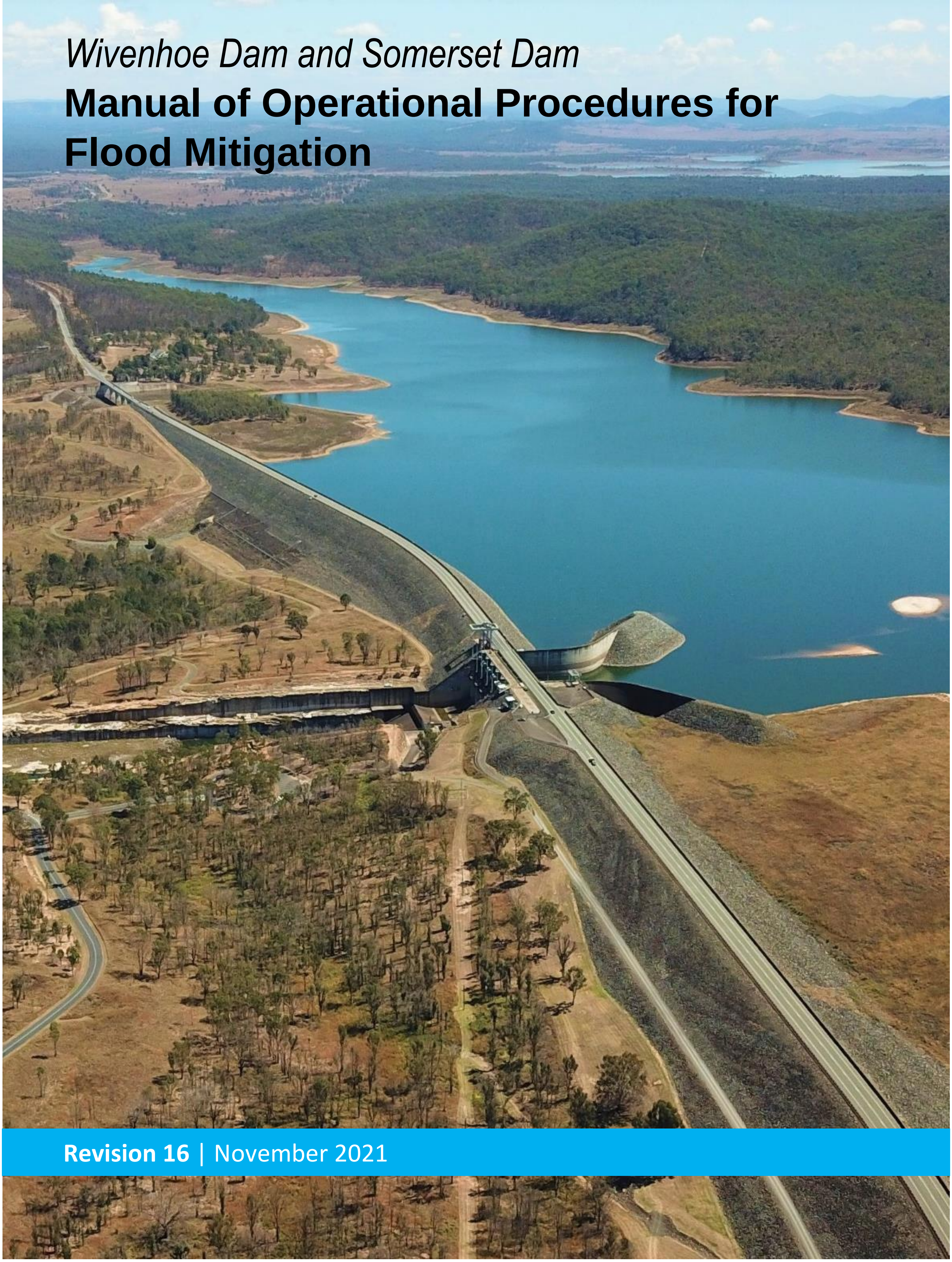
Wivenhoe Dam and Somerset Dam

Manual of Operational Procedures for Flood Mitigation



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Revision No.	Date	Amendment Details
0	27 October 1968	Original issue.
1	6 October 1992	Complete revision and re-issue.
2	13 November 1997	Complete revision and re-issue.
3	24 August 1998	Change to page 23.
4	6 September 2002	Complete revision and re-issue.
5	4 October 2004	Complete revision.
6	20 December 2004	Miscellaneous amendments and re-issue.
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9	November 2011	Insertion of Section 8 and consequential amendments.
10	October 2012	Revision but no substantive alteration of objectives, strategies or operating practices.
11	November 2013	Revision to take account of changes to the Act and improve clarity, but no substantive alteration of objectives or strategies. Operating practices amended to exclude consideration of Twin Bridges and Savages Crossing following stakeholder input.
12	November 2014	Significant revision including changes from WSDOS investigations, legislative changes and a number of general improvements.
13	November 2015	A number of minor updates to improve readability and application.
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15	November 2019	Revision
16	November 2021	Revision to include further explanation of operations targeted at a wider audience. No substantive revision to the Procedures from Revision 15.

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PREFACE

Preface

This Flood Mitigation Manual has been approved by the Minister for Regional Development and Manufacturing and Minister for Water in accordance with the provisions of the *Water Supply (Safety and Reliability) Act 2008* (Qld).

The Manual contains Procedures to be used for releasing water from Wivenhoe Dam and Somerset Dam:

1. during Flood Events;

2. to achieve a Temporary Full Supply Level declared by the Minister under the Act (see Section 17); and

3. to achieve a Reduced Full Supply Level implemented under section 399B of the Act (see Section 17).

Releases made outside points 1-3 above are governed by the Operations Manuals. This Manual does however contain Procedures to transition from releases under the Operations Manuals to releases made under this Manual.

Somerset Dam (on the Stanley River) and Wivenhoe Dam (on the Brisbane River) are located in the Brisbane River Basin. The Dams are dual-purpose: they provide water supply (including drinking water) to South East Queensland, as well as flood mitigation to areas below Wivenhoe Dam potentially affected by flood flows along the Brisbane River.

Flood mitigation is achieved by operating Wivenhoe Dam in conjunction with Somerset Dam in accordance with these Procedures. The Procedures aim to achieve an appropriate balance between preventing possible structural failure of the Dams, preserving regional water supply security, minimising risk to property, minimising disruption to transport and minimising environmental impacts. The Procedures are designed to minimise the risk to human life and safety by prioritising the structural safety of the Dam. Consideration with professional judgement is given to public safety at all the times during flood operations.

Flood Events that impact the Dams are caused by rainfall events that vary in intensity, duration and distribution over a total catchment area of more than 7,000 km^2 above the Dams. When making decisions about releasing water from the Dams during Flood Events, consideration is also given to rain falling in downstream Brisbane River catchment areas below Wivenhoe Dam. These catchment areas, which include the Lockyer Creek and Bremer River catchments, cover some 6,500 km^2 and rain falling in these catchments will also vary in intensity, duration and distribution over the course of a Flood Event.

History has shown that large flood events have and will continue to occur in the Brisbane River Basin, such as those of 1893, 1974 and 2011. During large flood events, the Dams are not able to prevent flood damage occurring in downstream urban areas.

GLOSSARY

Glossary

In this Manual, save where a contrary definition appears, the following meanings are attached to the indicated words and phrases.

Act means the *Water Supply (Safety and Reliability) Act 2008* (Qld), including any subordinate legislation made under it and any legislation amending, consolidating or replacing it.

Actual Lake Level means the Lake Level at the staff headwater gauge with reasonable adjustments (where possible made by an engineer) to take into account prevailing conditions.

ADFD means the Australia Digital Forecast Database containing weather forecast data produced by the Bureau of Meteorology.

AEP means annual exceedance probability; the probability of a specified event being exceeded in any year.

AHD means Australian Height Datum.

Alternative Procedure has the meaning set out in Section 18;

Authorisation Request Information has the meaning set out in Section 18.1;

Baseflow means ongoing small flows in rivers and creeks being principally supplied from groundwater (rather than immediately running off from rainfall). Usually insignificant when peak flows are being evaluated but can be significant in evaluating the final shutdown of Dam releases at the conclusion of a Flood Event.

Bureau means the Bureau of Meteorology. The Bureau of Meteorology is Australia's national weather, climate and water agency. The Bureau of Meteorology operates under the authority of the Meteorology Act 1955 (Cth) and the Water Act 2007 (Cth) which provide the legal basis for its activities, while its operation is continually assessed in accordance with the national need for climatic records, water information, scientific understanding of Australian weather and climate and effective service provision to the Australian community.

Bureau Provided Forecast or **BPF** means the rainfall forecast provided to Seqwater by the Bureau, that the Bureau considers to be the most appropriate rainfall forecast for the Dam catchments and downstream catchments.

Catchment inflows upstream of the Dams means the combination of the inflow to Somerset Dam from the catchment above Somerset Dam, and the inflow to Wivenhoe Dam from the catchment above Wivenhoe Dam, excluding any releases from Somerset Dam into Wivenhoe Dam; or the estimated inflow into Wivenhoe Dam if Somerset Dam was not constructed.

CEO means the Chief Executive Officer of Seqwater.

Chief Executive (DRDMW) means the Director General of DRDMW, (or any subsequent department that is responsible for administering the Act) or their nominated delegate.

Communications Protocol means the current version of the Communications Protocol for Flood Releases from Seqwater's Gated Dams (Wivenhoe Dam, Somerset Dam and North Pine Dam).

Dam Operator means a person with the required qualifications, experience and training (as set out in Section 3.8) who has been approved by Seqwater to fulfil the role of a Dam Operator under this Manual. Responsibilities of Dam Operators are outlined in Section 3.7.

GLOSSARY

Dam Safety means the structural safety of a dam or dams.

Dam Supervisor means the designated senior Dam Operator at Wivenhoe or Somerset Dam as the case may be. Responsibilities of the Dam Supervisor are outlined in Section 3.6.

Dams means Wivenhoe Dam and Somerset Dam and "Dam" means either Wivenhoe Dam or Somerset Dam depending on the context used.

Declaration means a declaration by the Minister under Section 390 of the Act to set a Temporary Full Supply Level for Somerset Dam and / or Wivenhoe Dam.

DEWS means the former Queensland Department of Energy and Water Supply.

Downstream Catchment Flow means the estimate of the flow from the catchments downstream of Wivenhoe Dam excluding the releases from Wivenhoe Dam, and is derived with the FFS.

DRDMW means the Queensland Department of Regional Development, Manufacturing and Water, or any subsequent department that is responsible for administering the Act.

Duty Engineer means either the Duty Senior Flood Operations Engineer (DSFOE) or a Duty Flood Operations Engineer (DFOE).

Duty Engineers means the DSFOE and all DFOEs.

Duty Flood Operations Engineer or **DFOE** means a Flood Operations Engineer (or Senior Flood Operations Engineer) who is on duty and, whilst on duty, has the responsibilities set out in Section 3.3. For the avoidance of doubt, more than one Duty Flood Operations Engineer may be on duty at any time.

Duty Senior Flood Operations Engineer or **DSFOE** means a Senior Flood Operations Engineer who is on duty and, whilst on duty, has the responsibilities set out in Section 3.2.

Emergency Action Plan or **EAP** when referring to Wivenhoe Dam means the current Emergency Action Plan for Wivenhoe Dam prepared and approved in accordance with Chapter 4 Part 1 Division 2A of the Act. When referring to Somerset Dam means the current Emergency Action Plan for Somerset Dam prepared and approved in accordance with Chapter 4 Part 1 Division 2A of the Act.

EL means elevation in metres Australian Height Datum.

FFS means the Flood Forecasting System. The FFS is described in Section 7.

Flood Closure of a downstream bridge or river crossing means the closure of a bridge or a river crossing judged necessary by the DSFOE for public safety reasons due to predicted future river flows at the site.

Flood Event means a flood event that commences in accordance with Section 13.2 or Section 17.3(c) and Section 17.4(b) and ends in accordance with Section 13.2. (See Section 2.5 for a simplified description of the commencement and end of Flood Events).

Flood Mitigation Guide Curve means the relationship between the Predicted Peak Lake Level in Wivenhoe Dam and the Target Flow at Moggill. It is developed from WSDOS to achieve an appropriate balance between use of the Flood Storage Compartments of the Dams and mitigation of downstream flooding. Refer to Figure 14.1.1 for the Flood Mitigation Guide Curve corresponding to an OFSL of 65.9 m AHD and Section 17.5 for modifications to the Flood Mitigation Guide Curve for other OFSLs.

Flood Officer means a person with the required qualifications, experience and training (set out in Section 3.8) who has been approved by Seqwater to fulfil the role of a Flood Officer under this Manual. Responsibilities of Flood Officers are outlined in Section 3.5).

Flood Operations Centre means the Centre used by Flood Operations Engineers to manage Flood Events.

Flood Operations Engineer means a person with the required qualifications, experience and training (set out in Section 3.8) who has been approved by Seqwater to fulfil the role of a Duty Flood Operations Engineer under this Manual.

Flood Storage Compartment means the storage volume in a Dam between the Operational Full Supply Level and the Maximum Flood Storage Level. Flood waters are temporarily stored in the Flood Storage Compartment during a Flood Event.

Full Supply Level (range of definitions). The following terms are used in this Manual:

> **Fixed Full Supply Level** or **Fixed FSL** or **FFSL** means the Lake Level associated with the Full Supply Volume used to calculate and report percentage storage volumes in the Dams:
>
> a. When referring to Wivenhoe Dam means 67.0 m AHD; and
> b. When referring to Somerset Dam means 99.0 m AHD.
>
> **Operational Full Supply Level** or **Operational FSL** or **OFSL** means the Lake Level defining the top of the Water Supply Compartment. The Operational Full Supply Level for a Dam is determined as follows:
>
> a. If neither a Temporary Full Supply Level nor a Reduced Full Supply Level is in place, then the Operational Full Supply Level is:
>   i. When referring to Wivenhoe Dam, the level specified in the Central Brisbane River Water Supply Scheme Resource Operations Licence, which is 65.9 m AHD;
>   ii. When referring to Somerset Dam, the level specified in the Stanley River Water Supply Scheme Resource Operations Licence, which is 97.0 m AHD.
> b. If a Temporary Full Supply Level is in place but no Reduced Full Supply Level is in place, then the Operational Full Supply Level is the Temporary Full Supply Level.
> c. If a Reduced Full Supply Level is in place but no Temporary Full Supply Level is in place, then the Operational Full Supply Level is the Reduced Full Supply Level.
> d. If both a Temporary Full Supply Level and a Reduced Full Supply Level are in place, then the Operational Full Supply Level is the lower of the two levels.
>
> **Reduced Full Supply Level** or **Reduced FSL** or **RFSL** means a Lake Level in the Dam reduced by Seqwater under Section 399B of the Act.
>
> **ROL FSL** means the full supply level listed in the Resource Operations Licence:
>
> a. When referring to Wivenhoe Dam, the level specified in the Central Brisbane River Water Supply Scheme Resource Operations Licence which is 65.9 m AHD;
> b. When referring to Somerset Dam, the level specified in the Stanley River Water Supply Scheme Resource Operations Licence which is 97.0 m AHD.
>
> **Temporary Full Supply Level** or **Temporary FSL** or **TFSL** means a Lake Level in the Dam declared by the Minister under Section 390 of the Act.

Gate Operations Model means a tool used to derive the Release Plan. The Gate Operations Model forms a part of the Flood Forecasting System, as described in Section 7.5.

Gauging Station means a location at which rainfall and/or water level is measured. Water level is measured in metres, either in reference to a local datum or to Australian Height Datum. Flow in cubic metres per second (m^3/s) can be inferred using a water level versus discharge rating.

judged likely or **judges it likely** means an event or circumstance being, in the professional judgement of a Duty Engineer, sufficiently certain to occur.

judged unlikely means an event or circumstance being, in the professional judgement of a Duty Engineer, not sufficiently certain to occur.

judged very likely means an event or circumstance being, in the professional judgement of a Duty Engineer, certain or near certain to occur.

Lake Level means the still water surface elevation in a Dam and when used in this Manual, "Lake Level" shall mean the Actual Lake Level, unless specifically indicated to the contrary, such as by the use of the prefix "predicted".

Manual, **Flood Mitigation Manual** or **Manual of Operational Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam** means the current version of this Manual.

Maximum Flood Storage Level means the defined Lake Level in a Dam above which it is considered that the Dam structure may fail suddenly and with little warning.

a. The Maximum Flood Storage Level for Wivenhoe Dam is 80.0 m AHD;
b. The Maximum Flood Storage Level for Somerset Dam is 108.7 m AHD with the removable flood barrier in position; and
c. The Maximum Flood Storage Level for Somerset Dam is 107.45 m AHD without the removable flood barrier in position.

Minister means the Minister (or the Minister's delegate) administering the Act.

Monitoring Network means the network of rainfall and water level Gauging Stations which provides data in near real-time and enables continuous monitoring of rainfall and stream levels within the Dams' catchments. The Monitoring Network is part of the FFS, as discussed in Section 7.2.

NWP means numerical weather prediction derived with mathematical models that simulate the atmosphere to predict weather.

Objectives means the flood operation objectives for this Manual as outlined in Section 9.

Operations Manual means either the Central Brisbane River Water Supply Scheme Operations Manual or the Stanley River Water Supply Scheme Operations Manual, depending on the context used, and is not used during Flood Events. The function of the Operations Manual is described further in Section 1.1.

Power Station means the Wivenhoe pumped storage hydro-electric power station associated with Wivenhoe Dam and Splityard Creek Dam.

predicted means, unless the context requires otherwise, the prediction of an event or circumstance made by the Duty Engineer using the FFS.

Predicted Peak, when referring to a Lake Level, means the Predicted Peak Lake Level that takes account all the releases (including operational releases made under the Operations Manual) planned from both Dams that are contained in the Release Plan.

GLOSSARY

Probable Maximum Flood means the flood resulting from the theoretical greatest depth of precipitation for a given duration that is physically possible over a particular catchment area, coupled with the worst flood-producing catchment conditions that can realistically be expected in the prevailing meteorological conditions.

Procedures means specific instructions and criteria listed in Sections 13.2, 14, 15, 16.4, 17.3, 17.4, 17.5 and 18.

Rain on Ground or **RoG** means rain that has already fallen in the catchment up to the time of the analysis and excludes rainfall forecasts.

Rainfall Forecast means a prediction of future rainfall provided by the Bureau (see also Bureau Provided Forecast or BPF).

Release Plan means the planned releases of water from the Dam approved by the DSFOE in accordance with this Manual and is used to issue Dam release directives to the Dam Supervisor. The Release Plan is described in more detail in Section 8.

Resource Operations Licence or **ROL** means:

a. In the case of Somerset Dam, the Stanley River Water Supply Scheme Resource Operations Licence (as amended from time to time);
b. In the case of Wivenhoe Dam, the Central Brisbane River Water Supply Scheme Resource Operations Licence (as amended from time to time).

Senior Flood Operations Engineer means a person with the required qualifications, experience and training (set out in Section 3.8) who has been approved by Seqwater to fulfil the role of a DSFOE under this Manual. Only one Senior Flood Operations Engineer can act in the role of DSFOE at a time.

Seqwater means the Queensland Bulk Water Supply Authority trading as Seqwater.

Strategies means the flood operations strategies for water releases from the Dams as defined in Sections 9, 10, 11, 14 and 15.

Target Flow at Moggill means a target for the water flow in the Brisbane River at Moggill as the result of planned and actual Wivenhoe Dam releases combined with Downstream Catchment Flow. The Target Flow at Moggill can be less than the peak Downstream Catchment Flow at Moggill.

Water Act means the *Water Act 2000* (Qld), including any subordinate legislation made under it and any legislation amending, consolidating or replacing it.

Water Supply Compartment means the storage volume in the reservoir up to the Operational Full Supply Level.

WSDOS means the *Wivenhoe and Somerset Dams Optimisation Study*.

WSDOS Report means the final DEWS Wivenhoe and Somerset Dams Optimisation Study Report (DEWS, 2014).

1 Introduction

1.1 Overview

Seqwater is a statutory authority which owns and operates the Dams.

The Dams are operated for dual purposes: to provide water supply for residents of South East Queensland[1] and to mitigate flood flows in the Brisbane River downstream of Wivenhoe Dam.

- The water supply operations of these dams are regulated under the Water Act;
- Requirements to manage the safety of the Dams and flood mitigation operations are regulated under the Act.

Within this legislative context, it is essential that flood operation procedures are clearly defined to balance the competing Objectives for Dam Safety, water supply and flood mitigation goals and protecting the environment. Objectives are described in Section 9.

Operations Manuals approved under the Water Act set out the circumstances in which water may be released below OFSL for water supply and other purposes unrelated to flood operations.

'Flood operations', or operations to protect the safety of the Dams and mitigate downstream flooding, are defined in this Manual, which has been approved under the Act. This Manual describes procedures to release water from the Dams during a Flood Event. The Procedures in this Manual impose strict constraints on the ability to release below OFSL during Flood Events to ensure that the Water Supply Compartments are full after a Flood Event.

This Manual is structured as follows:

- Section 2 describes the requirements for the Manual;
- Section 3 describes readiness and states the roles and responsibilities for flood operations under this Manual in accordance with Section 371D(d) of the Act;
- Sections 4 to 5 present background information related to flood operations under this Manual;
- Section 6 describes the Flood Operations Centre and communication with external stakeholders;
- Sections 7 and 8 describe the forecasting tools and processes used to support flood operations under this Manual;
- Sections 9 to 11 state (in accordance with Section 371D(a) and (b) of the Act):
    - the Objectives for flood mitigation for the Dam and their importance relative to each other;
    - the operational Strategies required to achieve the objectives for flood mitigation for the Dam;
    - how the Strategies achieve an appropriate balance in relation to matters in Section 371F of the Act.
- Section 12 describes the consideration of Rainfall Forecasts under this Manual;
- Section 13 sets out the circumstances in which the Flood Operations Centre is to be mobilised and demobilised, and how a Flood Event commences and ends in accordance with this Manual;
- Section 14 (for Wivenhoe Dam) and Section 15 (for Somerset Dam) state the Procedures required to achieve the Strategies for the Dams, including the Procedures for releasing water from the Dams in response to a Flood Event;
- Section 16 describes variation to the Procedures in Section 14 and 15 to deal with urgent circumstance, e.g. the Procedures to be followed if communications are disrupted or lost during a Flood Event;
- Section 17 states the Procedures for releasing water from the Dams in response to a declaration of a TFSL or RFSL for one or both Dams;
- Section 18 describes the process to seek authorisation of an Alternative Procedure (in accordance with Section 378 and 379 of the Act).

[1] Together, Wivenhoe and Somerset Dams provide 70% of the total South East Queensland water grid storage, which covers an area from the Sunshine Coast in the north to the Gold Coast in the south.

1.2 Purpose

This Manual is a technical document that contains:

- Descriptive text that aims to describe factors relating to flood operations at the Dams; and
- Definition of specific Procedures to be implemented in preparedness for Flood Events and in real-time operations over the course of a Flood Event, including constraints and considerations for permissible operations. The implementation of the Procedures requires professional knowledge and judgement by persons who have met the qualifications, experience and training requirement set out in Section 3.8.

The requirements of the Procedures prevail over any other part of this Manual to the extent of any inconsistency or ambiguity.

All terms and definitions are defined in the Glossary.

1.3 Agency Responsibilities

During Flood Events impacting the Brisbane River Basin, agencies have the following responsibilities:

- Seqwater owns and operates the Dams and manages releases from the Dams. This includes:
    - Forecasting catchment flows to the extent necessary to apply the Procedures in this Manual;
    - Operation of the Dams in accordance with this Manual;
    - Providing communications to agencies on matters related to dam outflows in accordance with a Gated Dams Communications Protocol (described further in Section 6.2);
    - Monitoring and responding to incidents and potential emergency events in accordance with the approved Emergency Action Plan[2] for the Dam (described further in Section 6.2).
- The Bureau forecasts flood levels and issues Flood Warnings to the public for areas along the Brisbane River, Bremer River, Warrill Creek and Lockyer Creek in accordance with the Service Level Specification for Flood Forecasting and Warning Services for Queensland[3];
- Local Governments and Disaster Management Groups interpret flood forecast information from the Bureau and provide information to the public on areas likely to be inundated by flood water;
- Local Governments and State Agencies close roads and bridges due to flooding;
- CleanCo operates Splityard Creek Dam. The potential effect of Splityard Creek Dam operations are considered when operating Wivenhoe Dam during Flood Events, and a communications protocol has been developed with CleanCo for use in Flood Events.

Communication with these agencies is described in Section 6.

1.4 Document Control

This document is the property of Seqwater. It must not be copied or reproduced in any way whatsoever without the authority of Seqwater. This document is uncontrolled when printed. An electronic database manages and stores the controlled version.

[2] The Emergency Action Plan does not state how to operate the Dams in emergencies. This Manual covers emergency dam operations.

[3] Available at: http://www.bom.gov.au/qld/flood/brochures/QLD_SLS_current.pdf

1.5 Significant Changes in this Revision

Revision 15 was approved for a two year period. In approving Revision 15, the Minister requested that Revision 16 improve the technical and legal precision and the form and presentation of the Manual, so that there was greater clarity for a wider audience beyond the responsible persons who carry out the Procedures. This Revision addresses this request by including:

- Further explanation of the legal requirements for the Manual (refer Section 2);
- Additional content to describe the factors involved in flood operations at the Dams (refer Sections 3 and 5);
- More detailed explanations of the FFS and the process of preparing a Release Plan (refer Sections 7 and 8);
- Additional content aimed at improving the descriptions of the Objectives (refer Section 9);
- Additional content aimed at improving the descriptions of the Strategies and how they meet the Objectives (refer Section 10);
- Improved clarity in the context for consideration of Rainfall Forecasts (refer Section 12) with additional context presented in Appendix J (Catchment flow hydrographs and Rain on Ground forecasts) and Appendix K (Additional information on Rainfall Forecast);
- Simplification of the Procedures that apply when a Temporary FSL or Reduced FSL are set at either or both Dams (Section 17); and
- Restructuring the overall content of the Manual to improve readability and usability during real-time operations while accommodating the additional content for a wider audience.

The operational intent of Revision 15 has not changed. Technical data (in Appendices and Tables) has been updated based on recent studies and/or survey for:

- The discharge rating of the Wivenhoe Dam auxiliary fuse plug spillway
- Flood storage capacity above 97 m AHD for Somerset Dam revised with recent lidar survey
- Annual Exceedance Probability of the Maximum Flood Storage Level for Wivenhoe Dam from recent hydrology revision.

This Manual will be reviewed and updated from time to time.

2 Requirements for the Manual

2.1 Overview

This Manual has been developed to meet the requirements of the Act.

The Act requires this Manual to be structured around Objectives, together with Strategies to achieve these Objectives, and Procedures to implement the Strategies.

Under normal operations, when communications between the Flood Operations Centre and the Dams are available, a Strategy for the Dams is selected. Over the course of a Flood Event, other Strategies may be selected, as prescribed in the Procedures of this Manual, according to changing flood conditions.

Once a Strategy has been selected, Release Plans[4] are then developed according to the Procedures of this Manual, which are then implemented at the Dams. Studies have been undertaken[5] that demonstrate that the selection of Strategies and development of Release Plans in accordance with the Procedures of this Manual will achieve an appropriate balance between the Objectives across a wide range of Flood Events.

2.2 Legal Requirements

2.2.1 Legal Context

Somerset and Wivenhoe Dams are required to have an approved flood mitigation manual under the Act. Seqwater, as the owner of the Dams, must prepare, and have an approved, flood mitigation manual for the Dams.

Chapter 4, Part 2, of the Act sets out requirements for the content of the Manual and the criteria for the Minister to apply in determining whether it is to be approved. Important legal requirements of the Manual are listed below, along with an overview of how they are addressed in the Manual.

The Manual defines four Objectives, together with four Strategies and supporting Procedures to implement these Strategies, for the operation of the Dams during Flood Events.

2.2.2 Content of Manual

Section 371D of the Act sets out specific content which must be included in the Manual. The table below sets out the requirements in Section 371D of the Act and the parts of the Manual where they are addressed.

[4] A Release Plan specifies the magnitude and timing of releases from the Dams over the course of a Flood Event.

[5] Wivenhoe and Somerset Dams Optimisation Study Report (DEWS, 2014).

Table 2.2.1 Overview of how section 371D of the Act is satisfied

Criteria in section 371D	Part(s) of the Manual where the criteria are addressed
State the objectives for flood mitigation for the Dams (the Objectives) and their importance relative to each other.	Section 9

State:
• the operational strategies (the Strategies) required to achieve the Objectives; and
• how the Strategies achieve an appropriate balance in relation to the following matters:
  • Preventing failure of the Dams, including protecting their structural integrity;
  • Minimising risk to property;
  • Minimising disruption to transport;
  • Maintaining the OFSL for the Dams after a Flood Event; and
  • Minimising environmental impacts on the stability of banks of watercourses and on riparian flora and fauna.
	Sections 9, 10, 11, 14 and 15

State the Operational Procedures (the Procedures) required to achieve the Strategies, including: • Procedures for releasing water from the Dams in response to a Flood Event; • Variations to the Procedures to deal with 'urgent circumstances' at the Dams during a Flood Event; and • Operational procedures for releasing water from the Dams in response to a declaration of a TFSL.	Sections 13.2, 14, 15, 16.4, 17.3, 17.4, 17.5 and 18 .
State: • The roles and responsibilities of each person (a responsible person) who is required to carry out operational procedures for flood mitigation under the Manual; • The qualifications and experience each responsible person must have; • The training each responsible person must complete; and • The procedures that are required to be carried out by Seqwater to verify the qualifications, experience and training for each responsible person.	Section 3
Provide for a Flood Forecasting System (FFS) to predict: • The amount of rainfall in, or affecting, the catchment area of the Dams; • The amount of inflow to the Dams; • The amount of outflow from the Dams required under the Manual; and • The level of the water surface in the Dams (Lake Level) required under the Manual.	Section 7

2.3 Criteria for approval of this Manual

The Minister may approve the Manual (section 371F of the Act) only if satisfied that:

a. The Manual complies with Section 371D of the Act (the required contents of the Manual, as outlined in Section 2.2 above);
b. The carrying out of the operational strategies and operational procedures under the Manual would minimise risk to human life and safety;
c. The Manual achieves an appropriate balance in relation to each of the following:

   i. Preventing failure of the Dams, including protecting their structural integrity;
   ii. Minimising risk to property;
   iii. Minimising disruption to transport;
   iv. Maintaining the OFSL for the Dams after a Flood Event; and
   v. Minimising environmental impacts on the stability of banks of watercourses and on riparian flora and fauna.

2.3.2 Requirement to Minimise Risk to Human Life and Safety

The Act requires that implementation of the Strategies and Procedures of this Manual minimise risk to human life and safety during a Flood Event. This is achieved in a number of ways:

- The Procedures in the Wivenhoe Dam Safety Strategy and the Somerset Dam Strategy minimise to an acceptable degree, the likelihood of peak Lake Levels reaching the Maximum Flood Storage Level, to reduce the chance of structural failure of the Dams;
- Mitigating downstream peak flood flows assists in reducing the risk to life and safety of affected people;
- Alerting other agencies on matters such as when Wivenhoe Dam releases are likely to inundate and require closure of downstream bridges; and
- Providing dam release information to the Bureau and emergency agencies to support their flood response activities, including flood forecasting, warning, evacuation, etc.

2.3.3 Requirement to Achieve an Appropriate Balance

The requirement that the Strategies and Procedures in the Manual achieve an ‘appropriate balance’ between the five criteria in Section 371F(c) of the Act is met through the following:

- The priority of the four Objectives shown in Table 9.1.1 align to all of the criteria in Section 371F(c) of the Act. Minimising risk to property and disruption to transport are addressed collectively in the lower order Objective of mitigate downstream flooding. This Manual allows for minimising disruption to transport to a limited extent that is reasonably practical within the context of all Objectives. Table 9.6.1 summarises how each Strategy achieves the Objectives;
- WSDOS simulated numerous potential flood events to assess the balance between preventing failure of the Dams, minimising risk to property, disruption to transport, maintaining full supply level in the Dams after a Flood Event, and environmental impacts. The Flood Mitigation Guide Curve in this Manual (refer Figure 14.1.1) has been developed from WSDOS to achieve an appropriate balance between use of the Flood Storage Compartments of the Dams and mitigation of downstream flooding;
- The preferred strategy from WSDOS excluded consideration of disruption to transport at low lying bridges in the Flood Mitigation Strategy (i.e. don’t aim to minimise inundation of low level bridges). Specific details are presented in the Procedures; and
- Consideration to protect the downstream environment is achieved with criteria for the rate of opening and closing the gates and timing of closing the gates.

2.4 Compliance with the Manual

If Seqwater (including its employees and agents) observes the Procedures in this Manual (or an Alternative Procedure authorised in accordance with the Manual) it does not incur civil liability for an act done, or omission made, honestly and without negligence in observing the Procedures.

2.5 Commencement and End of Flood Events

The designated commencement of a Flood Event is significant to the application of this Manual. It marks the formal changeover from normal operations at the Dams under the Water Act, to flood operations at the Dams under the Act, via this Manual.

When a Flood Event ends, operations at the Dams revert to normal operations, as regulated under the Water Act.

The Procedures for commencing a Flood Event are set out in Section 13.2 or Section 17.3(c) and Section 17.4(b).

The Procedures for ending a Flood Event are set out in Section 13.2.

3 Readiness, Roles and Responsibilities

3.1 Operational Arrangements

Seqwater must ensure that the following operational arrangements are undertaken:

Outside Flood Events:

a. A Senior Flood Operations Engineer is assigned to the role of DSFOE, and at least one Flood Operations Engineer is assigned to the role of Duty Flood Operations Engineer;
b. The Dams' radial gates, sluice gates and cone valves are kept in good working order at all times and are not to be removed from service for maintenance or any other reason without permission from the DSFOE;
c. The DSFOE is advised when the Dams' radial gates, sluice gates and cone valves are returned to service (after being removed from service in accordance with point b above);
d. A log of rainfall and stream height Gauging Station availability is maintained;
e. The Duty Engineers are on call on a 24/7 basis; and
f. Once a Flood Event commences in accordance with Section 13.2 or Section 17.3(c) and Section 17.4(b),) the Flood Operations Centre is mobilised within two hours so far as is reasonably practicable (if this has not already occurred in accordance with Section 13.1).

During a Flood Event:

a. A Duty Engineer is on duty at all times in the Flood Operations Centre to monitor rainfall and runoff and direct flood operations at the Dams during Flood Events;
b. At least one Flood Officer is on duty at all times in the Flood Operations Centre to assist the Duty Engineer/s during Flood Events;
c. A DSFOE is on call at all times during Flood Events, and able to travel to the Flood Operations Centre to assist with decision making within two hours of being called in so far as is reasonably practicable;
d. At least two Dam Operators are available to operate each of the Dams during a Flood Event, one of which is designated as the Dam Supervisor;
e. Unless communications are lost between the Flood Operations Centre and the Dams, release of water from the Dams during Flood Events is carried out under the direction of a DSFOE;
f. When communications are lost between the Flood Operations Centre and the Dams, release of water from the Dams during Flood Events is to be carried out in accordance with Section 16.4; and
g. The FFS (or other systems) records and stores the predicted Lake Levels and predicted flows that are derived with the FFS and applied in decision making for the Procedures in this Manual. The records are to be available for the preparation of Flood Event reports (that is, reporting required in sections 383 to 385 of the Act).

3.2 Responsibilities of the Duty Senior Flood Operations Engineer

The responsibilities of the DSFOE are as follows:

Outside Flood Events:

a. Lead the on-call team in monitoring conditions and carrying out routine flood preparation activities; and
b. Monitor weather forecasts and catchment conditions, and:
    i. if the conditions in Section 13.1 are met, organise mobilisation of the Flood Operations Centre.
    ii. determine when a Flood Event has commenced in accordance with the requirements of Section 13.2 or Section 17.3 and Section 17.4.

During a Flood Event:

a. Lead the flood operations team on duty in carrying out Dam operations under this Manual;
b. Select the Strategies in accordance with this Manual;
c. Approve the Release Plan and direct the operations of the Dams in accordance with this Manual;

d. Ensure incidents, communication summaries, and contextual information are recorded concisely in a Flood Event log (this task may be delegated);
e. Seek authorisation from the Chief Executive (DRDMW) to adopt Alternative Procedures, and adopt Alternative Procedures, as described in Section 18;
f. Provide a directive to the Dam Supervisors at the Dams near the commencement of the Flood Event to confirm the OFSL arrangements for the Loss of Communications Procedure in Section 16.4; and
g. Determine when a Flood Event has ended in accordance with Section 14.3 and Section 15.1.

3.3 Responsibilities of a Duty Flood Operations Engineer

The responsibilities of a Duty Flood Operations Engineer are as follows:

Outside Flood Events:

a. Monitor weather forecasts and catchment conditions, and advise the DSFOE when the conditions in Section 13.2 to commence a Flood Event are met.

During a Flood Event:

a. Direct the operation of the Dams in accordance with this Manual and instructions from the DSFOE; and
b. Follow any direction from the DSFOE in relation to adopting Alternative Procedures, which have been authorised in accordance with Section 18.

A Duty Flood Operations Engineer is to follow this Manual in managing Flood Events and is not to adopt any Alternative Procedure unless directed by the DSFOE or authorised to do so by the Chief Executive (DRDMW).

3.4 Flood Operations Engineer Professional Judgment

The DSFOE (or DFOE under direction from the DSFOE) is required to exercise professional judgement in applying this Manual.

Considerations for professional judgement for this Manual may include:

a. Highest priority for public safety at all times;
b. Urgency and time available to make a decision;
c. The potential consequences of a decision. The potential consequences may inform the assessment of the reliability of the information required for the decision[6];
d. Quality and availability (or absence) of information such as:
    i. Reliability (level of certainty) of quantitative information in the Flood Forecasting System (FFS, described in Section 7) inputs, calibration, and predictions of flows and levels;
    ii. Qualitative information (e.g. Dam Operator information on Dam performance);
    iii. The alignment or conversely conflict between available qualitative and quantitative information; and
    iv. Value of independently corroborated information.
e. Limitations of hydrology and forecasting; and
f. Consensus of judgement (utilise an avenue to call upon and brief off-shift Flood Operations Engineers) for difficult decisions.

Practical tolerances (particularly accuracy and precision of recorded levels and predicted levels) need to be considered with judgement of most if not all factors described above. Tolerances are judgements of ‘close enough’ or ‘far enough’ for a particular criterion.

[6] For example, the consequences of a decision to demobilise the Flood Operations Centre (Section 13.1) are significantly different to the consequences of a decision to select and apply the Dam Safety Strategy Procedures (Section 14.2).

3.5 Responsibilities of Flood Officers

The responsibilities of a Flood Officer under this Manual are as follows:

Outside Flood Events:

a. Undertake routine flood preparation duties, including completion of tasks listed on the handover brief.

During a Flood Event:

a. Assist the Duty Engineers in undertaking their responsibilities.

3.6 Responsibilities of Dam Supervisors

When rostered on duty during a Flood Event at a particular Dam, the responsibilities of a Dam Supervisor are as follows:

a. Carry out operations at that Dam in accordance with directions from a Duty Engineer; and
b. If difficulties are experienced in communications with the Flood Operations Centre, attempt to contact the Flood Operations Centre using the means listed in Section 16.4.
c. In the event of communications loss between the Flood Operations Centre and the Dam, assume responsibility for flood releases from the Dam, and apply the Procedures set out in Section 16.4.

3.7 Responsibilities of Dam Operators

When rostered on duty during a Flood Event at a particular Dam, the responsibilities of a Dam Operator (who is not the Dam Supervisor) are as follows:

a. Assist the Dam Supervisor in undertaking their responsibilities under this Manual.

3.8 Qualifications, Experience and Training of Flood Operations Staff

Qualifications and Experience of Flood Operations Engineers

The Flood Operations Engineers (including the Senior Flood Operations Engineers) must hold a current Certificate of Registration as a Registered Professional Engineer of Queensland and must have (at least):

a. Knowledge of the principles related to the structural, geotechnical and hydraulic design of large dams; and
b. A total of at least five years of suitable experience and demonstrated expertise in at least two of the following areas:
   i. Investigation, design or construction of major dams;
   ii. Operation and maintenance of major dams;
   iii. Hydrology with particular reference to flooding, estimation of extreme storms, water management or meteorology; and
   iv. Applied hydrology with particular reference to flood forecasting and/or flood forecasting systems.

The requirements in a. and b. above may be varied by the Chief Executive (DRDMW).

Summary of Requirements for Training of Flood Operations Engineers

The Flood Operations Engineers (including the Senior Flood Operations Engineers) are to be trained and achieve competency in the following areas relevant to the Dams:

a. The requirements of this Manual;
b. The requirements of the Emergency Action Plans for the Dams;
c. The duties and responsibilities of the DSFOE and Duty Flood Operations Engineer roles;

d. The procedures for mobilising the Flood Operations Centre;
e. The procedures for operation of the Flood Operations Centre during Flood Events;
f. Any restrictions or limitations which may apply to flood operations at the Dams;
g. The use and operation of the FFS; and
h. The requirements contained in the Communications Protocol.

Summary of Requirements for Training, Qualifications and Experience of Flood Officers

Flood Officers are to be trained to provide assistance to the Duty Engineers during Flood Events and maintain the FFS outside Flood Events.

The Flood Officers are to be trained and achieve competency in the following areas relevant to the Dams:

a. The requirements of this Manual as relevant to the role of Flood Officer;
b. The requirements of the Emergency Action Plans for the Dams;
c. The operation of the Flood Operations Centre during Flood Events;
d. The use and operation of the FFS; and
e. The requirements contained in the Communications Protocol.

Summary of Requirements for Training, Qualifications and Experience of Dam Operators

Dam Operators must successfully complete annual Flood Operations training overseen by a Senior Flood Operations Engineer before each wet season and, as part of this training, demonstrate competency in the following areas of Dam operations:

a. The requirements of this Manual as relevant to the role of Dam Operator;
b. The requirements of the Emergency Action Plans for the Dam as relevant to the role of Dam Operator;
c. The operation and maintenance of the flood release infrastructure at the Dam, including emergency operations;
d. The requirements for Dam Safety monitoring and surveillance during Flood Events.

Annual Briefings and Exercises

Briefings and exercises are to be conducted annually in order to maintain and enhance the abilities of flood operations staff, including:

a. An annual briefing prior to 1 October each year of all Flood Operations Engineers, Flood Officers and Dam Operators on the safety status of Dams including any operational restrictions that have been applied to the Dams, and FFS updates; and
b. An annual flood exercise that simulates a Flood Event and tests the application of the Dam Safety Strategy for Wivenhoe Dam.

Verification

Verification that this Section has been complied with is required, including:

a. Documenting the training activities and the areas of training covered;
b. Checking the registration of each Flood Operations Engineer;
c. Verifying that each Flood Operations Engineer has the required qualifications, experience and competency;
d. Verifying that all training has been completed as required; and
e. Verifying that annual briefings and exercises have been undertaken.

A summary of the qualifications, experience and training of flood operations staff is to be documented in the Annual Preparedness Report in accordance with the requirements of the Act.

3.9 Maintaining and Improving the FFS

The Flood Forecasting System (FFS) is not a single component or model but an integrated suite of tools used to support flood operations decision making. The components of the FFS are described in Section 7. Seqwater must:

a. Maintain the FFS and have it available for use by the Duty Engineers during Flood Events;
b. Provide appropriate levels of backup to enable the FFS to continue to operate under reasonably foreseeable risks such as partial failure of power, communications or network services;
c. Improve the practical operation of the FFS by:
    i. Implementing improvements identified during Flood Event reviews and flood exercises;
    ii. Improving model calibration as improved data becomes available;
    iii. Updating software in line with industry standards; and
    iv. Improving the coverage and reliability of the data collection network in conjunction with agencies and the Bureau.
d. Maintain a record of the performance of the Monitoring Network (being part of the FFS), including revised field calibrations and changes to the number, type and locations of rainfall and stream height gauges;
e. Maintain a record of the performance of the FFS and rectify any identified faults as soon as practicable;
f. Collect and catalogue all available data and documentation from each Flood Event for future use; and
g. Provide any information collected that is relevant to the calibration of its Gauging Stations to the Bureau and relevant agencies.

3.10 Maintenance of Communications Equipment

Seqwater must provide and maintain equipment to enable communication to exist at all times (as far as practicable) between the Seqwater Flood Operations Centre and Dam Operators at the Dams. This equipment shall include:

a. Landline telephone;
b. Mobile telephone;
c. Satellite telephone;
d. GWN radio network; and
e. Email.

This Manual also contains provisions about what to do when communications are lost (Section 16.4).

4 Background Information

This Section presents the following background information:

- Relevant information on the catchments of Wivenhoe and Somerset Dams and the greater Brisbane River Basin (including catchments downstream of Wivenhoe Dam).
- Pertinent information about the Dams. This knowledge is essential for understanding the physical constraints of temporarily storing flood waters in the Dams for subsequent release.
- General consequences of flooding downstream of the Dams. This information is important in deciding on an appropriate balance between the temporary storage and release of floodwaters at the Dams.

4.1 Other Reference Materials

Detailed technical information on flooding in the Brisbane River Basin is available in several previous comprehensive studies undertaken for the State of Queensland. Readers seeking more detailed information should refer to the following:

- **The Brisbane River Catchment Flood Study** (BMT WBM, 2017), which comprises a comprehensive hydrology study (completed in 2015) and a comprehensive hydraulic study (completed in 2017). This report provides more detailed information about the catchments, the magnitude of flood flows and flood volumes, flood mapping that indicates the extent of potential downstream flooding, and the potential impacts of climate change on floods.
- **The Brisbane River Strategic Floodplain Management Plan** (QRA, 2019), which was completed in 2019 and provides more detailed information about consequences of downstream flooding and the effectiveness of a range of measures to manage flood risk, including disaster management.
- **The Wivenhoe and Somerset Dams Optimisation Study Report** which was completed in 2014 and presents comprehensive information on studies undertaken to inform the State Government on the preferred balance between water supply and flood mitigation objectives, and the necessary dam operations to achieve this balance.

In addition, specific flood information and resources are available from the three Local Government Areas affected by flooding in the Brisbane River downstream of Wivenhoe Dam. Brisbane City Council, Ipswich City Council, and Somerset Regional Council all publish flood maps, local floodplain management plans, and have put in place Local Disaster Management Plans for flooding.

4.2 The Brisbane River Basin

The Brisbane River Basin (i.e. meaning the entire catchment to the mouth of the river) can be divided into six sub-catchments as shown on Figure 4.2.1. Details of sub-catchment areas are shown in Table 4.2.1.

Somerset Dam receives runoff from the Stanley River sub-catchment; Wivenhoe Dam receives runoff from the Upper Brisbane River sub-catchment, and outflows from Somerset Dam. The Dams do not modify the runoff generated in the other four sub-catchments, which flow into the Brisbane River downstream of Wivenhoe Dam.

Figure 4.2.1 Major Sub-Catchments of the Brisbane River

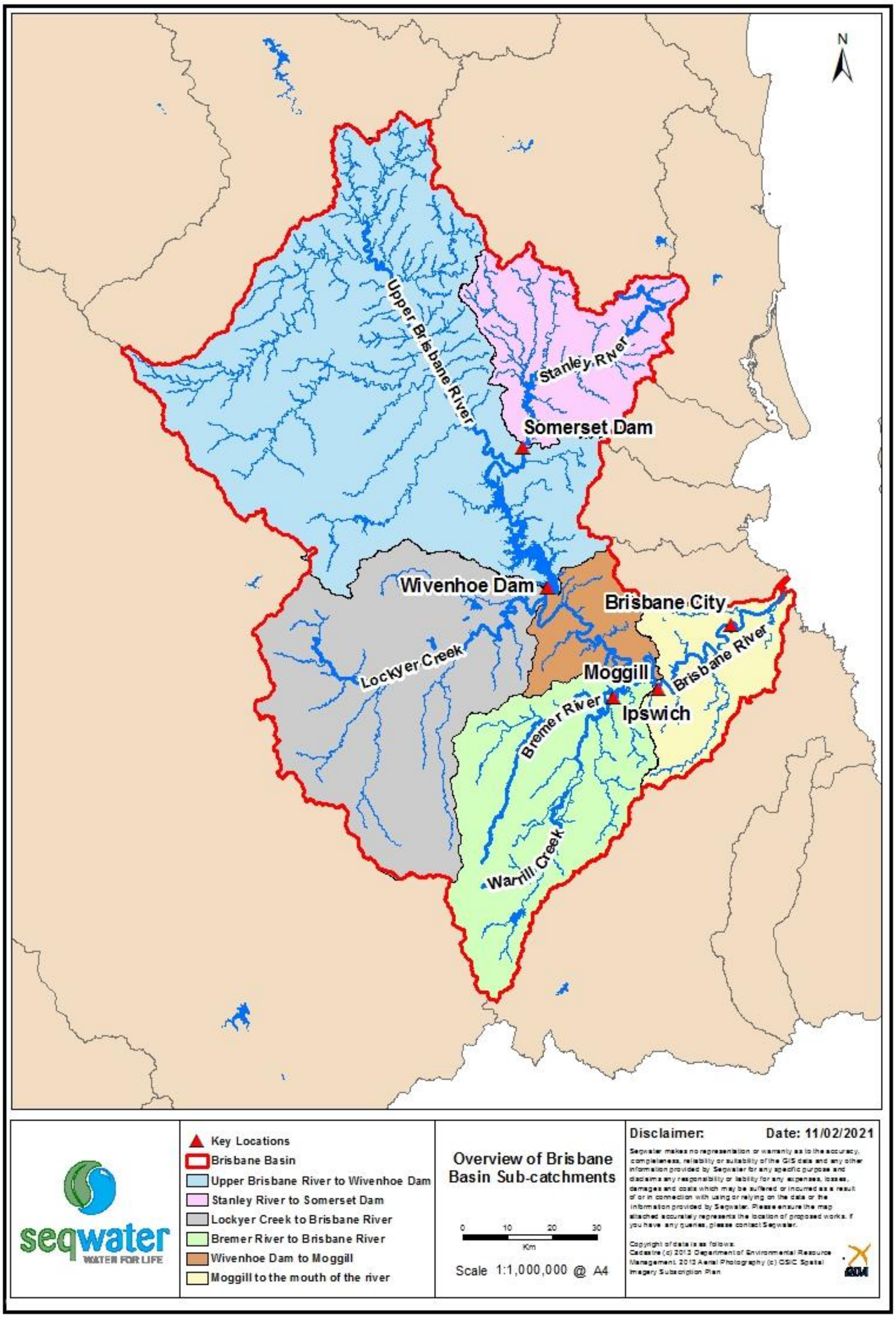


Table 4.2.1 Sub-Catchment Areas, Brisbane River Basin

Sub-Catchment	Area (km^2)	Percentage
Stanley River to Somerset Dam	1,330	10%
Upper Brisbane River to Wivenhoe Dam	5,690	42%
Lockyer Creek to Brisbane River	3,000	22%
Bremer River to Brisbane River	2,030	15%
Residual Catchment to Moggill	590	4%
Lower Brisbane River, Moggill to the mouth of the river	920	7%
Total	**13,560**	**100%**

The following characteristics of the sub-catchment areas of Table 4.2.1 should be noted:

a. The combined catchment area of Wivenhoe and Somerset Dams is approximately half the total Brisbane River Basin area[7]. Thus, at best, the two Dams can only mitigate (reduce) flood flows originating from around one-half of the total catchment.

b. Lockyer Creek and the Bremer River are major tributaries that flow into the Brisbane River downstream of Wivenhoe Dam:

    i. Lockyer Creek enters the Brisbane River 2 km downstream from Wivenhoe Dam and about 6 km upstream of the township of Lowood;

    ii. The Bremer River enters the Brisbane River approximately 2 km upstream from the Brisbane suburb of Moggill, which is 78 km (river-distance) downstream of Wivenhoe Dam.

    Together, these two sub-catchments account for a catchment area of 5,030 km^2, which represents 37% of the total Brisbane River Basin area and can generate significant contributions to flood flows at Moggill.

c. In addition, a number of smaller local creeks flow directly into the lower reach of the Brisbane River downstream of Wivenhoe Dam.

4.3 Flood flows in Brisbane River at Moggill

Flood flows in the Brisbane River at Moggill are of significant importance to the Procedures in this Manual.

Moggill is a key point of reference for flood mitigation operations at the Dams. Previous investigations[8] have found that the magnitude of the peak flood flow at Moggill is a good indicator of the peak flow in the reaches of the Brisbane River downstream of Moggill.

Under the Flood Mitigation Strategy, releases are largely based on limiting flood flows at Moggill to a target flow in combination with prudent use of the Wivenhoe Dam Flood Storage Compartment, as described in Section 10.4 and within the specific Procedures in Section 14.1.

The catchment upstream of Moggill represents 93% of the total Brisbane River Basin area. Flood flows at Moggill are a complex mix of unregulated flows from Lockyer Creek, the Bremer River and the residual catchment to Moggill, as well as releases from Wivenhoe Dam. The relative contributions from these four sources to the total peak flow at Moggill varies from Flood Event to Flood Event and varies with time over the course of a particular Flood Event.

Further, depending on the drainage and waterway characteristics of sub-catchments and main waterway reaches, it takes time (travel time) for upstream flood flows to reach downstream locations such as Moggill. Thus, the peak flow at

[7] The Brisbane River Basin is taken to mean the catchment area to the mouth of the Brisbane River, approximately 13,560 km^2.

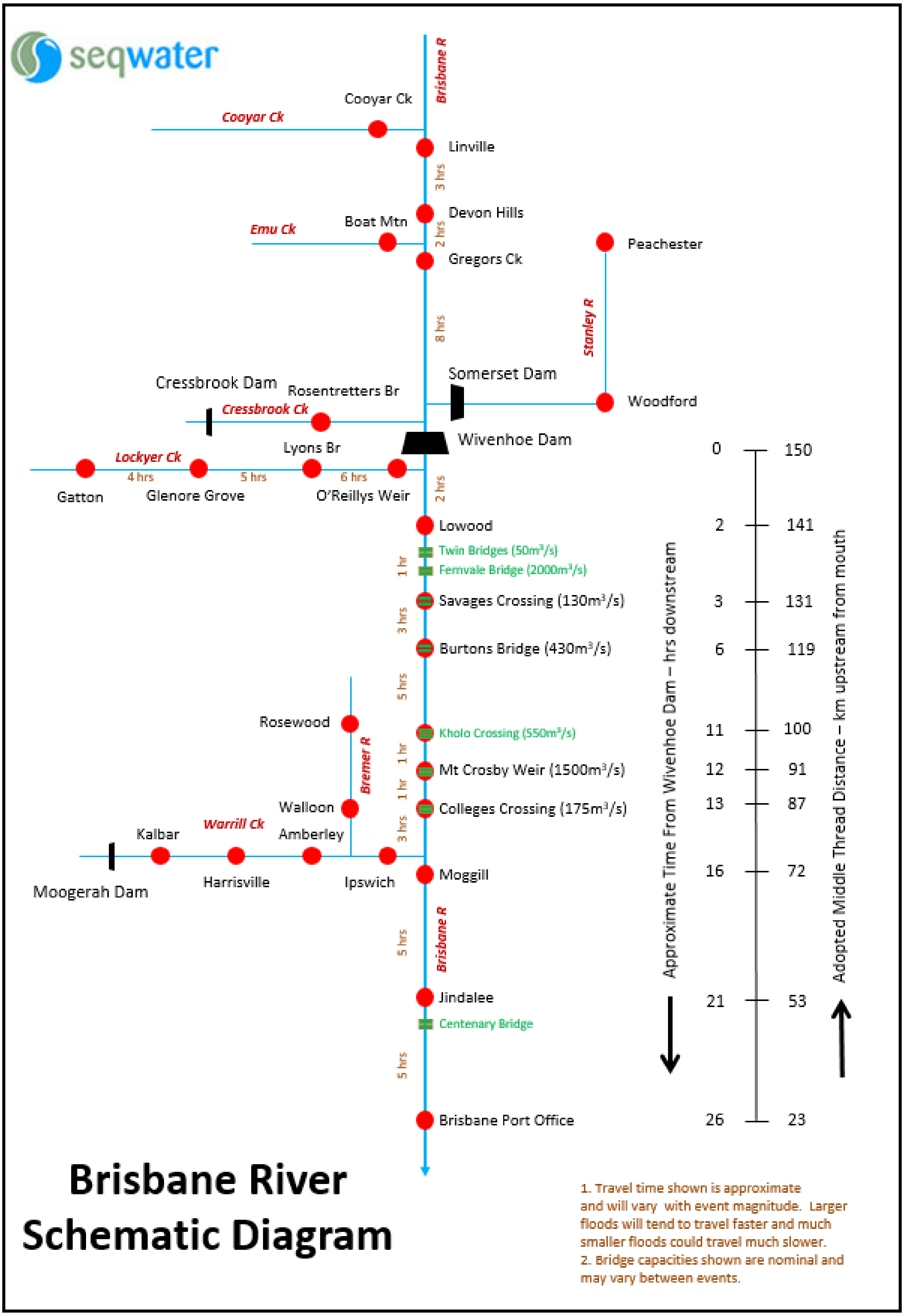
[8] Seqwater (2013) Brisbane River Flood Hydrology Models and BMT WBM (2017) Brisbane River Catchment Flood Study.

Moggill depends on the travel time of releases from Wivenhoe Dam and relative travel times of flows from Lockyer Creek, the Bremer River and the residual catchment to Moggill.

The travel time of downstream flows to Moggill is important and needs to be taken into account when determining the magnitude and timing of releases from Wivenhoe Dam to achieve target flows at Moggill.

Travel distance and indicative travel times between key locations in the Brisbane River Basin can be represented schematically, as shown on Figure 4.3.1. The indicative travel time for releases from Wivenhoe Dam to reach Moggill is 16 hours but varies with the magnitude of the flood and the contributions of tributary inflows. Travel time from the Dam to Moggill can vary from 12 to 24 hours.

Figure 4.3.1 Brisbane River Travel Distance-Indicative Travel Time Schematic



4.4 Full Supply Levels

Wivenhoe and Somerset Dams were designed for and are operated for dual purposes: to provide water supply for much of South East Queensland and to mitigate flood flows in the Brisbane River downstream of Wivenhoe Dam.

To balance these competing needs, the OFSL provides an important marker for the division between:

a. Water supply and other operations, which are not within the scope of this Manual and are regulated under the Water Act; and
b. Flood operations, defined in this Manual and regulated under the Act.

The Fixed Full Supply Level (FFSL) is solely for reporting water supply volumes and water supply management and does not impact the operations under this Manual.

The OFSL defines the boundary between the Water Supply Compartment and Flood Storage Compartment for operations of the Dams under this Manual. The OFSL is determined from:

a. The Resource Operations Licences which specify full supply levels for Wivenhoe and Somerset Dams in the absence of a Temporary or Reduced FSL (described below).
b. Under the Act, the Minister can declare a Temporary FSL (TFSL) for Wivenhoe Dam or Somerset Dam for mitigation of floods and/or droughts. A Temporary FSL changes the balance between the size of the Water Supply and Flood Storage Compartments. The procedures of this Manual have been designed to adapt to such changes.
c. Seqwater can enact a Reduced FSL (RFSL) in the circumstances set out in Section 399B of the Act.

To provide clarity for dam operations, the governing full supply level at any time is referred to as the Operational FSL or OFSL. Table 4.4.1 shows the OFSL for the various circumstances described above.

Table 4.4.1 Hierarchy of Determining Operational Full Supply Levels

Circumstance		Operational FSL
Temporary FSL	Reduced FSL	
Not in place	Not in place	As stated in Resource Operations Licence
In place	Not in place	Temporary FSL
Not in place	In place	Reduced FSL
In place	In place	Lower of Temporary FSL and Reduced FSL

The full supply levels specified in the ROLs (as at November 2020) are as follows:

- Wivenhoe Dam 65.9 m AHD.
- Somerset Dam 97.0 m AHD.

4.5 Wivenhoe Dam

Wivenhoe Dam is located on the Brisbane River to the west of Brisbane and 150 km (river-distance) upstream from the Brisbane River mouth in Moreton Bay. Additional technical information relating to Wivenhoe Dam is contained in Appendix A, Appendix B, Appendix C and Appendix D.

4.5.1 Main Embankment

The main embankment of Wivenhoe Dam is of zoned earth and rockfill construction, 2.3 km long, 50 m high, with a minimum crest level of 80.1 m AHD.

4.5.2 Saddle Dams

Wivenhoe Dam also has two earth-fill saddle dams along the eastern side of the reservoir to retain floodwaters. The crest level of the saddle dams is 80.0 m AHD.

4.5.3 Storage Details

Table 4.5.1 and Table 4.5.2 show basic details and storage characteristics of Wivenhoe Dam.

Table 4.5.1 Key Details, Wivenhoe Dam

Item	Detail
Catchment Area[a]	7,020 km^2
Main Embankment Crest Level	80.1 m AHD
Maximum Flood Storage Level	80.00 m AHD
Maximum Historic Flood Level (Jan. 2011)	75.06 m AHD

[a] Including the catchment area draining to Somerset Dam.

Table 4.5.2 Storage Characteristics, Wivenhoe Dam

Relative to Resource Operations Licence Full Supply Level[a]	
Operational FSL[a]	65.9 m AHD
Water Supply Compartment below OFSL	1,051,000 ML
Lake Surface Area at OFSL	9,900 ha
Flood Storage Compartment between OFSL and Maximum Flood Storage Level (80.0 m AHD)	2,081,000 ML
Flood Storage Compartment between OFSL and 75.0 m AHD, which is the upper limit of the Flood Storage Compartment reserved for flood mitigation purposes	1,180,000 ML
Flood Storage Compartment between OFSL and 75.7 m AHD, which is the level of lowest fuse plug embankment (See Table 4.5.4).	1,294,000 ML

[a] Based on the level specified in the ROL of 65.9 m AHD and assumes no TFSL or RFSL is in place at the Dam.

4.5.4 Details of Spillways and Outlet Works

4.5.5 Main Spillway

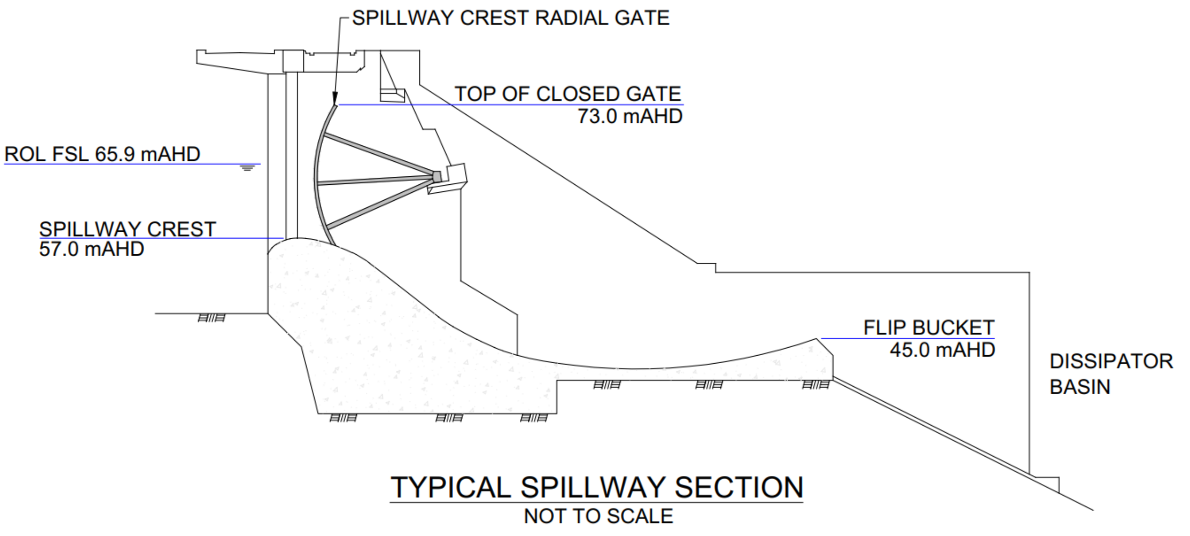
Table 4.5.3 and Figure 4.5.1 show details of the main spillway and outlet works at Wivenhoe Dam. The main spillway is a flip bucket dissipator discharging into an unlined plunge pool. The outlet works consist of:

a. Five (5) radial gates used to make releases in accordance with this Manual; and
b. A regulator cone valve for water supply releases and an outlet from a small hydroelectricity system located at the Dam.

Table 4.5.3 Details of Main Spillway and Outlet Works, Wivenhoe Dam

Item	Detail
Spillway Crest Level	57.0 m AHD
Crest Width	60 m
Radial Gates - 5 No.	12.0 m wide; 16.6 m high
Top of Closed Gates	73.0 m AHD
Maximum Flow through main spillway at Maximum Flood Storage Level (80.0 m AHD)	13,500 m^3/s
Lip of the flip bucket	45.0 m AHD

Figure 4.5.1 Main Spillway Cross-Section, Wivenhoe Dam



Detailed spillway rating tables are provided in Appendix A.

4.5.6 Auxiliary Spillway

In 2005, an auxiliary spillway containing three fuse plug embankments was constructed in the right-hand abutment of the main dam to improve the capacity of the Dam to safely pass extreme floods. The three fuse plug embankments are designed to wash out sequentially after the Lake Level exceeds the pilot channel level, thereby creating a progressively widening additional spillway to safely pass flood flows. It is important to note that the precise Lake Level at which the fuse plug embankment will breach is uncertain due to likely drawdown effects in the upstream approach channel and the depth of overtopping required to erode the embankment materials. Professional judgement is needed when operating around these levels and visual monitoring is recommended. Table 4.5.4 shows details of the auxiliary spillway. Figure 4.5.2 shows the auxiliary spillway and its fuse plug embankments (left and right is relative to looking downstream).

Table 4.5.4 Auxiliary Spillway Details, Wivenhoe Dam

Item	Central Fuse Plug	Left Fuse Plug	Right Fuse Plug
Sill Level	67.0 m AHD	67.0 m AHD	67.0 m AHD
Total Crest Width	34.0 m	64.5 m	65.5 m
Pilot channel level	75.7 m AHD	76.2 m AHD	76.7 m AHD
Total Flow at pilot channel level[a]	1,680 m^3/s (centre bay)	5,220 m^3/s (centre + left bay)	9,340 m^3/s (all bays)

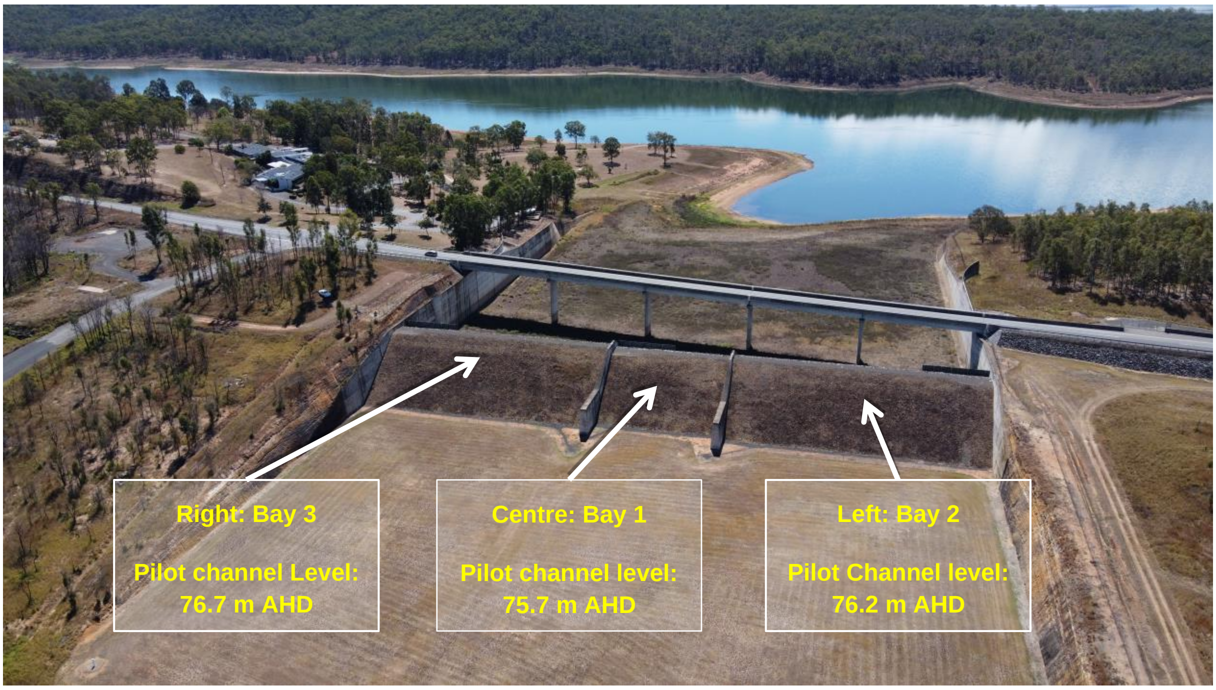
[a] Total Flow for all three fuse plugs.

Table 4.5.5 Wivenhoe Dam discharges relative to 76.7 m AHD and 80.0 m AHD

Lake Level (m AHD)	Central Fuse Plug Discharge (m^3/s)	Left Fuse Plug Discharge (m^3/s)	Right Fuse Plug Discharge (m^3/s)	Main Spillway Discharge (m^3/s)[a]	Total Discharge (m^3/s)
76.7	1,940	3,670	3,730	11,500	20,840
80.0	2,870	5,450	5,530	13,500	27,350

[a] Total flow from the main spillway with all gates fully open.

Figure 4.5.2 Wivenhoe Dam, Auxiliary Spillway Fuse Plugs (looking upstream)



4.6 Somerset Dam

Somerset Dam is located on the Stanley River 53 km (river-distance) upstream from Wivenhoe Dam. Construction of the Dam commenced in 1935, was delayed by World War II, and was completed in 1955, with the Dam commissioned in 1959. Additional technical information relating to Somerset Dam is contained in Appendix E, Appendix F and Appendix G.

4.6.1 Dam Wall

The wall of Somerset Dam is of mass-concrete gravity construction, 305 m long and 53 m high at its deepest section.

4.6.2 Storage Details

Table 4.6.1 and Table 4.6.2 show basic details and storage characteristics of Somerset Dam.

In 2016 a flood defence wall (parapet wall) and removable barrier (for doorways and right abutment) was installed on the dam crest to raise the level at which overtopping would occur from the original dam crest level of 107.45 m AHD to 108.7 m AHD. The Maximum Flood Storage Level with this removable barrier in place is 108.7 m AHD.

Table 4.6.1 Key Details, Somerset Dam

Item	Details
Catchment Area	1,340 km^2
Dam Crest Level (breezeway)	107.45 m AHD
Maximum Flood Storage Level with the removable flood barrier in place	108.7 m AHD
Maximum Flood Storage Level without the removable flood barrier in place	107.45 m AHD
Maximum Historic Flood Level (Jan 1974)	106.57 m AHD

Table 4.6.2 Storage Characteristics, Somerset Dam

Relative to Resource Operations Licence Full Supply Level	
Operational FSL[a]	97.0 m AHD
Water Supply Compartment below OFSL	303,000 ML
Lake Surface Area at OFSL	3,500 ha
Flood Storage Compartment between OFSL and Maximum Flood Storage Level with the removable flood barrier in place	705,000 ML
Flood Storage Compartment between OFSL and Maximum Flood Storage Level without the removable flood barrier in place	600,000 ML

[a] Based on the level specified in the ROL of 97.0 m AHD and assumes no TFSL or RFSL is in place at the Dam.

4.6.3 Details of Spillway and Outlet Works

Figure 4.6.1, Figure 4.6.2 and Table 4.6.3 show details of the outlet works and spillway at Somerset Dam.

Figure 4.6.1 Outlet Works, Somerset Dam

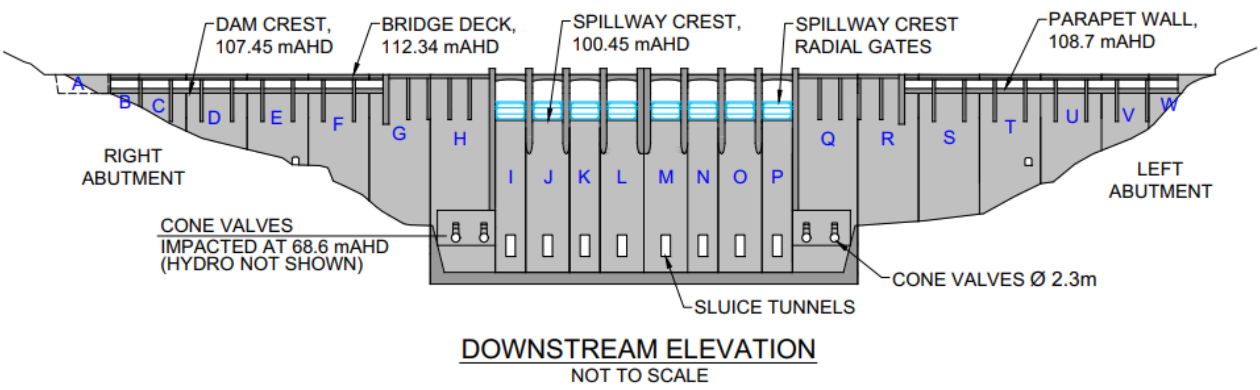


Figure 4.6.2 Typical Cross-Section, Somerset Dam

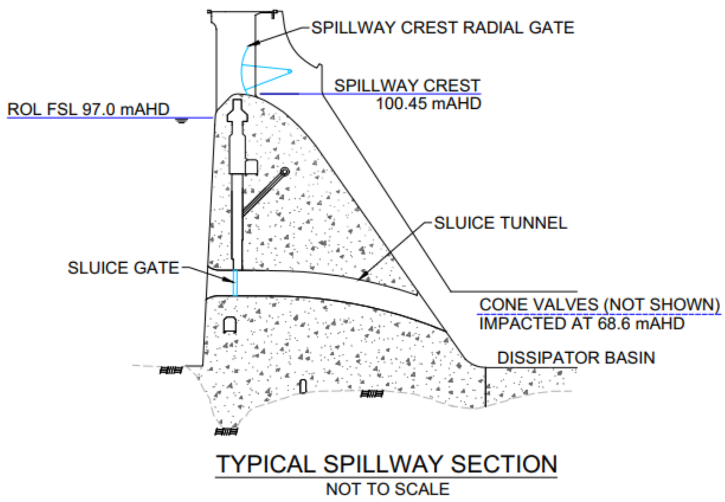


Table 4.6.3 Details of Spillway and Outlet Works, Somerset Dam

Item	Details
Spillway Crest Level	100.45 m AHD
Crest Width (total for 8 crest gates)	63.4 m
Low Level Sluice Gates - 8 No.	2.44 m wide; 3.66 m high
Sluice Gate Intakes	73.02 m AHD
Spillway Crest Radial Gates - 8 No.	7.9 m wide; 7.0 m high
Elevation of Top of Crest Gates	107.45 m AHD
Regulator Cone Valves - 4 No.	2.3 m dia.
Outflow[a] at Maximum Flood Storage Level[b]	5,150 m^3/s [c]

[a] Sluice gates fully open, crest gates fully opened, removable flood barrier in place, and regulators closed.

[b] Maximum Flood Storage Level with the removable flood barrier in place (108.7 m AHD).

[c] Detailed spillway rating tables are in Appendix E.

The outlet works at Somerset Dam consist of:

a. Eight (8) low level sluice gates, which discharge into a dissipation basin;
b. Eight (8) spillway crest radial gates, which are open at all times during Flood Events and not used to regulate the spillway flow;
c. Four (4) cone valves for water supply releases (not used during Flood Events when tailwater levels in the dissipation basin submerge the valves);
d. One (1) outlet from a 4 MW hydroelectricity system located adjacent to the dam wall (not used during Flood Events as capacity is insignificant); and
e. With all sluice gates fully open, all crest gates open and the removable flood barrier in place, the spillway capacity at Maximum Flood Storage Level (108.7 m AHD) is 5,150 m^3/s.

Outflows from Somerset Dam enter Wivenhoe Dam via the Stanley River, where they combine with flows from the Upper Brisbane River catchment.

4.6.4 Revised Operating Procedures at Somerset Dam

The joint flood operation of Somerset and Wivenhoe Dams are aimed at ensuring the safety of the Dams and mitigating flood flows along the Brisbane River downstream of Wivenhoe Dam.

In 2015, it was determined that changes to flood operations procedures at Somerset Dam were necessary to ensure Dam Safety until a proposed upgrade of the Dam was complete.

Flood operations procedures for Somerset Dam are designed to ensure Dam Safety by requiring floodwaters to be released at the maximum rate possible, as specified by the Manual.

This change reduces the probability of exceeding the Maximum Flood Storage Level of Somerset Dam (a priority for Dam Safety).

4.7 Splityard Creek Dam

Splityard Creek Dam, which is located 10 km by road to the north-east of Wivenhoe Dam on the eastern side of the reservoir, forms part of a pumped storage hydroelectric power generation system. Water is pumped from Wivenhoe Dam into Splityard Creek Dam during off-peak hours, generating hydroelectricity when it is released back into Wivenhoe Dam during peak hours. The maximum generating capacity is 500 MW.

The dam and its associated Wivenhoe Power Station have been operating since 1984 and are currently owned and operated by CleanCo.

The operation of Splityard Creek Dam is not within the scope of this Manual. The relevance of Splityard Creek Dam is to understand that the exchange of water between Wivenhoe Dam and Splityard Creek Dam can occur during Flood Events:

a. Over a 12-hour period, the maximum volume that can be pumped from and returned to Wivenhoe Dam is approximately 23,000 ML.
b. Communication Protocols have been established between the operators of both dams to provide information on such transfers during Flood Events.

4.8 Downstream Flood Impacts

4.8.1 Downstream communities

There are two major urban areas downstream of Wivenhoe Dam that are affected by large floods in the Brisbane River:

a. The reach of Brisbane River downstream from Moggill, which includes the Brisbane CBD; and
b. The lower reaches of the Bremer River upstream to around Ipswich, which is located 17 km (river-distance) from the confluence of the Brisbane and Bremer Rivers.

In addition, along the reach of the Brisbane River between Wivenhoe Dam and Moggill there are also rural areas, businesses and communities, such as Lowood and Fernvale, that are adversely affected by floods in the Brisbane River.

4.8.2 Impacts of Flooding

The flood impacts and flood damage estimates stated in QRA (2019) relate to surveyed floodplain development in 2017. Floodplain development is a dynamic process that continually changes over time. As such, it is not possible to precisely state the number of buildings likely to be inundated by Brisbane River floods of different severities and how this may have changed since 2017.

The peak flood flow at Moggill is a key indicator of flood consequences along the reach of the Brisbane River downstream of Wivenhoe Dam and is a key flood mitigation target for the dam operations under the Flood Mitigation Strategy[9].

Table 4.8.1 contains a guide of the indicative flood impacts of a range of peak flood flows at Moggill. For comparison, Table 4.8.1 also notes when the peak flow at Moggill and extent of flooding would exceed those of significant historical floods.

The number of buildings in listed in Table 4.8.1 are buildings with above ground level flooding and some may not have above floor level flooding. The number of buildings is the minimum number of buildings due to the Brisbane River flow. Higher numbers of buildings are possible in areas along the Bremer River and Lockyer Creek if the flood levels in those tributaries[10] are higher than the Brisbane River flood level at the tributary confluence with Brisbane River.

[9] This Strategy is described further in Section 10.4. The specific Procedures for the Strategy are set out in Section 14.1.
[10] Building in the tributaries are excluded because Wivenhoe Dam releases do not modify the tributary flood flows.

Table 4.8.1 Indicative Impacts of Brisbane River Floods Related to Peak Flood Flows at Moggill

Peak Flow at Moggill (m^3/s)	Indicative Impacts of Brisbane River Floods[a]
50 to 500	• Inundation of Colleges Crossing (Mount Crosby Road), a high-traffic bridge servicing urban areas and regional traffic. When inundated, an alternative route via Mount Crosby Weir Bridge is available. • Damage to irrigation pumps (if not removed prior to flooding). • Closure of low-traffic rural bridges.
500 to 1,500	• Increasing impacts to rural areas. • Impacts to recreational facilities at Colleges Crossing.
1,500 to 2,000	• Inundation of Mount Crosby Weir Bridge and Fernvale Bridge on Brisbane Valley Highway. • Increasing impacts to rural areas and non-urban industries, such as gravel extraction operations at Fernvale.
2,000 to 3,000	• Impacts to low lying recreation facilities in urban areas and inundation of some roads. • Flooding of around 100 residential and commercial premises (some with above floor flooding).
3,000 to 4,000	• Flooding of several hundred residential and commercial premises (many with above floor flooding).
4,000 to 7,000	• Urban inundation increases to over 1,000 residential and commercial premises. • Above 4,000 m^3/s flood flow, all suburbs on the northern side of the Brisbane River, from Karana Downs to Pullenvale in Brisbane's western suburbs become isolated. • Extent of flooding greater than that of the 2013 and 1996 Flood Events, which had an estimated peak flood flow at Moggill of around 4,000 m^3/s[b].
7,000 to 10,000	• Urban inundation increases to over 10,000 residential and commercial premises.
10,000 to 12,000	• Urban inundation increases to over 20,000 residential and commercial premises. • Extent of flooding greater than that of the 2011 Flood Event, which had an estimated peak flood flow at Moggill of approximately 10,000 m^3/s[b].
12,000 to 15,000	• Urban inundation increases to over 40,000 residential properties and commercial premises. • Extent of flooding greater than that of the 1974 flood event, which had an estimated peak flood flow at Moggill of approximately 12,000 m^3/s[b].
15,000 to 20,000	• Urban inundation increases to over 50,000 residential properties and commercial premises. • Extent of flooding greater than that of the 1893 flood event, which had an estimated peak flood flow at Moggill of 15,000 m^3/s to 16,000 m^3/s[b].

Table notes:

[a] Excludes possible higher flood levels along the lower reaches of Lockyer Creek and Bremer River that may occur when sub-catchment flows increase the levels along the lower reaches of these tributaries.

[b] Flow estimates for historical flood events are based on calibration studies undertaken by Seqwater (2013).

5 Mitigation of Peak Flood Flows by Somerset and Wivenhoe Dams

This Section describes how the storage and release of floodwaters at Somerset and Wivenhoe Dams can mitigate peak flood flows in the Brisbane River at Moggill and flood levels in the Bremer River at Ipswich. The degree of peak flood flow mitigation delivered by the Dams varies from event to event, depending on the amount, duration, and spatial and temporal patterns of the flood-producing rainfalls over the Brisbane River Basin.

5.1 How Dams Mitigate Flood Flows

Dams mitigate or reduce flood flows passing through the dam by temporarily storing and releasing upstream floodwaters. This reduces and delays the contribution of floodwaters generated upstream of the dam to flooding along the river reach downstream of the dam. If the rate of inflow into the dam is greater than the rate of outflow, the Lake Level will rise. When the inflow and outflow are equal the Lake Level is stable (not rising or falling). When the rate of inflow is less than the rate of outflow, the Lake Level will fall.

The ability of dams to mitigate a given Flood Event is dependent on both the volume of the inflow event and the rate of inflow:

a. Inflow volume is important as any inflow volume greater than the initial airspace below OFSL determines how much water has to be released over the course of a Flood Event[11]; and
b. Rate of inflow is important as any inflow rate greater than the outflow capacity (or current outflow rate) represents additional water that is stored.

The balance between water stored and water released determines the maximum Lake Level reached during the Flood Event.

There are physical limits to the rate at which the radial and sluice gates can release flood waters and there are physical limits to the amount of flood water that can be temporarily stored. There are also limits on how fast gates can be opened and closed during Flood Events.

During a Flood Event, both Wivenhoe and Somerset Dams are operated in accordance with Procedures which are used to determine the timing, magnitude and duration of flood releases.

In the context of Wivenhoe Dam, downstream flooding is a combination of dam outflows and flows generated from downstream catchments. This increases complexity for achieving downstream flood mitigation.

5.2 Mitigation of Peak Flood Flows at Moggill

Wivenhoe Dam flood mitigation operations are more complex than simply reducing the peak outflow from the Dam. The peak flood flow at Moggill is a measure of flood magnitude along the Brisbane River downstream of Moggill and along the lower reaches of the Bremer River. In many Flood Events, there are significant inflows to the Brisbane River from downstream catchments between Wivenhoe Dam and Moggill, principally Lockyer Creek and the Bremer River. To meet target peak flood flows at Moggill in these circumstances, it is also necessary to consider the relative travel times to Moggill of dam outflows and flows from the downstream catchments.

Flood flows at Moggill are a complex mix of floodwaters from four sources:

a. Releases from Wivenhoe Dam;
b. Flows from the Lockyer Creek catchment;
c. Flows from the Bremer River catchment; and

[11] If the Lake Level is at OFSL at the start of the Flood Event, the entire inflow volume needs to be released over the course of the Flood Event.

d. Flows from residual local catchments between Wivenhoe Dam and Moggill.

The flows from the above sources arrive at Moggill at different times, reflecting the influence of the different size and nature of their catchments and travel distances to and along the Brisbane River to Moggill. The relative timing of these flows is also influenced by the location and timing of rainfall (storm patterns) over the downstream catchments.

Therefore, when determining the timing and magnitude of releases from Wivenhoe Dam to meet target peak flood flows at Moggill, flood operations at Wivenhoe Dam must take into account estimates of the timing and magnitude of Downstream Catchment Flows.

Noting the travel time between Wivenhoe Dam and Moggill, changes to releases at Wivenhoe Dam will not influence flow at Moggill for around 16 hours (this time varies subjects to flood magnitude, refer Figure 4.3.1).

5.2.2 Variability and Limitations of Mitigating Flood Flows at Moggill

The extent to which flood operations at Wivenhoe Dam can mitigate flood flows at Moggill varies significantly depending on the unique characteristics of each Flood Event.

Seqwater has undertaken comprehensive studies of both historical and other simulated[12] flood events to assess the potential of Somerset and Wivenhoe Dams to mitigate flood flows along the downstream reach of the Brisbane River (WSDOS Report). Flood simulation models were used to simulate historical floods under 'No Dams' and 'With Dams' scenarios to assess the effectiveness of the presence and operation of the Dams in mitigating peak flood flows at Moggill.

The results of the WSDOS Report demonstrated that:

a. The presence and operation of Somerset and Wivenhoe Dams significantly reduce peak flood flows in the Brisbane River at Moggill;
b. The degree of flood mitigation can be highly variable, depending on the unique characteristics of each Flood Event, such as the magnitude, timing and location of rainfall upstream and downstream of the Dams.
c. It is not possible to pre-define a set of ‘optimal’ flood operations procedures for every Flood Event. Any material change to flood procedures at the Dams can produce better outcomes for some Flood Events, but worse outcomes for others. The Queensland Government’s[13] preferred flood operations procedures were evaluated in conjunction with Seqwater to define procedures, that on average, will produce appropriate flood mitigation outcomes across the many different Flood Events that could occur. In 2014, the Government selected the WSDOS operational option Alternative Urban 3 as the preferred flood operations procedure for Wivenhoe and Somerset Dams;
d. The Dams cannot eliminate downstream flooding. Downstream catchments can also contribute significantly to flood flows at Moggill, principally Lockyer Creek, the Bremer River and the residual catchment to Moggill, which accounts for 41% of the total catchment area of the Brisbane River Basin. The Dams cannot modify runoff flows from these catchments;
e. Flood inflows into the Dams with runoff volumes and inflow rates that exceed the storage capacity[14] and maximum outflow rate for the Flood Mitigation Strategy require higher releases to meet Dam Safety Objectives. For example, the inflow volume of the Probable Maximum Flood is approximately four to five-times larger than the combined volume of Flood Storage Compartments, and the peak inflow rate is nine-times higher than the maximum outflow rate for the Flood Mitigation Strategy. When very large floods trigger the Dam Safety Strategy, the Manual requires higher releases to prioritise Dam Safety.

Further information is available in the Wivenhoe and Somerset Dams Optimisation Study Report.

[12] Flood hydrographs have been simulated for over 5,000 'statistical' flood events.

[13] The Queensland Floods Commission of Inquiry 2012 found that the State Government has a responsibility to weigh up the benefits and disadvantages of different dam operation options and assess trade-offs on behalf of the greater community.

[14] Wivenhoe Dam 75 m AHD is the upper limit for the Flood Mitigation Strategy.

5.3 Mitigation of Peak Flood Levels at Ipswich

Elevated flood levels in the Brisbane River at its confluence with the Bremer River can back up water levels for many kilometres along the lower reaches of the Bremer River (known as the backwater effect). If there is no substantial flow in the Bremer River, water levels along the lower reaches will peak at the same level as the Brisbane River at its confluence with the Bremer River. If there is substantial flow in the Bremer River, water levels along the lower reaches will peak at higher levels than at its confluence.

Any increase in flood levels along the lower reaches of the Bremer River caused by this backwater effect will be greatest at the mouth of the Bremer River and will progressively dissipate with distance upstream from the mouth.

The influence of Brisbane River flood levels on Bremer River flood levels at Ipswich depends on:

a. Brisbane River flood levels at the mouth of the Bremer River, which can be influenced by releases from Wivenhoe Dam[15]; and
b. Flood flows generated in the Bremer River catchment, which cannot be influenced by Wivenhoe Dam.

Flood simulations under the 'With Dams' and 'No Dams' scenarios undertaken for WSDOS (as described in Section 5.2 above) demonstrate that the presence and operation of the Dams can also significantly reduce peak flood levels in the Bremer River at Ipswich, but that this does not occur for all Flood Events. Mitigation of flood levels at Ipswich may sometimes be minimal for Flood Events where flood flows from the Bremer River catchment dominate flood level at Ipswich.

5.4 Every Flood is Different

The variation in flooding in the Brisbane River Basin is complex and varies significantly from one Flood Event to another.

Variability of flood-producing rainfall events[16] are a primary driver of flood variability. The variability of rainfall events can include:

a. Significant rainfall events can occur in any month of the year, but are most frequent in the summer months, often associated with cyclones, monsoon activity and East Coast Lows. East Coast Lows can occur at any time throughout the year, and historical records indicate that floods have occurred in the Brisbane River Basin in winter;
b. Depending on the governing synoptics of weather systems, rainfall events can originate from any direction; and
c. Variability in the movement of rainfall events, as well as in the spatial and temporal patterns of rainfall across the Brisbane River Basin, affects the location and relative timing of flood runoff (both flow rates and flood volumes) in the various sub-catchments and the magnitude of downstream flood flows at locations of interest.

In addition to the above influences of rainfall events and patterns of rainfall, the following factors also affect the variability of flooding across the Brisbane River Basin:

- **Initial Catchment Conditions.** The initial catchment wetness determines the proportion of rainfall converted to surface runoff and subsequently into streamflow and flood flow. The wetter the catchment, the smaller the rainfall loss and the greater the surface runoff and flood flow. Conversely when the catchments are dry, runoff is less. In the January 2013 Flood Event, more than 150 mm of rainfall was absorbed by the ground in some parts of the Brisbane River Basin before substantial runoff occurred.
- **Initial Storage Conditions.** The presence and initial content of natural storage areas across the catchment, which need to fill and overflow before generating runoff. These storage areas can affect the timing and amount of runoff. The presence, initial content and operation of constructed storages, such as Somerset and Wivenhoe Dams, also store runoff generated by the rainfall event and affect flood variability in downstream areas.

[15] Releases from the Dam influence peak flood flows along the downstream reach of Brisbane River and the associated peak flood levels.

[16] Flood levels along the lower reaches of the Brisbane River are also influenced by the tidal variation of water levels and any storm surge effects, if present, in Moreton Bay. The impact of these factors on flood levels in the Brisbane River is most pronounced for smaller floods and progressively dissipates with distance upstream from the mouth of the Brisbane River.

- **Variation in Travel Times.** While records from past floods and calibrated flood simulation models can provide guidance on the likely flood flow travel time along the waterways, travel times can vary depending on factors such as vegetation growth along waterways and other changes that affect waterway hydraulics (natural changes to river channels such as erosion and sedimentation or man-made changes such as gravel extraction, etc).

5.5 How Much Flood Storage is Enough?

During the early to rising phases of a Flood Event (while rain is still falling heavily), it is not known how much of the Dams' Flood Storage Compartments will be needed for the current Flood Event. Forecasts of future runoff flows from upstream and downstream catchments are uncertain due to uncertainties in the magnitude, location and timing of rainfall, catchment rainfall losses, variation in flow travel times (which may be different to past events) and limitations of the simulation models used for flood flow forecasting purposes, as discussed in Section 7 and Section 12.

It is important to reserve adequate flood storage capacity to cater for more extreme rainfall that might eventuate over the course of the Flood Event. This is important for striking a balance between Flood Mitigation and Dam Safety Objectives; it is also important for striking a balance between the use of the Flood Storage Compartment to meet target flood flows at Moggill. This is discussed further in Section 9, Section 10 and Section 11.

6 Flood Operations Centre and Communications with the Public

This Section outlines a wide range of flood management activities, both outside and during Flood Events, to be prepared for and to conduct flood operations at Wivenhoe and Somerset Dams.

Important elements of these activities are the Flood Operations Centre and communication with external stakeholders during Flood Events, both of which are described below.

6.1 The Flood Operations Centre

The Flood Operations Centre forms the hub of operational decision-making for Wivenhoe and Somerset Dams during Flood Events. A number of crucial activities occur in the Flood Operations Centre during a Flood Event, including:

a. Mobilisation of staff that work in the Flood Operations Centre and at the Dams, in accordance with Section 13.1;
b. Maintaining communications between the Dams and the Flood Operations Centre during a Flood Event. Note, in the event that communications are lost, the Dam Supervisor is to follow the Emergency Procedures outlined in Section 16.4;
c. Using the FFS, in accordance with the requirements of the Manual, to assist in the selection of appropriate Operational Strategies and the formulation of appropriate Release Plans to implement these Strategies. The use of the FFS (for example, to predict future Lake Levels and flood flows across the Brisbane River Basin) is a crucial element of these technical assessments. The FFS is described in Section 7;
d. Issuing directives to Dam Operators containing details of Release Plans to be implemented at the Dams. Release Plans are described in Section 8;

6.2 Communicating with Other Agencies and Public Notifications

Seqwater is one of several agencies that contribute to the management of floods and their consequences in the Brisbane River Basin. Through the operation of the FFS information on current and predicted releases from the Dams is provided to these agencies.

Formal communications protocols are in place to facilitate communication arrangements to external stakeholders during Flood Events.

6.2.1 Emergency Action Plan and Gated Dam Communications Protocol

Under Sections 352E and 352H of the Act an Emergency Action Plan (EAP) for the Dam is required to provide notifications and warnings to persons that may be affected by dam hazards events and emergency events. The EAPs for the Dams are published on the Queensland Government website: https://www.business.qld.gov.au/industries/mining-energy-water/water/industry-infrastructure/dams/emergency-action-plans/map

The EAP does not describe procedures to operate the Dams. The EAP operates in parallel with this Manual.

Dam hazard events include flood releases from Wivenhoe Dam or Somerset Dam even if there is no threat to the safety of the Dams.

The Seqwater Communications Protocol for Flood Releases from Seqwater's Gated Dams (Wivenhoe Dam, Somerset Dam and North Pine Dam) is the document used to fulfill the EAP notification requirements for non-failure flooding. If there is potential or actual dam failure, notifications and warnings are undertaken using the EAP.

The Seqwater Communications Protocol for Flood Releases from Seqwater's Gated Dams (Wivenhoe Dam, Somerset Dam and North Pine Dam) also provides for other communications for non-failure flooding communications beyond the requirements of the EAP.

FLOOD OPERATIONS CENTRE AND COMMUNICATIONS WITH THE PUBLIC

When a Flood Event has commenced and until a Flood Event ends (both defined in accordance with this Manual) the Seqwater Flood Operations Centre goes to a Stand up level of activation.

The Communications Protocol serves the following purposes:

a. To provide dam release information in standard formats to stakeholder agencies;
b. To facilitate a collaborative approach to flood emergency management between federal, state and local government agencies;
c. To support the cross-government communications necessary as a result of Dam releases; and
d. To assist stakeholder agencies in developing and harmonising their key messages.

Notifications issued to external stakeholder agencies as part of the Communications Protocol include:

a. Activation level status, summarising the activation level of the Dams;
b. Advice on the planned commencement of releases from the Dams;
c. Advice on releases that are likely to inundate roads and bridges (It is noted that river crossings could also be inundated by flows not related to Dam releases);
d. Flood Event Situation Reports; and
e. Wivenhoe Dam outflow hydrographs to stakeholder agencies that operate flood modelling systems or flood warning systems.

6.2.1 Public Notifications

Seqwater also provides several information services to the general public via an opt-in basis:

a. 'Dam release notifications' by email, by SMS/text message to mobile phones, or by recorded messages to telephone landlines;
b. The 'Dam release notification hotline' provides information on dam releases and safety notices for recreation areas affected by elevated Lake Levels;
c. Dam storage information via its corporate website; and
d. Other information via social media platforms.

6.2.2 Bridge Closure Advice

Prior to the bridges downstream of Wivenhoe Dam listed in Appendix H being inundated due to releases of water from Wivenhoe Dam, the Duty Engineer should aim to ensure that the agency responsible for the closure of the bridge is notified. This notification should, where practicable, allow sufficient time for the agency responsible to close the bridge in a safe and orderly manner.

Runoff from areas downstream of the Dam can inundate these bridges at short notice (independent of Dam operations), and bridge flow capacities may change from time to time, so it will not always be possible for the Duty Engineer to provide advance notice of bridge inundation.

The Duty Engineer is responsible only for providing advice on Flood Closure for bridges and river crossings that are located on the Brisbane River between Wivenhoe Dam and Moggill, and then only when a release of water from Wivenhoe Dam is judged likely to contribute to the Flood Closure. Unless other information is available, the river flows to be used by the Duty Engineer for judging the potential for Flood Closure of downstream bridges and river crossings are contained in Appendix H.

6.2.3 Provision of Data to Agencies

At the commencement of a Flood Event, and whenever there is a significant change in Release Plan, Seqwater shall provide the following organisations with the details of Actual Lake Levels and predicted Lake Levels at Somerset Dam and Wivenhoe Dam, and actual and predicted water releases from Wivenhoe Dam:

a. Bureau;
b. DRDMW;
c. Brisbane City Council;
d. Ipswich City Council;
e. Somerset Regional Council;
f. Department of Transport and Main Roads – Maritime safety; and
g. Other stakeholders as defined in the Gated Dam Communication Protocol as amended from time to time.

The contact information for relevant organisations and agencies is contained in the Emergency Action Plans for the Dams, and communications protocols with these agencies are contained in the Communications Protocol.

7 The Flood Forecasting System

7.1 Overview

During a Flood Event, estimates of likely future flood conditions in the Brisbane River Basin are essential for the planning of effective and responsible flood operations at Wivenhoe and Somerset Dams in accordance with this Manual.

Seqwater has developed and continually maintains, improves, and operates a Flood Forecasting System (the FFS), as required under the Act.

Specifically, the purpose of the FFS is to provide estimates over the course of a Flood Event for:

a. Future flood inflows into the Dams;
b. Predicting Lake Levels in the Dams as part of developing Release Plans (planned outflows); and
c. Future flood flows at key locations in the Brisbane River Basin that are required to support operational decision making.

The FFS is an important decision-support tool that allows Duty Engineers to estimate Predicted Peak Lake Levels and peak flows in upstream and downstream catchments from recorded rainfall and Rainfall Forecasts, including the simulation and assessment of Release Plans. The FFS allows efficient trialling of a number of potential Release Plans to assess their effect on Predicted Peak Lake Levels and predicted peak downstream flood flows, using catchment and downstream river flow forecasts available at the time that the Release Plan is developed. In this way, an appropriate Release Plan that meets the Procedures can be adopted and implemented. Catchment flow forecasts and Release Plans are determined quantitatively with FFS using Rain on Ground and are revised many times during a Flood Event. The circumstances for qualitative situational awareness consideration of Rainfall Forecasts is described in Section 12.

The FFS consists of the following four integrated components, which are discussed below:

a. A Monitoring Network;
b. A Data Collection System;
c. A Modelling Platform; and
d. A Gate Operations Model.

7.2 Monitoring Network

The monitoring of rainfall and stream levels[17] in real-time across the Brisbane River Basin is essential to understanding current flood conditions during a Flood Event and to simulate catchment flow hydrographs and Lake Level hydrographs.

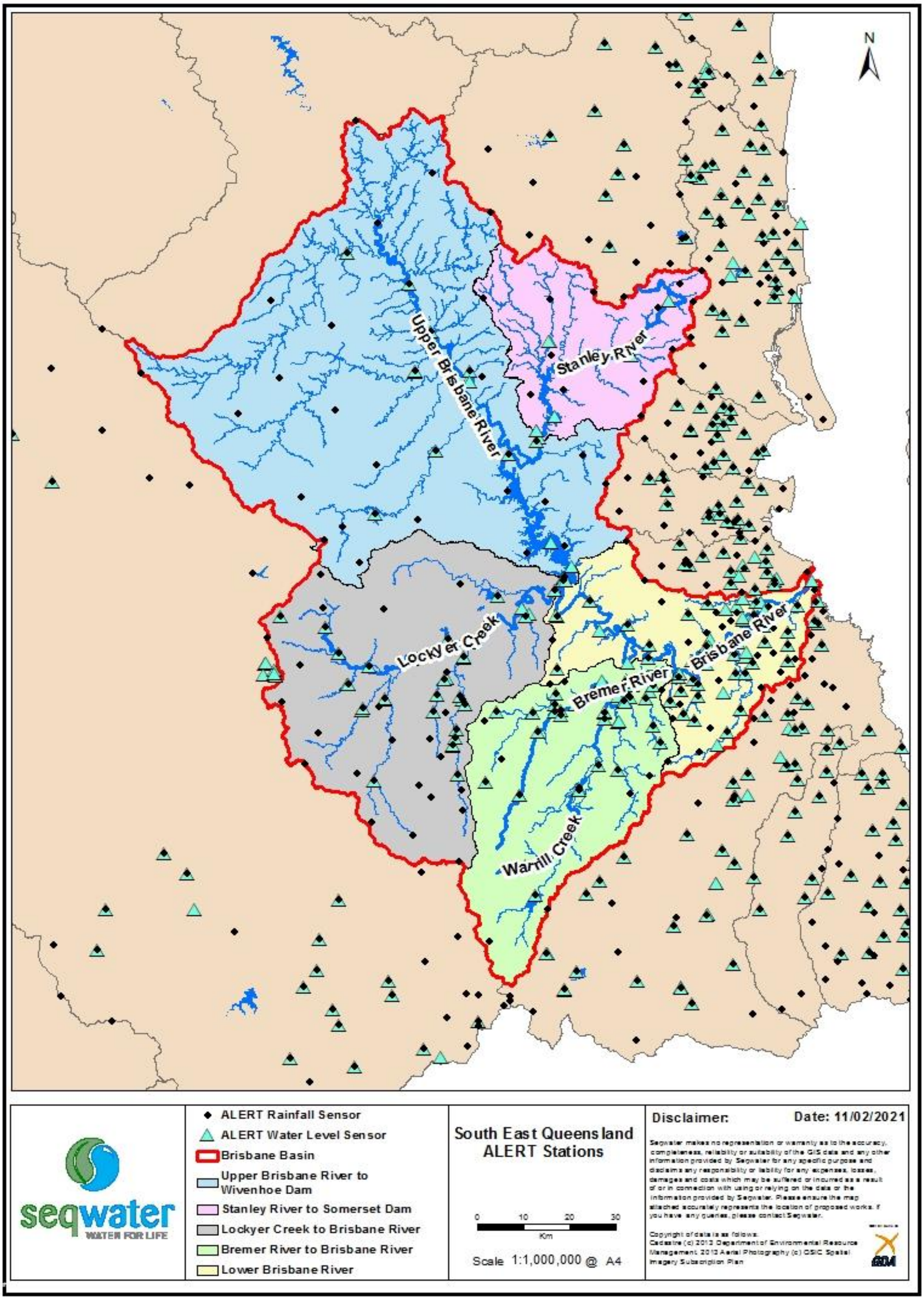
Seqwater receives rainfall and water level data from several hundred ALERT[18] sensors across South East Queensland. The network is comprised of gauges owned by Seqwater, local government agencies and the Bureau. Details of gauge ownership are available on the Bureau website.

Figure 7.2.1 shows the location of these gauges in South East Queensland, as at February 2021. Gauges owned and operated by other agencies provide an additional level of real-time data redundancy, should gauges fail during a Flood Event. Seqwater owned ALERT gauges are monitored and maintained on a regular basis.

[17] There are significant technical challenges in directly measuring streamflow. Most stream gauges simply measure water level. A rating curve can be used to estimate rated streamflow from the recorded water level.

[18] The acronym ALERT stands for Automated Local Evaluation in Real-Time. ALERT sensors automatically transmit rainfall and water level data by radio to designated base stations at prescribed intervals or when a change in reading occurs.

Figure 7.2.1 Location of ALERT Rainfall and Water Level Sensors, South East Queensland, as at 5 February 2021.



7.3 Data Collection System

The role of the Data Collection System is to collect rainfall, water level and manual observation data and transfer this data to the Modelling Platform, where the data is processed and stored for subsequent use in flood simulation modelling.

Data from three sources are collected and transferred to the FFS:

a. ALERT sensor data, via ALERT collection software[19];
b. Telemetry data, manually read water level data, and Dam gate and Dam outlet settings, via the WISKI hydrometric database[20]; and
c. Rainfall and water level data accessed from the Bureau via Registered User Services.

7.4 Modelling Platform

The purpose of the Modelling Platform is to facilitate the checking, analyses and visualisation of hydrometric data, together with the simulation of flood conditions using this data (which are sourced from a number of data feeds).

The Modelling Platform provides a versatile way of checking and screening possible suspect recorded rainfall and water level data. The Modelling Platform also imports Rainfall Forecast grids from the Bureau which provides information (with uncertainties) for situational awareness. With the data available, hydrological event-based flood simulation models can then be run to forecast catchment inflows and Lake Levels with such forecasts based on Rain on Ground for use in developing Release Plans. The role of Rainfall Forecasts for situational awareness is set out in Section 12.

The Modelling Platform used by Seqwater is based on Delft-FEWS, which is widely used across the world for flood forecasting purposes. This platform allows the following operations to be undertaken either automatically or manually:

a. The import and processing of real-time ALERT rainfall and water level data;
b. The import and processing of manually read data (from WISKI);
c. The import and processing of Bureau Rainfall Forecasts[21];
d. Data visualisation for quality control and situational awareness;
e. The generation of alerts and web reports;
f. Running of various flood models used to simulate flood conditions (see below);
g. The distribution and sharing of modelling results with other agencies; and
h. The archiving of modelling results.

[19] As at February 2021, the Enviromon software package is used to collect data from the ALERT stations of the Monitoring Network. Enviromon was developed by the Bureau and is widely used throughout Australia. As used by Seqwater, Enviromon has been configured to receive data from ALERT sensors operated by Seqwater, local government agencies and the Bureau via multiple communication pathways to provide a level of communications redundancy. The software also enables incoming data to be automatically checked and adjusted, if necessary.

[20] WISKI is the hydrometric database used by Seqwater for the entry, storage and retrieval of manually read water level and other hydrologic data.

[21] Refer to Section 12 regarding consideration of Rainfall Forecasts for situational awareness.

For the Brisbane River Basin, the FFS supports and facilitates the use of nine hydrologic runoff-routing models[22] that simulate flood flow hydrographs at key locations of interest across the following sub-catchments of the Brisbane River Basin (see Figure 7.4.1):

a. Stanley River catchment to Somerset Dam;
b. Upper Brisbane River catchment to Wivenhoe Dam;
c. Lockyer Creek catchment to O'Reilly's Weir;
d. Bremer River catchment to Walloon;
e. Reynolds Creek catchment to Moogerah Dam;
f. Warrill Creek catchment to Amberley;
g. Purga Creek catchment to Loamside;
h. Cabbage Tree Creek catchment to Lake Manchester Dam; and
i. The Brisbane River catchment (local inflows) downstream of Wivenhoe Dam.

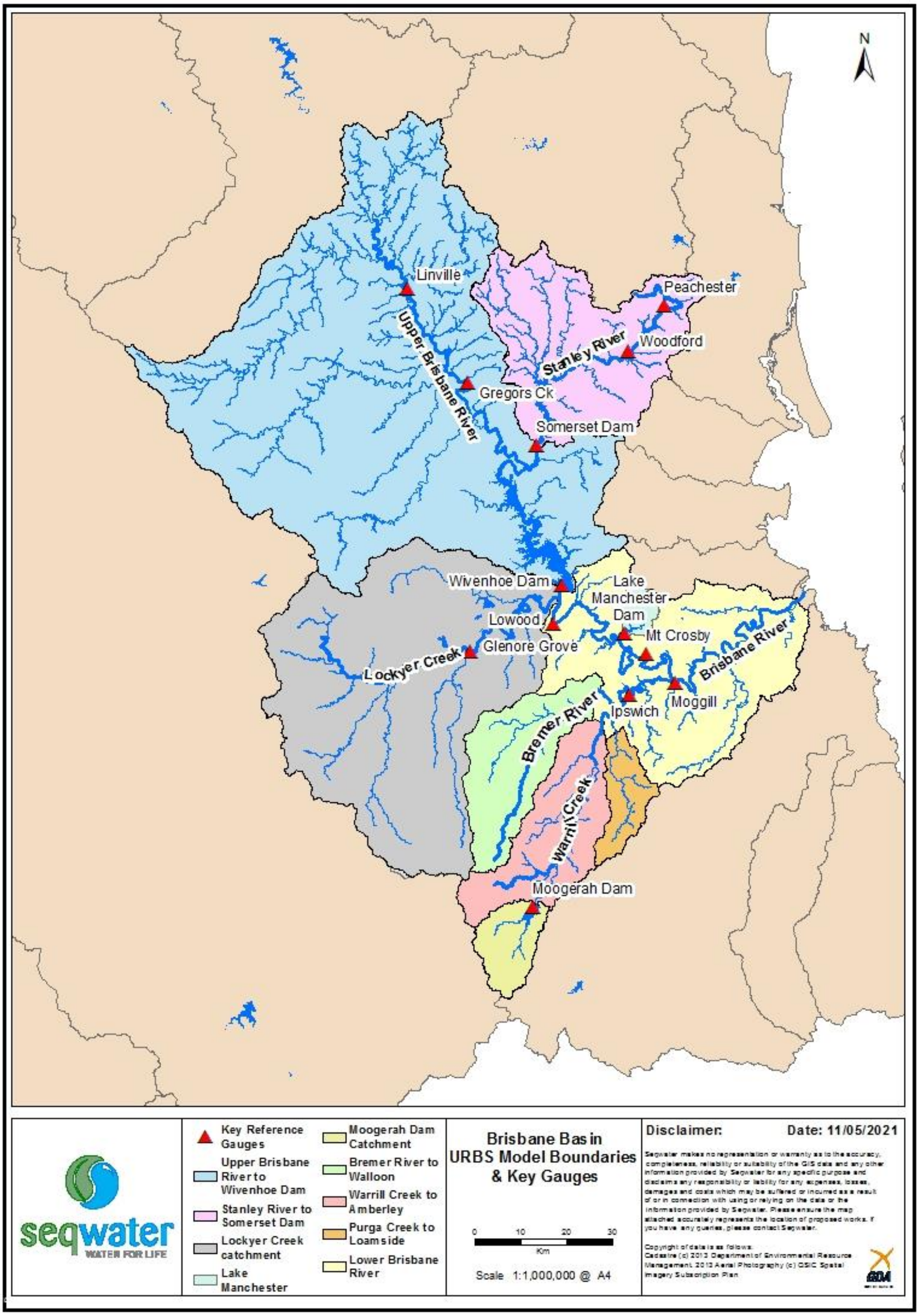
These models have been calibrated to reproduce flood hydrographs for historic Flood Events, as reported in Brisbane River Flood Hydrology Models (Seqwater, 2013).

Appendix J describes the important characteristics of flow hydrographs necessary for decision making to apply the Procedures in Section 13, 14, and 15 of this Manual and the strengths and limitations of forecasting with actual rainfall (Rain on Ground).

Appendix K describes uncertainties in Rainfall Forecasts and risks that could occur if catchment flow hydrographs were determined with Rainfall Forecasts (note this Manual is strictly limited to determining Release Plans using Rain on Ground catchment flow forecasts). Appendix K explains why Rainfall Forecasts are not used quantitatively to determine a Release Plan.

[22] Each of these models mathematically simulates catchment flow hydrographs, from the conversion of rainfall into catchment runoff, its subsequent movement as surface runoff, its passage downstream along the stream flow network, to its eventual transformation into an outflow hydrograph at the catchment outlet. In this way, the variation of flood flow over the course of a Flood Event (the flood hydrograph) can be simulated at points of interest in the Brisbane River Basin.

Figure 7.4.1 Flood Hydrology (Runoff Routing) Models of the FFS



During a Flood Event, the Modelling Platform allows model results to be compared to observed water levels and estimates of rated flows[23] at key locations in the Brisbane River Basin, thereby enabling model calibration to be reviewed and adjusted in real-time. The Duty Engineers can adjust the parameters of the flood simulation models, as needed, to improve the match between observed and simulated catchment flows and water levels. The importance of reasonable and reliable model calibration is described in Appendix J.

7.5 Gate Operations Model

The Gate Operations Model, the final component of the FFS, is used to decide release rates from the Dams that meet the criteria specified in the Procedures through the development of a Release Plan. These decisions are made using forecast catchment flows derived with the FFS using Rain on Ground. Release Plans are discussed further in Section 8. The release rates may be constrained by physical limitations of spillways, gates and outlets or by operational constraints listed in the Procedures.

The Release Plan is enacted through Directives issued by the Duty Engineers to operators at the Dams.

The Gate Operations Model simulates the combined effects of inflows to the Dams and outflows (controlled and uncontrolled releases) from the Dams on the Predicted Peak Lake Levels at each Dam and flood flows at Moggill. The magnitude and timing of controlled releases is the only variable that the Duty Engineers can modify within the constraints of the Procedures. The FFS simulations show the impact of Dam outflows on flood flows at key downstream locations, and so enables assessment of the ability of the Release Plan to meet the criteria of the relevant Procedures. After an appropriate Release Plan has been selected, details of planned releases are sent to internal and external stakeholders that have operational needs for the use of such data[24].

The Release Plan is regularly updated and modified as conditions change over the course of a Flood Event. The FFS is continually used to simulate evolving flood conditions. These results are used to assess the adequacy or otherwise of modifications to the Release Plan (described further in Section 8).

7.6 Predicted Peak Lake Levels

Key determinants of many decisions regarding flood operations at Wivenhoe and Somerset Dams are the Predicted Peak Lake Levels in the Dams and predicted peak flood flows in the Brisbane River at Moggill.

These predictions are made with the FFS, which has capability to predict future inflows to the Dams, peak Lake Levels in the Dams and peak flood flows downstream of the Dams with recorded rainfall (Rain on Ground).

Section 3.4 describes considerations for professional judgement when making decisions based on predicted Lake Levels.

[23] Recorded water levels are converted to estimated or rated streamflow using a rating curve for the location.

[24] For example, the Bureau requires dam release information for downstream flood forecasting and warning.

8 Release Plans

8.1 Overview

In this Manual, Procedures used to implement Strategies and changes from one Strategy to another centre on a range of criteria that relate to Lake Levels in the Dams, downstream flows at nominated locations, and in some cases combinations of both factors. Some criteria are specified in terms of current flood conditions (water levels and/or estimated flows). Other criteria are specified in terms of estimates of future flood conditions, as determined by simulations with the FFS derived with actual rainfall (Rain on Ground).

It is important to note that precise definitions in the Procedures and in the Glossary specify whether the nominated criteria relate to current (actual) flood conditions or to future (predicted) flood conditions.

Future Lake Levels in the Dams and the future downstream flows are influenced by both current and future releases from the Dams. Future Lake Levels in the Dams are also influenced by current and future inflows. In order to assess whether future releases will comply with the Procedures in this Manual, it is necessary to:

a. Estimate inflow hydrographs for the Dams and in the catchments downstream of the Dams in the FFS;
b. Trial a sequence of future releases (a Release Plan) in the Gate Operations Model and assess the impact of the proposed releases on the estimated future flood conditions (Predicted Peak Lake Levels for each Dam and downstream flows) to determine whether the proposed releases comply with the requirements of the Procedures within the current Strategy.

When the requirements of the Procedures within the current Strategy are met, the intended releases are specified in a Release Plan that prescribes the magnitude and timing of releases from the Dams, along with the gate settings required to achieve these releases.

A Release Plan at any point in time is based on the estimated inflow hydrographs at that point in time and includes:

a. Past releases from the start of the Flood Event to the current time; and
b. Planned future releases beyond the current time.

The Release Plan is updated as the flood conditions change over the course of the Flood Event. This occurs frequently during the rising stage of a Flood Event when catchment flows are increasing. It also occurs during the falling stages of a Flood Event in response to the availability of more complete rainfall and streamflow data, possible future rainfall, or improved calibration of catchment flows in the FFS.

In practice, gate operations over the course of a Flood Event do not follow a single Release Plan. In order to continue meeting the Procedures' criteria, Release Plans need to be updated in response to changing Flood Event conditions.

8.2 Developing a Release Plan

A Release Plan is developed through iterative analysis with interpretation of data and simulations with the FFS. This means that simulations using the FFS need to trial potential releases (magnitude and timing of releases) to assess possible outcomes of the assumed releases on Lake Levels and downstream flows. The iteration process continues with adjustments to the assumed potential releases until an acceptable Release Plan is defined that satisfies the criteria of the relevant Procedures for the selected Strategy.

If the iteration process cannot produce a Release Plan that satisfies the criteria of a Procedure, the Procedures direct the change to another Procedure, Strategy, or requirement to end the Flood Event.

The level of analysis and interpretation required in developing a Release Plan is a matter for professional judgement, together with consideration of the following factors:

a. The requirements of the Procedures for the selected Strategy (which are designed to achieve an appropriate balance between the Objectives).

b. Information providing situational awareness (or simply current conditions and the anticipated future trend) for:

    i. Recorded data, including observed rainfall, observed stream heights and rated flows, Actual Lake Levels in the Dams, and weather radar images;
    ii. Data analysis and simulated flooding using the FFS with recorded data, to produce estimated catchment flows (dam inflows and flows in downstream tributaries) and Predicated Peak Lake Levels in the Dams;
    iii. Potential trends including Rainfall Forecast and associated guidance provided by the Bureau, including qualitative information (such as weather warnings) and quantitative rainfall forecast products. There are important limitations in the use of rainfall forecasts in developing Release Plans (see Section 12); and
    iv. Professional judgement in relation to uncertainties in the above factors.

c. Other factors concerning dam safety and practical operations at the Dams are also taken into account including:

    i. Information from Dam Operators regarding Dam safety, operability of gates, spillway performance;
    ii. Any other matter pertaining to the safe operation of the Dams and the safety of dam operations staff; and
    iii. Information from emergency services, councils and other agencies regarding public safety.

As time progresses, additional data and model results become available through the FFS. This information is then used to review the appropriateness of the current Strategy and the application of the Procedures to update the Release Plan.

Gate operations at the Dams are implemented in accordance with the latest Release Plan until a new Release Plan is developed and communicated to Dam Operators.

The role of qualitative situational awareness guided by Rainfall Forecasts as a consideration for determining a Release Plan with flows derived from actual rainfall (Rain on Ground) is described in Section 12.

8.3 Predicted and Actual Flood Outcomes

Future flood predictions simulated with the FFS are only estimates which are uncertain. As the Flood Event progresses, it is possible that actual flooding conditions may deviate from the expected outcomes from earlier Release Plans because of further rainfall, or variations in rainfall, or additional data that becomes available to improve the FFS simulations used to estimate the upstream and Downstream Catchment Flows and dam levels, including the influence of the timing and magnitude of catchment flows (e.g. flood routing and flow travel times).

The changing estimates of catchment flows over the course of a Flood Event is a key reason why Release Plans are updated and requires professional judgement to be exercised as circumstances change and develop.

Section 3.4 provides context for professional judgement, Appendix J describes the importance of reliable catchment flow hydrographs for decision making, and Appendix K describes uncertainties and risks with Rainfall Forecasts.

8.4 Implementing the Release Plan

Release Plans are implemented through the following actions:

a. Gate directives (*'instructions'*) are issued to the Somerset and Wivenhoe Dam operators who in turn adjust the gate settings in accordance with those directives;
b. Advice is provided to agencies responsible for bridge closures on the inundation of bridges downstream of the Dams;
c. Actual and predicted Lake Levels in the Dams and actual and predicted releases from Wivenhoe Dam from the most up to date Release Plan are provided to relevant agencies;
d. General flood information is provided to flood response agencies via the situation reports in accordance with the Communications Protocol; and
e. The physical state of the Dams is monitored over the course of the Flood Event, to identify any impact of releases on the sidewalls of the plunge pool at Wivenhoe Dam or the development of unfavourable hydraulic conditions.

9 The Objectives and Overview of the Strategies

9.1 The Objectives

The Manual has four Objectives for flood operations at Wivenhoe and Somerset Dams, as summarised in Table 9.1.1 and further described below.

Table 9.1.1 Objectives, Wivenhoe and Somerset Dams

	Objective
Primary	Prevent structural failure of the Dams.
Secondary	Ensure the Water Supply Compartment of each Dam is full at the completion of a Flood Event.
Lower order	Mitigate downstream flooding.
Lower order	Protect the riverine and riparian environment.

9.2 Primary Objective - Prevent Structural Failure of the Dams

9.2.1 Background

The primary flood operation objective is to prevent structural failure of the Dams.

The structural failure of Wivenhoe or Somerset Dam during a Flood Event could generate a dambreak flood wave that would have catastrophic flooding impacts on downstream communities and impacts on regional water security for an extended period of time.

To manage the structural safety of the Dams during Flood Events, the Manual defines a Maximum Flood Storage Level for each Dam. The Strategies and Procedures in the Manual are designed to ensure that the probability of the Dams reaching their Maximum Flood Storage Levels is as low as practically possible while meeting an appropriate balance between the Objectives.

The Manual includes guidance on the management of structural emergencies at both Dams, in the extremely unlikely event that such emergencies arise. The Manual guides the operations while the communication and other actions are documented in Emergency Action Plans for Somerset and Wivenhoe Dams that are also required under the Act.

9.2.2 Wivenhoe Dam

The Maximum Flood Storage Level of Wivenhoe Dam is 80.0 m AHD.

The main embankment of Wivenhoe Dam is of zoned earth and rockfill construction. Such embankments are not resistant to overtopping and are susceptible to breaching should they overtop. Section 4.5 provides basic details of Wivenhoe Dam.

Studies estimate that an extreme rainfall event with approximately 980 mm of rainfall in 48 hours over the total catchment for Wivenhoe Dam can produce peak Lake Level reaching the Maximum Flood Storage Level of 80.0 m AHD if the Dam is operated using the Procedures in this Manual and when all radial gates are operable. The annual exceedance probability of this magnitude of extreme rainfall event is approximately 1 in 500,000.

If all five of the main spillway gates at Wivenhoe Dam are inoperable for the entire flood event, an extreme rainfall event with approximately 680 mm of rainfall in 48 hours over the total catchment for Wivenhoe Dam can produce peak Lake Level reaching the Maximum Flood Storage Level of 80.0 m AHD. The annual exceedance probability of this magnitude of extreme rainfall event is approximately 1 in 20,000. The probability of the five main spillway gates at Wivenhoe Dam being simultaneously inoperable is extremely low.

9.2.3 Somerset Dam

The Maximum Flood Storage Level of Somerset Dam is 108.7 m AHD with the removable flood barrier in place (or 107.45 m AHD if not). Section 4.6 provides basic details of Somerset Dam.

The structural safety of Somerset Dam is of paramount importance. Should the Dam fail during a flood, it could cause a cascade failure of Wivenhoe Dam.

The dam wall at Somerset Dam is of mass concrete construction with a crest level of 107.45 m AHD. In 2016, a concrete parapet wall and removable flood barrier were constructed atop the main wall, raising the Dam crest level to 108.7 m AHD with the removable crest barrier in place, or 107.45 m AHD without the removable flood barrier in place.

Concrete dams can generally withstand limited overtopping. However, should overtopping occur, Somerset Dam could fail due to erosion of the dam abutments or foundations, or due to instability of the structure itself.

Seqwater estimates that an extreme rainfall event with approximately 1,300 mm of rainfall in 72 hours over the catchment for Somerset Dam can produce a peak Lake Level reaching the Maximum Flood Storage Level of 108.7 m AHD if the Dam is operated using the Procedures in this Manual and when all crest gates and sluice gates are operable. The annual exceedance probability of this magnitude of extreme rainfall event is approximately 1 in 25,000.

If all eight spillway crest gates and eight sluices at Somerset Dam are inoperable for the entire flood event, a rainfall event with approximately 630 mm of rainfall in 96 hours over the catchment for Somerset Dam can produce peak Lake Level reaching the Maximum Flood Storage Level of 108.7 m AHD. The annual exceedance probability of this magnitude of rainfall event is approximately 1 in 100. The probability of eight spillway crest gates and eight sluices at Somerset Dam being simultaneously inoperable is extremely low.

9.3 Secondary Objective - Ensure Water Supply Compartments are full at the end of a Flood Event

As the Dams are a major water supply storage for South East Queensland, it is essential that all opportunities to fill the Dams to the OFSL are taken.

This Objective is necessary to ensure the maximum volume of future water supply reserves (i.e. water stored to OFSL) is held in the Dams at the end of Flood Event. This requirement is also necessary to meet statutory Water Plan objectives, such as water allocation security objectives, under the Water Act.

The secondary objective places constraints on the release of floodwater below the OFSL over the course of the Flood Event, not just at the end of the event.

In balancing water supply and flood mitigation requirements, the:

a. Water Supply Compartments must not be compromised for flood storage purposes; and
b. Flood Storage Compartments must not be compromised for water supply purposes.

The final Lake Level in the Dam at the conclusion of a Flood Event must be within the acceptable range of Lake Levels specified in the Procedures for the Drain Down Strategy in Section 14.3. For all practical purposes, this ensures that the Water Supply Compartment is full and the Flood Storage Compartment is empty at the conclusion of each Flood Event.

9.4 Lower Order Objective - Mitigate Downstream Flooding

The flood mitigation objective aims to mitigate flood flows in the Brisbane River downstream of Wivenhoe Dam.

Peak flood flows in the Brisbane River at Moggill are a key indicator of potential flood consequences downstream of Wivenhoe Dam[25]. Hence, Strategies for flood mitigation are centred on target peak flows at Moggill balanced with prudent use of the Flood Storage Compartment of Wivenhoe Dam.

River crossings downstream of Wivenhoe Dam will be impacted by flooding, both as a result of Dam operations and independent of Dam operations. Inundation of these river crossings can cause isolation and inconvenience to residents and businesses.

For the purposes of this Manual, only Brisbane River crossings between Wivenhoe Dam and Moggill are considered in the Procedures. In particular, the Brisbane Valley Highway Bridge at Fernvale (Fernvale Bridge) and the Mount Crosby Weir Bridge are regionally important transport connections. In smaller Flood Events, Procedures aim to avoid the inundation of these two bridges, and hence the Procedures in Section 14.1 explicitly consider the flow capacity of these bridges.

The other bridges between Wivenhoe Dam and Moggill have either lower usage or alternative routes are available. The flow capacities of the waterway area beneath these bridges are all less than 600m^3/s and these bridges are not explicitly considered in the Procedures for the Flood Mitigation Strategy, although the timing of bridge closure and opening may be considered when developing Release Plans for the Dams and when implementing the Drain Down Strategy (see Section 14.3).

9.5 Lower Order Objective - Protect Riverine and Riparian Environments

Flood flows have both beneficial and detrimental effects on the riverine and riparian environments: water tables are recharged; but riverbanks are susceptible to erosion over the course of a Flood Event and slumping during the recession phase; which can impact riverine and riparian habitats and fish populations.

The Objective to protect the riverine and riparian habitat is mostly applicable to the release of floodwaters from Wivenhoe Dam during the flood recession phase and closure of the radial gates at the end of a Flood Event. The radial gate closing requirements in the Wivenhoe Dam Procedures are designed to address this Objective.

Near the conclusion of a Flood Event, release strategies aim to minimise harm to fish populations in the vicinity of the gates and spillways of the Dams to the extent that the three over-riding flood operation objectives described above allow.

Attempts are made to end Flood Events in daylight hours to facilitate the safe retrieval of any fish stranded below the Dams.

[25] See Section 4.8 for a guide to the consequences of downstream flooding related to peak flood flows at Moggill.

9.6 Overview of The Strategies

The Strategies have been developed to achieve the Objectives. Each Strategy aims to meet multiple Objectives.

The Objectives are addressed in their priority order of importance (see Table 9.1.1).

Table 9.6.1 provides a high-level summary of how each Strategy aims to achieve one or more Objectives. The Strategies are explained in more detail in Section 10 and Section 11. The specific Procedures for each Strategy are set out in Sections 14.1, 14.2, 14.3 and 15.1.

Table 9.6.1 The Strategies, Wivenhoe and Somerset Dams

Dam	Strategy	How the Strategies Achieve the Objectives
Wivenhoe	The Flood Mitigation Strategy	• This Strategy only applies to situations where the Predicted Peak Lake Level will be below 75 m AHD to ensure sufficient storage is reserved for extreme floods to prevent structural failure of the Dam. • Criteria in the Procedures constrain releases below OFSL based on Rain on Ground to ensure the Water Supply Compartment can be refilled. • Peak flood flows in Brisbane River at Moggill are mitigated with reference to the Flood Mitigation Guide Curve (refer Figure 14.1.1) that defines a prudent balance between use of the Flood Storage Compartment and mitigation of downstream flooding. The Flood Mitigation Guide Curve also contributes to the objective to prevent structural failure of the Dam by requiring higher target flows (and thus higher releases) in larger Flood Events. • The Procedures aim to avoid Flood Closure of Mount Crosby Weir Bridge and Fernvale Bridge due to Wivenhoe Dam releases when the Predicted Peak Lake Level is less than three metres above the OFSL. • The rate at which flows can be released into the Brisbane River downstream of Wivenhoe Dam is controlled by limits applied to how fast gates can be opened or closed. This aims to limit rapid changes in downstream river conditions and to reduce adverse environmental outcomes from rapidly changed flow conditions. • Exit criteria to adopt a different Strategy.
	The Dam Safety Strategy	• Preventing structural failure of the Dam by increasing releases to reduce the chance of the Lake Level exceeding the Maximum Flood Storage Level and have radial gates fully open before the lowest fuse plug embankment is breached. • Criteria for exiting this Strategy to the Drain Down Strategy to ensure the Water Supply Compartment will be full at the end of the Flood Event. • In limited circumstances, consideration can be given to reducing the peak flow at Moggill to mitigate downstream flooding, providing the radial gates can be fully opened before the lowest fuse plug embankment is breached. • Exit criteria to adopt a different Strategy.
	The Drain Down Strategy	• Requirement to empty the Flood Storage Compartment within a specified time period to minimise the likelihood of structural failure of the Dam. This is necessary to ensure the Flood Storage Compartment is fully available should another Flood Event occur soon after the current event. • Criteria to end the Flood Event and ensure that the Water Supply Compartments of both Dams are full at the end of the Flood Event. • Mitigate downstream flooding with priorities for reducing flows at Moggill but considering inundation of downstream bridges as the flood recedes. • Protect the environment with criteria governing the rate of reduction in releases, aiming to reduce chances of riverbank slumping and aiming to cease releases in daylight hours to allow for safe recovery of stranded fish downstream of the spillway. • Exit criteria to adopt a different Strategy or end the Flood Event.
Somerset	The Somerset Dam Strategy	• Prevent structural failure of the Dam with releases at maximum practical capacity to reduce the chance of the Lake Level exceeding the Maximum Flood Storage Level. • Criteria in the Procedures constrain releases below OFSL to ensure the Water Supply Compartment is full at the end of the Flood Event. • Exit criteria to end the Flood Event.

9.7 Overview of the Procedures

The Strategies are implemented via the Procedures in this Manual. The Procedures are presented in the form of text, tables and charts to be used to develop Release Plans based on modelling undertaken in the FFS.

The Procedures in this Manual also define criteria to exit from a Strategy, to select another Strategy, or to end the Flood Event.

10 Flood Operations - Wivenhoe Dam

10.1 Overview

Three Strategies are defined for the operation of Wivenhoe Dam during Flood Events:

a. The Flood Mitigation Strategy;
b. The Dam Safety Strategy; and
c. The Drain Down Strategy.

The Dam is operating under one of these Strategies at all times during the course of a Flood Event.

Strategies always aim to meet Objectives in their priority order as outlined in Section 9. The Strategies for Wivenhoe Dam and their alignment to the Objectives are described below. See Section 11 for the corresponding description of flood operations at Somerset Dam.

10.2 Joint Operation of Wivenhoe and Somerset Dams

Wivenhoe and Somerset Dams are jointly operated during Flood Events. The following general aspects of these Strategies are noted:

a. A Strategy commences at each Dam once a Flood Event commences in accordance with this Manual;
b. Wivenhoe Dam is operating under one of its three Strategies at all times during the course of a Flood Event, with a change from one Strategy to another when conditions so dictate;
c. Somerset Dam is always operating under the Somerset Dam Strategy during the course of a Flood Event;
d. The Flood Mitigation Strategy and Drain Down Strategy at Wivenhoe Dam apply to all Flood Events; and
e. The Dam Safety Strategy at Wivenhoe Dam is typically activated only for large floods that will exceed the flood storage volume reserved for the Flood Mitigation Strategy.

The influence of releases from Somerset Dam on flood operations at Wivenhoe Dam is taken into account when predicting Lake Levels in Wivenhoe Dam with the FFS. More specifically, this means that storage-routing to predict the Lake Level of Wivenhoe Dam considers the combined effects of outflows from Somerset Dam to Wivenhoe Dam, inflows to Wivenhoe Dam from the Upper Brisbane River catchment, the exchange of water volumes with Splityard Creek Dam, and releases made under the Release Plan for Wivenhoe Dam.

10.3 Operation of Radial Gates

When the auxiliary spillway fuse plug embankments are intact (not overtopped) the releases from Wivenhoe Dam are controlled by the five radial gates on the main spillway. A Release Plan is put into effect by specifying the settings of the radial gates, i.e. the gate openings that define the outflow from each gate and how these openings change with time over the course of a Flood Event. The actual outflow from Wivenhoe Dam can be different for the same gate openings depending on the Lake Level, i.e. the higher the Lake Level the greater the outflow for the same gate opening.

There are prescribed limitations to the operation of the gates. The gates are large, 12 m wide by 16.6 m high, and if opened or closed too quickly, can result in undesirable rapid changes in downstream flows and water levels. Section 14.5 specifies the gate opening sequence and the rates at which the gates can be opened and closed. Limitations of the Wivenhoe Dam radial gate operations need be taken into account when determining Release Plans.

Practical limitations for gate operations include:

a. The gates must not be overtopped (i.e. they must be lifted sufficiently to ensure that the lake level is lower than the top of the gate);

b. At large gate openings, significant turbulence and vibration can be generated by interaction between the bottom of the gate and the spillway flow, with potential adverse impacts on the gate[26]; and
c. Significant turbulence and vibration can also be generated when an open gate is lowered into spillway flow after it has been lifted clear of the flow[27].

10.4 Wivenhoe Dam Flood Operations Strategies

10.4.1 Flood Mitigation Strategy

The Flood Mitigation Strategy is selected at the commencement of a Flood Event.

Flood Storage assigned to the Flood Mitigation Strategy

The upper limit of the Flood Storage Compartment in the Flood Mitigation Strategy is 75 m AHD. Once the Predicted Peak Lake Level in Wivenhoe Dam is judged likely to exceed 75 m AHD, steps must be taken to ensure the structural safety of Wivenhoe Dam.

Flood Mitigation Guide Curve

The appropriate use of the Flood Storage Compartment when the Predicted Peak Lake Level is between 0.5 m above OFSL and 75 m AHD and the corresponding downstream target flow at Moggill is defined in the Flood Mitigation Guide Curve (refer Figure 14.1.1).

The FFS is to be used in accordance with the Procedures in this Strategy to estimate two key parameters:

a. A Target Flow at Moggill; and
b. A Predicted Peak Lake Level in Wivenhoe Dam.

A Release Plan developed within the Flood Mitigation Strategy is acceptable when the combination of the Predicted Peak Lake Level for Wivenhoe Dam and the Target Flow at Moggill plots on an acceptable region of the Flood Mitigation Guide Curve (refer Figure 14.1.1). Achieving an acceptable outcome is likely to require an iterative process to develop the Release Plan.

Traffic Disruption

Subject to compliance with all of the Procedures for the Flood Mitigation Strategy, when the Predicted Peak Lake Level in Wivenhoe Dam is less than three metres above the OFSL, avoiding Flood Closure of the Brisbane Valley Highway bridge (Fernvale Bridge) and Mount Crosby Weir bridge can be considered. Both of these bridges are regionally significant traffic links[28].

Exit to Other Flood Operations Strategies

The Flood Mitigation Strategy has exit criteria to the Drain Down Strategy that applies when knowledge of the flood magnitude becomes well understood, with this being expressed as the rainfall event is judged very likely to be complete or nearly complete (specific criteria are in the Procedures).

Alternatively, if, whilst applying the Procedures of the Flood Mitigation Strategy, the Predicted Peak Lake Level is judged very likely to reach 75 m AHD, the Flood Mitigation Strategy has exit criteria to commence the Dam Safety Strategy.

[26] In these circumstances, the gate should be lifted clear of the outflowing water.

[27] In these circumstances, the gate should be further lowered until stable orifice flow is established.

[28] Brisbane Valley Highway is a regional transport route, and when Mt Crosby Weir bridge is inundated travel disruption occurs for a significant population with long diversions necessary.

Uncertainties in Targeting a Flow at Moggill

Release Plans developed according to the Procedures in this Manual may not always achieve the intended result due to a number of factors, including:

a. Uncertainty in rainfall estimates;
b. Future rainfall on downstream catchments;
c. River routing influences;
d. Uncertainty of flow estimates at gauges; and
e. Modelling uncertainties.

This is particularly relevant in real-time decision-making during a Flood Event, when estimating future flows in the Brisbane River at Moggill based on Dam releases and inflow estimates into the Brisbane River between Moggill and Wivenhoe Dam. Water released from Wivenhoe Dam reaches Moggill between 12 to 24 hours after the time the release is made, meaning that as a result of the above factors, or when heavy rain occurs below Wivenhoe Dam, it can become apparent in real-time that past Dam releases may cause the flow at Moggill to exceed the Target Flow.

It is noted that the Flood Mitigation Guide Curve (refer Figure 14.1.1) is solely a tool used in the development of the Release Plan at a particular time, as described in the Procedures for the Flood Mitigation Strategy (refer Section 14). Should significant rain continue to fall past the time of development of a particular Release Plan, it is likely that the Target Flow at Moggill will need to be revised. The Flood Mitigation Guide Curve (refer Figure 14.1.1) is therefore not an applicable tool for post-event assessment to evaluate flood mitigation outcomes based on Actual Lake Levels and flow at Moggill.

10.4.2 Dam Safety Strategy

The Dam Safety Strategy applies during larger Flood Events, where increased relative emphasis is required on the primary Objective to prevent structural failure of the Dam. The Procedures require a range of communication notifications to be made when this Strategy is selected.

The Dam Safety Strategy shifts the emphasis towards managing Wivenhoe Dam Lake Levels rather than a maximum target flow at Moggill.

Auxiliary Spillway Considerations

The Procedures require the radial gates to be fully open prior to the triggering of the first fuse plug embankment in the auxiliary spillway.

The auxiliary spillway is designed as an emergency spillway only and, when breached will likely cause downstream erosion. The magnitude and location of the erosion resulting from one or more fuse plug embankment breaches is uncertain.

The estimated AEP of breaching the lowest fuse plug embankment is approximately 1 in 500. When the main spillway gates are fully open and the fuse plug embankments are breached, the Dam is releasing water at its maximum discharge rate and outflow from Wivenhoe Dam becomes uncontrolled. After the Lake Level peaks, releases via the radial gates can be reduced based on professional judgement with caution. It should be noted that lower tailwater levels can occur with closing of radial gates while the fuse plug embankment is breached and this can pose risk of increasing erosion downstream of the auxiliary spillway.

Exit to Other Strategies

If a Flood Event is large enough to meet criteria for entry into the Dam Safety Strategy, the inflows into the Dams are sufficient to meet the Objective of ensuring the Water Supply Compartment will be full at the end of the Flood Event.

The exit criteria from the Dam Safety Strategy are either:

a. Enter into the Drain Down Strategy when knowledge of the flood magnitude becomes well understood with this being expressed as rainfall event is judged to be practically complete (specific criteria are in the Procedures); or
b. Enter into the Flood Mitigation Strategy if the Lake Level is judged unlikely to reach 75 m AHD.

10.4.3 Drain Down Strategy

The criteria that apply for the Drain Down Strategy are that the rainfall event is judged very likely to be complete or nearly complete, the Dam inflows are well understood and the combined Dam storage volume starts to fall.

The exit criteria from the Drain Down Strategy are either:

a. Finish the Flood Event (successfully drained back to OFSL with consideration of Baseflow and within tolerances); or
b. Enter into the Flood Mitigation or the Dam Safety Strategy (specific criteria are in the Procedures) if it appears that significant rises in downstream flows would be required in order to meet the drain down period requirement and the weather outlook is uncertain.

10.5 Tides in the Brisbane River are not Considered

There are tidal influences along the lower reaches of the Brisbane River from Mount Crosby Weir to the river mouth, and along the lower reaches of the Bremer River from around Ipswich to its confluence with the Brisbane River.

Water levels in these river reaches are influenced by tidal variations and flood flows from the upstream catchments. As flood flows increase, the influence of the tide on water levels decreases (the tidal effect is drowned out by the flow). This effect varies at different locations along the river. For example, at Moggill, the tidal influence is drowned out by relatively small floods (around 2,000 to 3,000 m^3/s), whereas at Brisbane City, the tidal influence is still evident in relatively large floods (over 10,000 m^3/s).

Tidal effects are not considered in the operation of Wivenhoe Dam because it is not physically practical to modify Dam releases to avoid high tides. That is because the tidal influence is driven by ocean levels in Moreton Bay (effectively the high tide travels upstream from the river mouth) and the influence of the flood flows travels downstream. This means that it is inevitable that peak flood flows will coincide with high tides at some locations along the estuarine reaches of the Brisbane River. It is not practical to modify the timing of the Wivenhoe Dam releases to avoid high tides.

11 Flood Operations - Somerset Dam

11.1 Overview

Releases from Somerset Dam flow directly into the upper reaches of the lake formed by Wivenhoe Dam and thus influence Wivenhoe Dam flood operations.

11.2 Operation of Cone Valves, Sluice Gates and Crest Gates

Releases from Somerset Dam can be made via four cone valves (limited to certain conditions), eight low-level outlet sluice gates and the spillway which has eight crest gates.

11.2.1 Crest Gates

The crest gates at Somerset Dam are physically capable of being operated in either the fully open or fully closed position, but are not used to actively control releases from the Dam.

Before construction of Wivenhoe Dam, the crest gates for Somerset Dam were used to regulate spillway flow and mitigate flooding. When Wivenhoe Dam was constructed, a review of the flood operation procedures in the 1980s determined that the most appropriate flood operations procedure was for all spillway crest gates at Somerset Dam to be fully open during Flood Events. Current estimates of extreme floods up to the Probable Maximum Flood confirm that operating with spillway crest gates fully open for all floods is necessary to limit the risk of structural failure of the Dam. Within this operational context, spillway flow from Somerset Dam during Flood Events is not controlled, with water spilling from the Dam when the Lake Level exceeds the dam spillway crest elevation of 100.45 m AHD.

11.2.2 Regulated Releases

Releases from the Dam are regulated through sluice gates and cone valve settings. The mini-hydropower outlet at Somerset Dam has a small and insignificant outflow capacity; it is not used for flood operations.

The cone valves can only be operated when not submerged by high tailwater levels downstream of the dam, i.e. at water levels below 68.6 m AHD on the downstream side of the Dam. Submergence of the cone valves occurs when there are higher water levels within Wivenhoe Dam. Operating the cone valves when submerged can damage the valves.

The low-level sluice gates are operated in the fully open or fully closed position and these can be operated for all downstream tailwater conditions.

The Procedures state the sequence of opening and closing the sluice gates, together with maximum allowable rates of opening and closing the cone valves and sluice gates. The aim of these constraints is to balance the need to preserve the structural integrity of the Dam without creating very rapid changes in the outflows from Somerset Dam to Wivenhoe Dam.

11.3 Somerset Dam Strategy

There is only one Strategy for Somerset Dam because it has insufficient spillway capacity for extreme floods and with that context there is very limited flexibility in the way that Somerset Dam can be operated during floods given the Objectives for Flood Operations and their relative importance.

Changes were made to the flood operations for Somerset Dam in the 2016 revision of the Flood Manual in response to an updated understanding of the Dam Safety risks associated with large floods. To appropriately manage these Dam Safety risks it was established through technical assessments that releases from Somerset Dam during floods need to release floodwaters at the maximum capacity possible whilst concurrently addressing the Objective to ensure the Dam's Water Supply Compartment is full at the end of a Flood Event. The Strategies and Procedures were modified to reflect this required change.

The Somerset Dam Strategy places a greater emphasis on the highest priority Dam Safety Objective by requiring releases at the maximum capacity possible.

Criteria in the Procedures constrain releases below OFSL to ensure the Water Supply Compartment is full at the end of the Flood Event with consideration of on-going Baseflow into the Dam.

This necessary mode of operation for Somerset Dam has practically no flexibility to regulate, or adjust, releases. The Strategy for Somerset Dam does not remove the benefits for flood mitigation. When releases are made at the maximum release capacity (sluices open, crest gates open, and cone valves open if possible) the flood passage through the Dam is very similar to an un-gated dam. The criteria restricting releases below OFSL means that peak outflow will be less than peak inflow for the Flood Event thereby providing passive flood mitigation particularly in medium to large floods.

A revision of the Somerset Dam Strategy (and Procedures) is anticipated as part of or following the planned future Dam upgrade works.

12 Consideration of Rainfall Forecasts

12.1 Overview

12.1.1 Primary basis of Release Plans

The primary intent and application of the Procedures (refer Section 14 and 15) is to quantitatively develop Release Plans with catchment flow hydrographs derived with the FFS using observed rainfall in the catchment (Rain on Ground) because this provides a reliable basis to achieve the Objectives. Appendix J describes the requirements for reliable catchment flow hydrographs and forecasting flows derived with Rain on Ground.

The Procedures in this Manual provide a robust method of developing Release Plans based on predictions of catchment flow based on Rain on Ground in order to meet the Objectives. There are multiple aspects of uncertainty in Rainfall Forecasts that mean that quantitative derivation of catchment flows with Rainfall Forecasts are not reliable for decision making and pose risks to meeting the Objectives in this Manual. Further description on uncertainty and risks associated with using Rainfall Forecasts are described in Appendix K (for information purposes only).

12.1.2 Situational awareness consideration

Aspects of the Procedures involve professional judgements in the magnitude and timing of releases. In exercising that professional judgment consideration can be given qualitatively to the Rainfall Forecast (for example, indicative trend) within the constraints of the Procedures. The Release Plan will still be developed based on the catchment flow hydrograph derived from the FFS using Rain on Ground.

While caution with Rainfall Forecasts is necessary, there can be benefits from qualitative consideration of Rainfall Forecasts in different ways. In this context it is important to distinguish:

a. Consideration of Rainfall Forecasts for **situational awareness**. This involves using forecasts qualitatively. Situational awareness guides qualitative professional judgement decisions. Examples where such qualitative judgements are made include a decision to mobilise the Flood Operations Centre (described in Section 12.3) and judging whether rainfall is complete or nearly complete (described in Section 12.4).

b. An **outlook of the potential trend of the Flood Event** estimated with Rainfall Forecast data and is not used quantitatively as a basis of decisions for determining the Release Plan. An outlook of potential trend builds upon situational awareness to provide an indication of "what-if" scenario guidance of possible future conditions. The outlook requires acknowledgement of uncertainty and caution that it is not reliable. An example is to gain an indicative Lake Level outlook by applying the Rainfall Forecast (even if it is uncertain) to test a Release Plan that has been pre-determined with catchment flows that are based on Rain on Ground.
   The outlook of the potential trend can assist for matters associated with flood operations such as discussions with stakeholder agencies on possible inundation of downstream bridges, an indication of possibility of reaching Emergency Action Plan trigger levels, or for an indication of the possible duration of the Flood Event to guide extension of rostering of staff at the Dams and the Flood Operations Centre.

Bureau rainfall forecasts

The Bureau is Australia's national weather, climate and water agency. The Bureau of Meteorology operates under the authority of the *Meteorology Act 1955* (Cth) and the *Water Act 2007* (Cth) which provide the legal basis for its activities, while its operation is continually assessed in accordance with the national need for climatic records, water information, scientific understanding of Australian weather and climate and effective service provision to the Australian community.

The Rainfall Forecasts to be considered for this Manual are solely limited to official products provided by the Bureau (Bureau Provided Forecast or BPF). The Bureau forecasts include Bureau numerical weather prediction (NWP) models and the Bureau has access to other independent international NWP model outputs to generate consensus forecasts.

For this Manual, the current routine BPF is the Australian Digital Forecast Database[29] (ADFD) grids which are used for consideration of situational awareness or, for an outlook of the potential trend of a Flood Event.

During and prior to a Flood Event, Seqwater requests advice from the Bureau as to what it considers to be the most appropriate ADFD rainfall forecast grid for the relevant catchments for the current time and the short term forecast period.

The routine frequency of receiving the ADFD rainfall forecasts is at a minimum of two times each day. The Bureau sometimes issue non-routine updates within the routine update cycle if an update to the forecast is warranted.

Further information on the ADFD and important limitations of these forecasts is presented in Appendix K.

12.2 Pre-emptive releases

This Manual does not allow for pre-emptive release of water below the OFSL before the occurrence of rainfall based on Rainfall Forecasts. This limitation is strict because uncertain Rainfall Forecasts do not provide sufficient assurance for the Objective to ensure the Water Supply Compartment is full at the end of a Flood Event, or do not provide clarity of the true need to commence a Flood Event (that is, the likelihood that the Lake Level will actually exceed OFSL).

The Procedures in this Manual adapt to lower OFSLs if a Temporary FSL is declared by the Minister under Section 390 of the Act (Section 17). A Temporary FSL can allow for the Lake Level to be lowered before the onset of a significant rainfall event (irrespective of the lead time for the potential rainfall event). A temporary FSL can also provide significant flood mitigation.

Once a Flood Event has commenced (Section 13.2), the Procedures in Section 14 and 15 do allow for release of water below OFSL. Such releases can only be made based on Rain on Ground. The Release Plan must also ensure that the Water Supply Compartment will be full at the end of the Flood Event.

12.3 Consideration of Rainfall Forecasts in Flood Operations Centre Mobilisation

This provision is based on situational awareness (refer section 12.1).

The DSFOE may take a cautious approach to Flood Operations Centre mobilisation to ensure that adequate preparation is in place for the onset of a Flood Event. This is because the consequences of early mobilisation do not impact the Objectives of this Manual as releases are not made until a Flood Event has commenced. However, the timing of mobilisation is a professional judgement that must also consider the disadvantages of unnecessarily fatiguing flood operations staff, both in the Flood Operations Centre and at the Dams.

When considering the timing of Flood Operations Centre mobilisation, the DSFOE may apply weight to the Dam inflow predictions and predicted Lake Levels which have been derived from the FFS based on a BPF. Other aspects of a BPF and other advice from the Bureau that may be considered include:

- Catchment conditions including possible rainfall losses;
- The forecast start time for significant rainfall in the Dam catchments and advice from the Bureau on the uncertainty at the lead time indicated in the forecast;
- Advice regarding severe weather that may impact safe travel of staff to the Dams and the Flood Operations Centre;
- The issue of a Flood Watch by the Bureau for areas in and adjacent to the Brisbane River Basin.

[29] The ADFD is the product that generates the 'MetEye' forecast maps on the Bureau website available to the public.

12.4 Consideration of Rainfall Forecasts in judging whether Rainfall is Complete or Nearly Complete

This provision is based on situational awareness (refer section 12.1).

Procedures in Section 14 and 15 require judgement on whether rainfall is complete or nearly complete. This decision requires consideration of both Rainfall Forecasts and the trend observed in actual rainfall. In general, the BPF can reliably indicate when there is a degree of certainty that minimal or no rain is likely to fall over or near the Brisbane River Basin.

Therefore, although the DSFOE must take a cautious approach when judging whether rainfall is complete or nearly complete, the DSFOE must give weight to the BPF in making this judgement.

13 Commencement and Ending of Operations

13.1 Flood Operations Centre Mobilisation and Demobilisation

The DSFOE may mobilise the Flood Operations Centre where there is considerable uncertainty regarding future weather conditions and a Flood Event is considered possible. However, the DSFOE must mobilise the Flood Operations Centre if it is judged likely that a Flood Event will occur due to an approaching weather system.

Once the Flood Operations Centre is mobilised, the DSFOE must ensure notifications under the Communications Protocol are completed as required.

The DSFOE may demobilise the Flood Operations Centre without commencing a Flood Event if it is judged likely that the conditions do not require a Flood Event to commence.

Once a Flood Event commences, the Flood Operations Centre must remain mobilised for the duration of the Flood Event. Once a Flood Event has concluded, the Flood Operations Centre may be demobilised by the DSFOE.

13.2 Flood Event Commencement and Ending

The DSFOE:

a. may make a determination that a Flood Event has commenced when it is judged likely that the predicted Lake Level in Wivenhoe Dam[30] will rise above the OFSL.

b. must make a determination that a Flood Event has commenced when it is judged likely that the predicted Lake Level will:

   i. rise more than 0.1 metres above the OFSL at Wivenhoe Dam[30]; or

   ii. rise more than 1.0 metre above the OFSL at Somerset Dam[31].

Such determinations:

- Must be made with dam catchment flows determined from Rain on Ground; and
- May be made before the Actual Lake Level in the Dam rises above the OFSL.

For the purposes of other documents including Emergency Action Plans, that reference this Manual, the point in time at which the DSFOE makes a determination that a Flood Event has commenced is the point in time at which the Flood Event has been declared.

When a Flood Event commences (except in the circumstances set out in Section 17 for Temporary FSL or Reduced FSL being lower than Actual Level), the Strategy is set to the Flood Mitigation Strategy at Wivenhoe Dam (Section 14.1) and the Somerset Dam Strategy at Somerset Dam (Section 15.1).

The DSFOE will determine that a Flood Event has ended when either the conditions listed in Section 14.3 are met or the conditions listed in Section 15.1 are met. The relevant Section (either 14.3 or 15.1) that is used to determine the end of the Flood Event will depend on the prevailing circumstances of the Flood Event.

[30] When calculating the predicted Lake Level in Wivenhoe Dam for the purpose of determining if a Flood Event has commenced, it is assumed that no radial gate releases will be made from Wivenhoe Dam. This is because the Release Plan will contain zero Wivenhoe Dam radial gate releases prior to Flood Event commencement. However, all planned releases from Somerset Dam into Wivenhoe Dam must be included whenever the Predicted Peak Lake Level in Wivenhoe Dam is calculated.

[31] When calculating the predicted Lake Level in Somerset Dam for the purpose of determining if a Flood Event has commenced, the prediction includes operational releases from Somerset Dam. One metre above 97.0 m AHD is about 37,000 ML. This volume of water can be released within 8 hours with 8 sluice gates open, therefore poses low risks for the safety of the Dam.

14 Wivenhoe Dam Strategies and Procedures

The content of this Section is limited to the specific Procedures and information relating to the implementation of the Wivenhoe Dam Strategies. Additional information is contained in the following Sections:

- **Background Information**: Section 3 contains background information relating to the Dams, Splityard Creek Dam and an overview of the downstream impacts;
- **Flood Mitigation Objectives**: Section 9 contains a description of the Objectives, the priority of these Objectives and reasoning for their prioritisation;
- **Flood Operations – Wivenhoe Dam**: Section 10 contains a description of the Strategies and Procedures to meet the Objectives;
- **Technical Appendices**: Appendix A, Appendix B, Appendix C and Appendix D contain additional technical information relating to Wivenhoe Dam.

14.1 Flood Mitigation Strategy

At the start of a Flood Event (except in the circumstances set out in Section 17), the Flood Mitigation Strategy must be set for Wivenhoe Dam. This may also be commenced according to the exit criteria in the other Strategies. When in this Strategy, the following Procedures apply. The Procedures are designed to minimise the risk to human life and safety by prioritising the structural safety of the Dam. Consideration with professional judgement is given to public safety at all the times during flood operations.

ID	Procedures for Flood Mitigation Strategy
1. Determine a Release Plan with inflow, Downstream Catchment Flow, and Lake Level predictions from the FFS based on Rain on Ground.	
1a	Procedure 1a is used: • at the commencement of a Flood Event; and / or • when the Predicted Peak Lake Level of Wivenhoe Dam is less than 0.5 metres above the OFSL. Under this Procedure, the Release Plan should aim to maintain the Predicted Peak Lake Level of Wivenhoe Dam to less than 0.5 metres above the OFSL while applying the following criteria: i. The water stored in the Water Supply Compartment of the Dam must be preserved. Radial gate releases may commence at the beginning of a Flood Event before the Actual Lake Level exceeds the OFSL only if the DSFOE judges it very likely, that after accounting for all releases in the Release Plan, the Lake Level will exceed the OFSL. ii. Once releases commence, the Release Plan must always ensure that the Water Supply Compartment will be full at the end of the Flood Event. If this cannot be achieved in a Release Plan, releases must immediately cease. iii. Must aim to avoid Flood Closure of the Mount Crosby Weir Bridge and Fernvale Bridge due to Wivenhoe Dam releases. iv. Must aim to avoid the flow at Moggill exceeding 2,000 m^3/s due to Wivenhoe Dam releases. v. Issues associated with community safety and disruption to community activities, including the provision of reasonable warning of downstream bridge closures to responsible agencies must be considered when developing the Release Plan. vi. The criteria in Procedure 1c must be satisfied. Providing the above criteria are met, it is acceptable for the peak release rate to exceed the Rain on Ground predictions of peak catchment inflow into the Dams. In this circumstance the predicted peak catchment inflow into the Dams is calculated by adding the Rain on Ground predicted catchment inflow into Wivenhoe Dam to the Rain on Ground predicted catchment inflow into Somerset Dam at a corresponding point in time. Once the Predicted Peak Lake Level of Wivenhoe Dam can no longer be maintained to less than 0.5 metres above the OFSL while applying the above constraints, determine a Release Plan in accordance with Procedure 1b below.

<table>
<tr><th>ID</th><th>Procedures for Flood Mitigation Strategy (continued from previous page)</th></tr>
<tr><td>1b</td><td>Procedure 1b is used when the Predicted Peak Lake Level of Wivenhoe Dam is greater than 0.5 metres above the OFSL.

This Procedure relies on the developing the Release Plan with the Flood Mitigation Guide Curve shown in Figure 14.1.1.[32]

When applying this Procedure, use an iterative approach to develop a Release Plan by trialling one or more Target Flows at Moggill and adjusting Dam releases to achieve the target flow until the Predicted Peak Lake Level at Wivenhoe Dam is determined to be within the acceptable range on the Flood Mitigation Guide Curve for the adopted target flow.

The Release Plan must meet all of the following criteria.

i. Subject to criteria in 1b(vi) and 1c, the Release Plan should aim to achieve a relatively constant flow in the Brisbane River at Moggill that is close to but not greater than the selected Target Flow at Moggill.

ii. The Release Plan must meet the requirements for acceptability contained in the Flood Mitigation Guide Curve shown in Figure 14.1.1, based on the data in the Gate Operations Model that is used to develop the Release Plan.

iii. The water stored in the Water Supply Compartment of the Dam must be preserved. Radial gate releases may commence at the beginning of a Flood Event before the Actual Lake Level exceeds the OFSL only if the DSFOE judges it very likely, that after accounting for all releases in the Release Plan, the Lake Level will exceed the OFSL.

iv. Once releases commence, the Release Plan must always ensure that the Water Supply Compartment will be full at the end of the Flood Event. If this cannot be achieved in a Release Plan, releases must immediately cease.

v. When the Predicted Peak Lake Level is below three metres above the OFSL, the Release Plan combined with Downstream Catchment Flow should aim to avoid the Flood Closure of the Mount Crosby Weir Bridge and Fernvale Bridge.

vi. Within the criteria of this Procedure, the Release Plan should aim to minimise Dam releases during periods when the Downstream Catchment Flow is greater than the selected Target Flow at Moggill.

vii. The criteria in Procedure 1c must be satisfied.

Providing the above criteria are met, it is acceptable for the peak release rate to exceed the Rain on Ground predictions of peak catchment inflow into the Dams. In this circumstance the predicted peak catchment inflow into the Dams is calculated by adding the predicted Rain on Ground catchment inflow into Wivenhoe Dam to the predicted Rain on Ground catchment inflow into Somerset Dam at a corresponding point in time.</td></tr>
<tr><td>1c</td><td>Release Plans developed in accordance with Procedures 1a and 1b must also:

i. Meet the following additional criteria in Section 14.5:

a. The minimum gate operation intervals should be observed in the Release Plan.

b. The Release Plan must not allow the radial gates to be overtopped.

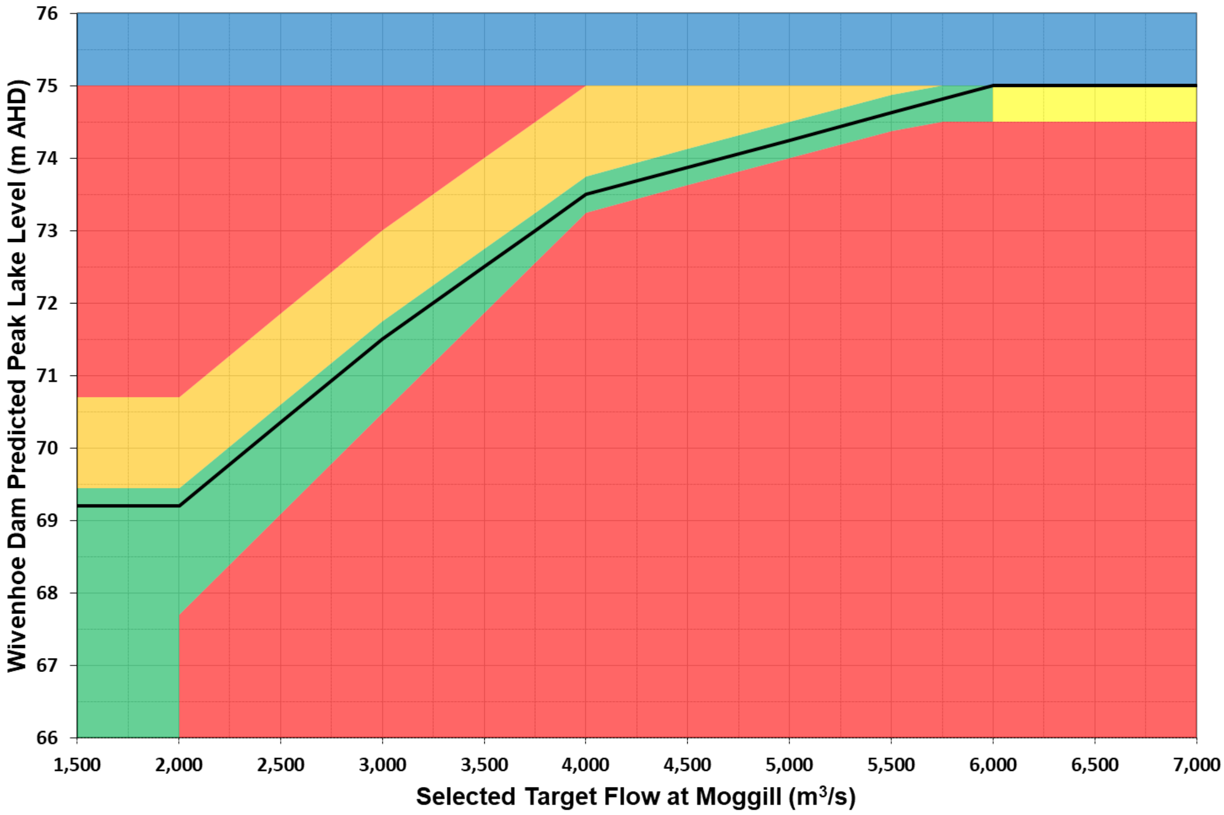
c. The Release Plan must not generate turbulence or vibration that can damage the radial gates or threaten the structural safety of the Dam.

ii. Account for outflows from Somerset Dam determined in accordance with the Somerset Dam Strategy in Section 15.1, with inflows for the Somerset Dam catchment derived in the FFS using Rain on Ground.</td></tr>
</table>

[32] Figure 14.1.1 corresponds to an OFSL of 65.9 m AHD and must be updated in accordance with Section 17 for any other OFSL.

ID	Procedures for Flood Mitigation Strategy (continued from previous page)
2.	**Check Strategy Exit Criteria**
2a	If the Predicted Peak Lake Level is judged very likely to reach 75 m AHD and the criteria in Procedure 1b cannot be satisfied, the strategy must change to the Dam Safety Strategy.
2b	If the rainfall event is judged very likely to be complete or nearly complete[2], the inflow to the Dams is judged likely to be well understood, Wivenhoe Dam is being operated under Procedure 1a and the combined storage volume of the Dams is judged likely to commence falling within 12 hours, the strategy may change to the Drain Down Strategy.
2c	If the rainfall event is judged very likely to be complete or nearly complete[2], the inflow to the Dams is judged likely to be well understood, and the combined storage volume of the Dams has started to fall, the strategy must change to the Drain Down Strategy.
[2] Refer to Section 12.4	

Figure 14.1.1 Flood Mitigation Guide Curve (OFSL is 65.9 m AHD)



LEGEND

Flood Mitigation Strategy Target Line (based on WSDOS)

Release Plan Acceptable

Release Plan Not Acceptable

Release Plan Acceptable only if the rainfall event is judged likely to be complete or nearly complete and it is expected the Drain Down Strategy will be selected in the next 12 hours

Release Plan Acceptable only if the selected Target Flow at Moggill is less than the estimated peak flow in the Brisbane River excluding releases from Wivenhoe Dam

Release Plan Not Acceptable, Strategy must transition to the Dam Safety Strategy.

Note: if an OFSL other than that shown in Figure 14.1.1 is in use, adjust the Flood Mitigation Guide Curve in accordance with Section 17.5.

14.2 Dam Safety Strategy

The Dam Safety Strategy may be commenced according to the exit criteria in other Strategies. When in this Strategy, the following Procedures apply. The Procedures are designed to minimise the risk to human life and safety by prioritising the structural safety of the Dam. Consideration with professional judgement is given to public safety at all the times during flood operations.

ID	Procedures for Dam Safety Strategy
1. Endeavour to Inform the CEO and Chief Executive	
1a	Once a decision is made to use this Strategy, make reasonable attempts to inform the CEO and the Chief Executive (DRDMW) that this Strategy is to be used.
2. Request the Cessation of Hydropower Releases from Splityard Creek Dam	
2a	Make reasonable attempts to contact CleanCo to request the cessation of hydropower releases from Splityard Creek Dam into Wivenhoe Dam.
3. Determine a Release Plan Focused on Dam Safety with inflow and Lake Level predictions from the FFS based on Rain on Ground	
3a	The primary criteria for developing the Release Plan is that all radial gates must be fully open before the Wivenhoe Dam Actual Lake Level exceeds 75.7 m AHD (or the point at which flow commences over the lowest intact fuse plug embankment). Section 14.4 contains modifications to this criteria if one or more fuse plug embankments are not in place. Under this primary criteria, the Duty Engineer uses professional judgement to apply: i. Procedure 3b or 3c or a combination of both if the Predicted Peak Lake Level in Wivenhoe Dam or Somerset Dam is judged unlikely to exceed the Maximum Flood Storage Level; or ii. Procedure 3d if the Predicted Peak Lake Level in Wivenhoe Dam is judged likely to exceed Maximum Flood Storage Level or, Predicted Peak Lake Level in Somerset Dam is judged likely to exceed the Maximum Flood Storage Level. There are no minimum radial gate opening interval timings in this Strategy. As a lower priority to the other guidelines in this Strategy, when developing the Release Plan, endeavour to limit very rapid increases in downstream flows. Release Plans developed in accordance with Procedures 3b, 3c or 3d must also: iii. Meet the following additional criteria in Section 14.5: a. The Release Plan must not allow the radial gates to be overtopped. b. The Release Plan must not generate turbulence or vibration that can damage the radial gates or threaten the structural safety of the Dam. iv. Account for outflows from Somerset Dam determined in accordance with the Somerset Dam Strategy in Section 15.1, with inflows for the Somerset Dam catchment derived in the FFS using Rain on Ground. Provided the criteria above are met, it is acceptable for the peak release rate to exceed the Rain on Ground predicted peak catchment inflow into the Dams. In this circumstance the Rain on Ground predicted peak catchment inflow into the Dams is calculated by adding the Rain on Ground predicted catchment inflow into Wivenhoe Dam to the Rain on Ground predicted catchment inflow into Somerset Dam at a corresponding point in time.

ID	Procedures for Dam Safety Strategy
3b	Table 16.4.1 (see Section 16.4– Dam Operator Actions in the Event of Communications Failure) may be used to guide releases from the Dam. If the release rate differs from the release rate in Table 16.4.1 when this Strategy is invoked, a Release Plan may be developed using professional judgement and the general guidance provided by the table, and ensuring radial gates are fully open before the Actual Lake Level reaches the first fuse plug embankment pilot channel level.
3c	In this Procedure the Release Plan is developed with inflow, Downstream Catchment Flow and Lake Level predictions from the FFS based on Rain on Ground. The Release Plan must aim to limit the rise in Lake Level and may consider the timing of planned releases to mitigate the peak flow at Moggill[1]. The following criteria must be met: i. Any Release Plan that does not achieve full opening of the spillway gates must ensure that the Predicted Peak Lake Level is below the first fuse plug embankment pilot channel level. ii. The Release Plan must be capable of being modified to achieve full opening of the spillway gates before the Actual Lake Level reaches the first fuse plug embankment pilot channel level. There is no criterion for the maximum rate of opening the radial gates, however the practical limit and rate at which it is safe for Dam Operators to perform the required gate opening must be considered in consultation with the Dam Supervisor. iii. The target flow in the Brisbane River at Moggill must be at least 6,000 m^3/s. iv. Judgement of the balance between the Predicted Peak Lake Level and the Target Flow at Moggill must maintain primary consideration on the Objective to prevent the structural failure of the Dam. Adopting a higher target flow at Moggill is necessary in situations where it is judged likely that there is potential for further increase in the Dam inflows.
3d	If the Predicted Peak Lake Level in Wivenhoe Dam or Somerset Dam is judged likely to exceed the Maximum Flood Storage Level for the Dam, the Duty Engineer must use the guidance in Section 16.2. Release rates higher than contained in the guidance provided in Table 16.4.1 (see Section 16.4– Dam Operator Actions in the Event of Communications Failure) are permissible in these circumstances.
4.	**Consider If the Rainfall Event Is Complete or Nearly Complete**
4a.	It is permissible to release at a lower rate than indicated by the Procedures above when the following conditions are met: i. It is judged very likely that the Lake Level will not rise to breach a fuse plug embankment; and ii. The rainfall event is judged likely to be complete or nearly complete[2]; and iii. The Duty Engineer judges it likely that the FFS model predictions are adequately calibrated; and iv. The Drain Down Strategy criteria in Procedure 5b have not been satisfied but it is anticipated that the Drain Down Strategy will be selected within 12 hours.
5.	**Check Strategy Exit Criteria**
5a	If the Lake Level is judged unlikely to reach 75 m AHD and the criteria in Procedure 5b are not all satisfied, the Strategy may change to the Flood Mitigation Strategy (see Section 14.1).
5b	If the rainfall event is judged very likely to be complete or nearly complete[2], the inflow to the Dams is judged likely to be well understood, and the combined storage volume of the Dams has started to fall, the Strategy must change to the Drain Down Strategy (see Section 14.3).

[1] Developing a Release Plan in this situation is complex in real-time. Post event analysis with the benefit of hindsight may show that the flow at Moggill achieved by applying this procedure could exceed the outcome of applying procedure 3b.

[2] Refer to Section 12.4.

14.3 Drain Down Strategy

The Drain Down Strategy is commenced according to the exit criteria in other Wivenhoe Dam Strategies. When in this Strategy the following Procedures apply. The Procedures are designed to minimise the risk to human life and safety by prioritising the structural safety of the Dam. Consideration with professional judgement is given to public safety at all the times during flood operations.

ID	Procedures for Drain Down Strategy
1. Determine a Release Plan for Drain Down with inflow, Downstream Catchment Flow, and Lake Level predictions from the FFS based on Rain on Ground	
1a	The Release Plan should be determined with the aim of reducing impacts downstream as soon as reasonably possible, while emptying the Flood Storage Compartment of Wivenhoe Dam within seven days of the commencement of this Strategy and finishing the Flood Event with a full Water Supply Compartment.
1b	The Release Plan should be developed initially to empty the Flood Storage Compartment of Wivenhoe Dam within seven days (refer to conclusion of event conditions in 3b below), observing the minimum gate operation intervals provided in Table 14.5.1. However, if a favourable weather outlook is available, the drain down period may be extended, at any time in the Drain Down Strategy if such action: i. Aims to reduce the duration of flow at Moggill over 4,000 m^3/s ; and ii. Does not extend the total drain down period beyond 14 days; and iii. Does not pose significant additional risk to the structural safety of the Dams.
1c	Within the drain down period, the criteria for developing and revising the Release Plan for Wivenhoe Dam releases are listed below in order of priority: i. Aim to avoid exceeding the actual peak flow of the Flood Event at Moggill. ii. Reduce the flow at Moggill to less than 4,000 m^3/s. iii. Reduce the flow at Moggill to a flow between 2,000 m^3/s and 4,000 m^3/s. iv. Reduce the flow at Moggill to less than 2,000 m^3/s. v. Reduce the flow to allow the Fernvale and Mount Crosby Weir bridges to be opened. vi. Reduce the flow to allow Burtons Bridge to be opened. vii. Reduce the flow to allow Colleges Crossing to be opened.
1d	Consideration may also be given to the following criteria when developing the Release Plan: i. Minimising community disruption and limiting impacts on community safety. ii. Minimising the impacts on riparian flora and fauna. Appendix I provides some guidance on recession rates for flows below 2,000 m^3/s. iii. Limiting adverse impacts on water quality and other impacts on water supplies downstream of Wivenhoe Dam. iv. Ceasing flood releases from Wivenhoe Dam in daylight to allow a safe and adequate time for fish recovery operation.
1e	Account for outflows from Somerset Dam.

ID	Procedures for Drain Down Strategy (continued from previous page)
2.	**Check Gate Conditions**
2a	In accordance with Section 14.5 adjust the Release Plan if it is judged likely that the gate settings in the Release Plan may lead to the gates being overtopped.
2b	In accordance with Section 14.5 adjust the Release Plan if it is judged likely that the gate settings in the Release Plan may lead to adverse turbulence or vibration.
3.	**Check Strategy Exit Criteria**
3a	During the drain down period, if it is judged likely that actual or forecast rainfall would mean that significant renewed rises in downstream flows would be required in order to meet the drain down period criteria, and an uncertain weather outlook does not allow Procedure 1b to be applied, then exit to: i. the Wivenhoe Dam Flood Mitigation Strategy if the Predicted Peak Lake Level is judged unlikely to exceed 75 m AHD, or ii the Dam Safety Strategy if the Predicted Peak Lake Level is judged very likely to exceed 75 m AHD.
3b	The criteria for ceasing releases at Wivenhoe Dam that are made under the authority of this Manual are as follows. These criteria ensure that the Wivenhoe Dam Water Supply Compartment is full at the conclusion of the Flood Event. If releases of water from Somerset Dam under the authority of this Manual have already ceased for the Flood Event in accordance with Section 15.1 (Somerset Dam Strategy), ceasing releases from Wivenhoe Dam will define the conclusion of the Flood Event. i. Releases of water made under the authority of this Manual may cease when both: a. The Actual Lake Level is between 0.3 metres below and 0.1 metres above the OFSL; and b. it is judged likely that the Lake Level will rise to between the OFSL and 0.1 metres above the OFSL after considering both ongoing Baseflow from the Flood Event and ongoing operational releases. ii. Releases of water made under the authority of this Manual must cease when either: a. The Actual Lake Level is more than 0.3 metres below the OFSL; or b. the Actual Lake Level is below the OFSL and it is judged likely that the Lake Level will not rise to the OFSL without further rainfall, after considering ongoing Baseflow from the Flood Event.

14.4 Modification to Flood Operating Procedures if a Subsequent Flood Event Occurs Prior to the Reconstruction of Breached Fuse Plugs

When one or more fuse plug embankments have been previously breached, the discharge from the breached fuse plug/s are to be taken into account when determining the Release Plan. If a partial breach of a fuse plug has occurred, this may be considered when estimating the fuse plug discharges. Other than this, there is no change to the Flood Mitigation Strategy (Section 14.1) or the Drain Down Strategy (Section 14.3).

In the Dam Safety Strategy (Section 14.2), Procedure 3a should be modified as follows when one or more fuse plug embankments have previously been breach:

a. If one or two fuse plug embankments have previously been breached and have not been reconstructed, all gates must be fully opened before the lowest fuse plug trigger level for the remaining intact fuse plug/s is reached.
b. If all three fuse plug embankments have previously been breached and have not been reconstructed, all gates must be fully opened before the Lake Level reaches 76.78 m AHD.

14.5 Radial Gate Operation

14.5.1 Radial Gate Opening and Closing Intervals

Rapid opening or closing of the radial gates can cause rapid changes in downstream river flows and levels. Accordingly, the aim in opening or closing radial gates is to operate the gates one at a time at intervals that will minimise adverse impacts. Examples of adverse impacts include:

a. Rapid increases at low downstream flow rates can increase downstream river levels rapidly, causing risks to public safety.
b. Rapid decreases at low downstream flow rates can impact on bank stability and may cause fish to become stranded.
c. Long intervals between gate operations reduce the ability of the Dams to provide flood mitigation and adjust to changing circumstances.

Table 14.5.1 shows the target minimum intervals for gate operations. The Duty Engineer may select a longer gate operations interval based on professional judgement. The Duty Engineer may reduce these target intervals as necessary in any of the following circumstances:

a. The safety of Wivenhoe Dam is at risk;
b. The radial gates are at risk of being overtopped; or
c. There is a requirement to preserve stored water or to reduce downstream flooding.

When directing gate operations at the Dam, the Duty Engineer will take into account the infrastructure and personnel related limitations involved in undertaking rapid gate movements under flood conditions.

Table 14.5.1 Target Minimum Intervals for Radial Gate Operations

Estimated Flow in the Brisbane River at Fernvale Bridge (m^3/s)[1]	Opening Interval (0.5 metre increment)	Closing Interval (0.5 metre increment)
Up to 500	30 minutes	45 minutes
500 – 1,000	20 minutes	30 minutes
1,000 – 1,500	15 minutes	20 minutes
1,500 – 6,000	10 minutes	10 minutes
6,000+ (or in the Dam Safety Strategy)	No minimum interval	No minimum interval

[1] The estimated flow downstream of the junction with Lockyer Creek prior to the next radial gate operation commencing. For the avoidance of doubt, this includes releases from Wivenhoe Dam.

14.5.2 Radial Gate Operation Sequences

Under normal operation, the following gate operation sequence should be adopted:

a. The sequence shown in the Table 14.5.2 is to be adopted until all radial gates are open to five metres.
b. Once all radial gates are open to five metres, radial gates are generally operated in the order of 3, 2, 4, 1, 5 until either the flow in the Brisbane River at Fernvale Bridge is predicted to exceed 6,000 m^3/s or the Dam Safety Strategy is adopted.
c. Once either the flow in the Brisbane River at Fernvale Bridge is predicted to exceed 6,000 m^3/s or the Dam Safety Strategy is adopted the radial gates can be operated in any sequence to meet the requirements of the Release Plan.
d. Once all radial gates are open to fifteen metres, the next opening on each gate generally fully opens that gate, to Fully Open.

Variations are permitted at any time to reduce or prevent erosion adjacent to and downstream of the Wivenhoe Dam spillway.

Any inoperable radial gates are to be dropped from the opening or closing sequences and under these circumstances flow in the spillway should be made as symmetrical as possible.

Radial gate closure at Wivenhoe Dam, in usual circumstances, occurs in the reverse order to radial gate opening.

During the initial opening or final closure sequences of gate operations, it is permissible to replace the discharge through a radial gate by discharge from the cone valve or hydro outlet as this allows for greater control of low flows.

Table 14.5.2 Wivenhoe Dam gate opening sequence

Gate 1 Opening (m)	Gate 2 Opening (m)	Gate 3 Opening (m)	Gate 4 Opening (m)	Gate 5 Opening (m)	Gate/s Operated	Total Opening (m)
0.0	0.0	0.0	0.0	0.0	-	
0.0	0.0	0.5	0.0	0.0	3	0.5
0.0	0.0	1.0	0.0	0.0	3	1.0
0.0	0.0	1.5	0.0	0.0	3	1.5
0.0	0.0	2.0	0.0	0.0	3	2.0
0.0	0.0	2.5	0.0	0.0	3	2.5
0.0	0.0	3.0	0.0	0.0	3	3.0
0.0	0.0	3.5	0.0	0.0	3	3.5
0.0	0.5	3.5	0.0	0.0	2	4.0
0.0	0.5	3.5	0.5	0.0	4	4.5
0.0	0.5	4.0	0.5	0.0	3	5.0
0.0	1.0	4.0	0.5	0.0	2	5.5
0.0	1.0	4.0	1.0	0.0	4	6.0
0.5	1.0	4.0	1.0	0.0	1	6.5
0.5	1.0	4.0	1.0	0.5	5	7.0
0.5	1.5	4.0	1.0	0.5	2	7.5
0.5	1.5	4.0	1.5	0.5	4	8.0
1.0	1.5	4.0	1.5	0.5	1	8.5
1.0	1.5	4.0	1.5	1.0	5	9.0
1.0	2.0	4.0	1.5	1.0	2	9.5

Gate 1 Opening (m)	Gate 2 Opening (m)	Gate 3 Opening (m)	Gate 4 Opening (m)	Gate 5 Opening (m)	Gate/s Operated	Total Opening (m)
1.0	2.0	4.0	2.0	1.0	4	10.0
1.5	2.0	4.0	2.0	1.0	1	10.5
1.5	2.0	4.0	2.0	1.5	5	11.0
1.5	2.5	4.0	2.0	1.5	2	11.5
1.5	2.5	4.0	2.5	1.5	4	12.0
1.5	2.5	4.5	2.5	1.5	3	12.5
2.0	2.5	4.5	2.5	1.5	1	13.0
2.0	2.5	4.5	2.5	2.0	5	13.5
2.5	2.5	4.5	2.5	2.0	1	14.0
2.5	2.5	4.5	2.5	2.5	5	14.5
2.5	3.0	4.5	2.5	2.5	2	15.0
2.5	3.0	4.5	3.0	2.5	4	15.5
2.5	3.5	4.5	3.0	2.5	2	16.0
2.5	3.5	4.5	3.5	2.5	4	16.5
3.0	3.5	4.5	3.5	2.5	1	17.0
3.0	3.5	4.5	3.5	3.0	5	17.5
3.0	4.0	4.5	3.5	3.0	2	18.0
3.0	4.0	4.5	4.0	3.0	4	18.5
3.0	4.0	5.0	4.0	3.0	3	19.0
3.5	4.0	5.0	4.0	3.0	1	19.5
3.5	4.0	5.0	4.0	3.5	5	20.0
3.5	4.5	5.0	4.0	3.5	2	20.5
3.5	4.5	5.0	4.5	3.5	4	21.0
4.0	4.5	5.0	4.5	3.5	1	21.5
4.0	4.5	5.0	4.5	4.0	5	22.0
4.5	4.5	5.0	4.5	4.0	1	22.5
4.5	4.5	5.0	4.5	4.5	5	23.0
4.5	5.0	5.0	4.5	4.5	2	23.5
4.5	5.0	5.0	5.0	4.5	4	24.0
5.0	5.0	5.0	5.0	4.5	1	24.5
5.0	5.0	5.0	5.0	5.0	5	25.0

14.5.3 Protection of the Spillway Walls

The flip bucket spillway is designed to dissipate the energy of the discharge from Wivenhoe Dam. The flip throws the discharge clear of the concrete spillway structures and into a plunge pool where the energy is dissipated by turbulence. Under non-symmetric flow conditions, or when Gates 1 and 5 are not operating, the discharge jet may impinge on the walls of the plunge pool. As these walls have been excavated into erodible sandstone rock, this impingement may cause unpredictable erosion. Upstream migration of this erosion is to be avoided. This can be achieved by operating Gates 1 and 5 to deflect the discharge away from the walls of the plunge pool.

Therefore, in operating the spillway, the principles to be observed in order of priority are:

a. The discharge jet into the plunge pool is not to impinge on the right or left walls of the plunge pool; and
b. The flow in the spillway is to be as symmetrical as possible.

14.5.4 Overtopping of the Gates

When operating the Dam, care must be taken to ensure that the radial gates are not overtopped. Overtopping of the radial gates may result in damage that causes the gates to become inoperable.

The top and bottom levels of the gates for various gate openings are shown in Appendix A, to enable consideration to be given to this possibility in developing the Release Plan. Additionally, if this condition is observed during flood operations, then the Release Plan should be adjusted to prevent overtopping of the gates.

14.5.5 Lifting Radial Gates Clear of the Release Flow

At large gate openings, having the bottom edge of a radial gate close to the downstream release flow surface may cause adverse turbulence or vibration that could adversely impact on the radial gates. Accordingly, if adverse turbulence or vibration is observed during flood operations, then the bottom edge of the radial gate should be lifted clear of the water surface.

14.5.6 Lowering Radial Gates That Have Been Lifted Clear of the Release Flow

Lowering a radial gate after the bottom edge of the gate has been lifted clear of the water surface may cause adverse turbulence or vibration that could adversely impact on the gate. Accordingly, if adverse turbulence or vibration is observed during flood operations, the bottom edge of the radial gate should be lowered sufficiently to restore stable orifice flow through the spillway.

15 Somerset Dam Strategy and Procedures

The content of this Section is limited to the specific operational Procedures and information relating to the implementation of the Somerset Dam Strategy. Additional information is contained in the following Sections:

- **Background Information**: Section 3 contains background information relating to the Dams, Splityard Creek Dam and an overview of the downstream impacts;
- **Flood Mitigation Objectives**: Section 9 contains a description of the Objectives, the priority of these Objectives and reasoning for their prioritisation;
- **Flood Operations – Somerset Dam**: Section 11 contains a description of the Strategy and the Procedures;
- **Technical Appendices**: Appendix E, Appendix F and Appendix G contains additional technical information relating to Somerset Dam.

The Procedures to develop Release Plans for Somerset Dam have the following general principles:

a. The safety of Somerset Dam cannot be assured at Lake Levels exceeding 108.7 m AHD if the removable flood barrier is in place and 107.45 m AHD if the removable flood barrier is not in place and therefore operations aim to minimise the probability of the Somerset Dam Lake Level reaching these levels.
b. The Somerset Dam crest gates should not be closed at any stage during the Flood Event due to the Dam Safety risks associated with such closure.
c. No regard is given to the Wivenhoe Dam Lake Level when operating Somerset Dam during a Flood Event unless either Wivenhoe Dam or the fuse plugs at Wivenhoe Dam are judged likely to be overtopped or Wivenhoe Dam is at imminent risk of structural failure via an identified failure mechanism that has initiated.

The Section below provides details of the Procedures to be used for flood operations at Somerset Dam based on the above general principles.

15.1 Somerset Dam Strategy

Once a Flood Event commences, the following Procedures will apply until the Flood Event concludes. The Procedures are designed to minimise the risk to human life and safety by prioritising the structural safety of the Dam. Consideration with professional judgement is given to public safety at all the times during flood operations.

ID	Procedures for Somerset Dam Strategy
1.	**Determine a Release Plan for Somerset Dam when the rainfall event is judged very unlikely to be complete or nearly complete. The Release Plan is to use inflow and Lake Level predictions from the FFS based on Rain on Ground.**
1a	A Release Plan is to be developed by operating the Somerset Dam Crest Gates, Cone Valves and Sluice Gates in accordance with Procedures 1b to 1d.
1b	The Somerset Dam Crest Gates are to be fully opened at the start of the Flood Event and are to remain fully open until the Flood Event concludes.

ID	Procedures for Somerset Dam Strategy
1c	The Somerset Dam Cone Valves are to be operated in accordance with the following criteria and with the aim of achieving a release through the Cone Valves that always approaches the maximum allowable release rate: i. The water stored in the Water Supply Compartment of the Dam must be preserved. Cone Valve releases may commence at the beginning of a Flood Event before the Actual Lake Level exceeds the OFSL only if the DSFOE judges it very likely, that after accounting for all releases in the Release Plan, the Lake Level will exceed the OFSL. ii. Once releases commence, the Release Plan must always ensure that the Water Supply Compartment will be full at the end of the Flood Event. If this cannot be achieved in a Release Plan, releases must immediately cease. iii. Subject to the criteria in ii. above, the Cone Valves can be opened or closed progressively at 1 hour intervals while the water level immediately downstream of Somerset Dam is less than 68.6 m AHD. iv. The Cone Valves must be closed at 1 hour intervals when the water level immediately downstream of Somerset Dam is greater than 68.6 m AHD[33] and the Predicted Peak Lake Level at Somerset Dam is less than 107.0 m AHD. v. The Cone Valves may be opened at 1 hour intervals when the water level immediately downstream of Somerset Dam is greater than 68.6 m AHD and it is judged likely that such actions are necessary to prevent the structural failure of Somerset Dam. vi. The Cone Valves may be opened as quickly as possible and at intervals less than 1 hour if it is judged likely that such action is necessary to prevent the structural failure of Somerset Dam. vii. If the Predicted Peak Lake Level in Wivenhoe Dam or Somerset Dam is judged likely to exceed the Maximum Flood Storage Level for the Dam, the Duty Engineer must use the guidance in Section 16.2.
1d	The Somerset Dam Sluice Gates are to be operated in accordance with the following criteria and with the aim of achieving a release through the Sluice Gates that always approaches the maximum allowable release rate: i. The water stored in the Water Supply Compartment of the Dam must be preserved. Sluice Gate releases may commence at the beginning of a Flood Event before the Actual Lake Level exceeds the OFSL only if the DSFOE judges it very likely, that after accounting for all releases in the Release Plan, the Lake Level will exceed the OFSL. ii. Once releases commence, the Release Plan must always ensure that the Water Supply Compartment will be full at the end of the Flood Event. If this cannot be achieved in a Release Plan, releases must immediately cease. iii. The Sluice Gates may be opened or closed progressively at 1 hour intervals. iv. The Sluice Gates may be opened as quickly as possible and at intervals less than 1 hour only if it is judged likely that such action is necessary to prevent the structural failure of Somerset Dam. v. If the Predicted Peak Lake Level in Wivenhoe Dam or Somerset Dam is judged likely to exceed the Maximum Flood Storage Level for the Dam, the Duty Engineer must use the guidance in Section 16.2.

[33] Operating the Somerset Dam Cone Valves when the water level immediately downstream of Somerset Dam is greater than 68.6 m AHD damages the Cone Valves due to water cavitation. However, as such operations are unlikely to cause the Cone Valves to fail catastrophically, releases of water from the Cone Valves is acceptable in all circumstances when such releases are judged necessary to protect the safety of the Dams.

ID	Procedures for Somerset Dam Strategy
2.	**Determine a Release Plan for Somerset Dam when the rainfall event is judged very likely to be complete or nearly complete[1]. The Release Plan is to use inflow and Lake Level predictions from the FFS based on Rain on Ground.**
2a	The aim of the Release Plan is to return the Lake Level to the OFSL in a time that approaches the shortest possible while operating within the following criteria: i. The Sluice Gates and Cone Valves must be operated at interval not less than 1 hour. ii. The Cone Valves must be closed while the water level immediately downstream of Somerset Dam is greater than 68.6 m AHD. iii. The Sluice Gates may be closed with the objective of preserving the structural safety of Wivenhoe Dam or preventing overtopping of a fuse plug at Wivenhoe Dam if the predicted Lake Level of Somerset Dam is judged very likely to remain below 106.5 m AHD (which is the maximum recorded Somerset Dam Lake Level). Reasonable attempt is to be made to provide the Chief Executive DRDMW with information to advise of the planned action to close the Sluice Gates under the provision of this criteria.
2b	The criteria for ceasing releases at Somerset Dam that are made under the authority of this Manual are as follows. These criteria ensure that the Somerset Dam Water Supply Compartment is full at the conclusion of the Flood Event. If releases of water from Wivenhoe Dam have already ceased for the Flood Event in accordance with Section 14.3 (or were not made during the Flood Event), ceasing releases from Somerset Dam will define the conclusion of the Flood Event. i. Releases of water made under the authority of this Manual may cease when both: a. The Actual Lake Level is between 0.3 metres below and 0.3 metres above the OFSL; and b. it is judged likely that the Lake Level will rise to between the OFSL and 0.3 metres above the OFSL after considering both ongoing Baseflow from the Flood Event and ongoing operational releases. ii. Releases of water made under the authority of this Manual must cease when either: a. The Actual Lake Level is more than 0.3 metres below the OFSL; or b. the Actual Lake Level is below the OFSL and it is judged likely that the Lake Level will not rise to the OFSL without further rainfall, after considering ongoing Baseflow from the Flood Event.

15.2 Cone Valve, Sluice Gate and Crest Gate Operation

15.2.1 Operating Intervals

Releases from Somerset Dam flow directly into Wivenhoe Dam and have limited impact on the downstream river environment. Therefore, the flow impact considerations associated with radial gate operations at Wivenhoe Dam do not apply to Somerset Dam.

Table 15.2.1 below shows the target minimum intervals for operating cone valves, sluice gates and crest gates at Somerset Dam during Flood Events. These intervals are reflected in the Somerset Dam Strategy and have been chosen to prevent the structural failure of Somerset Dam.

When directing gate operations at the Dam, the Duty Engineer will take into account the infrastructure and personnel related limitations involved in undertaking rapid gate movements under flood conditions.

Table 15.2.1 Target Minimum Intervals for Flood Operations

Item	Opening	Closing
Cone valves (operated either fully open or fully closed)	1 hour	1 hour
Sluice gates (operated either fully open or fully closed)	1 hour	1 hour
Crest gates (operated either fully open or fully closed)	No minimum	No minimum

15.2.2 Sluice Gate Operation Sequences

The order of operation for opening the sluice gates under the strategy is:

L – M – K – N – J – O – I – P

Sluice gates are to be closed in reverse order of opening. Any inoperable sluice gates are to be dropped from the opening or closing sequences.

15.2.3 Cone Valve Considerations

During the initial opening or final closure sequences of sluice gate operations it is permissible to replace the discharge through a sluice gate by the opening of one or more cone valves. This allows for greater control of low flows and enables a smooth transition on opening and closing sequences.

Cone valves are normally kept fully closed when the water level directly downstream of Somerset Dam is above the invert of the valves (68.6 m AHD). Operating the valves under these circumstances can damage the valves, although they are unlikely to fail catastrophically. However, this requirement may be ignored if the structural safety of Somerset Dam is judged likely to be at risk.

15.2.4 Closing the Crest Gates

There are no detailed operational records of instances during which the Somerset Dam crest gates have been used to regulate flow. Accordingly, making a decision to close the crest gates when the Somerset Dam Lake Level is greater than 100.45 m AHD carries with it the risk that the crest gates jam in the closed position, see Appendix F for further information. This risk and its consequences must be carefully considered in the formulation of a Release Plan under an Alternative Procedure that involves closing the crest gates.

16 Emergency Flood Operations

16.1 Introduction

While every care has been exercised in the design and construction of the Dams, there still remains a low risk that the Dams may develop an emergency condition as a result of Flood Events or other causes. Vigilance is required to recognise emergency flood conditions such as:

a. Occurrence of a flood that may cause the Lake Level to exceed the Maximum Flood Storage Level for the Dams;
b. Failure of the operation of one or more radial gate, cone valve, sluice gate or crest gate during a Flood Event;
c. Development of a piping failure through the embankment of Wivenhoe Dam;
d. Damage to the Dams by earthquake; or
e. Damage to the Dams as a result of an act of terrorism.

Responses to these conditions are contained in the primary guidance document for emergency conditions at the Dams, the Emergency Action Plans.

The following Sections provide some additional guidance for particular circumstances.

16.2 Overtopping of Dams

Preserving the structural safety of the Dams is the primary consideration in the operation of the Dams during Flood Events.

In the extreme circumstance that it is predicted that one or both of Wivenhoe and Somerset Dams will exceed their Maximum Flood Storage Levels, 80.0 m AHD at Wivenhoe Dam, and 108.7 m AHD at Somerset Dam (with the removable flood barrier in place), a Release Plan may be developed using professional judgement in an attempt to minimise the likelihood of Dam failure and/or to maximise the chance that one of the Dams may survive.

In this circumstance, reasonable attempts should be made to inform the CEO and the Chief Executive (DRDMW) and consult and collaborate on the available options, the proposed Release Plan, and the Release Plan to be adopted.

Whatever the circumstances, every endeavour must be made to prevent the Lake Levels reaching these critical levels.

Should it be judged very likely that Wivenhoe Dam will fail, consideration should be given to minimising the chance of Somerset Dam also failing.

Should it be judged very likely that Somerset Dam will fail, consideration should be given to the ability of Wivenhoe Dam to absorb the flood wave from Somerset Dam.

The structural response of the Dams at such extreme Lake Levels is highly unpredictable. The concrete Somerset Dam may be better able to withstand a greater depth of overtopping than the earthfill Wivenhoe Dam, but the extent of erosion downstream of Somerset Dam in such a large event is unpredictable, and failure of Somerset Dam may lead to a cascade failure of Wivenhoe Dam. It is acknowledged that a Release Plan developed to minimise the likelihood of Dam failure and/or to maximise the chance that one of the Dams may survive may not achieve its objectives.

16.3 Structural Failure of the Dams During Flood Events

The Dams may fail at Lake Levels below the Maximum Flood Storage Levels nominated in this Manual in Flood Events owing to failure modes such as described in Section 16.1. In this circumstance, an Alternative Procedure may be developed using professional judgement in an attempt to minimise the likelihood of Dam failure and/or to maximise the chance that one of the Dams may survive.

In this circumstance the Alternative Procedures provisions in Section 18 applies.

The structural capacity and integrity of the Dams at levels above the Maximum Flood Storage Level has high uncertainty. A Release Plan developed to minimise the likelihood of Dam failure and/or to maximise the chance that one of the Dams may survive may not achieve its objectives.

16.4 Dam Operator Actions in the Event of Communications Failure

16.4.1 Loss of Communications - General Procedure for Both Dams

During a Flood Event, it is possible that communications could be lost between a Dam and the Flood Operations Centre. If difficulties are experienced in communications with the Flood Operations Centre, the Dam Supervisor should attempt to contact the Flood Operations Centre using each of the following means:

a. Landline telephone;
b. Mobile telephone;
c. Satellite telephone;
d. GWN radio network;
e. Email;
f. Via the Dam Supervisor at the other Dam or via the Dam Supervisor at North Pine Dam; and
g. Via Police and Emergency Services personnel.

If communications still cannot be established with the Flood Operations Centre, the Dam Supervisor is to assume responsibility for flood releases from the Dam and:

a. Take all practicable measures to restore communications and periodically check the lines of communication for any change;
b. Log all actions in the event log;
c. Remain in the general vicinity of the Dam while on duty; and
d. Follow the procedures set out below for the relevant Dam to determine the appropriate gate openings.

The Dam Supervisor remains responsible for flood operations at the Dam until communications are re-established with the Duty Engineers. Dam conditions should be monitored regularly during loss of communications periods, even if the rainfall event appears to be over, and the Procedures for each Dam below applied as required. Once communications are re-established with the Duty Engineers, the responsibility for directing Dam operations is returned to the Duty Engineers.

16.4.2 Wivenhoe Dam Loss of Communications – Gate Operations Procedure

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 16.4.1. Minimum increment opening intervals listed in Table 16.4.2 must be followed when progressing through this table. Where one or more fuse plug embankments in the auxiliary spillway have been eroded, the relevant table contained in Appendix B is to be substituted for the table below.

Table 16.4.1 Wivenhoe Dam Loss of Communications – Radial Gate Operations

Lake Level	Gate 1 Opening	Gate 2 Opening	Gate 3 Opening	Gate 4 Opening	Gate 5 Opening	Total Opening	Discharge	Gate/s Operated
m AHD	(m)	(m)	(m)	(m)	(m)	(m)	(m^3/s)	
OFSL or lower	-	-	-	-	-	-	-	-
OFSL + 0.2 m	0.0	0.0	0.5	0.0	0.0	0.0	-	3
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

Lake Level	Gate 1 Opening	Gate 2 Opening	Gate 3 Opening	Gate 4 Opening	Gate 5 Opening	Total Opening	Discharge	Gate/s Operated
m AHD	(m)	(m)	(m)	(m)	(m)	(m)	(m^3/s)	
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
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	2,610	5
72.85	4.5	4.5	5.0	4.5	4.0	22.5	2,670	1
72.90	4.5	4.5	5.0	4.5	4.5	23.0	2,740	5
LINES BELOW HERE MAY CONTAIN MORE THAN ONE GATE MOVEMENT. ADHERE TO MINIMUM OPENING INTERVAL REQUIREMENTS.								
72.95	4.5	5.0	5.0	5.0	4.5	24.0	2,850	2,4
73.00	5.0	5.0	5.0	5.0	5.0	25.0	2,970	1,5
73.10	5.0	5.0	5.5	5.0	5.0	25.5	3,030	3
73.20	5.0	5.5	5.5	5.5	5.0	26.5	3,130	2,4
73.30	5.5	5.5	5.5	5.5	5.5	27.5	3,280	1,5
73.40	5.5	5.5	6.0	5.5	5.5	28.0	3,340	3
73.50	5.5	6.0	6.0	6.0	5.5	29.0	3,460	2,4

Lake Level	Gate 1 Opening	Gate 2 Opening	Gate 3 Opening	Gate 4 Opening	Gate 5 Opening	Total Opening	Discharge	Gate/s Operated
m AHD	(m)	(m)	(m)	(m)	(m)	(m)	(m^3/s)	
73.60	6.0	6.0	6.0	6.0	6.0	30.0	3,590	1,5
73.70	6.0	6.0	6.5	6.0	6.0	30.5	3,680	3
73.80	6.0	6.5	6.5	6.5	6.0	31.5	3,780	2,4
73.90	6.5	6.5	6.5	6.5	6.5	32.5	3,900	1,5
74.00	6.5	6.5	7.0	6.5	6.5	33.0	3,970	3
NO MINIMUM OPENING INTERVAL BEYOND THIS LEVEL.								
74.10	7.0	7.0	7.0	7.0	7.0	35.0	4,210	2,4,1,5
74.20	7.5	7.5	7.5	7.5	7.5	37.5	4,510	3,2,4,1,5
74.30	8.0	8.0	8.0	8.0	8.0	40.0	4,810	3,2,4,1,5
74.40	8.5	8.5	8.5	8.5	8.5	42.5	5,110	3,2,4,1,5
74.50	9.0	9.0	9.0	9.0	9.0	45.0	5,430	3,2,4,1,5
74.60	9.5	9.5	9.5	9.5	9.5	47.5	5,750	3,2,4,1,5
74.70	10.0	10.0	10.0	10.0	10.0	50.0	6,070	3,2,4,1,5
GATES ARE OPENED IN ONE METRE INCREMENTS ABOVE 74.7 m AHD.								
74.80	11.0	11.0	11.0	11.0	11.0	55.0	6,740	3,2,4,1,5
74.90	12.0	12.0	12.0	12.0	12.0	60.0	7,440	3,2,4,1,5
75.00	13.0	13.0	13.0	13.0	13.0	65.0	8,200	3,2,4,1,5
75.10	14.0	14.0	14.0	14.0	14.0	70.0	9,010	3,2,4,1,5
75.20	15.0	15.0	15.0	15.0	15.0	75.0	9,880	3,2,4,1,5
75.30	Fully Open	Fully Open	Fully Open	Fully Open	Fully Open	Fully Open	10,160	3,2,4,1,5

Table 16.4.1 shows individual sequence steps against a target Lake Level. The minimum time intervals between each step in the radial gate opening sequence are shown in the Table 16.4.2. Falling behind or being in front of the target gate openings is permissible when the Lake Level is less than 74.0 m AHD, but not allowed when the Lake Level is greater than 74.0 m AHD. When the Lake Level is below 74.0 m AHD, the operating intervals shown in the Table 16.4.2 below must be followed and can only be reduced to prevent the structural failure of Wivenhoe Dam.

Table 16.4.2 Minimum Intervals Between Radial Gate Operations

Item	Minimum Opening Interval (0.5 m increment)	Minimum Closing Interval (0.5 m increment)
Lake Level <74.0 m AHD	10 minutes	20 minutes
Lake Level ≥ 74.0 m AHD, or radial gate movements required to prevent overtopping	No minimum	No minimum

When operating under this scenario, care must also be taken to ensure the radial gates are not overtopped. Overtopping of the radial gates may result in damage that causes the gates to become inoperable. Accordingly, the minimum radial gate openings shown in the Table 16.4.3 apply to ensure the radial gates are not overtopped.

Table 16.4.3 Minimum Radial Gate Openings to Prevent Overtopping

Lake Level (m AHD)	Minimum Radial Gate Opening Required for each Gate (metres)
72.50 – 72.99	0.5
73.00 – 73.49	1.0
73.50 – 73.99	1.5
74.00+	2.0

In the event of one or more radial gates becoming jammed, the remaining gates are to be operated to provide the same total gate opening (in metres) for a particular Lake Level, as shown in Table 16.4.1 above. In the event of one or more radial gates becoming jammed, while one or more fuse plugs in the auxiliary spillway have been breached (eroded), the relevant table contained in Appendix B shows the total gate opening (in metres) for a particular Lake Level that is to be matched.

In these circumstances, gates are preferably operated in the order of **3, 2, 4, 1, and 5** moving through the sequence shown in the table.

When extreme rises in Lake Level are being experienced, Dam Operators may have difficulty in continually matching minimum gate openings to Lake Level. In these circumstances it is permissible to estimate target Lake Levels one hour in advance, based on Lake Level rises in the previous hour and undertake gate operations on this basis.

16.4.3 Somerset Dam Loss of Communications – Gate Operations Procedure

Crest Gate Operations

The Somerset Dam crest gates are to be fully opened as soon as practicable and remain fully open until the Flood Event concludes.

Sluice Gate and Cone Valve Operations

There are restrictions on operation of the cone valves when the water level directly downstream of Somerset Dam is above 68.6 m AHD.

The sluice gate and cone valve operations depend on the OFSL. It is expected that for the life of this Manual, an OFSL of 97 m AHD will be in force at Somerset Dam.

The Dam Supervisor must check the Flood Event Log at the Dam to confirm any advice received from the Duty Engineer before communications were lost for the applicable OFSL for the Flood Event.

The Dam Supervisor is then to operate the Dam in accordance with the applicable table below. The appropriate table to use depends on the OFSL at the Dam.

Table 16.4.4 Sluice and Cone Valve Operations – Use this table when there is an OFSL in place that is set to 97.0 m AHD

Somerset Dam Lake Level	Cone Valve	Sluice Gate
Above 97.0 m AHD	If the water level directly downstream of Somerset Dam is below 68.6 m AHD, open a cone valve each hour in the order **2 – 3 – 12 – 13**, until all cone valves are open. If the water level directly downstream of Somerset Dam is at or above 68.6 m AHD, close a cone valve each hour in the order **13 – 12 – 3 – 2**, until all cone valves are closed.	Open a sluice gate each hour in the order **L – M – K – N – J – O – I – P**, until all sluice gates are open.
Between 96.7 m AHD and 97.0 m AHD	If the water level directly downstream of Somerset Dam is below 68.6 m AHD, do not change the cone valve settings. If the water level directly downstream of Somerset Dam is at or above 68.6 m AHD, close a cone valve each hour in the order **13 – 12 – 3 – 2**, until all cone valves are closed.	Do not change the sluice gate settings.
Below 96.7 m AHD	Close a cone valve each hour in the order **13 – 12 – 3 – 2**, until all cone valves are closed.	Close a sluice gate each hour in the order **P – I – O – J – N – K – M – L**, until all sluice gates are closed.
Note cone valve and sluice gate operations are done together.		

Table 16.4.5 Sluice and Cone Valve Operations – Use this table when the OFSL is not 97.0 m AHD

Somerset Dam Lake Level	Cone Valve	Sluice Gate
Above the OFSL	If the water level directly downstream of Somerset Dam is below 68.6 m AHD, open a cone valve each hour in the order **2 – 3 – 12 – 13**, until all cone valves are open. If the water level directly downstream of Somerset Dam is at or above 68.6 m AHD close a cone valve each hour in the order **13 – 12 – 3 – 2**, until all cone valves are closed.	Open a sluice gate each hour in the order **L – M – K – N – J – O – I – P**, until all sluice gates are open.
Between the OFSL and 0.3 metres below the OFSL	If the water level directly downstream of Somerset Dam is below 68.6 m AHD, do not change cone valve settings. If the water level directly downstream of Somerset Dam is at or above 68.6 m AHD, close a cone valve each hour in the order **13 – 12 – 3 – 2**, until all cone valves are closed.	Do not change the sluice gate settings.
More than 0.3 metres below the OFSL	Close a cone valve each hour in the order **13 – 12 – 3 – 2**, until all cone valves are closed.	Close a sluice gate each hour in the order **P – I – O – J – N – K – M – L**, until all sluice gates are closed.
Note cone valve and sluice gate operations are done together.		

16.5 Equipment Failure

In the event of equipment failure, the action to be taken is indicated in Appendix C for Wivenhoe Dam and Appendix F for Somerset Dam.

16.6 Failure of one or more components of the FFS

The components of the FFS are described in more detail in Section 7. The FFS is a robust system with a number of levels of redundancy in the Monitoring Network, Data Collection Component, Modelling Platform and Gate Operations Module, and the logistical systems (power, computer network, communications, office space/equipment, etc.) supporting these components. These systems are interdependent and therefore a failure of any one of these components can reduce the accuracy and reliability of the FFS and may result in the development of sub-optimal Release Plans.

In the unlikely event that:

a. one or more components of the FFS should fail or partially fail; or
b. the DSFOE has a reasonable basis to believe that one or more components of the FFS has failed or partially failed;

the DSFOE may apply similar alternative methods to develop a Release Plan using professional judgement.

In the event of critical failure of the FFS and/or logistical systems, the Duty Engineer may use the Loss of Communications Procedures (described in Section 16.4) to guide the operation of the Dams.

17 Declarations of Temporary Full Supply Levels for Flood Mitigation or the application of a Reduced Full Supply Level

17.1 Purpose

Section 17.3 to Section 17.4 sets out the Procedures that apply to releases of water which are to be made to lower the Actual Lake Level of a Dam to either a Temporary Full Supply Level which has been declared by the Minister to mitigate the impacts of a potential flood or a Reduced Full Supply Level.

If a TFSL and RFSL are in effect at the same time, the Procedures in Sections 17.3 to Section 17.4 are to be followed so as to reach the lower of the two levels.

Section 17.5 provides guidance on the changes to be made to the Procedures in Sections 14, 15 and 16.4 when a Temporary FSL or Reduced FSL applies.

17.2 Application

The Procedures in Section 17.3 to Section 17.4 only apply where a TFSL Declaration is made or a Reduced FSL is applied and, at the time the Actual Lake Level in a Dam exceeds the OFSL as a result of the Declaration.

17.3 Procedures for Release of Water Stored Above the Temporary Full Supply Level or Reduced Full Supply Level at Wivenhoe Dam

A Flood Event is deemed to have commenced when the Flood Operations Centre mobilises to prepare for releases to lower the lake level to the OFSL (generally within 24 hours subject to circumstances and professional judgment of matters such as public safety considerations and reasonable time for notifications and other communications). The Drain Down Strategy is selected to apply the Procedures outlined in Section 14.3.

The relevant Procedure criteria and/or Flood Mitigation Guide Curves shall be adjusted in accordance with Section 17.5.

17.4 Procedures for Release of Water Stored above the Temporary Full Supply Level or Reduced Full Supply Level at Somerset Dam

A Flood Event is deemed to have commenced when the Flood Operations Centre mobilises to prepare for releases to lower the lake level to the OFSL (generally within 24 hours subject to circumstances and professional judgment of matters such as public safety considerations and reasonable time for notifications and other communications). The Somerset Dam Strategy is selected at Somerset Dam (Section 15.1).

17.5 Modifications to Strategies and Procedures When a Temporary Full Supply Level or a Reduced Full Supply Level is in Force

The Strategies and Procedures provided in Sections 14, 15 and 16 continue to be applied when a Temporary FSL or a Reduced FSL is in force, with the following minor modifications:

a. The Flood Mitigation Guide Curve (Figure 14.1.1) is to be modified as described below.

Flood Mitigation Guide Curve

When a Temporary FSL applies, the Flood Mitigation Guide Curve provided in the Flood Mitigation Strategy (Section 14.1) is to be modified using the rationale that is described below and was used to develop the Government's preferred operations option of "Alternative Urban 3".

Alternative Urban 3 sought to improve mitigation of infrequent major floods. The factors that define the Flood Mitigation Guide Curve under the Alternative Urban 3 operations option are as follows:

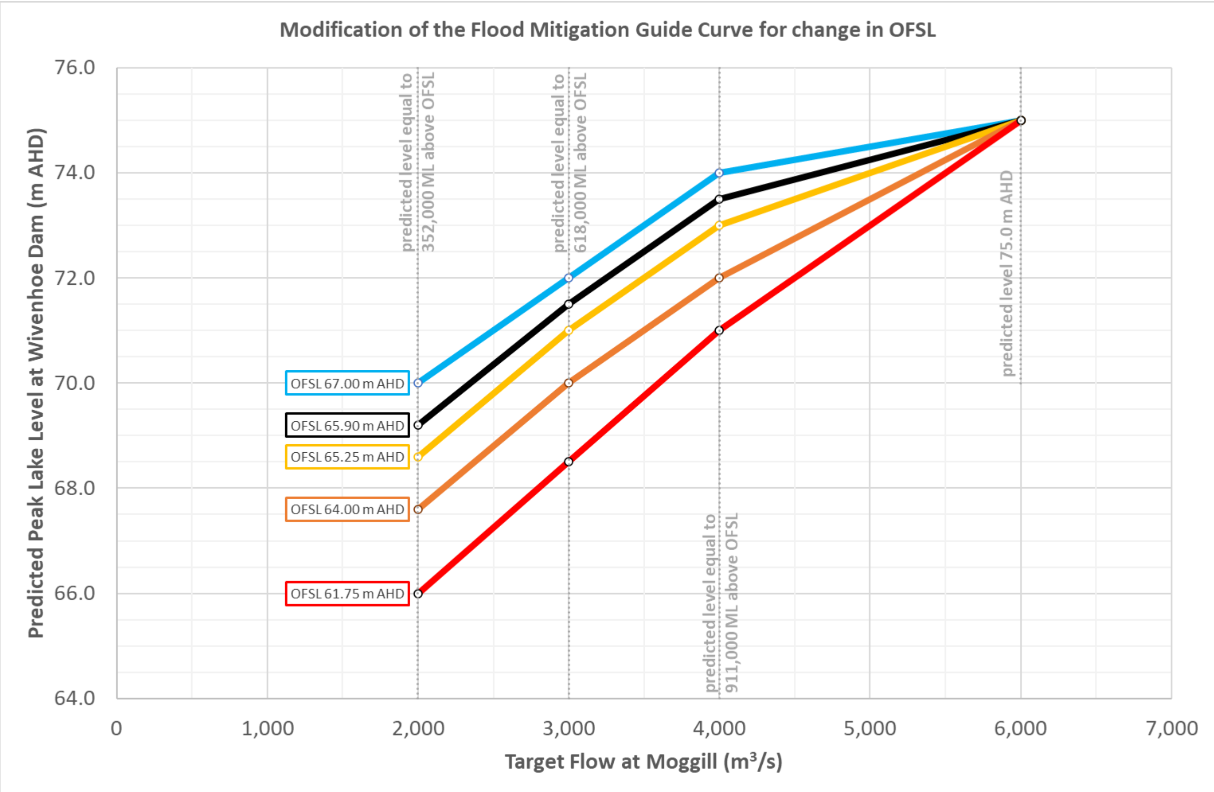
- Up to a Predicted Peak Lake Level that is defined as a level where 352,000 ML of water is stored above the OFSL, the Release Plan should:
    - Have no regard to road crossings of the Brisbane River between Wivenhoe Dam and Moggill that are inundated at flows below 1,500 m^3/s;
    - Aim to avoid the inundation of the Mount Crosby Weir Bridge and Fernvale Bridge;
    - Set a Target Flow at Moggill that aims to approach 2,000 m^3/s.
- When the Predicted Peak Lake Level is between a level where 352,000 ML of water is stored above the OFSL and a level where 618,000 ML of water is stored above the OFSL, the Target Flow at Moggill should aim to approach a flow that increases uniformly from 2,000 m^3/s to 3,000 m^3/s.
- When the Predicted Peak Lake Level is between a level where 618,000 ML of water is stored above the OFSL and a level where 911,000 ML of water is stored above the OFSL, the Target Flow at Moggill should aim to approach a flow that increases uniformly from 3,000 m^3/s to 4,000 m^3/s.
- When the Predicted Peak Lake Level is between a level where 911,000 ML of water is stored above the OFSL and 75.0 m AHD, the Target Flow at Moggill should aim to approach a flow that increases uniformly from 4,000 m^3/s to 6,000 m^3/s.

Lake Levels that are calculated from volumes of water above the OFSL are rounded up to the nearest 0.2 metres for the Lake Level that is defined as a level where 352,000 ML of water is stored above the OFSL and rounded up to the nearest 0.5 metres for all other levels. Based on these factors, the WSDOS Report provided the following Flood Mitigation Guide Curve examples for an OFSL that is less than the Fixed FSL.

Table 17.5.1 Summary of key points used to define the Flood Mitigation Guide Curve in accordance with Alternative Urban 3 for varying OFSL

Parameter	Lake Level or Volume	Wivenhoe Dam OFSL			
		67.00 m AHD	65.25 m AHD	64.00 m AHD	61.75 m AHD
Target up to 2,000 m^3/s at Moggill and allow consideration of Fernvale and Mount Crosby Weir bridges	Storage above OFSL	352,000 ML			
	Max Lake Level	70.00 m AHD	68.60 m AHD	67.60 m AHD	66.00 m AHD
Target up to 3,000 m^3/s at Moggill	Storage above OFSL	618,000 ML			
	Max Lake Level	72.00 m AHD	71.00 m AHD	70.00 m AHD	68.50 m AHD
Target up to 4,000 m^3/s at Moggill	Storage above OFSL	911,000 ML			
	Max Lake Level	74.00 m AHD	73.00 m AHD	72.00 m AHD	71.00 m AHD
Target up to 6,000 m^3/s at Moggill	Storage above OFSL	Varies each OFSL Scenario more available in lower OFSL Scenarios			
	Max Lake Level	75.00 m AHD			

Figure 17.5.1 Examples of the Flood Mitigation Guide Curve for change in OFSL



18 Alternative Procedures

18.1 Alternative Procedures

When This Section Applies

Section 18 applies if the DSFOE reasonably considers that:

a. An operating strategy set out in Section 14 and Section 15 (Somerset Dam Strategy and Procedures) of this Manual does not provide or does not adequately provide for the Flood Event or an aspect of the Flood Event; and
b. To achieve an Objective set out in Section 9 of the Manual and respond effectively to the Flood Event it is necessary to:
    i. Disregard a Procedure set out in Sections 14 to 15 of this Manual (an ***existing procedure***); and
    ii. Observe a different operational Procedure (an ***Alternative Procedure***).

Seeking Authorisation from Chief Executive (DRDMW)

The DSFOE must, on behalf of Seqwater, seek authorisation from the Chief Executive (DRDMW) to observe an Alternative Procedure.

When seeking authorisation from the Chief Executive (DRDMW), the DSFOE must, as soon as practicable, give the Chief Executive (DRDMW) the following information (the ***Authorisation Request Information***):

a. The grounds for considering that:
    i. An existing Strategy does not provide or does not adequately provide for the Flood Event or an aspect of the Flood Event; and
    ii. To achieve an Objective set out in Section 9 and respond effectively to the Flood Event it is necessary to disregard an existing procedure and observe an Alternative Procedure;
b. The facts and circumstances that are the basis for the grounds;
c. Information to identify the existing procedure;
d. Details of the Alternative Procedure;
e. The time by which Seqwater would need the Chief Executive (DRDMW) to make a decision for Seqwater to be able to respond effectively to the Flood Event; and
f. Other information to enable the Chief Executive (DRDMW) to make a decision whether or not to authorise the DSFOE, on behalf of Seqwater, to disregard the existing procedure and observe the Alternative Procedure.

The DSFOE can:

a. Seek authorisation for a number of Alternative Procedures from the Chief Executive (DRDMW) at the one time (but the circumstances which would give rise to each Alternative Procedure being adopted must be identified and the Chief Executive (DRDMW) will not decide, as between procedures, which is the most appropriate); and
b. Provide the Authorisation Request Information to the Chief Executive (DRDMW) orally. If the Authorisation Request Information is provided to the Chief Executive (DRDMW) orally, the DSFOE must record the Authorisation Request Information provided to the Chief Executive (DRDMW) in writing as soon as practicable after giving the Chief Executive (DRDMW) the information orally.

In making contact with the Chief Executive (DRDMW), the DSFOE will use the Protocol for Seeking Authorisation of Alternative Procedures in Section 18.2.

Alternative Procedure Cannot be Adopted Unless Authorised by Chief Executive (DRDMW)

After providing the Authorisation Request Information to the Chief Executive (DRDMW), the DSFOE:

a. Must not adopt an Alternative Procedure until receiving the advice from the Chief Executive (DRDMW) about whether or not the Alternative Procedure has been authorised; and
b. After receiving the advice from the Chief Executive (DRDMW):
    i. Is only authorised to adopt an Alternative Procedure if the Chief Executive (DRDMW) gives advice that the Alternative Procedure is authorised;
    ii. Must not adopt the Alternative Procedure where the Chief Executive (DRDMW) gives advice that the Alternative Procedure is not authorised; and
c. Must not adopt a different operational procedure other than the Alternative Procedure for which authorisation from the Chief Executive (DRDMW) was sought.

To avoid any doubt, the DSFOE is not authorised to adopt an Alternative Procedure where the Chief Executive (DRDMW) has been contacted and provided the Authorisation Request Information but is considering the Authorisation Request Information.

Alternative Procedure Where the Chief Executive (DRDMW) Cannot Be Contacted

If the DSFOE:

a. Makes reasonable efforts to contact the Chief Executive (DRDMW) to give the Chief Executive (DRDMW) the Authorisation Request Information; but
b. Cannot contact the Chief Executive (DRDMW) (using the contact methods referred to in Section 18.2) within a reasonable time to respond effectively to the Flood Event, or, having made contact with the Chief Executive (DRDMW) but before the Chief Executive (DRDMW) makes a decision, loses contact with the Chief Executive (DRDMW) and cannot re-establish contact by the time in which Seqwater would need a decision on the request;

the DSFOE:

a. Is authorised to adopt an Alternative Procedure considered necessary to respond effectively to the Flood Event; and
b. Must, as soon as practicable after failing (after reasonable efforts) to contact the Chief Executive (DRDMW) or losing contact with the Chief Executive (DRDMW), record the Authorisation Request Information in writing and give that information to the Chief Executive (DRDMW).

18.2 Protocol for Seeking Authorisation of Alternative Procedures

Scope

Division 8 of Chapter 4 of the Act applies when the Dam owner is seeking authorisation to observe a different operational procedure (an Alternative Procedure) to that specified in an approved Flood Mitigation Manual.

This protocol provides clarity and guidance for communication between the Chief Executive (DRDMW) and the DSFOE when seeking authorisation of alternative operational procedures.

Contact positions

The Chief Executive (DRDMW), or nominated delegates of the Chief Executive (DRDMW), are the contacts for communications by the Dam owner.

Means of Communication

The following means of communication are to be used for communication by the Dam owner – subject to the guidance set out below:

a. Mobile telephone;
b. Landline telephone;
c. Satellite telephone;
d. GWN Radio Network;
e. Email;
f. Face to Face / Courier;
g. Letter.

Guidance

Relevant contact details will be established on approval of this Flood Mitigation Manual and maintained as required (but at least annually) by exchange of letters.

While there is no strict hierarchy to the contacts or means of communication, the means of communication adopted will be dependent on the:

a. Available means of communication;
b. Proximity of the parties;
c. Time available to make the decision;
d. Extent of prior knowledge the decision maker has of the circumstances leading up to the request;
e. The complexity and quantity of data/information required to support/justify the decision;
f. Consequences of the decision.

Matters to be considered include:

a. Means of communication should be chosen that are two-way in nature as first preference;
b. Initial communication should preferably be by the most direct means;
c. Multiple means of communication may be appropriate as part of a coordinated approach;
d. For operational communications the order of contacts would normally be those listed;
e. For operational purposes, contact need only be established with one responsible delegate;
f. Communications must be continually reviewed against timeframes and consequences.

What needs to be provided:

a. Authorisation Request Information in accordance with Section 379 of the Act (see “Seeking Authorisation from Chief Executive (DRDMW)” in Section 18.1 above);
b. Time available to make the decision;
c. Any other factors the Dam owner considers critical to effective alternate operations.

19 References

BMT WBM (2017) Brisbane River Catchment Flood Study, Technical Summary Report, Comprehensive Hydrologic and Hydraulic Assessments, 13 February 2017.

QRA (2019) *Brisbane River Strategic Floodplain Management Plan*. Queensland Reconstruction Authority, February 2019.

Seqwater (2013) *Brisbane River Flood Hydrology Models,* Seqwater, December 2013.

Seqwater (2014) Wivenhoe and Somerset Dams Optimisation Study – Simulation of Alternative Flood Operation Options, Seqwater, July 2014.

Water Resources Commission (June 1989) Interim Report on Operation of Wivenhoe Dam During floods (April – May 1989).

APPENDICES

Appendix A— Wivenhoe Dam Technical Data

Table A.1 Significant Levels

Key Level (m AHD)	Description
45.0	Lip of Flip Bucket
57.0	Spillway Crest
65.9	Operational Full Supply Level as at November 2020[1]
67.0	Fixed Full Supply Level (FFSL)
73.0	Top of Closed Radial Gate
75.06	Flood of Record – January 2011
75.7 – 76.7	Fuse Plug Embankment Crest Levels (see Figure A.1 for details)
80.0	Saddle Dam Crest
80.0	Estimated Maximum Flood Storage Level
80.1	Dam Crest Level (Minimum Level of the Top of Wave Wall)

[1] Assumes no TFSL or RFSL is in place.

Table A.2 Discharge Relationships

See notes following table.

Lake Level (m AHD)	Reservoir Capacity ($x10^3$ ML)	Temporary Flood Storage Capacity[2] ($x10^3$ ML)	Discharge per Cone Valve[1] (m^3/s)	Discharge per Spillway Bay[1,4] (m^3/s)	Maximum Available Discharge[3,5] (m^3/s)
57.0	414	-	24.9	0	50
57.5	453	-	25.2	4	69
58.0	466	-	25.4	15	128
58.5	494	-	25.7	32	211
59.0	523	-	25.9	53	316
59.5	553	-	26.2	77	439
60.0	584	-	26.4	105	579
60.5	616	-	26.6	136	735
61.0	649	-	26.9	170	905
61.5	683	-	27.1	207	1,090
62.0	719	-	27.3	246	1,290
62.5	756	-	27.5	288	1,495
63.0	795	-	27.8	333	1,720
63.5	835	-	28	379	1,950
64.0	877	-	28.2	428	2,195
64.5	920	-	28.4	479	2,450
65.0	965	-	28.7	532	2,720
65.5	1,012	-	28.9	587	2,995
65.9	1,052	0	29.0	633	3,223
66.0	1,061	10	29.1	645	3,280

APPENDIX A (WIVENHOE DAM DATA)

Lake Level (m AHD)	Reservoir Capacity ($x10^3$ ML)	Temporary Flood Storage Capacity[2] ($x10^3$ ML)	Discharge per Cone Valve[1] (m^3/s)	Discharge per Spillway Bay[1,4] (m^3/s)	Maximum Available Discharge[3,5] (m^3/s)
66.5	1,112	61	29.3	704	3,580
67.0	1,165	114	29.5	765	3,885
67.5	1,220	168	29.7	828	4,200
68.0	1,276	224	29.9	893	4,525
68.5	1,334	282	30.1	959	4,860
69.0	1,393	342	30.3	1,028	5,200
69.5	1,454	403	30.5	1,098	5,550
70.0	1,517	465	30.7	1,170	5,910
70.5	1,581	530	30.9	1,244	6,280
71.0	1,647	595	31.1	1,319	6,660
71.5	1,714	663	31.3	1,396	7,040
72.0	1,783	732	31.5	1,474	7,430
72.5	1,854	802	31.7	1,554	7,840
73.0	1,926	875	31.9	1,636	8,240
73.5	2,000	949	32.1	1,719	8,660
74.0	2,076	1,024	32.3	1,804	9,080
74.5	2,153	1,101	32.5	1,890	9,520
75.0	2,232	1,180	32.7	1,978	9,960
75.5	2,313	1,261	32.9	2,067	10,400
76.0	2,402	1,350	33.1	2,158	10,860
76.5	2,480	1,428	33.3	2,250	11,320
77.0	2,566	1,515	33.4	2,343	11,780
77.5	2,655	1,604	36.6	2,438	12,260
78.0	2,746	1,694	33.8	2,535	12,740
78.5	2,839	1,787	34.0	2,632	13,230
79.0	2,934	1,883	34.2	2,700	13,500
79.5	3,032	1,980	34.4	2,700	13,500
80.0	3,132	2,080	34.6	2,700	13,500

1. This is the maximum discharge of an individual spillway bay or cone valve. Total discharge is calculated by adding the contributions of each gate or cone valve.
2. The temporary storage is assumed to be the storage above the ROL FSL of 65.9 m AHD. If a Temporary FSL or a Reduced FSL is in use, the temporary storage values should be adjusted accordingly.
3. The table does not include Fuse Plug discharges. The first fuse plug is designed to trigger at 75.7 m AHD. Once fuse plugs are triggered, the release through the emergency spillway should be added to the values in the Maximum Available Discharge column.
4. 'Discharge per Spillway Bay' refers to discharge without the gate interfering with the flow; that is, as an uncontrolled flow.
5. If the mini-hydro is in operation during a Flood Event, the discharge should be assumed as 13 m^3/s, unless advised differently by the Dam Supervisor on duty.

Table A.3 Individual Gate Rating

Outflow in m³/s

Lake Level	Gate Opening (m Tangential Travel)																																	
m AHD	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0
57.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63.0	0	38	76	113	149	183	215	246	275	302	327	333																							
63.2	0	39	78	115	151	186	219	250	280	308	335	351																							
63.4	0	40	79	117	154	189	223	255	286	315	342	368	370																						
63.6	0	40	80	119	156	192	227	260	291	321	349	376	389																						
63.8	0	41	81	121	159	195	231	264	297	327	356	384	408																						
64.0	0	41	82	122	161	199	235	269	302	333	363	391	418	428																					
64.2	0	42	83	124	164	202	238	273	307	339	370	399	426	448																					
64.4	0	42	85	126	166	205	242	278	312	345	376	406	435	462	469																				
64.6	0	43	86	127	168	208	246	282	317	350	383	413	443	471	489																				
64.8	0	44	87	129	170	210	249	286	322	356	389	420	451	480	508	511																			
65.0	0	44	88	131	173	213	253	290	327	362	395	427	458	488	517	532																			
65.2	0	45	89	132	175	216	256	294	331	367	401	434	466	497	526	554																			
65.4	0	45	90	134	177	219	259	298	336	372	407	441	474	505	535	565	576																		
65.6	0	46	91	136	179	222	263	302	341	378	413	448	481	513	544	575	599																		
65.8	0	46	92	137	181	224	266	306	345	383	419	454	488	521	553	584	615	622																	
66.0	0	47	93	139	184	227	269	310	350	388	425	461	495	529	562	594	625	645																	
66.2	0	47	94	140	186	230	273	314	354	393	431	467	503	537	570	603	635	667	668																
66.4	0	48	95	142	188	232	276	318	359	398	436	473	510	545	579	612	645	678	692																
66.6	0	48	96	143	190	235	279	322	363	403	442	480	516	552	587	621	655	689	716																
66.8	0	49	97	145	192	238	282	325	367	408	447	486	523	560	595	630	665	699	733	740															
67.0	0	49	98	146	194	240	285	329	372	413	453	492	530	567	603	639	675	709	744	765															
67.2	0	49	99	148	196	243	288	333	376	418	458	498	537	574	611	648	684	720	755	790															
67.4	0	50	100	149	198	245	291	336	380	422	464	504	543	582	619	657	693	730	766	802	815														
67.6	0	50	101	151	200	248	294	340	384	427	469	510	550	589	627	665	702	740	777	814	841														
67.8	0	51	102	152	202	250	297	343	388	432	474	515	556	596	635	673	712	750	787	825	863	867													
68.0	0	51	103	154	204	253	300	347	392	436	479	521	562	603	642	682	721	759	798	837	876	893													
68.2	0	52	104	155	206	255	303	350	396	441	484	527	569	610	650	690	729	769	808	848	888	919													
68.4	0	52	105	156	207	257	306	354	400	445	489	532	575	616	657	698	738	778	818	859	899	940	946												
68.6	0	53	105	158	209	260	309	357	404	450	494	538	581	623	665	706	747	788	829	870	911	953	973												
68.8	0	53	106	159	211	262	312	360	408	454	499	543	587	630	672	714	755	797	838	880	923	965	1,000												
69.0	0	54	107	160	213	264	315	364	412	458	504	549	593	636	679	722	764	806	848	891	934	977	1,022	1,028											
69.2	0	54	108	162	215	267	317	367	415	463	509	554	599	643	686	729	772	815	858	901	945	989	1,035	1,056											
69.4	0	54	109	163	217	269	320	370	419	467	514	560	605	649	693	737	780	824	868	912	956	1,001	1,047	1,084											
69.6	0	55	110	164	218	271	323	373	423	471	518	565	611	656	700	744	789	833	877	922	967	1,013	1,060	1,107	1,112										

Outflow in m³/s

Lake Level	Gate Opening (m Tangential Travel)																																		
m AHD	**0.0**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**9.5**	**10.0**	**10.5**	**11.0**	**11.5**	**12.0**	**12.5**	**13.0**	**13.5**	**14.0**	**14.5**	**15.0**	**15.5**	**16.0**	**16.5**	**17.0**
69.8	0	55	111	166	220	273	326	377	427	475	523	570	616	662	707	752	797	842	887	932	978	1,025	1,072	1,121	1,141										
70.0	0	56	112	167	222	276	328	380	430	479	528	575	622	668	714	759	805	850	896	942	989	1,036	1,085	1,134	1,170										
70.2	0	56	112	168	224	278	331	383	434	484	532	580	628	674	721	767	813	859	905	952	1,000	1,048	1,097	1,147	1,198	1,199									
70.4	0	56	113	170	225	280	334	386	437	488	537	586	633	680	727	774	821	867	914	962	1,010	1,059	1,109	1,160	1,212	1,229									
70.6	0	57	114	171	227	282	336	389	441	492	542	591	639	687	734	781	828	876	923	972	1,020	1,070	1,121	1,173	1,226	1,258									
70.8	0	57	115	172	229	284	339	392	445	496	546	596	644	693	741	788	836	884	932	981	1,031	1,081	1,133	1,185	1,239	1,289									
71.0	0	58	116	173	230	286	341	395	448	500	551	601	650	699	747	795	844	892	941	991	1,041	1,092	1,144	1,198	1,252	1,309	1,319								
71.2	0	58	117	175	232	289	344	398	452	504	555	605	655	705	754	802	851	900	950	1,000	1,051	1,103	1,156	1,210	1,266	1,323	1,349								
71.4	0	58	117	176	234	291	347	401	455	508	559	610	661	710	760	809	859	908	959	1,009	1,061	1,114	1,167	1,222	1,279	1,337	1,380								
71.6	0	59	118	177	235	293	349	404	458	512	564	615	666	716	766	816	866	916	967	1,019	1,071	1,124	1,179	1,234	1,292	1,350	1,410	1,411							
71.8	0	59	119	178	237	295	352	407	462	515	568	620	671	722	773	823	874	924	976	1,028	1,081	1,135	1,190	1,246	1,304	1,364	1,425	1,443							
72.0	0	60	120	180	239	297	354	410	465	519	572	625	676	728	779	830	881	932	984	1,037	1,091	1,145	1,201	1,258	1,317	1,377	1,439	1,474							
72.2	0	60	121	181	240	299	357	413	469	523	577	629	682	733	785	837	888	940	993	1,046	1,100	1,156	1,212	1,270	1,330	1,391	1,454	1,506							
72.4	0	60	121	182	242	301	359	416	472	527	581	634	687	739	791	843	895	948	1,001	1,055	1,110	1,166	1,223	1,282	1,342	1,404	1,468	1,533	1,538						
72.6	0	61	122	183	243	303	361	419	475	531	585	639	692	745	797	850	903	956	1,009	1,064	1,119	1,176	1,234	1,293	1,354	1,417	1,482	1,548	1,570						
72.8	0	61	123	184	245	305	364	422	478	534	589	643	697	750	803	856	910	963	1,018	1,073	1,129	1,186	1,245	1,305	1,367	1,430	1,496	1,563	1,603						
73.0	0	62	124	185	247	307	366	425	482	538	593	648	702	756	809	863	917	971	1,026	1,081	1,138	1,196	1,255	1,316	1,379	1,443	1,509	1,577	1,636						
73.2	2	62	124	187	248	309	369	427	485	542	597	653	707	761	815	869	924	978	1,034	1,090	1,147	1,206	1,266	1,327	1,391	1,456	1,523	1,592	1,663	1,669					
73.4	6	62	125	188	250	311	371	430	488	545	602	657	712	767	821	876	931	986	1,042	1,099	1,156	1,216	1,276	1,339	1,403	1,469	1,536	1,606	1,678	1,702					
73.6	11	64	126	189	251	313	373	433	491	549	606	662	717	772	827	882	937	993	1,050	1,107	1,166	1,225	1,287	1,350	1,414	1,481	1,550	1,620	1,693	1,736					
73.8	17	69	127	190	253	315	376	436	495	553	610	666	722	778	833	888	944	1,001	1,058	1,116	1,175	1,235	1,297	1,361	1,426	1,494	1,563	1,635	1,708	1,770					
74.0	23	74	129	191	254	317	378	438	498	556	614	671	727	783	839	895	951	1,008	1,065	1,124	1,184	1,245	1,307	1,372	1,438	1,506	1,576	1,648	1,723	1,800	1,804				
74.2	31	80	133	192	256	319	380	441	501	560	618	675	732	788	845	901	958	1,015	1,073	1,132	1,192	1,254	1,317	1,382	1,449	1,518	1,589	1,662	1,738	1,815	1,838				
74.4	39	87	139	195	257	321	383	444	504	563	622	679	737	793	850	907	964	1,022	1,081	1,140	1,201	1,264	1,327	1,393	1,461	1,530	1,602	1,676	1,752	1,831	1,873				
74.6	47	94	145	200	259	322	385	447	507	567	626	684	741	799	856	913	971	1,029	1,089	1,149	1,210	1,273	1,337	1,404	1,472	1,542	1,615	1,690	1,767	1,846	1,908				
74.8	56	103	153	206	262	324	387	449	510	570	629	688	746	804	862	919	978	1,036	1,096	1,157	1,219	1,282	1,347	1,414	1,483	1,554	1,628	1,703	1,781	1,861	1,943				
75.0	66	112	161	213	267	326	390	452	513	574	633	692	751	809	867	926	984	1,044	1,104	1,165	1,227	1,291	1,357	1,425	1,494	1,566	1,640	1,717	1,795	1,876	1,960	1,978			
75.2	76	121	169	220	274	330	392	455	516	577	637	697	756	814	873	932	991	1,051	1,111	1,173	1,236	1,301	1,367	1,435	1,506	1,578	1,653	1,730	1,809	1,891	1,976	2,013			
75.4	87	131	178	229	281	336	394	457	519	581	641	701	760	819	878	938	997	1,057	1,119	1,181	1,245	1,310	1,377	1,446	1,517	1,590	1,665	1,743	1,823	1,906	1,992	2,049			
75.6	98	141	188	237	289	343	399	460	522	584	645	705	765	824	884	944	1,004	1,064	1,126	1,189	1,253	1,319	1,386	1,456	1,527	1,601	1,678	1,756	1,837	1,921	2,007	2,085			
75.8	109	152	198	247	298	350	405	463	525	587	649	709	769	829	889	949	1,010	1,071	1,133	1,197	1,261	1,328	1,396	1,466	1,538	1,613	1,690	1,769	1,851	1,936	2,023	2,112	2,121		
76.0	121	164	209	257	307	359	412	468	528	591	652	713	774	834	895	955	1,016	1,078	1,141	1,205	1,270	1,337	1,405	1,476	1,549	1,624	1,702	1,782	1,865	1,950	2,038	2,129	2,158		
76.2	133	175	220	268	317	368	421	475	532	594	656	718	779	839	900	961	1,023	1,085	1,148	1,212	1,278	1,346	1,415	1,486	1,560	1,636	1,714	1,795	1,878	1,965	2,053	2,145	2,194		
76.4	146	187	232	279	327	378	429	483	539	597	660	722	783	844	906	967	1,029	1,092	1,155	1,220	1,286	1,354	1,424	1,496	1,570	1,647	1,726	1,808	1,892	1,979	2,069	2,161	2,231		
76.6	159	200	244	290	338	388	439	492	546	603	664	726	788	849	911	973	1,035	1,098	1,162	1,228	1,295	1,363	1,434	1,506	1,581	1,658	1,738	1,820	1,905	1,993	2,084	2,177	2,268		
76.8	173	213	257	302	350	399	449	501	554	610	668	730	792	854	916	978	1,041	1,105	1,170	1,235	1,303	1,372	1,443	1,516	1,591	1,669	1,750	1,833	1,919	2,007	2,099	2,193	2,289	2,306	
77.0	186	226	270	315	362	410	460	511	564	618	674	734	797	859	921	984	1,047	1,112	1,177	1,243	1,311	1,380	1,452	1,526	1,602	1,680	1,762	1,845	1,932	2,021	2,113	2,208	2,306	2,343	
77.2	200	240	283	328	374	422	471	522	574	627	682	739	801	864	927	990	1,054	1,118	1,184	1,250	1,319	1,389	1,461	1,536	1,612	1,691	1,773	1,858	1,945	2,035	2,128	2,224	2,322	2,381	

Outflow in m^3/s

Lake Level	Gate Opening (m Tangential Travel)																																		
m AHD	**0.0**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**9.5**	**10.0**	**10.5**	**11.0**	**11.5**	**12.0**	**12.5**	**13.0**	**13.5**	**14.0**	**14.5**	**15.0**	**15.5**	**16.0**	**16.5**	**17.0**
77.4	215	254	297	341	387	435	483	533	584	637	691	747	806	869	932	996	1,060	1,125	1,191	1,258	1,327	1,398	1,470	1,545	1,622	1,702	1,785	1,870	1,958	2,049	2,143	2,239	2,339	2,419	
77.6	230	269	311	355	400	447	496	545	595	647	700	756	813	873	937	1,001	1,066	1,131	1,198	1,265	1,335	1,406	1,479	1,555	1,633	1,713	1,796	1,882	1,971	2,063	2,157	2,255	2,355	2,457	
77.8	245	283	325	369	414	461	508	557	607	658	711	765	821	880	942	1,007	1,072	1,138	1,205	1,273	1,343	1,414	1,488	1,564	1,643	1,724	1,808	1,894	1,984	2,076	2,172	2,270	2,371	2,475	2,496
78.0	260	299	340	383	428	474	522	570	619	670	722	775	831	888	948	1,012	1,078	1,144	1,211	1,280	1,351	1,423	1,497	1,574	1,653	1,735	1,819	1,907	1,997	2,090	2,186	2,285	2,387	2,492	2,535
78.2	276	314	355	398	442	488	535	583	632	682	733	786	840	896	954	1,018	1,084	1,150	1,218	1,288	1,358	1,431	1,506	1,583	1,663	1,745	1,831	1,919	2,010	2,104	2,200	2,300	2,403	2,509	2,573
78.4	291	329	369	412	456	501	548	595	644	693	744	796	850	905	960	1,023	1,090	1,157	1,225	1,295	1,366	1,440	1,515	1,593	1,673	1,756	1,842	1,931	2,022	2,117	2,215	2,316	2,419	2,526	2,612
78.6	307	344	384	426	470	515	561	608	656	705	755	807	859	913	965	1,029	1,096	1,163	1,232	1,302	1,374	1,448	1,524	1,602	1,683	1,767	1,853	1,943	2,035	2,131	2,229	2,331	2,435	2,543	2,651
78.8	322	359	399	441	484	529	574	621	668	717	766	817	869	921	971	1,034	1,102	1,170	1,239	1,310	1,382	1,456	1,533	1,612	1,693	1,778	1,865	1,955	2,048	2,144	2,244	2,346	2,451	2,560	2,689
79.0	338	374	414	455	498	542	588	634	681	729	778	827	878	929	977	1,040	1,108	1,176	1,246	1,317	1,390	1,465	1,542	1,621	1,703	1,788	1,876	1,967	2,061	2,158	2,258	2,361	2,467	2,577	2,700
79.2	353	389	428	470	512	556	601	646	693	740	789	838	888	938	983	1,046	1,114	1,183	1,253	1,324	1,398	1,473	1,551	1,631	1,714	1,799	1,887	1,979	2,074	2,171	2,272	2,376	2,483	2,594	2,700*
79.4	368	404	443	484	526	570	614	659	705	752	800	848	897	946	988	1,051	1,120	1,189	1,260	1,332	1,406	1,481	1,560	1,640	1,724	1,810	1,899	1,991	2,086	2,185	2,287	2,391	2,499	2,610	2,700*
79.6	384	419	458	498	540	583	627	672	717	764	811	859	907	954	994	1,057	1,126	1,195	1,266	1,339	1,413	1,490	1,569	1,650	1,734	1,820	1,910	2,003	2,099	2,198	2,301	2,407	2,516	2,627	2,700*
79.8	399	435	473	513	554	597	640	685	730	775	822	869	916	963	1000	1,062	1,132	1,202	1,273	1,346	1,421	1,498	1,578	1,659	1,744	1,831	1,922	2,015	2,112	2,212	2,315	2,422	2,532	2,644	2,700*
80.0	415	450	487	527	568	610	654	697	742	787	833	879	926	971	1006	1,068	1,137	1,208	1,280	1,354	1,429	1,507	1,586	1,669	1,754	1,842	1,933	2,027	2,125	2,226	2,330	2,437	2,548	2,661	2,700*

* Flow impacted by bridge deck

Gate overtopped
Uncontrolled outflow

Table A.4 Wivenhoe Radial Gates

Wivenhoe Dam Radial Gates Top and Bottom Gate Levels for Various Gate Openings					
Gate Opening (m tangential opening)	Bottom of Gate[1] (m AHD)	Top of Gate (m AHD)	Gate Opening (m)	Bottom of Gate[1] (m AHD)	Top of Gate (m AHD)
0.0	56.36	73.00	9.0	64.97	78.88
0.5	56.79	73.42	9.5	65.47	79.08
1.0	57.24	73.83	10.0	65.97	79.28
1.5	57.69	74.23	10.5	66.47	79.45
2.0	58.14	74.62	11.0	66.96	79.62
2.5	58.61	75.00	11.5	67.45	79.77
3.0	59.08	75.37	12.0	67.94	79.90
3.5	59.55	75.73	12.5	68.43	80.02
4.0	60.03	76.08	13.0	68.91	80.12
4.5	60.51	76.41	13.5	69.39	80.21
5.0	61.00	76.74	14.0	69.86	80.28
5.5	61.49	77.05	14.5	70.33	80.34
6.0	61.98	77.35	15.0	70.79	80.38
6.5	62.48	77.64	15.5	71.24	80.41
7.0	62.97	77.91	16.0	71.69	80.42
7.5	63.47	78.17	16.5	72.13	80.41
8.0	63.97	78.42	17.0	72.57	80.39
8.5	64.47	78.66			

[1] Owing to the curvature of the water surface over the ogee crest this level does not directly equate to Lake Level. See previous table for an indication of when the bottom edge may emerge from the water, in reference to issues associated with shallow submergence described in Section 14.5.

Figure A.1 Fuse Plug Plan

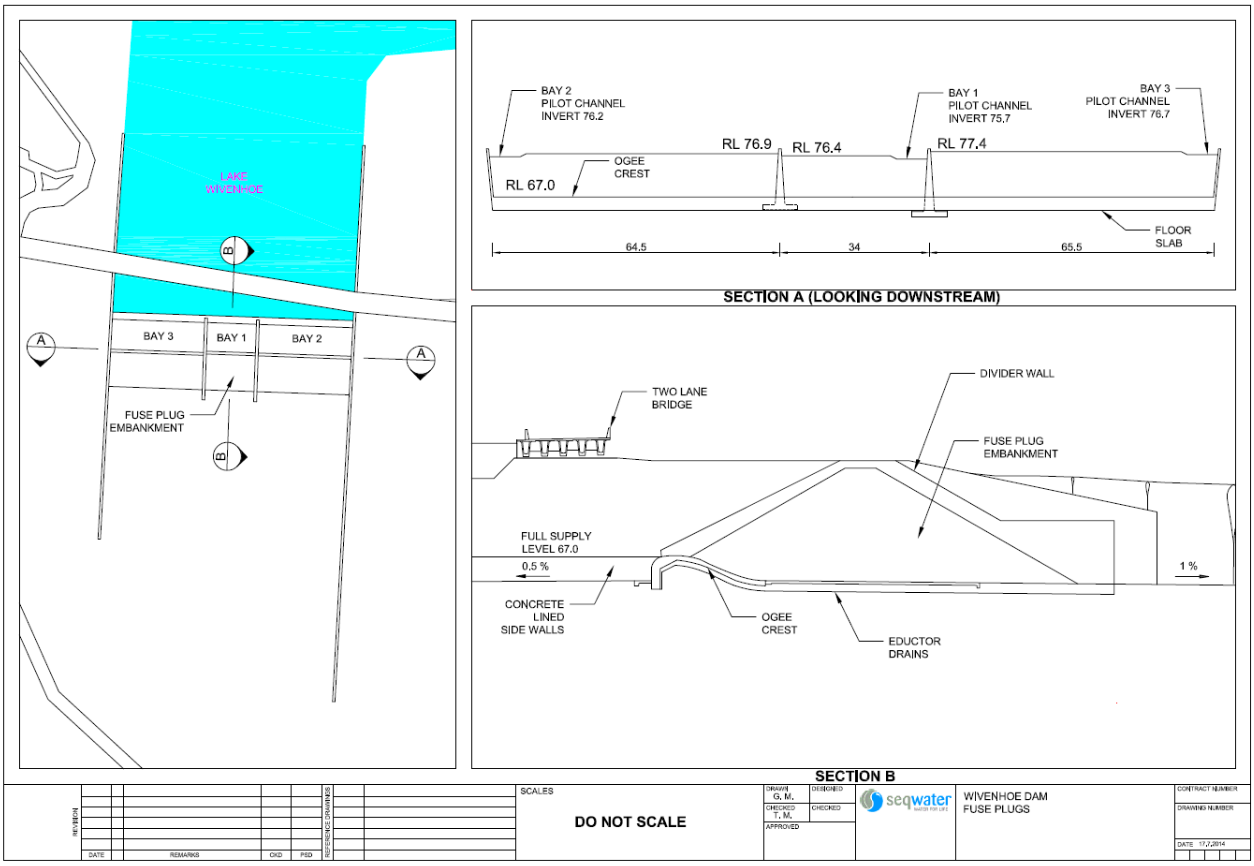


Table A.5 Fuse Plug Details

Fuse Plug	Type	Width (L) (m)	Ogee Crest Level (m AHD)	Fuse Plug Pilot Channel Invert Level (m AHD)
Bay 1	Ogee	34.0	67	75.7
Bay 2	Ogee	64.5	67	76.2
Bay 3	Ogee	65.5	67	76.7

Discharge for each fuse plug may be approximated using the following equation:

$$Q_{\text{Fuse Plug}} = C*L*(\text{Lake Level} - 67.0)^{1.5}$$

Where L = Width of fuse plug bay in metres

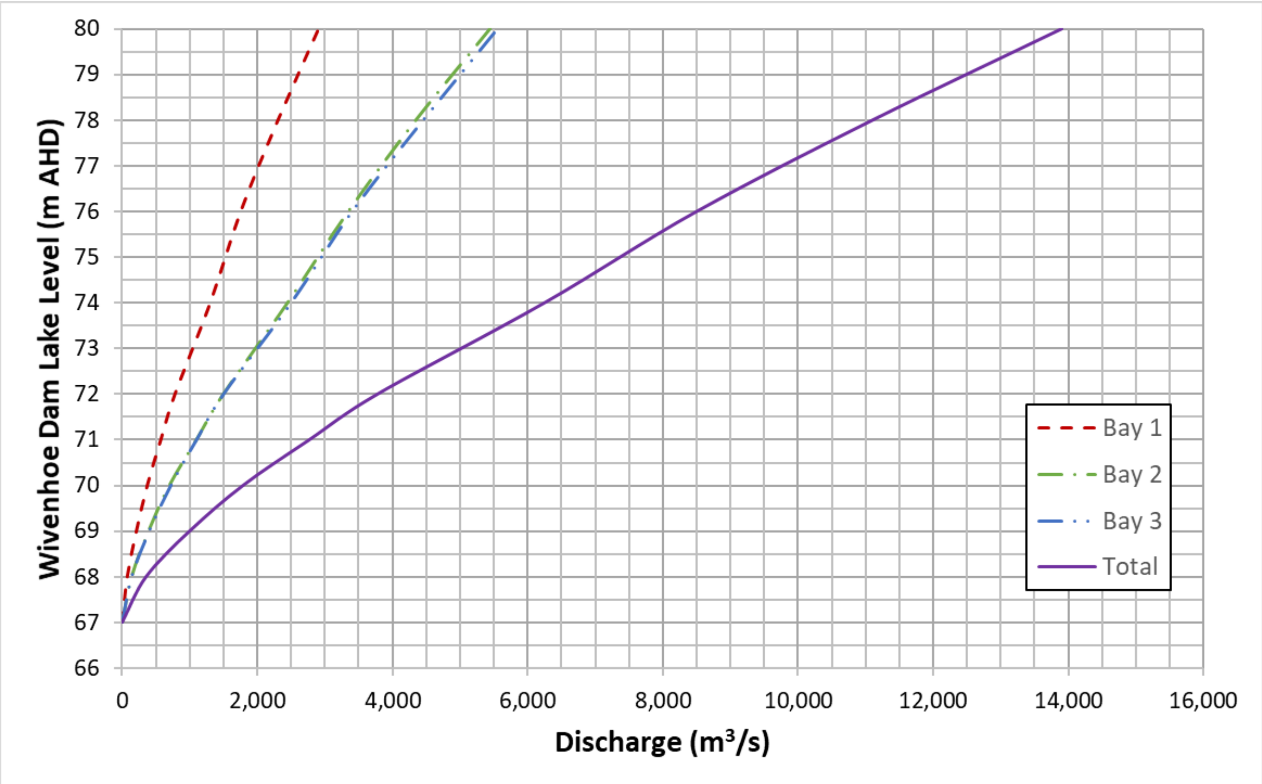
C = Coefficient of discharge as per the table below

Table A.6 Fuse Plug Ratings

Lake Level (m AHD)	Coefficient of Discharge	Fuse Plug Discharge			
		Bay 1 (m^3/s)	Bay 2 (m^3/s)	Bay 3 (m^3/s)	Total (m^3/s)
67.0	2.11	0	0	0	0
68.0	2.11	75	140	140	355
69.0	2.11	210	390	400	1,000
70.0	2.09	370	700	720	1,790
71.0	2.07	570	1,100	1,100	2,770
72.0	2.05	780	1,500	1,500	3,780
74.0	2.03	1,300	2,450	2,500	6,250
76.0	1.90	1,750	3,350	3,400	8,500
78.0	1.85	2,300	4,350	4,450	11,100
80.0	1.80	2,900	5,450	5,550	13,900

This table has been revised in 2021 with consideration of detailed hydraulic modelling studies to re-evaluate the fuse plug spillway discharge capacity.

Figure A.2 Fuse Plug Ratings



APPENDIX B
DAM OPERATOR LOSS OF COMMUNICATIONS PROCEDURES FOR BREACHED FUSE PLUG

Appendix B— Wivenhoe Dam – Breached Fuse Plug Scenarios

This Appendix applies in the circumstances set out in Section 16.4 (and may provide guidance under the Dam Safety Strategy).

Table B.1 Wivenhoe Dam radial gate settings when one fuse plug embankment has eroded

Wivenhoe Dam Radial Gate Settings Loss of Communications Centre 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)	Total Opening (m)	Actual Total Outflow – Fuse Plug Breach and Gates (m^3/s)
OFSL or lower	-	-	-	-	-	-	-
OFSL + 0.2 m	0.0	0.0	0.5	0.0	0.0	0.5	-
67.75	0.0	0.0	0.5	0.0	0.0	0.5	97
68.25	0.0	0.0	1.0	0.0	0.0	1.0	204
68.75	0.0	0.0	1.5	0.0	0.0	1.5	325
69.00	0.0	0.0	2.0	0.0	0.0	2.0	416
69.25	0.0	0.0	2.5	0.0	0.0	2.5	509
69.50	0.0	0.0	3.0	0.0	0.0	3.0	604
69.75	0.0	0.0	3.5	0.0	0.0	3.5	701
70.00	0.0	0.5	3.5	0.0	0.0	4.0	805
70.25	0.0	0.5	3.5	0.5	0.0	4.5	911
70.50	0.0	0.5	4.0	0.5	0.0	5.0	1,016
70.75	0.0	1.0	4.0	0.5	0.0	5.5	1,128
71.00	0.0	1.0	4.0	1.0	0.0	6.0	1,242
71.25	0.5	1.0	4.0	1.0	0.5	7.0	1,417
71.50	0.5	1.5	4.0	1.5	0.5	8.0	1,596
71.75	1.0	1.5	4.0	1.5	1.0	9.0	1,778
72.00	1.0	2.0	4.0	2.0	1.0	10.0	1,961
72.25	1.5	2.0	4.0	2.0	1.5	11.0	2,150
72.50	1.5	2.5	4.0	2.5	1.5	12.0	2,339
72.75	2.0	2.5	4.0	2.5	2.0	13.0	2,528
73.00	2.5	2.5	4.0	2.5	2.5	14.0	2,725
73.25	2.5	3.0	4.0	3.0	2.5	15.0	2,922
73.50	3.0	3.5	4.0	3.5	3.0	17.0	3,241
73.75	3.5	3.5	4.0	3.5	3.5	18.0	3,443
74.00	4.0	4.0	4.0	4.0	4.0	20.0	3,764
74.10	4.5	4.5	4.5	4.5	4.5	22.5	4,090

APPENDIX B
DAM OPERATOR LOSS OF COMMUNICATIONS PROCEDURES FOR BREACHED FUSE PLUG

Wivenhoe Dam Radial Gate Settings Loss of Communications Centre 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)	Total Opening (m)	Actual Total Outflow – Fuse Plug Breach and Gates (m^3/s)
74.20	5.0	5.0	5.0	5.0	5.0	25.0	4,413
74.30	5.5	5.5	5.5	5.5	5.5	27.5	4,734
74.40	6.0	6.0	6.0	6.0	6.0	30.0	5,054
74.50	6.5	6.5	6.5	6.5	6.5	32.5	5,375
74.60	7.0	7.0	7.0	7.0	7.0	35.0	5,698
74.70	7.5	7.5	7.5	7.5	7.5	37.5	6,024
74.80	8.5	8.5	8.5	8.5	8.5	42.5	6,647
74.90	9.5	9.5	9.5	9.5	9.5	47.5	7,293
75.00	10.5	10.5	10.5	10.5	10.5	52.5	7,969
75.10	12.0	12.0	12.0	12.0	12.0	60.0	9,035
75.20	13.0	13.0	13.0	13.0	13.0	65.0	9,822
75.30	13.5	13.5	13.5	13.5	13.5	67.5	10,264
75.40	13.5	13.5	13.5	13.5	13.5	67.5	10,321
75.50	13.5	13.5	13.5	13.5	13.5	67.5	10,377
75.60	13.5	13.5	13.5	13.5	13.5	67.5	10,433
75.70	15.0	15.0	15.0	15.0	15.0	75.0	11,750
75.80	Fully Open	Fully Open	Fully Open	Fully Open	Fully Open	Fully Open	12,304
>75.80	Fully Open	Fully Open	Fully Open	Fully Open	Fully Open	Fully Open	12,419#
# This is the discharge for 75.90 m AHD (not for all higher Lake Levels).							

Table B.2 Wivenhoe Dam radial gate settings when two fuse plug embankments have eroded

WIVENHOE DAM RADIAL GATE SETTINGS LOSS OF COMMUNICATIONS TWO FUSE PLUGS ERODED			
Lake Level (m AHD)	Actual Total Outflow – Fuse Plug Breach and Gates (m^3/s)	Radial Gate Opening (required for all gates) (m)	Total Required Radial Gate Opening (m)
≤72.5	2,598#	0	0
72.50	2,901	0.5*	2.5
73.00	3,571	1.0*	5
73.50	4,263	1.5*	7.5
74.00	4,975	2.0*	10
74.10	5,046	2.0*	10
74.20	5,118	2.0*	10
74.30	5,189	2.0*	10
74.40	5,576	2.5*	12.5
74.50	5,649	2.5*	12.5
74.60	5,721	2.5*	12.5
74.70	5,793	2.5	12.5
74.80	6,490	3.5	17.5
74.90	7,172	4.5	22.5
75.00	7,841	5.5	27.5
75.10	8,797	7	35
75.20	9,468	8	40
75.30	9,852	8.5	42.5
75.40	9,937	8.5	42.5
75.50	10,022	8.5	42.5
75.60	10,106	8.5	42.5
75.70	11,807	11	55

WIVENHOE DAM RADIAL GATE SETTINGS LOSS OF COMMUNICATIONS TWO FUSE PLUGS ERODED			
75.80	11,899	11	55
75.90	11,989	11	55
76.00	12,080	11	55
76.10	12,537	11.5	57.5
76.20	14,183	13.5	67.5
76.30	16,351	Fully Open	Fully Open

* Radial gates must be opened to prevent overtopping. The total discharge from the Dam will exceed the target discharge in these circumstances, due to uncontrolled outflows from the auxiliary spillway.

This is the discharge for 72.5 m AHD (not for all lower Lake Levels).

Table B.3 Wivenhoe Dam radial gate settings when all three fuse plug embankments have eroded

WIVENHOE DAM RADIAL GATE SETTINGS LOSS OF COMMUNICATIONS THREE FUSE PLUGS ERODED			
Lake Level (m AHD)	Actual Total Outflow – Fuse Plug Breach and Gates (m^3/s)	Radial Gate Opening (required for all gates) (m)	Total Required Radial Gate Opening (m)
≤72.5	4,326#	0	0
72.5	4,629	0.5*	2.5
73	5,535	1.0*	5
73.5	6,472	1.5*	7.5
74	7,438	2.0*	10
74.1	7,554	2.0*	10
74.2	7,670	2.0*	10
74.3	7,787	2.0*	10
74.4	8,219	2.5*	12.5
74.5	8,336	2.5*	12.5
74.6	8,453	2.5*	12.5
74.7	8,571	2.5*	12.5
74.8	9,003	3.0*	15
74.9	9,121	3.0*	15
75	9,240	3.0*	15
75.1	9,358	3.0*	15
75.2	9,790	3.5*	17.5
75.3	9,909	3.5*	17.5

APPENDIX B

DAM OPERATOR LOSS OF COMMUNICATIONS PROCEDURES FOR BREACHED FUSE PLUG

WIVENHOE DAM RADIAL GATE SETTINGS LOSS OF COMMUNICATIONS THREE FUSE PLUGS ERODED			
75.4	10,027	3.5*	17.5
75.5	10,146	3.5*	17.5
75.6	10,578	4.0*	20
75.7	11,614	5.5	27.5
75.8	11,736	5.5	27.5
75.9	11,858	5.5	27.5
76	11,980	5.5	27.5
76.1	12,120	5.5	27.5
76.2	12,260	5.5	27.5
76.3	16,259	11.5	57.5
76.4	16,414	11.5	57.5
76.5	16,570	11.5	57.5
76.6	16,726	11.5	57.5
76.7	16,882	11.5	57.5
76.8	20,988	Fully Open	Fully Open

* Radial gates must be opened to prevent overtopping. The total discharge from the Dam will exceed the target discharge in these circumstances, due to uncontrolled outflows from the auxiliary spillway.

[#] This is the discharge for 72.5 m AHD (not for all lower Lake Levels).

Appendix C— Wivenhoe Dam - Guidance on Gates and Equipment Operation

C.1 Radial Gate Operation – General Considerations

The radial gates are sequentially numbered from 1 to 5 from left to right looking in the downstream direction. Plans of the Dam and spillway are contained in Appendix D.

The flip bucket spillway is designed to control the discharge from the reservoir and to dissipate the energy of the discharge. The flip throws the discharge clear of the concrete structures into a plunge pool where the energy is dissipated by turbulence. Under non-symmetric flow conditions, or when gates 1 and 5 are not operating, the discharge jet may impinge on the walls of the plunge pool, which has been excavated into erodible sandstone rock, and cause non-predictable erosion. Upstream migration of this erosion is to be avoided. The wing walls adjacent to the flip bucket deflect the discharge away from the walls of the plunge pool when gates 1 and 5 are operated.

Therefore, in operating the spillway, the principles to be observed are, in descending order of priority:

a. The discharge jet into the plunge pool is not to impinge on the right or left walls of the plunge pool; and
b. The flow in the spillway is to be generally symmetrical.

C.2 Radial Gate Operating Equipment

Each radial gate consists of a cylindrical upstream skin-plate segment that is attached to the radial arms. The cylindrical axis is horizontal. Each gate rotates about two spherical trunnion bearings that are on this axis.

The position of a radial gate is controlled by two hydraulically driven winches that are located on the piers either side of each radial gate. Wire ropes attach the downstream face of the radial gate skin plate to each winch through a pulley system. The hydraulic motors work off a common pressure manifold and apply an equal lifting force to each side of the radial gate. This system does not sense rope travel and will take up slack rope. The system corrects skewing of the skin plate segment between the piers. If skewing occurs, skids will come into contact with the side seal plates to limit movement. The design of the system is such that it is not possible to operate a single winch independently of the second winch attached to a radial gate.

When the hydraulic winch motors are not energised, the radial gates are held in position by spring loaded friction brakes on the winches. There are two brake bands per winch and each band is capable of supporting half the weight of the radial gate. One winch can support the total weight of a radial gate on both its brake bands, but not on one.

Each radial gate can be fully opened in 35 minutes or at a rate of one metre every two minutes. Up to two radial gates can be operated simultaneously. Maximum mechanical capability is not a constraint when undertaking radial gate operations during Flood Events unless a mechanical failure is experienced.

While the radial gates have been designed to withstand some overtopping, it should be avoided if possible. The Lake Levels and the structural state of the radial gates when in the closed position are as follows:

Table C.1 Radial gate stress conditions on closed gate for key levels

Lake Level (m AHD)	Radial Gate Stress Condition with Gate Closed
73.0	Within design limits of radial gate
77.0	Limit of structural security (33% overstressed)
79.0	Critical structural failure likely

Once overtopped, the radial gates become inoperable if the lifting tackle is fouled by debris from the overflow. However, the radial gates will remain structurally secure until the Lake Level exceeds 77.0 m AHD. Above this Lake Level, structural damage that causes the radial gates to become inoperable is possible.

C.3 No Free Fall of the Radial Gates

Under no circumstances are the radial gates allowed to free fall. The lower skin plate sections are overstressed if a freefall of 60 millimetres is arrested by the seal plate on the spillway.

If a radial gate becomes stuck in an open position, attempts are to be made to free the radial gate by applying positive lifting forces. Under no circumstances are the winches to be unloaded and the direct weight of the radial gates used to yield the obstruction.

C.4 Operation in High Wind

Other than during Flood Events, the radial gates are not to be raised or lowered when clear of water, during periods of high winds. The radial gates can however, be held on their brakes in any position in the presence of high wind.

The term "high wind" means any wind that causes twisting or movement of the radial gate. A precise figure cannot be placed on these velocities, as it is also a function of wind direction.

This limitation is required to prevent the radial gate from twisting from skew on one side to skew on the other side. While the radial gate is being raised or lowered, skewing cannot be prevented by the hydraulic lifting system and any impact forces encountered may damage the radial gate.

C.5 Maintenance Considerations

Maintenance on the Dam release infrastructure (gates and cone valves) should be scheduled to minimise the risk of release infrastructure not being available for use in a Flood Event.

C.6 Bulkhead Gate Operating Limitations

The bulkhead gate can be used to control discharge in an emergency situation where a radial gate is inoperable. It is transported to and lowered upstream of the inoperable radial gate by means of the gantry crane. The following considerations apply in these circumstances:

a. the bulkhead gate can always be lowered with any type of underflow; and
b. it is not possible to raise the bulkhead gate once it has been lowered past certain levels depending on upstream conditions without there being a pool of water between it and the radial gate.

It is thus possible to preserve storage by effectively closing the spillway even with one radial gate inoperable. However, it will not be possible to raise the bulkhead gate until the inoperable radial gate has been lowered and is again storing water.

The bulkhead gate is not to be used for flood regulation until the Lake Level has fallen below the OFSL and not likely to rise within the period needed to repair the inoperable radial gate.

The spillway gantry crane is to be used to raise and lower the bulkhead gate. The crane operates at two speeds, 1.5 metres/minute and 3.0 metres/minute. When within the bulkhead gate guides, the bulkhead gate is to be moved only at 1.5 metres/minute.

C.7 Bulkhead Gate Overtopping

In the event that the bulkhead gate is overtopped (Lake Level exceeds 69.0 m AHD when bulkhead gate is closed), it cannot be removed unless a pool of water fills the space between it and the upstream side of the radial gate. The closed bulkhead becomes critically stressed when the Lake Level overtops it to 71.4 m AHD.

It is not possible to engage the lifting tackle while overtopping is occurring. While there is any risk that the bulkhead gate may be overtopped, the lifting gear is to be left engaged so that the bulkhead gate can be raised once the downstream radial gate becomes operable.

C.8 Bulkhead Operation into Flow

This procedure should only be used if the safety of Wivenhoe Dam is at direct risk or to preserve the water supply stored in Wivenhoe Dam.

In the event that a radial gate is inoperable in a partially open position, the bulkhead gate can placed into flow provided that the lower lip of the radial gate is clear of the underflow jet.

Where a pool exists between the bulkhead gate and a radial gate under flow conditions, the bulkhead gate will be subjected to additional pull-down and possibly subjected to vortex-induced vibrations. When this condition occurs, the bulkhead gate is to be lowered to dewater the pool. The bulkhead gate can then be adjusted to regulate the flow provided the underflow jet remains below the lower lip of the radial gate.

C.9 Equipment Malfunction

Normal gate operation is by means of two electric hydraulic pumps supplied by external mains supply electric power, with Pump Number 1 connected to radial gates 1 and 2 and the penstock gate, and Pump Number 2 connected to radial gates 3, 4 and 5.

Normal radial gate operation may not be possible in the event of equipment malfunctions during the passing of a flood. The procedures to be followed under the various scenarios are outlined below.

C.9.1 Failure of External Electric Power

The fixed diesel electric generator at the Dam is used to provide a power supply. The generator supplies sufficient power to operate the radial gates normally.

C.9.2 Failure of One Electric Hydraulic Pump

If one electric hydraulic pump fails, the connecting valves between pumps are to be switched such that both sets of hydraulic lines are connected to the operable pump, thus permitting operation of all five gates from the operating pump.

C.9.3 Failure of Two Electric Hydraulic Pumps

In the event that both electric hydraulic pumps fail, either the mobile or the fixed emergency diesel hydraulic pump is to be used to operate the radial gates, one gate at a time.

C.9.4 Rupture of Hydraulic Lines

Depending on location and severity, a hydraulic line rupture may cause a radial gate to become inoperable. Accordingly any ruptures to the hydraulic lines are to be repaired as soon as practicable. Depending on the location of the rupture, it may be possible to use the mobile emergency diesel hydraulic pump to operate the impacted radial gate.

C.9.5 Contamination of Winch Brakes

Oil contamination of the winch brakes will reduce their holding capacity and possibly allow the radial gate to fall. The brake bands are to be inspected regularly and cleaned immediately if any contamination is observed.

C.9.6 Fouling of Radial Gate Lifting Tackle

The lifting tackle consists of blocks, wire ropes and winch drums. If the radial gate is overtopped, debris may be collected on the wire ropes that may in turn foul the blocks or the winch drums. This may result in jamming of the wire rope or in uneven lifting, both of which may cause the radial gate to jam.

C.9.7 Fouling of Side Skids

The side skids have been designed to limit the side-sway and skew of the radial gates during operation. Under ideal conditions, the skids should not be in contact with the side seal plates.

If the winches are lifting the radial gates unevenly or in a skewed position, the lifting gear should be adjusted.

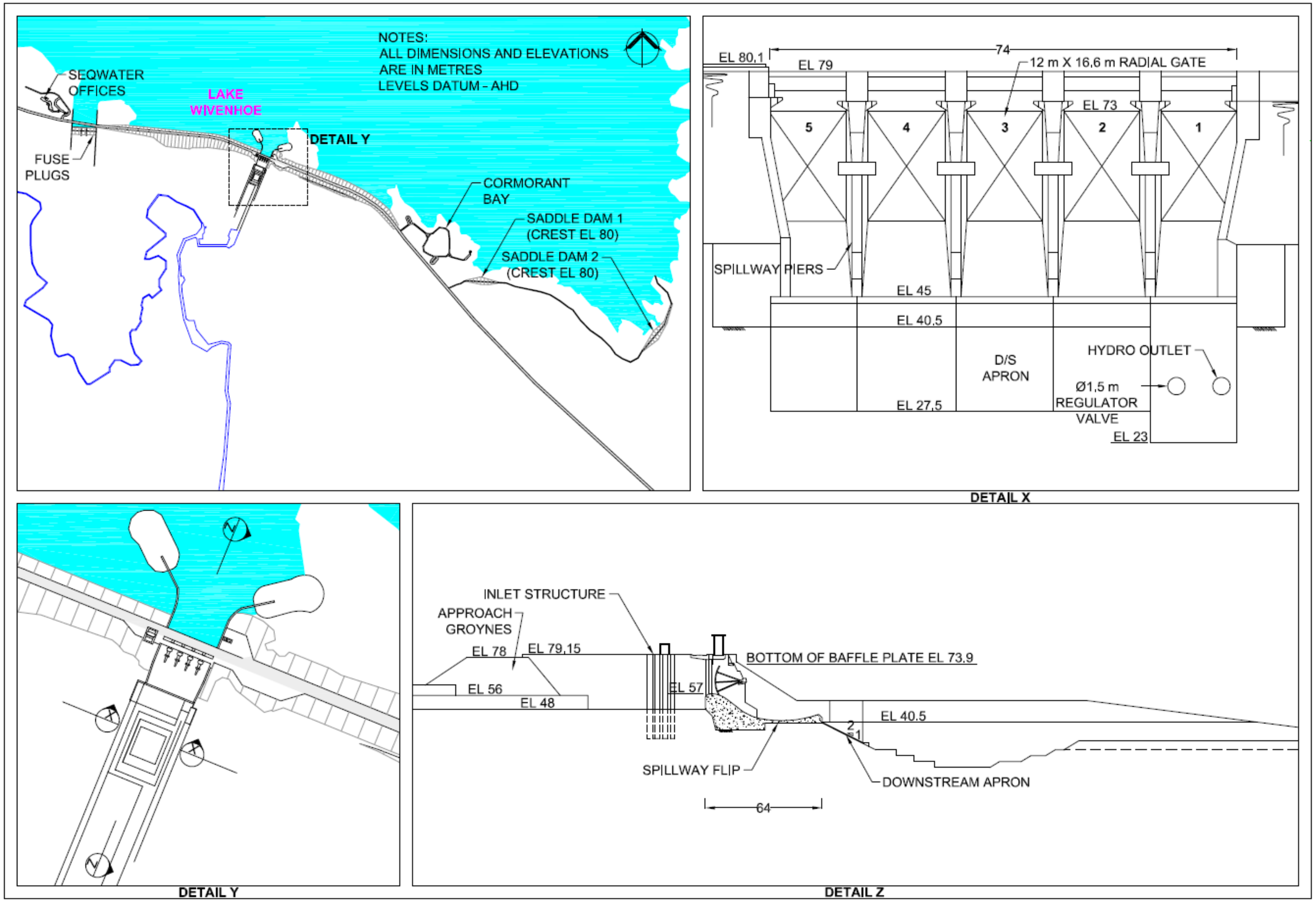
Appendix D— Wivenhoe Dam – Plans, Maps and Photographs

Figure D.1 Wivenhoe Dam Aerial View

Figure D.2 Wivenhoe Dam Main Spillway (looking upstream)

Figure D.3 Wivenhoe Fuse Plugs (looking upstream)

Figure D.4 Wivenhoe Dam General Arrangement



Appendix E— Somerset Dam Technical Data

Table E.1 Significant Levels

Key Level (m AHD)	Description
~ 54.7	Dam foundation
57.8	Foundation tunnels
60.96	Stilling basin dissipator slab floor
~ 61	Stanley River channel invert
~ 66.0	Lower gallery
67.77	Sluice outlets (downstream centreline)
69.97	Cone valve Regulators (centreline)
73.02	Sluice gate intakes (upstream centreline); crest of dissipator retaining walls
88.8	Upper gallery
97.0	Operational Full Supply Level (OFSL) as at November 2020
99.0	Fixed Full Supply Level (FFSL)
100.45	Ogee Spillway crest; change of slope for non-overflow monoliths
106.57	Flood of Record – January 1974
107.45	Dam crest (“breezeway” section) – Original design maximum flood level for the Dam
107.45	Top of closed crest gates
107.45	Maximum Flood Storage Level without the removeable flood barrier in place
108.7	Maximum Flood Storage Level with the removable flood barrier in place
110.8	Top of bridge piers
112.34	Bridge deck

Table E.2 Discharge Relationships

Lake Level (m AHD)	Reservoir Capacity ($x10^3$ ML)	Temporary Flood Storage ($x10^3$ ML)[1]	Discharge per Cone Valve (m^3/s)	Discharge per Sluice (m^3/s)	Discharge per Spillway Bay (m^3/s)	Maximum Available Discharge (m^3/s)[2]
90.0	120	-	57	163	-	1,527
90.5	130	-	58	165	-	1,549
91.0	139	-	58	167	-	1,570
91.5	150	-	59	170	-	1,592
92.0	161	-	60	172	-	1,613
92.5	172	-	60	174	-	1,633
93.0	184	-	61	176	-	1,654
93.5	197	-	62	179	-	1,674
94.0	210	-	62	181	-	1,694
94.5	224	-	63	183	-	1,713
95.0	239	-	64	185	-	1,733
95.5	254	-	64	187	-	1,752
96.0	269	-	65	189	-	1,771
96.5	286	-	66	191	-	1,790
97.0	303	0	66	193	-	1,809
97.5	321	18	67	195	-	1,827
98.0	340	37	67	197	-	1,845
98.5	359	56	68	199	-	1,863
99.0	380	77	69	201	-	1,881
99.5	401	98	69	203	-	1,899
100.0	424	121	70	205	-	1,917
100.5	448	145	70	207	0	1,935
101.0	472	169	71	209	4	1,987
101.5	498	195	72	211	13	2,074
102.0	525	222	72	212	25	2,187
102.5	554	251	73	214	40	2,323
103.0	583	280	73	216	58	2,480
103.5	614	311	74	218	78	2,657
104.0	646	343	74	220	100	2,852
104.5	679	376	75	221	125	3,065
105.0	713	410	75	223	151	3,295
105.5	749	446	76	225	180	3,540
106.0	786	483	76	226	211	3,801
106.5	824	521	77	228	243	4,077
107.0	863	560	77	230	278	4,368
107.5	904	601	78	232	314	4,673

Lake Level (m AHD)	Reservoir Capacity ($x10^3$ ML)	Temporary Flood Storage ($x10^3$ ML)[1]	Discharge per Cone Valve (m^3/s)	Discharge per Sluice (m^3/s)	Discharge per Spillway Bay (m^3/s)	Maximum Available Discharge (m^3/s)[2]
108.0	946	643	78	233	352	4,992
108.5	989	686	79	235	391	5,324
109.0	1,034	731	79	236	433	5,712
109.5	1,080	777	80	238	476	6,212
110.0	1,128	825	80	240	520	6,781

[1] The temporary storage is assumed to be the storage above the ROL FSL of 97.0 m AHD. If a Temporary FSL or a Reduced FSL is in use, the temporary storage values should be adjusted accordingly.

[2] The Maximum Available Discharge is a combination of discharges from four cone valves, eight sluice gates, eight crest gates and flow over the Dam crest with the removable flood barrier in place.

The outlet works for Somerset Dam consist of:

- four (4) cone valves;
- eight (8) sluice gates; and
- eight (8) crest gates.

The cone valves are drowned out when the water level immediately downstream of Somerset Dam reaches 68.6 m AHD and the valves should, in most circumstances, not be used under these conditions. Discharge for each cone valve may be calculated using the following equation:

$$Q_{\text{cone valve}} = 12.714*(\text{Lake Level} - 70.20)^{0.5}$$

Discharge for each sluice gate may be calculated using the following equation:

$$Q_{\text{Sluice}} = 40.022*(\text{Lake Level} - 73.15)^{0.4963}$$

The crest gates are normally kept open and come into operation whenever the Lake Level exceeds 100.45 m AHD. Discharge for each crest gate may be calculated using the following equation:

$$Q_{\text{Crest}} = 12.137*(\text{Lake Level} - 100.45)^{1.6653}$$

At108.7 m AHD, floodwaters commence to flow over the Dam crest. To account for this discharge, the Dam crest is assumed to operate as a sharp crested weir with a spillway width of 135.33 metres and a weir coefficient of 1.9. Discharge in these circumstances may be calculated using the following equation:

$$Q_{\text{Overflow}} = 1.9*135.33*(\text{Lake Level} - 108.7)^{1.5}$$

Appendix F— Somerset Dam - Guidance on Gates and Equipment Operation

Plans and photographs of Somerset Dam are available in Appendix G.

F.1 Emergency Power Supply

In the event of a power failure at Somerset Dam, both a fixed and a mobile diesel generator are available to operate the cone valves, sluice gates and crest gates. The fixed generator can also power the crane. A mobile auxiliary generator is also available for emergency operation of the cone valves and gates.

F.2 Maintenance Considerations

Maintenance on the Dam release infrastructure (gates and cone valves) should be scheduled to minimise the risk of release infrastructure not being available for use in a Flood Event.

F.3 Spillway Crest Gates Operating Considerations

As described in the Section 15, the Somerset Dam crest gates must be fully opened and left fully open during Flood Events.

The top of the closed crest gates at Somerset Dam is at 107.45 m AHD. Overtopping of the crest gates may lead to fouling of the lifting tackle, which means the crest gate may become inoperable for the remainder of the Flood Event. Additionally, overtopping of the crest gates may lead to structural damage to the gates, which again may mean the crest gates may become inoperable for the remainder of the Flood Event. If a crest gate becomes inoperable in a closed or partially closed position, and the Lake Level continues to rise, the safety of the Dam may be threatened.

F.4 Failure of Sluice Gate Machinery

In the event of a sluice gate being jammed in the open position or the lifting machinery failing, the coaster gate at the Dam can be lowered over the inlet to the sluice to preserve the Water Supply Compartment.

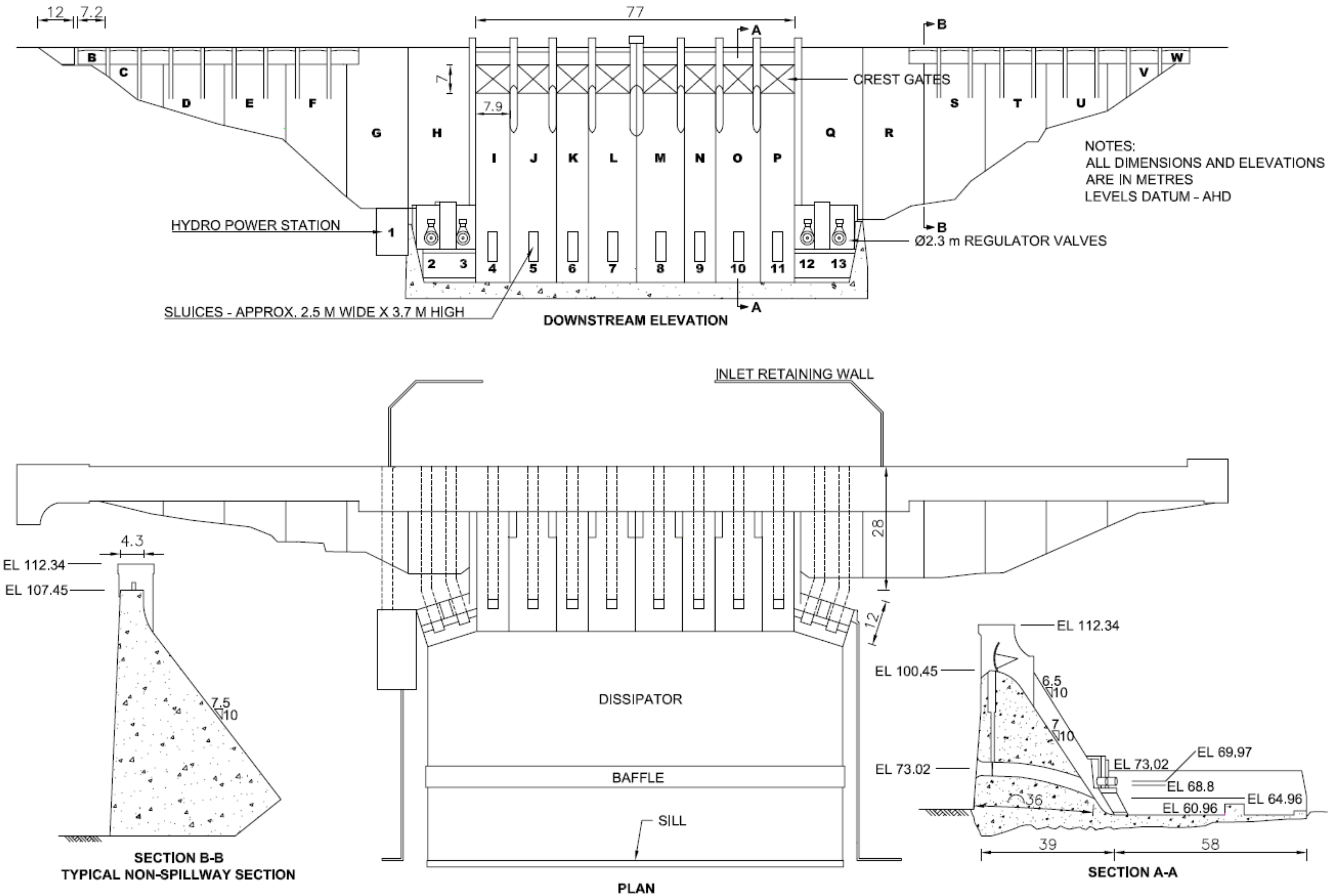
Appendix G— Somerset Dam – Plans, Maps and Photographs

Figure G.1 Somerset Dam Aerial Photograph

Figure G.2 Somerset Dam with Sluice Releases

Figure G.3 Somerset Dam Looking Upstream

Figure G.4 Somerset Dam central plan and elevation of Dam



Appendix H— Bridges and Dam Recreation Areas Impacted By Floods

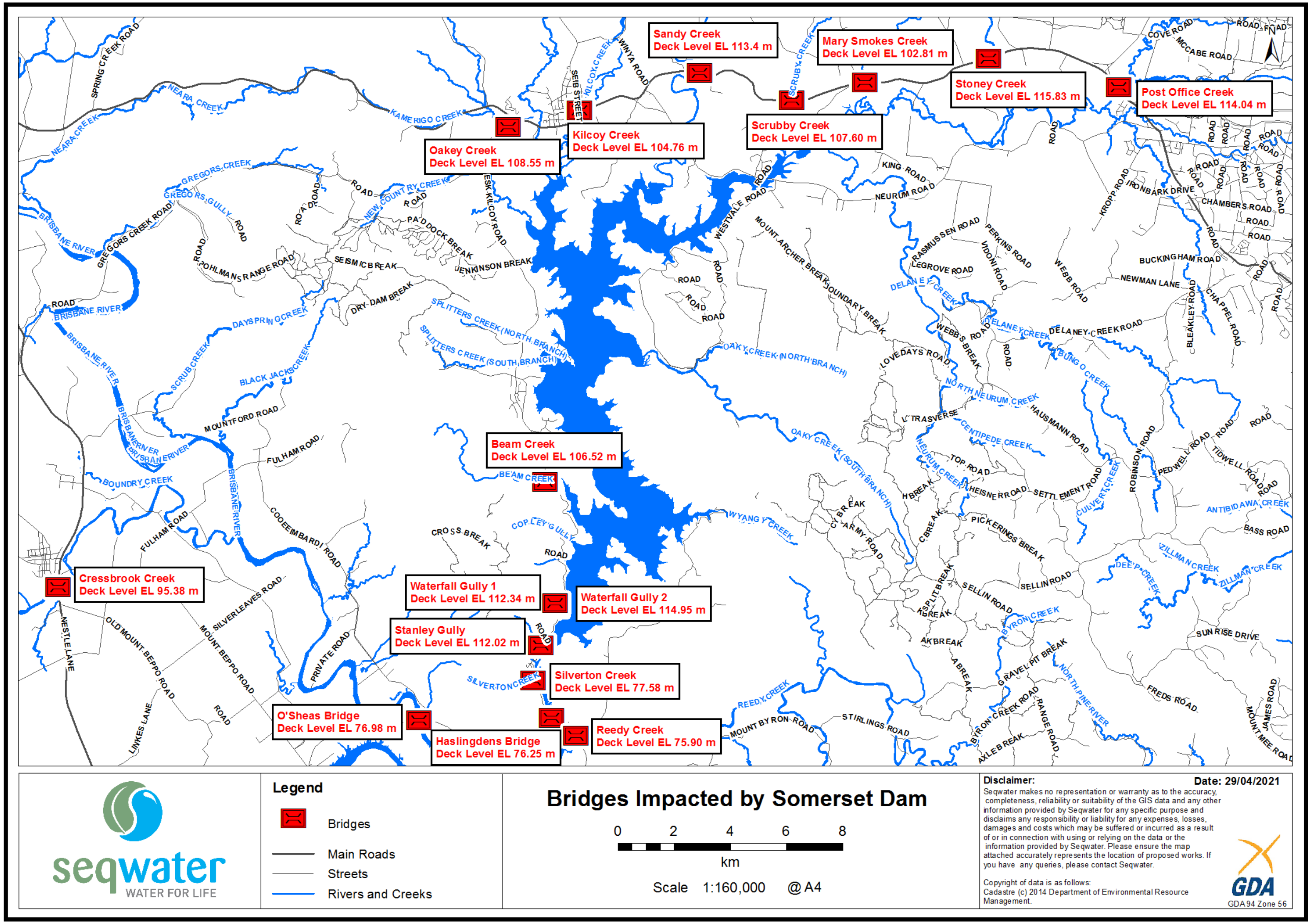
Table H.1 Bridges Impacted by Elevated Lake Levels in Somerset Dam

Watercourse	Road	Deck Elevation (m AHD)	Local Authority Area
Mary Smokes Creek	D'Aguilar Highway	102.81	Somerset Regional Council
Kilcoy Creek	D'Aguilar Highway	104.76	Somerset Regional Council
Beam Creek	Esk Kilcoy Road	106.52	Somerset Regional Council
Scrubby Creek	D'Aguilar Highway	107.60	Somerset Regional Council
Oakey Creek	Esk Kilcoy Road	108.55	Somerset Regional Council

Table H.2 Recreation Areas Affected by Elevated Lake Levels in Somerset Dam

Somerset Dam Lake Level (m AHD)	Description of Impacts
99.5	Close Somerset Dam Recreation Area.
100.5	Remove Recreation Area Infrastructure.
101.5	Recreation Area Office Flooded (Electrical disconnection required).
103.0	Inundation of Sewage Holding Tank

Figure H.1 Bridges and Recreation Areas Impacted by Elevated Lake Levels in Somerset Dam



APPENDIX H (BRIDGES IMPACTED BY FLOODS)

Table H.3 Bridges Impacted by Elevated Lake Levels in Wivenhoe Dam

Bridge/ Watercourse	Road	Deck Elevation (m AHD)	Local Authority Area
A&PM Conroy Bridge at Sandy Creek	Wivenhoe Somerset Road	69.61	Somerset Regional Council
Deep Creek	Wivenhoe Somerset Road	72.95	Somerset Regional Council
Kipper Creek	Wivenhoe Somerset Road	73.00	Somerset Regional Council
Meirs Gully	Esk Kilcoy Road	74.63	Somerset Regional Council
Tea Tree Creek	Brisbane Valley Highway	74.82	Somerset Regional Council
Logan Creek	Brisbane Valley Highway	74.88	Somerset Regional Council
Five Mile Creek	Brisbane Valley Highway	75.81	Somerset Regional Council
Reedy Creek	Wivenhoe Somerset Road	75.90	Somerset Regional Council
Haslingdens Bridge at Stanley River	Esk Kilcoy Road	76.25	Somerset Regional Council
Coal Creek	Brisbane Valley Highway	76.51	Somerset Regional Council
O'Sheas Bridge at Brisbane River	Esk Kilcoy Road	76.98	Somerset Regional Council
Tea Tree Gully	Brisbane Valley Highway	77.90	Somerset Regional Council
Middle Creek	Wivenhoe Somerset Road	78.70	Somerset Regional Council

Table H.4 Recreation Areas Affected by Elevated Lake Levels in Wivenhoe Dam

Wivenhoe Dam Lake Level (m AHD)	Description of Impacts
67.5	Commence closure of Wivenhoe Dam Camping Grounds.

Figure H.2 Bridges Impacted by Elevated Lake Levels in Wivenhoe Dam

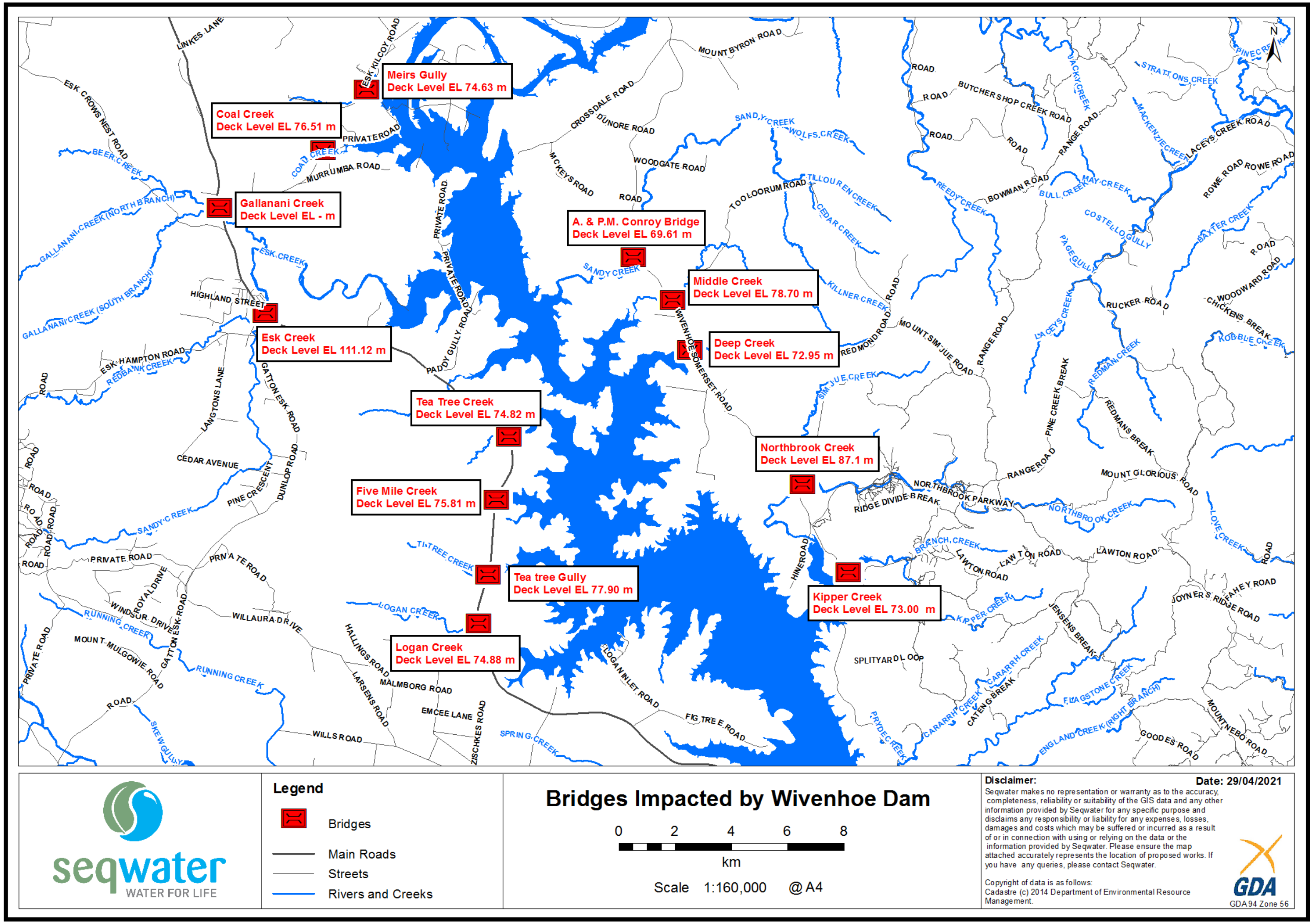
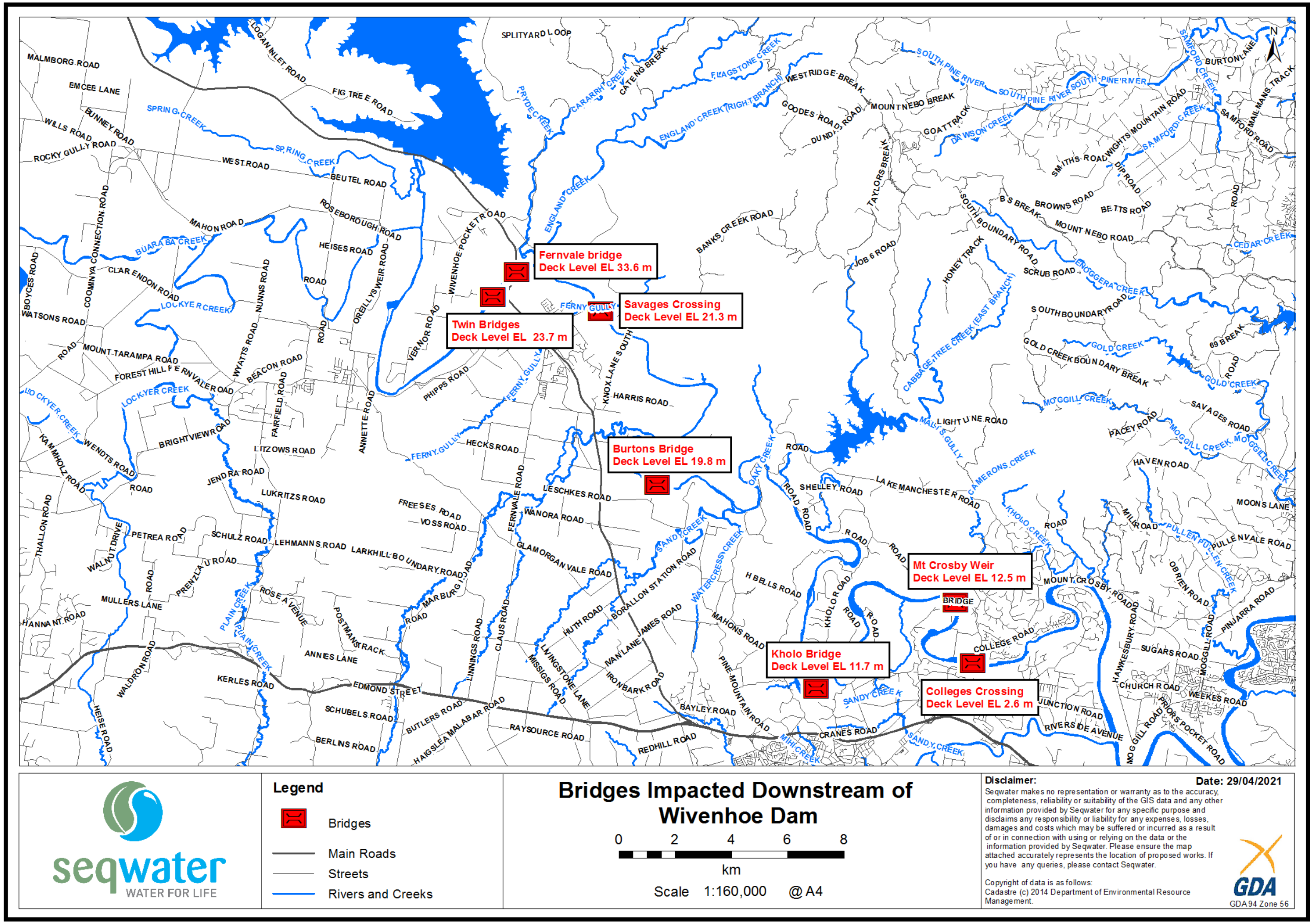


Table H.5 Bridges Impacted by Releases from Wivenhoe Dam

Bridge Name	Road	Capacity[1]	Elevation[4] (m AHD)		Local Authority Area[3]
		(m^3/s)	Soffit	Deck	
Twin Bridges	Wivenhoe Pocket Road	50	233.3	23.7	Somerset Regional Council
Fernvale Bridge	Brisbane Valley Highway	2,000	31.1	33.6	Somerset Regional Council
Savages Crossing	Banks Creek Road	130	20.5	21.3	Somerset Regional Council
Burtons Bridge	E Summerville Road	430	18.1	19.8	Somerset Regional Council
Kholo Bridge	Kholo Road	550	11.2	11.7	Brisbane/Ipswich City Councils
Mount Crosby Weir	Allawah Road	1,500	11.2	12.5	Brisbane/Ipswich City Councils
Colleges Crossing	Mount Crosby Road	175[2]	2.2	2.6	Brisbane/Ipswich City Councils

1 It is noted that the flow carrying capacity of the bridges downstream of Wivenhoe Dam are estimates as the actual capacity will vary from year to year depending on the time since the last Flood Event, the amount of erosion/deposition at the location and the amount of vegetation in the channel.
2 Affected by tidal flows.
3 Contact details for the officers at the agencies responsible for closure of the bridges are contained in the Communications Protocol.
4 Data sourced from BMT WBM (2017).

Figure H.3 Bridges Impacted by Releases from Wivenhoe Dam



Appendix I— Historical Floods

I.1 Estimated Peak Inflows and Outflows to Somerset and Wivenhoe Dams in Historical Events

The tables below show recorded peak Lake Levels and estimated peak inflow and outflow flow rates and volumes for selected historical events, drawn from Table 5-3 and 5-4 of the Brisbane River Flood Hydrology Models report (Seqwater Dec 2013). All flows are estimates only and were developed based on assumptions described in that report.

Table I.1 Somerset Dam Flood Data

Event (yyyymmdd)	Start Lake Level (m AHD)	Peak Lake Level (m AHD)	Peak		Flood Volume	
			Inflow (m^3/s)	Outflow (m^3/s)	Inflow (ML)	Outflow (ML)
19550325	96.28	103.47	3,600	900	546,000	465,000
19560307	96.74	98.95	1,400	700	294,000	295,000
19590215	93.85	96.92	580	10	99,200	6,800
19591108	93.39	97.96	1,200	900	242,000	132,000
19740124	98.90	106.57	3,400	1,800	714,000	439,000
19760119	98.24	100.46	1,200	1,100	180,000	141,000
19830620	99.75	101.58	1,400	200	166,000	112,000
19890331	99.25	102.59	3,600	2,000	364,000	377,000
19890423	99.06	102.69	3,600	2,000	338,000	350,000
19960430	94.00	99.45	1,100	0	189,000	0
19990207	93.67	102.96	3,400	800	452,000	243,000
20040304	92.52	94.94	650	0	65,400	0
20081116	98.45	98.56	250	270	27,100	31,600
20090518	98.41	99.66	840	880	114,000	107,000
20100226	98.74	99.45	720	880	206,000	187,000
20101006	99.00	101.37	2,100	1,100	284,000	284,000
20101201	99.04	99.68	240	140	92,200	83,300
20101216	99.12	100.43	720	410	134,000	136,000
20101223	99.05	100.00	550	820	148,000	141,000
20110102	99.06	105.11	3,900	1,700	822,000	820,000
20120121	99.16	100.28	740	410	166,000	160,000
20120220	99.10	100.61	560	410	122,000	114,000
20120316	99.22	100.15	200	200	82,800	89,000
20130123	98.68	101.62	2,200	1,000	261,000	243,000
20150501	99.00	99.24	700	800	77,000	77,000

Table I.2 Wivenhoe Dam Flood Data

Event (yyyymmdd)	Start Lake Level (m AHD)	Peak Lake Level (m AHD)	Peak		Flood Volume	
			Inflow (m^3/s)	Outflow (m^3/s)	Inflow (ML)	Outflow (ML)
19890331	67.06	69.78	3,200	1,600	670,000	660,000
19890423	66.99	71.45	5,200	1,500	880,000	830,000
19960430	61.60	65.74	2,100	0	360,000	0
19990207	63.92	70.45	7,300	1,800	1,190,000	810,000
20010130	66.85	67.39	640	290	110,000	80,000
20040304	61.05	62.01	630	0	73,000	0
20081116	54.74	56.30	520	0	71,000	0
20090518	58.68	62.18	1,600	0	230,000	0
20100226	61.93	66.51	1,300	0	400,000	0
20101006	67.03	69.91	2,400	1,500	620,000	600,000
20101201	66.97	67.33	320	300	190,000	120,000
20101216	67.10	68.24	1,600	1,500	370,000	350,000
20101223	67.26	69.33	1,600	1,600	530,000	510,000
20110102	67.11	75.06	10,300	7,500	2,750,000	2,710,000
20120121	64.02	64.76	860	410	270,000	240,000
20120220	64.14	64.75	510	450	160,000	160,000
20120316	64.06	64.64	340	120	130,000	100,000
20130123[1]	66.08	70.32	5,400	1,800	830,000	860,000
20150501	66.77	67.58	1,500	1,000	170,000	150,000

[1] Temporary FSL of 65.6m declared for Wivenhoe Dam during event.

I.2 Estimated Historical Flows Downstream of Wivenhoe Dam (from WSDOS)

The following table shows estimated flood peak flows for a range of Flood Events up to 2013 under the basin configuration applicable at the time of the event, drawn from Table 8-4 in the Brisbane River Flood Hydrology Models report (Seqwater, 2013). All flows are estimates only and were developed based on assumptions described in that report.

Table I.3 Estimated flood peak flows for a range of Flood Events up to 2013

Event (yyyymmdd)	Basin Configuration	Brisbane R at Wivenhoe (m^3/s)	Brisbane R at Mount Crosby (m^3/s)	Bremer R at Ipswich (m^3/s)	Brisbane R at Moggill (m^3/s)
18870119	No Dams	5,100	6,460	3,950	8,720
18900306		6,910	8,900	1,730	9,630
18930129		15,370	15,980	1,100	16,330
18930215		14,410	14,260	2,010	15,500
18930606		8,320	8,590	1,180	8,870
18980107		9,300	9,410	460	9,100
18980303		6,210	6,200	460	6,450
19080312		5,370	6,500	1,110	6,970
19310129		6,920	7,790	820	7,980
19470122		220	960	1,220	2,280
19550325	With Somerset Dam	6,790	5,800	1,200	5,900
19560307		1,860	1,850	270	1,840
19590215		800	2,610	1,260	3,060
19591108		2,310	3,470	1,020	3,810
19650718		1,250	2,060	660	2,610
19670607		1,060	1,820	840	2,570
19680107		2,810	3,720	700	3,900
19710216		4,210	4,010	810	4,050
19711226		660	750	90	750
19720201		1,290	1,360	100	1,450
19730705		3,790	3,470	90	3,340
19740124		7,860	10,460	3,770	11,750
19760119		1,380	2,050	450	2,230
19760209		330	1,160	1,580	1,790
19830620	With Somerset & Wivenhoe Dams	1,100	2,430	970	3,040
19880401		0	1,200	1,350	1,880
19890331		1,620	1,640	440	1,980
19890423		1,490	1,780	490	1,980
19910205		0	250	680	710
19911210		0	700	1,440	1,950
19920314		0	760	120	1,000
19960430		0	2,810	1,470	3,580
19990207		1,800	2,530	720	2,770
20010130		290	470	400	620
20040304		0	530	210	620

Event (yyyymmdd)	Basin Configuration	Brisbane R at Wivenhoe (m³/s)	Brisbane R at Mount Crosby (m³/s)	Bremer R at Ipswich (m³/s)	Brisbane R at Moggill (m³/s)
20081116	With Somerset & Wivenhoe Dams	0	600	1,100	1,730
20090518		0	540	960	1,460
20100226		0	200	240	420
20101006		1,500	1,550	370	1,580
20101201		300	400	330	540
20101216		1,460	1,660	300	1,730
20101223		1,590	1,580	1,010	1,710
20110102		7,470	9,130	2,770	10,300
20120121		410	500	240	680
20120220		450	440	370	460
20120316		120	130	10	130
20130123		1,820	2,380	1,920	3,640
20130215		1,840	1,970	820	2,140

I.3 Estimated Basin Average Rainfall and Flood Volumes for Historical Events

The following table shows estimated Brisbane River Basin average rainfall and flood volumes for selected historical events up to 2013 drawn from Table 2-1 in the Wivenhoe and Somerset Dam Optimisation Study – Simulation of alternative flood operations options report (Seqwater 2014). All volumes are estimates only and were developed based on assumptions described in that report.

Table I.4 Estimated Brisbane River Basin average rainfall and flood volumes for selected historical events up to 2013

Flood Event (year.mth)	Basin Average Rainfall (mm)	Stanley River (ML)	Upper Brisbane River (ML)	Lockyer Creek (ML)	Bremer River (ML)	Lower Brisbane to Moggill (ML)	Total Volume (Moggill) (ML)
1887.01	250	284,000	617,000	268,000	588,000	176,000	1,933,000
1890.03	270	639,000	1,585,000	721,000	344,000	250,000	3,539,000
1893.01	377	1,436,000	2,186,000	547,000	250,000	220,000	4,639,000
1893.02	315	629,000	1,621,000	700,000	527,000	287,000	3,764,000
1893.06	211	315,000	834,000	285,000	234,000	120,000	1,788,000
1898.01	280	865,000	1,296,000	298,000	172,000	168,000	2,799,000
1898.03	145	672,000	958,000	157,000	120,000	116,000	2,023,000
1908.03	250	219,000	818,000	325,000	229,000	165,000	1,756,000
1931.01	302	483,000	924,000	295,000	154,000	157,000	2,013,000
1955.03	209	516,000	634,000	177,000	162,000	59,000	1,548,000
1959.11	191	245,000	471,000	200,000	158,000	71,000	1,145,000
1971.02	164	288,000	528,000	98,000	110,000	44,000	1,068,000
1973.07	195	271,000	440,000	41,000	12,000	62,000	826,000
1974.01	426	630,000	1,394,000	567,000	676,000	328,000	3,595,000
1983.06	146	269,000	656,000	164,000	155,000	53,000	1,297,000
1989.04	156	349,000	447,000	77,000	63,000	45,000	981,000
1996.04	358	192,000	315,000	566,000	380,000	258,000	1,711,000
1999.02	235	449,000	884,000	85,000	99,000	89,000	1,606,000
2011.01	425	800,000	1,910,000	570,000	477,000	230,000	3,987,000
2013.01	369	232,000	627,000	326,000	320,000	96,000	1,601,000

Note: The volumes presented in this table are for a total duration of 430 hours and have been estimated using the assumptions presented in the Wivenhoe and Somerset Dams Optimisation Study – Simulation of alternative flood operations options report (Seqwater 2014), and hence may differ slightly from event volumes reported in other sources.

Historical Flood Recessions at Savages Crossing

The graph below provides the flow rates during flood recessions in a range of historical events. This graph may be used to provide guidance in the selection of recession rates during Dam operations.

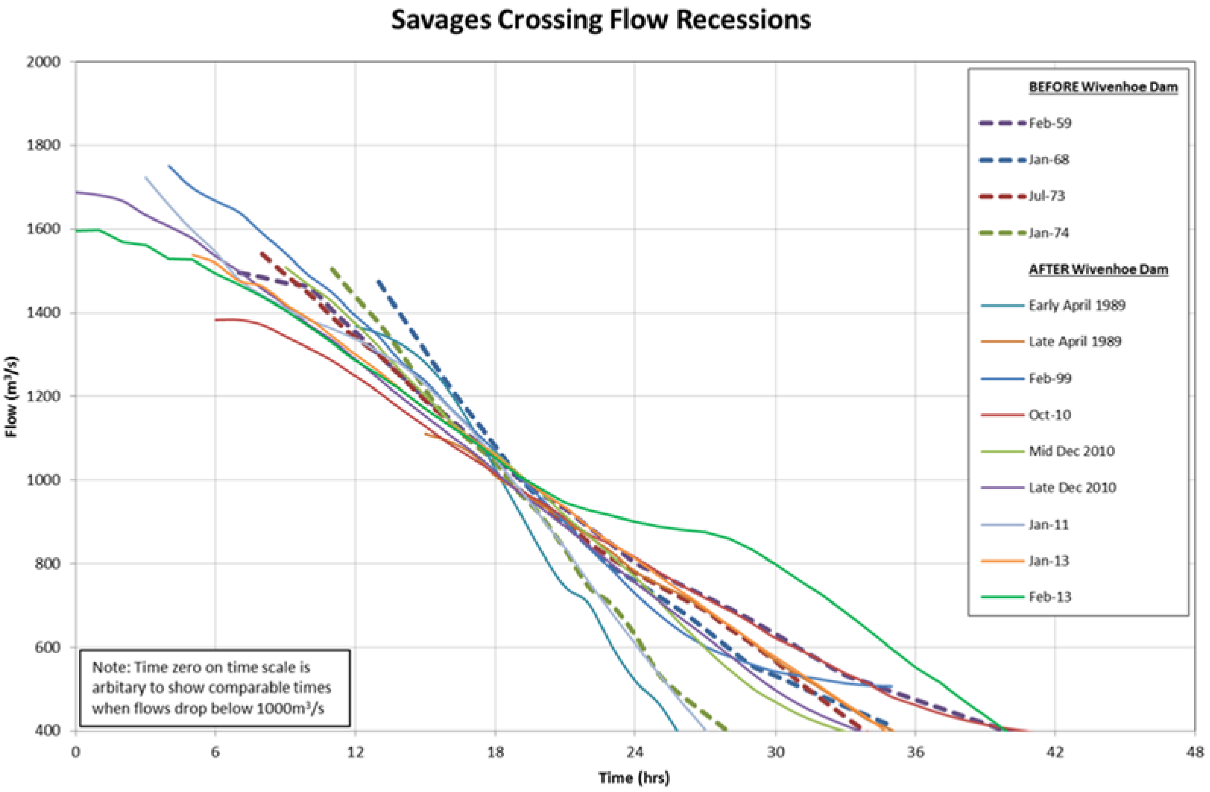


Figure I.1 Savages Crossing Flow Recessions

In interpreting this graph, it should be noted that:

- Events post 1984 are affected by the historical operation of Wivenhoe Dam and Somerset Dam, the 1959-74 events are affected by the historical operation of Somerset Dam.
- Savages Crossing is downstream of the Lockyer Creek inflow.
- Some of the plotted events did not peak much higher than the portion of the hydrograph shown, while others were much larger events.
- Every event has a different spatial and temporal pattern of rainfall, and the causes of bank slumping are complex.

It is understood that significant bank slumping occurred in the early April 1989 event (as reported in the *Interim Report on Operations of Wivenhoe Dam During Floods (April-May 1989)* (Water Resources Commission, 1989)), and hence the recession rate for that event is considered too steep.

This graph is useful for evaluating the desired recession during the portion of drain down when releases are being reduced from targeting Mount Crosby Weir Bridge (1,500 m^3/s) to Burtons Bridge (430 m^3/s). Based on this graph, it is suggested that this reduction in downstream flows should be undertaken over 18 hours or longer.

Appendix J— Catchment flow hydrographs and Rain on Ground flow forecasts

J.1 Overview

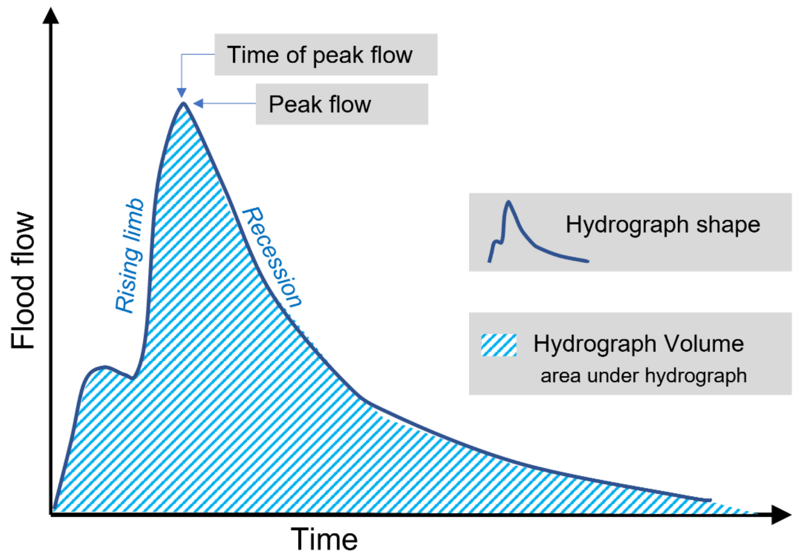
This Appendix contains content on:

- Definition of reliable catchment flow hydrographs in Section J.2
- Requirements for reliable catchment flow hydrographs to determine Release Plans for this Manual in Section J.3
- Forecasting catchment flow hydrographs with actual rainfall (Rain on Ground) in Section J.4

J.2 Definition of reliable catchment flow hydrographs

Figure J.1 below illustrates important characteristics of a catchment flow hydrograph.

Figure J.1 Important characteristics of catchment flow hydrograph



The Procedures in this Manual[34] require multiple characteristics of the forecasted catchment flow hydrographs to be reliable for multiple catchments to meet the Objectives. These include:

a. The hydrograph shape, including the rising limb before the peak and recession after the peak;
b. The time and magnitude of the peak flow rate; and
c. The hydrograph volume (area under the hydrograph which is the accumulation of flow over time).

The requirements for reliable catchment flow hydrographs and their influence on decision making to apply the Procedures in this Manual are described further in Appendix J.3.

Experience[35] has shown that all these important characteristics of a catchment flow hydrograph (volume, timing and magnitude of the peak inflow and overall shape of the hydrograph) are sensitive to the definition of rainfall over the catchment.

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34 Apart from the Procedures in Section 16.4, which apply when communication is lost with the Flood Operations Centre.

35 Experience in hydrological simulations for model calibration, in past real-time flood operations, and in simulated flood exercises.

Multiple aspects of the definition of rainfall over the catchment that are important include:

a. The rainfall amounts over the entire catchment (this is often reported as the catchment average rainfall). An example of catchment average rainfall defined in 15-minute intervals for the Upper Brisbane River catchment is shown in Figure J.2 – this alone does not define variation within the catchment;

b. The temporal pattern for timing and intensity of rainfall in different parts of the catchment. An example of temporal pattern variation in different parts of the Upper Brisbane River catchment is shown in Figure J.3;

c. The spatial pattern (for example, which parts of the catchment have the heaviest rainfall and which parts of the catchment have lower rainfall or possibly no rainfall). An example of spatial variation of accumulated rainfall totals over the Upper Brisbane River catchment is shown in Figure J.4;

Reliable rainfall definition for the aspects described above is necessary to produce reliable flow hydrographs for catchments upstream and downstream of the Dams that can affect the decision making.

Figure J.2 Example catchment average rainfall (in 15-minute intervals) over Upper Brisbane River catchment (February 2015)

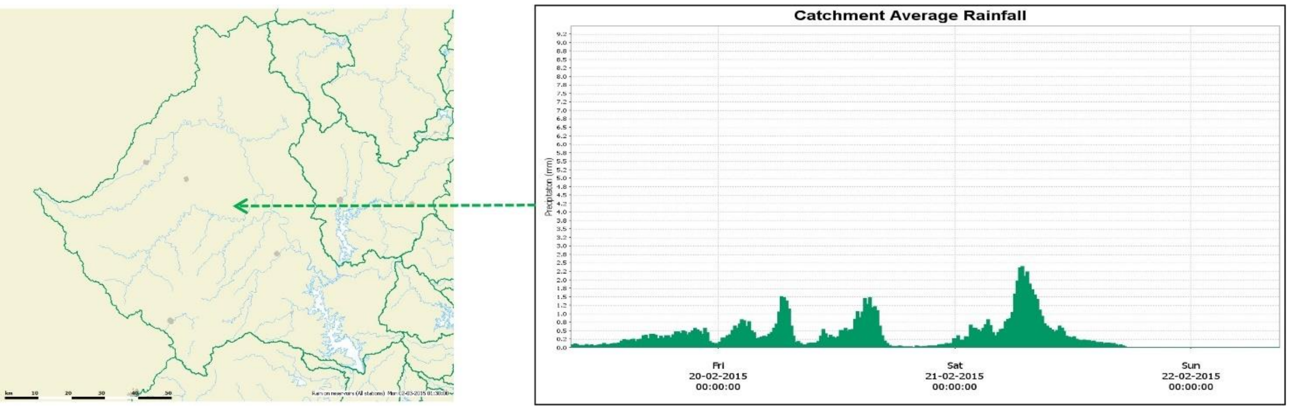


Figure J.3 Example temporal pattern (in 15-minute intervals) for different parts of Upper Brisbane River catchment (February 2015)

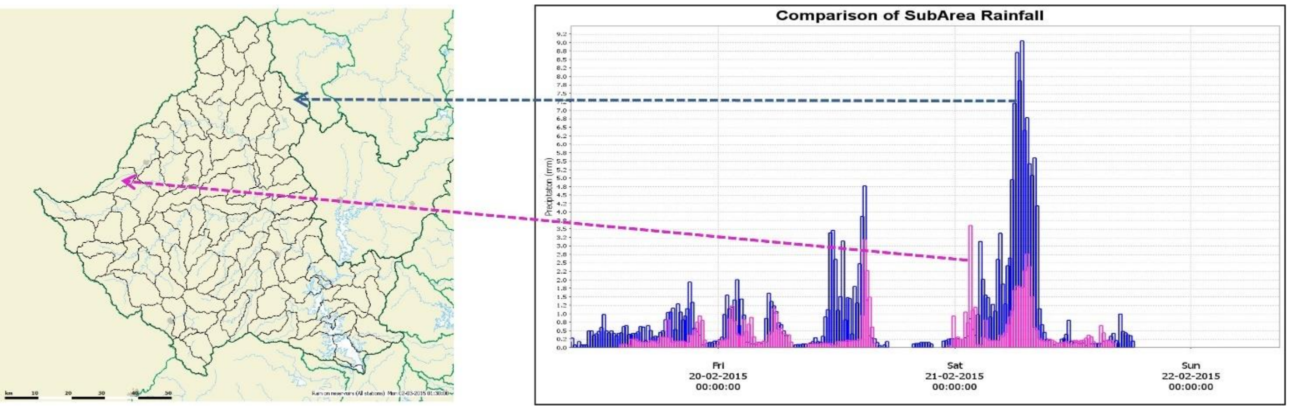
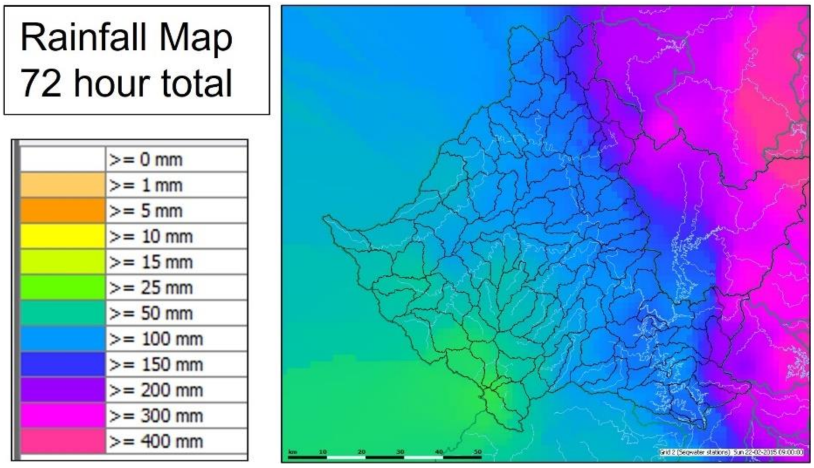


Figure J.4 Example spatial variation of 72 hour rainfall total over Upper Brisbane River catchment



Forecast catchment flow hydrographs are also sensitive to uncertainty in the hydrological model for estimated rainfall losses to calculate runoff (that is, loss is how much rain soaks into the ground and does not contribute to runoff), and flow routing parameters which define the travel time of runoff flows through the catchment which affects the hydrograph shape, peak flow and time of peak flow. Further description of modelling uncertainty is presented in Section 5.4.

In real-time operations the hydrological model parameters are calibrated based on rainfall that has occurred (Rain on Ground) when runoff is observed at key water level gauges. Calibration is continually refined and improved as more data becomes available as the Flood Event progresses (refer Section 7.4).

J.3 Requirements for reliable flow hydrographs to develop a Release Plan

Sufficiently reliable definitions of the catchment flow hydrographs are required in order to develop Release Plans within the Procedures that meet the Objectives. The characteristics of the catchment flow hydrographs that are particularly important for applying the Procedures in this Manual include:

a. The total inflow volumes (separately for Wivenhoe Dam and Somerset Dam) must be reliable for releasing water when the actual Lake Level is below OFSL for each Dam. The Release Plan must always demonstrate that the Water Supply Compartments for both Dams will be full at the end of the Flood Event (within tolerances specified in the Procedures).
b. The shape of the inflow hydrograph for Somerset Dam affects the predicted Lake Level for Somerset Dam. The effect of the inflow hydrograph shape on predicted Lake Level also affects the predicted releases for Somerset Dam. This is because a substantial portion of the release flow from Somerset Dam is uncontrolled flow over the spillway (when the Lake Level exceeds the spillway crest level of 100.45 m AHD). Reliable estimates of the releases from Somerset Dam are important to define the total inflow into Wivenhoe Dam.
c. The shape of the total inflow hydrograph for Wivenhoe Dam is influenced by the inflow hydrograph from Upper Brisbane River catchment and releases from Somerset Dam described in (b) above. The shape of the inflow hydrograph for Wivenhoe Dam affects the predicted Lake Level for Wivenhoe Dam, including the time when any fuse plug is expected to be initiated (if applicable). If the total inflow hydrograph shape for Wivenhoe Dam is unreliable this can materially impact the predicted Lake Level for Wivenhoe Dam.
d. The definition of the downstream catchment flow hydrograph at Moggill[36] is important to develop a Release Plan for Wivenhoe Dam for parts of the Procedures that involve aiming to achieve a target flow at Moggill. There are multiple influences on how the characteristics of the downstream catchment flow hydrograph at Moggill affects the development of a Release Plan for Wivenhoe Dam when targeting a flow at Moggill. Determining a Release Plan from Wivenhoe Dam to achieve a specific target flow at Moggill requires reliable definition of:
    i. The peak Downstream Catchment Flow. This affects the magnitude of releases in the periods when the releases should be minimised (that is, to minimise adding extra flow to the peak Downstream Catchment Flow);

[36] Hydrograph for flow at Moggill excluding Wivenhoe Dam releases. This represents the contribution of the downstream catchments to flow at Moggill. These flows need to be subtracted from the target flow at Moggill to determine releases from Wivenhoe Dam to achieve target flow at Moggill taking account of travel time between the Dam and Moggill.

ii. The time of the peak Downstream Catchment Flow. This affects the timing of the period of minimum releases; and

iii. The shape of the Downstream Catchment Flow hydrograph. This affects the overall scheduling of varying release rates at different time points in the Release Plan to maintain the selected target flow at Moggill.

e. If the downstream catchment flow hydrograph at Moggill is not reliable as described in (d) above this can compromise the Objective to mitigate downstream flooding. The timing of downstream catchment peak flow is particularly important.

f. The compounded influence of all matters in (a) to (e) above can simultaneously affect the selection of target flow at Moggill[37], achievement of target flow at Moggill[38], and the Wivenhoe Dam Predicted Peak Lake Level[39].

J.4 Forecasting flow hydrographs with Rain on Ground

Forecasting with Rain on Ground provides reliable definition of rainfall for all relevant catchments as rainfall occurs. This provides a robust basis to derive reliable catchment flow hydrographs if the model is reasonably well calibrated. Forecasting with Rain on Ground does not provide complete definition of the entire Flood Event catchment flow hydrographs until most of the heaviest rainfall for the event has occurred. This is a limitation of real-time flood forecasting.

Rainfall Forecasts have the potential to extend the lead time of catchment flow forecasts, however the uncertainty in the Rainfall Forecasts will produce uncertainty in the flow hydrographs (described in Appendix K). Vulnerability to risks of not achieving the Objectives with use of uncertain Rainfall Forecasts is described in Appendix K.

Although forecasting of catchment flow hydrographs with Rain on Ground has limitations it does provide reliable emerging knowledge of the catchment flood flows as the Flood Event progresses. The benefits of deriving catchment flow hydrographs with Rain on Ground for development of Release Plans with the Procedures include:

a. The observed rainfall inputs used for forecasting catchment flows with Rain on Ground provides the necessary reliable definition of the accumulated depth, intensity, temporal pattern, and spatial pattern of rainfall, for all catchments where flow hydrographs are necessary to inform decision making;

b. The derived catchment flow hydrographs can be checked with real-time water level gauge data to ensure they are producing a reasonable representation of observed data;

c. There is low latency[40] between rainfall occurring and receiving data to simulate catchment flows in the FFS. This ensures real-time capability to update derived catchment flow hydrographs when rainfall is occurring;

d. The Release Plans developed in accordance with the Procedures can be updated frequently which is important when rainfall and flood conditions are changing significantly. This enables decision making to adapt to the emerging actual trend of the Flood Event;

e. For the size and response time of catchments in the Brisbane River Basin, the Rain on Ground forecasting provides the capability to predict future flows and Lake Levels (albeit with lead time limitations) to apply predictive decision making for the Dam operations. For example, the peak Lake Level for Wivenhoe Dam can often be predicted 12 hours or more before it occurs, and peak flow at Moggill can often be predicted around 12 to 18 hours before the peak occurs. This enables the appropriate balance between Lake Level rise in the Flood Storage Compartment and releasing water with consideration of the impact of releases on flows at Moggill to be determined in real-time before the peak Lake Level occurs;

f. The prediction of catchment flows with Rain on Ground enables release of water below OFSL subject to criteria in the Procedures to achieve the Objective to ensure the Water Supply Compartments of the Dams are full at the end of the Flood Event;

g. The Rain on Ground catchment flow forecasts provide a robust basis to respond to the relative magnitude of upstream and downstream flood flows as it is based on observed rainfall. This is important because an appropriate balance between downstream flooding and Predicted Peak Lake Level for Wivenhoe Dam is sensitive to the shape and volume of the flow hydrographs for the catchments upstream and downstream of the Dams.

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[37] The selection of the target flow at Moggill involves a balance against Predicted Peak Lake Level for Wivenhoe Dam.

[38] Even if an appropriate target flow at Moggill is selected, it may not be achieved if the Release Plan misjudges the timing of the downstream catchment peak flow.

[39] Predicted Peak Lake Level is affected by the Release Plan and definition of the inflows.

[40] Latency refers to the time period between rainfall occurring and data from gauges recording rainfall being transferred into the FFS. The frequency of updated rainfall in the FFS is every 15 minutes.

APPENDIX J
(FORECASTING FLOW HYDROGRAPHS WITH ACTUAL RAINFALL)

The main limitation of forecasting catchment flows with Rain on Ground is that the lead time is limited to around 24 hours[41]. This means for example that a possible action to increase releases many days before a possible prediction of a high peak Lake Level in the Dams is not foreseeable because the Rain on Ground forecast lead time is limited. Conversely using uncertain Rainfall Forecasts to extend the lead time of the flow hydrograph predictions does not necessarily mean that a longer lead time flow hydrograph prediction will be sufficiently reliable. Further information on uncertainty in Rainfall Forecasts is presented in Appendix K.

[41] Lead time varies for different catchments – larger lead time for larger catchments, and smaller lead time for smaller catchments.

Appendix K— Additional information on rainfall forecasts

K.1 Overview of the contents of this Appendix

This Appendix presents a range of comprehensive information on Rainfall Forecasts. There are multiple aspects of uncertainty in Rainfall Forecasts that mean that the quantitative derivation of catchment flows with Rainfall Forecasts are not reliable for decision making and pose risks to meeting the Objectives in this Manual. Therefore, Rainfall Forecasts are not used in this Manual for meeting the Objectives for flood mitigation, except for qualitative situational awareness. It is structured with the following sections in the first part of this appendix for the overview content:

- K.2 Overview of the Australian Digital Forecast Database (ADFD) product
- K.3 General matters of uncertainty in rainfall forecasts
- K.4 Impact of rainfall forecast uncertainty on catchment flow hydrographs
- K.5 Summary of potential benefits risks and vulnerabilities in quantitatively using rainfall forecasts

The second part of this appendix has the following more detailed technical content:

- K.6 Limitations of benefits to prevent structural failure of the dams
- K.7 Risks to ensuring the Water Supply Compartments are full at the end of a Flood Event
- K.8 Potential benefits to mitigate downstream flooding
- K.9 Risks for mitigation of downstream peak flood flow
- K.10 Risks to downstream peak flood level for some parts of the floodplain
- K.11 Consequences for potential benefits and risks for downstream flooding
- K.12 Potential benefits and risks for environmental impacts
- K.13 Further technical information on the Australian Digital Forecast Database (ADFD) product
- K.14 International research on errors in location of heavy rainfall in rainfall forecasts

K.2 Overview of the Australian Digital Forecast Database (ADFD)

For this Manual, the current routine BPF is the Australian Digital Forecast Database[42] (ADFD) grids which are used for consideration of situational awareness or, for an outlook of the potential trend of a Flood Event. The ADFD is considered to be not sufficiently reliable to use for deriving flow and lake level predictions with the FFS to determine Release Plans.

During and prior to a Flood Event, Seqwater requests advice from the Bureau as to what it considers to be the most appropriate ADFD rainfall forecast grid for the relevant catchments for the current time and the short term forecast period.

The routine frequency of receiving the ADFD rainfall forecasts is at a minimum of two times each day. The Bureau sometimes issue non-routine updates within the routine update cycle if an update to the forecast is warranted.

The spatial resolution for the ADFD for South East Queensland is a 6 km by 6 km grid. The temporal resolution for the ADFD rainfall grids is defined in 3-hour time increments for some rainfall grids and, daily time increments for other rainfall grids. The ADFD forecast is based on Bureau NWP forecast data, independent international agency NWP forecast data and, further processing steps including adjustments made by professional meteorologists. Further information about the ADFD is available on the Bureau website[43]. Further description of the ADFD rainfall forecast grids together with a range of detailed technical limitations and characteristics of this product is presented in Appendix K.13.

Primary limitation of the ADFD

A key primary limitation of the ADFD rainfall forecast to forecast catchment flow hydrographs for this Manual is that the product is limited to providing point rainfall forecasts. The limitation for point rainfall forecasts from the ADFD is that the forecast for one location (a point of interest for rainfall) does not define what rainfall will occur at the same time for another location. For example, if the high end of the rainfall forecast for Brisbane CBD occurs, it does not mean that high end of the rainfall forecast for Ipswich CBD will occur, and Ipswich may only get the middle range or low end of the rainfall forecast.

[42] The ADFD is the product that generates the 'MetEye' forecast maps on the Bureau website available to the public.

[43] http://www.bom.gov.au/weather-services/about/forecasts/australian-digital-forecast-database.shtml

The ADFD rainfall forecast is not designed to provide areal rainfall forecasts that are necessary for application to a catchment for hydrological modelling. Areal rainfall needs to define rainfall that will occur simultaneously at all points over the entire area of the catchment and how that will vary with time (the technical term for this is spatial and temporal coherence).

The ADFD rainfall forecast does not provide probability of areal rainfall which means that the uncertainty is not defined. The ADFD rainfall forecast also has limitations of not defining uncertainty of the potential errors in the location of where the heaviest rainfall could occur (this is described further in Appendix K.13).

The limitations and undefined uncertainties of the ADFD rainfall forecast product make it unsuitable to achieve the necessary reliable characteristics of flow hydrographs that are required for quantitative decision making to develop Release Plans (described in Appendix J).

If the Bureau advise the use of other rainfall forecast products for the current time and short term forecast period for the relevant catchments consideration of such forecasts for qualitative situational awareness will depend on the scope of information content provided with such forecasts and the digital format of the forecast data.

K.3 General matters of uncertainty in Rainfall Forecasts

There can be considerable uncertainties in Rainfall Forecasts. The uncertainties in Rainfall Forecasts vary across a range of perspectives including but not limited to:

a. Forecast lead time – there is more uncertainty in Rainfall Forecasts at longer lead times. For example, rainfall for the third day of a forecast is more uncertain than rainfall for the first day of the forecast.
b. Timing and temporal probability for a specific time interval of interest. For example the probability of rainfall within a specific 3-hour period is different to the probability of rainfall over a 24-hour period.
c. Spatial scale and location – the uncertainty for a specific areal extent and spatial-temporal pattern of rainfall forecast over each specific catchment in the Brisbane River Basin is different to the uncertainty of rainfall over a broader region (e.g. South East Queensland). Location errors for heavy rainfall are a common occurrence in Rainfall Forecasts. Further information in Appendix K.14 summarises research on location errors.
Location errors are a significant problem for risks to achieving the Objective to mitigate downstream flooding (further described in Appendix K.9 to K.11),
d. Specific weather events and rate of rainfall. Examples include:
    i. Unique meteorological conditions of each rainfall producing weather event can affect the rainfall predictability.
    ii. The uncertainty in low intensity Rainfall Forecasts is different to the uncertainty in high intensity Rainfall Forecasts.
    iii. High intensity rainfall events that cause significant flood conditions in Queensland often have convective[44] rainfall. There is greater uncertainty of forecasts for weather events with convective rainfall due to the complex physical processes that cause heavy rainfall, and limitations of numerical weather prediction models to simulate convective rainfall.

Literature[45] on guidance and research for the use of Rainfall Forecasts for streamflow forecasting widely reports issues with systematic bias in NWP models ('raw' forecasts). Systematic bias means a consistent difference between forecast and actual outcomes. Each individual NWP model have unique systematic biases and biases can also vary depending on the meteorological conditions in different weather events, and geographical location. Systematic biases also change when new versions of NWP models become operational.

Use of raw forecasts directly from NWPs are not recommended for hydrological application. Rainfall Forecasts sourced from ensemble forecasts or multi-model ensemble forecasts are recommended, preferably with bias correction. The ADFD rainfall forecast is a post processed form of ensemble forecasts from multiple NWP models with some bias adjustment that is relevant for point rainfall forecasts, but not areal rainfall forecasts. The limitations of ADFD rainfall forecasts to define areal rainfall are described in Appendix K.2 and K.13.

[44] There are various definitions of convective rainfall. For a specific contemporary scientific definition of convective rainfall reference is made to the American Meteorological Society definition: https://glossary.ametsoc.org/wiki/Convective_precipitation

[45] Handbook of Hydrometeorological Ensemble Forecasting (2019): https://www.springer.com/gp/book/9783642399244

K.4 Impact of rainfall forecast uncertainty on catchment flow hydrographs

Uncertainty in the amount and location for forecasts of high rainfall (particularly displacement error where the forecast location for heavy rainfall is different to where heavy rainfall actually occurs) has significant adverse impact on the reliability of the flow hydrographs derived from Rainfall Forecasts. The requirements for the flow hydrographs that are important for this Manual are described in Appendix J. Uncertainty on the location of heavy rainfall is also critical for the relative magnitude of upstream and downstream catchment flow hydrographs even if the forecast catchment average rainfall for the entire Brisbane River Basin is correct.

Uncertainty spread is a term used to define the range of deviation in data. Seqwater has observed common occurrence of high spread in the amount of Rainfall Forecast. For example, the ADFD 10% chance exceedance rainfall grid is often in the order of 200% to 500% of the forecast ADFD mean grid. Similar high spread in Rainfall Forecasts is evident in the Bureau 7-day short term streamflow forecast products[46]. When there is wide variation in the location of heavy rainfall across a range of NWP models, or different ensemble members of an ensemble NWP this can contribute significantly to high spread in the forecast amount of rainfall.

The objective assessment of forecast location error (displacement) of areal rainfall extent and position of heavy rainfall is significantly more complex than conventional forecast verification and there have been comparatively fewer investigations of location error. A compendium of research findings is presented in Appendix K.14 on location or displacement error of areal rainfall (including global NWP models that have simple representation of convection and higher resolution NWP models that have more advance representation of convection). Common findings of the available research are that location error is a key limitation of forecasts for areas of high rainfall. Displacement errors in the order of 50 km to over 100 km have been found in a range of NWP models. These findings are consistent with Seqwater's experience and observations for high rainfall events in South East Queensland.

Location errors of heavy rainfall in Rainfall Forecasts have a significant influence on catchment flow hydrographs. Location error in Rainfall Forecasts can make a difference between heavy rainfall occurring within or otherwise outside the Brisbane River Basin. It can also make a difference between heavy rainfall occurring upstream or downstream of the Dams.

Uncertain forecast rainfall applied to hydrological simulation of catchment flows results in a range of uncertainties propagated to the derived catchment flow hydrograph. These include:

a. The uncertainty in the catchment average rainfall affects the overall magnitude of the forecast catchment flow hydrograph (total inflow volume, timing and magnitude of the peak flow).
b. Further uncertainty in the peak flow and hydrograph shape is influenced by uncertainty in the spatial and temporal patterns of rainfall within the catchment even if the catchment average forecast rainfall is correct.
c. Uncertainty in the peak flow (magnitude and timing) and hydrograph shape can occur due to spatial rainfall pattern uncertainty (including location error of heavy rainfall) as this affects the travel time of flows from different parts of the catchment even if the temporal pattern is accurate.
d. Location error of forecast heavy rainfall is particularly pertinent for forecasting the flow hydrograph at Moggill for the contribution from the catchment downstream of Wivenhoe Dam. For example, if the forecast for the heaviest area of rainfall is over the Lockyer Creek catchment but the heaviest rain then occurs over the Bremer River catchment this can produce a significant error in the forecasted timing and magnitude of peak Downstream Catchment Flow at Moggill.

The impact of uncertainty in the forecast location of heavy rainfall compounds the uncertainty in decision making for development of Release Plans for Wivenhoe Dam because decisions need to rely upon forecast catchment flows for multiple catchments to achieve the Objective to mitigate downstream flooding. Decisions for Release Plans are markedly different if the heavier rainfall is upstream or downstream of the Dam.

Additional uncertainty in deriving catchment flow hydrographs arises when calibration is not possible before runoff is observed at key water level gauges. In these situations, the uncertainties in Rainfall Forecasts and the hydrological model rainfall loss parameters increase the uncertainties in the derived catchment flow hydrographs. There is a higher risk that Rainfall Forecasts will result in a false indication of a potential Flood Event if the actual rainfall does not occur or,

[46] The Bureau's 7-day streamflow forecasts are not available for all catchments in the Brisbane River Basin and are not suitable for flood operations. Nonetheless the published rainfall forecast for this product for other locations in South East Queensland is another indication of spread of rainfall forecast uncertainty.

is less than forecast resulting in no catchment runoff or insufficient runoff to cause the Lake Level rise above OFSL for each Dam.

Seqwater has observed multiple occasions of Rainfall Forecasts providing false indications of Flood Events in South East Queensland. For this reason, this Manual precludes pre-emptive releases based on Rainfall Forecasts (refer Section 12.2).

Rainfall Forecasts for the same forecast period can frequently change in the lead up to and during a Flood Event. Variation of uncertainty at different lead times in the forecast, and variations as forecasts are updated can result in significant changes to catchment flow hydrographs derived from Rainfall Forecasts during the Flood Event.

Indications of forecast error trends from recent previous forecasts during a Flood Event (such as comparison of actual rainfall with forecast rainfall for forecast cycles prior to the current forecast) may not be a reliable indication of current forecast error. Forecast error trends can be misleading particularly in situations where there is location error for the area of heaviest rainfall and such location error is varying at different forecast update cycles. The apparent or perceived recent forecast error trends may also be inconsistent between catchments upstream and downstream of the Dams[47].

K.5 Potential benefits, risks, and vulnerabilities in using Rainfall Forecasts

The use of catchment flow hydrographs derived from Rainfall Forecasts for the development of Release Plans creates risks in the ability to meet the Objectives for flood operations (Objectives are described in Section 9). Benefits are also possible for some Objectives if catchment flow hydrographs derived from Rainfall Forecasts can produce reasonably reliable definition of the flow hydrographs that inform decision making. The potential benefits versus risks may not be balanced and may also vary for the unique circumstances of each specific Flood Event.

Uncertainties in the forecasted catchment flow hydrographs (for example, volume, hydrograph shape, timing and magnitude of the Predicted Peak flow) for one or multiple catchments that affects decision making for a Release Plan can have adverse consequences. The risks of adverse consequences are not readily assessable in a real-time Flood Event as the uncertainty is undefined[48]. If an adverse consequence from prior Release Plans from use of Rainfall Forecast in an early stage of a Flood Event does emerge to become known later in the Flood Event, it may be too late to intervene to mitigate adverse impacts of prior releases[49]. Table K.1 presents a summary of potential benefits and risks that can occur for each of the Objectives if Rainfall Forecasts are used quantitatively in the catchment flow hydrographs used to develop a Release Plan.

Table K.1 Potential benefits and risks to each specific Objective for Wivenhoe Dam and Somerset Dam flood operations

Objective	Potential benefits and risks of quantitative use of Rainfall Forecast
Prevent structural failure of the Dam.	**Potential benefit:** Lower Peak Lake Levels in one or both Dams are possible if Rainfall Forecasts predict higher Peak Lake Level leading to decision to increase releases earlier in the Flood Event. In extreme events (albeit very limited situations) the Rainfall Forecast could potentially assist to avoid exceeding the Maximum Flood Storage Levels for the Dams. <u>The benefit for reducing the chance of exceeding the Maximum Flood Storage Level is likely to be limited.</u> Using Rainfall Forecasts could influence decisions to increase releases in order to reduce the chance of breaching the Wivenhoe Dam fuse plugs. **Risk:** Breaching of the Wivenhoe Dam fuse plug spillway is possible in some limited situations if the downstream catchment Forecast Rainfall is higher than actual rainfall (leading to releases from Wivenhoe Dam being reduced), or if the forecast downstream catchment time of peak flow is incorrect (as this affects the scheduling of releases from Wivenhoe Dam).

[47] For example a previous forecast cycle may have had under-forecast on upstream catchments and over-forecast on downstream catchments, but that does not mean the same should be expected for the current forecast or future forecast updates.

[48] Methods for dam operation decision making with ensemble flow forecasts that have defined uncertainty are complex. Tested methods for dam operation decision making with ensemble flow forecasts do not currently exist for Wivenhoe Dam and Somerset Dam.

[49] One example is excessive releases below OFSL based on over-forecast of the volume of inflows resulting in being unable to fill the Water Supply Compartment. Another example is a previous target flow at Moggill decided on the basis of over-forecast of the Dam inflows and/or downstream catchment flows resulting in higher target flow than was necessary (i.e. higher downstream flooding).

Objective	Potential benefits and risks of quantitative use of Rainfall Forecast
Ensure Water Supply Compartments are full at the end of a Flood Event.	**Potential benefit:** None. Inflows derived from Rain on Ground are better for this Objective. **Risk:** If the forecast inflow volume is too high, or the rate of outflow continually exceeds the rate of inflow, there is risk that the Water Supply Compartment will not be refilled. Failing to refill the Water Supply compartment can affect water security for a large population in South East Queensland.
Mitigate downstream flooding.	**Potential benefit:** Lower flooding downstream is possible if forecasts can provide a reliable prediction of a high Predicted Peak Lake Level for Wivenhoe Dam. This can guide increasing the target flow at Moggill earlier in the Flood Event to preserve the Flood Storage Compartment to reduce the peak flood flow at Moggill later in the Flood Event. A higher target flow at Moggill earlier in a Flood Event is not universally beneficial to reduce downstream flooding for all areas of the downstream floodplain, particularly in terms of the flood level at Ipswich and in Flood Events affected by storm surges. **Risk:** Higher flooding downstream is possible if the forecast catchment flow hydrographs for the upstream and/or downstream catchments are not reliable and results in selection of a target flow at Moggill that is higher than necessary. If the time and magnitude of the forecast peak flow for the downstream catchment is not reliable higher downstream flooding is also possible even if the target flow at Moggill is appropriate. The duration of inundation of downstream bridges could be longer if releases start earlier based on Rainfall Forecasts.
Protect the riverine and riparian environment.	**Potential benefit:** Less downstream environmental damage is possible if lower downstream peak flood flow is achieved. **Risk:** The potential for higher downstream flooding can increase environmental damage to downstream riverbanks. Higher susceptibility to riverbank slumping failures is also possible if the duration of downstream flooding is increased as sustained periods of high river flows can increase the time available for the river flows to saturate the riverbanks. Unnecessary fish stranding impacts could occur if potential false Flood Event indications from the use of Rainfall Forecasts influence initiation of flood releases that are not necessary (due to over-forecast inflows).

Summary of vulnerabilities to risks and opportunities for potential benefits with use of Rainfall Forecasts

This section summarises key vulnerabilities identified for the range of risks described across the Objectives of this Manual. This content summarises more detailed technical descriptions in Appendix K.6 to K.12.

Appropriate management of the risks with using uncertain Rainfall Forecasts to provide a reasonable balance of outcomes across the Objectives requires awareness and consideration of the following combined vulnerabilities:

a. Over-forecast of the catchment flow hydrograph volume for inflows into the Dams can:

   i. risk meeting the Objective to ensure the Water Supply Compartment will be full at the end of the Flood Event when releasing water when the actual Lake Level is below OFSL; and
   ii. risk selecting a target flow at Moggill that is too high. This impacts the Objective to mitigate downstream flooding (and environmental impacts).

b. Potential errors in the hydrograph shape and definition of the peak flow for the dam catchment flow hydrographs can result in over-prediction of the Predicted Peak Lake Level for Wivenhoe Dam. This impacts on the selection of an appropriate target flow at Moggill which impacts the Objective to mitigate downstream flooding.

c. Potential errors in the volume, hydrograph shape and definition of magnitude and timing of the peak Downstream Catchment Flow can:

   i. risk the selection of a target flow at Moggill that is too high. This impacts the Objective to mitigate downstream flooding (and environmental impacts);
   ii. add more flow than necessary to the peak Downstream Catchment Flow. This results in increased downstream flooding (and environmental impacts) if there is error in the time and magnitude of peak flow from the downstream catchment. This can occur even if the target flow at Moggill is suitable; and
   iii. increase the risk of overtopping and breaching the Wivenhoe Dam auxiliary spillway fuse plug embankments particularly if the Downstream Catchment Flow is over-forecast (too high).

The opportunity to realise benefits using Rainfall Forecasts providing the above vulnerabilities can be managed are:

a. reducing the risk of overtopping and breaching the Wivenhoe Dam auxiliary spillway fuse plug embankments if a higher target flow at Moggill can be selected earlier in the Flood Event and for Flood Events that would require the selection of the Wivenhoe Dam Safety Strategy.
b. reducing the magnitude of downstream flooding with:
    i. higher releases below OFSL whilst still meeting the Objective to ensure that the Water Supply Compartment will be full at the end of the Flood Event; and
    ii. selection of a higher flow target flow at Moggill earlier in a Flood Event in large flood events that would escalate to requiring application of the Wivenhoe Dam Safety Strategy.

There is a high level of uncertainty in Rainfall Forecasts (described in Appendix K.3) and the uncertainty is not quantitatively defined in way that can be used for risk-informed decision making for the dam operations in real time. For this reason, this Manual does not permit the use of uncertain Rainfall Forecasts. Comprehensive studies are required before use of uncertainty-informed decision making can be incorporated into future Flood Manuals.

Benefits are possible in specific circumstances where Rainfall Forecasts have low uncertainty. In real-time operations it is not possible to know if Rainfall Forecasts have low uncertainty for the specific Flood Event.

K.6 Limitations to benefits of use of Rainfall Forecasts to prevent structural failure of the Dams

Rainfall Forecasts producing a higher Predicted Peak Lake Level compared to Rain on Ground may result in releases being increased earlier in a Flood Event. This may reduce the actual peak Lake Level which occurs in the Flood Event.

For Somerset Dam there is no or very limited practical benefit because the Procedures for Somerset Dam in this Manual (Section 15) require releasing at the maximum achievable capacity when the Lake Level rises above OFSL.

For Wivenhoe Dam the potential opportunity to reduce the risk of exceeding the Maximum Flood Storage Level is limited to a very narrow range of extreme Flood Events. The probability of exceeding the Maximum Flood Storage Level is extremely low (refer Section 8.2). This is explained further below with an example extreme Flood Event. The example is hypothetical only and does not imply that forecasts are sufficiently reliable to achieve benefits. The example is solely to demonstrate that potential benefits are very limited because in an extreme flood that could exceed the Maximum Flood Storage Level the possibility to open spillway gates earlier has relatively little effect on peak lake level outcomes.

K.6.1 Example Extreme Flood Event

This example is provided to explain potential limited benefits of using Rainfall Forecasts with regards to impact on peak Lake Level in very extreme Flood Events that may get close to or reach the Maximum Flood Storage Level for Wivenhoe Dam.

An extreme Flood Event that could reach the Maximum Flood Storage Level in Wivenhoe Dam (80 m AHD) is described for contrasting scenarios of the flood operation of the Dam. This example extreme Flood Event is generated from a 1 in 500,000 annual exceedance probability rainfall event for the Wivenhoe Dam catchment. This extreme event example flood has 980 mm catchment average rainfall in 48 hours over the total Wivenhoe Dam catchment. The inflow volume (combined for Somerset Dam and Wivenhoe Dam) is approximately 6,700,000 ML and the peak inflow into Wivenhoe Dam is approximately 36,000 m^3/s (combined flow from the Upper Brisbane River catchment and Somerset Dam outflows).

The chart in Figure K.1 shows the inflow hydrograph and the Wivenhoe Dam Lake Level and outflow hydrographs to demonstrate the influence of the fuse plug auxiliary spillway capacity in an extreme event. Three scenarios are presented for the Wivenhoe Dam Lake Level and outflow hydrographs that represent:

- The Lake Level and outflow in dark blue for simulated application of the Procedures in this Manual with Rain on Ground forecasts, with OFSL at 65.9 m AHD, and initial Lake Level at OFSL. In this scenario the requirement to have the spillway gates fully open prior to breaching the first fuse plug at the auxiliary spillway is implemented. The Wivenhoe Dam Safety Strategy is implemented at 20 hours after the start of rainfall when the forecasts based on Rain on Ground predict that the Wivenhoe Dam Lake Level will exceed 75 m AHD. The actual Lake Level at the time when the Wivenhoe Dam Safety Strategy is implemented is 70 m AHD.

- The simulated Lake Level and outflow in brown for a hypothetical scenario where the rainfall forecast immediately leading into the rain event successfully identifies a need to immediately open the spillway gates at the fastest practical rate from the time that rainfall starts in the catchment. The initial Lake Level is at OFSL (65.9 m AHD).
- The simulated Lake Level and outflow in orange for a hypothetical scenario where the rainfall forecast many days prior to the event successfully identifies a need for pre-emptive release to lower the Lake Level well before the event. This scenario assumes that pre-emptive releases have lowered the Lake Level to 63 m AHD (equivalent to 256,000 ML below OFSL) before onset of rainfall. The scenario then assumes that further rainfall forecasts identify a need to immediately fully open the spillway gates when rainfall starts in the catchment.

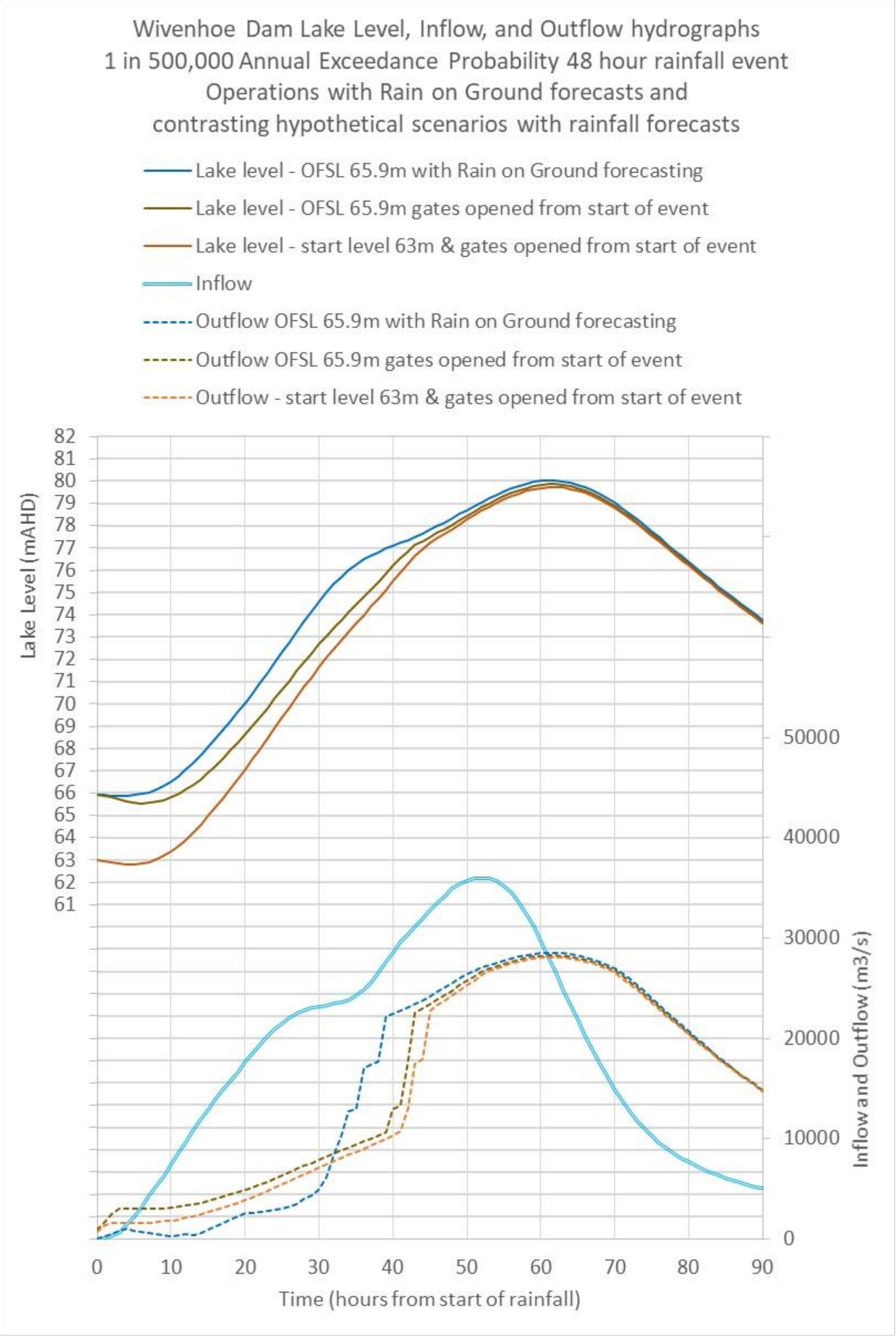
It is important to note that second and third hypothetical scenarios are conceptual and have only been included for demonstration purposes. It should not be interpreted that rainfall forecasts have sufficient reliability for such scenarios to occur. For clarity the second and third scenarios above are not in accordance with the Procedures in the Manual – they are simply hypothetical scenarios to demonstrate limited benefits of very high early releases for very extreme floods.

In all the above scenarios the simulations assume a maximum achievable rate of 20 metres total gate opening per hour which is about the limit at which the Dam Operators could safely perform the required gate opening in extreme weather conditions. Table K.2 presents key time points and information for these scenarios and should be read with reference to Figure K.1. Value differences stated in the table for the hypothetical scenarios are comparing to the baseline scenario (Rainfall on Ground forecasts).

Table K.2 Scenario Comparison (refer Figure K.1 for chart)

Scenario	Rain on Ground forecasts	Rainfall forecast influences immediate opening of spillway gates	Lowered initial lake level and rainfall forecasts influences immediate opening of spillway gates
Initial lake level (m AHD)	65.9	65.9	63.0
Time spillway gates fully open	33 hours	4 hours	4 hours
Time first fuse plug breach	33 hours	39 hours (*6 hours later)*	41 hours (*8 hours later)*
Time second fuse plug breach	35 hours	41 hours (*6 hours later)*	42 hours (7 *hours later)*
Time third fuse plug breach	38 hours	42 hours (4 *hours later)*	44 hours (*6 hours later)*
Peak lake level (mAHD)	80.04	79.84 (*0.2 m lower*)	79.74 (*0.3 m lower*)
Time of peak lake level	61 hours	61 hours	62 hours

Figure K.1 Wivenhoe Dam extreme flood example (1 in 500,000 AEP 48 hour rainfall event)



The simulated outflow and Lake Level hydrographs for the three scenarios for this example very extreme Flood Event demonstrate that:

- A major portion of the Dam outflows in an extreme event occur with the spillway gates fully open and flows passing through the auxiliary spillway after the fuse plugs have breached. Most of the extreme flood outflow release is passive and is not being controlled by the spillway gates;
- Significantly increasing releases through the spillway gates at the highest possible rate early in the Flood Event would produce lower Lake Level early in the event before the fuse plugs breach. However, the scenarios releasing at the highest possible rate early in the Flood Event also delays the breaching of the fuse plugs at the auxiliary spillway which delays the necessary increase of releases that the fuse plugs provide to pass an extreme flood;
- The effect of delay in breaching of the fuse plugs in the scenarios releasing at the highest possible rate from the start of the Flood Event only produces a minor different to the peak Lake Level.

In this specific example for a flood that just reaches the Maximum Flood Storage Level, the minor difference in peak Lake Level could potentially mean the difference between the Dam failing and not failing. This example is a very limited specific situation where a benefit to prevent Dam failure may be possible with releasing at the highest possible rate from the start of the rainfall event and with no regard for the earlier increased downstream flooding that would occur with higher early releases. This would require very high confidence in the rainfall forecasts. The skill of rainfall forecasts for very extreme rainfall intensity is not known.

In an extreme Flood Event that is slightly smaller than this example flood, the difference in peak Lake Level from releasing early at the maximum possible rate would also be minor and outcomes would likely produce Lake Level not exceeding the Maximum Flood Storage Level in all scenarios.

In a more extreme Flood Event that is larger than this example flood, the difference in peak Lake Level from releasing early at the maximum possible rate would also be minor and the outcomes would likely produce Lake Level exceeding the Maximum Flood Storage Level in all scenarios.

The important overall summary of the information described above is that it is the combined interaction of the main spillway gate releases and timing of the auxiliary spillway fuse plug breaching that affects the peak Lake Level for Wivenhoe Dam in extreme floods. The effect of higher releases from the main spillway gates is counteracted by delayed breaching of the auxiliary spillway.

K.6.2 Pre-emptive lowering of Lake Level

Pre-emptive lowering of the Lake Level below OFSL based on Rainfall Forecasts (for either Dam) has relatively insignificant benefit to reduce the peak Lake Level in extreme Flood Events. The potential additional storage space that could be gained below OFSL is very small compared to the very large inflow volumes that occur in extreme Flood Events. The example in Section K.6.1 demonstrates this for Wivenhoe Dam.

The level of uncertainty in Rainfall Forecasts for very extreme rainfall intensities is more unknown than the uncertainty of Rainfall Forecasts for more common rainfall events. Caution is essential as the action to significantly increase releases in response to a Rainfall Forecast that indicates very extreme rainfall can produce adverse outcomes for the other Objectives particularly for downstream flood mitigation if the Rainfall Forecast is overestimated.

K.6.3 Fuse plug overtopping and breach

In contrast to very extreme floods, there is greater potential benefit of using Rainfall Forecasts to reduce the probability of overtopping and breaching the auxiliary spillway fuse plug embankments. This potential benefit has relevance for Dam Safety, public safety, flood mitigation, and environmental damage. The potential benefit for reducing the chance of breaching the fuse plug would require increasing releases at Lake Levels before the fuse plug level is reached. Increasing releases can have adverse outcomes for other Objectives if the dam catchment Rainfall Forecast is overestimated.

Early overtopping and breaching the auxiliary spillway fuse plug embankments are possible using Rainfall Forecasts. This may occur if Rainfall Forecast for the downstream catchment is higher than actual rainfall leading to decisions to reduce or cease releases from Wivenhoe Dam to allow the downstream catchment flood peak to pass. Reducing releases from Wivenhoe Dam increases the Lake Level when the release rate is less than the Dam inflow. If inflows in

Wivenhoe Dam then increase, further Lake Level rises could overtop and breach the auxiliary spillway fuse plug embankments. This risk is also possible if the Rainfall Forecasts produce incorrect forecast of the time of peak flow for the downstream catchment flow hydrograph (as this affects the timing of releases from Wivenhoe Dam to maintain the selected target flow). This risk can be mitigated by limiting decision making to use of reliable forecasts for the downstream catchment flow hydrographs as this ensures that planned periods and magnitude of lower release (or no release) from Wivenhoe Dam are limited to the extent that is essential for the Objective to mitigate flooding.

K.7 Risks for ensuring the Water Supply Compartments are full at the end of the Flood Event

The use of Rainfall Forecasts for the dam catchments is a potential risk for the Objective to ensure the Water Supply Compartment will be full at the end of the Flood Event, for releasing from the Dams when the actual Lake Level is below OFSL. Vulnerability to this risk occurs when the forecast dam inflow volumes are too high (over-forecast).

There is higher vulnerability of over-forecast inflow volumes early in a Flood Event before sufficient actual runoff is observed to calibrate the hydrological model parameters for the dam catchment forecast flow hydrographs due to the combined uncertainty in estimates of the catchment losses and uncertainty in the Rainfall Forecast. On large catchments (such as the Upper Brisbane River catchment) continued uncertainty in the catchment loss estimates occurs after the start of runoff when only part of the catchment is producing runoff.

Failing to meet the Objective to ensure the Water Supply Compartment will be full at the end of the Flood Event can have adverse outcomes for the security of water supply to a large population across South East Queensland.

K.8 Potential benefits to mitigate downstream flooding

The use of Rainfall Forecasts can provide benefit to mitigate downstream flooding if the Rainfall Forecasts are sufficiently reliable:

a. to increase releases below OFSL at the start of a Flood Event without compromising the Objective to ensure the Water Supply Compartment is full at the end of the Flood Event and, the higher early releases can avoid adding excessive extra flow to early downstream catchment flood flow peaks. This potential benefit requires:
    i. A reasonably accurate estimate of the forecast dam inflow volume (to ensure it is not overestimated); and
    ii. to have reliable definition of the timing and magnitude of the peak Downstream Catchment Flow.
b. for all requirements described in Appendix J (volume, hydrograph shape, peak flow, and time of peak flow) for all catchments upstream and downstream of the dams to foresee that a higher target flow at Moggill will be necessary. If reliable forecast catchment flow hydrographs for all catchments can be achieved, the benefit of Rainfall Forecasts can guide selection of a reasonable higher target flow at Moggill earlier in the Flood Event with a corresponding benefit to preserve the Flood Storage Compartment and reduce the target flow at Moggill later in the Flood Event. With these conditions an outcome of reduced peak downstream flooding is possible.

Limitations to potential benefits

Important limitations for the potential benefits to mitigate downstream flooding are:

a. Reliable definition of forecast catchment flow hydrographs is simultaneously required for multiple catchments upstream and downstream of the Dams;
b. The lowest possible magnitude of peak flood flow downstream of Wivenhoe Dam (combined dam release and Downstream Catchment Flow) will always be limited to the peak Downstream Catchment Flow. The peak Downstream Catchment Flow is a physical limit to maximum achievable flood mitigation. The relevance of this physical limit is described further below; and
c. While increasing the target flow at Moggill earlier in a Flood Event can reduce the magnitude of peak flood flow in the downstream reaches of the Brisbane River, in some Flood Events this may not universally produce lower levels of flooding for all areas of the downstream floodplain. Outcomes of higher flood levels are possible in some Flood Events for some floodplain locations when the target flow at Moggill is increased earlier in a Flood Event (this is described in risks below).

The physical limit of achievable mitigation of downstream flood flow described in point (b) above, is relevant for the context of the capacity of Wivenhoe Dam to mitigate downstream flooding and the benefits of using flow forecasts derived with Rain on Ground to determine Release Plans. Assessments[50] with numerous flood event simulations undertaken for the WSDOS investigations have found that statistically over a large number of Flood Event, the Procedures in this Manual when applied with catchment flow forecasts derived with Rain on Ground can achieve close to the physical limit of achievable flood mitigation in many floods defined by approximate limits of:

a. Minor and Moderate floods with peak flow at Moggill in the range of 2,000 m^3/s up to approximately 6,000 m^3/s;
b. These Flood Events are typically from rainfall events up to approximately 240 mm catchment rainfall in 3 days (that is, for rainfall over the total area upstream and downstream to Moggill); and
c. These are Flood Events that can be operated within the limits of the Wivenhoe Dam Flood Mitigation Strategy and do not require escalation to the application of the Wivenhoe Dam Safety Strategy.

For the range of Flood Events defined above, the use of Rain on Ground forecast flow hydrographs with the Procedures in this Manual achieves close to the maximum achievable flood mitigation in many Flood Events due to the combination of size of the Flood Storage Compartment of Wivenhoe Dam, the reliability of forecasting catchment flow hydrographs with Rain on Ground, and the appropriate balance between use of the Flood Storage Compartment against target flow at Moggill defined by the Flood Mitigation Guide Curve (refer Figure 14.1.1).

This context means that the use of Rainfall Forecasts is likely to have limited practical benefit to reduce downstream flooding in many minor and moderate Flood Events. It also means that potential benefits that can be gained from use of Rainfall Forecasts are more likely to be significant for larger Flood Events with catchment average rainfall exceeding 240 mm in 3 days (averaged over the total area of all catchments contributing to flow to Moggill) and Flood Events that would escalate to require application of the Wivenhoe Dam Safety Strategy.

K.9 Risks for mitigation of downstream peak flood flow

The use of uncertain Rainfall Forecasts is a significant and sensitive risk for the Objective to mitigate downstream flooding. Determining a Release Plan for Wivenhoe Dam that aims to achieve a target flow at Moggill requires reasonably reliable catchment flow hydrographs for multiple catchments upstream and downstream. The sensitivity of downstream flood mitigation outcomes is affected by the combination of:

a. the Wivenhoe Dam predicted Lake Level which is affected by the Release Plan and inflow hydrograph;
b. the Downstream Catchment Flow hydrograph used to determine a Release Plan to achieve a selected target flow at Moggill; and
c. the time of the forecast peak Downstream Catchment Flow needs to be reliable to achieve the benefit of minimising adding extra flow to the peak Downstream Catchment Flow.

The risk of higher downstream flooding can occur if the Rainfall Forecasts produce catchment flow hydrographs that influence selection of a target flow at Moggill that is higher than necessary. The potential selection of a target flow at Moggill that is higher than necessary is vulnerable to:

a. Over-forecast dam inflow hydrographs (volume or peak flow is too high) into Wivenhoe Dam and/or Somerset Dam. This influences higher Predicted Peak Lake Level for Wivenhoe Dam requiring selection of a higher target flow at Moggill.
b. Over-forecast downstream catchment hydrograph contribution to the flow at Moggill (volume and peak flow are too high) as this:
   i. reduces the releases that can be made for an initial iteration of target flow at Moggill;
   ii. has a corresponding impact on increasing the predicted peak Lake Level for Wivenhoe Dam; and,
   iii. then requires increasing the target flow at Moggill to produce an appropriate balance of target flow at Moggill against predicted peak Lake Level for Wivenhoe Dam.
c. Error in the relative time and magnitude of the peak flow or the hydrograph shape for the downstream catchment flow hydrograph and/or for the Wivenhoe Dam inflow hydrograph as this affects the:
   i. the timing of releases in the Release Plan to achieve at target flow at Moggill;
   ii. the Predicted Peak Lake Level for Wivenhoe Dam that will occur with the Release Plan; and,
   iii. if the predicted peak Lake Level for Wivenhoe Dam is too high this will then require selection of a higher target flow at Moggill.

[50] These assessments were undertaken by Seqwater after WSDOS was published and utilised the results of numerous stochastic flood simulations from the WSDOS investigations.

The multiple factors described above that influence the selection of a target flow at Moggill means that there are multiple vulnerabilities to unreliable characteristics in the catchment flow hydrographs that can lead to increased downstream flooding due to selection of a target flow at Moggill that is too high.

The 'best final' target flow at Moggill for the overall Flood Event is not known in real-time flood operations until after Rain on Ground forecasts can provide a reliable estimate of the likely actual flood peaks for the upstream and downstream catchments combined with a reliable estimate of the likely actual peak Lake Level for Wivenhoe Dam.

The risks of increased downstream flooding are not limited to selection of a target flow at Moggill that is too high.

The impact of uncertain Rainfall Forecasts on potential errors in the forecast time and magnitude of the peak Downstream Catchment Flow hydrograph, or more generally the hydrograph shape, can result in the Release Plan misjudging the magnitude of minimum releases and time of minimum releases required to minimise adding extra flow to the peak Downstream Catchment Flow. Unreliable Downstream Catchment Flow hydrographs based on uncertain Rainfall Forecasts are a vulnerability for achieving the target flow at Moggill even if the selection of the target flow is appropriate. Location errors in the areal position and extent of heavy localised rainfall over the downstream catchments, or more generally the spatial pattern error for rainfall over the downstream catchments, can produce significant errors in the timing and magnitude of the peak Downstream Catchment Flow due to the differences in flow travel distance from different parts of the downstream catchments to Moggill.

It is important to note that the vulnerabilities to risks for downstream flooding that are described above are also relevant to the reliability of forecast catchment flow hydrographs derived from Rain on Ground and more generally the inherent uncertainties in hydrological modelling. This places significant emphasis on applying reasonable attempts in the real time model calibration to derive reliable catchment flow hydrographs for decision making even if limited to Rain on Ground. An important distinction that is necessary is that forecasting catchment flow hydrographs for decision making with uncertain Rainfall Forecasts significantly increases the risks for mitigation of downstream flooding.

K.10 Risks to downstream peak flood level in some parts of the floodplain

There are also further risks from the use of Rainfall Forecasts for increased levels of downstream flooding that are limited to some parts of the downstream floodplain and are for conditions that only occur in some Flood Events. These risks can arise from selection of a higher target flow at Moggill earlier in a Flood Event, or more generally from higher releases early in a Flood Event.

These additional risks are relatively specific to the floodplain for the Brisbane River and lower Bremer River. Specifically, there are dynamic influences in some Flood Events that mean lower peak flood flows in the Brisbane River do not universally translate to lower peak flood levels including:

a. the influence of the Bremer River flow and Brisbane River on the flood level at Ipswich (backwater effect); and
b. the influence of ocean levels particularly storm surge conditions on peak flood levels in the estuarine reaches of the Brisbane River particularly areas closer to Brisbane City and further downstream beyond Brisbane City.

In some Flood Events the peak level and time of peak level in the Bremer River at Ipswich is influenced by the peak flow in the Bremer River and the level (or flow) of the Brisbane River at Moggill that occurs concurrently with the Bremer River flow. The influences on peak flood level at Ipswich are described in Section 5.3.

The peak level in Ipswich can often occur well before the time of peak flow and level in the Brisbane River at Moggill. When the peak flow in the Bremer River occurs early, the peak level at Ipswich is affected by flow at Moggill early in the Flood Event. This means that increasing the target flow at Moggill earlier in a Flood Event can produce a higher level at Ipswich in some Flood Events. The potential for impact on flood levels at Ipswich from the dam operation decisions for selection of target flow at Moggill was demonstrated in the WSDOS investigations[51] that found that higher flood levels at Ipswich can occur if the target flow at Moggill is increased earlier in a Flood Event. The risk is likely to be more sensitive for increasing the target flow at Moggill in the range of 2,000 m^3/s to around 4,000 m^3/s in the early stages of a Flood Event. This risk means that while the use of Rainfall Forecasts (with reliable catchment flow hydrographs) can reduce the later peak flood flow in the Brisbane River it can also produce an adverse impact on the peak level at Ipswich.

[51] The alternative Urban 1 and Urban 2 options tested in WSDOS demonstrated this affect.

In some Flood Events the weather event that produces the riverine flooding also produces elevated ocean levels in Moreton Bay (this is often called ‘storm surge’). Examples of combined river flood and ocean storm surge events include the January 2013 flood and May 1996 flood.

Elevated ocean levels from storm surge can produce peak river levels in the lower estuarine reaches of the Brisbane River that occur earlier than the time of peak flood flow in the Brisbane River. This is more prevalent well downstream of Moggill around Brisbane City and further downstream[52]. The peak storm surge ocean level often occurs around the time of the peak rainfall. The lag time for runoff flows from the catchment to the tidal reaches of the Brisbane River including delay of peak flows provided by Wivenhoe and Somerset Dam can often result in the peak river flow occurring well after the ocean storm surge peak level. The January 2013 flood is an example of a recent flood with delay between peak ocean level storm surge and peak river flow.

Risks of higher flood levels are possible in some locations in the estuarine reaches when there is elevated ocean storm surge if Rainfall Forecasts are used to select a target flow at Moggill earlier in the Flood Event. High early releases or increasing target flows at Moggill early in a Flood Event can increase tidal reach river levels that are already elevated well above normal tidal range due to the ocean level storm surge. This risk does not occur in all Flood Events.

The additional risks described above for peak flood levels are complex and do not necessarily occur in all Flood Events. The Procedures in Section 14 do not directly address the peak level at Ipswich or ocean level storm surge conditions. However, the Procedures do implicitly guide the appropriate selection of a target flow at Moggill with the Flood Mitigation Guide Curve (refer Figure 14.1.1) when it is applied with Rain on Ground.

These risks are noted here simply as an additional caution for increasing the target flow at Moggill earlier in a Flood Event based on the use of Rainfall Forecasts.

K.11 Consequences for potential benefits and risks for downstream flooding

The magnitude of material beneficial consequences versus the material adverse consequences for impacts on downstream flooding with the use of Rainfall Forecasts are significantly influenced by the high sensitivity of downstream floodplain to the magnitude of flooding. The Brisbane River Strategic Floodplain Management Plan (QRA, 2019) has developed a comprehensive understanding of the sensitivity of the downstream floodplain impacts relative to flood magnitude and has been used to inform the indicative consequences of flooding described in Section 4.8 and Table 4.8.1.

The information from the Brisbane River Strategic Floodplain Management Plan shows that the relationship between peak flood flow in the Brisbane River at Moggill and the resulting flood impacts is highly non-linear. This means that a relatively small percentage increase in peak flood flow at Moggill produces a larger adverse consequence compared to the beneficial consequence of the same percentage decrease in peak flood flow at Moggill.

As an example of the relativity of flooding consequences for +/- 20 percent change in peak flood flow can be described with a hypothetical scenario follows:

a. Rain on Ground - Baseline. Assume a large Flood Event with dam operations conducted with the Procedures in this Manual with Rain on Ground is used to derive catchment flow forecasts. This (baseline) produces a peak flood flow at Moggill of 10,000 m^3/s.
   The magnitude of peak flood flow would produce above-floor level inundation for approximately 8,000 buildings.

b. Potential Benefit with Rainfall Forecasts. If reliable Rainfall Forecasts were used and assuming the forecasts produced reliable catchment flow hydrographs which reduced the peak flood flow at Moggill by 20% to 8,000 m^3/s, then:
   i. Approximately 4,500 buildings will experience above floor-level inundation.
   ii. The benefit of a 20% decrease in peak flood flow at Moggill is approximately 3,500 buildings that have flooding reduced to below floor level.

c. Potential risk with Rainfall Forecasts. If uncertain Rainfall Forecasts were used and produce unreliable catchment flow hydrographs and this results in increase of the peak flood flow at Moggill by 20% to 12,000 m^3/s, then:

[52] Refer to Brisbane River Catchment Flood Study for information on combined effects of river flood flow and ocean storm surge.

i. Approximately 18,000 buildings will experience above floor-level inundation.
ii. The adverse consequence of a 20% increase in peak flood flow at Moggill for is approximately 10,000 buildings that have flooding increased to above floor level.

The example above is simply to demonstrate that downstream flooding consequences are highly sensitive due to the non-linear relationship between peak flood flow and flooding consequences.

If a specific rainfall event and Rainfall Forecasts for that event provide equal chance of risk or benefit and the risk and benefit has the same impact in terms of percentage of increase or decrease in peak flow at Moggill, the adverse consequence risk will outweigh the beneficial consequence opportunity.

In real-time flood operations, it is not possible to foresee or form judgment on the relative chance between risk of using Rainfall Forecasts and chance of realising the opportunity to gain a benefit from using Rainfall Forecasts. Similarly, it is not possible to foresee or judge the magnitude of a potential percentage increase in peak flood flow that could occur (for the risk) versus the magnitude of a potential reduction in peak flood flow (for the potential benefit).

While it is not possible to foresee or judge the relative increase or decrease in peak flow at Moggill that may be possible for risk and benefit for a specific rainfall event, the following general guidance is relevant:

a. Potential benefit scope of possible reduction in peak flow at Moggill. The absolute physical limit to reduction in peak flow at Moggill will always be limited to the peak Downstream Catchment Flow. The achievable reduction in peak flow at Moggill will depend on accuracy[53] and precision[54] of the Rainfall Forecasts, quality of the hydrological model calibration for all catchments[55], professional judgement applied with the Procedures, and the magnitude of the Flood Event[56].
b. Potential risk scope of possible increase in peak flow at Moggill. The worst case theoretical upper limit to potential increase in peak flow at Moggill is the maximum discharge capacity of the Wivenhoe Dam spillway with the spillway gates fully open which depends on the Lake Level around 12 to 16 hours before the time of the peak flow in the downstream catchment. The worst case theoretical upper limit is a very low probability scenario that would only occur for a Rainfall Forecast that has very extreme error (for example, a Rainfall Forecast that gives false impression that dam failure or fuse plug breach is possible). The more likely magnitude of the potential increase in peak flow at Moggill that could occur for the risks with uncertain Rainfall Forecasts will depend on the inaccuracy and imprecision of the Rainfall Forecasts, quality of the hydrological model calibration for all catchments, professional judgement, and magnitude of the Flood Event.

With the context described above, it is possible that the potential percentage decrease in peak flow at Moggill for potential benefits is less than the potential percentage increase in peak flow at Moggill for risks of using Rainfall Forecasts. The actual balance between benefit and risk for the Objective to mitigate downstream flooding depends on the unique circumstances of each Flood Event and it is not possible to judge this in real-time.

K.12 Potential benefits and risks for environmental impacts

The potential benefits with use of Rainfall Forecasts for environmental impacts of flooding are similar to the potential benefits of possible reduced downstream flooding that are described above. Reduced downstream river flooding can reduce risks for some riverbanks where the mode of bank failure is due to the erosive force of the river flow. Conversely the potential risks with the use of Rainfall Forecasts for the potential to increase downstream flooding can also increase environmental damage to riverbanks and riparian habitat.

The risks associated with the use of Rainfall Forecasts can also increase the susceptibility of bank failure for some riverbanks where the mode of bank failure is due to slumping after riverbanks become saturated and the river level recedes. These risks can be exacerbated if the use of Rainfall Forecasts significantly increases the duration of river flows with consequent impact on increased potential to saturate the riverbanks.

[53] Accuracy is how close the Rainfall Forecast is to the Actual Rainfall (for all catchments).

[54] Precision is the ability for the multiple Rainfall Forecasts to produce consistent levels of accuracy.

[55] Even if the Rainfall Forecasts are accurate, the modelling requires good calibration of rainfall losses and flow routing parameters.

[56] To prevent gate overtopping it is not possible to have the Wivenhoe Dam spillway gates fully closed when Lake Level exceeds EL 73 m AHD. Similarly breaching of the fuse plugs cannot be eliminated in rare flood events when the Lake Level exceeds EL 75.7 m AHD. These practical limitations means that Wivenhoe Dam releases cannot avoid adding to the peak Downstream Catchment Flow in large flood events.

The differences of risks and potential benefits between riverbanks susceptible to failure due to the erosive force of the river flow versus riverbanks that may be more prone to slumping failure are complex. The current Manual guidance for managing the rate of reducing dam releases when downstream flows are receding prior to the end of a Flood Event is the primary guidance to protect riverbanks.

There is some risk of causing unnecessary fish stranding impacts near the Wivenhoe Dam spillway, if spillway releases are initiated unnecessarily when a decision to start releases is misguided by an uncertain rainfall forecast. This is possible if Rainfall Forecast over-predicts the amount of rainfall for the dam catchments leading to the extent that the forecasts indicate the potential rise in Lake Level will meet the criteria for commencement of a Flood Event.

Notwithstanding the uncertainty of benefits and risks with the use of Rainfall Forecasts for environmental impacts on riverbanks and the riparian habitat, the potential benefits and risks for the other Objectives of this Manual would significantly outweigh the environmental impacts and benefits in most Flood Events.

K.13 Further technical information on Australian Digital Forecast Database (ADFD) Rainfall Forecasts

Summary: The ADFD is designed for point rainfall forecasts. The ADFD does not provide areal rainfall forecasts (refer Section K.2 and further information below). The ADFD does not provide uncertainty (or probability) of areal rainfall for a catchment.

The ADFD suite of forecast parameters has a range of point location rainfall forecast estimates, including chance of any rainfall at each point, potential rainfall amounts corresponding to defined probabilities of exceedance (75%, 50%, 25%, 10%) and mean rainfall amounts, within a specific time interval (rainfall for 3-hour periods, or rainfall for 1-day periods). Because these products are developed to define point rainfall forecast representation and not areal rainfall representation there are important limitations in the use of ADFD rainfall forecast data for deriving areal rainfall forecast input over multiple catchments that are needed for hydrological model simulations. These limitations and other characteristics include:

a. **Daily timestep:** The daily timestep resolution rainfall (mm/day) is too coarse for hydrological simulation for the Brisbane River Basin.
b. **Three-hourly timesteps:** The three-hour timestep resolution rainfall is more suitable than daily timestep resolution rainfall however it is still more coarse than the time intervals of the FFS data feed for actual rainfall observations (which are defined at 15 minute timesteps). The difference in timestep definition of actual rainfall observations and forecast rainfall means that the forecast rainfall will not necessarily produce similar flow hydrographs in comparison to forecasts derived with actual rainfall (even if the forecast rainfall has perfect accuracy). There are also additional hydrological modelling uncertainties in estimating a continuing rainfall loss rate when the actual rainfall used for calibration is at a different rainfall definition timestep to the forecast rainfall definition timestep.
c. **Spatial aggregation:** Spatial aggregation of the point rainfall amounts for a specific probability of exceedance rainfall grid over a catchment area (to define areal rainfall required for a hydrological model) is not statistically coherent. The probability of exceedance becomes distorted with spatial aggregation and the probability of exceedance then loses meaningful value.
d. **Temporal aggregation:** Temporal aggregation of the point rainfall amounts for a specific probability of exceedance rainfall grid over multiple timesteps (for example, to define a 24-hour rainfall forecast sequence from the 3-hour rainfall forecast time-intervals) is not statistically coherent. The probability of exceedance becomes distorted with temporal aggregation and the probability of exceedance then loses meaningful value.
e. **Combined spatial and temporal aggregation:** The combined influence of spatial and temporal aggregation described in items (c) and (d) above can result in significantly increased uncertainty for an areal rainfall forecast definition, including excessively high rainfall amounts particularly for the ADFD 10% chance exceedance forecast rainfall grids.
f. **ADFD mean not assigned a probability of exceedance:** The ADFD mean rainfall forecast data is the only product from the ADFD suite that has validity to aggregate in time (multiple time steps) and space (areal rainfall over a catchment). While aggregation is suitable, the aggregated ADFD mean rainfall does not provide a spectrum of probability of the rainfall forecast to inform the uncertainty of the rainfall forecast.
g. **Smoothed areal rainfall fields:** Due to their origins sourced from multiple NWP and the subsequent ensemble rainfall forecast data processing, the ADFD mean rainfall grid and other ADFD rainfall grids tends to smooth the areal rainfall field with less definition of possible higher localised rainfall of smaller areal extent within the broader

rainfall spatial field. The potential size of an area of higher localised rainfall, its position, and rainfall rate in higher localised rainfall is not defined well in the ADFD products. When actual rainfall has areas of higher localised rainfall intensity this can have significant influence on catchment flood flow hydrographs that is unlikely to be represented in catchment flows derived with hydrological simulation of the rainfall forecast.

h. **Limited variance in spatial positioning of heavy rainfall:** The ADFD rainfall forecast grids may produce misleading impressions of the general locations of potential higher rainfall within the broader rainfall spatial field of the weather system. Notably the spatial positioning of locations of higher potential rainfall tends to be overly consistent across the range of ADFD rainfall grids and is not representative of the wider variation and uncertainty in possible locations of higher rainfall that is evident across individual raw NWP model outputs (that is, the range of positioning across source deterministic and ensemble NWP models tends to portray more variation and uncertainty in the location of potential heavier rainfall). This generally means that ADFD rainfall forecast grids do not provide a representation of potential spatial displacement uncertainty which can be particularly important for making decisions on the flood operation of Wivenhoe Dam which is influenced by catchment flow hydrographs upstream and downstream of the Dam.

K.14 International research on errors in location of heavy rainfall in rainfall forecasts

This section presents a summary of international literature on location or displacement errors in rainfall forecasts.

Methods to assess the location error of rainfall forecasts require different approaches to conventional rainfall verification for specific point locations. Ebert et al (2000) developed object-oriented verification procedures for gridded quantitative precipitation forecasts (QPFs) and observations within a framework of “contiguous rain areas” (CRAs). While Australian research (Ebert) has contributed significantly to the methods for contiguous rain area verifications cited in international literature there have been no published recent verification studies or systematic long period verification studies for location error in precipitation forecasts in Australia. Ebert et al (2009) presents some of the challenges and strengths of CRA verification.

Tartaglione et al (2008) investigated rainfall forecast location errors with CRA verification for 200 events in Italy for several numerical weather prediction models. The study found all models seem to show statistically poor abilities in forecasting the correct precipitation pattern position over the verification domain. Results identified a mean error of little more than 40 km in longitude and 50 km in latitude in a 24 hour precipitation forecast.

Shahrban et al (2016) investigated assessment of forecast rainfall from the Australian Community Climate Earth-System Simulator (ACCESS) NWP model for 2010 and 2011 using radar observations in south eastern Australia. This analysis found that both location and magnitude errors were the main sources of forecast uncertainties.

Gallus et al (2016) undertook a study focussed on Iowa USA to better understand the limits of predictability of short-term (12 h) quantitative precipitation forecasts (QPFs) that might be used in hydrology models. The context and motivation for the study noted that “Numerous studies have tried to find the limitations of QPF and methods to improve it. However, the essential challenge in short- and medium-range QPFs is that numerical models are highly nonlinear, so the uncertainties of the models are still poorly understood.” The findings of the study noted that “the main cause of poor skill was large displacement errors.” The study noted that “for hydrological use, in order to obtain skilful QPFs during this period, besides the overprediction/underprediction of storm numbers, more attention should be paid to the large location errors.” For that study area the findings also noted that location errors also varied depending on time of day.

Chen et al (2018) investigated the spatial spread-skill relationship for forecasts from a convection-permitting ensemble numerical weather prediction model for China. The study considered weather events producing small coverage (SC) and large coverage (LC) of rainfall over the study domain. This distinction found that the spatial spread-skill relationship depends highly on the weather regime and the spatial spread-skill relationship under SC is poorer and shows more diurnal variation compared to that under LC. The study findings noted that with increasing precipitation, the relative impact of precipitation intensity on the spread-skill relationship gradually decreases, and the influence of precipitation placement becomes dominant.

Kiel (2018) investigated displacement errors in the USA North Central River Forecast Center area of operations for two high resolution convective permitting numerical weather prediction models over the period 2017-2018. This study found mean displacement errors in the order of 60 to 70 km with a standard deviation in the order of 40 to 45 km.

Sharma et al (2019) investigated forecast precipitation for India summer monsoon rainfall with a 9-year verification data set. That study found significant individual event variation in displacement errors exceeding one degree (latitude and longitude) and mean errors were around half to one degree. The findings also identified that for that study region for Indian Summer Monsoon the rainfall spatial pattern error was more significant than location error.

Ponzano et al (2020) investigated heavy precipitation events with a long 30-year period of reforecast data from the global ensemble model Prévision d'Ensemble ARPEGE (PEARP) in France. The heavy precipitation events in that study ranged from 100 to 500 mm in 24 hours. The findings noted:

- The location of heavy precipitation events is poorly forecasted at long lead times
- Forecast errors are mainly related to a low consistency between observed and forecasted fields, rather than to an inability of the prediction system to produce intense precipitation amounts.
- The combination of Structure Amplitude and Location (SAL) verification and clustering is a relevant approach to show systematic errors associated with regional features for intense precipitation forecasting. This achievement is only enabled by the availability of a long re-forecast dataset.

Carlsberg et al (2020) investigated the potential benefits of shifting the forecast rainfall field to increase ensemble size for catchment flow forecasting for potential flood events. Their conclusions found that the ensemble using the shifted QPFs had an improved frequency of non-exceedance and probability of detection, and thus better predicted flood occurrence. However, false alarm ratio did not improve, likely because shifting multiple QPF ensembles increases the potential to place heavy precipitation in a basin where none actually occurred.

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