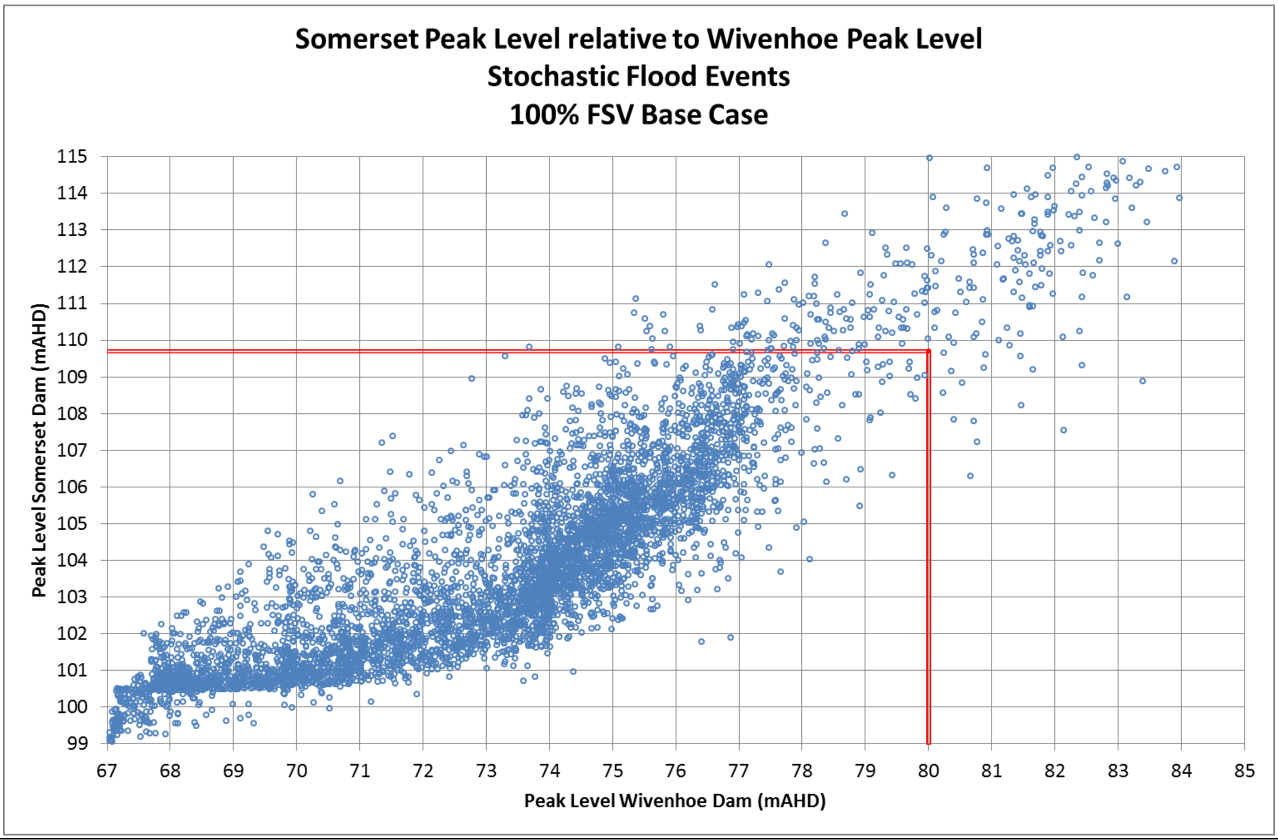


Figure 13 – Peak Somerset Dam Level relative to Peak Wivenhoe Dam Level



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