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Brisbane River Catchment Flood Studies: Hydrology Phase

Dam Operations Module Implementation Report

Prepared for the State of Queensland (acting through): Department of State Development, Infrastructure and Planning/Department of Natural Resources and Mines

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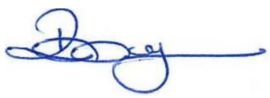
Author signature		Approver signature	
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Aurecon team

The Aurecon Team consists of Aurecon as lead consultant, supported by Deltares, Royal HaskoningDHV, and Don Carroll Project Management and Hydrobiology.

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1 Introduction

The Brisbane River Catchment Flood Study (BRCFS) – hydrology project requires a comprehensive hydrologic assessment to be conducted of the Brisbane River Catchment in accordance with Recommendation 2.2 of the Final Report of the Queensland Floods Commission of Inquiry. The project parties are Aurecon, the overall study client, Department of State Development, Infrastructure and Planning, with the Department of Natural Resources and Mines being the nominated Project Manager for this phase of the study. Aurecon will be assisted in the delivery of this project by sub-consultants Royal Haskoning DHV, Deltares and Don Carroll Project Management Pty Ltd. The project team will be referred to as 'Team Aurecon'.

In the BRCFS, frequency curves are derived for two conditions: 'No-dams conditions' and 'With-dams conditions'. For 'With-dams conditions', the following dams are considered:

- Wivenhoe
- Somerset
- Moogerah
- Lake Manchester
- Perseverance
- Cressbrook Creek

Moogerah, Lake Manchester, Perseverance and Cressbrook Dams are modelled in the URBS hydrological model as level pool storages with fixed crest spillway relationships. The storage representation and associated relationships are consistent with the description contained in the Brisbane River Flood Models, Seqwater (2013). No alterations have been made to the URBS model with respect to these four dams within the context of the BRCFS. The modelling of these four dams will therefore not be further discussed in this report, with the focus is on Somerset Dam and Wivenhoe Dam.

This report discusses the implementation of the Dam Operations Module within the real-time control software RTC tools as a component of the Delft-FEWS framework for use in assessing the 'With-dams conditions' design flood estimates associated with the Monte Carlo Simulation techniques of flood estimation. The report outlines the basis of the operating rules adopted for representing the dam operations, which reflects the latest *Manual of Operation Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam* Revision 11 (Seqwater, 2013).

The Dam Operations Module is based upon the Loss of Communications (LOC) emergency flood operation procedure described in the Flood Manual. The RTC Tools configuration of the model has been verified against Seqwater's Flood Operation Simulation Model (FOSM) and this benchmarking is described. The implications in adopting the LOC approach are discussed in view of the use of the 'With-dams conditions' flood estimates for subsequent phases of the Brisbane River Catchment Flood Study. The report also notes that there is likely to be a revision of the way in which the dams are operated as a consequence of the ongoing public consultation process being conducted by the Department of Energy and Water Supply.

2 Flood manual

2.1 Introduction

Somerset Dam and Wivenhoe Dam are operated in accordance with procedures outlined in the *Manual of Operation Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam* Revision 11 (Seqwater, 2013). The dams are multi-purpose storages that provide urban water supplies (including drinking water) to South East Queensland, as well as flood mitigation benefits to areas below Wivenhoe Dam potentially impacted by flood flows along the Brisbane River and its tributaries.

Under normal circumstances the operation of the dams is directed by a Senior Flood Engineer who has access to real time hydrometric data from the entire Brisbane River basin. Decisions made on releasing flood water from the dams during flood events takes into consideration rainfall falling both within and downstream of the dam catchment areas.

Maximum overall flood mitigation can be achieved by operating Wivenhoe Dam in conjunction with Somerset Dam.

The capacity of the urban water supply compartment that relates to Wivenhoe Dam's Full Supply Level (FSL) is 1,165,000 ML. The dam can also store up to a maximum of 1,967,000 ML as temporary flood storage up to EL 80.0 m. Flood releases are made through the main gated spillway, (which contains five radial gates), and also an auxiliary spillway that consists of a three bay fuse plug embankment. The radial gates should be fully open prior to the initiation of the first fuse plug embankment.

For Somerset Dam, the capacity of the urban water supply compartment related to its FSL is 380,000 ML, with 721,000 ML volume available for use for temporary flood storage up to EL 109.7 m. Somerset Dam is equipped with four regulator cone dispersion valves, eight sluice gates and eight sector gates. During flood operations the eight sector gates are fully opened to allow free overflow over the spillway prior to the onset of the flood. The regulator valves are generally not used for flood releases as elevated tailwater levels tend to impair the performance of the valves. Therefore the eight sluice gates and the spillway flows are the main flood release mechanisms for Somerset Dam during a flood event.

Decisions on the flood operation of the dam are made having regard to the flood objectives specified in the Flood Manual. These objectives specified in the Flood Manual are reported in the following sections for completeness.

2.2 Flood operation objectives

The primary objectives of the operational strategies specified in the Flood Manual, listed in descending order of importance, are 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
- Minimise impacts to riparian flora and fauna during the drain down phase of the Flood Event

2.2.1 Structural safety of dams

The structural safety of the dams is the primary consideration in the operation of the dams during Flood Events.

Wivenhoe Dam

The structural safety of Wivenhoe Dam is of paramount importance. Structural failure of Wivenhoe Dam could have catastrophic consequences. Wivenhoe Dam is predominantly a central core rockfill dam. Such dams are not resistant to overtopping and are susceptible to breaching should such an event occur. Overtopping is considered a major threat to the security of Wivenhoe Dam. Wivenhoe Dam is overtopped by an event with a 1 in 100,000 AEP, when the Lake Level reaches EL 80.0 m, Wivenhoe Alliance Design Report (2004).

Somerset Dam

The structural safety of Somerset Dam also is of paramount importance. Failure of Somerset Dam could have catastrophic consequences as it may also cause Wivenhoe Dam to fail due to the cascading effect of the flood wave produced when Somerset Dam fails. Whilst Wivenhoe Dam has the capacity to mitigate the flood effects of such a failure in the absence of any other flooding, if the failure were to occur during major flooding, Wivenhoe Dam could be overtopped and destroyed also.

Somerset Dam is a mass concrete Dam. Such dams can withstand *limited* overtopping without damage. Stability calculations have indicated that Somerset Dam can safely withstand being overtopped to a Lake Level of at least EL 109.7 m AHD, provided all crest gates are fully open. With all crest gates fully open, Lake Levels in Somerset Dam in excess of EL 109.7 m AHD could cause a Dam failure that may occur suddenly and without warning, creating very severe and destructive flood waves. The AEP of an event that could cause this situation to arise is estimated to be about 1 in 100,000, Seqwater, (2009).

Extreme floods and closely spaced large floods

Recent estimates of Design Flood Events suggest that both dams are at risk of overtopping (Somerset Dam is expected to be able handle *limited* overtopping). Protracted overtopping could result in the destruction of the dams. Such events however require several days of extremely intense rainfall to produce the necessary run-off.

Historical records show that there is a significant probability of two or more flood producing rain systems occurring in the Brisbane River basin within a short time of each other. Therefore, the flood operation procedures require that the dams be drained within a specified period (usually seven days), whilst minimising the impact on rural and urban areas and riparian flora and fauna.

2.2.2 Optimum protection of urbanised areas from inundation

Once the objective to ensure the structural safety of the dams is satisfied, the second objective is to reduce flooding in the urban areas of the flood plains below Wivenhoe Dam. The objective is to ensure, as far as practicable, that the flow at Moggill does not exceed 4,000 m^3/s. Moggill is just downstream of where the last major tributary, the Bremer River, joins the Brisbane River. Accordingly, the flow at Moggill represents the aggregate of flows from the Lockyer Creek, the Bremer River, controlled releases from Wivenhoe Dam and the local area between these locations.

The Flood Manual adopts a flow of 4,000 m^3/s at Moggill as the target upper aggregate flow limit, even though some flood Damage will occur in the urban areas below Moggill as a result of a flow rate of less than 4,000 m^3/s at that location.

As a large part of the Brisbane River basin is below Wivenhoe Dam, consideration must always be given to downstream inflows when releasing floodwaters from the dams.

2.2.3 Disruption to rural areas

Inundation of various bridges located in the Brisbane Valley can cause isolation and inconvenience to residents in the Brisbane Valley.

While the dams are being used for flood mitigation purposes, bridges and areas upstream of the dams may be temporarily inundated. Downstream of Wivenhoe Dam, bridges and adjacent low level flood plains may be submerged. This includes inundation of the Brisbane Valley Highway at Fernvale Bridge.

Disruption to navigation in the Brisbane River can also be taken into account when considering disruption to rural areas downstream of Wivenhoe Dam. This disruption is normally associated with high flood debris loads in the Brisbane River. In most circumstances, this consideration is secondary to considerations associated with limiting bridge inundation.

2.2.4 Retention of FSL at conclusion of flood event

As the dams are a major urban water supply for South East Queensland, it is important that all opportunities to fill the dams are taken.

There should be no reason why each of the dams should not be near its FSL following a Flood Event. However, it is permissible for the dams to be drained below FSL before final gate closure where it is judged likely that continued base flow will return the Lake Level to near FSL following gate closure.

2.2.5 Minimising Impact on riparian flora and fauna

Near the conclusion of a flood event, consideration is to be given to minimising the impacts on riparian flora and fauna. In particular, strategies aimed at minimising harm to fish populations in the vicinity of the dams' structures are to be instigated, provided such procedures do not adversely impact on other flood mitigation objectives.

Additionally, consideration should also be given to reducing potential bank slumping. Rapid draw down of stream levels where banks are saturated should be avoided if this can be managed within the other flood mitigation objectives. In most circumstances, gate closure sequences should aim to mimic the natural flood recession that would have occurred had the dams not been constructed.

2.3 Operational strategies

There are four strategies for the operation of Wivenhoe Dam and two strategies for Somerset Dam. All of the strategies are based on the flood objectives set out above. Each strategy is based on a single primary objective, but lower level objectives under each strategy's primary objective can be considered when making decisions under a particular strategy. However, the primary objective must always be satisfied.

The strategies for Wivenhoe Dam are:

- Rural (WR) with a focus on minimising disruption to rural life whilst limiting inundation to urban areas and protecting the safety of the dam
- Urban (WU) with a focus on limiting inundation of urban areas while protecting the safety of the dam
- Safety (WS) with a focus on protecting the safety of the dam
- Drain Down (DD) with a focus on draining both dams to FSL within seven days while minimising impacts on rural and urban areas and riparian flora and fauna

The strategies for Somerset Dam are:

- Flood (SS) with a focus on protecting the safety of both dams while aiming to make the best use of the Dams combined storage volume to mitigate flooding downstream of Wivenhoe Dam
- Drain Down (DD) with a focus on draining both dams to FSL within seven days while minimising impacts on rural and urban areas and riparian flora and fauna

The Flood Manual outlines how each of the strategies is implemented under normal circumstances. The decision making process involves the use of engineering judgement in determining the strategy to be applied and this is based on assessing a comparatively reliable prediction based on rain which has already fallen and a number of predictions based on the rainfall forecasts. The interpretation of the actual and predicted lake levels, downstream flows and required release rates forms the basis of the release plan that is implemented by the Flood Engineer.

2.4 Emergency flood operations

The Flood Manual also contains emergency flood operation procedures (section 7) for Wivenhoe Dam and Somerset Dam as a fall-back or redundancy option in the event of a dam safety emergency at either Dam, such as when communications are lost between the Dam Supervisors and the Flood Engineer directing operations.

In the event of communications loss between the Flood Operations Centre and Wivenhoe Dam or Somerset Dam, the Dam Supervisor at each dam is to assume responsibility for flood releases from the Dam. Once it has been established that communications have been lost, the Dam Supervisor at Wivenhoe Dam or Somerset Dam follows the emergency flood procedures outlined in the Flood Manual.

2.4.1 Wivenhoe Dam

If communications with the Flood Operations Centre are lost, appropriate radial gate openings at Wivenhoe Dam are determined by following the radial gate operating sequence as set out in Table 7.3.1 of the Flood Manual (Table A.1, appendix A, of the current report). This table provides a listing of the minimum gate setting required for a given lake level. Therefore the Dam Supervisor operates the Dam on the basis of the only information that is likely to be available to them (headwater level), and no regard is made to downstream flows.

Where one or more fuse plugs in the auxiliary spillway have been eroded, the relevant table contained in Appendix F of the Flood Manual (Tables A2-A4, appendix A, of the current report) is to be substituted for Table 7.3.1.

There are limits on the time interval between the successive opening and closure of the gates as specified in Table 7.3.2 of the Flood Manual. Care must also be taken to ensure that the gates are not overtopped and as a consequence, Table 7.3.3 provides an indication of the minimum gate setting required for various lake levels.

2.4.2 Somerset Dam

The Dam Supervisor at Somerset Dam is in the position of knowing what the lake level is for both Somerset Dam and Wivenhoe Dam as they have access to the level of Wivenhoe Dam downstream of Somerset Dam. Therefore, the decision making process at Somerset Dam takes into consideration the behaviour in Lake Wivenhoe. This is done by reference to Figure 7.3.1 of the Flood Manual which is commonly referred to as the *'interaction diagram'* refer to Figure 2-1.

The interaction diagram is graph that allows the lake level at Somerset Dam to be plotted against the lake level at Wivenhoe Dam at a corresponding time. The diagram is divided into four Zones delineated by the relative levels in each of the dams by an 'Operating Target Line'. The diagram is used to determine what action is required in relation to the opening and closing of sluice gates at Somerset Dam. The diagram is used to decide if more floodwater should be stored in Somerset Dam or if the floodwater should be released into Wivenhoe Dam. The Target Operating Line is used to balance the level in both dams thereby ensuring that each dam is used to its maximum effect to achieve mitigation of the flood event.

Table 7.3.4 of the Flood Manual specifies the maximum number of sluice gates allowed to be opened for various lake levels. Limits on the time between successive gate openings or closures vary depending upon the Zone on the interaction diagram.

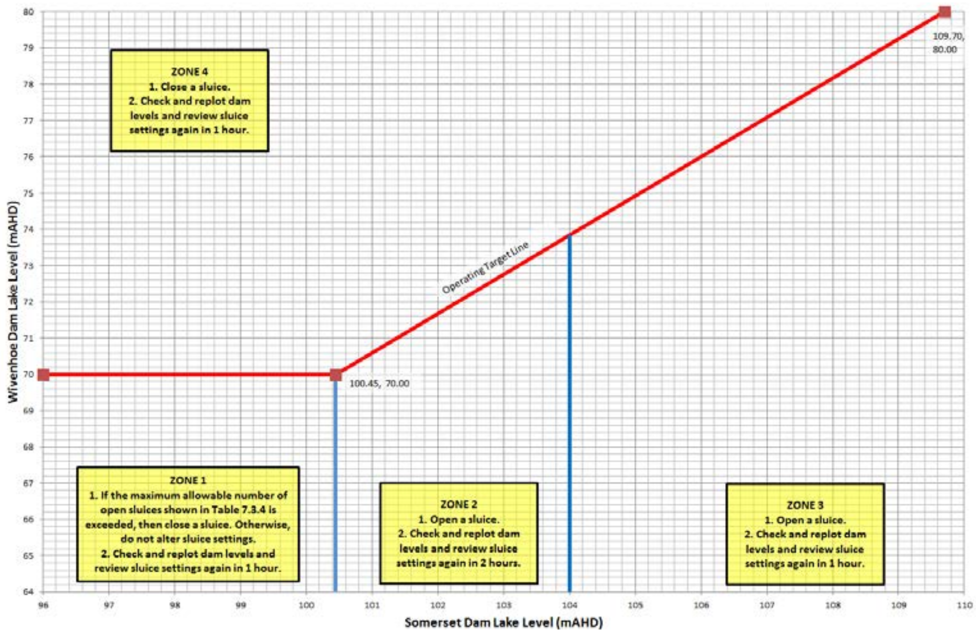


Figure 2-1 Somerset Dam loss of communications procedure

3 Wivenhoe and Somerset Dam optimisation study

3.1 Flood operations simulation model

The State of Queensland initiated a comprehensive review of the operation of the flood mitigation dams located in southeast Queensland as part of the Wivenhoe and Somerset Dam Optimisation Study (WSDOS), (DEWS 2014). A Dam operations model (referred to as Flood Operations Simulation Model, FOSM) was developed by Seqwater (2014), to perform stochastic simulations of the Wivenhoe and Somerset Dam flood operations for thousands of synthetic flood events and allow the complex interaction between dam operations, flood release and downstream catchment flows to be examined. As part of this process, the dam operations model which was developed using Goldsim®, was used to represent the application of the strategies outlined in the Flood Manual and for a range of alternate operating scenarios.

Important points to note about the representation of the flood operations implemented in the FOSM include:

- Dam release decisions as Flood Engineers would apply, with limited foresight of how the flood will develop in time ahead (This is a fundamental model assumption based on operational experience)
- Inputs into the model are flood event hydrographs at specified Locations and “parameters” for operating the dams (as defined by the Flood Manual)
- Outputs from the model are flood flows at downstream Locations and levels in the dams

FOSM is based upon the following concepts:

- Dam routing uses level pooling routing
- Downstream river routing replicates hydrologic (URBS) model
  - Conceptual Muskingum channel routing combined with conceptual flood plain storage as S-Q relationships
- Estimated flood level at Ipswich replicates hydrologic (URBS) model dependant rating
  - Ipswich level depends on Bremer River catchment flow and level in Brisbane River at Moggill

FOSM uses inputs from the following catchments:

- Stanley River to Somerset Dam
- Upper Brisbane River to Wivenhoe Dam (excluding Somerset Dam)
- Lockyer Creek to O’Reillys Weir
- Bremer River to Ipswich

- 6 Local catchments situated between Wivenhoe Dam and Moggill
  - Local Area to Brisbane Valley Highway
  - Local Area to Savages Crossing
  - Local Area to Burtons Bridge
  - Local Area to Mount Crosby Weir
  - Local Area to Moggill
  - Local Area for Lower Bremer

Figure 3-1 shows the Location of the main inputs into the FOSM.

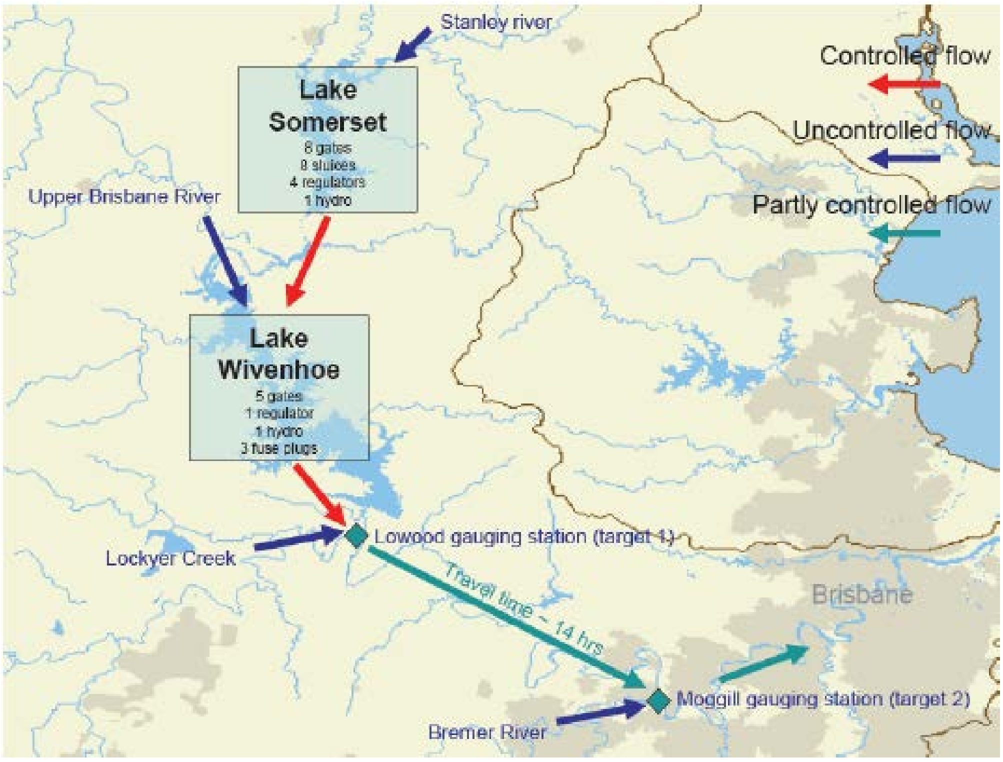


Figure 3-1 Schematic of the location of Wivenhoe and Somerset Dams

Decisions for Dam releases included in FOSM are based upon the following process which is outlined in the Flood Manual:

- Select Strategy
- Prepare Release Plan
- Predict Dam level
- Confirm Operational Procedure criteria and Strategy
  - If Predicted Wivenhoe Dam level too high: revise Release Plan, or change Strategy Selection
- Requires an estimate of flow from downstream catchments and upstream inflows into the dams
  - Realistic limits of foresight, (as would be predicted with reliable data available at the decision time)
  - Represented as a “flood evolution” concept

Key assumptions included in the FOSM include:

- Rural Strategy: prudent to use low gate open and close intervals early in flood events when flow are relatively small
  - Assumed maximum rate of 0.5 m/hour (one gate increment per hour)
- Urban Strategy: maximum gate opening and closing intervals as per Flood Manual
- Dam Safety Strategy: no limits in Flood Manual for gate opening and closing intervals
  - Assumed maximum rate of 10 m/hour (20 gate increments per hour)
- Predictions of Wivenhoe Dam level response to Release Plan to check implementation of Strategy:
  - Forecast horizon 24 hours for most decisions
  - Forecast horizon 48 hours for trigger to exclude consideration of the higher bridges in Urban Strategy
- Drain down Strategy starts after the ‘peak’ of the event which is characterised as follows:
  - Notional ‘trigger’ to commence drain down nominally 12 hours after peak dam inflow and peak dam level has fallen 0.1 m
  - In real flood operations, significant professional judgement is required to select appropriate start time for drain down
- Drain down Release Plan assumes full foresight knowledge of flood hydrographs in 7 days ahead

FOSM was validated against a range of historic flood events, including the events of February 1999, October 2010, January 2011 and January 2013, assuming these events were operated in accordance with the latest Flood Manual.

As a result of the validation of FOSM, Seqwater noted that the downstream results are considered to be:

- +/- 10% accuracy for peak flows in Brisbane River
- +/- 1 m accuracy for peak level at Ipswich

WSDOS considers the relative comparison of options and hence subtle changes that are less than the observed tolerances above can still be identified. It should be recognised that a flow rate of 16,000 m^3/s is a reasonable upper limit of downstream flow results due to the uncertainty of downstream floodplain routing representation. This was a function of the underlying hydrologic model calibration constraints, Seqwater (2013).

In addition to the normal operations model, Seqwater also established a version of the FOSM that depicts the implementation of the Loss of Communications (LOC) procedure.

3.2 Comparison between normal operation and LOC

Seqwater have produced a comparison of the performance of the Loss of Communications (LOC) flood operations procedure and against the normal current operating procedure as represented in the FOSM. This case was referenced as Base Case 100% Full Supply Volume (FSV) in WSDOS.

The LOC procedure was tested against the same range of flood events used in the WSDOS assessment (Seqwater, 2014). These events include:

- Large historical flood events from the last 125 years comprising 1887, 1890, 1893,1898, 1908, 1931, 1959, 1971, 1973, 1974, 1983, 1989, 1996, 1999, 2011 and 2013
- Almost 4,000 stochastically generated synthetic floods

A comparison between peak outflow from Wivenhoe Dam and associated peak lake level for the range of stochastic floods illustrates the form of the outflow relationship adopted for the LOC procedure. This is shown in Figure 3-2.

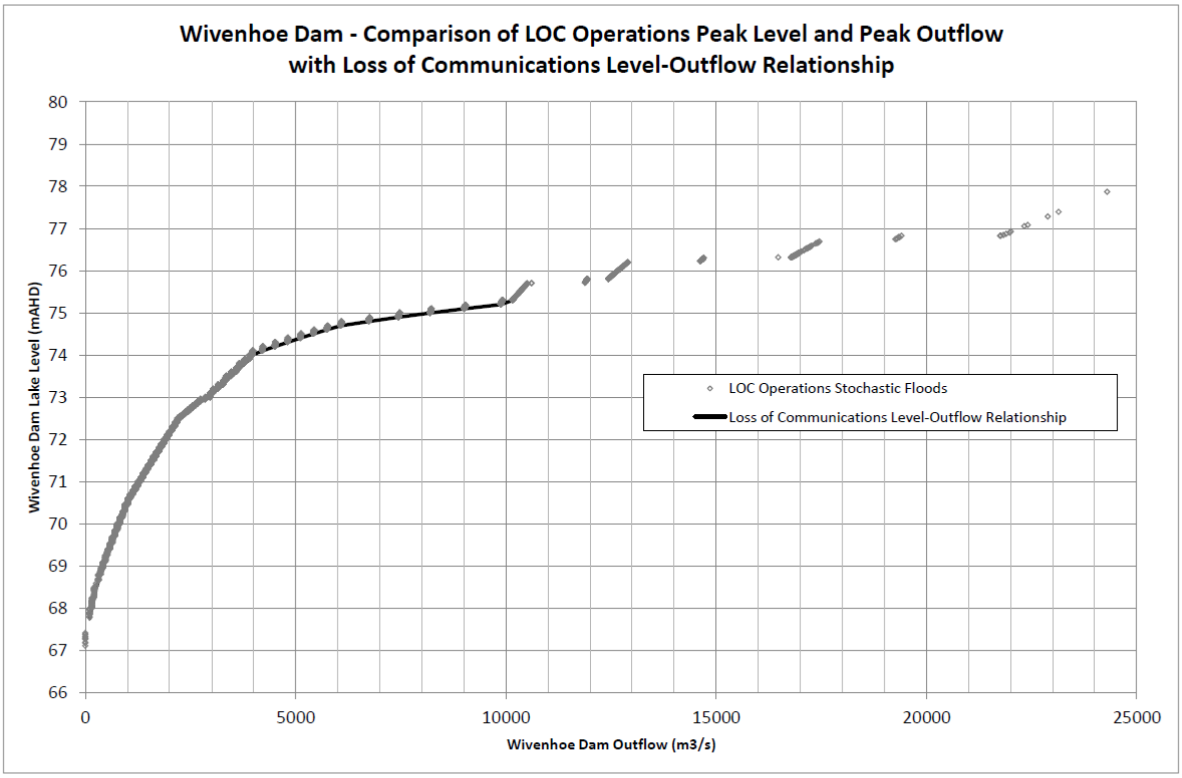


Figure 3-2 Wivenhoe Dam LOC relationship

It should be noted that the Base Case 100% FSV approach and the LOC approach tend to converge once the Dam Safety Strategy threshold of EL74.0 m AHD is exceeded. Therefore the relationship shown is similar for both cases in the range of lake levels (EL74.0 m AHD to EL75.7 m AHD) that lead to the initiation of the three fuse plug embankments.

Figure 3-3 shows the comparison between peak lake levels in Wivenhoe Dam for the range of stochastic flood events. This plot emphasizes that below a lake level of EL69.0 m AHD, the LOC approach tends to result in higher lake levels (up to +2 m higher), whereas between EL69.0 m AHD and EL74.0 m AHD the LOC approach results in peak lake levels that are within -2 m and +2 m of the Base Case 100% FSV approach. Beyond EL74.0 m AHD the peak levels tend to converge to be similar, with the LOC approach providing slightly lower peak lake levels.

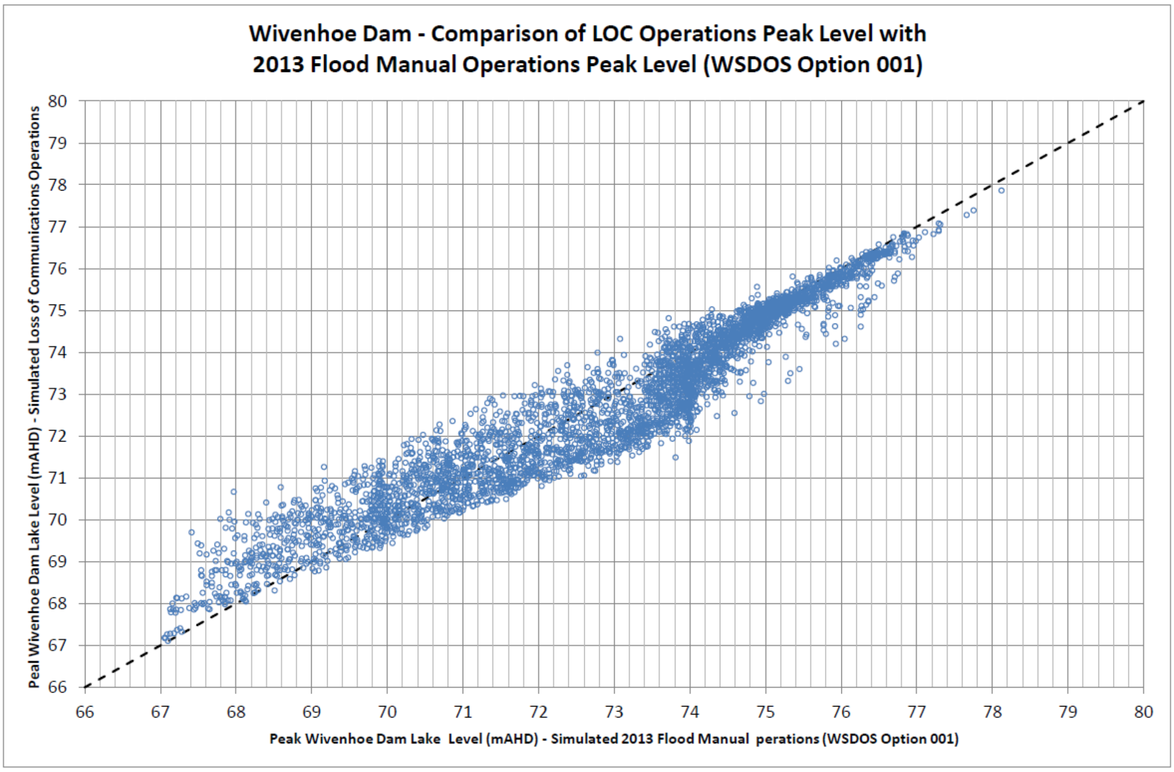
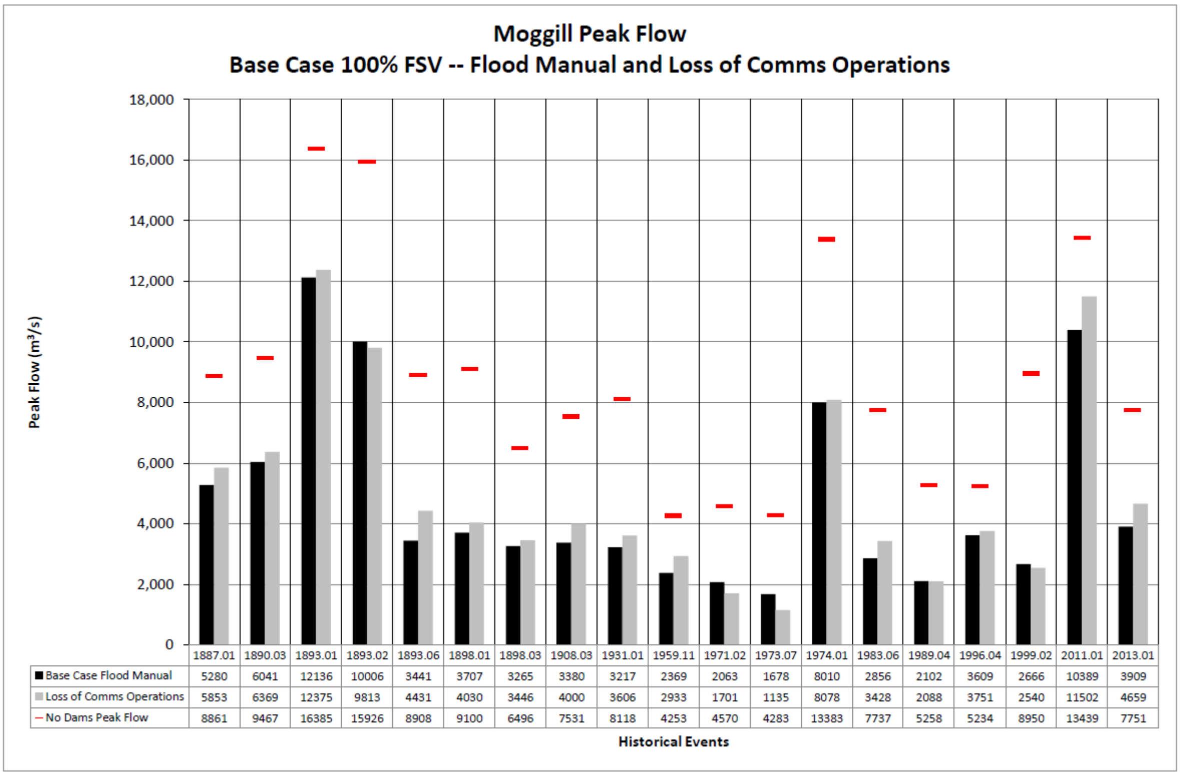


Figure 3-3 Comparison of peak lake levels in Wivenhoe Dam: Base case 100% FSV and LOC

The comparison of the performance of the LOC procedure against the Base Case 100% FSV for the range of historic flood events is shown in Figure 3-4, Figure 3-5 and Figure 3-6.

Figure 3-4 shows a comparison of the peak flow at Moggill for both the Base Case 100% FSV and LOC approaches, and it also provides an indication of the 'No-dams conditions' estimate for each of the twenty historic floods. As can be seen from this comparison, the LOC approach generally (14 out of 20 events) results in a slightly higher peak flow at Moggill than the normal flood operations approach. The percentage increase in peak flows is in the order of between 5 and 10% overall, but it obviously worse for some events such as June 1893, November 1959, January 2011 and January 2013.

Both approaches show the degree of mitigation that is achieved by the operation of the dams is between 20 and 70% for the events considered. This degree of mitigation reflects both the effects of antecedent conditions for particular events (ie February 1999) and the nature of the flood event and where the rainfall falls (ie upstream or downstream of the dam). Obviously for those events were the rain falls predominately downstream of the dam, the mode of operation of the dam will have a reduced influence on the peak flow at Moggill.



	1887.01	1890.03	1893.01	1893.02	1893.06	1898.01	1898.03	1908.03	1931.01	1959.11	1971.02	1973.07	1974.01	1983.06	1989.04	1996.04	1999.02	2011.01	2013.01
Base Case Flood Manual	5280	6041	12136	10006	3441	3707	3265	3380	3217	2369	2063	1678	8010	2856	2102	3609	2666	10389	3909
Loss of Comms Operations	5853	6369	12375	9813	4431	4030	3446	4000	3606	2933	1701	1135	8078	3428	2088	3751	2540	11502	4659
No Dams Peak Flow	8861	9467	16385	15926	8908	9100	6496	7531	8118	4253	4570	4283	13383	7737	5258	5234	8950	13439	7751

Figure 3-4 Comparison of peak flow at Moggill, historic flood events: Base case 100% FSV and LOC

Figure 3-5 shows the peak flow at Savages Crossing and this reflects a similar trend to that shown in Figure 3-4 for Moggill, although the difference in mitigation between the Base Case 100% FSV and the LOC approach is slightly more pronounced due to the fact that only the Lockyer Creek flows influence the peaks at Savages Crossing and hence the releases from Wivenhoe Dam are more prominent.

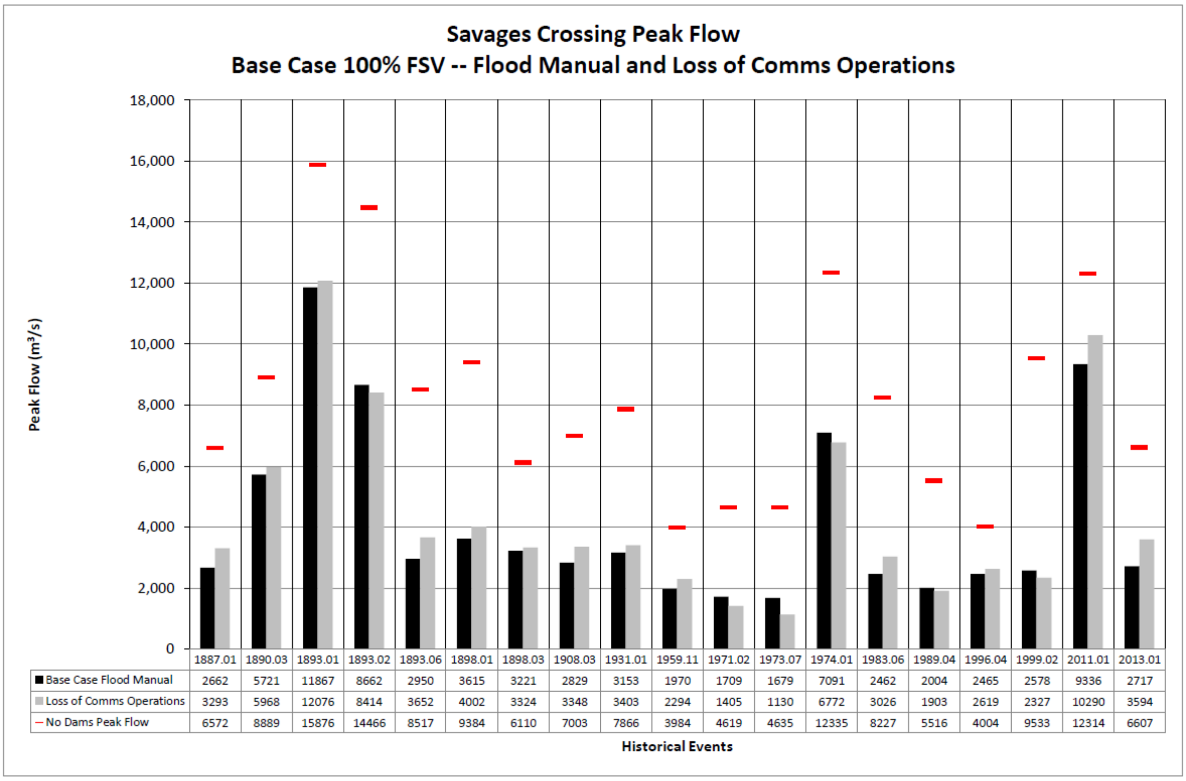


Figure 3-5 Comparison of peak flows at Savages crossing: Base case 100% FSV and LOC

Figure 3-6 shows the comparison of peak levels at Ipswich. The maximum differences between the Base Case 100% FSV and the LOC approach is +1.2 m for the June 1893 event and -1.2 m for the July 1973 event, but most events are generally shown to be within 0.5 m of each other. The difference in levels is driven by the relative timing of the peak flows at the confluence of the Brisbane River and Bremer River. In general, the LOC approach tends to release more flood water earlier in the event compared to the Base Case 100% FSV. The average travel time from Wivenhoe Dam to Moggill is estimated to be approximately 16 hours, although this varies depending upon the magnitude of the event.

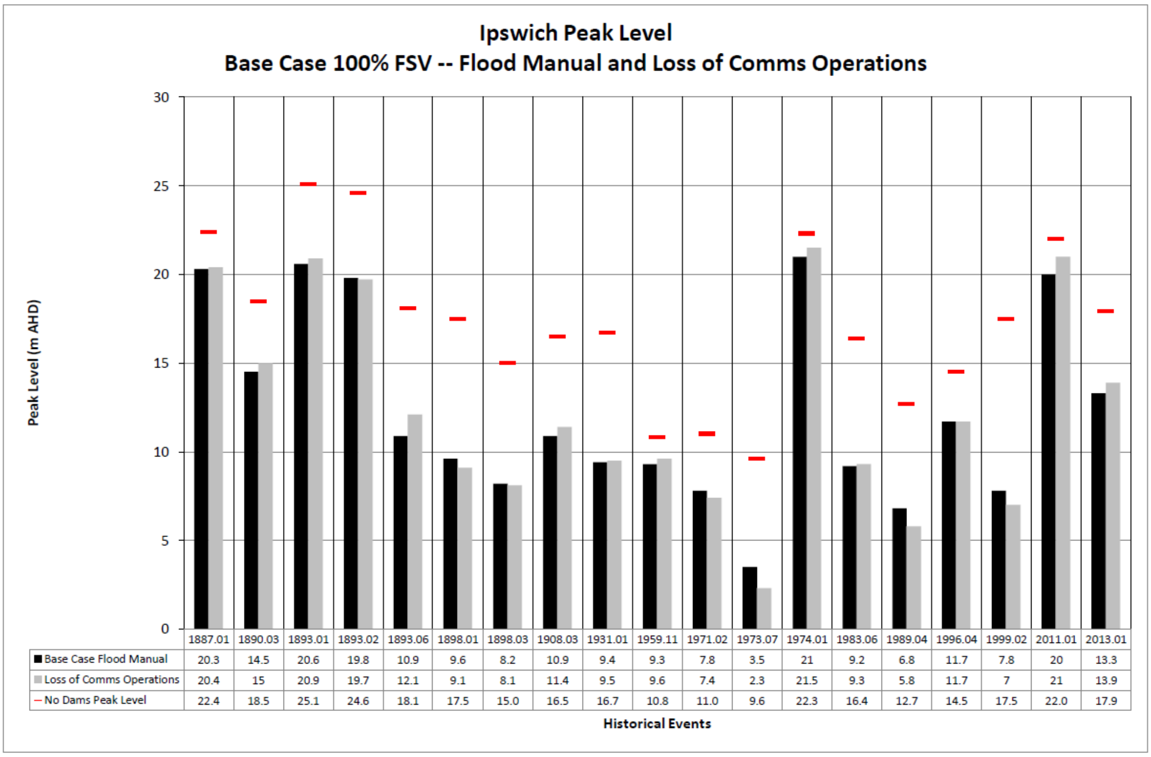


Figure 3-6 Comparison of peak levels at Ipswich: Base case 100% FSV and LOC

In terms of the comparison of the Base Case 100% FSV to the LOC approach using the stochastic flood events, Figure 3-6 shows a comparison of the peak flow at Moggill for the full range of events.

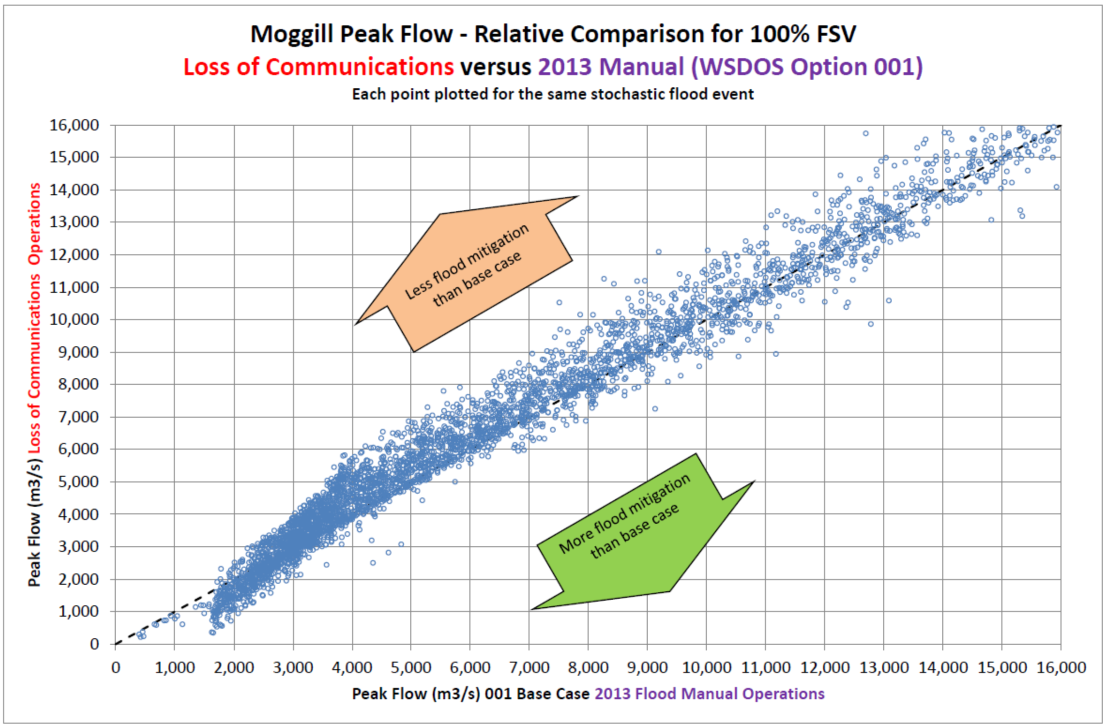


Figure 3-7 Comparison of peak flow at Moggill, stochastic flood events: Base case 100% and LOC

As can be seen on this plot, the LOC approach tends to provide less mitigation than the Base Case 100% FSV approach, especially for flows above about 2,500 m^3/s. Again there is a degree of variation in the events based upon the nature of the event in terms of predominate location of the rainfall (upstream or downstream of the dams).

4 RTC implementation

4.1 Introduction

This section provides an outline of the implementation of Wivenhoe and Somerset Dams in the Brisbane River Catchment Flood Study. The Deltares software 'RTC Tools' has been used in order to simulate the dam operations procedure known as the 'Loss of Communications (LOC)' scenario. The reason to implement the LOC scenario instead of the regular dam operation strategy is the fact that the latter is relatively complex to implement especially in a Monte Carlo Simulation framework. The computational burden of numerous iterations for each event simulation was considered a significant impediment to inclusion within a Monte Carlo framework. Bearing in mind that:

- The project has a tight time schedule
- The purpose of this study is for floodplain management (ie not operational management of the dams)
- The implementation of the LOC was preferred

The LOC schematization is based on the Manual of Operation Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam (Seqwater, 2013). RTC-Tools is an open source, modular toolbox dedicated to real-time control (RTC) of hydraulic structures like weirs, pumps, hydro turbines, water intakes, etc. It can be used standalone or in combination with hydraulic models for general modelling studies as decision support component in operational forecasting and decision-support systems.

4.2 General set-up

Somerset Dam and Wivenhoe Dam have an independent operation during the "Loss of Communications operation strategy", but they are in a dependent system. Somerset Dam and Wivenhoe Dam will therefore be modelled in a joined RTC model, to prevent an iterative process between separate models at each time step. As the 'Loss of Communications' scenario for the Dam operations requires control time steps of 15 minutes (in case of Wivenhoe Dam), the RTC-Tools model is set up and run with 15 minute model time step. The main output, Wivenhoe Dam releases are provided as 1 hour time series. This series is used as the upstream boundary for URBS model runs for the Lower Brisbane River reach downstream of Wivenhoe Dam.

4.3 Wivenhoe Dam

The target release of Wivenhoe Dam is based on Wivenhoe Dam headwater levels only. Headwater levels are determined by inflow and release rates. Inflow into and outflow from the Wivenhoe Dam reservoir will result in level changes of Wivenhoe Dam. The Level-Volume relation for Wivenhoe Dam is taken from the Wivenhoe Technical Data, as described in Appendix E of the Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam (Seqwater, 2013).

Wivenhoe Dam has two relevant inflows:

1. The unregulated inflow from the Upper Brisbane River, as simulated with the URBS hydrological model
2. The releases from Somerset Dam, as determined from the RTC model of Somerset Dam

As release rates influence the lake level and the lake level influences target outflow rates, the control actions are determined at each time step, based on the situation in the previous time step and taking into account any constraints that may apply. The current implementation of rating curves (level versus total outflow) for the main gated spillway Wivenhoe Dam flow, as well as for the situation of fuse plug breaches is based on the available tables in the Flood Manual (Table 7.3.1 and Appendix F of Seqwater, 2013). For the sake of completeness, these tables are also shown in Appendix A of the current report. For practical purposes, the individual (radial) gates of Wivenhoe Dam are not modelled in the RTC model. However, constraints related to the successive gate operations (opening and closing) are taken into account in the form of lookup tables. Table 4-1 presents a snapshot of the resulting rating table as an example.

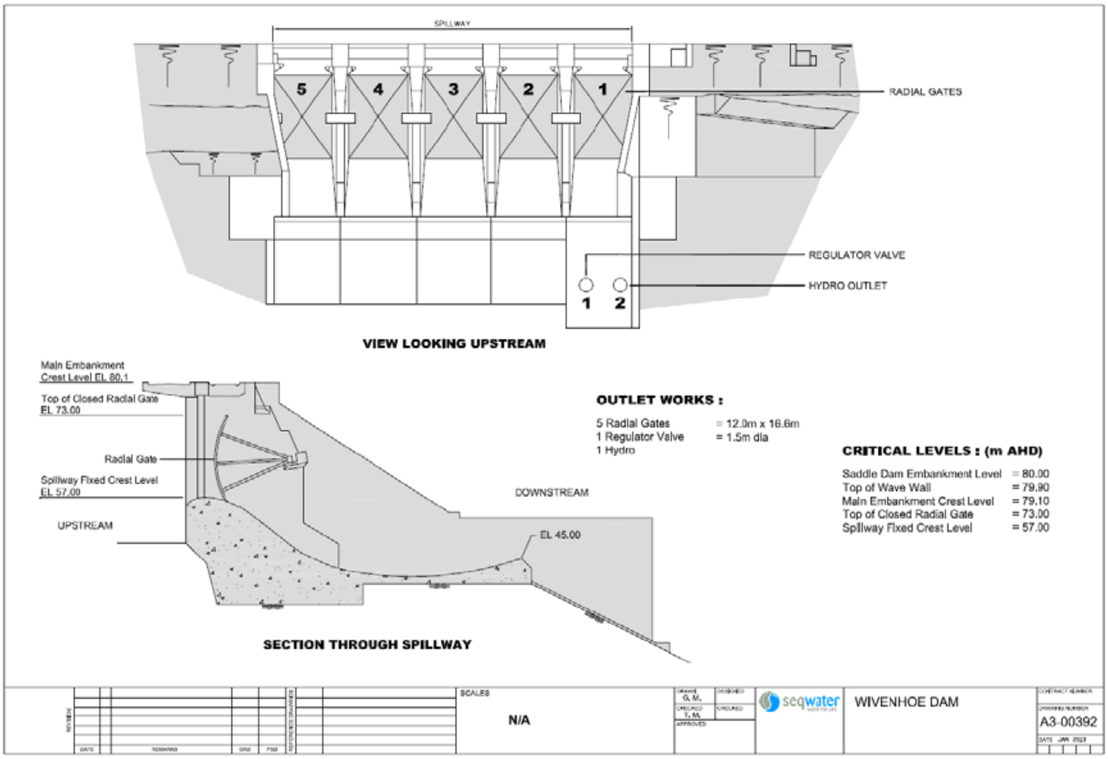


Figure 4-1 Schematic view of Wivenhoe Dam

Table 4-1 Example of rating table for Wivenhoe Dam releases

Wivenhoe Dam lake level (m+AHD)	Release (m^3/s)			
	0 fuse plugs breached	1 fuse plug breached	2 fuse plugs breached	3 fuse plugs breached
72.65	2430	2503	3283	5153
72.7	2490	2542	3353	5247
72.75	2550	2580	3423	5342
72.8	2610	2621	3492	5436
72.85	2670	2663	3562	5530
72.9	2740	2704	3632	5625

The approach of using combined lookup tables instead of individual gate modelling is sufficient to mimic the Wivenhoe Dam outflow dynamics according to the LOC approach. This has been tested extensively in close cooperation with Seqwater (see section 5).

The discharge increment value (per control time step) is used as a rate of change constraint for the combination of Wivenhoe Dam radial gates. For lake levels below EL74.0 m AHD, a limit of 6 increments per hour, or 3 m/hour, (1 increment = 0.5 m) is taken as the constraint in case the water level is rising and a limit of 3 increments per hour, or 1.5 m/hour, is taken as the constraint in case the water level is falling. For lake levels above EL74.0 m AHD there is no formal constraint, but a limit of 20 increments per hour (10 m/hour) is considered reasonable (Michel Raymond, Seqwater, pers. comm.).

Crest overtopping can also occur, which is modelled as a sharp crested weir for the main dam (dimensions: 2000 m effective weir length, crest level EL80.1 m AHD, weir coefficient 1.7) and a broad crested weir for the saddle dams (dimensions: 580 m combined effective weir length, crest level 80.0 m AHD, weir coefficient 1.4).

It is assumed that Wivenhoe Dam will not fail if it is overtopped and therefore dam failure will not be modelled. In reality, as stated earlier, overtopping is considered a major threat to the security of Wivenhoe Dam. Wivenhoe Dam is overtopped by an event with a 1 in 100,000 AEP, when the Lake Level reaches EL 80.0 m. However, the process of dam breaching and subsequent flooding downstream is out of the scope of the BRCFS project and therefore the dam is assumed not breach under any circumstance. Events that do result in Lake levels in excess of the dam crest will be identified.

4.4 Somerset Dam

The decision to determine which control action to take at Somerset Dam is dependent on the headwater levels of both Wivenhoe Dam and Somerset Dam. Headwater levels are determined by inflow and release rates. The Level-Volume relation for Somerset Dam is taken from the Somerset Technical Data, as described in Appendix B of the Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam (Seqwater, 2013). Somerset Dam has one relevant inflow: the Stanley River as simulated with the URBS hydrologic model. The target outflow from Somerset Dam is directly routed to Wivenhoe Dam reservoir without any delay. That is the travel time between the two reservoirs is assumed to be instantaneous.

A lookup table is implemented in RTC tools to describe the relation between outflow releases on one hand and the Somerset HW level and the state of the sluice gates on the other hand. The equations for flow through a fully opened sluice gate is shown below:

$$Q_{Sluice} = 40.022*(h - 73.15)^{0.4963}$$

Besides releases through the sluice gates, Somerset Dam can also make releases through the radial gates over an ogee crest spillway. The ogee spillway crest level is EL100.45 m AHD.

The following equation was used as the basis to construct the lookup table for each individual spillway crest gate:

$$Q_{crest} = 12.137*\left[h - 100.45\right]^{1.6653}$$

At EL107.45 m AHD, flood waters commence to flow over the dam crest and flow occurs through the 'breeze way'. To account for this discharge, the dam crest is assumed to operate as a broad crested weir with a spillway width of 135.33 m, a spillway level of EL107.45 m AHD and a weir coefficient of 1.7.

$$Q_{Overflow} = 1.7*135.33*(h - 107.455)^{1.5}$$

As with Wivenhoe Dam, Somerset Dam is assumed not to fail if it is overtopped and so therefore failure is not modelled.

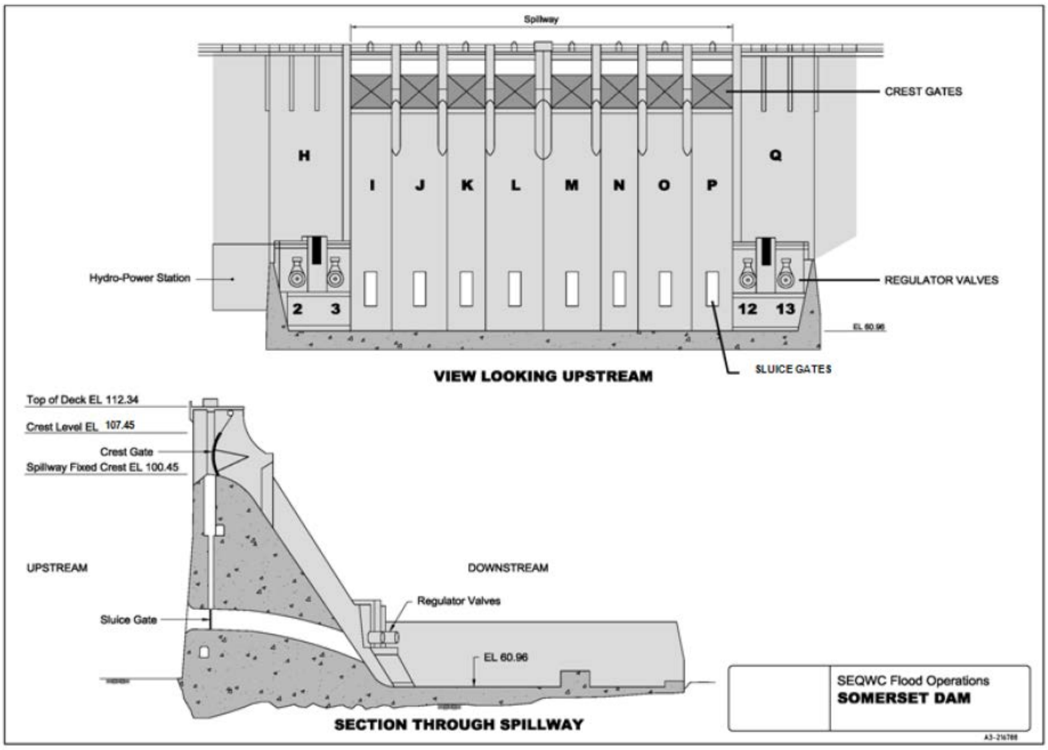


Figure 4-2 Schematic view of Somerset Dam

Only sluice gates are used to adjust the release from Somerset Dam. For this purpose, the *'interaction diagram'* of Figure 2-1 is used. The interaction diagram uses the Somerset Dam Headwater level and Wivenhoe Dam Headwater level as the basis for decision making in regard to storing or releasing flood water from Somerset Dam using the Somerset Dam sluice gates. The diagram is divided into four zones, describing for classes of combinations of Wivenhoe and Somerset headwater levels.

In RTC tools, a fifth zone is added after consultation with Seqwater (Michel Raymond, pers. Communication). This additional zone is a buffer zone around the operating target line. When the combination of Wivenhoe Dam and Somerset Dam water levels are in Zone 5 (the buffer zone), no Somerset control action is taken on the sluice gates. This zone is introduced (also in the GoldSim model of Seqwater) to prevent unnecessary oscillating behaviour of headwater levels and gate openings. The five zones and control actions are implemented as follows:

Zone 1: *Level Somerset Dam < 100.45 and Level Wivenhoe Dam < 70.0*

As long as the Wivenhoe Dam level is below 70.0 mAHD and the level at Somerset Dam< 100.45 m AHD, RTC Tools will apply no control action to open/close a sluice gate of Somerset Dam, taking into account the constraint of maximum number of sluice gates allowed being open (Table 4-2). When too many sluice gates are open, a sluice gate will be closed. The next control action is in 1 hour.

Zone 2: 100.45 <= *Level Somerset Dam < 104 and Level Wivenhoe Dam < Operating Target Line*

RTC Tools will apply a control action to open a sluice gate of Somerset Dam, taking into account the constraint of maximum number of sluice gates allowed to be open. The next control action is in 2 hours.

Zone 3: *Level Somerset Dam >= 104 and Level Wivenhoe Dam < Operating Target Line*

RTC Tools will apply a control action to open a sluice gate of Somerset Dam, taking into account the constraint of maximum number of sluice gates allowed to be open. The next control action is in 1 hour.

Zone 4: Any *Level Somerset Dam /Level Wivenhoe Dam combination where Level Wivenhoe Dam >= Operating Target Line*

RTC Tools will apply a control action to close a sluice gate of Somerset Dam. The next control action is in 1 hour.

Zone 5: Any *Level Somerset Dam/Level* Wivenhoe Dam *combination where (Level* Wivenhoe Dam <= *Operating Target Line + 3cm) AND (Level Wivenhoe Dam >= Operating Target Line – 3 cm)*

RTC Tools will apply no control action to close a sluice gate of Somerset Dam. The next check to see whether a control action is needed is in 15 minutes.

Table 4-2 Maximum number of sluice gates that are allowed being open

Somerset Dam Lake Level (EL metres)	Maximum Allowable Number of Open Sluice Gates
Less than or equal to EL 99.00	0
Between EL 99.00 and EL 99.05	1
Between EL 99.05 and EL 99.15	2
Between EL 99.15 and EL 99.30	3
Between EL 99.30 and EL 99.50	4
Between EL 99.50 and EL 99.75	5
Between EL 99.75 and EL 100.00	6
Between EL 100.00 and EL 100.45	7
Greater than EL 100.45	8

On the basis of all equations and constraints, a rating table was constructed for the releases through the sluice gates, flow over the spillway (with the radial gates fully opened), and flow over the dam crest. The regulator valves are not modelled and are assumed to be closed during a flood event.

5 Benchmark testing

A benchmarking exercise has been undertaken to ensure that the Delft-FEWS representation adequately replicates the Seqwater GoldSim model performance for the Loss of Communications procedure. The benchmarking exercise was conducted using 24 synthetic events as generated by Seqwater, ranging from moderate to extreme flood events. The 24 synthetic events are characterised by inflow series as shown in Appendix B. Figure 5-1 shows the peak inflows of these events. Note that Wivenhoe Dam inflow series are Upper Brisbane River flows, excluding Somerset Dam outflows. The testing was done to compare the performance of the Delft-FEWS RTC Tools dam operations module against the FOSM GoldSim model by determining the resultant releases from both Somerset Dam and Wivenhoe Dam and the associated headwater levels.

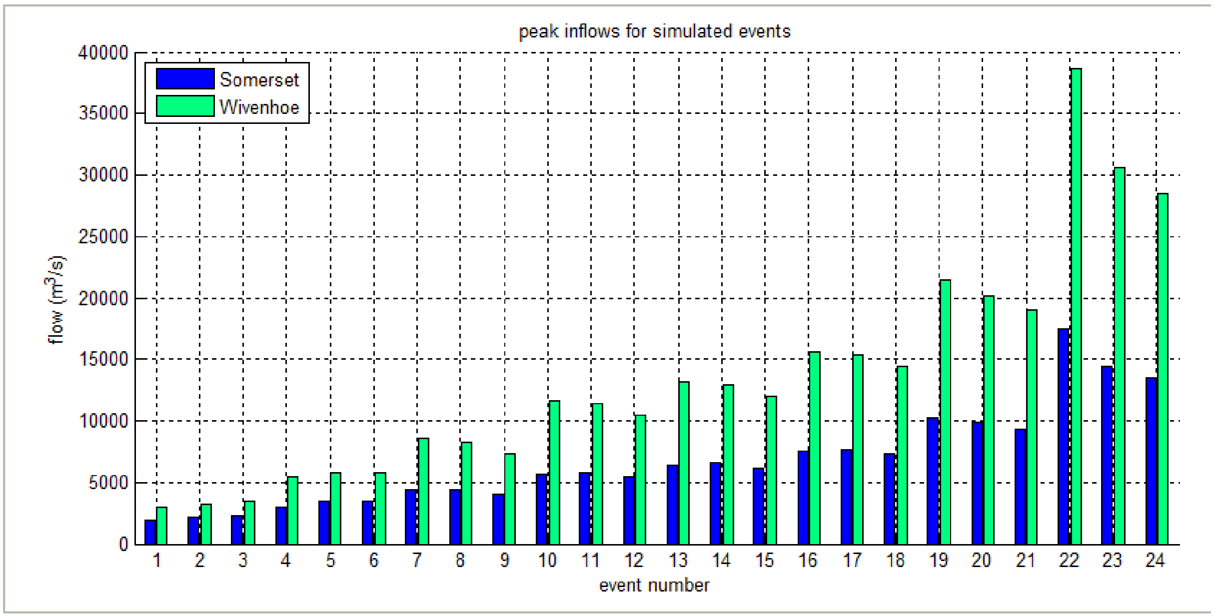


Figure 5-1 Peak inflow of Somerset Dam and Wivenhoe Dam (excluding Somerset outflow) for the 24 simulated synthetic events

Figures showing the relative performance of each of the models against each of the test cases are presented in Appendix B. The Figures show the total release from Wivenhoe Dam as computed with both models. Other variables such as Somerset outflow, outflow through gates and fuse plugs, overflow discharges, Somerset and Wivenhoe headwater levels etc. have been analysed as well and discussed with Seqwater. For the current report we chose to show only Figures of Wivenhoe outflows to keep the number of figures limited, as the Wivenhoe Dam release is the main output of the reservoir simulation model that will be used to simulate the 'With-dams conditions'.

To summarize the comparison between model results of RTC tools and GoldSim, the mutual differences of computed Wivenhoe outflows have been quantified with the Nash-Sutcliffe model efficiency coefficient, *E*:

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_{RTC}(t) - Q_{GS}(t) \right)^2}{\sum_{t=1}^{T} \left(Q_{RTC}(t) - \bar{Q}_{GS} \right)^2} \qquad (1)$$

In this equation, *t* represents time, *T* is the number of time steps in the simulated event, Q_{RTC} is the discharge as computed with RTC-tools, Q_{GS} is the discharge as computed with GoldSim and $\bar{Q}_{\mathrm{GS}}$ is the mean discharge over the event as computed with GoldSim. The Nash-Sutcliffe model efficiency coefficient is generally used to assess the quality of predictions of hydrological models, in which case model predictions are compared with observed data. If data and model predictions have a perfect match, the value of *E* is equal to 1. If E is equal to 0, the model essentially has no predictive value. In our case we do not compare model results with data, but we compare RTC model results with GoldSim model results.

Table 5-1 shows the resulting E-values for the 24 events. Furthermore, this table shows the percentage difference in predicted peak flows. The table shows that for each event an *E*-value of 0.985 or higher is achieved, with the exception of event 16 (E=0.91). In hydrological modelling, *E*-values of 0.985 are exceptionally high, but that of course has to do with the fact that we have compared two models instead of model output with observed data. Nevertheless, it shows that differences between RTC model results and GoldSim model results are small especially in relation to other uncertainties in the MCS framework.

The relatively low *E*-value as observed for event 16 (0.91) is caused by a fuse plug breach. The RTC hydrograph shows a "spike" around the peak flow corresponding to the imitation of a fuse plug that is not existent in the outflow hydrograph as computed with GoldSim (see appendix B). In this event, the Wivenhoe headwater level in the RTC model just exceeds the first fuse plug breach level, whereas in the GoldSim model the headwater level just stays below this breach level (see Figure 5-2). As a consequence the fuse plug breaches in the RTC model, while this does not happen in the GoldSim model. The breaching of the fuse plug causes the spike in the outflow in the RTC model. Because the fuse plug breaches, Wivenhoe Dam gates are closed in the RTC model which causes the total outflow discharge of Wivenhoe Dam to be more or less the same as in the GoldSim model after a few time steps. The breaching of the fuse plug is the reason why the largest difference in peak outflow is also observed for event 16 (17.9%).

Figure 5-2 shows that even for this event (16) the RTC tools module closely mimics the GoldSim module as the headwater levels are nearly the same for the entire period. However, as shown in Figure 3-2, the existence of the fuse plugs cause a discontinuity in the relation between Wivenhoe headwater levels and Wivenhoe peak outflows. This is the reason why minor differences in headwater levels can sometimes lead to significant differences in peak outflows. As long as simulated headwater levels of the two modules are nearly the same (and results of the 24 simulated show that this is indeed the case) these events will be the exception to the rule and are of no concern to the BRCFS with respect to derived 'with-dams conditions' frequency curves.

Table 5-1 Nash-Sutcliffe model efficiency coefficient and percentage difference in peaks of Wivenhoe Dam outflows; comparison of the RTC and GoldSim reservoir simulation models

Event	Nash-Sutcliffe model efficiency parameter	Percentage difference in peak outflow (RTC-GoldSim)
001	0.994	1.1%
002	0.996	0.2%
003	0.997	3.0%
004	0.998	-0.2%
005	0.998	0.6%
006	0.997	5.7%
007	0.998	2.1%
008	0.998	6.7%
009	0.999	2.7%
010	0.996	6.6%
011	0.997	-0.2%
012	0.999	-0.3%
013	0.996	7.1%
014	0.997	1.6%
015	0.999	0.3%
016	0.910	17.9%
017	0.996	0.1%
018	0.997	-0.1%
019	0.985	2.7%
020	0.992	0.2%
021	0.995	0.1%
022	0.987	5.4%
023	0.995	3.2%
024	0.995	2.7%

The figures in Appendix B reveal that the main difference between RTC tools and GoldSim is the fact that the outflow discharges of the latter show a "staircase" behaviour, whereas the RTC tools outflow is more smooth. This is especially visible for the "moderate events" (events 001 – 010). This has to do with the fact that GoldSim uses a larger gate operation time step than RTC tools when it comes to changing the gate settings. The operation time step as used in RTC tools is in accordance with the 2013 manual, except for zone 2 (see Figure 2-1) were it is shorter (1 hour). GoldSim, on the other hand, sometimes uses a larger operation time than prescribed in the 2013 manual for practical reasons ie to reduce the number of gate operations. The difference in operation time step is the main source of differences in peak outflows as quantified in column 3 of Table 5-1.

Figure 5-2 shows a noticeable difference between the two models that is observed for other events as well: In the draining phase, the Wivenhoe level stays at 70 m AHD for a period of approximately one day in the GoldSim model, whereas in the RTC model this is not the case. The reason is that the GoldSim model is implementing the 2012 version of the Reservoir operations Manual, which defines separately LCS1 and LCS2 procedures (Michel Raymond, Seqwater, personal communication), whereas RTC tools uses the 2013 version of the manual. The LCS1 procedure in the 2012 Manual that is simulated in GoldSim occurs when Somerset Dam level is below 100.45 m AHD and it commences to drain Lake Somerset (by opening sluices) when Wivenhoe Dam level is below 70 m AHD and the Wivenhoe Dam level is falling. This tends to drain Somerset Dam more quickly and maintain a near constant Wivenhoe level just below 70 m AHD for a period of about 1 day. The difference between the models for this aspect is not a significant concern for the BRCFS. Furthermore, the difference is caused by the fact that GoldSim deviates from the 2013 manual in this respect, whereas the RTC model is in line with the 2013 manual.

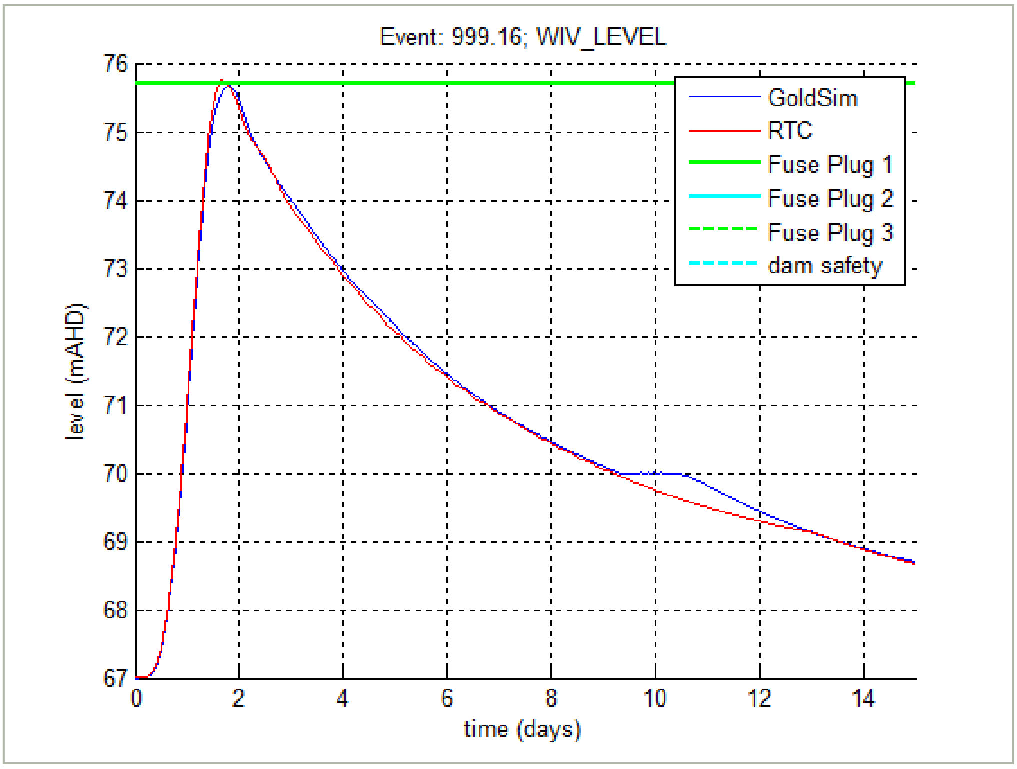


Figure 5-2 Comparison of Wivenhoe headwater levels as simulated with RTC tools and GoldSim for synthetic event 16

6 Implications of LOC

The use of the LOC as opposed to the normal procedures introduces a degree of bias into the downstream flood impacts. As indicated earlier in section 3 the LOC procedure tends to produce lower releases for smaller events, (releases of up to 2,000 m^3/s), with consequent higher associated lake levels in Wivenhoe Dam, but higher releases for moderate to major flood events, (releases in excess of 2,000 m^3/s). For events that result in Peak Lake levels that exceed the Dam Safety threshold level in Wivenhoe Dam (EL 74.0 m AHD), the LOC procedure and the normal operation procedure tend to converge, resulting in similar releases for the rare to extreme flood events.

The implications form this bias is that the LOC procedure will, on average, produce higher releases compared to the normal operation procedure. This implies that the degree of mitigation achieved by Somerset Dam and Wivenhoe Dam will be less for the LOC procedure.

The normal operation procedure, on average, provides a mitigation ratio of approximately 30% for the flood mitigation strategies. The mitigation ratio being the ratio of the peak release compared to the peak inflow. The LOC procedure therefore will reduce this ratio to something closer to 20-25% on average. The mitigation ratio is of course dependent upon the initial level in the dams, and there are examples such as the February 1999 flood event, where the dams can provide much more substantial mitigation (ie 70% mitigation ratio) due to the fact that they are drawn down prior to the flood event.

The other implication of using the LOC procedure is on the draw-down or recession simulation of the release hydrograph. The LOC procedure results in a much longer drainage phase, as the draw-down of the reservoirs is not governed by a minimum time requirement (seven days) to drain the flood compartment back to FSL, but rather the draw-down is controlled by the fixed relationship between lake level and minimum gate opening specified in Table 7.3.1 of the Flood Manual. Figure 6-1 shows an example of the impact of the LOC on the flows in the draw-down phase. After 288 hours, the full operation strategy (red line) maintains flows at Moggill around 3500 m^3/s whereas Moggill flows keep declining in case of LOC. Even though the latter may seem advantageous, it also means of course that the reservoir levels decline at a much slower rate in case of LOC and will not be back at FSL within seven days.

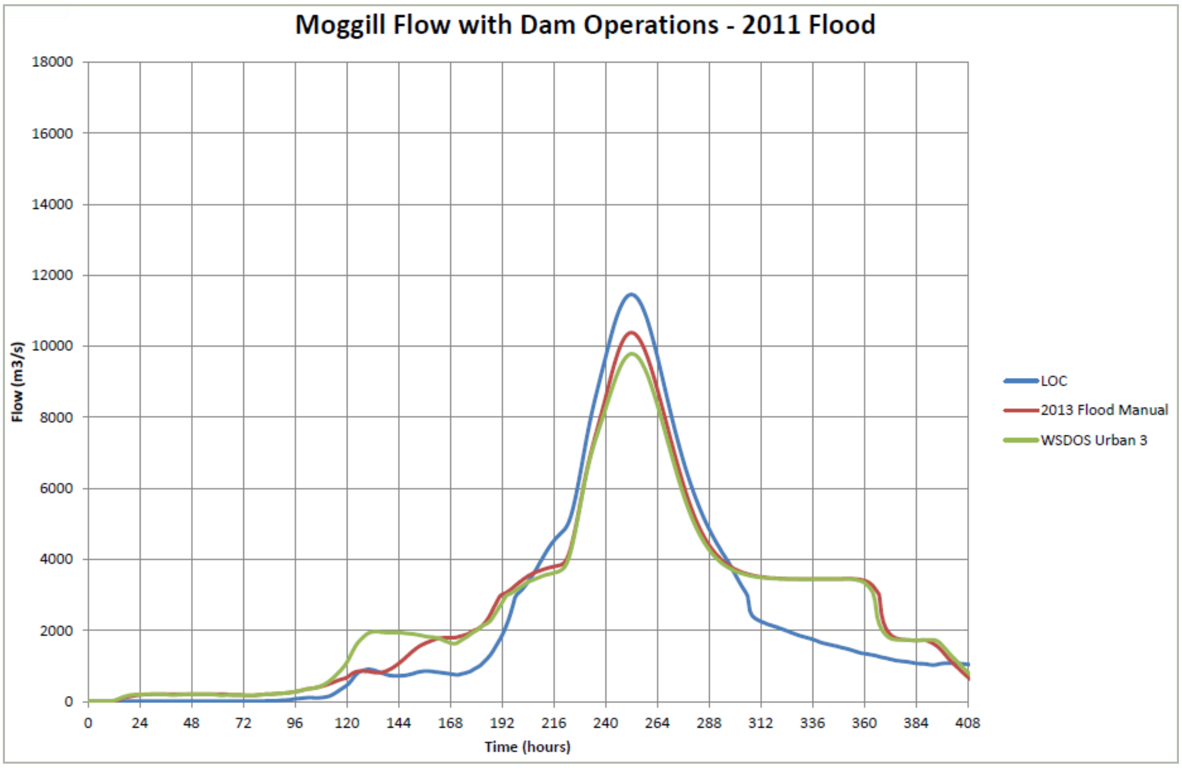


Figure 6-1 Simulated discharges at Moggill for three different dam operation strategies; January 2011 event

7 Adapted version of the LOC implementation

It is reasonable to assume that in reality, loss of communications will only occur for a relatively short period. In other words: in the drawdown phase communication will be back to a level at which the full operation strategy can be applied. The draw-down process incorporated into the LOC has therefore been modified to reflect, as much as possible, the normal operation procedure. For this purpose, the following three trigger levels were introduced:

L1: 430 m^3/s

L2: 1,800 m^3/s

L3: 3,500 m^3/s

For the drawdown phase, one of these three trigger levels is selected. The choice of trigger level depends on the peak discharge of the event:

- Events with peak discharges between L1 and L2: trigger level L1 is selected
- Events with peak discharges between L2 and L3: trigger level L2 is selected
- Events with peak discharges higher than L3: trigger level L3 is selected

The selected trigger level, serves as the *minimum* outflow of Wivenhoe Dam during the drawdown phase, until Wivenhoe Lake is back at FSL. This means if, according to the LOC procedure, the Wivehoe outflow should be lower than the trigger level, the LOC procedure is overruled and the outflow is kept at a constant rate equal to the trigger level. If, according to the LOC procedure, the Wivenhoe outflow should be higher than the trigger level, the LOC procedure is followed.

The trigger levels were implemented in RTC tools after completion of the benchmark test (as described in section 5). During this implementation an additional modification to the RTC tools model was made: In the existing version of the RTC tools model, a decision on reservoir operations was made every 75 minutes whereas this should have been every 60 minutes according to the flood manual. This small bug was repaired during the most recent implementation of the reservoir model, which resulted in minor changes in simulated Wivenhoe Dam outflows.

Figure 7-1 compares the resulting Wivenhoe outflows between the original LOC implementation and the adapted LOC-version. The figure shows that the drawdown phase of the adapted model is now more in accordance with the drawdown characteristics of the full operation strategy, as shown in Figure 6-1.

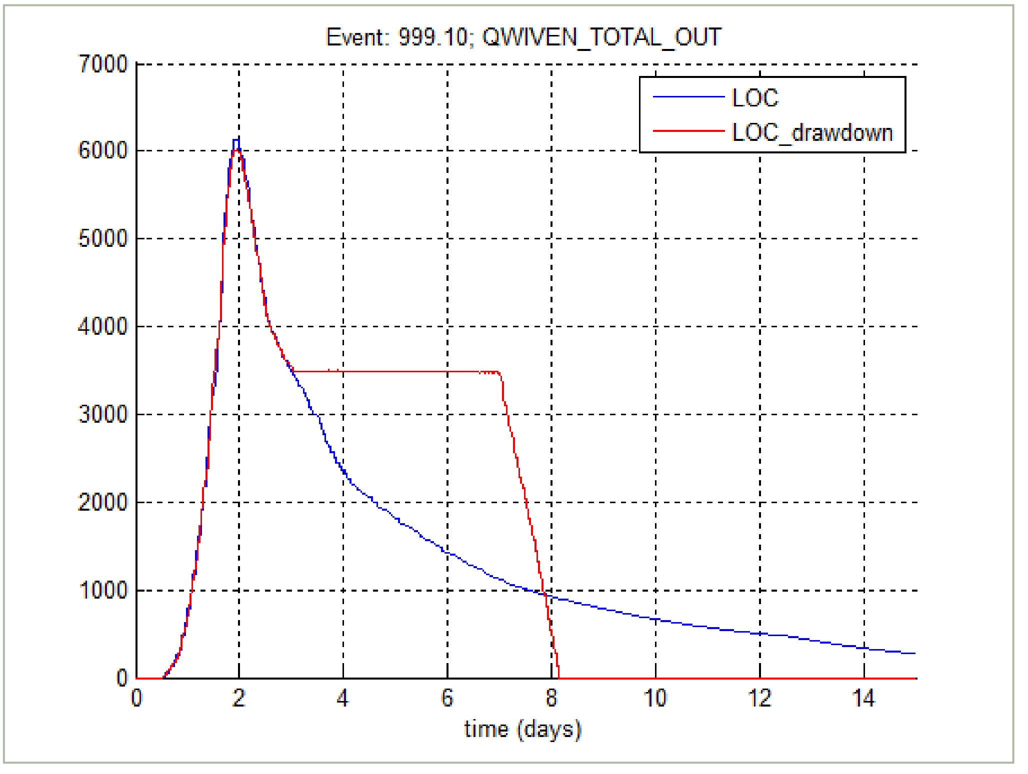


Figure 7-1 Simulated outflow of Wivenhoe dam; original LOC model versus the adapted LOC model for the drawdown phase

8 Alternate procedures

8.1 Introduction

DEWS, on behalf of the State of Queensland conducted public consultation in regard to the operation of Somerset Dam and Wivenhoe Dam. This process commenced in March 2014 with the release of a discussion paper and report outlining the findings for the WSDOS. A series of public meetings were also conducted to outline the results of the WSDOS study and discuss the various options considered during the investigation.

Seqwater has assessed eight variations of the Dam flood operating strategy for the WSDOS project, giving a combination of 32 dam level and operation scenarios. For seven of these variations, the flood operating strategy is dependent upon operating the dam relative to downstream catchment flows, while the final variation uses simple prescriptive operations. These scenarios are discussed further in *'Wivenhoe-Somerset Dam Optimisation Study – Simulation of Alternative Flood Operations Options'* (Seqwater 2014). The design scenario combinations examined using the integrated assessment methodology and a description of each strategy are listed in Table 8-1.

Table 8-1 Wivenhoe FSV and Dam flood operation scenarios assessed for WSDOS

<table>
<tr><th>Scenario</th><th>Wivenhoe FSV</th><th>Dam flood operation</th></tr>
<tr><td>001</td><td>100%</td><td rowspan="4">Base case flood manual representing the 2013 Flood Manual and adaptations for lower FSV scenarios using a level-scaling approach to define the Urban target guide curve</td></tr>
<tr><td>002</td><td>85%</td></tr>
<tr><td>003</td><td>75%</td></tr>
<tr><td>004</td><td>60%</td></tr>
<tr><td>005</td><td>100%</td><td rowspan="4">Rural Strategy Bypass. Flood operations start directly in the Urban Strategy. A maximum release rate equal to the average inflow expected over next 24 hours applies when Wivenhoe level is below FSL + 3m to ensure early releases do not drain Wivenhoe excessively below FSL. This maximum release rate rule is applied to manage risks to water supply security as it is necessary to ensure the Dam will be at FSL at the end of the flood event</td></tr>
<tr><td>006</td><td>85%</td></tr>
<tr><td>007</td><td>75%</td></tr>
<tr><td>008</td><td>60%</td></tr>
<tr><td>009</td><td>100%</td><td rowspan="4">Alternative Urban 1, with a stepped change in the downstream target flow at Moggill used in the Urban strategy</td></tr>
<tr><td>010</td><td>85%</td></tr>
<tr><td>011</td><td>75%</td></tr>
<tr><td>012</td><td>60%</td></tr>
<tr><td>013</td><td>100%</td><td rowspan="3">Alternative Urban 1 with Rural Strategy Bypass</td></tr>
<tr><td>014</td><td>85%</td></tr>
<tr><td>015</td><td>75%</td></tr>
</table>

Scenario	Wivenhoe FSV	Dam flood operation
016	60%	
017	100%	**Alternative Urban 2**, with a “softer” stepped change in the downstream target flow in combination with increased maximum downstream target flow and raising the Dam Safety Strategy trigger level Alternative Urban 2 scenarios adopt the Rural Strategy Bypass
018	85%	
019	75%	
020	60%	
021	100%	**Alternative Urban 3**, with storage based approach to define the Urban target guide curve in combination with increased maximum downstream target flow and raising the Dam Safety Strategy trigger level Alternative Urban 3 scenarios adopt the Rural Strategy Bypass
022	85%	
023	75%	
024	60%	
025	100%	**Alternative Urban 4**, which adapts the Base Case option with raising the Dam Safety Strategy trigger level (to operate in the Urban Strategy with allowing the lowest fuse plug to breach) and with no change to the maximum downstream target flow for the Urban Strategy. This variation is markedly different to the other Urban Strategy variations in that it would tend to make Dam operations store more flood water
026	85%	
027	75%	
028	60%	
029	100%	**Prescriptive Operations**, which is focused on maximising air-space available in Wivenhoe and Somerset Dam irrespective of downstream flooding conditions
030	85%	
031	75%	
032	60%	

The discussion paper indicated that the preferred options include Alternate Urban 3 and Alternate Urban 4. These options tend to release more flow earlier in the event reducing the flood warning time to downstream communities, but this provides a greater opportunity to mitigate events in the large flood range. The changes from the Base Case 100% FSV is shown to be typically between a 2 to 4% reduction in flood damage costs of the equivalent Base Case costs. Overall, the study highlights that there is no simple solution that demonstrates or guarantees a marked reduction in total costs.

8.2 Potential impacts on flood frequencies

The current dam operations module as implemented in RTC Tools is based on the Loss of Communications (LOC) procedure as outlined in the Flood Manual Revision 11 (Seqwater, 2013). During the Brisbane River Catchment Flood Study – hydrology phase it was noted that a revision of the way in which the dams are operated was likely but it was expected that alternate operating strategies would retain the same LOC operation as specified in Revision 11 of the Manual (Note in the finalising stages of the project this turned out to be not entirely true, as will be discussed in section 8.3). This meant that the dam operations module could not be used to quantify changes in ‘With-dams conditions’ flood frequency curves that would result from a shift to the alternate options Urban 3 and Urban 4. Therefore, only a rough estimate could be provided, as will be discussed in the current section.

As stated in the previous section, the alternate strategies tend to release more flow earlier in the event. For “minor” flood events (ie releases less than 2,000 m^3/s) this means more water may be released with the alternate strategies than would have been necessary in hindsight (ie in hindsight the entire peak flow could have been stored in the reservoirs even without additional early releases). For those events the additional early releases may therefore increase peak flows downstream. The increase peak flows depends on the timing of the releases in relation to the timing of peak flows of

Lockyer and Bremer. For large events, the additional early releases of the alternate strategies are expected to pay off as the increase in available reservoir storage volume helps to mitigate peak flows downstream. For extreme events, the increase in available reservoir storage volume with alternate strategies will most likely be too small to have a significant reducing effect on peaks downstream.

To summarise, the alternate strategies are expected to have the following effect on 'with-dams conditions' flood frequency curves at Locations along the Lower Brisbane River:

- A slight *increase* in peak discharge for minor-moderate flood events (high AEP)
- A slight *decrease* in peak discharge for moderate-large events (low AEP)
- Little to no effect for extreme events (very low AEP)

Further support for this reasoning was provided by simulation results from the WSDOS study which, for Location Moggill, are summarised in Figure 8-1. This figure compares 'with-dams conditions' peak flows with 'no-dams conditions' peak flows for two dam operation strategies: the current strategy (flood manual 2013) and the Urban 3 strategy. It shows that:

- For events with 'No-dams conditions' peaks below 5,000 m^3/s, the 'With-dams conditions' peaks will be *higher* for the urban 3 strategy, but this is only a 100 – 200 m^3/s
- For events with 'No-dams conditions' peaks between 9,000 m^3/s and 15,000 m^3/s the 'With-dams conditions' peaks will be *lower* for the urban 3 strategy. Differences are largest between 12,000 m^3/s and 13,500 m^3/s up to a maximum of about 500 m^3/s (estimated from the Figure)
- For events with 'No-dams conditions' peaks > 15,000 m^3/s there appears to be no difference in 'With-dams conditions' peak flows between the two strategies

It is relevant to note that the figure shows median peak flows as derived from multiple simulations. No uniform impacts can be expected for flood events in the same order of magnitude, because of the complexity of the catchment and of the operating rules.

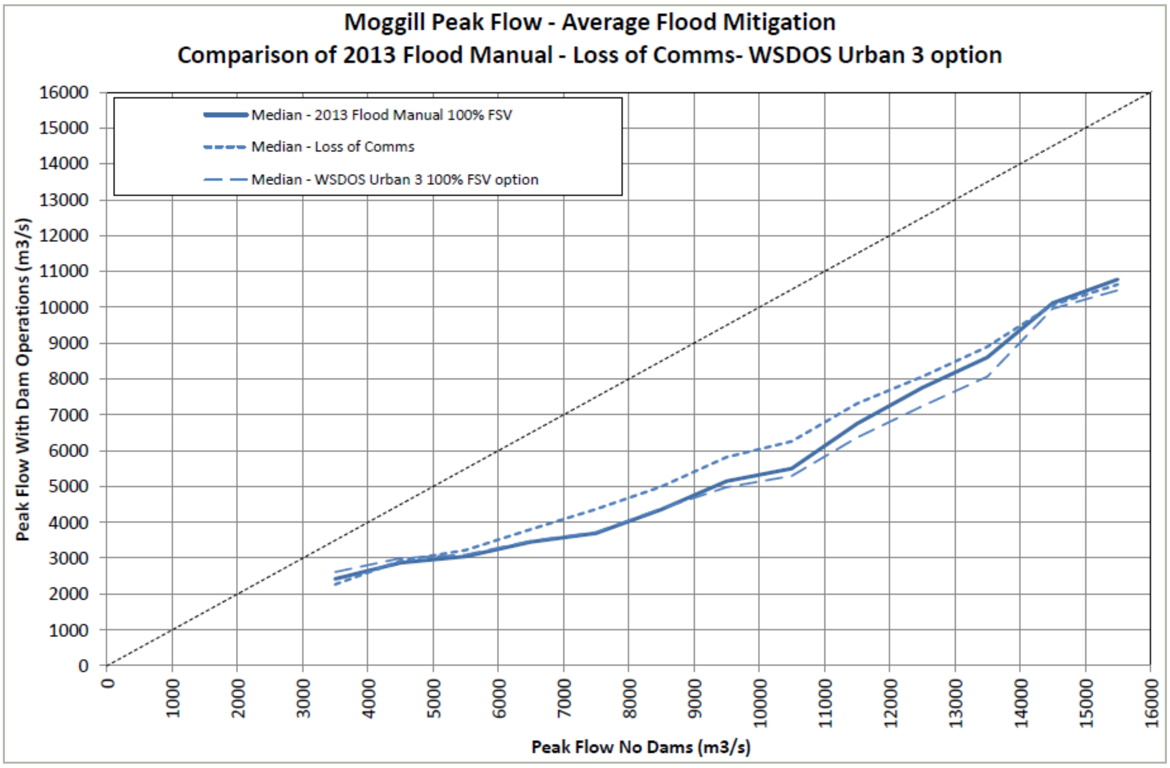


Figure 8-1 Median 'With-dams conditions' peak flows versus 'no-dams conditions' peak flows: comparison of 2 Dam operation strategies

8.3 Recent developments

A new Revision 12 of the Manual was adopted in November 2014. While the LOC emergency procedure in Revision 12 is very similar to that in Revision 11, it is not exactly the same. This means the assumption as stated in the previous section (no change in LOC procedure) is not correct. The instructions in Revision 12 for Wivenhoe dam releases are based solely on dam water level and gate settings and are identical to those in Revision 11. So there are only (minor) differences in LOC procedures between revisions 11 and 12 for Somerset dam:

- Only the sluice gates are used to adjust releases from Somerset Dam into Wivenhoe Dam
- Somerset Dam Headwater level and Wivenhoe Dam Headwater level are used as the basis for decision whether to store or release flood water from Somerset Dam
- This decision making is guided by the Wivenhoe Somerset Interaction diagram in Figure 6.3.1 of Revision 11 and by the Somerset Dam Guide Curve in Figure 6.2.1 of Revision 12
- The Somerset Dam Guide Curve of Revision 12 is broadly similar to the Wivenhoe Somerset Interaction diagram of Revision 11 but it is different in shape

It is conceivable that the history of water level in Wivenhoe Dam could be affected by the changes in Somerset Dam LOC procedure, resulting in some change in the history of releases from Wivenhoe Dam.

The changes to the LOC in Revision 12 are unlikely to have a significant effect, although this has not been quantified. It is recommended to update the LOC dam operations model in RTC tools if/once the dam safety assessment of Somerset Dam and Wivenhoe Dam is completed.

9 Bias corrections

9.1 Introduction

The dam operations module as developed in the BRCFS is based on the LOC procedure. This procedure results in peak flows downstream of Wivenhoe that are on average 5-10% higher compared to the situation where FOS is applied (see section 6). The use of LOC therefore introduces a bias in the ‘with-dams conditions’ flood frequency curves which need to be corrected for. Furthermore, as described in section 8, The State of Queensland is considering adopting a new dam operation strategy, referred to as ‘Urban 3’. The use of this alternative strategy will also affect the derived ‘with-dams conditions’ flood frequency curves.

This section briefly describes the approach of a ‘bias correction method’ that corrects for differences between the different strategies. The actual implementation of the bias correction will be carried out in a later phase. The method is described for the case in which the bias correction is applied to account for differences between LOC and the full operation strategy according to the 2013 Flood Manual (FOS). The bias correction for differences between LOC and Urban 3 can be carried out in exactly the same fashion and is therefore not described separately.

9.2 Basic concept of the proposed approach

The bias adjustment is derived from simulation results of 3840 synthetic events as provided by Seqwater. Figure 9-1 shows the median ‘With-dams conditions’ peak flows in relation to ‘No-dams conditions’ peak flows as derived in WSDOS. This Figure was provided by Seqwater. This median was derived from the 3840 simulated events. The figure shows that the required bias adjustment depends on the magnitude of the event.

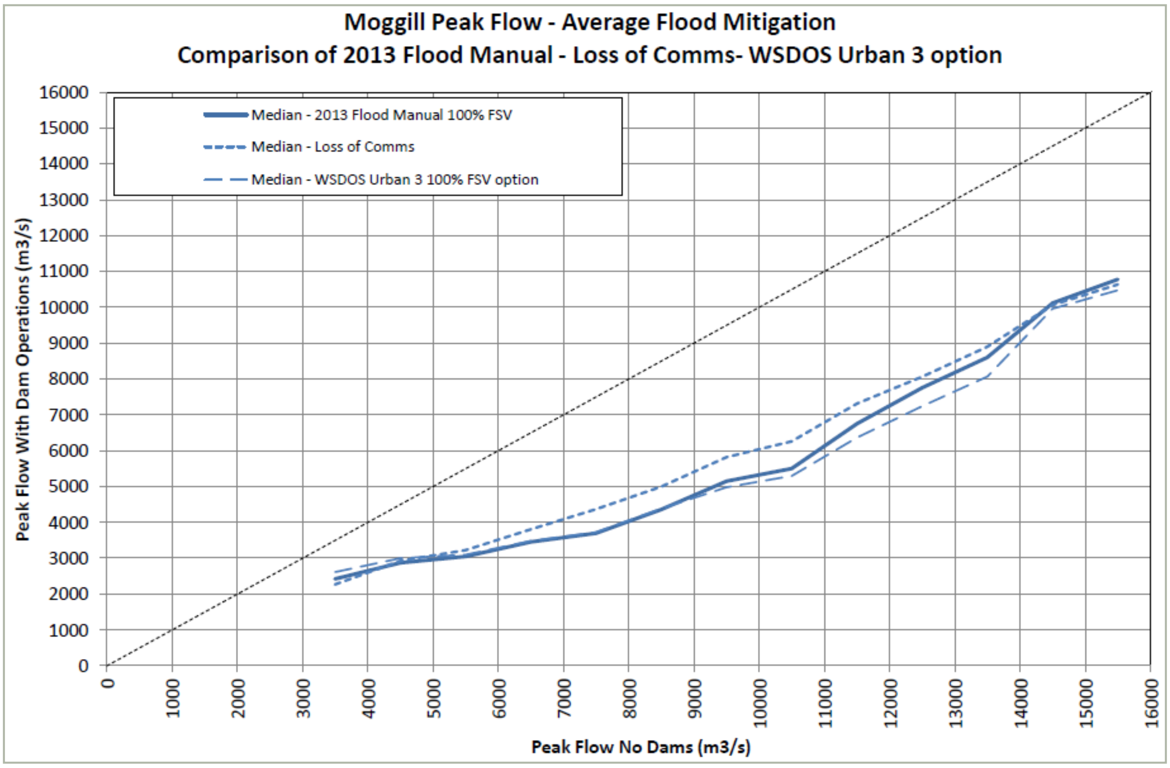


Figure 9-1 Median 'With-dams conditions' peak flows versus 'no-dams conditions' peak flows: comparison of 2 Dam operation strategies (Figure provided by Seqwater)

The same set of simulation results can be used to derive a relation between peak discharges of FOS and LOC:

$$Q_{FOS} = Q_{LOC} + w(Q_{LOC}) \qquad (1)$$

In which:

Q_{FOS}	= peak discharge, corresponding to the FOS strategy
Q_{LOC}	= peak discharge, corresponding to the LOC strategy
$w(Q_{LOC})$	= bias adjustment, as a function of QLOC

The bias adjustment depends on the magnitude of the event, which is represented in eq. (1) by the LOC peak discharge, Q_{LOC}. Note that a more advanced alternative option, in which w is modelled as a random variable, has been considered as well, but after discussions with the client and the independent panel of experts it was decided that the deterministic approach would suffice for the objectives of the study.

The bias adjustment will initially be computed for the locations where WSDOS simulation results for the 3840 events are available. These are the following locations:

1. Somerset Dam outflow
2. Wivenhoe Dam outflow
3. Savages Crossing
4. Moggill
5. Ipswich (note: only water levels, not discharges)

Besides these five locations, bias adjustments are also required for Mount Crosby, Centenary Bridge and Brisbane. For location Mount Crosby, the bias adjustment will be assumed identical to Savages Crossing. For Centenary Bridge and Brisbane the bias adjustment for Moggill is taken.

9.3 Derivation of peak flow frequency curves for all locations

9.3.1 Moggill

Figure 9-2 shows a scatter plot of the difference in peak flow between LOC and FOS (vertical axis) in relation to LOC peak flows (horizontal axis). The scatter plot is based on the results of the 3840 model simulations as carried out for the WSDOS study. The Figure also shows moving averages of the mean and the median of the difference between LOC and FOS results, where a window of 50 values is used, which means each value on the red and blue lines is based on 50 model simulation results. The mean and median are almost identical, which indicates that either one can be used for the required bias adjustment. Both lines display some noise, which can be eliminated by fitting a smoothed curve through the derived moving averages, as shown in Figure 9-3. A piece-wise linear fit was used because it is easy to use and still capable of capturing the main trend. This fitted line is the proposed bias adjustment as a function of the magnitude of the event (variable $w(Q_{LOC})$ in Formula (1)).

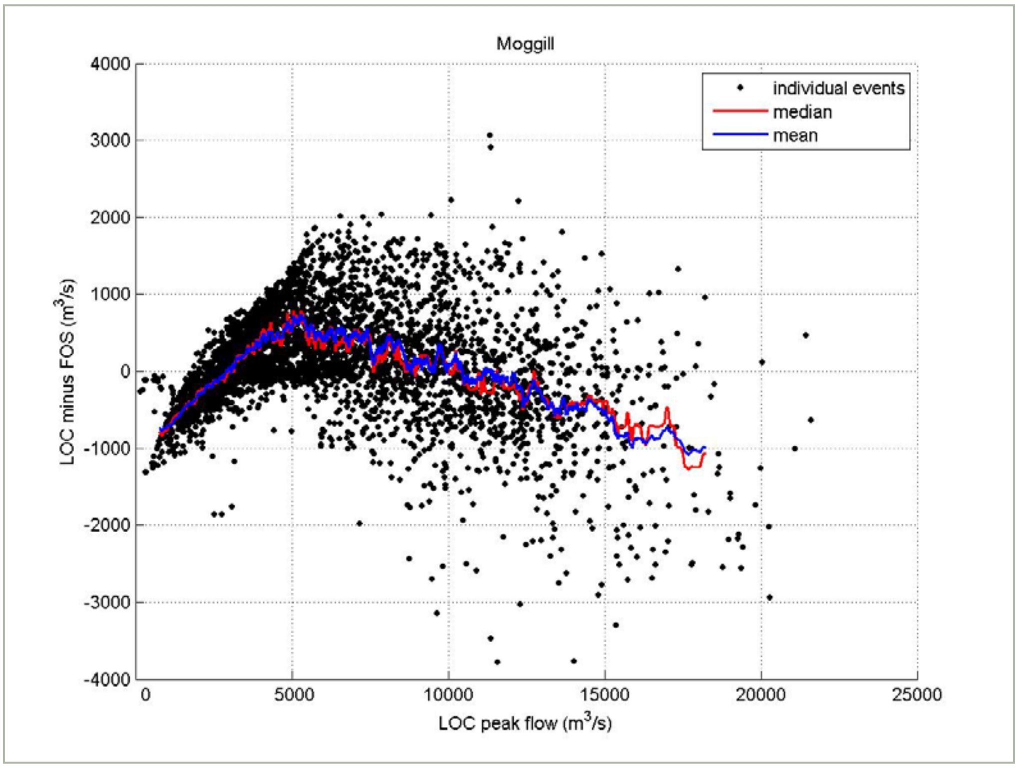


Figure 9-2 Scatter plot of the differences between LOC and FOS peak flows (vertical axis) versus LOC peak flows (horizontal axis) based on 3840 model simulations, including moving averages of the mean and median differences; location Moggill

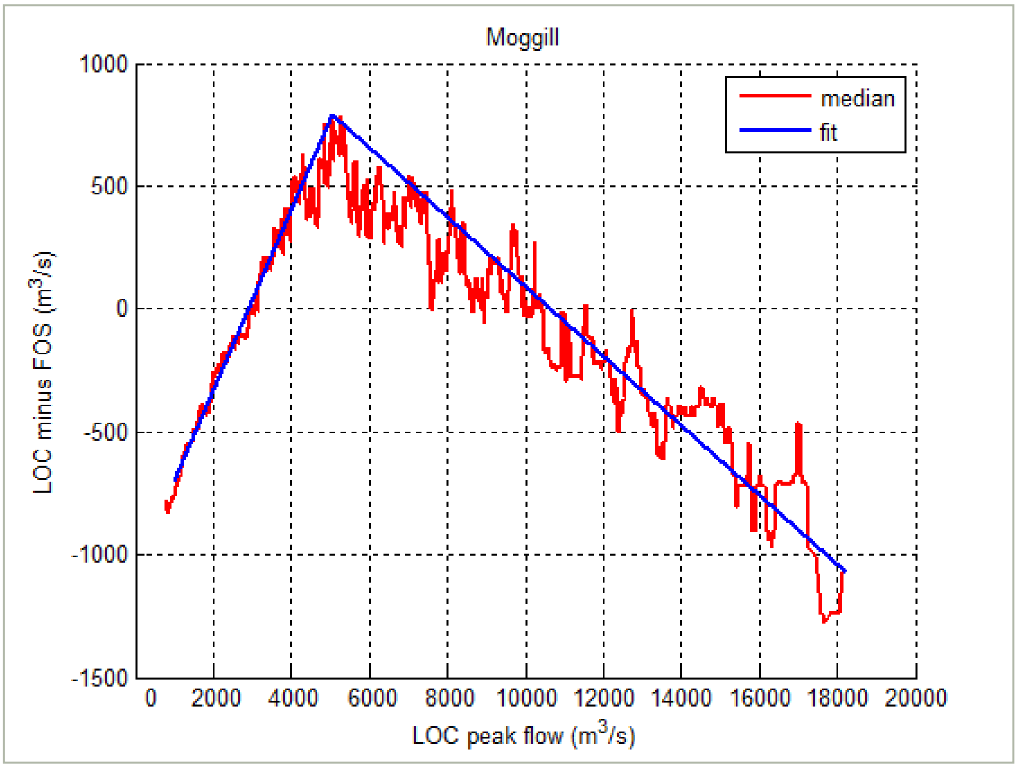


Figure 9-3 Moving median and corresponding fit of the difference between LOC and FOS (vertical axis) as a function of LOC peak flows (horizontal axis); location Moggill

The following is observed from Figure 9-3:

I. For moderate events (LOC peak flows at Moggill up to 3,000 m^3/s) the LOC procedure usually results in *lower* peak discharges at Moggill than the FOS procedure
II. For large events (LOC peak flows at Moggill between 3,000 m^3/s and 10,500 m^3/s) the LOC procedure usually results in *higher* peak discharges at Moggill than the FOS procedure
III. For extreme events (LOC peak flows at Moggill above 10,500 m^3/s) the LOC procedure usually results in *lower* peak discharges at Moggill than the FOS procedure

This means peak discharges between 3,000 m^3/s and 10,500 m^3/s need to be *decreased* in the derived 'With-dams conditions' frequency curves for location Moggill to correct for the fact that MCS and DEA simulation results are based on the LOC procedure instead of the FOS procedure. In contrast, peak discharges below 3,000 m^3/s and peak discharges above 10,500 m^3/s would need to be increased in the derived 'With-dams conditions' frequency curves for location Moggill that are representative for the FOS strategy.

However, the adjustment for peak discharges above 10,500 m^3/s is disputable. According to Michel Raymond (personal communication) of Seqwater, the routing behaviour of the GoldSim model (the simulation model of the WSDOS study) downstream of Wivenhoe dam is beyond its calibration limits for these extreme events. That means the derived bias adjustment has insufficient scientific basis for this range of flows and should not be used. On the other hand, the trend of the bias adjustment for increasing discharge indicates that the FOS procedure might produce higher peak discharges for extreme events than the LOC procedure. If that is the case, then not using the bias adjustment for extreme events leads to an underestimation of the risk.

With respect to this dilemma, we propose the following:

- The bias adjustment for extreme events (LOC peak flows at Moggill above 10,500 m^3/s) will be set to 0, *for the time being*. This approach will be followed in the draft reconciliation results that are provided on 24 October 2014
- During the next IPE-meeting, this item will be put on the agenda and a decision will be made on the approach to be adopted for the final reconciliation results

9.3.2 Savages Crossing

Results for Savages Crossing show similar trends as the results for Moggill (see Figure 9-4 and Figure 9-5). Again, three ranges of peak flows can be distinguished:

I. For moderate events (LOC peak flows at Savages Crossing up to 2,500 m^3/s) the LOC procedure usually results in *lower* peak discharges at Savages Crossing than the FOS procedure
II. For large events (LOC peak flows at Savages Crossing between 2,500 m^3/s and 7,500 m^3/s) the LOC procedure usually results in *higher* peak discharges at Savages Crossing than the FOS procedure
III. For extreme events (LOC peak flows at Savages Crossing above 7,500 m^3/s) the LOC procedure usually results in lower peak discharges at Savages Crossing than the FOS procedure

Similar to Moggill, the bias adjustment for range [III] will be set to zero for the moment.

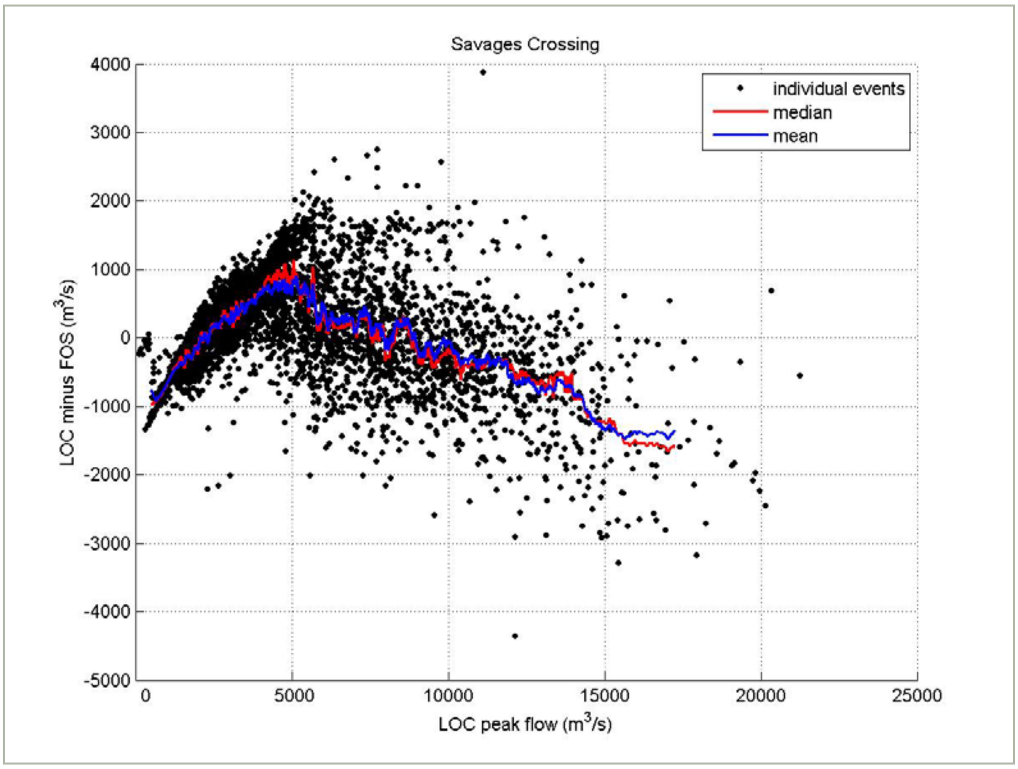


Figure 9-4 Scatter plot of the differences between LOC and FOS peak flows (vertical axis) versus LOC peak flows (horizontal axis) based on 3840 model simulations, including moving averages of the mean and median differences; location Savages Crossing

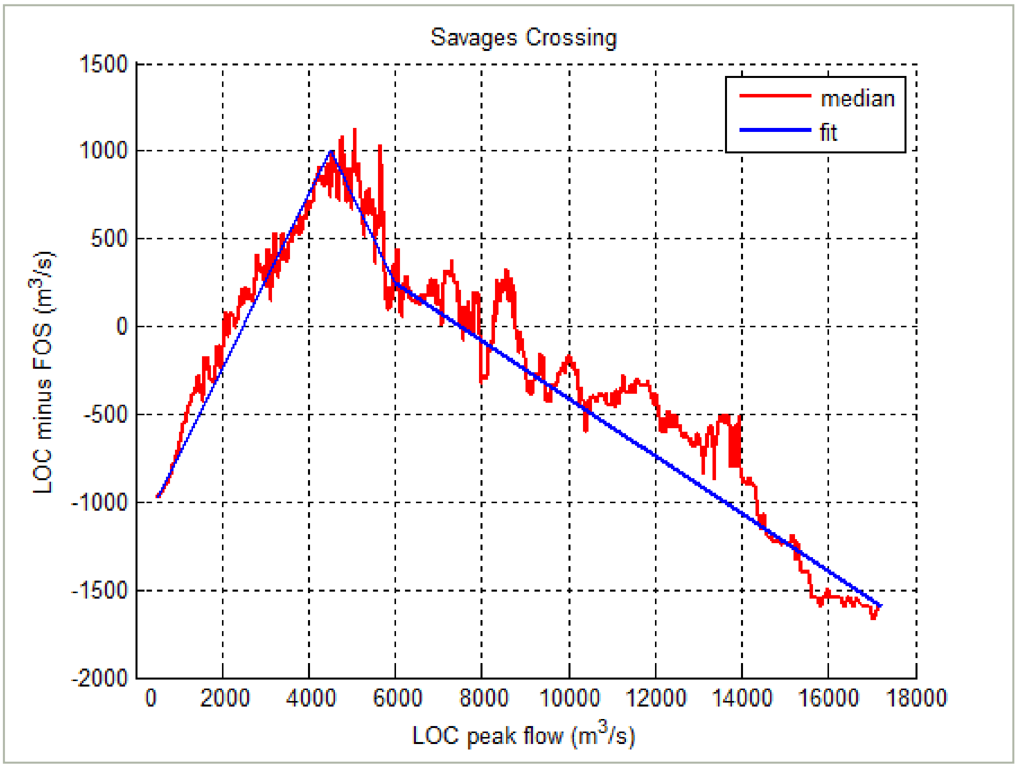


Figure 9-5 Moving median and corresponding fit of the difference between LOC and FOS (vertical axis) as a function of LOC peak flows (horizontal axis); location Savages Crossing

9.3.3 Wivenhoe Dam

Figure 9-6 shows that for Wivenhoe dam outflows the model results show an even more erratic behaviour than for Moggill and Savages Crossings. This is especially the case for flows above 10,000 m^3/s where breaching of the fuse plugs have a major influence on peak flows. The only systematic behaviour in Figure 9-6 is that differences are negative on average, indicating that in most cases the FOS strategy results in higher peak outflows than the LOC strategy. We therefore propose to use a constant bias adjustment, as indicated in Figure 9-7. This means peak discharges need to be increased in the derived 'With-dams conditions' frequency curves for location Wivenhoe to correct for the fact that MCS and DEA simulation results are based on the LOC procedure instead of the FOS procedure.

9.3.4 Somerset Dam

For location Somerset, differences in peak flows between LOC and FOS are small on average (see Figure 9-8). A small bias adjustment is proposed for events with Somerset peak outflows above 3,000 m^3/s, see Figure 9-9.

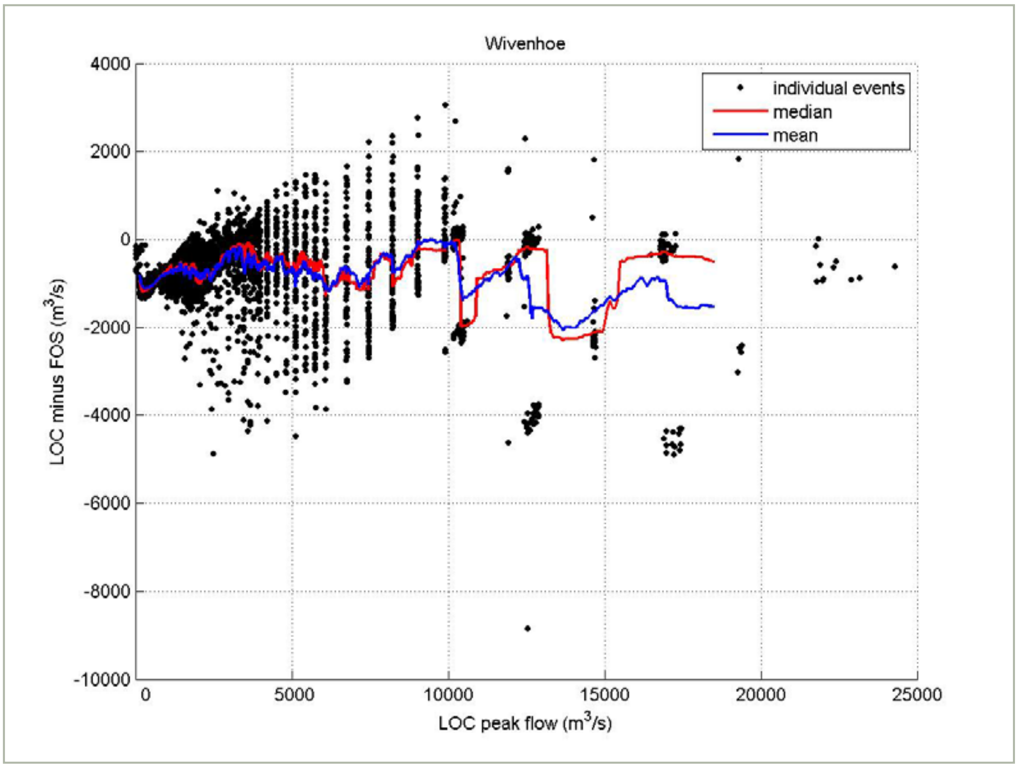


Figure 9-6 Scatter plot of the differences between LOC and FOS peak flows (vertical axis) versus LOC peak flows (horizontal axis) based on 3840 model simulations, including moving averages of the mean and median differences; location Wivenhoe

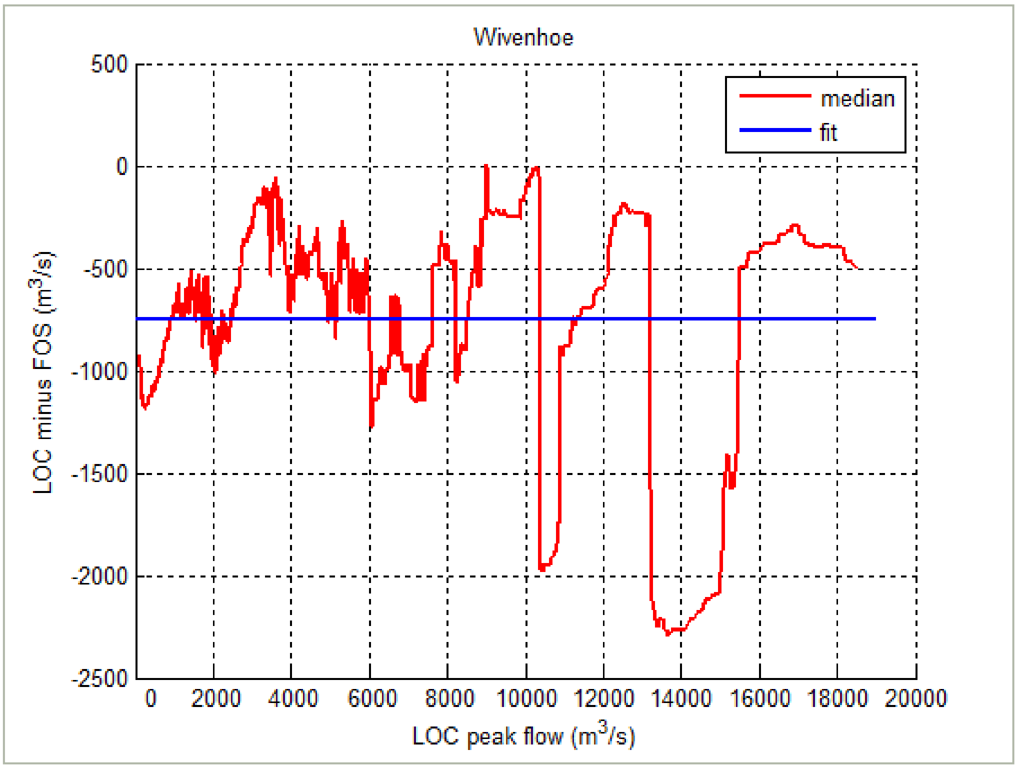


Figure 9-7 Moving median and corresponding fit of the difference between LOC and FOS (vertical axis) as a function of LOC peak flows (horizontal axis); location Wivenhoe

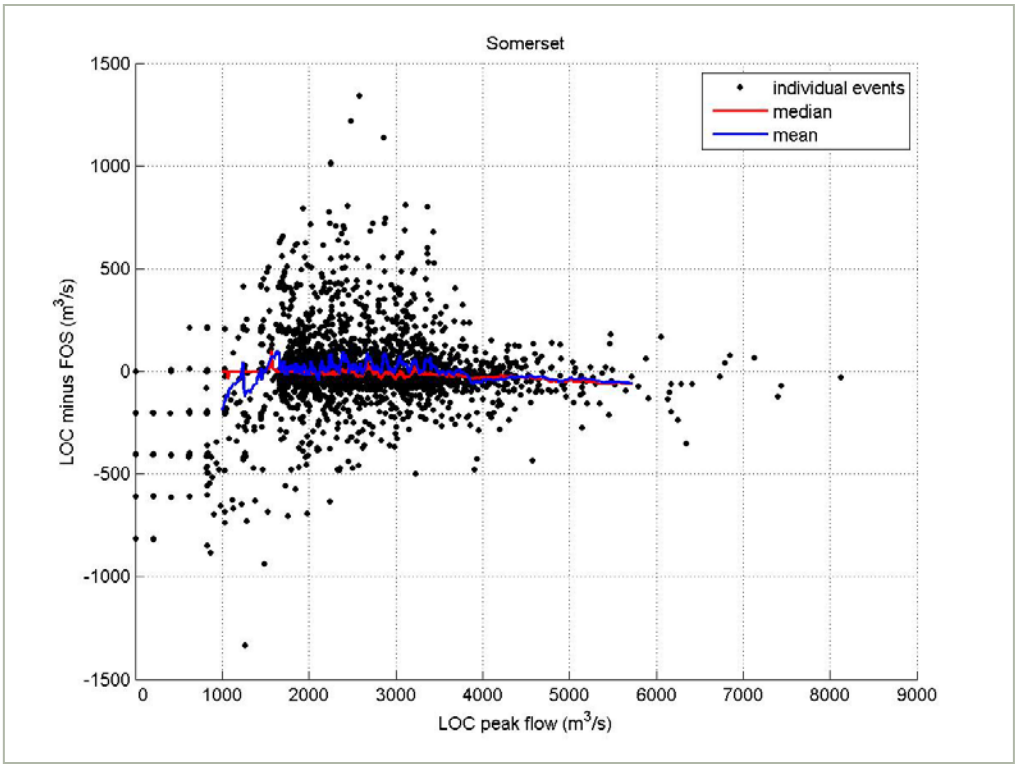


Figure 9-8 Scatter plot of the differences between LOC and FOS peak flows (vertical axis) versus LOC peak flows (horizontal axis) based on 3840 model simulations, including moving averages of the mean and median differences; location Somerset

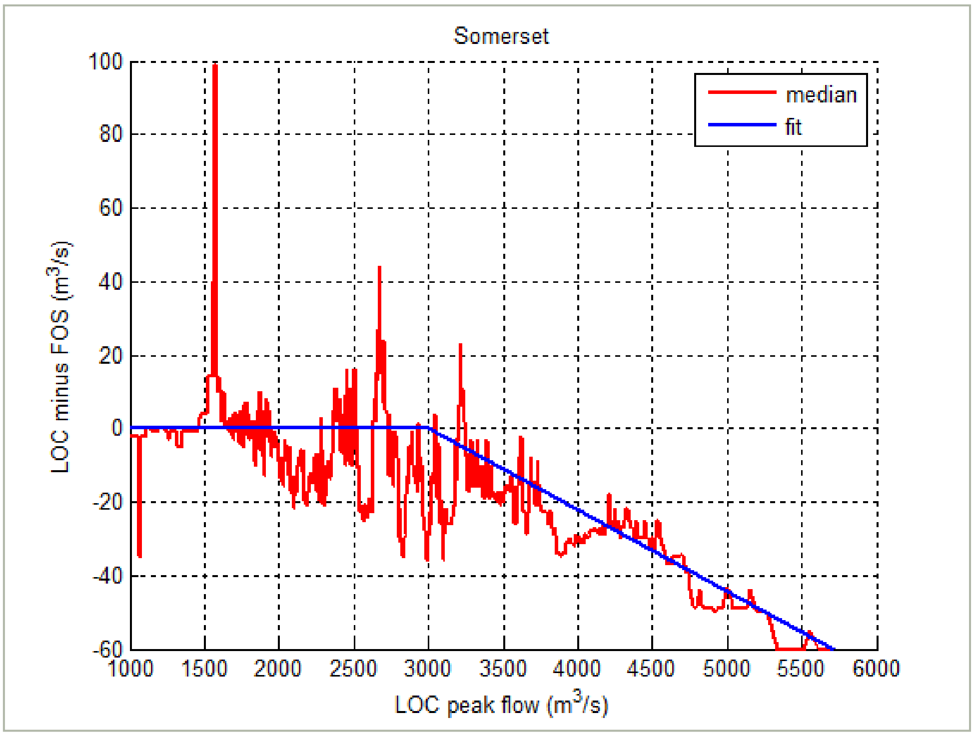


Figure 9-9 Moving median and corresponding fit of the difference between LOC and FOS (vertical axis) as a function of LOC peak flows (horizontal axis); location Somerset

9.3.5 Ipswich

For location Ipswich, only peak water levels of the WSDOS simulations are available, no peak discharges. Figure 9-10 shows the scatter plot for peak water levels. Due to the fact that water levels are rounded to 0.1 m, the moving median shows a “staircase” behaviour. For this reason, the proposed bias adjustment for Ipswich is derived from the moving average of the mean instead of the median (see Figure 9-11). Note that this bias adjustment will not be applied in the hydrology phase of the Brisbane River Catchment Flood Study, since only design flows are derived in the hydrology phase. The bias adjustment will serve as input for the hydraulics phase.

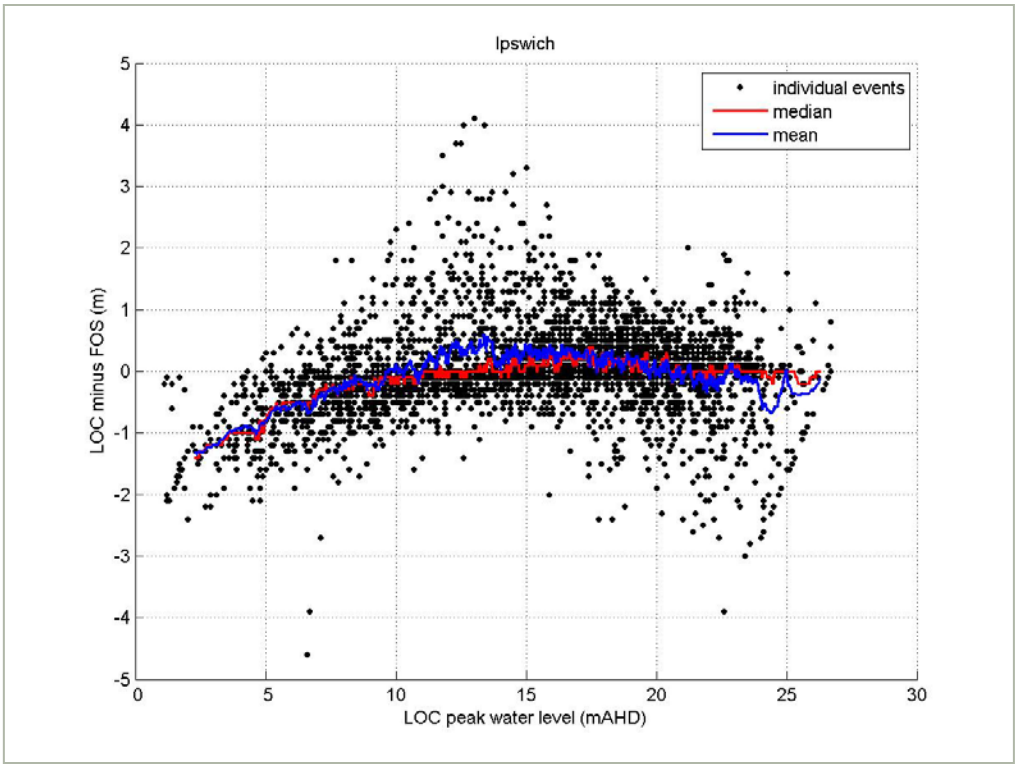


Figure 9-10 Scatter plot of the differences between LOC and FOS water levels (vertical axis) versus LOC water levels (horizontal axis) based on 3840 model simulations, including moving averages of the mean and median differences; location Ipswich

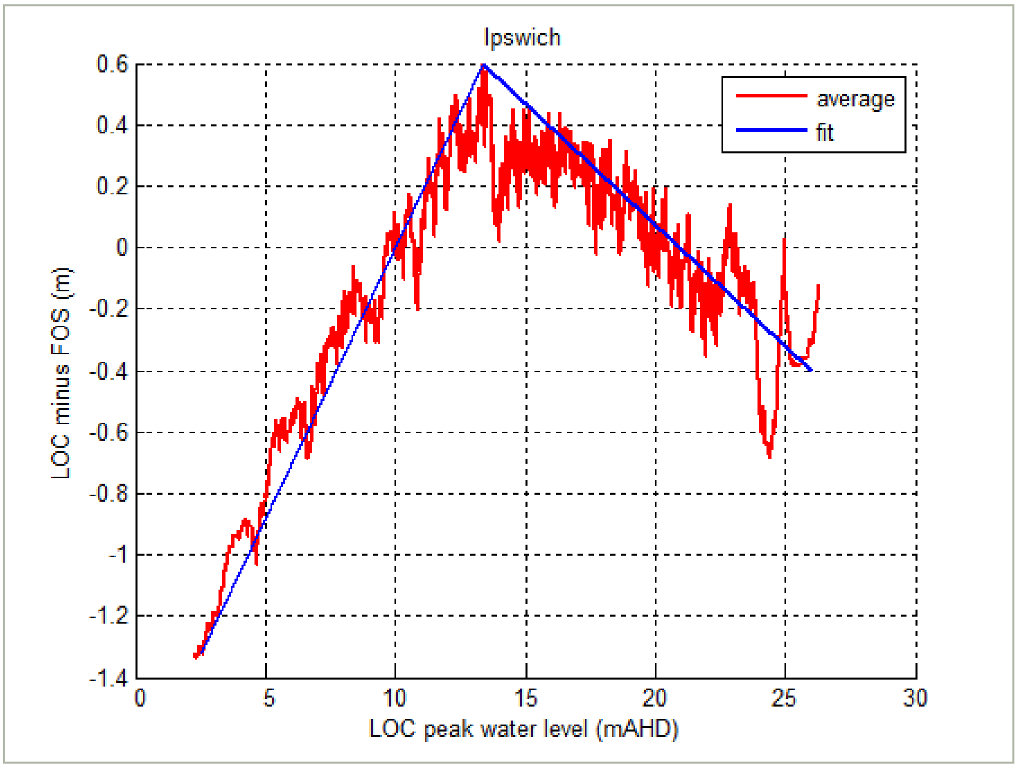


Figure 9-11 Moving median and corresponding fit of the difference between LOC and FOS (vertical axis) as a function of LOC peak water levels (horizontal axis); location Ipswich

9.4 Derivation of peak flow frequency curves for the DEA approach

Table 9-1 shows derived bias adjustments for a range of discharges (and water levels at Ipswich). For each location, the value in the first column corresponds to a peak discharge with the Loss of Communications (LOC) strategy, the second column shows the bias adjustment, ie the value that needs to be subtracted to obtain the peak discharge that is associated with the Full Operation Strategy (FOS). A negative value in the second column indicates the LOC value needs to be increased to obtain the peak discharge that is associated with the FOS.

Table 9-1 Derived bias adjustments

Somerset		Wivenhoe		Savages Crossing		Moggill		Ipswich	
Q (m^3/s)	bias (m^3/s)	Q (m^3/s)	bias (m^3/s)	Q (m^3/s)	bias (m^3/s)	Q (m^3/s)	bias (m^3/s)	h (mAHD)	bias (m)
1000	0	0	-750	500	-972	1000	-700	2.5	-1.3
1200	0	500	-750	1000	-726	1500	-517	3.5	-1.1
1400	0	1000	-750	1500	-479	2000	-333	4.5	-1
1600	0	1500	-750	2000	-233	2500	-150	5.5	-0.8
1800	0	2000	-750	2500	14	3000	34	6.5	-0.6
2000	0	2500	-750	3000	261	3500	217	7.5	-0.4
2200	0	3000	-750	3500	507	4000	401	8.5	-0.3
2400	0	3500	-750	4000	754	4500	584	9.5	-0.1
2600	0	4000	-750	4500	1000	5000	768	10.5	0.1

Somerset		Wivenhoe		Savages Crossing		Moggill		Ipswich	
Q (m^3/s)	bias (m^3/s)	Q (m^3/s)	bias (m^3/s)	Q (m^3/s)	bias (m^3/s)	Q (m^3/s)	bias (m^3/s)	h (mAHD)	bias (m)
2800	0	4500	-750	5000	750	5500	727	11.5	0.3
3000	0	5000	-750	5500	500	6000	656	12.5	0.4
3200	-4	5500	-750	6000	250	6500	585	13.5	0.6
3400	-9	6000	-750	6500	168	7000	515	14.5	0.5
3600	-13	6500	-750	7000	86	7500	444	15.5	0.4
3800	-18	7000	-750	7500	4	8000	374	16.5	0.4
4000	-22	7500	-750	8000	0	8500	303	17.5	0.3
4200	-26	8000	-750	8500	0	9000	232	18.5	0.2
4400	-31	8500	-750	9000	0	9500	162	19.5	0.1
4600	-35	9000	-750	9500	0	10000	91	20.5	0
4800	-40	9500	-750	10000	0	10500	21	21.5	0
5000	-44	10000	-750	10500	0	11000	0	22.5	-0.1
5200	-48	10500	-750	11000	0	11500	0	23.5	-0.2
5400	-53	11000	-750	11500	0	12000	0	24.5	-0.3
5600	-57	11500	-750	12000	0	12500	0	25.5	-0.4
		12000	-750	12500	0	13000	0		
		12500	-750	13000	0	13500	0		
		13000	-750	13500	0	14000	0		
		13500	-750	14000	0	14500	0		
		14000	-750	14500	0	15000	0		
		14500	-750	15000	0	15500	0		
		15000	-750	15500	0	16000	0		
		15500	-750	16000	0	16500	0		
		16000	-750	16500	0	17000	0		
		16500	-750	17000	0	17500	0		
		17000	-750			18000	0		
		17500	-750						
		18000	-750						
		18500	-750						
		19000	-750						

10 Conclusions

In the Brisbane River Catchment Flood Studies, frequency curves are derived for two conditions: 'No-dams conditions' and 'With-dams conditions'. For 'With-dams conditions', the following dams are considered:

- Wivenhoe
- Somerset
- Moogerah
- Lake Manchester
- Perseverance
- Cressbrook Creek

Moogerah, Manchester, Perseverance and Cressbrook Dams are modelled in the URBS hydrological model as level pool storages with fixed crest spillway relationships. The storage representation and associated relationships are consistent with the description contained in the Brisbane River Flood Models, Seqwater (2013). No alterations have been made to the URBS model with respect to these four dams within the context of the BRCFS. The modelling of these four dams was therefore not further discussed in this report, the focus was on Somerset Dam and Wivenhoe Dam.

The Somerset and Wivenhoe Dam Operations Module was implemented within the real-time control software RTC tools as a component of the Delft-FEWS framework for use in assessing the 'With-dams' Condition design flood estimates associated with the Monte Carlo Simulation techniques of flood estimation. The Dam Operations Module was based upon the Loss of Communications (LOC) emergency flood operation procedure described in the Flood Manual. The reason to implement the LOC scenario instead of the regular dam operation strategy is the fact that the latter is relatively complex to implement especially in a Monte Carlo Simulation framework. Bearing in mind that the project has a tight time schedule and that the purpose of this study is for floodplain management (ie not operational management), the implementation of the LOC was preferred.

The Loss of Communications (LOC) emergency flood operation procedure was successfully implemented in the RTC tools model. This model will be used within the Delft-FEWS framework for use in assessing the 'With-dams' Condition design flood estimates associated with the Monte Carlo Simulation techniques of flood estimation. The model performance of the RTC tools dam operations model was compared to Seqwater's GoldSim model. Model results were compared for 24 synthetic events, ranging from moderate to extreme flood events. The comparison showed that predicted Wivenhoe Dam outflow hydrographs of RTC tools closely matched the predicted hydrographs of the GoldSim model. As a follow-up activity, the drain-down process incorporated into the LOC was modified to reflect the normal operation procedure and mimic the seven day drainage requirement.

The LOC scenario on average results in slightly ‘conservative’ estimates of peak discharges and flow volumes in the Lower Brisbane River. For floods within the range of 2,000 m^3/s to 16,000 m^3/s, the peak flow in the mid-Brisbane River and Lower Brisbane River according to the LOC scenario are *on average* in the order of 5 to 10% higher than the peak discharges that result from the dam operations using the Flood Manual procedures (2013 flood Manual). This means the derived frequency curves for the ‘With-dams conditions’ scenario will be conservative as well.

The IPE originally recommended that it would be desirable to apply a bias adjustment on the peak flow frequency curves using the information outlined. The IPE response was based on the assessment at the time that:

1. That the degree of bias in simulated peak flows for the with-dam conditions was significant
2. That the WSDOS simulation results provided a sound basis for the estimation of a bias adjustment

Subsequent detailed comments by Seqwater in the Memo of 16 September 2014 have put both of these suppositions into question.

The following points in that Memo were noted and accepted by the IPE.

- The median bias shown in the WSDOS simulation results for the two modes of operation – Full Operation Strategy (FOSM) and Loss of Communications (LOC) emergency operation – is relatively small in comparison to the degree of variability (as shown in the various scatter plots presented in the Aurecon report)
- The 3840 events used in the WSDOS simulations are not directly applicable to the events to be used in the simulations within the BRCFS MCS framework for design flood estimation
- The GoldSim implementation of the FOSM operations gives a simplified representation of the likely actual operation for large floods which tends to result in overestimation of peak flows. This means that for the floods that trigger the Dam Safety Strategy the apparent favourable bias of the LOC simulations may be greater than the actual bias

From these considerations the IPE has concluded that, while it would be desirable to make a bias adjustment if that could be done with confidence:

- The Seqwater Goldsim modelling that is suitable for many other tasks contains assumptions that make it unsuitable for reliably estimating bias adjustment
- Therefore, there is no sound justification for the degree of detail in the bias adjustment recommended in the Aurecon Report (which implies that the FOSM simulations provide a reliable benchmark)
- The most defendable course of action would be to apply no bias adjustment

As a result, it was determined that no bias adjustment was applied to the subsequent peak flow frequency curves.

The current dam operations module as implemented in RTC Tools is based on the Loss of Communications (LOC) procedure as outlined in the Flood Manual Revision 11 (Seqwater, 2013). During the Brisbane River Catchment Flood Study – hydrology phase it was noted that a revision of the way in which the dams are operated was likely but it was expected that alternate operating strategies would retain the same LOC operation as specified in Revision 11 of the Manual. A new Revision 12 of the Manual was adopted in November 2014. While the LOC emergency procedure in Revision 12 is very similar to that in Revision 11, it is not exactly the same. The changes to the LOC in Revision 12 are unlikely to have a significant effect, although this has not been quantified. It is recommended to update the LOC dam operations model in RTC tools if/once the dam safety assessment of Somerset Dam and Wivenhoe Dam is completed.

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12 Glossary

12.1 Hydrologic terms

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 (m), the standard reference level in Australia

AR&R: Australian Rainfall and Runoff (AR&R) is a national guideline document for the estimation of design flood characteristics in Australia. It is published by Engineers Australia. The current 2003 edition is now being revised. The revision process includes 21 research projects, which have been designed to fill knowledge gaps that have arisen since the 1987 edition

CHA: Comprehensive Hydrologic Assessment

CL: Continuing Loss (mm/hour). The amount of rainfall during the later stages of the event that infiltrates into the soil and is not converted to surface runoff in the hydrologic model

CRC-CH: Cooperative Research Centre – Catchment Hydrology. In this report, CRCH-CH usually refers to a Monte Carlo sampling method that was developed by the CRC-CH

CSS: Complete Storm Simulation. This is one of the proposed Monte Carlo sampling methods

Cumulative probability: The probability of an event occurring over a period of time, any time in that period. This probability increases over time

DEA: Design Event Approach. A semi-probabilistic approach to establish flood levels, which only accounts for the variability of the rainfall intensity

Design flood event: Hypothetical flood events based on a design rainfall event of a given probability of occurrence (ie 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 (EA, 2003)

DMT: Disaster Management Tool. Work completed by BCC in 2014 for Queensland Government as part of the development of an interim disaster management tool until the completion of the BRCFS

DTM: Digital Terrain Model

EL (m AHD): Elevation (in metres) above the Australian Height Datum

FFA: Flood Frequency Analysis – a direct statistical assessment of flood characteristics

Flood mitigation manual (Flood Manual): A flood mitigation manual approved under section 371E(1)(a) or 372(3) of the Water Supply (Safety and Reliability) Act 2008 (QLD)

FOSM: Flood Operations Simulation Model (refer Seqwater 2014)

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

GEV: Generalised Extreme Value statistical distribution

GIS: Geographic Information System

GL: Gigalitres This is a unit of volume used in reservoir studies. A Gigalitre = 1,000,000,000 litres or equivalently 1,000,000 m^3

GSDM: Generalised Short Duration Method of extreme precipitation estimation for storms of less than 6 hour duration and catchments of less than 1,000 km^2. Refer BoM, 2003

GTSMR: Revised Generalised Tropical Storm Method of extreme precipitation estimation for storms of tropical origin. Applicable to storm durations of up to 168 hours and catchments up to 150,000 km^2. Refer BoM, 2003

IFD-curves: Intensity-Frequency-Duration curves, describing the point- or area-rainfall statistics. In the current report rainfall depth is generally used as an alternative to rainfall intensity. Rainfall depth is the product of duration and intensity. It was decided to maintain the term “IFD” as this is the terminology that the reader is most likely to be familiar with

IL: Initial Loss (mm). The amount of rainfall that is intercepted by vegetation or absorbed by the ground and is therefore not converted to runoff during the initial stages of the rainfall event

LOC: Loss of Communications dam operating procedure, refer Flood Manual (Seqwater 2013)

LPIII: Log-Pearson Type III statistical distribution

IQQM: Integrated Quantity and Quality Model for water resources planning

JPA: Joint Probability Approach. A general term for probabilistic methods to establish design flood levels

MCS: Monte Carlo Simulation

MHWS: Mean High Water Spring Tide level

ML: Megalitre. This is a unit of volume used in reservoir studies. A megalitre is equal to 1,000,000 litres or, equivalently, 1,000 m^3

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

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 (EA, 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; EA 2003)

PMP DF: Probable Maximum Precipitation Design Flood – the flood event that results from the PMP event

Quantiles: Values taken at regular intervals from the inverse of the cumulative distribution function (CDF) of a random variable

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

TPT: Total Probability Theorem. This is one of the fundamental theorems in statistics. In this report, TPT refers to a Monte Carlo sampling method that is based on stratified sampling and, hence, makes use of the total probability theorem

URBS: Unified River Basin Simulator. A rainfall runoff routing hydrologic model (Carroll, 2012)

12.2 Study related terms

BCC: Brisbane City Council

BoM: Australian Bureau of Meteorology

BRCFS: Brisbane River Catchment Flood Study

BRCFM: Brisbane River Catchment Floodplain Management Study

BRCFMP: Brisbane River Catchment Floodplain Management Plan

Delft-FEWS: Flood Early Warning Systems, a software package developed by Deltares, initially for the purpose of real-time flood forecasting. Delft-FEWS is used all over the world, including by the Environment Agency (UK) and the National Weather Service (US). Currently, it is also being implemented by Deltares and BoM for flood forecasting in Australia. The Monte Carlo framework for the BRCFS-Hydrology Phase will be implemented in Delft-FEWS

DEWS: Department of Energy and Water Supply

DIG: Dams Implementation Group

DNRM: Department of Natural Resources and Mines

DSITIA: Department of Science Information Technology, Innovation and the Arts

DSDIP: Department of State Development and Infrastructure Planning

EA: Engineers Australia formally known as The Institute of Engineers, Australia

GA: General Adapter, an interface between the Delft-FEWS environment and an external module

IC: Implementation Committee of the BRCFS

ICC: Ipswich City Council

IPE: Independent panel of experts to the BRCFS

LVRC: Lockyer Valley Regional Council

ND: No-dams condition. This scenario represents the catchment condition without the influence of the dams and reservoirs. The reservoir reaches have effectively been returned to their natural condition

NPDOS: North Pine Dam Optimisation Study conducted in response to the QFCOI Final Report

PIG: Planning Implementation Group

QFCOI: Queensland Floods Commission of Inquiry

RTC: Real-Time Control. A software package for simulations of reservoir operation. RTC tools is used for the simulation of Wivenhoe and Somerset reservoirs

SC: Steering Committee of the BRCFS

SRC: Somerset Regional Council

TWG: Technical Working Group

WD: With-dams condition. This scenario represents the catchment condition with the influence of the dams and reservoirs represented in their current (2013) configuration

WSDOS: Wivenhoe and Somerset Dam Optimisation Study conducted in response to the QFCOI Final report

Appendices

Appendix A
Wivenhoe Dam emergency flood procedure

The Tables on the following pages show the radial settings for Wivenhoe Dam for the emergency flood procedure. Table A1 shows the radial settings under "normal" circumstances when all three fuse plugs are in place. Table A2 – Table A4 show the respective radial setting for the cases in which one, two and three fuse plugs have been eroded.

Table A1 Radial gate settings: No fuse plug eroded

Lake Level	Gate 1 Opening	Gate 2 Opening	Gate 3 Opening	Gate 4 Opening	Gate 5 Opening	Total Opening	Discharge	Gate Operated
EL (m)	(m)	(m)	(m)	(m)	(m)	(m)	(m3/s)	
67.00	-	-	-	-	-	-		
67.25	0.0	0.0	0.0	0.0	0.0	0	0	
67.50	0.0	0.0	0.5	0.0	0.0	0.5	50	3
67.75	0.0	0.0	1.0	0.0	0.0	1.0	100	3
68.00	0.0	0.0	1.5	0.0	0.0	1.5	150	3
68.25	0.0	0.0	2.0	0.0	0.0	2.0	210	3
68.50	0.0	0.0	2.5	0.0	0.0	2.5	260	3
68.65	0.0	0.0	3.0	0.0	0.0	3.0	310	3
68.80	0.0	0.0	3.5	0.0	0.0	3.5	360	3
68.95	0.0	0.5	3.5	0.0	0.0	4.0	430	2
69.10	0.0	0.5	3.5	0.5	0.0	4.5	470	4
69.25	0.0	0.5	4.0	0.5	0.0	5.0	520	3
69.40	0.0	1.0	4.0	0.5	0.0	5.5	570	2
69.55	0.0	1.0	4.0	1.0	0.0	6.0	640	4
69.70	0.5	1.0	4.0	1.0	0.0	6.5	700	1
69.85	0.5	1.0	4.0	1.0	0.5	7.0	760	5
70.00	0.5	1.5	4.0	1.0	0.5	7.5	820	2
70.15	0.5	1.5	4.0	1.5	0.5	8.0	880	4
70.30	1.0	1.5	4.0	1.5	0.5	8.5	940	1
70.45	1.0	1.5	4.0	1.5	1.0	9.0	1,000	5
70.60	1.0	2.0	4.0	1.5	1.0	9.5	1,070	2
70.70	1.0	2.0	4.0	2.0	1.0	10.0	1,130	4
70.80	1.5	2.0	4.0	2.0	1.0	10.5	1,190	1
70.90	1.5	2.0	4.0	2.0	1.5	11.0	1,250	5
71.00	1.5	2.5	4.0	2.0	1.5	11.5	1,310	2
71.10	1.5	2.5	4.0	2.5	1.5	12.0	1,370	4
71.20	1.5	2.5	4.5	2.5	1.5	12.5	1,430	3
71.30	2.0	2.5	4.5	2.5	1.5	13.0	1,500	1
71.40	2.0	2.5	4.5	2.5	2.0	13.5	1,560	5

Lake Level EL (m)	Gate 1 Opening (m)	Gate 2 Opening (m)	Gate 3 Opening (m)	Gate 4 Opening (m)	Gate 5 Opening (m)	Total Opening (m)	Discharge (m3/s)	Gate Operated
71.50	2.5	2.5	4.5	2.5	2.0	14.0	1,620	1
71.60	2.5	2.5	4.5	2.5	2.5	14.5	1,680	5
71.70	2.5	3.0	4.5	2.5	2.5	15.0	1,750	2
71.80	2.5	3.0	4.5	3.0	2.5	15.5	1,810	4
71.90	2.5	3.5	4.5	3.0	2.5	16.0	1,870	2
72.00	2.5	3.5	4.5	3.5	2.5	16.5	1,930	4
72.10	3.0	3.5	4.5	3.5	2.5	17.0	2,000	1
72.20	3.0	3.5	4.5	3.5	3.0	17.5	2,060	5
72.30	3.0	4.0	4.5	3.5	3.0	18.0	2,130	2
72.40	3.0	4.0	4.5	4.0	3.0	18.5	2,190	4
72.50	3.0	4.0	5.0	4.0	3.0	19.0	2,250	3
72.55	3.5	4.0	5.0	4.0	3.0	19.5	2,310	1
72.60	3.5	4.0	5.0	4.0	3.5	20.0	2,370	5
72.65	3.5	4.5	5.0	4.0	3.5	20.5	2,430	2
72.70	3.5	4.5	5.0	4.5	3.5	21.0	2,490	4
72.75	4.0	4.5	5.0	4.5	3.5	21.5	2,550	1
72.80	4.0	4.5	5.0	4.5	4.0	22.0	2610	5
72.85	4.5	4.5	5.0	4.5	4.0	22.5	2670	1
72.90	4.5	4.5	5.0	4.5	4.5	23.0	2740	5
72.95	4.5	5.0	5.0	5.0	4.5	24.0	2850	2,4
73.00	5.0	5.0	5.0	5.0	5.0	25.0	2970	1,5
73.10	5.0	5.0	5.5	5.0	5.0	25.5	3030	3
73.20	5.0	5.5	5.5	5.5	5.0	26.5	3130	2,4
73.30	5.5	5.5	5.5	5.5	5.5	27.5	3280	1,5
73.40	5.5	5.5	6.0	5.5	5.5	28.0	3340	3
73.50	5.5	6.0	6.0	6.0	5.5	29.0	3460	2,4
73.60	6.0	6.0	6.0	6.0	6.0	30.0	3590	1,5
73.70	6.0	6.0	6.5	6.0	6.0	30.5	3680	3
73.80	6.0	6.5	6.5	6.5	6.0	31.5	3780	2,4
73.90	6.5	6.5	6.5	6.5	6.5	32.5	3900	1,5
74.00	6.5	6.5	7.0	6.5	6.5	33.0	3970	3
74.10	7.0	7.0	7.0	7.0	7.0	35.0	4210	1,2,4,5
74.20	7.5	7.5	7.5	7.5	7.5	37.5	4510	1,2,3,4,5
74.30	8.0	8.0	8.0	8.0	8.0	40.0	4810	1,2,3,4,5

Lake Level	Gate 1 Opening	Gate 2 Opening	Gate 3 Opening	Gate 4 Opening	Gate 5 Opening	Total Opening	Discharge	Gate Operated
EL (m)	(m)	(m)	(m)	(m)	(m)	(m)	(m3/s)	
74.40	8.5	8.5	8.5	8.5	8.5	42.5	5110	1,2,3,4,5
74.50	9.0	9.0	9.0	9.0	9.0	45.0	5430	1,2,3,4,5
74.60	9.5	9.5	9.5	9.5	9.5	47.5	5750	1,2,3,4,5
74.70	10.0	10.0	10.0	10.0	10.0	50.0	6070	1,2,3,4,5
74.80	11.0	11.0	11.0	11.0	11.0	55.0	6740	1,2,3,4,5
74.90	12.0	12.0	12.0	12.0	12.0	60.0	7440	1,2,3,4,5
75.00	13.0	13.0	13.0	13.0	13.0	65.0	8200	1,2,3,4,5
75.10	14.0	14.0	14.0	14.0	14.0	70.0	9010	1,2,3,4,5
75.20	15.0	15.0	15.0	15.0	15.0	75.0	9880	1,2,3,4,5
75.30	17.5	17.5	17.5	17.5	17.5	Fully Open	10160	1,2,3,4,5
75.40	17.5	17.5	17.5	17.5	17.5	Fully Open	10250	
75.50	17.5	17.5	17.5	17.5	17.5	Fully Open	10340	

Table A2 Radial gate settings: One fuse plug eroded

Lake Level m+AHD	Radial gate 1 Opening m	Radial gate 2 Opening m	Radial gate 3 Opening m	Radial gate 4 Opening m	Radial gate 5 Opening m	Outflow (m^3/s)
67.00	0	0	0	0	0	0
67.75	0	0	0.5	0	0	100
68.25	0	0	1	0	0	209
68.75	0	0	1.5	0	0	332
69.00	0	0	2	0	0	425
69.25	0	0	2.5	0	0	519
69.50	0	0	3	0	0	616
69.75	0	0	3.5	0	0	716
70.00	0	0.5	3.5	0	0	823
70.25	0	0.5	3.5	0.5	0	931
70.50	0	0.5	4	0.5	0	1037
70.75	0	1	4	0.5	0	1153
71.00	0	1	4	1	0	1270
71.25	0.5	1	4	1	0.5	1448
71.50	0.5	1.5	4	1.5	0.5	1630
71.75	1	1.5	4	1.5	1	1815
72.00	1	2	4	2	1	2004
72.25	1.5	2	4	2	1.5	2197
72.50	1.5	2.5	4	2.5	1.5	2388
72.75	2	2.5	4	2.5	2	2580
73.00	2.5	2.5	4	2.5	2.5	2787
73.25	2.5	3	4	3	2.5	2988

Lake Level m+AHD	Radial gate 1 Opening m	Radial gate 2 Opening m	Radial gate 3 Opening m	Radial gate 4 Opening m	Radial gate 5 Opening m	Outflow (m^3/s)
73.50	3	3.5	4	3.5	3	3308
73.75	3.5	3.5	4	3.5	3.5	3517
74.00	4	4	4	4	4	3844
74.10	4.5	4.5	4.5	4.5	4.5	4170
74.20	5	5	5	5	5	4496
74.30	5.5	5.5	5.5	5.5	5.5	4817
74.40	6	6	6	6	6	5143
74.50	6.5	6.5	6.5	6.5	6.5	5464
74.60	7	7	7	7	7	5790
74.70	7.5	7.5	7.5	7.5	7.5	6116
74.80	8.5	8.5	8.5	8.5	8.5	6743
74.90	9.5	9.5	9.5	9.5	9.5	7394
75.00	10.5	10.5	10.5	10.5	10.5	8071
75.10	12	12	12	12	12	9142
75.20	13	13	13	13	13	9934
75.30	13.5	13.5	13.5	13.5	13.5	10380
75.40	13.5	13.5	13.5	13.5	13.5	10437
75.50	13.5	13.5	13.5	13.5	13.5	10498
75.60	13.5	13.5	13.5	13.5	13.5	10555
75.70	15	15	15	15	15	11877
75.80	Fully open	Fully open	Fully open	Fully open	Fully open	12433
>75.80	Fully open	Fully open	Fully open	Fully open	Fully open	12555

Table A3 Radial gate settings: two fuse plug eroded

Lake Level m+AHD	Target Outflow (m^3/s)	Radial gate opening (all gates) (m)	Total radial gate opening (all gates) (m)
≤72.5	2769	0	0
72.5	3074	0.5	2.5
73	3771	1.0	5
73.5	4494	1.5	7.5
74	5232	2.0	10
74.1	5313	2.0	10
74.2	5394	2.0	10
74.3	5475	2.0	10
74.4	5871	2.5	12.5
74.5	5953	2.5	12.5

Lake Level m+AHD	Target Outflow (m^3/s)	Radial gate opening (all gates) (m)	Total radial gate opening (all gates) (m)
74.6	6030	2.5	12.5
74.7	6111	2.5	12.5
74.8	6818	3.5	17.5
74.9	7511	4.5	22.5
75	8188	5.5	27.5
75.1	9155	7	35
75.2	9838	8	40
75.3	10231	8.5	42.5
75.4	10324	8.5	42.5
75.5	10421	8.5	42.5
75.6	10514	8.5	42.5
75.7	12228	11	55
75.8	12331	11	55
75.9	12434	11	55
76	12532	11	55
76.1	12998	11.5	57.5
76.2	14623	13.5	67.5
76.3	16829	Fully open	Fully Open

Table A4 Radial gate settings: three fuse plug eroded

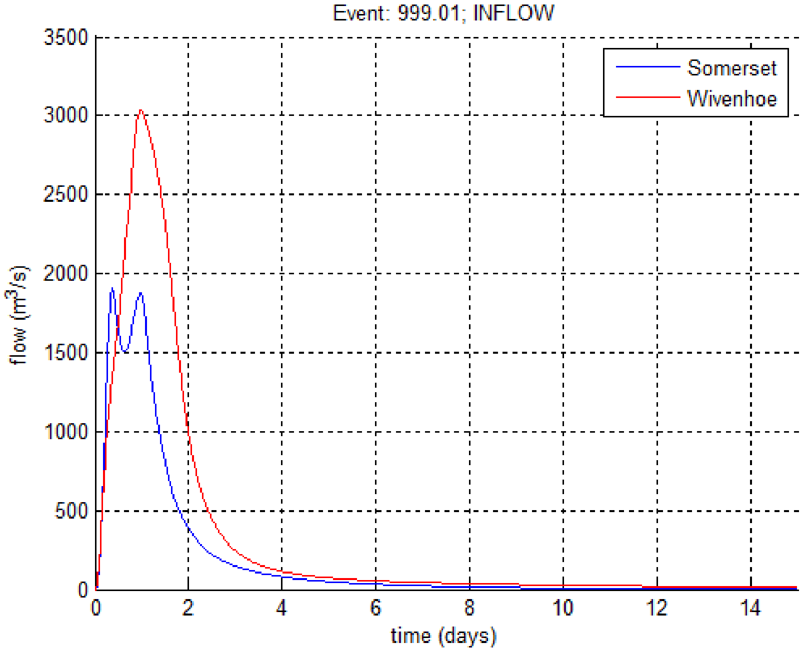
Lake Level m+AHD	Target Outflow (m^3/s)	Radial gate opening (all gates) (m)	Total radial gate opening (all gates) (m)
≤72.5	4564#	0	0
72.5	4869	0.5	2.5
73	5814	1.0	5
73.5	6795	1.5	7.5
74	7800	2.0	10
74.1	7930	2.0	10
74.2	8060	2.0	10
74.3	8191	2.0	10
74.4	8637	2.5	12.5
74.5	8768	2.5	12.5
74.6	8895	2.5	12.5
74.7	9026	2.5	12.5
74.8	9473	3.0	15
74.9	9610	3.0	15

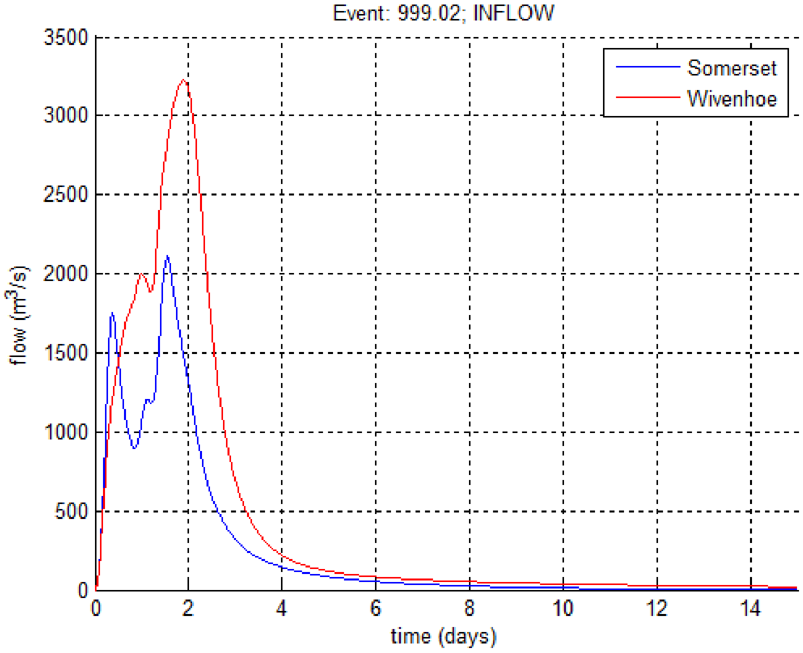
Lake Level m+AHD	Target Outflow (m^3/s)	Radial gate opening (all gates) (m)	Total radial gate opening (all gates) (m)
75	9743	3.0	15
75.1	9876	3.0	15
75.2	10323	3.5	17.5
75.3	10456	3.5	17.5
75.4	10590	3.5	17.5
75.5	10728	3.5	17.5
75.6	11172	4.0	20
75.7	12225	5.5	27.5
75.8	12364	5.5	27.5
75.9	12503	5.5	27.5
76	12642	5.5	27.5
76.1	12798	5.5	27.5
76.2	12949	5.5	27.5
76.3	16955	11.5	57.5
76.4	17122	11.5	57.5
76.5	17289	11.5	57.5
76.6	17457	11.5	57.5
76.7	17625	11.5	57.5
76.8	21744	Fully open	Fully Open

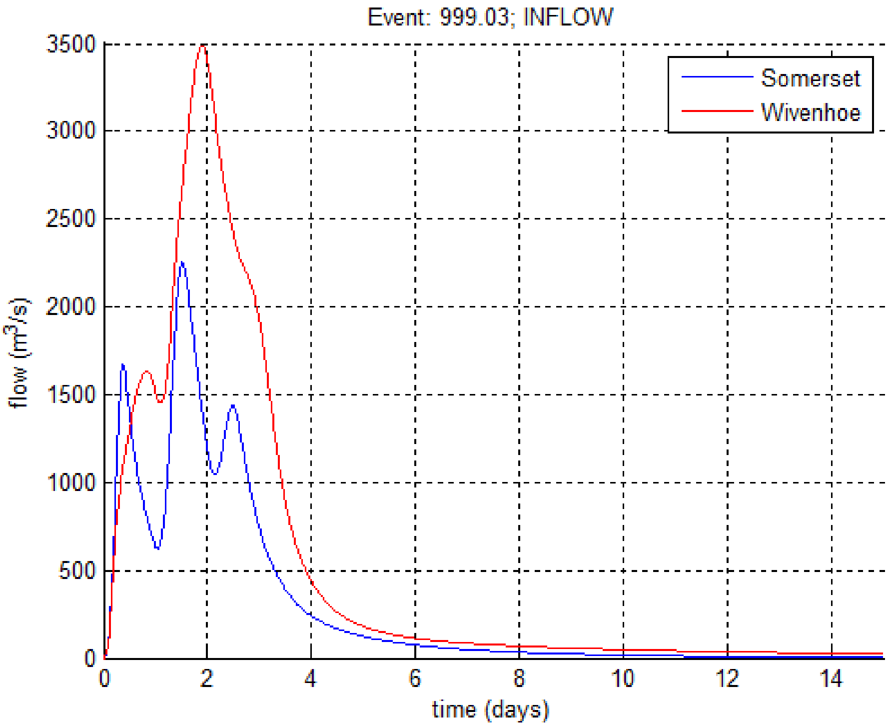
Appendix B
Benchmark test results

This appendix shows figures in which simulated Wivenhow outflow discharges of the RTC tools and GoldSim reservoir models are compared for 24 synthetic events ranging from moderate to extreme flood events. First, inflow series for Someerset Dam and Wivenhoe Dam for the simulated sythetic events are shown. Note that Wivenhoe Dam inflow series are Upper Brisbane River flows, excluding Somerset Dam outflows.

Somerset and Wivenhoe inflow series



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Somerset
Wivenhoe
flow (m3/s)
time (days)
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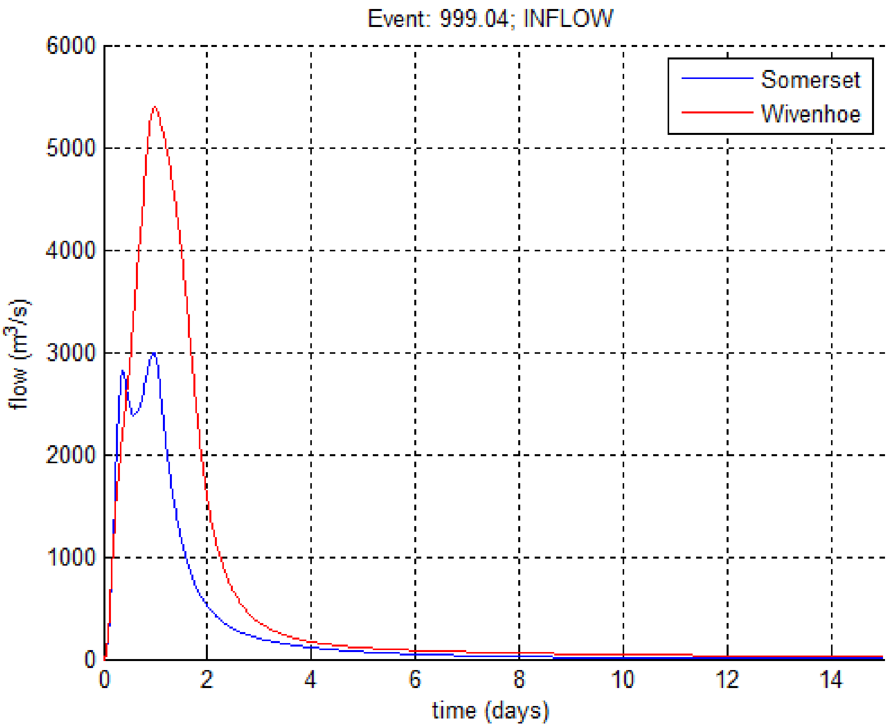
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14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Somerset
Wivenhoe
flow (m3/s)
time (days)
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5000
4000
3000
2000
1000
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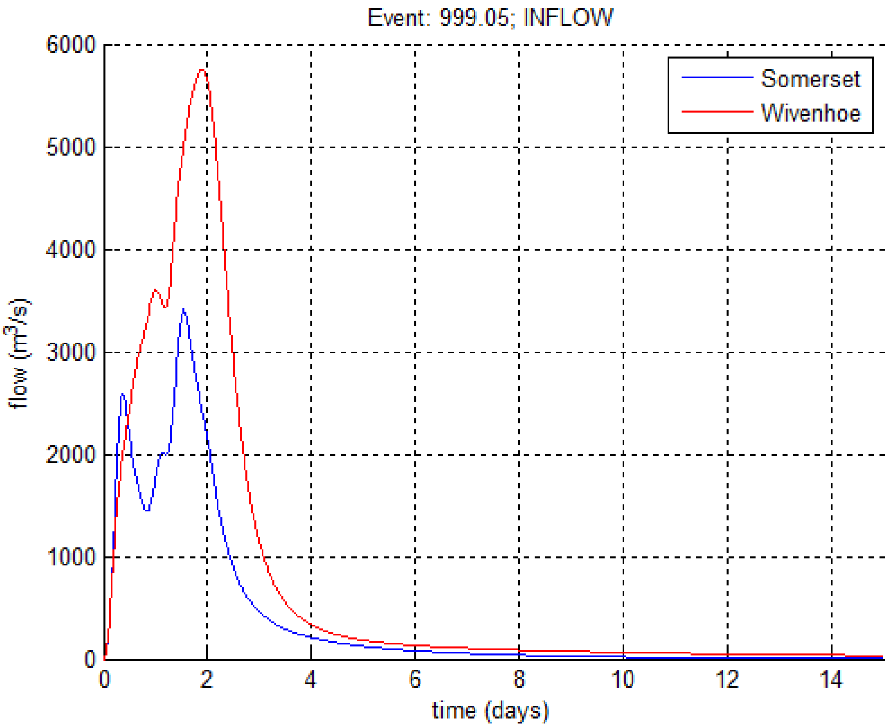
0
2
4
6
8
10
12
14



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Somerset
Wivenhoe
flow (m^3/s)
time (days)
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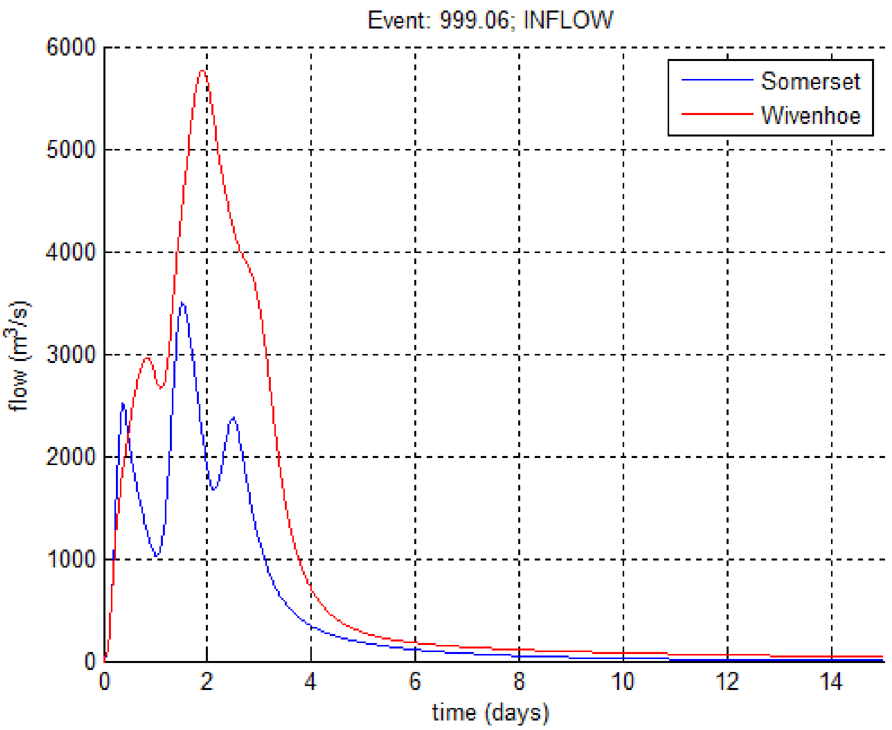
1000
2000
3000
4000
5000
6000
0
2
4
6
8
10
12
14



Event: 999.06; INFLOW
Somerset
Wivenhoe
flow (m^3/s)
time (days)
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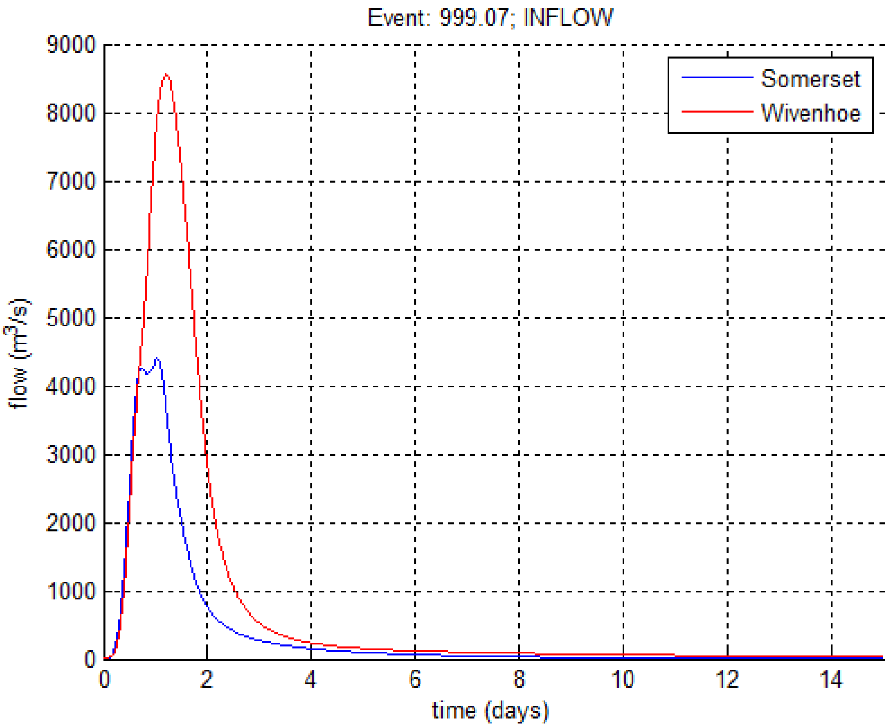
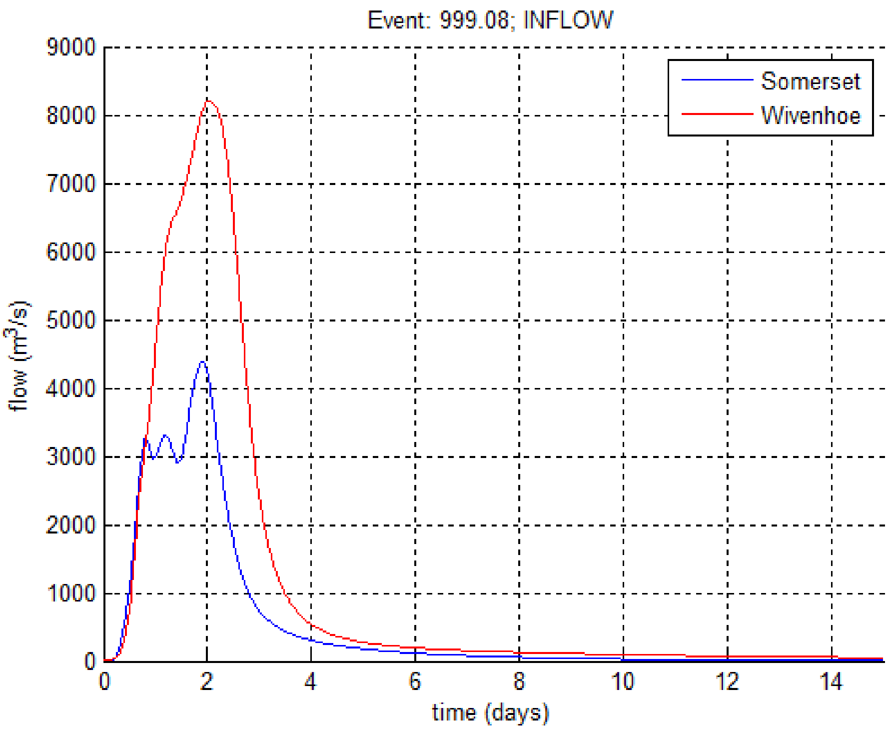
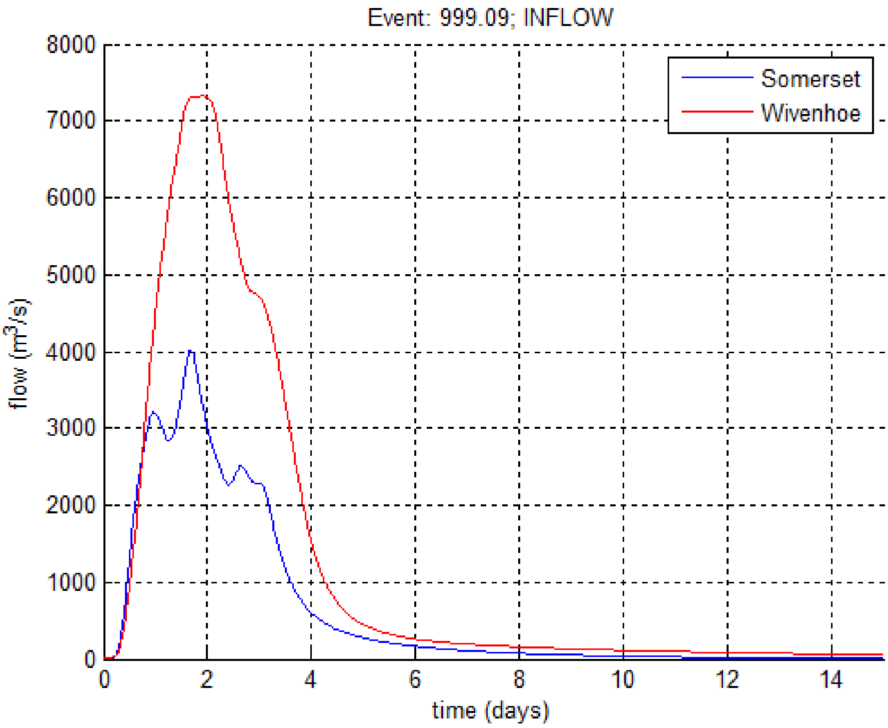
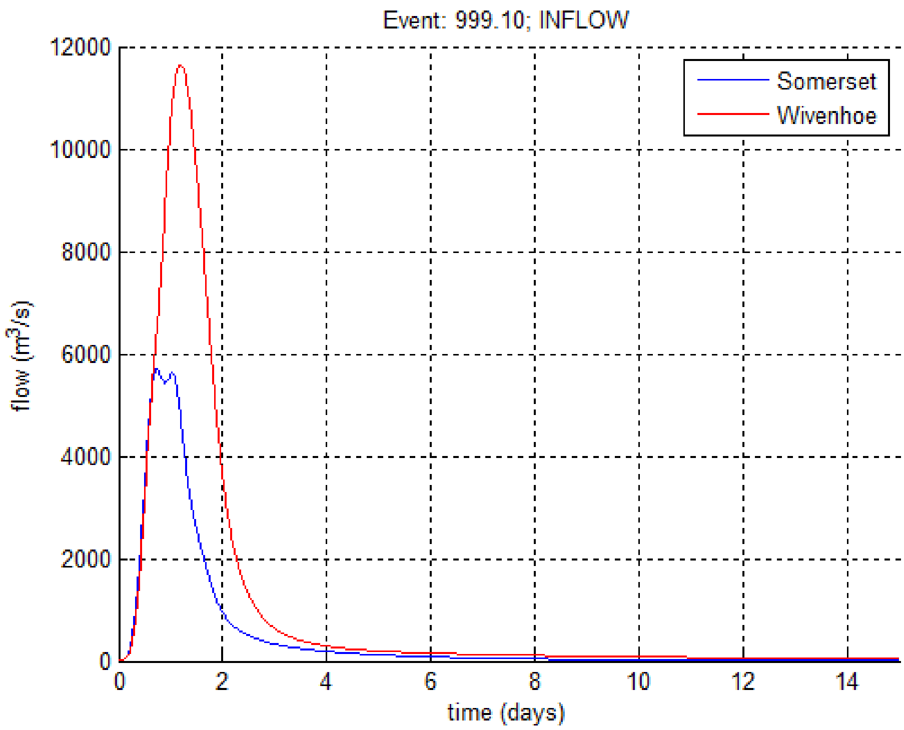
1000
2000
3000
4000
5000
6000
0
2
4
6
8
10
12
14


Event: 999.07; INFLOW
Somerset
Wivenhoe
flow (m3/s)
time (days)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
2
4
6
8
10
12
14

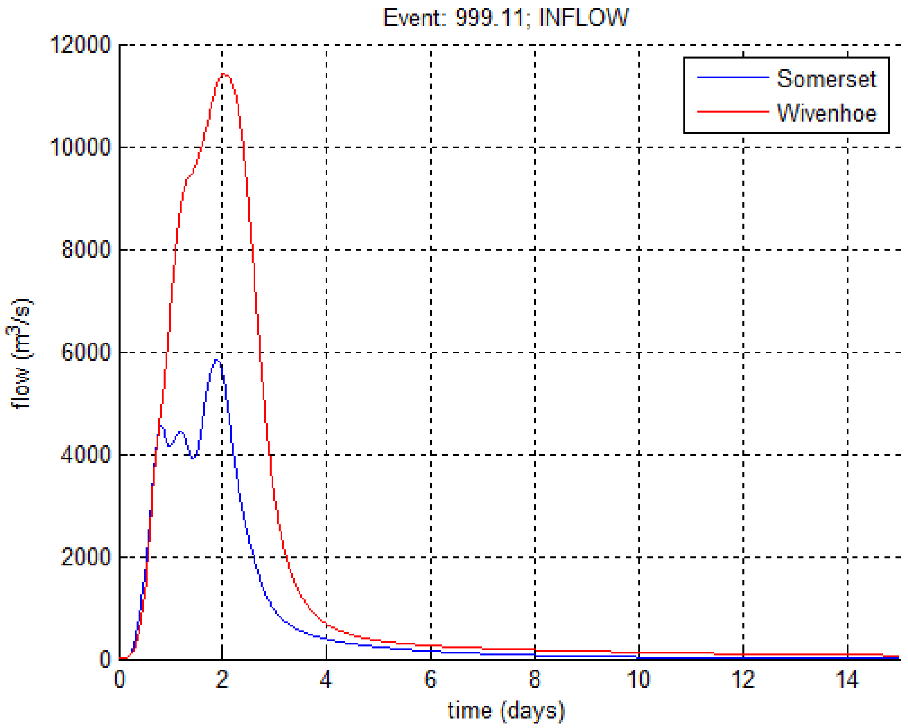

Event: 999.08; INFLOW
Somerset
Wivenhoe
flow (m3/s)
time (days)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
2
4
6
8
10
12
14

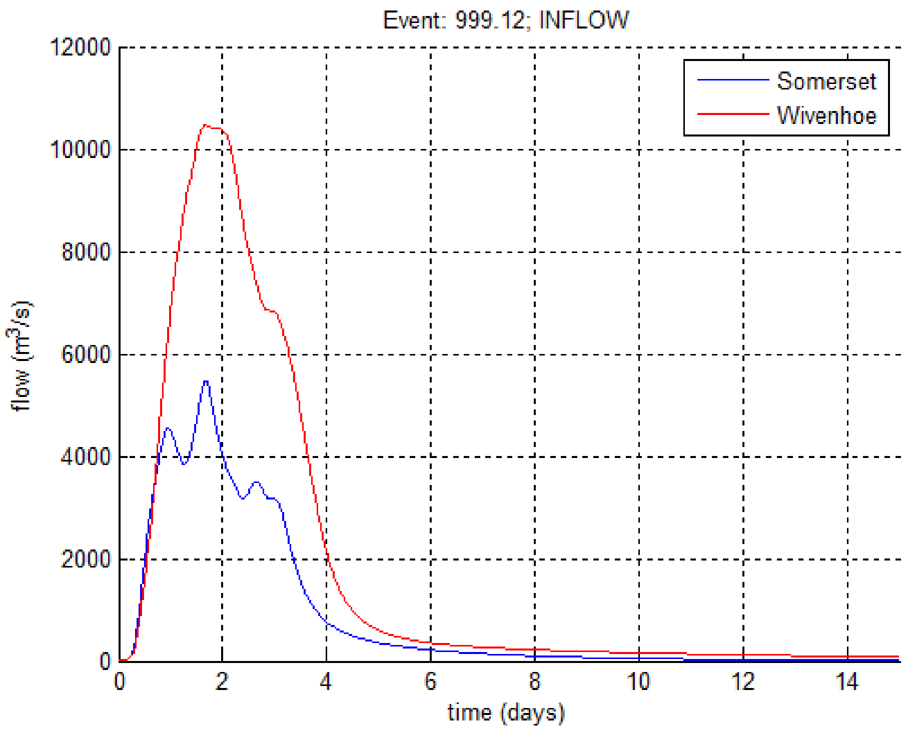


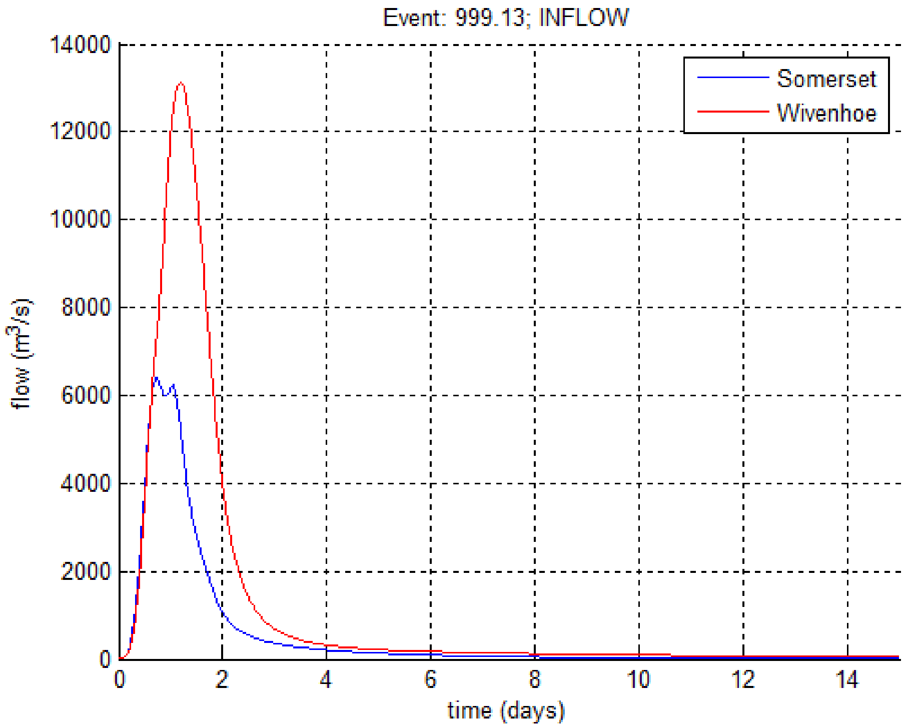
Event: 999.09; INFLOW
flow (m3/s)
time (days)
Somerset
Wivenhoe
0
1000
2000
3000
4000
5000
6000
7000
8000
0
2
4
6
8
10
12
14

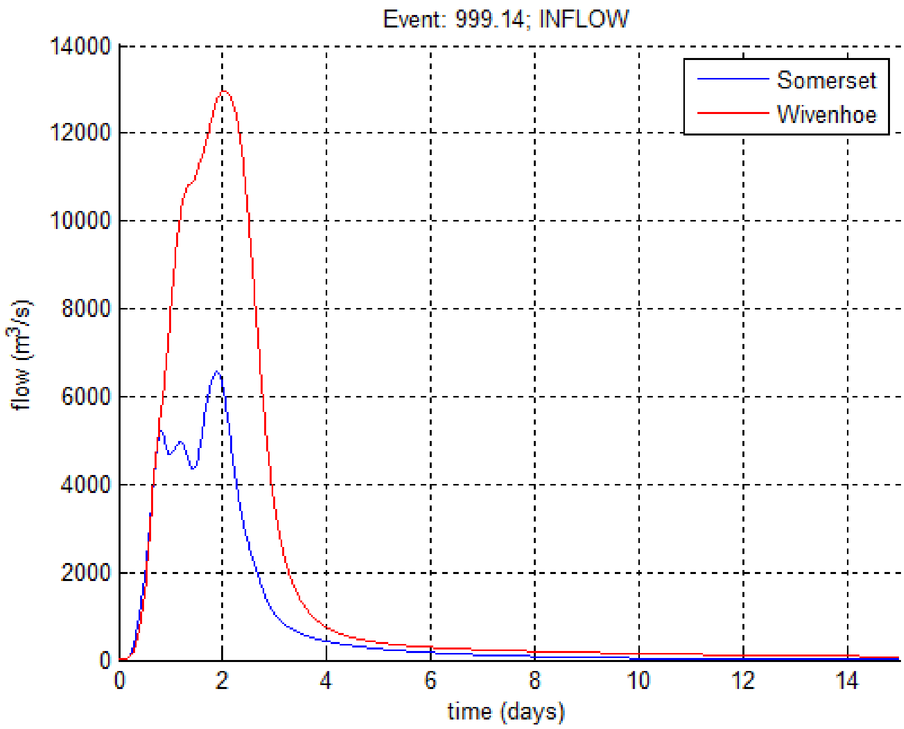


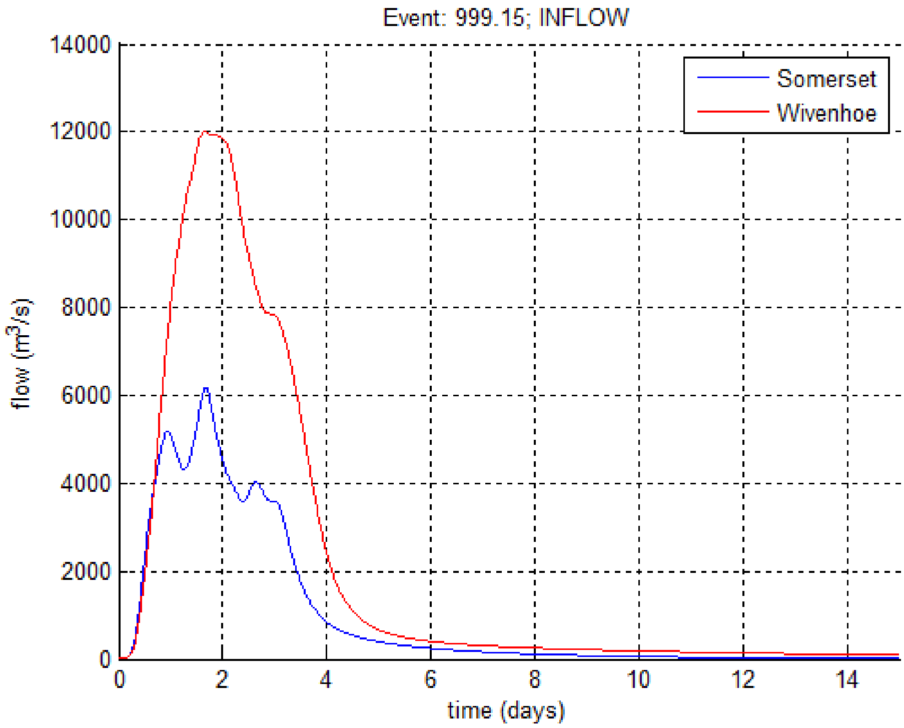
Event: 999.10; INFLOW
flow (m3/s)
time (days)
Somerset
Wivenhoe
0
2000
4000
6000
8000
10000
12000
0
2
4
6
8
10
12
14

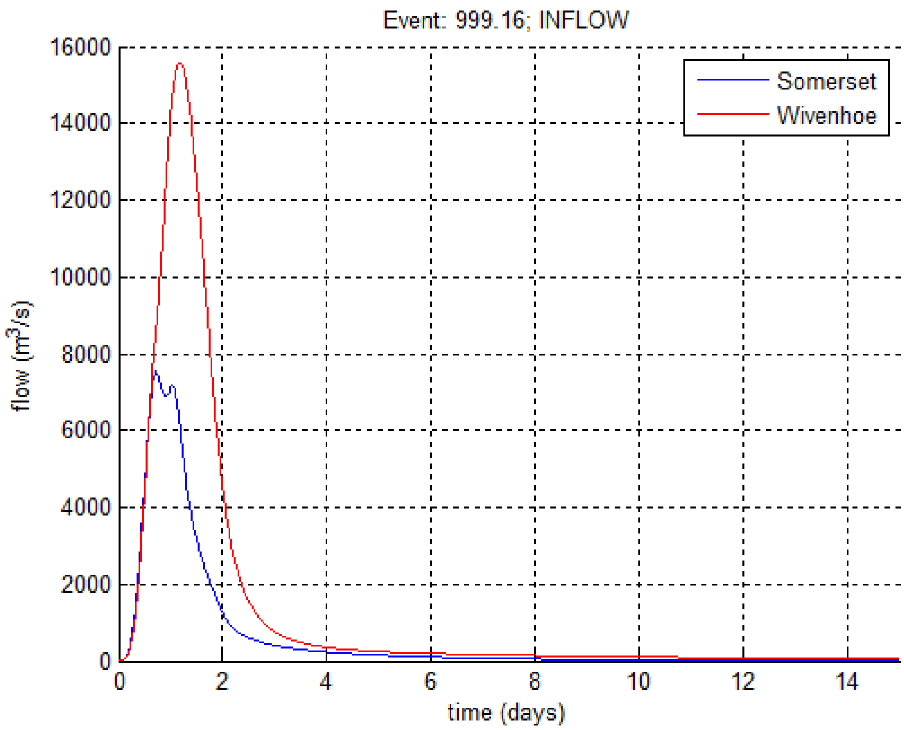

Event: 999.11; INFLOW
Somerset
Wivenhoe
flow (m3/s)
time (days)
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14

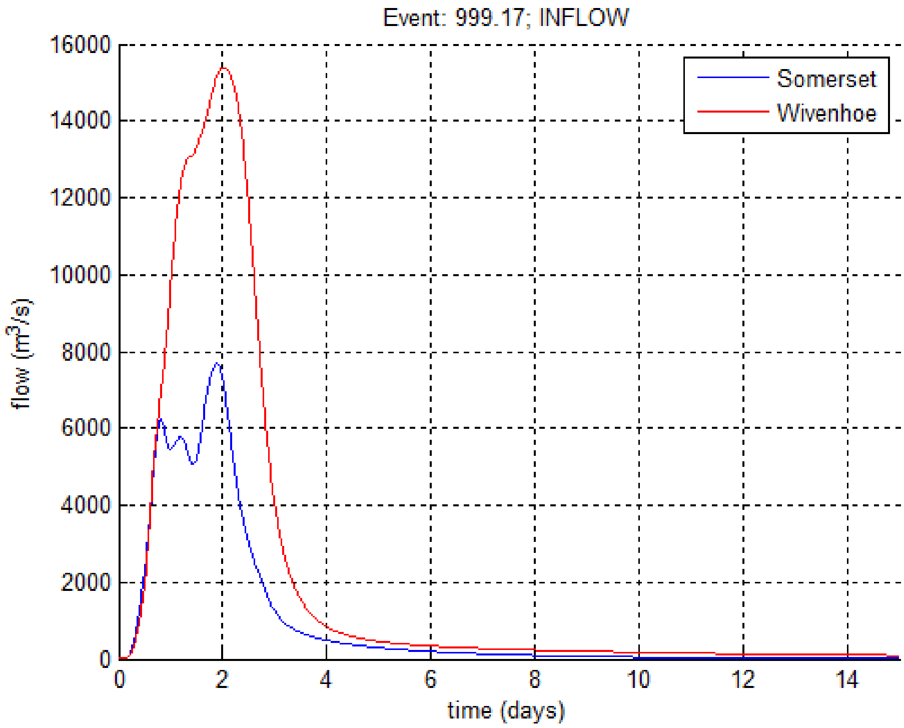

Event: 999.12; INFLOW
Somerset
Wivenhoe
flow (m3/s)
time (days)
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14

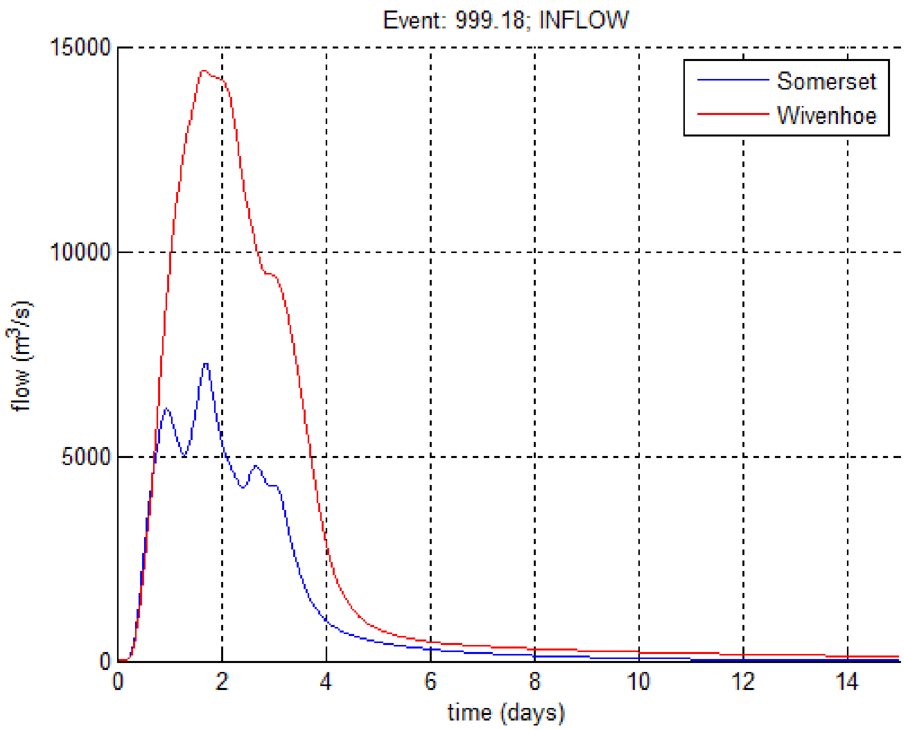

Event: 999.13; INFLOW
flow (m3/s)
time (days)
Somerset
Wivenhoe
0
2000
4000
6000
8000
10000
12000
14000
0
2
4
6
8
10
12
14

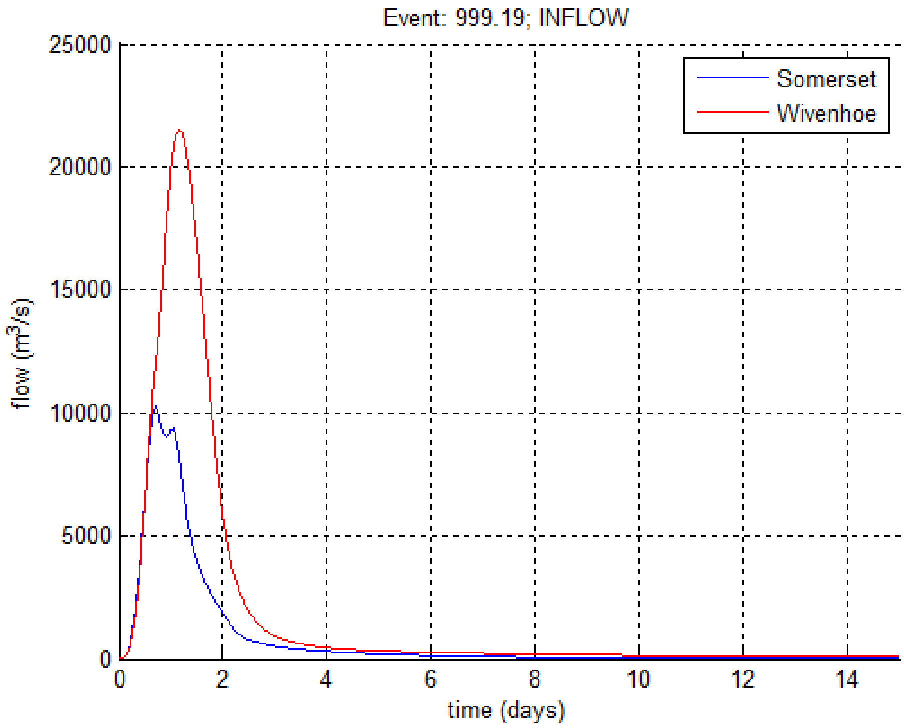

Event: 999.14; INFLOW
flow (m3/s)
time (days)
Somerset
Wivenhoe
0
2000
4000
6000
8000
10000
12000
14000
0
2
4
6
8
10
12
14

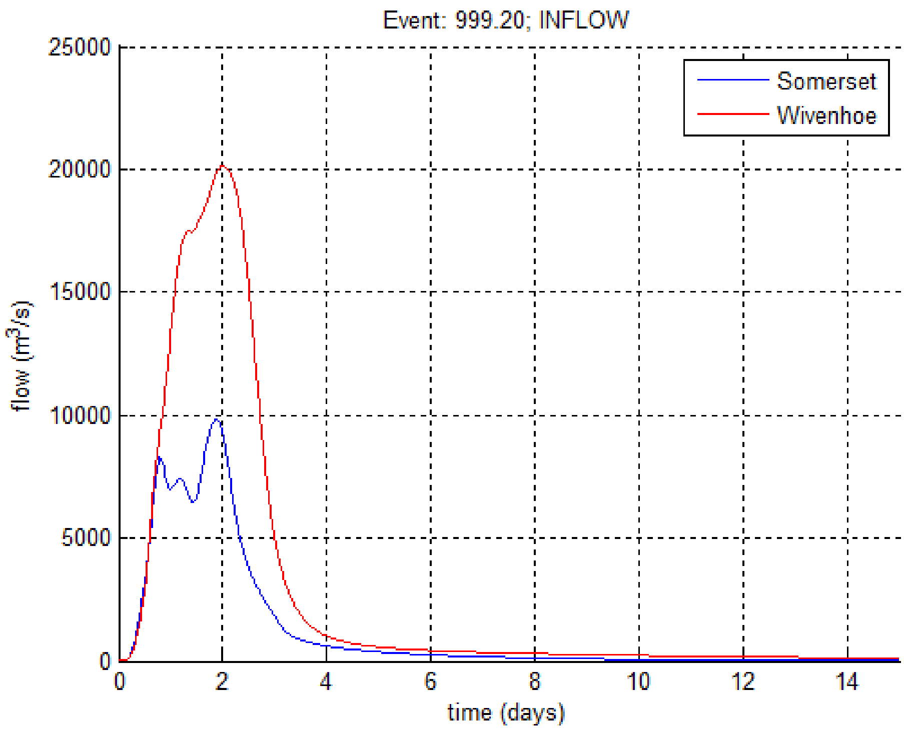

Event: 999.15; INFLOW
Somerset
Wivenhoe
flow (m3/s)
time (days)
0
2000
4000
6000
8000
10000
12000
14000
0
2
4
6
8
10
12
14

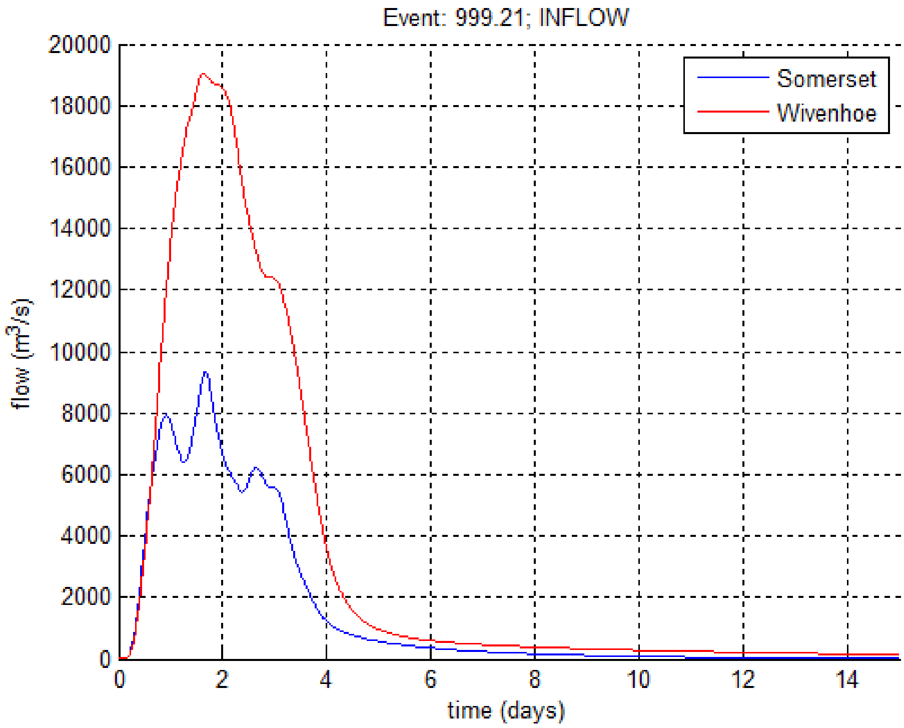

Event: 999.16; INFLOW
Somerset
Wivenhoe
flow (m3/s)
time (days)
0
2000
4000
6000
8000
10000
12000
14000
16000
0
2
4
6
8
10
12
14

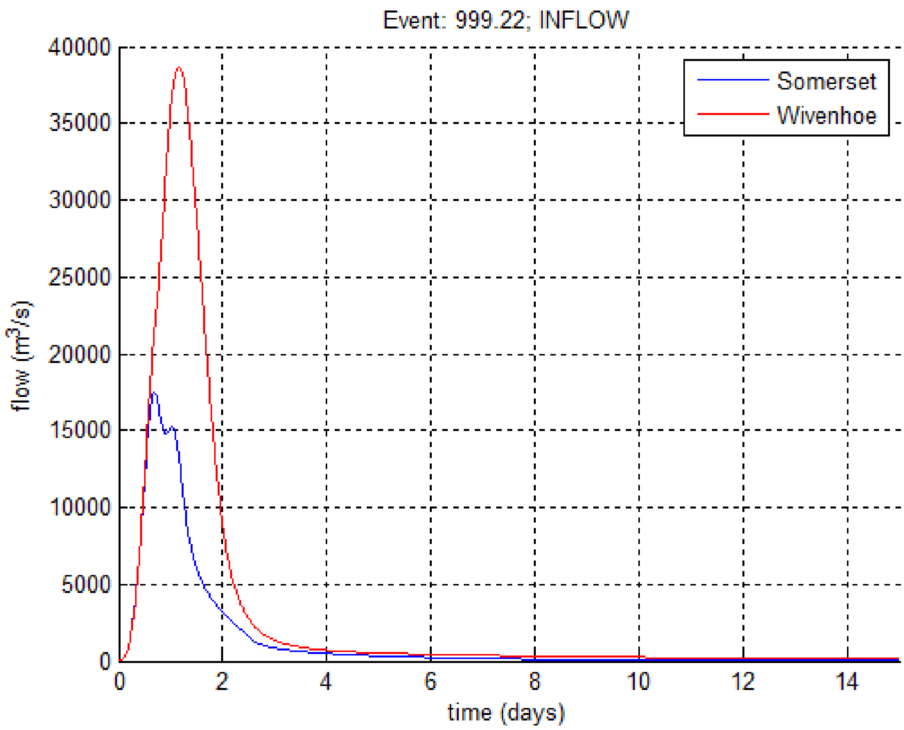

Event: 999.17; INFLOW
16000
14000
12000
10000
8000
6000
4000
2000
0
flow (m3/s)
0
2
4
6
8
10
12
14
time (days)
Somerset
Wivenhoe

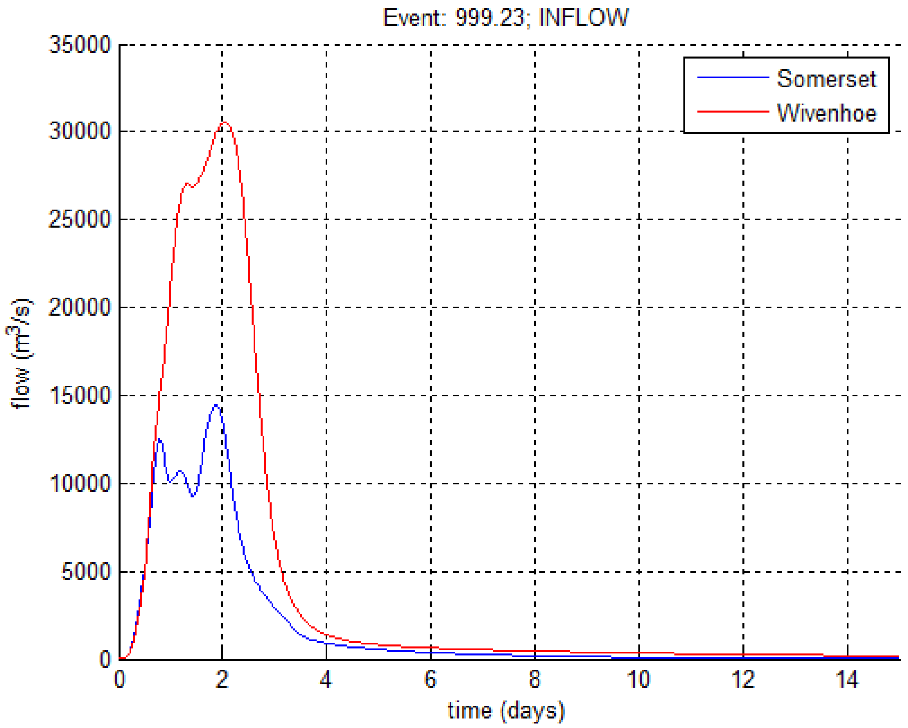

Event: 999.18; INFLOW
15000
10000
5000
0
flow (m3/s)
0
2
4
6
8
10
12
14
time (days)
Somerset
Wivenhoe

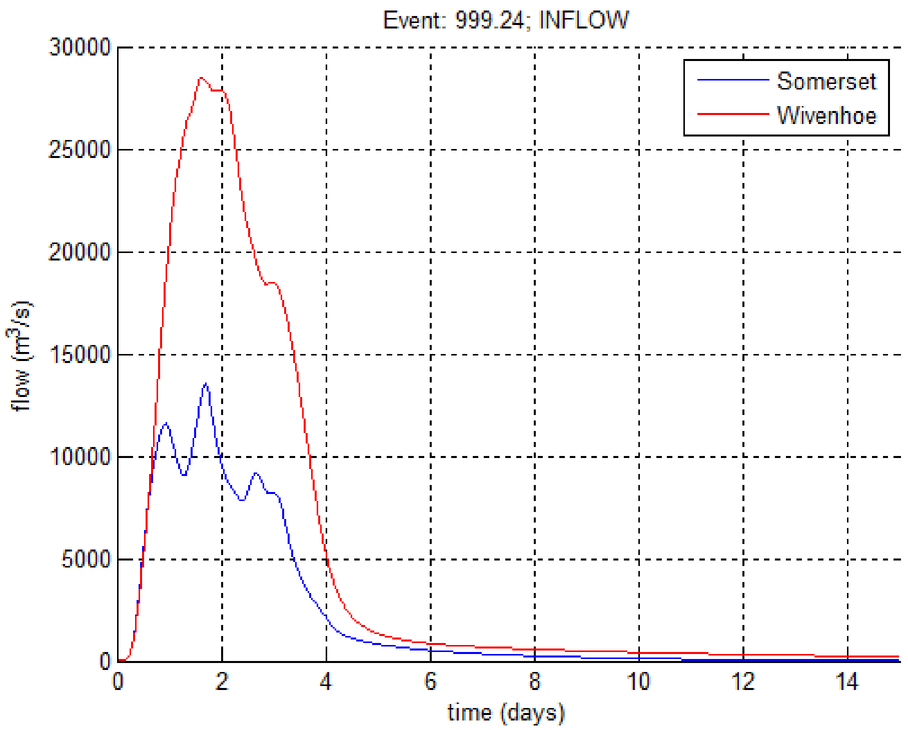

Event: 999.19; INFLOW
Somerset
Wivenhoe
flow (m3/s)
25000
20000
15000
10000
5000
0
0
2
4
6
8
10
12
14
time (days)


Event: 999.20; INFLOW
Somerset
Wivenhoe
flow (m3/s)
25000
20000
15000
10000
5000
0
0
2
4
6
8
10
12
14
time (days)

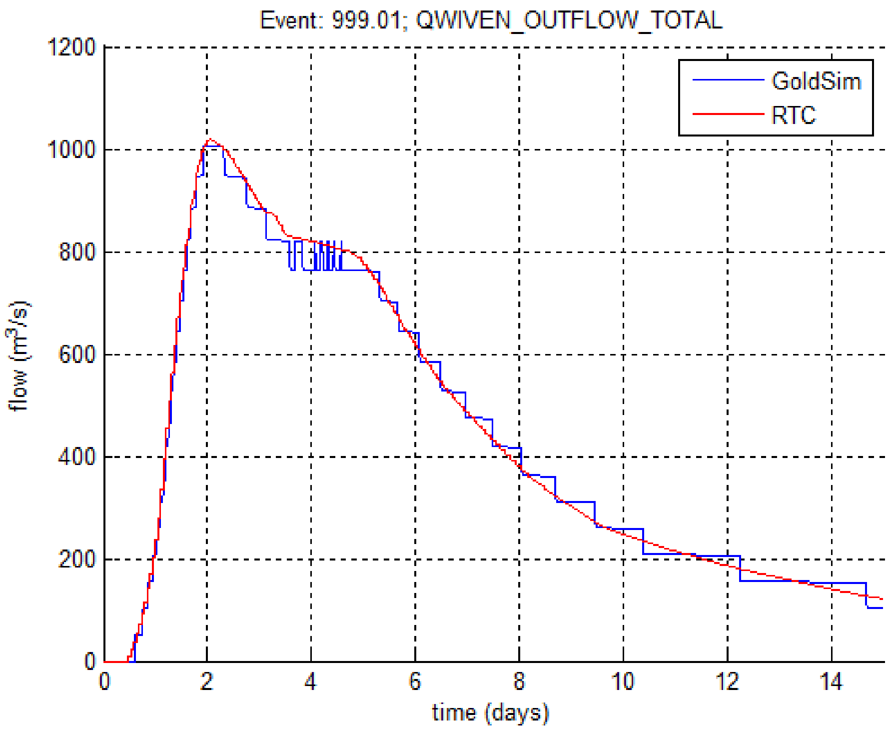

Event: 999.21; INFLOW
flow (m3/s)
time (days)
Somerset
Wivenhoe
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
0
2
4
6
8
10
12
14

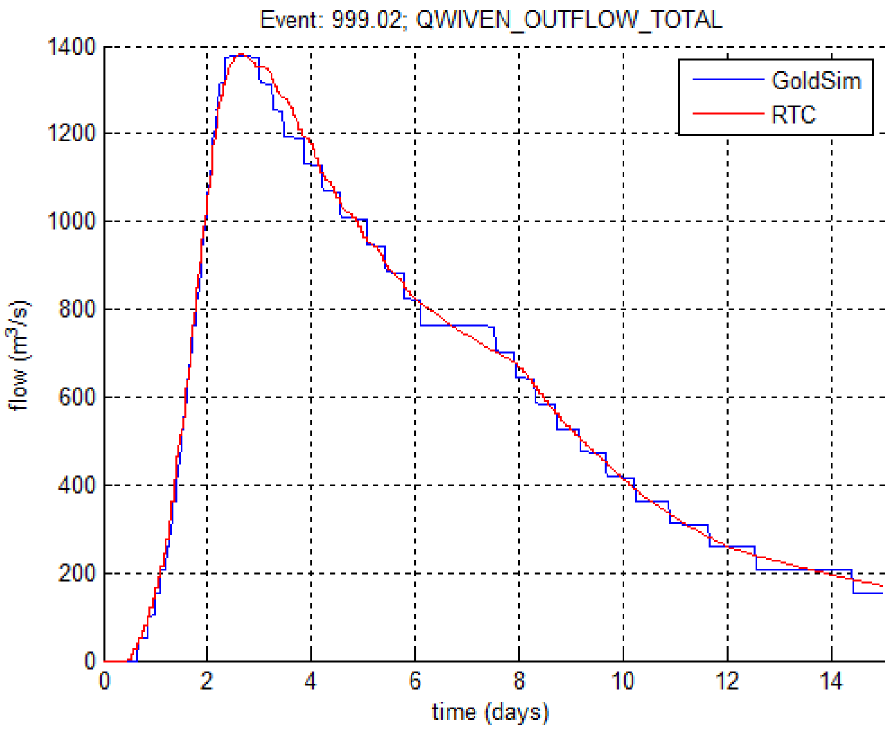

Event: 999.22; INFLOW
flow (m3/s)
time (days)
Somerset
Wivenhoe
0
5000
10000
15000
20000
25000
30000
35000
40000
0
2
4
6
8
10
12
14

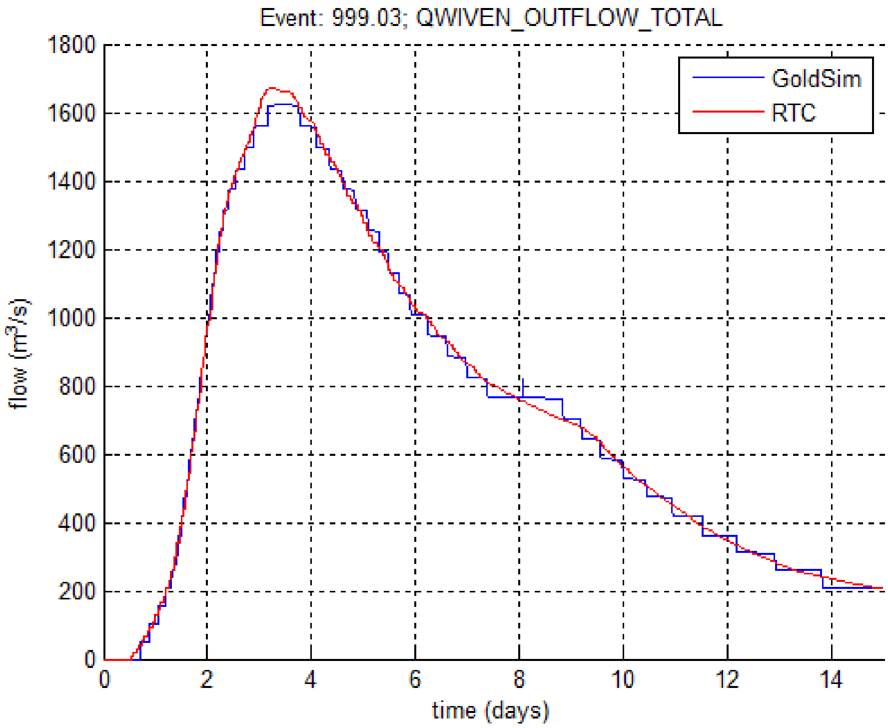

Event: 999.23; INFLOW
Somerset
Wivenhoe
flow (m3/s)
time (days)

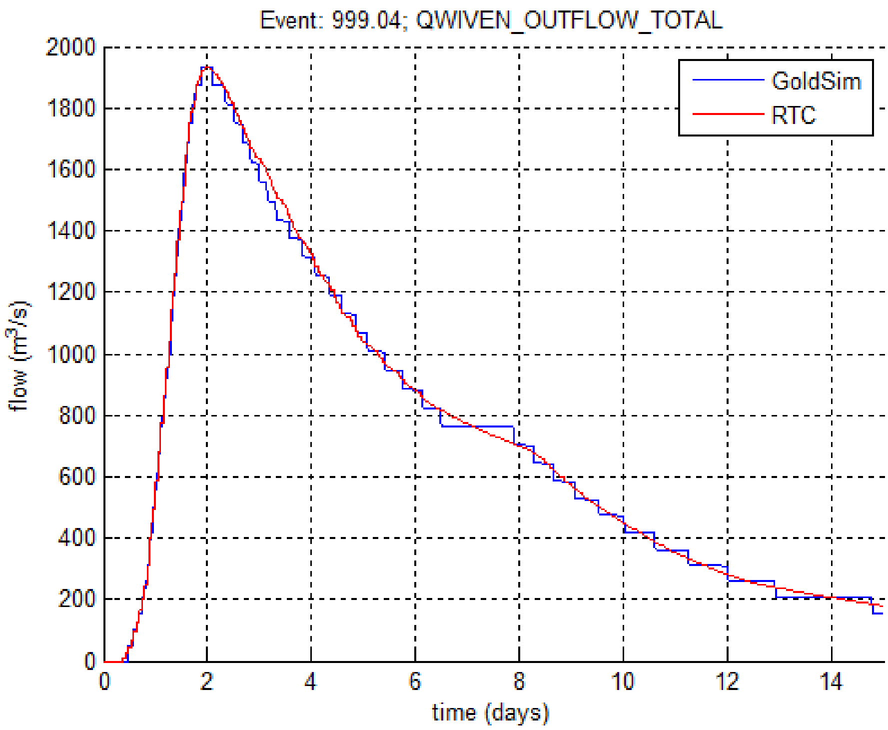

Event: 999.24; INFLOW
Somerset
Wivenhoe
flow (m3/s)
time (days)

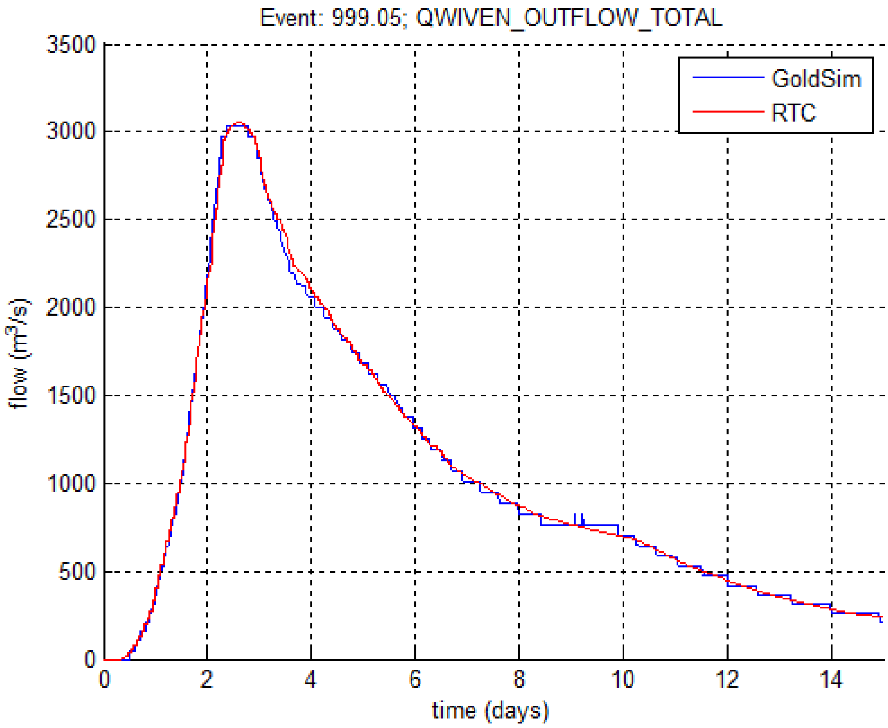
Wivenhoe Dam outflow series

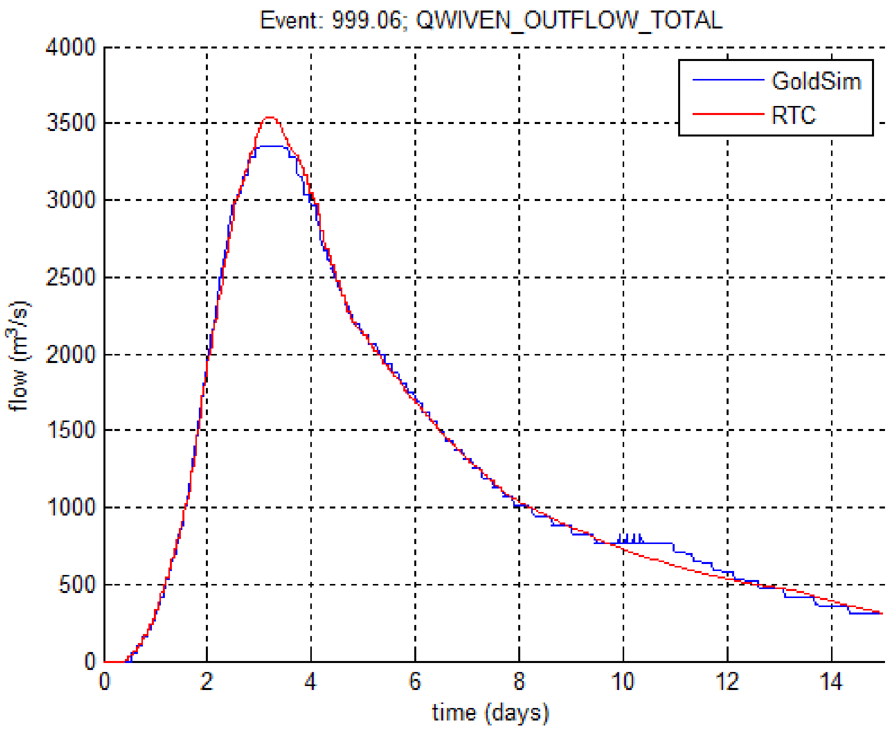


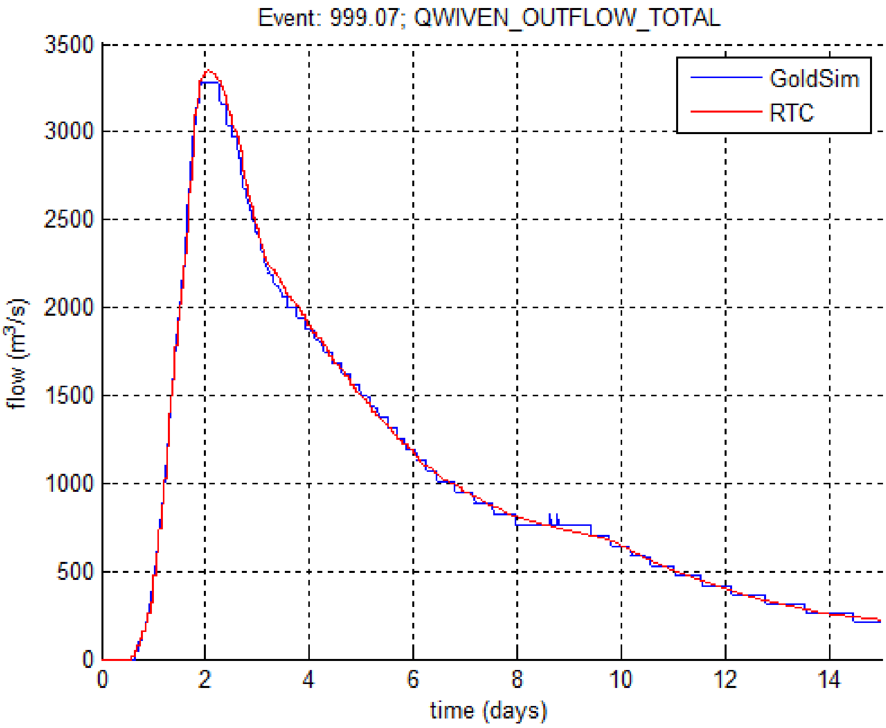


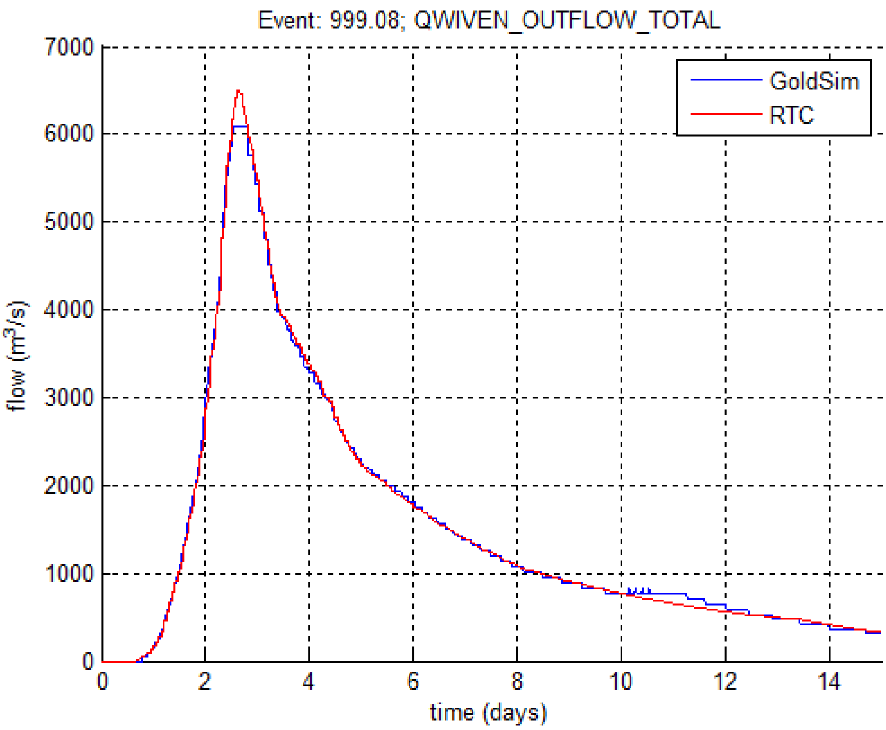

Event: 999.03; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
0
200
400
600
800
1000
1200
1400
1600
1800
0
2
4
6
8
10
12
14

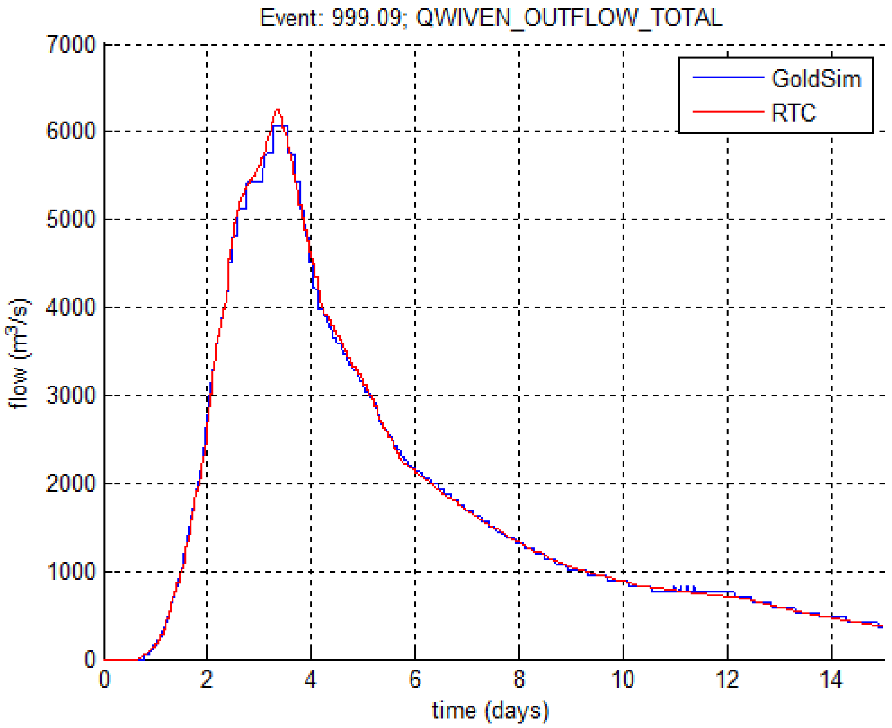

Event: 999.04; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
2
4
6
8
10
12
14

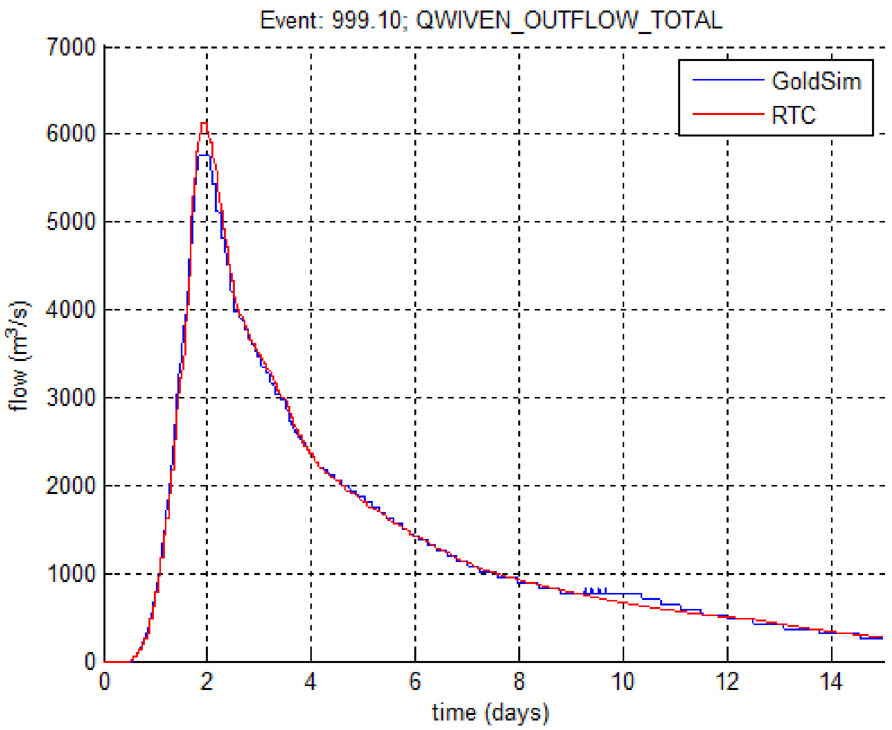

Event: 999.05; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m^3/s)
time (days)

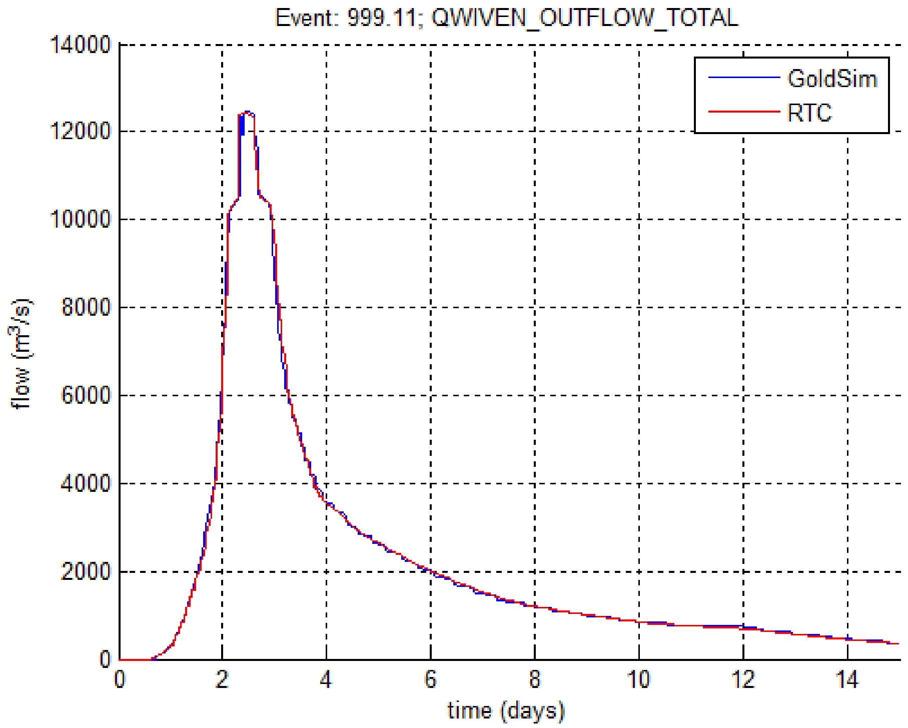

Event: 999.06; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m^3/s)
time (days)

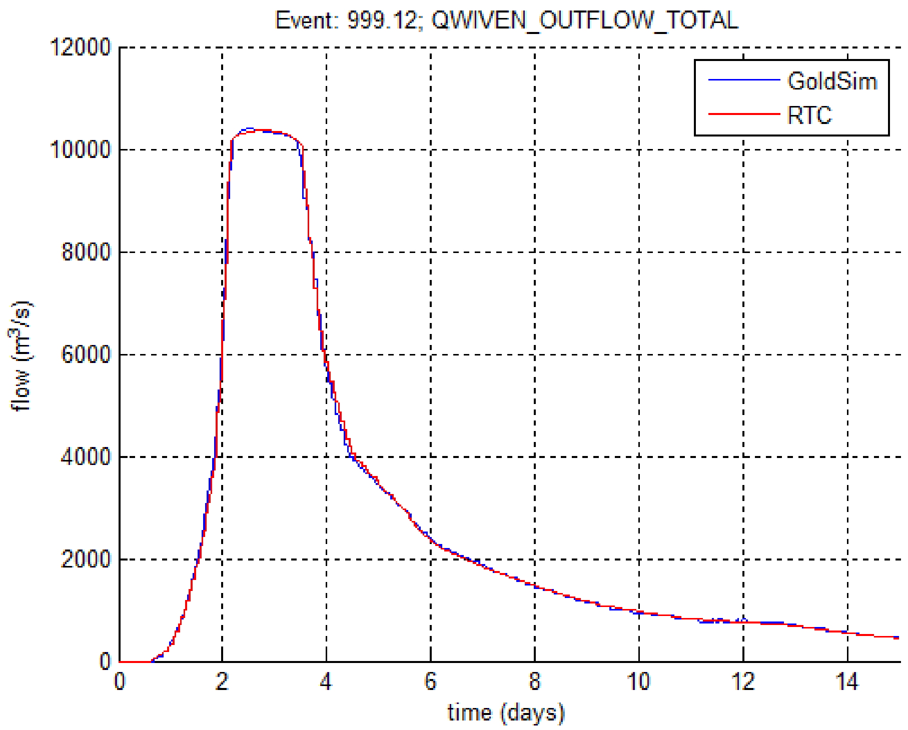

Event: 999.07; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14

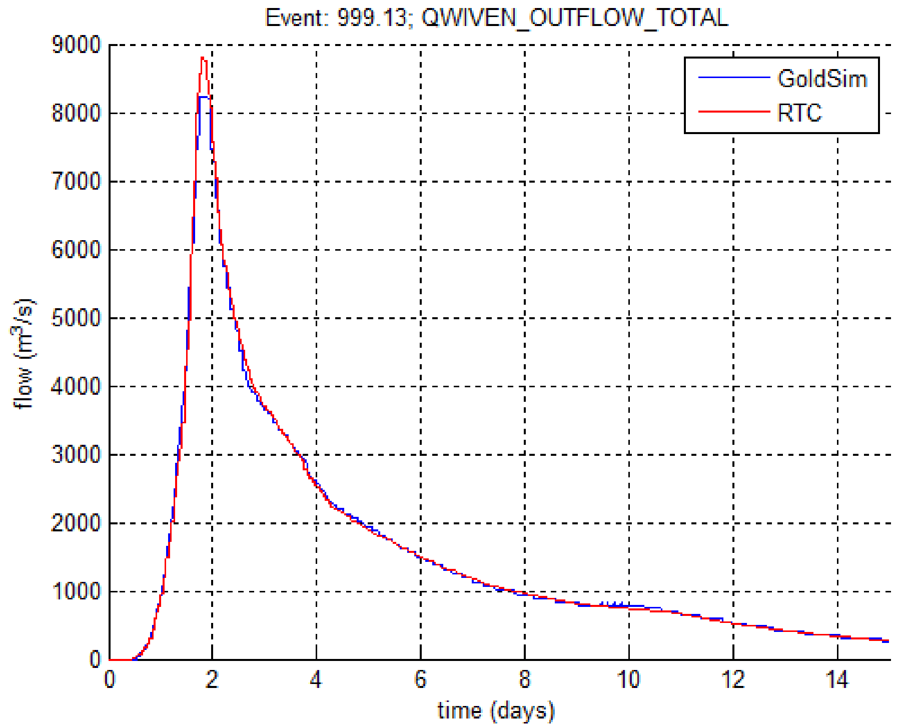

Event: 999.08; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14

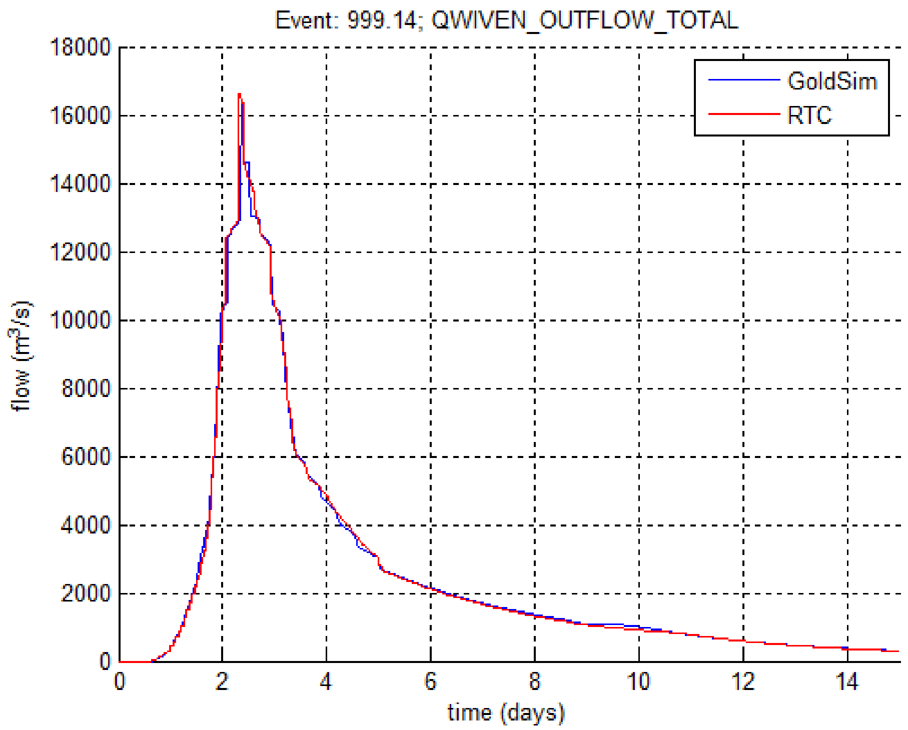

Event: 999.09; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
0
1000
2000
3000
4000
5000
6000
7000
0
2
4
6
8
10
12
14

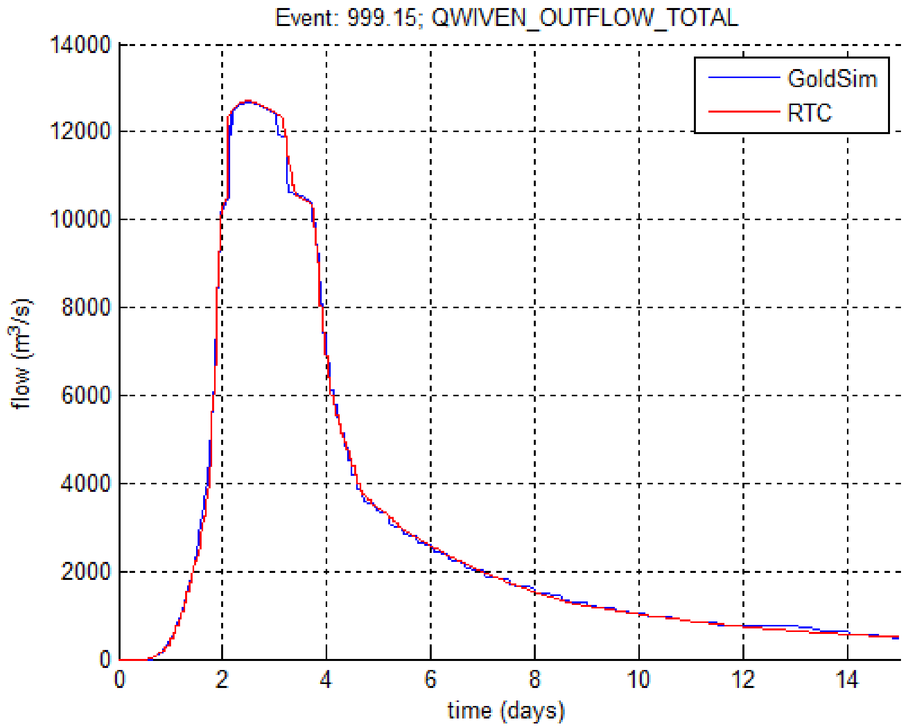

Event: 999.10; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
0
1000
2000
3000
4000
5000
6000
7000
0
2
4
6
8
10
12
14

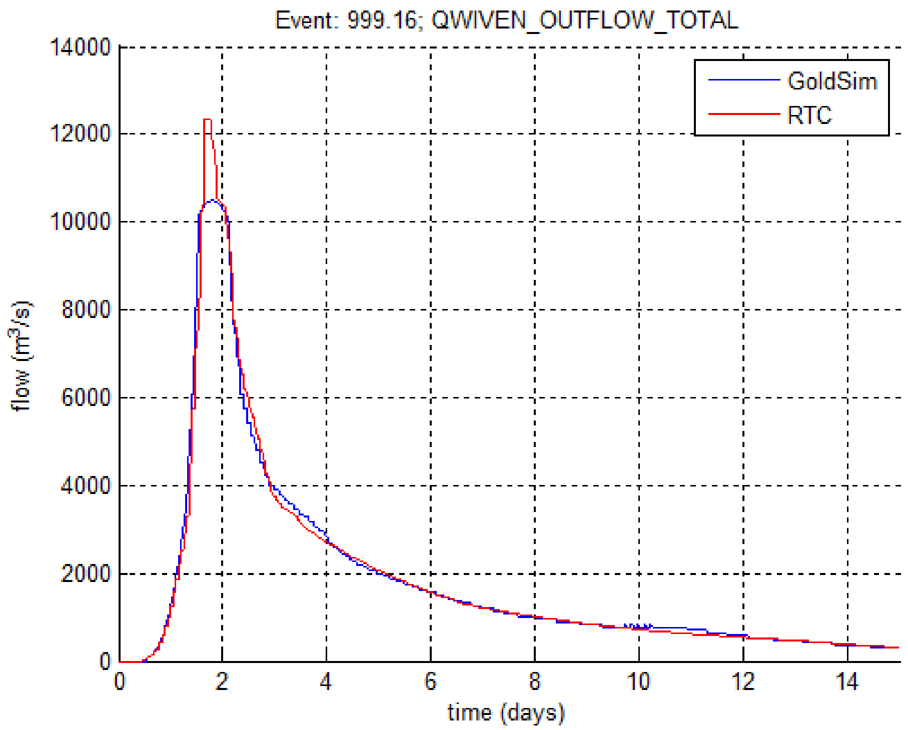

Event: 999.11; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
14000
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14

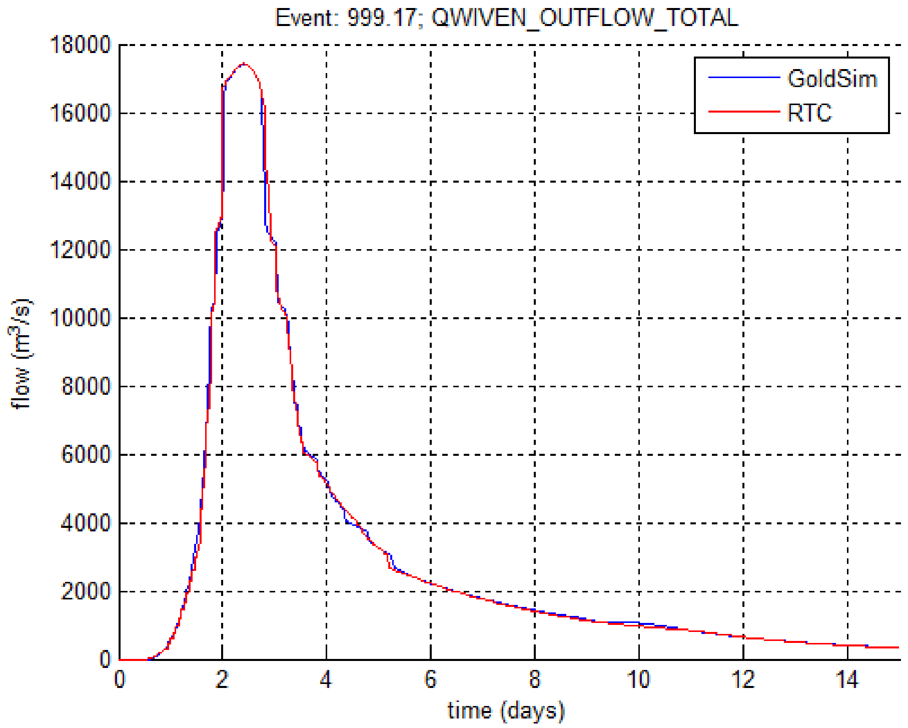

Event: 999.12; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14

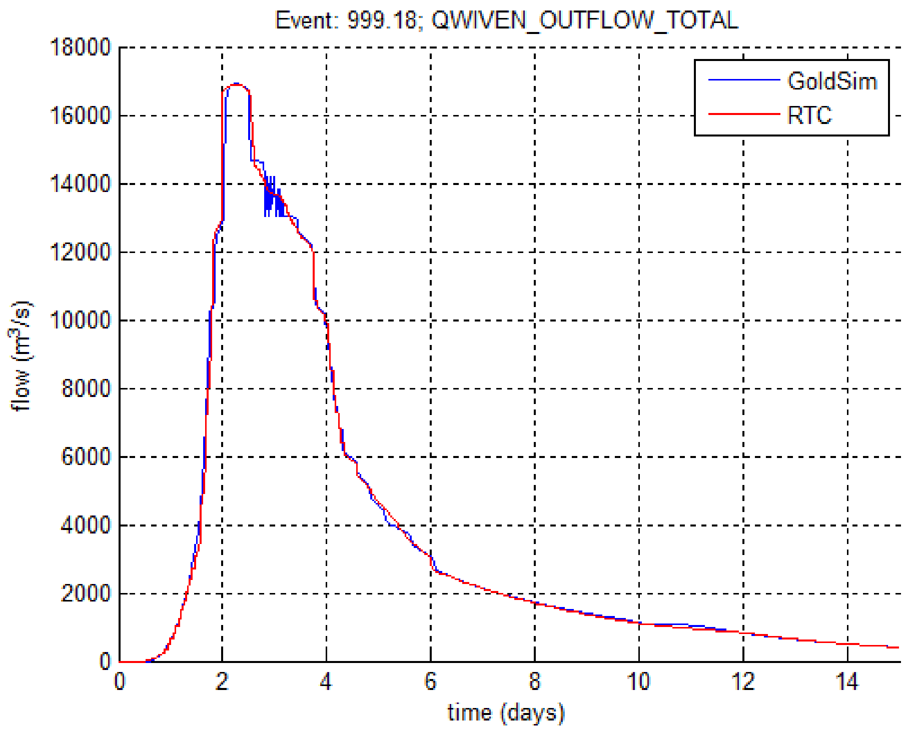

Event: 999.13; QWIVEN_OUTFLOW_TOTAL
flow (m3/s)
time (days)
GoldSim
RTC
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14

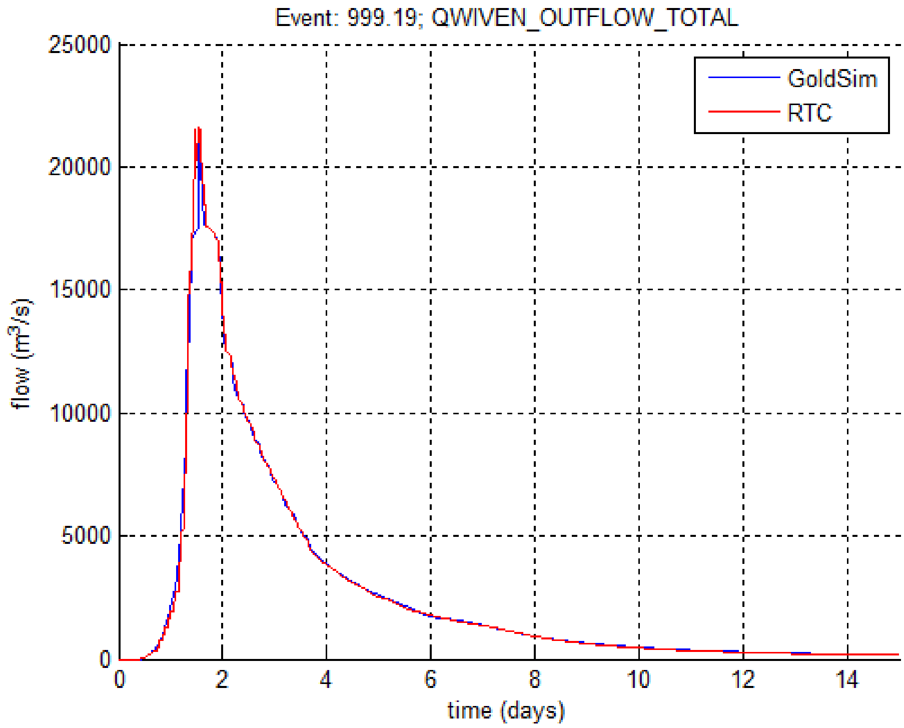

Event: 999.14; QWIVEN_OUTFLOW_TOTAL
flow (m3/s)
time (days)
GoldSim
RTC
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14

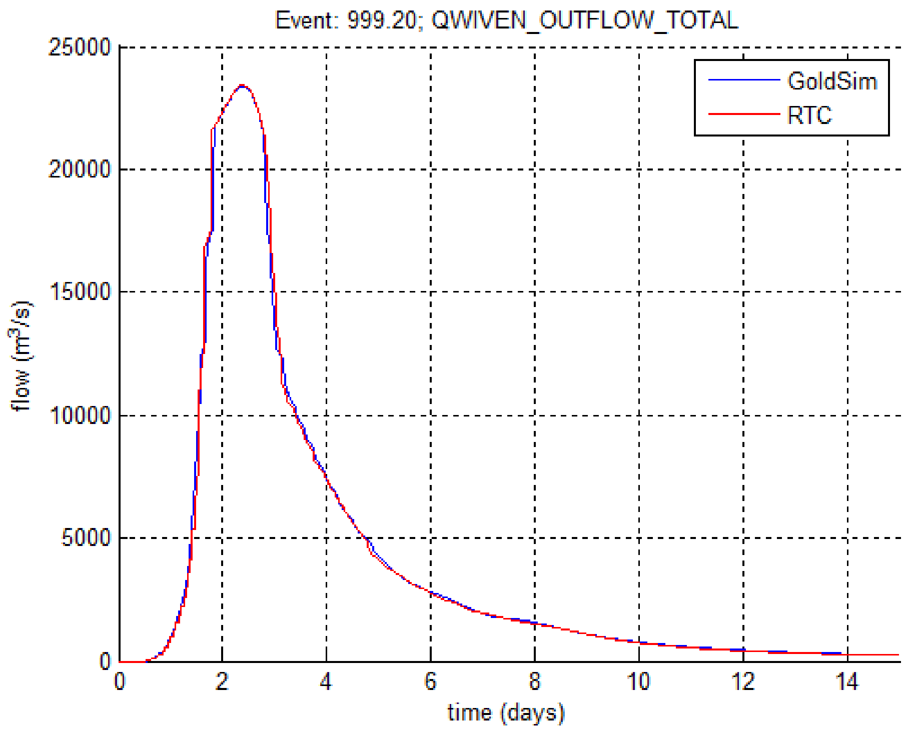

Event: 999.15; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
0
2000
4000
6000
8000
10000
12000
14000
0
2
4
6
8
10
12
14

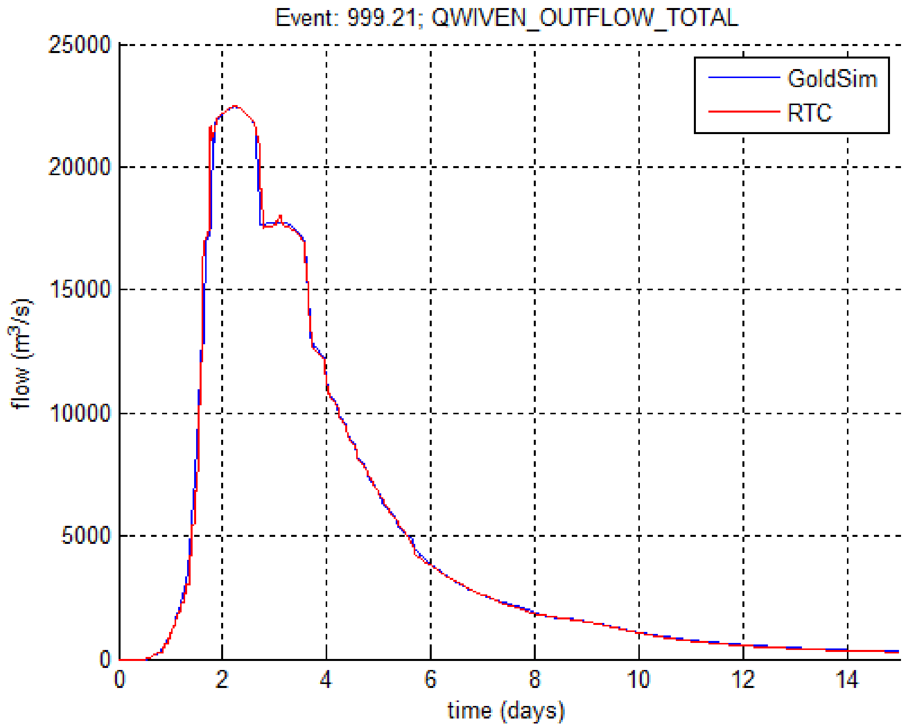

Event: 999.16; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
0
2000
4000
6000
8000
10000
12000
14000
0
2
4
6
8
10
12
14


Event: 999.17; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14

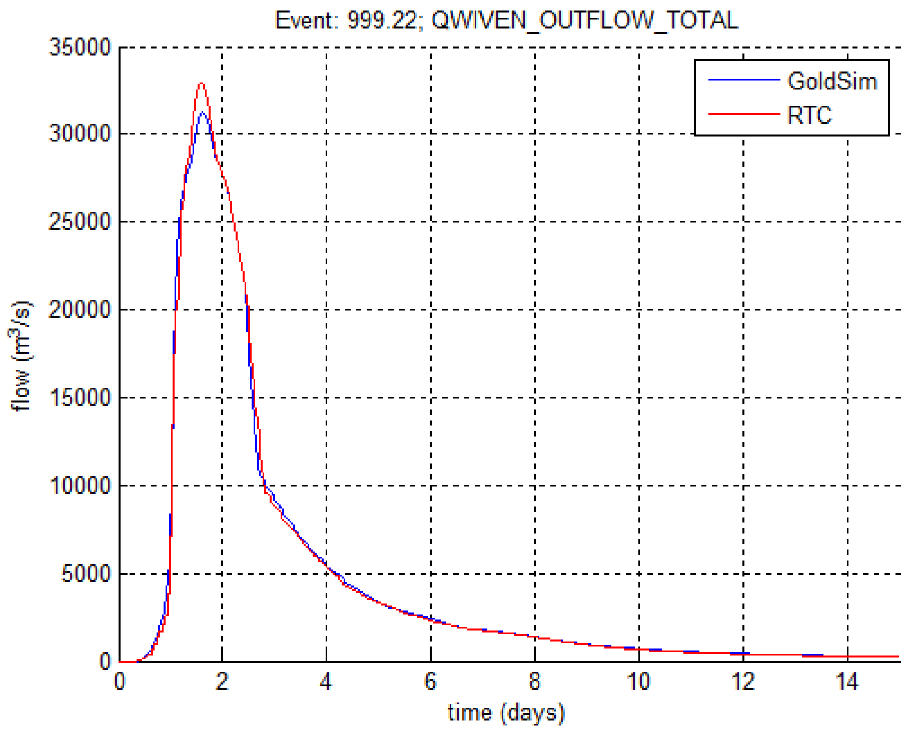

Event: 999.18; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14


Event: 999.19; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
0
5000
10000
15000
20000
25000
0
2
4
6
8
10
12
14

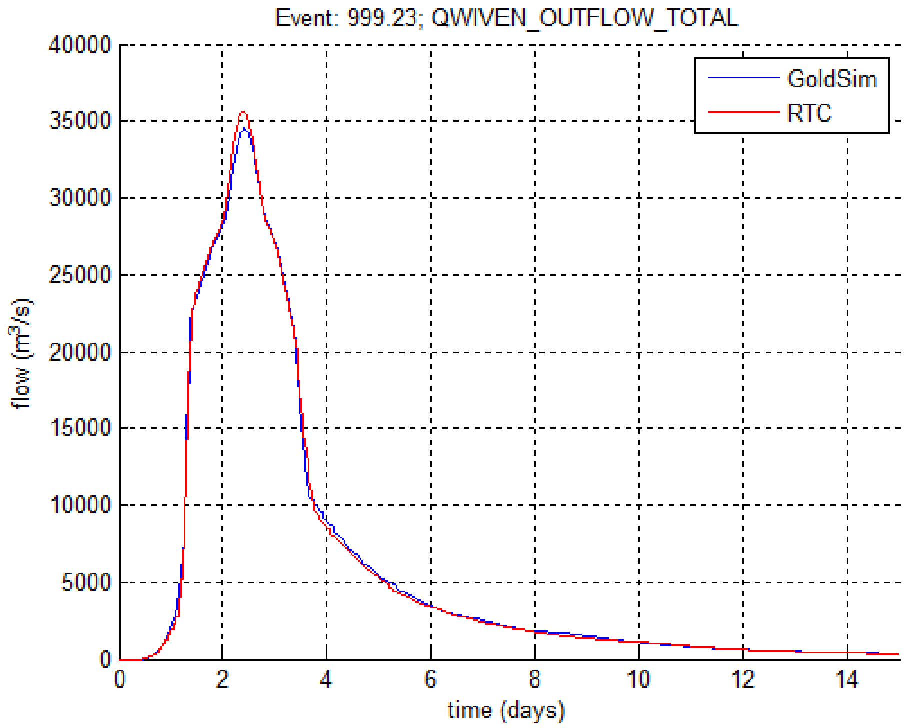

Event: 999.20; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
0
5000
10000
15000
20000
25000
0
2
4
6
8
10
12
14

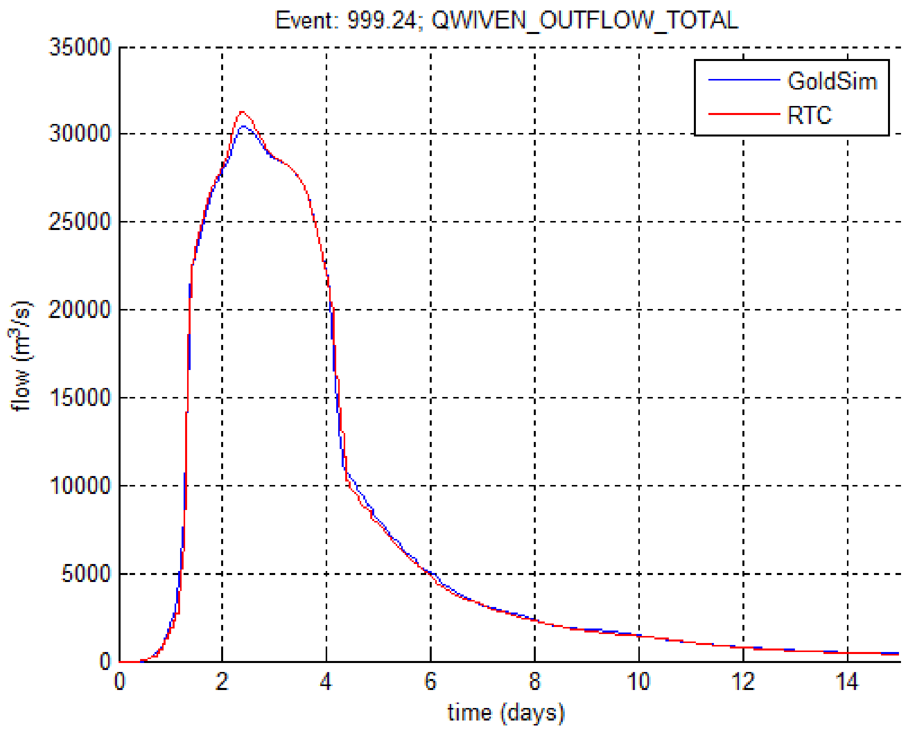


Event: 999.21; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
25000
20000
15000
10000
5000
0
0
2
4
6
8
10
12
14
time (days)



Event: 999.22; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
35000
30000
25000
20000
15000
10000
5000
0
0
2
4
6
8
10
12
14
time (days)


Event: 999.23; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
40000
35000
30000
25000
20000
15000
10000
5000
0
0
2
4
6
8
10
12
14


Event: 999.24; QWIVEN_OUTFLOW_TOTAL
GoldSim
RTC
flow (m3/s)
time (days)
35000
30000
25000
20000
15000
10000
5000
0
0
2
4
6
8
10
12
14

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