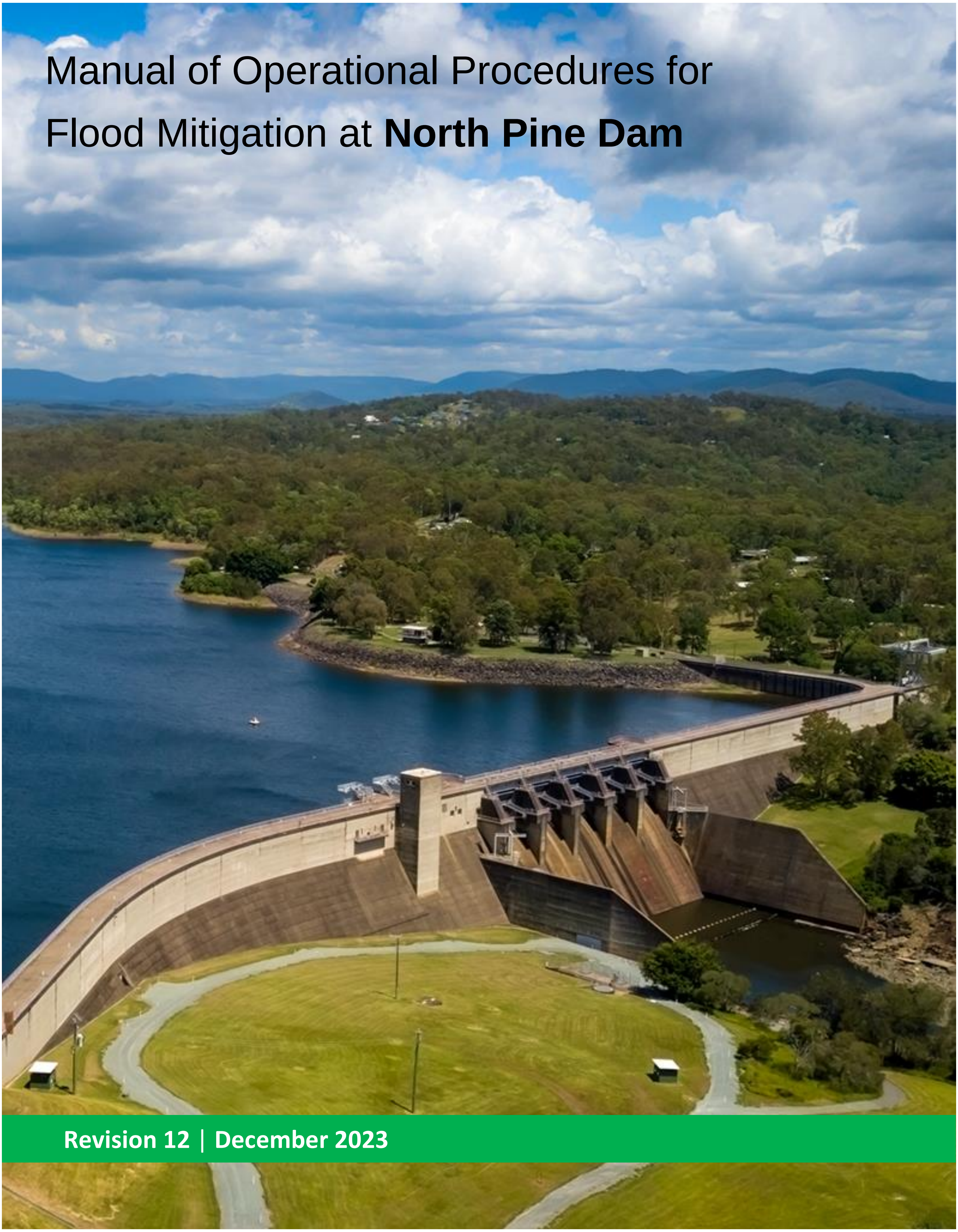
Manual of Operational Procedures for Flood Mitigation at **North Pine Dam**



Revision 12 | December 2023

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Revision No.	Date	Amendment Details
0	10 December 1986	Original Issue
1	6 October 1992	Complete revision and re-issue
2	13 November 1997	Complete revision and re-issue
3	26 July 2002	Complete revision and re-issue
4	5 September 2007	Complete revision and re-issue
5	August 2010 (approved by gazette notice dated 17 December 2010)	Complete revision and re-issue
6	October 2011	Revision
7	October 2012	Minor revision only
8	November 2013	Revision
9	November 2014	Revision based on outcomes of the North Pine Dam Optimisation Study and Government policy decision
10	November 2019	Revision
11	November 2021	Revision to include further explanation of operations targeted at a wider audience. Changes to the Procedures include refinements to Appendix C (in response to the implementation of a Reduced Full Supply Level), and addition of Flood Operations Strategy Procedure 1C to improve clarity.
12	December 2023	Revision addressed recommendations made in the 2022 Flood Event reports and learnings from training of flood operations personnel.

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Preface

This Flood Mitigation Manual has been approved by the Minister for Regional Development, Manufacturing and 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 North Pine Dam:

1. During Flood Events.

2. To achieve a Temporary Full Supply Level declared by the Minister under the Act (see Section 15); and

3. To achieve a Reduced Full Supply Level implemented under section 399B of the Act (see Section 15).

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

The Procedures aim to achieve an appropriate balance between preventing structural failure of the Dam, 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.

The Dam on the North Pine River is located within the Pine River Basin in South East Queensland. The Dam provides urban water supply, including drinking water to South East Queensland communities.

History has shown that large flood events impact the Pine River Basin, such as that which occurred in 2011 and 2022. The Dam is not able to prevent flood damage occurring in urban areas in large flood events.

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 16.

Authorisation Request Information has the meaning set out in Section 16.

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 catchment and downstream catchments.

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 means North Pine Dam.

Dam Operator 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 Dam Operator under this Manual. Responsibilities of Dam Operators are outlined in Section 3.7.

Dam Safety means the structural safety of a dam.

Dam Supervisor means the designated senior Dam Operator at the Dam. Responsibilities of the Dam Supervisor are outlined in Section 3.6.

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

GLOSSARY

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

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 both the DSFOE and all DFOEs.

Duty Flood Operations Engineer 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 of this Manual. 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 of this Manual.

EL means elevation in metres Australian Height Datum.

Emergency Action Plan or **EAP** means the current Emergency Action Plan for North Pine Dam prepared and approved in accordance with Chapter 4 Part 1 Division 2A of the Act.

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

Flood Event means a flood event that commences in accordance with Section 12.2 or Section 15.3 and ends in accordance with Section 13.2.

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 location 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 the 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 Dam. For North Pine Dam the Fixed FSL is 39.6 m AHD as set out in the Resource Operations Licence.
>
> **Operational Full Supply Level or Operational FSL or OFSL** means the level defining the top of the Water Supply Compartment. The Operational Full Supply Level has the primary significance for this Manual and it 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 the Fixed Full Supply Level;
> 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.

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 is discussed in more detail 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 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 the 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 or **Manual of Operational Procedures for Flood Mitigation at North Pine 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. The Maximum Flood Storage Level for the Dam is 41.7 m AHD.

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 Dam catchment. The Monitoring Network is part of the FFS and is described in Section 7.2.

NPDOS means the North Pine Dam Optimisation Study.

NPDOS Report means the final DEWS North Pine Dam Optimisation Study Report (DEWS, 2014).

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 the Pine Valleys Water Supply Scheme Operations Manual and is not used during Flood Events. The function of the Operations Manual is described further in Section 1.1.

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

Predicted Future Peak Lake Level, means the peak Lake Level at or beyond the time the prediction is made. The Lake Level prediction is made using the FFS and must account for all the releases (including operational releases made under the Operations Manual) planned from the Dam that are contained in the Release Plan.

Predicted Event Peak means the predicted peak value of a flow or level hydrograph that has caused the current Flood Event. The predicted event peak is based on professional judgement (see Section 3.4) as to the most reasonable prediction available at that time in the FFS to apply in the Procedures. The time of the predicted event peak may be before or after the current time.

Procedures means the specific instructions and criteria listed in Sections 12.2, 13, 14, 15.3 and 16 (including cross reference to data tables in Appendix C).

Rain on Ground 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 discussed in more detail in Section 8.

Resource Operations Licence or **ROL** means the Pine Valleys 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 Dam as defined in Sections 10 and 13.

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.

1 Introduction

1.1 Overview

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

The Dam is operated primarily to provide water supply for residents of South East Queensland[1]. The original purpose of the Dam did not extend to mitigation of flooding in the Pine River and the Dam has a relatively small Flood Storage Compartment. There is limited storage capacity above OFSL for the temporary storage of the flood water to pass floods to protect the safety of the Dam. Investigations undertaken for the NPDOS found that the Dam does provide some flood mitigation benefit depending on what the OFSL is for a Flood Event. The Procedures in this Manual aim to mitigate flood flows in the Pine River downstream of North Pine Dam to a limited extent during flood operations to protect the Dam.

The Dam is operated in accordance with the following instruments:

- The water supply operations of the Dam are regulated under the Water Act;
- Requirements to manage the safety of the Dam 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, flood mitigation and protecting the environment. Objectives for the flood operations of the Dam are described in Section 9.

The Operations Manual approved under the Water Act sets 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 Dam 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 Dam 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 Compartment is 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 and 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 and 10 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;
  - how the Strategies achieve an appropriate balance in relation to matters in Section 371F of the Act.
- Section 11 describes the consideration of Rainfall Forecasts under this Manual;
- Section 12 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 13 states the Procedures required to achieve the Strategies for the Dam, including the Procedures for releasing water from the Dam in response to a Flood Event;
- Section 14 describes variation to the Procedures in Section 13 to deal with urgent circumstances, e.g. the Procedures to be followed if communications are disrupted or lost during a Flood Event;
- Section 15 states the Procedures for releasing water from the Dam in response to a declaration of a TFSL or RFSL for the Dam;

[1] North Pine Dam provides approximately 10% 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.

- Section 16 describes the process to seek authorisation of an Alternative Procedure (in accordance with Section 378 and 379 of the Act).

1.2 Purpose

This Manual is a technical document that contains:

- Descriptive text that aims to describe factors relating to flood operations at the Dam; 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 Dam, agencies have the following responsibilities:

- Seqwater owns and operates the Dam and manages releases from the Dam. This includes:
  - Forecasting catchments flows to the extent necessary to apply the Procedures in this Manual;
  - Operation of the Dam 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 management of 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 provides rainfall and weather forecast information to stakeholder agencies and the public;
- Local Governments and Disaster Management Groups 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.

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.

1.5 Significant Changes in this Revision

Nine Flood Events occurred in 2022. The 2022 Flood Event reports (prepared in accordance with sections 383 and 385 of the Act) recommended changes to Revision 11 that would allow the Manual to deal with similar Flood Events more effectively.

This Revision addresses the recommended amendments to the Manual in the 2022 Flood Event reports. This Revision also includes minor administrative amendments to improve clarity, reflect learnings from the 2022 Flood Events and training of flood operations personnel.

The operational intent of Revision 12 has not changed.

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

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

2 Requirements of 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.

When communications between the Flood Operations Centre and the Dam are available, a Strategy for the Dam 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[3] are then developed according to the Procedures of this Manual, which are then implemented at the Dam. Studies undertaken in 2014 for NPDOS[4] assessed and determined an appropriate balance between the Objectives across a wide range of Flood Events. The Procedures in this Manual have built upon the outcomes of NPDOS.

In 2019 a Reduced FSL at 36.0 m AHD was implemented in response to the adoption of a lower Maximum Flood Storage Level for the safety of the Dam. These changes increase the weight given to preventing structural failure of the Dam. This also has the effect of improving mitigation of peak outflow but can result in increased disruption to transport, particularly in terms of the frequency and duration of inundation of Youngs Crossing.

2.2 Legal Requirements

2.2.1 Legal Context

Seqwater, as the owner of the Dam, must prepare, and have an approved, flood mitigation manual for the Dam under the Act.

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 two Strategies and supporting Procedures to implement these Strategies, for the operation of the Dam 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.

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

[4] North Pine Dam Optimisation Study Report (DEWS, 2014).

Table 2.2.1 Overview of how section 371D and section 371F 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 Dam (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 Dam, including protecting the structural integrity;
  • Minimising risk to property;
  • Minimising disruption to transport;
  • Maintaining the OFSL for the Dam after a Flood Event; and
  • Minimising environmental impacts on the stability of banks of watercourses and on riparian flora and fauna.
	Sections 10 and 13

State the Operational Procedures (the Procedures) required to achieve the Strategies, including: • Procedures for releasing water from the Dam in response to a Flood Event; and • Variations to the Procedures to deal with 'urgent circumstances' at the Dam during a Flood Event; and • Operational procedures for releasing water from the Dam in response to a declaration of a TFSL.	Sections 12.2, 13, 14, 15, 16
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; and • The qualifications and experience each responsible person must have; and • 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 Dam; and • The amount of inflow to the Dam; and • The amount of outflow from the Dam required under the Manual; and • The level of the water surface in the Dam (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); and
b. The carrying out of the operational strategies and operational procedures under the Manual would minimise risk to human life and safety; and
c. The Manual achieves an appropriate balance in relation to each of the following:
   i. Preventing failure of the Dam, including protecting the structural integrity;
   ii. Minimising risk to property;
   iii. Minimising disruption to transport;
   iv. Maintaining the OFSL for the Dam 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 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 Dam;
- 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 dam releases are likely to inundate and require closure of downstream bridges; and
- Providing dam release information to emergency agencies to support their flood response activities, including flood 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 in Section 9 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 to mitigate downstream flooding and Procedures to implement the Strategies. This Manual allows for minimising disruption to transport to a limited extent that is reasonably practical within context of all Objectives;
- Implementing the NPDOS recommendations derived from the analysis of numerous simulated potential flood events to assess the balance between preventing failure of the Dam, minimising risk to property, disruption to transport, maintaining full supply level in the Dam after a Flood Event, and environmental impacts;
- Subsequent to NPDOS, the adoption of a lower Maximum Flood Storage Level and implementation of a Reduced FSL in 2019 has placed more emphasis on the balance necessary to prevent structural failure of the Dam;
- The Procedures provide for mitigating downstream flooding and minimisation of disruption to transport to the extent practicable with a limited Flood Storage Compartment and the higher priority required to prevent structural failure of the Dam; and
- Consideration to protect the downstream environment is achieved with criteria for the rate of opening and closing the gates, timing of closing the gates and limiting release rates for small flood events.

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 operations of the Dam under the Water Act, to flood operations of the Dam under the Act, via this Manual.

When a Flood Event ends, the Dam reverts to operations, as regulated under the Water Act.

The Procedures for commencing a Flood Event are set out in Section 12.2 and Section 15.3.

The Procedures for ending a Flood Event are set out in Section 12.2.

3 Readiness, Roles and Responsibilities

3.1 Operational Arrangements

Seqwater must ensure that the following operational arrangements are undertaken:

3.1.1 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. A log of rainfall and stream height Gauging Station availability is maintained;
c. The Dam's radial gates and the 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;
d. The DSFOE is advised when the Dam radial gates and cone valves are returned to service (after being removed from service in accordance with the point above);
e. The Duty Engineers are on call on a 24/7 basis; and
f. Once a Flood Event commences in accordance with Section 12.2 or 15.3, 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 12.1).

3.1.2 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 Dam 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 the Dam during a Flood Event, one of which is designated the Dam Supervisor;
e. Unless communications are lost between the Flood Operations Centre and the Dam, release of water from the Dam during Flood Events is carried out under the direction of a DSFOE;
f. When communications are lost between the Flood Operations Centre and the Dam, release of water from the Dam during Flood Events is to be carried out in accordance with Section 14.3; 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).

The Flood Operations Centre is usually a specified physical location at Seqwater's premises. However, in situations where personnel safety or service continuity is at risk the DSFOE may nominate an alternative physical location or virtual operating environment provided communications with the Dams and stakeholders are maintained and access to the FFS can be maintained.

3.2 Responsibilities of the Duty Senior Flood Operations Engineer

The responsibilities of the DSFOE are as follows:

3.2.1 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 12.1 are met, organise the mobilisation of the Flood Operations Centre; and
   ii. determine when a Flood Event has commenced in accordance with the requirements of Section 12.2 or Section 15.3.

3.2.2 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 Dam 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 16;
f. Provide a directive to the Dam Supervisor at the Dam near the commencement of the Flood Event to confirm the OFSL arrangements for the Loss of Communications Procedure in Section 14.3; and
g. Determine when a Flood Event has ended in accordance with Section 13.2.

3.3 Responsibilities of a Duty Flood Operations Engineer

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

3.3.1 Outside Flood Events:

a. Monitor weather forecasts and catchment conditions and advise the DSFOE when the conditions in Section 12.2 to commence a Flood Event are met.

3.3.2 During a Flood Event:

a. Direct the operation of the Dam 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 16.

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 by the Chief Executive (DRDMW).

3.4 Flood Operations Engineer Professional Judgement

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[5];
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.

[5] For example, the consequences of a decision to demobilise the Flood Operations Centre (Section 12.1) are significantly different to the consequences of a decision to select and apply the Flood Operation Strategy Procedures (Section 13.1).

3.5 Responsibilities of Flood Officers

The responsibilities of a Flood Officer are as follows:

3.5.1 Outside Flood Events:

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

3.5.2 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 the Dam, the responsibilities of a Dam Supervisor are as follows:

a. Carry out operations at the 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 14.3.
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 14.3.

3.7 Responsibilities of Dam Operators

When rostered on duty during a Flood Event at the 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

3.8.1 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).

3.8.2 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 Dam:

a. The requirements of this Manual;
b. The requirements of the Emergency Action Plan for the Dam;
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 Dam;
g. The use and operation of the FFS; and
h. The requirements contained in the Communications Protocol.

3.8.3 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 Dam:

a. The requirements of this Manual as relevant to the role of Flood Officer;
b. The requirements of the Emergency Action Plan for the Dam;
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.

3.8.4 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 prior to 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 Plan 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; and
d. The requirements for Dam Safety monitoring and surveillance during Flood Events.

3.8.5 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 the Dam including any operational restrictions that have been applied to the Dam, and FFS updates; and
b. An annual flood exercise that simulates a Flood Event.

3.8.6 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 Dam. 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 14.3).

4 Background Information

This section presents the following background information:

- Relevant information on the catchment of the Dam and the Pine River Basin.
- Pertinent information about the Dam. This knowledge is essential for understanding the physical constraints of temporarily storing flood waters in the Dam for subsequent release.
- General consequences of flooding downstream of the Dam. This information is solely for background context which may potentially inform consideration of Alternative Procedures (Section 16) should the need arise.

4.1 Other Reference Materials

Detailed technical information on flooding in the Pine River Basin is available in a previous comprehensive study undertaken for the State of Queensland. Readers seeking more detailed information should refer to the:

- **North Pine Dam Optimisation Study Report** (DEWS, 2014), which presents a comprehensive assessment against competing objectives for dam operations, in particular balancing water supply security, Dam Safety and impacts downstream of the Dam. This information was used to inform the State Government on the preferred balance between water supply and flood mitigation benefits.

In addition, specific flood information and resources are available from the two Local Government Areas affected by flooding in the Pine River Basin downstream of the Dam. City of Moreton Bay and Brisbane City Council publish flood maps, local floodplain management plans, and have put in place local Disaster Management Plans for flooding.

It is important to note that:

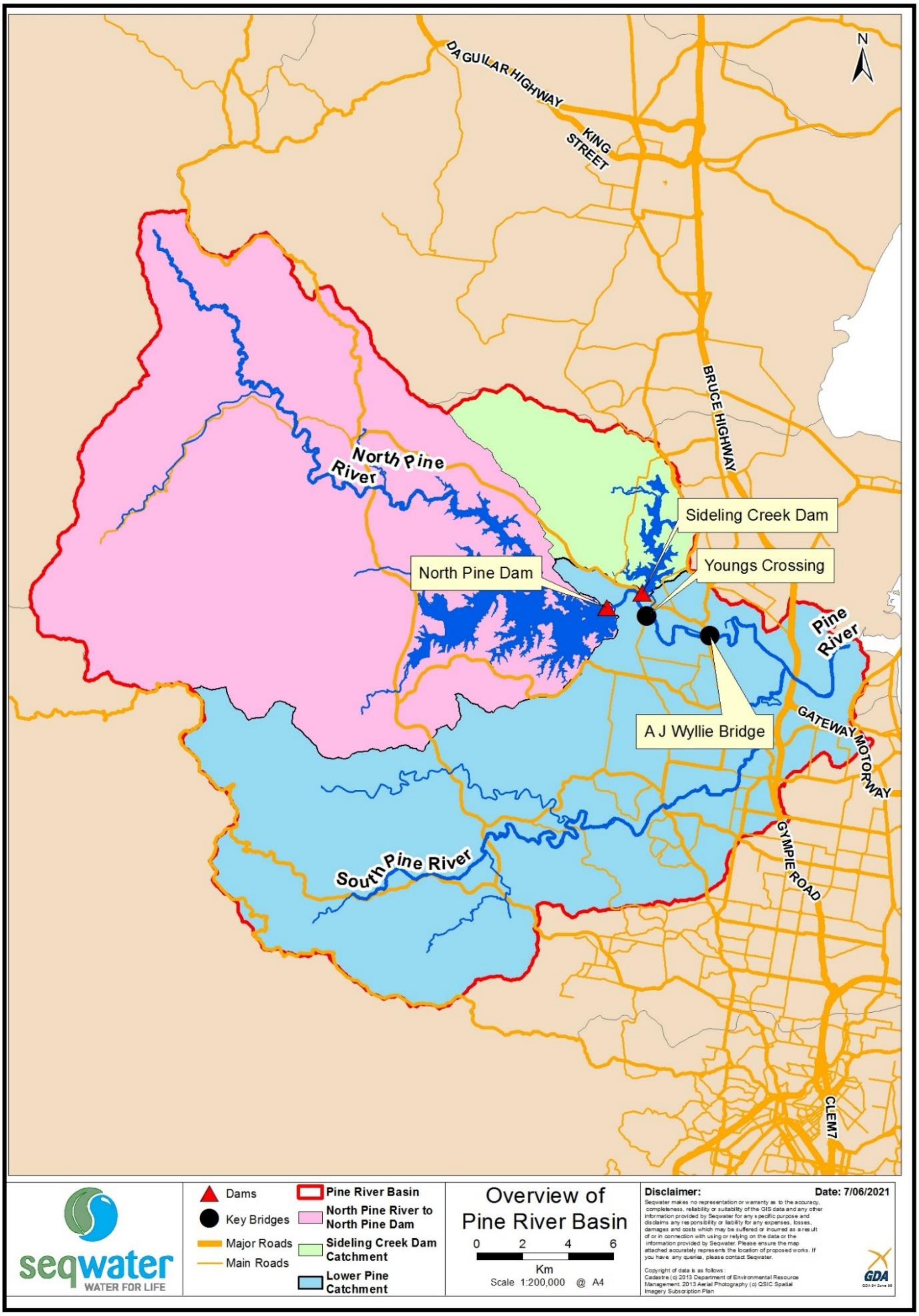
- Flood information derived specifically for flood maps and flood study reports published by Local Governments prepared or updated after NPDOS may provide more up to date information on downstream flood probability (note council studies are subject to assumptions of an applicable OFSL for North Pine Dam); and
- Notwithstanding flood studies and maps published by Local Governments the NPDOS investigations remains as the definitive study for investigating different operations for the Dam.

4.2 The Pine River Basin

The Pine River Basin has three sub-catchments[6] shown on Figure 4.2.1.

[6] River catchments can be divided into sub-catchments in different ways depending on purpose. The sub-catchment division shown in Figure 4.2.1 for this Manual represents the division represented in the hydrological models in the FFS (Section 7 describes the FFS).

Figure 4.2.1 Overview of Pine River Basin



North Pine Dam receives runoff from the North Pine sub-catchment.

Sideling Creek Dam is a small un-gated structure used for water supply purposes. It receives runoff from Sideling Creek catchment, a northern tributary that flows into the North Pine River at Youngs Crossing Road, which is downstream of the Dam.

The South Pine River flows into the North Pine River at Lawnton Pocket Road, which is about 13 km (river-distance) downstream of North Pine Dam. Downstream of this confluence, the river system is named as the Pine River, which discharges into Bramble Bay a further 7 km downstream from the confluence.

North Pine Dam does not modify the runoff generated in the Sideling Creek or Lower Pine sub-catchments, which flow into the North Pine River and Pine River downstream of North Pine Dam.

The D'Aguilar Range forms the western boundary of the catchment of the North Pine sub-catchment. The upper parts of the sub-catchment are in relatively steep terrain. It takes a short time for runoff to reach the Dam. There are multiple smaller tributaries of the North Pine River which directly enter the reservoir. These factors can produce large flood flows from short periods of rainfall of 12 hours or less (i.e. a fast catchment response time). This fast response time of the catchment and the limited size of the Flood Storage Compartment of the Dam are important factors in defining Procedures which aim to ensure the structural safety of the Dam.

Table 4.2.1 Sub-Catchment Areas, Pine River Basin

Sub-Catchment	Area (km^2)	Percentage
North Pine River to North Pine Dam	345	49%
Sideling Creek to Sideling Creek Dam	53	8%
Residual downstream sub-catchment to the mouth of the Pine River (includes South Pine River catchment)	305	43%
Total	703	**100%**

4.3 Full Supply Levels

North Pine Dam was designed and constructed as a water supply dam. It has limited capacity above the OFSL for flood water storage.

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 Dam under this Manual. The OFSL is determined from:

a. The Resource Operations Licence which specifies the full supply level for the Dam in the absence of a Temporary or Reduced FSL (described below);
b. Under the Act, the Minister can declare a Temporary FSL (TFSL) for the Dam for mitigation of floods and/or droughts. A Temporary FSL changes the balance between the size of the Water Supply Compartment and Flood Storage Compartment. 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 4.3.1 shows the OFSL for the various circumstances described above.

Table 4.3.1 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 level specified in the ROL (as at the date of the Manual) for North Pine Dam is 39.6 m AHD. The current OFSL for North Pine Dam is 36.0 m AHD which is based on the RFSL enacted by Seqwater in December 2019. The RFSL is expected to be in effect for the life of this revision of the Manual. The Procedures in this Manual have been developed on the assumption that the OFSL will be no higher than 36.0 m AHD.

4.4 North Pine Dam

North Pine Dam is located on the North Pine River, five kilometres upstream from Petrie. The Dam has a mass gravity concrete section, incorporating a central spillway structure with five radial gates, and is extended by earthfill embankments on either side. There are three saddle dams located further around the reservoir. Additional technical information relating to North Pine Dam is contained in Appendix A, Appendix B, Appendix C and Appendix D.

Figure 4.4.1 shows the general layout of North Pine Dam.

Figure 4.4.1 General layout of North Pine Dam showing component dam crest elevation and length

4.4.1 Main Dam

The main dam consists of a mass gravity[7] concrete section with a central gated spillway and is extended on each side by earthfill embankments. The main concrete section is 579 m long with a crest elevation of 43.28 m AHD, rising a maximum of 46 m above the bed of the North Pine River. The earthfill embankments are 188 m and 265 m in length on the left and right sides of the concrete section (looking downstream).

[7] Mass concrete dams use the weight of the concrete to generate friction between the dam and foundation to resist the water pressures acting on the upstream face and base of the dam.

4.4.2 Saddle Dams

In addition to the main dam structure, there are three earthfill saddle dams located along the southern side of the reservoir to retain floodwaters. All saddle dams have a crest width of approximately 11 m and various length and crest elevations as stated in Figure 4.4.1.

4.4.3 Storage Details

Table 4.4.1, Table 4.4.2 and Table 4.4.3 show basic details and storage characteristics of North Pine Dam.

Table 4.4.1 Key Details, North Pine Dam

Item	Details
Catchment Area	345 km^2
Main Embankment Crest Level	43.28 m AHD
Maximum Flood Storage Level (revised in 2019)	41.70 m AHD
Maximum Historic Flood Level (Jan. 2011)	41.11 m AHD

Table 4.4.2 Storage Characteristics, North Pine Dam (relative to Fixed Full Supply Level)

Relative to Fixed Full Supply Level [a]	
Fixed FSL defined in the Resource Operations Licence [a]	39.6 m AHD
Water Supply Storage below Fixed FSL	214,300 ML
Lake Surface Area at Fixed FSL	2,200 ha

[a] Based on the Fixed FSL of 39.6 m AHD and assumes no TFSL or RFSL is in place at the Dam.

Table 4.4.3 Storage Characteristics, North Pine Dam (relative to Reduced Full Supply Level)

Relative to the current Operational Full Supply Level [a]	
Operational FSL[a]	36.0 m AHD
Water Supply Compartment below OFSL	145,500 ML
Lake Surface Area at OFSL	1,700 ha
Flood Storage Compartment between OFSL and Maximum Flood Storage Level (41.7 m AHD)	117,900 ML

[a] Based on the current OFSL of 36.0 m AHD, which is based on the RFSL implemented by Seqwater in December 2019.

4.4.4 Details of Spillways and Outlet Works

Table 4.4.4 and Figure 4.4.2 show details of the spillway and outlet works at North Pine Dam. The spillway is a roller-bucket dissipator design. The outlet works consist of:

- Five (5) radial gates that regulate the flow of water over the spillway until the gates are lifted clear of flow;
- Two (2) cone valves (1,370 mm diameter); and
- A 300 mm diameter low flow regulator (not shown on Figure 4.4.2).

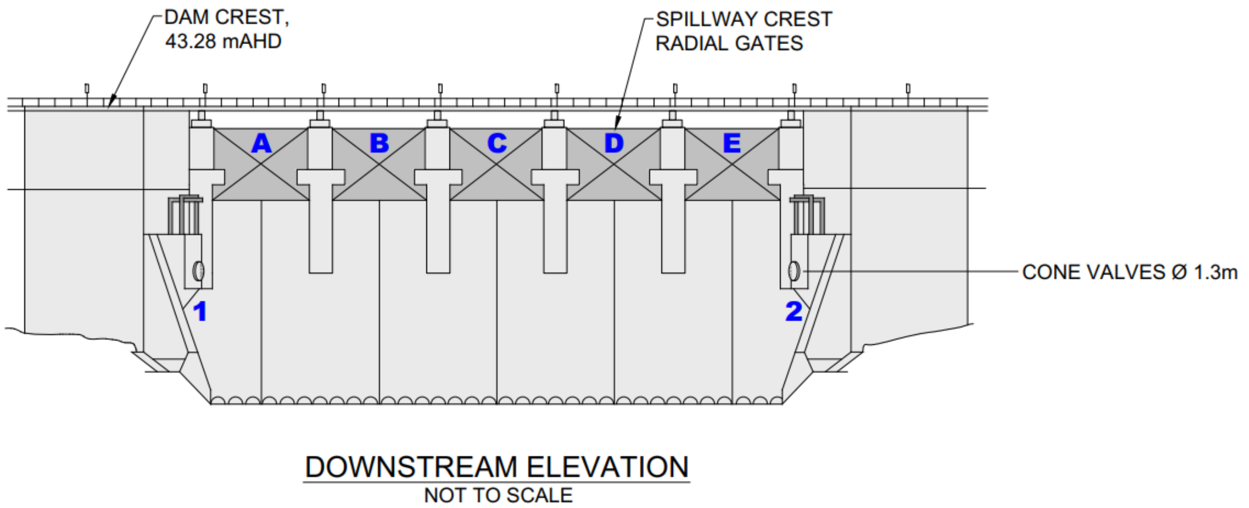
Radial gate and cone valve ratings are presented in Appendix B.

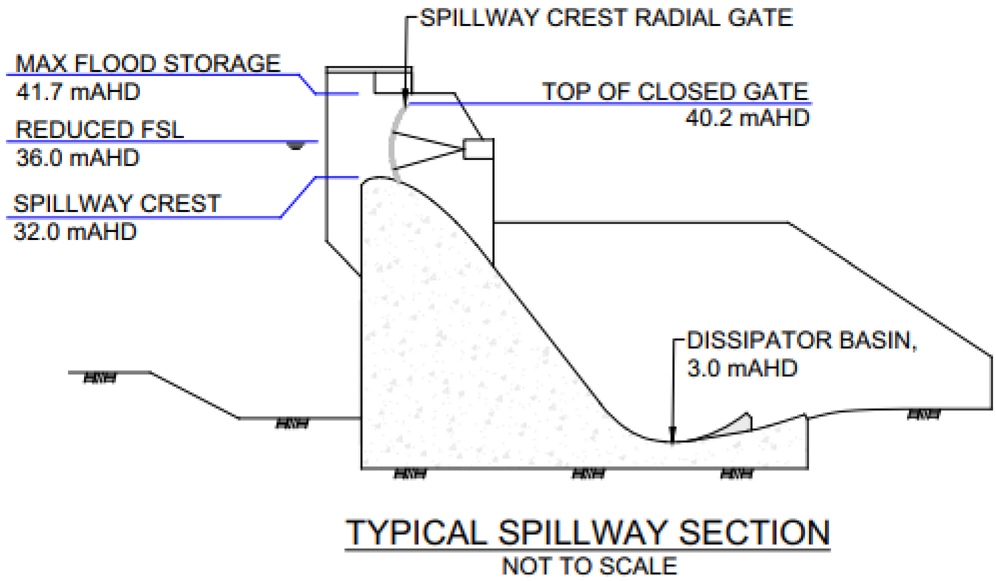
Table 4.4.4 Details of Main Spillway and Outlet Works, North Pine Dam

Item	Details
Spillway Crest Level	32.0 m AHD
Crest Width (excluding width of piers)	61 m
Radial Gates - 5 No.	12.2 m wide; 8.6 m high
Top of Closed Gates	40.23 m AHD
Maximum Flow through main spillway at Maximum Flood Storage Level (41.7 m AHD)[a]	3,770 m^3/s

[a] assumes all radial gates are fully opened.

Figure 4.4.2 Details of Spillway and Outlet Works, North Pine Dam





4.5 Sideling Creek Dam

Sideling Creek is a north bank tributary of the North Pine River with a catchment area of 53 km^2 to Sideling Creek Dam, a small dam located just over 1 km (river-distance) upstream from the confluence of Sideling Creek and the North Pine River. The dam is used for water supply purposes.

Due to its position in the catchment, outflows from Sideling Creek Dam contribute to flow at Youngs Crossing. Therefore, these outflows are considered when estimating flows in the North Pine River at Youngs Crossing only for parts of the Procedures that have relevance to consideration of Youngs Crossing inundation in limited circumstances.

The catchment for Sideling Creek Dam, together with the storage and spillway rating characteristics of Sideling Creek Dam are included in the flood routing models in the FFS described in Section 7. Sideling Creek Dam spillway flow commences when its Lake Level exceeds 20.37 m AHD; the water supply storage capacity of Sideling Creek Dam below its spillway level is 14,192 ML.

4.6 Downstream Flood Impacts for inundation of buildings

There are urban areas downstream of the Dam that can be impacted by inundation of the floodplains of the North Pine River and Pine River.

Investigations undertaken for NPDOS found relatively few buildings downstream of the Dam experienced above floor flooding for design events up to the 1 in 100 AEP flood, noting that the number of affected buildings was dependent on available data at that time. A more recent assessment provided by City of Moreton Bay (known as Moreton Bay Regional Council at the time of this assessment) identified a greater number of buildings for a given flood magnitude (flow rate) than that previously identified in NPDOS. This increase in number of affected properties is a result of improved information available to City of Moreton Bay regarding building footprint and floor level estimates.

The Procedures in this Manual that have influence on mitigating downstream flooding prescribe criteria for outflows from the Dam rather than targeting flows at a downstream location.

It is not practical for the flood operations at the Dam to target flows at a downstream location (say for example to consider flows in the South Pine River) because of the combined limitations of:

- the Dam has a relatively small Flood Storage Compartment (refer Section 4.4) which provides little capacity to store floodwater above OFSL to assist in targeting a downstream flow location; and
- the North Pine River sub-catchment (upstream of the Dam) has a fast response time – i.e., large flood inflows can occur very quickly (refer Section 4.2).

Table 4.6.1 provides a guide to the indicative downstream flood impacts related to peak outflows from the Dam. This information has been provided by City of Moreton Bay.

The indicative downstream flood impacts information is not required for real-time decision-making which must follow the Procedures.

It should be further noted as the information is related to outflow from the Dam the modelling used by City of Moreton Bay to derive this information has assumptions for concurrent flooding in the South Pine River and Sideling Creek Dam catchments. This means that actual flood impacts could be higher or lower than indicated in the table depending on the level of concurrent flooding – or simply this information must be interpreted as indicative impacts.

Table 4.6.1 Indicative Number of Properties and Impacts of Pine River Floods Related to Peak Outflow from North Pine Dam

Peak Outflow at North Pine Dam (m^3/s)	Minimum number of properties with above floor flooding with no flow in downstream catchment	Potential number of properties with above floor flooding with additional flow from downstream catchments	Notes on additional potential Pine River flooding impacts	Notes on downstream flows for potential property estimates	
				Downstream flow at Youngs Crossing (m^3/s)	Downstream catchment flow South Pine River at Cashs Crossing (m^3/s)
0	0	Approximately 10		50	320
300	0	Approximately 10		350	320
1,000	0	Approximately 50	Minor to moderate flooding in some areas due to river levels. **Flooding impacts exceeding January 2013 Flood Event**	1,200	1,000
1,500	1	Approximately 90	Major flooding in some areas due to river levels. **Flooding impacts similar to February 2022**	1,800	1,500
2,000	2	Approximately 170		2,500	2,000
2,500	10	Approximately 220	**Flooding impacts similar to January 2011 Flood Event.**	3,000	2,000
3,000	20	Approximately 360		3,500	2,000
4,000	100	Approximately 700	*Caution see note 3*	4,600	2,000

Important notes:

1. All values in the table have been reported to one or two significant figures.
2. Indicative impacts have been informed by modelling undertaken by City of Moreton Bay (known as Moreton Bay Regional Council at the time of this assessment) and contain assumptions about the magnitude of the concurrent flood in the catchments downstream of North Pine Dam.
3. For the Maximum Flood Storage Level at 41.7 m AHD the maximum outflow from North Pine Dam with all spillway gates fully open is approximately 3,750 m^3/s. North Pine Dam could fail at levels above 41.7 m AHD. This means caution is necessary for the last row in the table (for outflow 4,000 m^3/s) as failure of the Dam could occur before this outflow is achieved. The data in the table above for 4,000 m^3/s assumes the Dam has not failed above 41.7 m AHD.

4.7 Flood impacts at Downstream Crossings

4.7.1 Youngs Crossing

Youngs Crossing Road is approximately 3 km downstream of the Dam and 1 km downstream of Sideling Creek Dam. It is a major north-south transport link connecting the Moreton Bay and Brisbane City regions. The road is currently used by approximately 20,000 vehicles a day to cross the North Pine River; this is expected to increase to 22,500 vehicles by 2026[8].

The crossing consists of a low-level causeway with a flow capacity around 10 m^3/s. It can be inundated by water releases from North Pine Dam or spillway flows from Sideling Creek Dam or local catchment runoff or a combination of those flows.

The minimum radial gate opening setting at the Dam will result in the closure of Youngs Crossing Road as the release rate exceeds the flow capacity of the causeway. Extended releases from North Pine Dam greater than 10 m^3/s can result in long duration closures of Youngs Crossing.

[8] City of Moreton Bay: https://www.moretonbay.qld.gov.au/Services/Projects/Youngs-Crossing

4.7.2 AJ Wyllie Bridge

The AJ Wyllie Bridge is an important north-south traffic link across the North Pine River located 6.5 km downstream of North Pine Dam. The Bridge becomes untrafficable at a flow rate around 1,500 m^3/s. The bridge is infrequently affected by flood releases and is generally only impacted by moderately large flood events.

5 Mitigation of Peak Flood Flows by North Pine Dam

This Section describes how the storage and release of floodwaters at North Pine Dam can mitigate peak flood flows in the North Pine River. The extent of flood mitigation varies from event to event, depending on the amount, duration, spatial and temporal patterns of the flood-producing rainfalls over the Pine River Basin.

5.1 How the Dam Mitigates Flood Flows

The Dam can mitigate or reduce flood flows passing through the Dam by temporarily storing a portion of the flood inflows by restricting outflow. This can reduce and delay 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[9]; 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 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, North Pine Dam is operated in accordance with Procedures which are used to determine the timing, magnitude and duration of flood releases. The Procedures consider the inflow rate and volume, and the flood routing through the Dam[10] to consider predicted Lake Levels with actual and planned outflows to determine a Release Plan (this is described further in Section 8). With the relatively limited capacity of the Flood Storage Compartment above the OFSL and the importance of the Objective for Dam Safety (Section 9), temporary storage of flood water to significantly reduce outflow must be undertaken cautiously. Notwithstanding these limitations, studies[11], previous flood event operations[12], and simulated flood exercises[13] have consistently shown that peak outflow can be significantly mitigated relative to peak inflow in many flood events, particularly large flood events that have significant downstream impacts.

The Procedures allow for peak outflow to exceed peak inflow for outflows up to 300 m^3/s. This threshold was agreed with stakeholders following the NPDOS because flow rates up to 300 m^3/s are expected to have limited downstream impacts. While this means that some small floods are not mitigated it increases the ability to mitigate larger Flood Events.

[9] 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.

[10] Using the FFS described in Section 7.

[11] NPDOS simulations.

[12] Data in Appendix F.

[13] Undertaken as part of annual flood readiness activities (refer Section 3.8).

5.2 Flood Mitigation Downstream

The mitigation of peak dam outflows in larger events (Section 5.1) assists to mitigate peak flood flows further downstream along the North Pine River and Pine River below the junction with the South Pine River compared to a situation where the Dam had not been constructed.

The degree of mitigation further downstream will vary across Flood Events as the actual downstream flooding depends on the magnitude and timing of dam outflows combined with downstream catchment flows (Sideling Creek Dam outflows, South Pine River sub-catchment, and other areas contributing flow to the Lower Pine sub-catchment).

The Procedures in this Manual do not contemplate adjusting Release Plans to account for downstream catchment flows (for example to target a downstream flow location). This is due to the fact that the Dam has a small Flood Storage Compartment, there is a relatively fast catchment response time (refer Section 4.2), and the necessary higher priority to prevent structural failure of the Dam. One exception in the Procedures for circumstances limited to small floods is provision to consider the timing of inundation of Youngs Crossing (specific criteria are in the Procedures). This exception is intended more to reduce disruption to transport (given the significance of traffic volumes on Youngs Crossing) rather than mitigation of peak flood flows.

5.3 Every Flood is Different

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

Variability of flood-producing rainfall events[14] 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 Pine 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 Pine 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 Pine 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 160 mm of rainfall was absorbed by the ground in some parts of the Pine 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 North Pine Dam, also store runoff generated by the rainfall event and affect flood variability in downstream areas.
- **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).

[14] Flood levels along the lower reaches of the Pine 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 Pine River is most pronounced for smaller floods and progressively dissipates with distance upstream from the mouth of the Pine River.

6 Flood Operations Centre and Communications with Stakeholders

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 North Pine Dam.

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 North Pine Dam during Flood Events. A number of 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 Dam, in accordance with Section 12.1;
b. Maintaining communications between the Dam 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 14.3;
c. Using the FFS, in accordance with the requirements of the Manual, to assist in the selection of appropriate 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 Pine 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 Dam. 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 Pine River Basin. Through the operation of the FFS information on current and predicted releases from the Dam 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 Dam 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 Dam. The EAP operates in parallel with this Manual.

Dam hazard events include flood releases from North Pine Dam even if there is no threat to the safety of the Dam.

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.

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 Dam;
b. Advice on the planned commencement of releases from the Dam;
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. North Pine Dam outflow hydrographs to stakeholder agencies that operate flood modelling systems or flood warning systems.

6.2.2 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.

6.2.3 Bridge Closure Advice

Prior to the commencement of flood releases from the radial gates all reasonable steps should be taken to ensure that City of Moreton Bay has been advised of the commencement of the flood releases.

Runoff from areas downstream of the Dam can inundate roads and 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 to provide advance notice of bridge inundation.

6.2.4 Provision of Data to Agencies

At the commencement of a Flood Event, and whenever there is a significant change in Release Plan, the details of actual and predicted Lake Levels and outflows for North Pine Dam are provided to City of Moreton Bay and Brisbane City Council.

The contact information for City of Moreton Bay and Brisbane City Council are contained in the Emergency Action Plan for the Dam, and communications protocols with the councils are contained in the Communications Protocol.

7 The Flood Forecasting System

7.1 Overview

During a Flood Event, estimates of flood conditions in the Pine River Basin are essential for the planning of effective and responsible flood operations at North Pine Dam 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. Flood inflows into the Dam;
b. Predicted Lake Levels in the Dam as part of developing Release Plans (planned outflows); and
c. Flood flows primarily for the North Pine Dam catchment but some Procedures also require flows in the broader Pine River Basin to support operational decision making.

The FFS is an important decision-support tool that allows Duty Engineers to estimate predicted Lake Levels and flows in upstream and downstream catchments, including the simulation and assessment of Release Plans in accordance with the Procedures. The FFS allows efficient trialling of potential Release Plans to assess their effect on predicted Lake Levels and predicted downstream flood flows[15], based on information 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 the FFS using Rain on Ground and are revised many times during a Flood Event. The circumstances for qualitative situational awareness considerations of Rainfall Forecasts are described in Section 11.

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[16] in real-time across the Pine 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[17] 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.

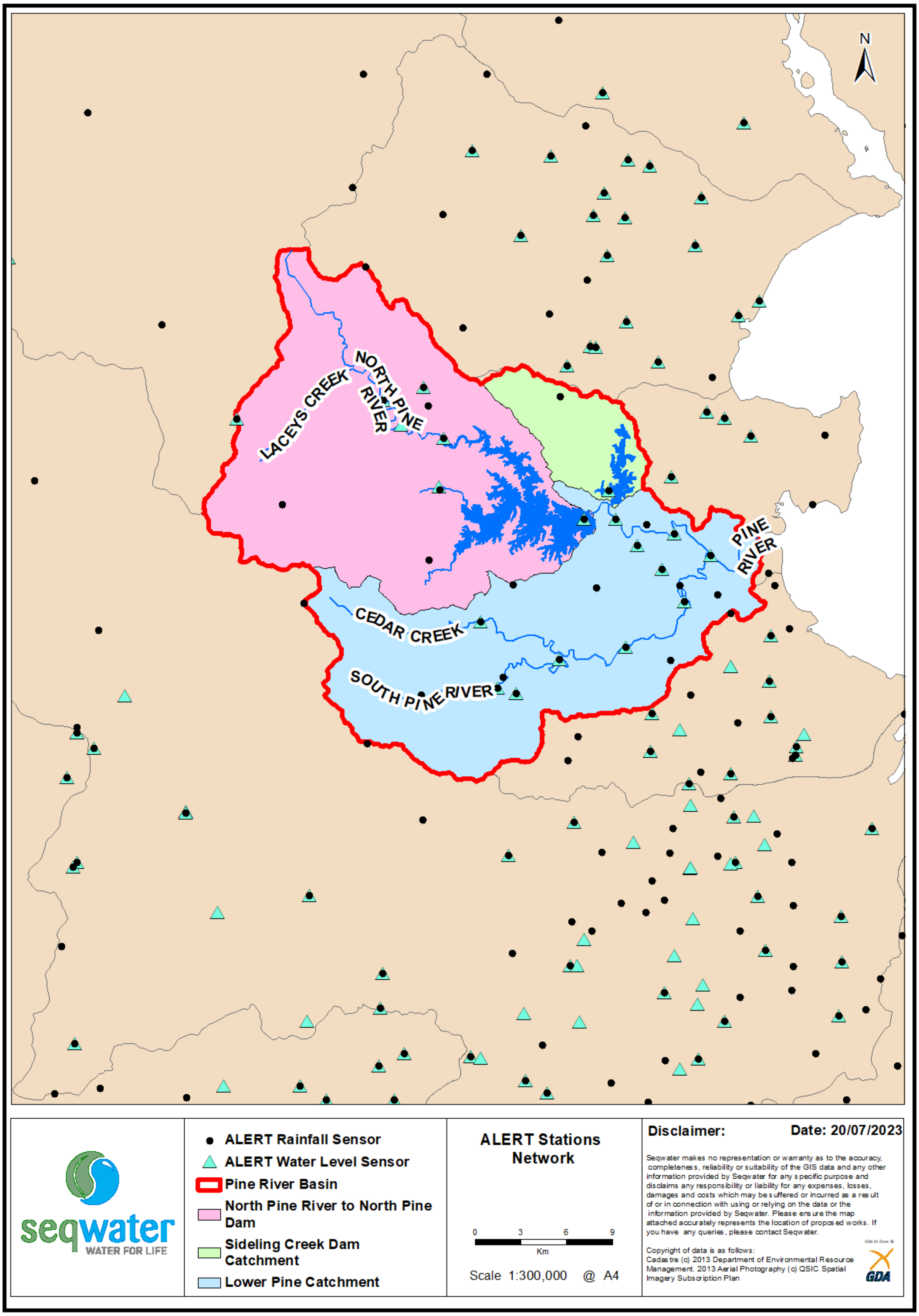
Figure 7.2.1 shows the location of these gauges near the Pine River Basin, as at July 2023. Gauges owned and operated by other agencies provide an additional level of real-time data redundancy, should gauges fail during a Flood Event. Seqwater owned ALERT gauges are monitored and maintained on a regular basis.

[15] Predicted downstream flows are required at a minimum for some aspects of the Procedures relating to consideration of Youngs Crossing (in limited circumstances as defined by the Procedures) and also to advise agencies of potential inundation of AJ Wyllie Bridge. The FFS intent for predicting downstream flows is solely limited to these requirements, the predicted downstream flows are not of the level of accuracy equivalent to predicting inflows (due to limitations of gauges for calibration), and downstream predictions are not purported to be suitable for flood warning other than the limited requirements for advising of potential bridge inundation.

[16] 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.

[17] 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, Pine River Basin and adjacent areas, as at July 2023.



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[18];
b. Telemetry data, manually read water level data, and Dam gate and Dam outlet settings, via the WISKI hydrometric database[19]; 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 predict catchment inflows and Lake Levels with such predictions based on Rain on Ground for use in developing Release Plans. The role of Rainfall Forecasts for situational awareness is set out in Section 11.

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[20];
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.

For the Pine River Basin, the FFS supports and facilitates the use of three hydrologic runoff-routing models[21] that simulate flood flow hydrographs at key locations of interest across the following sub-catchments of the Pine River Basin (see Figure 7.4.1):

a. North Pine River to North Pine Dam. This model has prime importance for dam operation decisions as it is used to predict inflows to the Dam;
b. Sideling Creek to Sideling Creek Dam. This model is used to determine whether Youngs Crossing will be inundated due to combined North Pine Dam and Sideling Creek Dam outflows; and
c. Lower Pine River, downstream of North Pine Dam and Sideling Creek Dam to the mouth of the Pine River. This incorporates the South Pine River catchment. This model is used to determine whether AJ Wyllie Bridge will be inundated due to combined North Pine Dam outflow and downstream catchment flows.

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[18] As at June 2023, 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.

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

[20] Refer to Section 11 regarding consideration of Rainfall Forecasts for situational awareness.

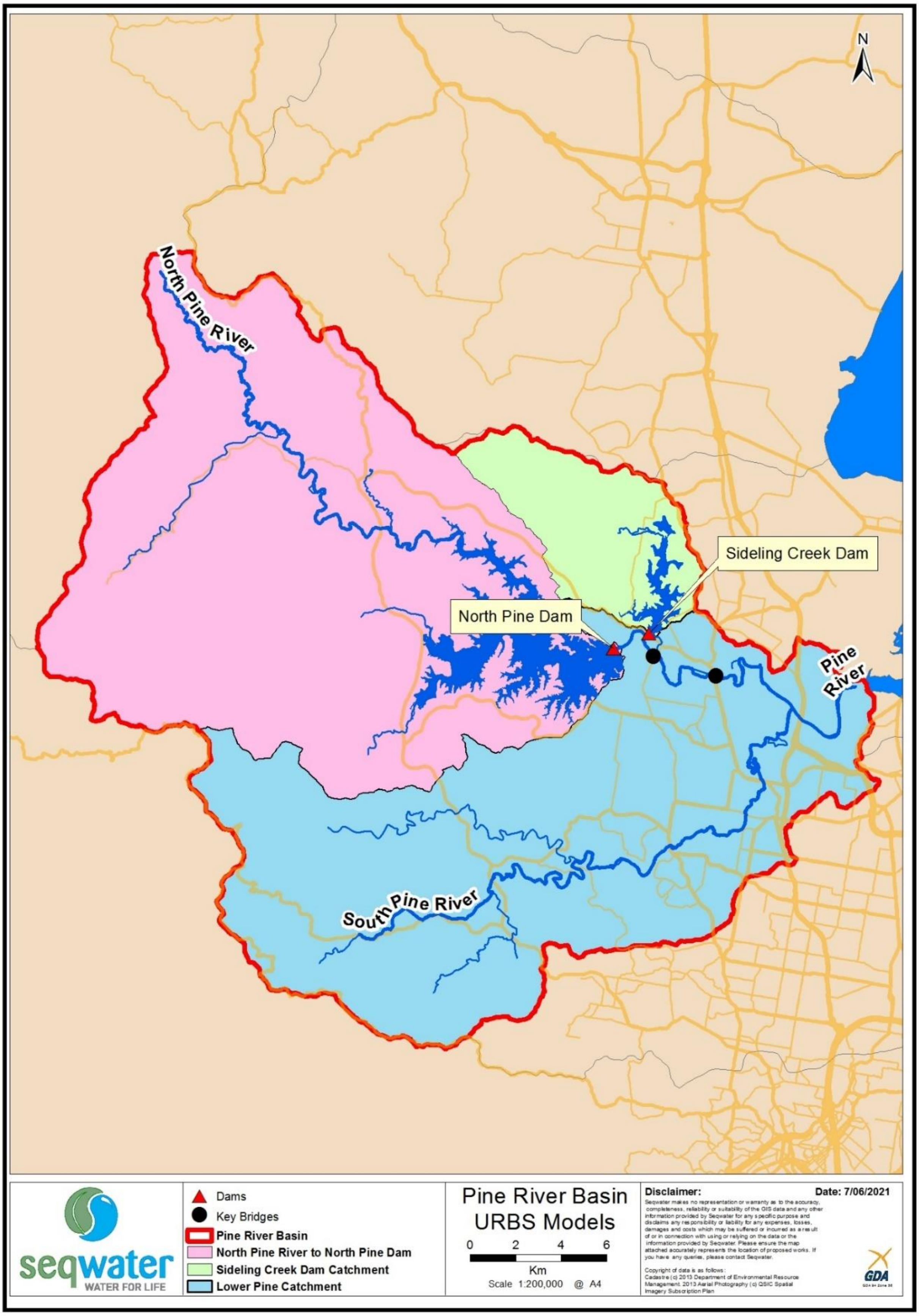
[21] Each of these models mathematically simulates catchment flow hydrographs, from the conversion of rainfall into catchment runoff, its subsequent movement as surface runoff, its passage downstream along the stream flow network, to its eventual transformation into an outflow hydrograph at the catchment 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 Pine River Basin.

These models have been calibrated to reproduce flood hydrographs for historic Flood Events.

Appendix G describes the important characteristics of flow hydrographs necessary for decision making to apply the Procedures in Section 12 and 13 of this Manual and the strengths and limitations of forecasting with actual rainfall (Rain on Ground).

Appendix H 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 H explains why Rainfall Forecasts are not used quantitatively to determine a Release Plan.

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[22] at key locations in the Pine 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 G.

7.5 Gate Operations Model

The Gate Operations Model, the final component of the FFS, is used to decide release rates from the Dam that meet the criteria specified in the Procedures through the development of a Release Plan. These decisions are made using predicted 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 Dam.

The Gate Operations Model simulates the combined effects of inflows to the Dam and outflows from the Dam on the predicted Lake Levels. The magnitude and timing of 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 predicted Lake Levels and flood flows at key downstream locations[23] 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.

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 Lake Levels and dam inflows

The predicted Lake Levels, Predicted Event Peak inflow and Predicted Future Peak Lake Levels are key determinants in many decisions regarding flood operations at North Pine Dam.

These predictions are made with the FFS. The predicted dam inflows are derived with the FFS using Rain on Ground. The predicted Lake Levels are determined based on the predicted future inflows to the Dam (derived with the FFS using Rain on Ground) with the current and projected releases set out in the Release Plan.

Section 8 describes the process for developing and implementing a Release Plan.

Section 3.4 describes important aspects of professional judgement when making decisions based on predicted Lake Levels.

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

[23] There are only limited circumstances (as defined by the Procedures) where the downstream flow impacts are required for determining if a Release Plan is appropriate.

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 the Lake Level in the Dam and outflow from the Dam.

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 predicted (event or future) flood conditions.

Predicted Lake Levels in the Dam are derived using the FFS with observed rainfall (Rain on Ground). These predictions are influenced by both current and future releases from the Dam. Predicted Lake Levels are also influenced by predicted 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 Dam using the FFS;
b. Trial a sequence of future releases (a Release Plan) in the Gate Operations Model and 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 Dam, 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 releases on Lake Levels and downstream flows[24]. The iteration process continues with adjustments to the 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).

[24] Impact of releases on downstream flows to inform decisions on Release Plans meeting criteria in the Procedures is limited to circumstances for potential inundation of Youngs Crossing in small Flood Events only. In these circumstances, the predicted flow at Youngs Crossing considers releases from North Pine Dam, spillway flow from Sideling Creek and local catchment flow.

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 Dam, 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 predicted Lake Levels in the Dam;
   iii. Potential trends including Rainfall Forecasts and associated guidance provided by the Bureau, including qualitative information (such as weather warnings) and quantitative rainfall forecast products; and
   iv. Professional judgement in relation to uncertainties in the above factors.

c. Other factors concerning Dam Safety and practical operations at the Dam are also taken into account including:

   i. Information from Dam Operators regarding Dam Safety, operability of gates, and spillway performance;
   ii. Any other matter pertaining to the safe operation of the Dam 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 Dam 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 11.

8.3 Predicted and Actual Flood Outcomes

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

a. further rainfall; or
b. variations in rainfall; or
c. additional data that becomes available to improve the calibration of the FFS simulations.

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

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

8.4 Implementing the Release Plan

Release Plans are implemented through the following actions:

a. Gate directives are issued to the Dam Operators who in turn adjust the gate settings in accordance with those directives;
b. Advice is provided to agencies responsible for bridge closures (refer to Section 6.2.3);
c. Actual and predicted Lake Levels in the Dam and actual and predicted releases from the Dam from the most up to date Release Plan are provided to relevant agencies (refer to Section 6.2.4);
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 Dam is monitored over the course of the Flood Event, to identify the development of unfavourable hydraulic conditions.

9 The Objectives

9.1 Introduction

In 2014, the Queensland Government completed the North Pine Dam Optimisation Study (NPDOS). NPDOS was initiated in response to the recommendations of the Queensland Floods Commission of Inquiry to investigate potential alternative operations of North Pine Dam during floods. The outcomes of NPDOS have been used to consider appropriate priorities and definition of objectives for the flood operations of the Dam.

9.2 Flood Operation Objectives

The Objectives for flood operations of the Dam and their importance relative to each other are as follows. When implementing the procedures that relate to each Objective, consideration is given to public safety.

Table 9.2.1 Objectives, North Pine Dam

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

Achieving these Objectives is the aim of flood operations, but circumstances can occur when not all Objectives will be met. This occurs because the Dam has a finite capacity and cannot fully protect downstream areas from flooding or safely pass all extreme floods.

Sections 9.3 to 9.6 below provide additional detail on the four Objectives listed above.

9.3 Primary Objective - Prevent structural failure of the Dam

The consequences of a structural failure of the Dam during a Flood Event would far outweigh any flood mitigation benefits arising from its operation.

Studies (North Pine Dam Stability Review, GHD, 2019) have shown that the most likely cause of a failure of the Dam is a structural failure of the mass concrete section of the Dam. The Dam is also likely to fail if the earth embankment sections, including the saddle dams, are overtopped (refer Table 9.3.1). The structural stability of the concrete section of the embankment cannot be assured once the Lake Level exceeds 41.7 m AHD.

Techniques for estimating extreme floods show that Flood Events that can potentially fail or overtop the Dam are possible. Failure of the Dam would produce catastrophic flooding consequences downstream and compromise regional water supply security for an extended period.

The structural safety of the Dam relies upon the operation of the radial gates. The electrical control equipment that operates the radial gates is located within the Dam structure and can become inundated by flood water during a Flood Event if the water level in the Dam continues to rise after the point that all radial gates are fully opened and the maximum possible dam release is being made. If this electrical control equipment becomes inundated by flood water, a back-up hydraulic control system is then used to operate the radial gates. These radial gate control systems are regularly tested as part of the routine maintenance schedule.

The critical levels for the operation of the Dam and the consequence of their exceedance are outlined in Table 9.3.1 below.

Table 9.3.1 Critical levels of relevance for structural safety of the Dam or capability to operate the Dam

Description	m AHD	Possible Consequence of Exceeding Critical Level
Top of spillway radial gate when in closed position	40.23	When flow overtops a closed radial gate damage to the gate is possible and/or there is uncertainty on whether it will be possible to open the gate.
Failure of the electrical control equipment that operates the radial gates due to flood water inundation	41.66	When gates are operable and following the Procedures in this manual, all radial gates will be fully open well below this level. Inundation of the electrical control equipment by flood water is likely to make this equipment unusable for the duration of the Flood Event. A back-up hydraulic control system provides capability to continue operating the gates if the electrical control system has failed.
Potential failure of the mass concrete sections of the Dam (Maximum Flood Storage Level)	41.7	The structural stability of the mass concrete section is no longer assured.
Likely failure of the earth embankment sections of Saddle Dam 3	43.23	Overtopping of the Saddle Dam 3 earth embankment and probable breach by erosion.
Likely failure of the earth embankment sections of Saddle Dam 2	43.26	Overtopping of the Saddle Dam 2 earth embankment and probable breach by erosion.
Likely failure of the earth embankment sections of the Main Dam	43.28	Overtopping of the earth embankment sections and probable breach of earth embankment sections by erosion.
Likely failure of the earth embankment sections of Saddle Dam 1	43.29	Overtopping of the Saddle Dam 1 earth embankment and probable breach by erosion.

As listed in Table 9.3.1, the Maximum Flood Storage Level for the Dam is 41.7 m AHD. Although the primary radial gate control gear fails at 41.66 m AHD, the back-up systems can maintain the operation of the radial gates until a point of dam failure. However, when the Actual Lake Level of the Dam reaches 41.7 m AHD, the concrete section of the Dam can potentially fail. Seqwater currently estimates that catchment rainfall exceeding 1,200 mm over a 36 hour period could cause a Flood Event to produce a peak Lake Level exceeding 41.7 m AHD with all spillway gates functioning, the OFSL at 36.0 m AHD, and the Dam is operated in accordance with this Manual during the Flood Event. The probability of a rainfall event of this magnitude is approximately 1 in 70,000 AEP.

The probability of exceeding the Maximum Flood Storage Level increases if one or more spillway gates are inoperable. In a worst case scenario with all five spillway gates inoperable, catchment rainfall exceeding 400 mm could cause a Flood Event to produce a peak Lake Level exceeding the Maximum Flood Storage Level with the OFSL at 36.0 m AHD. The probability of a rainfall event of this magnitude occurring over a number of days is approximately 1 in 20 AEP and rarer than 1 in 100 AEP if the rainfall occurs over a period of 18 to 36 hours. The probability of complete inoperability of all five spillway gates is very low, however if any gate becomes inoperable, and it is judged likely that the Predicted Future Peak Lake Level may exceed the Maximum Flood Storage Level, then early evacuation of potentially impacted downstream populations in accordance with the Emergency Action Plan should be considered.

9.3.1 Closely Spaced Large Floods

Historical records show that there is a significant probability of two or more flood producing rain systems occurring in the Pine River Basin within a short time of each other.

To protect the structural safety of the Dam against the risk of another closely spaced rainfall event, it is important that the Flood Storage Compartment is emptied soon after a rainfall event. Accordingly, the Procedures in this Manual reflect this requirement.

9.4 Secondary Objective - Ensure Water Supply Compartment is full at the end of a Flood Event

As the Dam is a major water supply storage for South East Queensland, it is essential that all opportunities to fill the Dam to the OFSL are taken. North Pine Dam has a critical support capability role for regional water supply to utilise the production rate at North Pine Water Treatment Plant when other regions are in drought (such as Sunshine Coast region), to cater for maintenance shutdowns in other parts of the water grid, and to meet peak demands for water supply. This means that although the North Pine Dam water storage percentage of the total grid storage is relatively low there is critical operational reliance upon that water supply.

This Objective is necessary to ensure the maximum volume of future water supply reserves (i.e. water stored to OFSL) is held in the Dam 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 13.2. 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.

9.5 Lower Order Objective - Mitigate Downstream Flooding

This Objective collectively addresses minimising risk to property and minimising disruption to transport to the extent practicable with the limited capacity of the Flood Storage Compartment of the Dam.

Flood releases can result in the submergence of bridges and floodplains which disrupts the communities downstream of the Dam. Background information on downstream flooding impacts is described in Section 4.6 and 4.7. Bridges downstream of the Dam are closed as they become inundated by flood releases. The estimated flow capacity of Youngs Crossing (8 to 10 m^3/s) is less than the outflow from one radial gate setting meaning that any radial gate release will cause the closure of Youngs Crossing and disruption to the downstream communities.

There is very limited opportunity to prevent inundation of Youngs Crossing during a Flood Event. This is because inundation can only be avoided if the radial gates are kept closed (subject to any runoff downstream of the Dam). Changing the timing of releases through the radial gates to reduce transport disruption can conflict with the highest priority Objective to prevent structural failure of the Dam, especially in larger Flood Events. The Procedures (Section 13) set out limited circumstances where radial gate releases may be delayed or suspended to minimise disruption to transport for small floods when there is low risk to the safety of the Dam to provide an appropriate balance between the Objectives.

Reducing risk to property and safety generally aims to reduce the magnitude of flooding downstream of the Dam compared to if the Dam had not been constructed. The Procedures aim to produce peak outflow less than the Predicted Event Peak inflow[25] if the Predicted Event Peak inflow exceeds 300 m^3/s. A threshold of 300 m^3/s dam release was agreed with stakeholders following the NPDOS because it was found to have limited impacts in terms of damage to property and the environment. Releases may exceed Predicted Event Peak inflow if the Predicted Future Peak Lake Level is judged likely to exceed 39.0 m AHD in circumstances where this may be necessary for opening of the radial gates in extreme floods[26] (specific criteria are in the Procedures).

A diagram of the Pine Basin and key locations is shown in Figure 4.2.1. Downstream bridges impacted by floods are outlined in Appendix E.

[25] The Predicted Event Peak inflow is determined using the FFS with Rain on Ground.
[26] This aligns to the highest priority to prevent structural failure of the Dam.

9.6 Lower Order Objective – Protect the Riverine and Riparian Environment

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 the 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 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 spillway of the Dam 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 Dam.

10 Strategies and overview of Flood Operations

10.1 Overview

Two Strategies are defined for the operation of North Pine Dam during Flood Events:

- The Flood Operations Strategy; and
- The Drain Down Strategy.

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. The Flood Operations Strategy is generally intended for the rising stages of a Flood Event until the peak of the Flood Event when the estimates of the flood magnitude are changing regularly. The Drain Down Strategy is generally intended for the falling stages of the Flood Event with an intention to drain the Lake Level to return to the OFSL. The Drain Down Strategy also applies when the Flood Event commences in response to the declaration of TFSL or RFSL in accordance with Section 15.3. These generalisations are a simple plain language description. Specific criteria for the selection of a Strategy are set out in the Procedures.

Table 10.1.1 provides a high-level summary of how each Strategy aims to achieve the Objectives. The Strategies are explained in more detail in Section 10.3. The specific Procedures for each Strategy are set out in Section 13.

Table 10.1.1 The Strategies, North Pine Dam

Strategy	How the Strategies Achieve the Objectives
Flood Operations Strategy	• Strategy applies when the Lake Level is expected to rise above the actual peak Lake Level which has already occurred in that Flood Event and rainfall is expected to continue. This ensures sufficient storage is reserved for extreme floods to prevent structural failure of the Dam. • Procedures require higher releases at higher Lake Levels to prevent structural failure of the Dam. • Peak outflow may exceed the Predicted Event Peak inflow if the Predicted Future Peak Lake Level is judged likely to exceed 39.0 m AHD. This level is an extreme flood and provides for the highest priority of preventing structural failure of the Dam. • Criteria in the Procedures constrain releases below OFSL to ensure the Water Supply Compartment can be refilled. • Releases up 300 m^3/s are permitted irrespective of Predicted Event Peak inflow. This preserves flood storage which assists to mitigate peak outflow in larger floods. Releases of less than 300 m^3/s are understood to have minimal impact on property or the environment. • If the Predicted Event Peak inflow exceeds 300 m^3/s and the Predicted Future Peak Lake Level is judged unlikely to exceed 39.0 m AHD, releases must not exceed the Predicted Event Peak inflow rate. This mitigates flooding in larger floods by aiming to ensure that peak outflow is less than peak inflow. • When the Predicted Future Peak Lake Level will exceed 0.2 m above OFSL the Procedures require minimum releases depending on the Lake Level. This permits early high releases which preserves flood storage (consistent with the Objective of ensuring the structural safety of the Dam) while reducing the outflow from the Dam compared to peak inflow. • When the Predicted Future Peak Lake Level will not exceed 0.2 m above OFSL the Procedures allow for delay or temporary suspension of releases to minimise disruption to transport (Youngs Crossing). • Limits apply to how fast gates can be opened or closed to reduce adverse environmental outcomes from rapidly changing flow conditions. • Exit criteria to adopt Drain Down Strategy.
Drain Down Strategy	• Requirement to empty the Flood Storage Compartment within 72 hours. This is necessary to ensure the Flood Storage Compartment is fully available should another Flood Event occur soon after the current event (for the Objective to prevent structural failure of the Dam). • Criteria to end the Flood Event ensures that the Water Supply Compartment is full at the end of the Flood Event. • Procedures define maximum release rates to ensure outflow will not increase above the peak outflow for the Flood Event or 300 m^3/s (for the Objective for mitigation of downstream flooding). • If releases have exceeded 1,500m^3/s, the Strategy contains Procedures to reduce releases below 1,500 m^3/s to minimise disruption to transport by allowing AJ Wyllie Bridge to be reopened. • Procedures permit suspending gate releases if the Predicted Future Peak Lake Level will not exceed 0.2 m above OFSL to minimise transport disruption (Youngs Crossing). • Protection of 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 Flood Operations Strategy if the Lake Level is predicted to rise above the actual peak Lake Level that has occurred, or there is an uncertain weather outlook.

10.2 Operation of Radial Gates

Releases from North Pine Dam are controlled by the five radial gates across the main spillway. Gate outflow is governed by the gate opening and Lake Level. The actual outflow from the Dam can be different for the same gate opening depending on the actual Lake Level, i.e. the higher the Lake Level, the greater the gate outflow for the same gate opening.

There are prescribed limitations to the operation of the gates. The gates are 12.2 m wide and 8.6 m high, and if opened or closed too quickly, can cause undesirable rapid changes in downstream flows and water levels. The Procedures in Section 13 specify the gate opening sequence and the maximum rates at which the gates can be opened and closed.

Limitations of radial gate operation at North Pine Dam need be taken into account when determining Release Plans. Practical limitations for gate operations at include:

- The gates must not be overtopped;
- Interaction between the bottom of the gate and the spillway flow can generate significant turbulence and vibration, with potential adverse impacts on the gate[27]; and
- Significant turbulence and vibration can also be generated when an open gate is lowered back into the spillway flow[28] after it has been lifted clear of the flow.

The radial gate rating table in Appendix B provides guidance on the hydraulic control regime for a range of potential Lake Levels and gate openings.

10.3 The Flood Operations Strategy

The Flood Operations Strategy is selected at the commencement of a Flood Event (as defined in Section 12.2) except if a Flood Event commences in accordance with provisions set out in Section 15.3 (in response to the declaration of TFSL or implementation of RFSL).

The Flood Operation Strategy applies until the Actual Lake Level has peaked (i.e. future predicted Lake Levels are equal to or less than the actual peak Lake Level) and that rainfall is judged likely to be complete or nearly complete. Both criteria must be met to cease using the Flood Operations Strategy.

In some Flood Events it may be necessary to re-enter the Flood Operations Strategy. This can occur after operating in the Drain Down Strategy. This is addressed in the exit criteria for the Drain Down Strategy.

The Procedures for the Flood Operations Strategy are set out in Section 13.1.

Procedure 1a contains criteria for a Release Plan to achieve an appropriate balance between the Objectives for small Flood Events when there is very low risk to the safety of the Dam.

Procedure 1b places greater emphasis on the primary Objective to prevent structural failure of the Dam with a corresponding balance across lower order Objectives.

Procedure 1c defines requirements to ensure radial gates are fully opened in extreme floods to prevent structural failure of the Dam and the continuing requirements while the radial gates are fully open. When the radial gates are fully opened, extreme floods pass through the Dam similar to an ungated dam. When this occurs peak outflow in most situations will be less than peak inflow[29]. There is some potential for peak outflow to exceed peak inflow in very limited circumstances during or immediately following the transition to achieve gates fully open. This requires careful judgement about the rate to achieve radial gates fully open for the circumstances of the particular Flood Event.

10.4 The Drain Down Strategy

The Drain Down Strategy generally applies after Flood Operations Strategy, except if the Flood Event has commenced in accordance with Section 15.3 (in response to the declaration of TFSL or implementation of RFSL).

The Drain Down Strategy is selected when:

- the Actual Lake Level has peaked (i.e. future predicted Lake Levels are equal to or less than the actual peak Lake Level during the course of the Flood Event to that time); and
- the rainfall is judged likely to be complete or nearly complete.

Both criteria must be met to apply the Drain Down Strategy.

The Procedures for the Drain Down Strategy are set out in Section 13.2.

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

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

[29] For ungated dams, the peak outflow is universally less than the peak inflow due to the storage routing influence of the dam.

11 Consideration of Rainfall Forecasts

11.1 Overview

11.1.1 Primary basis of Release Plans

The primary intent and application of the Procedures (refer Section 13) 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 G 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 H (for information purposes only).

11.1.2 Situational awareness consideration

Aspects of the Procedures involve professional judgements in the magnitude and timing of releases. In exercising that professional judgement 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 is necessary with the uncertainty in Rainfall Forecasts, there can be benefits from qualitative consideration of Rainfall Forecasts. In this context it is important to distinguish:

a. Consideration of Rainfall Forecasts for **situational awareness**. This involves using forecasts qualitatively. Situational awareness can be useful in guiding qualitative professional judgement decisions. Examples where such qualitative judgements are made include the decision to mobilise the Flood Operations Centre (described in Section 11.3) and judging whether rainfall is complete or nearly complete (described in Section 11.4).
b. An **outlook of the potential trend of the Flood Event** estimated with Rainfall Forecast data that 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 the forecast uncertainty and suitable caution as 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 the 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 Dam 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[30] (ADFD) grids which are used for consideration of situational awareness or, for an outlook of the potential trend of a Flood Event.

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

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 H.

11.2 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 15.3). 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).

Once a Flood Event has commenced (Section 12.2), the Procedures in Section 13 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.

11.3 Consideration of Rainfall Forecasts in Flood Operations Centre Mobilisation

This provision is based on situational awareness (refer Section 11.1).

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 Dam.

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 catchment 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 Dam and the Flood Operations Centre;
- The issue of a Flood Watch by the Bureau for areas in and adjacent to the Pine River Basin.

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

This provision is based on situational awareness (refer Section 11.1).

Procedures in Section 13 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 Pine 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.

12 Commencement and Ending of Operations

12.1 Flood Operations Centre Mobilisation and Demobilisation

The DSFOE may mobilise the Flood Operations Centre when 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.

12.2 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[31] in the Dam 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 rise more than 0.1 metres above the OFSL.

Such determinations:

i. must be made based on Rain on Ground;

ii. may be made before the Actual Lake Level in the Dam rises above the OFSL.

When a Flood Event commences in accordance with this section the Strategy is set to the Flood Operations Strategy. If a Flood Event commences in accordance with provisions in Section 15.3 (declaration of Temporary FSL or implementation of Reduced FSL), the Strategy is set to the Drain Down Strategy.

The DSFOE will determine that a Flood Event has ended when the conditions listed in the Drain Down Strategy in Section 13.2 are met.

[31] When calculating the predicted Lake Level in the Dam for the purpose of determining if a Flood Event has commenced, it is assumed that no radial gate releases will be made from the Dam. This is because the Release Plan will contain zero radial gate releases prior to Flood Event commencement.

13 North Pine Dam Strategy and Procedures

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

- **Background information**: Section 4 contains background information relating to the Dam, Sideling Creek Dam and 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 at North Pine Dam**: Section 10 contains a description of the Strategies and Procedures to meet the Objectives;
- **Technical Appendices**: Appendix A, Appendix B and Appendix D contain additional technical information relating to North Pine Dam.

13.1 Flood Operations Strategy

At the start of a Flood Event (except in the circumstances set out in Section 15.3), the Flood Operations Strategy must be selected. This Strategy may also be selected according to the exit criteria of the Drain Down Strategy. 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 Operations Strategy
1.	**Determine a Release Plan with inflow and Lake Level predictions from the FFS based on Rain on Ground**
1a	Procedure 1a is used when: • the Predicted Future Peak Lake Level is judged likely to be less than or equal to 0.2 metres above OFSL with a maximum release limit of 300 m^3/s and applying the criteria set out below; and • the exit criteria for the Flood Operations Strategy (Procedure 2) are not met. The Release Plan must meet all 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 if the DSFOE judges it very likely, that the predicted Lake Level will exceed the OFSL after accounting for all releases in the Release Plan. ii. Once releases commence, the Release Plan must always ensure 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 maximum radial gate opening and closing rates are not more than two (2) metres of opening or closing (total movement across one or more gates) in one hour. iv. It is permissible to delay or temporarily suspend radial gate releases for the purpose of minimising disruption to downstream communities by altering the time which inundation of Youngs Crossing occurs. v. If a complete closure of the radial gates is required, the timing of radial gate closure should consider the requirements for a safe and adequate fish recovery operation downstream of the Dam. vi. Releases can exceed the Predicted Event Peak inflow into the Dam, and must not exceed 300 m^3/s. vii. In accordance with Section 13.3, adjust the Release Plan if it is judged likely that the gate settings in the Release Plan may lead to adverse turbulence or vibration that can damage the radial gates or threaten the structural safety of the Dam. viii. The Release Plan is developed to avoid the Predicted Future Peak Lake Level exceeding 0.2 metres above the OFSL. If the criteria in (i) to (viii) cannot be met, apply Procedure 1b.

ID	Procedures for Flood Operations Strategy (continued)
1.	**Determine a Release Plan with inflow and Lake Level predictions from the FFS based on Rain on Ground**
1b	Procedure 1b is used when: • the criteria for Procedure 1a cannot be met, and • the Predicted Future Peak Lake Level is judged unlikely to exceed 39.0 m AHD with the application of the criteria in (i) to (vi) below, and • the exit criteria for the Flood Operations Strategy (Procedure 2) are not met. The Release Plan must meet all 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 if the DSFOE judges it very likely, that the predicted Lake Level will exceed the OFSL after accounting for all releases in the Release Plan. ii. Once releases commence, the Release Plan must always ensure 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 maximum radial gate opening and closing rates are not more than three (3) metres of opening or closing in one hour (total movement across one or more gates). This can be exceeded to ensure that the minimum release requirements in criteria (v) are met. iv. The peak release in the Release Plan must not exceed the Predicted Event Peak inflow rate or 300 m^3/s (whichever is greater). v. Within two hours of commencing Procedure 1b, the gate settings must equal or exceed those required by Appendix C unless this would result in the release rate exceeding the limit in criteria (iv). If applying gate settings equal to or exceeding those required by Appendix C would result in the release rate exceeding the limit in criteria (iv), the release rate must be as close as possible to the limit in criteria (iv) without exceeding it. For the avoidance of doubt, the Lake Levels and corresponding release rates in Appendix C are to be read as applying to the predicted Lake Level and total gate settings at each time point in the Release Plan. vi. In accordance with Section 13.3, adjust the Release Plan if it is judged likely that the gate settings in the Release Plan may lead to the gates being overtopped, or to adverse turbulence or vibration that can damage the radial gates or threaten the structural safety of the Dam. If it is judged likely that the application of the criteria in (i) to (vi) above will result in the Predicted Future Peak Lake Level exceeding 39.0 m AHD, apply Procedure 1c.

ID	Procedures for Flood Operations Strategy (continued)
1.	**Determine a Release Plan with inflow and Lake Level predictions from the FFS based on Rain on Ground**
1c	Procedure 1c is used when: • the Predicted Future Peak Lake Level is judged likely to exceed 39.0 m AHD with the application of the criteria in Procedure 1b; and, • the exit criteria of the Flood Operations Strategy (Procedure 2) are not met. Important contextual information on conditions that could occur with this Procedure: • An Actual Lake Level of 39.0 m AHD is higher than the level at which the radial gates should be fully open; • The predictions made with Rain on Ground forecasts of inflows and Lake Levels could result in situations in some very extreme Flood Events where the Actual Lake Level is lower than 39.0 m AHD and the radial gates are not yet fully open at the time that this Procedure is required. The relevant procedures to apply depend on whether or not the radial gates are fully open. **If the radial gates are currently in the fully open position:** i. Maintain the gates in fully open position until the Lake Level has peaked. ii. While further gate movements are not possible with gates fully open, continue forecasting of the Predicted Future Peak Lake Level for the purpose of informing possible actions necessary for the Emergency Action Plan. iii. Maintain gates in the fully open position after the Actual Lake Level peak until: a. conditions are met for the exit criteria of the Flood Operations Strategy (Procedure 2) or; b. if it is not possible to meet the exit criteria of the Flood Operations Strategy (Procedure 2) and the Actual Lake Level is below 39.0 m AHD and it is judged likely that the predicted Lake Level will remain below 39.0 m AHD, then apply Procedure 1b. **If the radial gates are currently not in the fully open position:** iv. A Release Plan must be developed that increases the gate settings to equal or exceed those required by Appendix C. Rate of opening gates should be at minimum three (3) metres per hour. v. 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. vi. The releases may exceed the Predicted Event Peak inflow if this is necessary for faster gate opening in circumstances when the Predicted Future Peak Lake Level is judged likely to significantly exceed 39.0 m AHD. vii. Until the radial gates are fully open continue reassessing criteria (iv) to (vi) until one of the following conditions are met: a. radial gates are fully open; or b. conditions are met for the exit criteria for the Flood Operations Strategy (Procedure 2); or c. if it is not possible to meet the exit criteria for the Flood Operations Strategy (Procedure 2) and the Actual Lake Level is below 39.0 m AHD and it is judged likely that the predicted Lake Level will remain below 39.0 m AHD, then apply Procedure 1b. viii. In accordance with Section 13.3, adjust the Release Plan if it is judged likely that the gate settings in the Release Plan may lead to the gates being overtopped, or to adverse turbulence or vibration that can damage the radial gates or threaten the structural safety of the Dam.

ID	Procedures for Flood Operations Strategy (continued)
2.	**Check Exit Criteria**
2a	The Drain Down Strategy must be selected if: i. The rainfall is judged likely to be complete or nearly complete; and ii. It is judged likely that, when taking into account the current Release Plan, predicted inflows will not cause a Lake Level rise above the actual peak Lake Level observed since the Flood Event commenced.

13.2 Drain Down Strategy

The Drain Down Strategy is commenced according to the Exit Criteria in the Flood Operations Strategy or when the circumstances in Section 15.3 apply. 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 with inflow and Lake Level predictions from the FFS based on Rain on Ground**
1a	The aim of this strategy is to empty the Flood Storage Compartment of the Dam within 72 hours of entering Drain Down Strategy. Procedure 1 requires the application of the following criteria (as applicable) until exit criteria for the Drain Down Strategy are met (Procedure 2a) or a Flood Event is ended in accordance with Procedure 2b: i. In accordance with Section 13.3, adjust the Release Plan if it is judged likely that the gate settings in the Release Plan may lead to either the gates being overtopped or adverse turbulence or vibration; ii. The maximum release rate cannot exceed the greater of 300 m^3/s or the peak release of the current Flood Event; iii. To protect the downstream environment, aim to reduce releases by closing the radial gates no faster than two (2) metres per hour (total movement across one or more gates). Faster closing rates may be used if considered necessary to ensure the Water Supply Compartment will be full at the conclusion of the Flood Event; iv. If the peak release for the current Flood Event exceeded 1,500 m^3/s, aim to reduce the release to less than 1,500 m^3/s to allow the AJ Wyllie Bridge to be opened; v. It is permissible to delay or temporarily suspend radial gate releases for the purpose of minimising disruption to downstream communities only if the Predicted Future Peak Lake Level is not predicted to rise more than 0.2 metres above the OFSL; vi. Procedure 2b must be considered when the Actual Lake Level is less than 0.1 metres above the OFSL; vii. The timing of the final radial gate closure should consider the requirements for a safe and adequate fish recovery operation downstream of the Dam.

ID	Procedures for Drain Down Strategy
2.	**Check Strategy Exit Criteria**
2a	i. The Flood Operations Strategy **may** be selected if: a. During the drain down period, it is judged likely that predicted inflows will cause the Lake Level to rise significantly, and/or an uncertain weather outlook does not allow Drain Down Procedure 1a(ii) to be applied. ii. The Flood Operations Strategy **must** be selected if: a. The rainfall is judged unlikely to be complete or nearly complete; or b. It is judged likely that, when taking into account the current Release Plan, the Predicted Future Peak Lake Level rise above the actual peak Lake Level observed since the Flood Event commenced.
2b	i. The Flood Event **may** end 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. The Flood Event **must** end 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 and ongoing operational releases.

13.3 Radial Gate Operation

13.3.1 Radial Gate Operation Sequence

The nominated sequence of operating different radial gates for each increment of movement is:

C – C – E – E – A – A – D – D – B – B when using 0.5 metre increments.

The aim of the nominated opening sequence is to minimise the time a gate may be positioned within the transition flow region of the single gate rating when lifting the gate clear of flow (refer Figure B.1). The nominated opening sequence is contained in Appendix C table which requires multiple movements of a single radial gate before movements occur at a different radial gate. Appendix C provides primary guidance for sequence of specific movements.

Radial gates are normally closed in reverse order of opening. The Duty Senior Flood Operations Engineer may modify the opening and closing sequence for consideration of risks to the operability of radial gates, to aid the fish recovery operation or, to reduce probability of potential damage to the Dam, providing that the release rates intended by the Procedures are achieved. The DSFOE must issue a Directive to the Dam Supervisor for any modifications to the radial gate opening or closing sequence.

When directing radial gate operations at the Dam, consideration should be given to the infrastructure and personnel related limitations involved in undertaking rapid gate movements under flood conditions.

13.3.2 Gate Failure or Malfunction Procedures

If one or more radial gates are inoperable during the course of the Flood Event, the openings of the remaining radial gates are to be adjusted to provide approximately the same total release for a particular Lake Level. When adjusting the radial gate settings and sequence, endeavour to maintain the flow in the spillway as symmetrical as practicable.

Appendix C contains radial gate settings against Lake Levels for the situations where all gates are operating.

13.3.3 Lifting Radial Gates Clear of the Release Flow

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. Guidance for the possible occurrence of such conditions is provided in Figure B.1 in Appendix B. If adverse turbulence or vibrations are observed during flood operations, then the bottom edge of the radial gate should be lifted clear of the water surface.

The maximum radial gate opening rates in the Procedures in Section 13.1 and 13.2 apply to movement of the gate while in contact with the flow.

13.3.4 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 unusual turbulence that could adversely impact on the radial gate. Guidance for the possible occurrence of such conditions is provided in Figure B.1 in Appendix B. If this condition is observed during flood operations, then the bottom edge of the radial gate should be lowered sufficiently to restore stable orifice flow through the spillway.

The maximum radial gate closing rates in the Procedures in Section 13.1 and 13.2 apply to movement of the gate while in contact with the flow.

14 Emergency Flood Operations

14.1 Introduction

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

- Occurrence of a Flood Event that may cause the Lake Level to exceed the Maximum Flood Storage Level or overtopping of the Dam;
- Failure of the operation of one or more radial gates during a Flood Event;
- Development of a piping failure through the embankment of the Dam;
- Damage to the Dam by earthquake; or
- Damage to the Dam as a result of an act of terrorism.

Responses to these conditions are contained in the primary guidance document for emergency conditions at the Dam, which is the Emergency Action Plan.

The following sections provide some additional guidance. This additional guidance does not replace the requirements in the Emergency Action Plan. The guidance is for flood operation of the dam in the event of possible or actual emergency situations.

14.2 Dam Failure Considerations

Preventing a structural failure of the Dam is the primary consideration in the operation of the Dam during Flood Events. In the extreme circumstance the Predicted Future Peak Lake Level will exceed the Maximum Flood Storage Level of 41.7 m AHD, a Release Plan may be developed using professional judgement in an attempt to avoid dam failure. This may involve fully opening all radial gates as quickly as possible. However, it is acknowledged that a Release Plan developed to minimise the likelihood of dam failure in these circumstances may not always achieve its objective.

In this circumstance, the notifications and actions (including the evacuation of potentially impacted downstream populations) specified under the Emergency Action Plan should be undertaken.

Whatever the circumstances, every endeavour must be made to prevent the Lake Level reaching the Maximum Flood Storage Level by the progressive opening of radial gates. If the Lake Level reaches the Maximum Flood Storage Level, the Dam may fail.

Reaching the Maximum Flood Storage Level may result from extreme floods or in lesser floods when inundation or failure of the radial gate control equipment occurs and there is subsequent loss of gate control. The behaviour of the Dam at such extreme levels is unpredictable, and failure of the Dam at Lake Levels at or above the Maximum Flood Storage Level is not certain.

In the unlikely event that other unexpected potential dam failure scenarios arise during the course of a Flood Event a Release Plan should be developed using professional judgement in an attempt to minimise the likelihood of dam failure.

14.3 Dam Operator Actions in the Event of Communications Failure

During a Flood Event, it is possible that communications could be lost between the 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 Wivenhoe Dam or the Dam Supervisor at Somerset Dam; and
g. Via the Police and Emergency Services personnel.

If communications still cannot be established with the Flood Operations Centre, the Dam Supervisor is to follow the procedures below.

14.3.1 North Pine Dam Loss of Communications Procedure

In the event of communication loss between the Flood Operations Centre and the Dam, the Dam Supervisor is to assume responsibility for flood releases from the Dam. Once it has been established that communications have been lost, the Dam Supervisor is to:

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 to determine the appropriate radial gate settings.

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 outlined below applied as required. Once communications are re-established with the Duty Engineers, the responsibility for directing flood operations is returned to the Duty Engineers.

If communications with the Flood Operations Centre are lost, appropriate radial gate settings at the Dam are determined by following Appendix C. The guidance is as follows:

a. Check the applicable OFSL in the first Directive issued by the Flood Operations Centre. If no Directives have been received, determine the OFSL as defined in the Glossary at the start of this Manual. Note that the OFSL is the maximum level for water supply storage and is not the current Actual Lake Level.
b. Once the OFSL is determined, follow Appendix C (when the Lake Level is rising and falling).
c. If the radial gate settings shown in Appendix C are greater than the current radial gate settings, open the radial gates as quickly as is safe and practical to achieve the settings shown in Appendix C.
d. If the radial gate settings shown in Appendix C are less than the current radial gate settings, close the radial gates at 0.5 m (or one gate movement) every thirty minutes until the current radial gate settings match the required settings shown in Appendix C (Further guidance under additional considerations below is provided for situations if the current gate position is not in contact with the spillway flow).
e. If the Actual Lake Level is lower than the OFSL, commence closing all gates as quickly as is safe and practical.

Additional Considerations

a. If one or more radial gates are, or become, inoperable, use the remaining operable gates to provide the total gate opening required while aiming to keep the spillway flow as symmetrical as possible.
b. Aim 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.
c. When the gate opening involves lifting the radial gate clear of spillway flow, the radial gate should be opened an additional gate setting to ensure the gate remains clear of spillway flow and be fully opened as soon as practicable.
d. When closing of the radial gate is required and the radial gate is currently lifted clear of spillway flow, the gate movement is to lower the radial gate into the flow to the highest setting in Appendix C that allows the gate to have stable contact with the spillway flow. This generally means having the bottom of the gate at least 0.3 metres into the flow. For the purpose of limits to the time intervals for closing gates, this is considered one gate movement.

14.4 Equipment Failure

In the event of equipment failure, refer to Appendix D.

14.5 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 14.3) to guide the operation of the Dam.

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

15.1 Purpose

Sections 15.2 and 15.3 set out the operational procedures that apply to releases of water which are to be made to lower the Actual Lake Level of the Dam to a Temporary Full Supply Level which has been declared by the Minister to mitigate the impacts of a potential flood or if a Reduced Full Supply Level is enacted by Seqwater.

If a Temporary FSL and Reduced FSL are in effect at the same time, the operational procedures in Section 15.3 are to be followed so as to reach the lower of the two levels.

15.2 Application

The Procedures in Section 15.3 only apply where a Temporary FSL Declaration is made or a Reduced FSL is applied and, at the time the Actual Lake Level exceeds the resulting OFSL.

15.3 Procedures for Release of Water Stored Above the Temporary Full Supply Level or Reduced Full Supply Level at North Pine Dam

If the Actual Lake Level is higher than the OFSL at the time that a Temporary Full Supply Level is declared, or Reduced Full Supply Level is enacted, the following applies:

- 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 judgement of matters such as public safety considerations and reasonable time for notifications and other communications) and,
- The Drain Down Strategy is selected to apply the Procedures outlined in Section 13.2.

15.4 Effect of Temporary Full Supply Level or Reduced Full Supply Level on Procedures

The Procedures in Section 13 of this Manual and the supporting table in Appendix C (Loss of Communications) are designed to adapt to the OFSL if the OFSL changes by means of a Temporary Full Supply Level or Reduced Full Supply Level up to an assumed maximum OFSL at 36.0 m AHD.

For avoidance of doubt, the Maximum Flood Storage Level does not change if the OFSL changes.

16 Alternative Procedures

16.1 Alternative Procedures

16.1.1 When this Section Applies

This Section applies if the DSFOE reasonably considers that:

a. A Strategy set out in 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 Section 13 of this Manual (an existing Procedure); and
   ii. observe a different Procedure (an Alternative Procedure).

16.1.2 Seeking Authorisation from Chief Executive (DRDMW)

Inform the CEO before authorisation is sought from the 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 of this Manual 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 Alternative Procedures for Communication in Section 16.2.

16.1.3 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.

16.1.4 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 16.2) 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).

16.2 Protocol for Seeking Authorisation of Alternative Procedures

16.2.1 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.

16.2.2 Contact positions

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

16.2.3 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; or
g. Letter.

16.2.4 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; and
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; and
f. Communications must be continually reviewed against timeframes and consequences.

16.2.5 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 16.1 above);
b. Time available to make the decision; and
c. Any other factors the Dam owner considers critical to effective alternate operations.

17 References

DEWS, 2014 *North Pine Dam Optimisation Study Report,* Department of Energy and Water Supply, Final Report

APPENDICES

Appendix A — North Pine Technical Data

Table A.1 Storage data for North Pine Dam

Lake Level	Storage	Lake Level	Storage	Lake Level	Storage
m AHD	ML	m AHD	ML	m AHD	ML
32.0	89,071	37.4	170,054	40.9	243,897
32.2	91,445	37.6	173,778	41.0	246,285
32.4	93,867	37.8	177,559	41.1	248,689
32.6	96,337	38.0	181,401	41.2	251,109
32.8	98,852	38.2	185,304	41.3	253,545
33.0	101,413	38.4	189,267	41.4	255,997
33.2	104,018	38.6	193,291	41.5	258,465
33.4	106,669	38.8	197,374	41.6	260,950
33.6	109,365	39.0	201,517	41.7	263,450
33.8	112,108	39.1	203,610	41.8	265,967
34.0	114,898	39.2	205,719	41.9	268,500
34.2	117,736	39.3	207,842	42.0	271,049
34.4	120,623	39.4	209,980	42.1	273,614
34.6	123,558	39.5	212,133	42.2	276,195
34.8	126,544	39.6	214,302	42.3	278,792
35.0	129,579	39.7	216,486	42.4	281,406
35.2	132,665	39.8	218,685	42.5	284,035
35.4	135,802	39.9	220,899	42.6	286,680
35.6	138,990	40.0	223,129	42.7	289,340
35.8	142,230	40.1	225,374	42.8	292,017
36.0	145,522	40.2	227,635	42.9	294,710
36.2	148,867	40.3	229,910	43.0	297,420
36.4	152,264	40.4	232,201	43.1	300,147
36.6	155,715	40.5	234,508	43.2	302,890
36.8	159,219	40.6	236,831	43.3	305,650
37.0	162,776	40.7	239,170		
37.2	166,387	40.8	241,525		

Table A.2 North Pine Dam radial gate levels

North Pine 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)
0.0	31.61	40.23
0.5	32.08	40.55
1.0	32.56	40.83
1.5	33.05	41.09
2.0	33.54	41.32
2.5	34.04	41.52
3.0	34.54	41.69
3.5	35.04	41.83
4.0	35.53	41.94
4.5	36.03	42.01
5.0	36.51	42.05
5.5	36.99	42.06
6.0	37.45	42.06
6.5	37.91	42.06
7.0	38.34	42.06

[1] Owing to the curvature of the water surface over the ogee crest this level does not directly equate to Lake Level. See Appendix B for an indication of when the bottom edge may emerge from the water, in reference to issues associated with shallow submergence described in Section 13.3.

Appendix B — Radial Gate and Cone Valve Ratings

Figure B.1 Individual gate rating at North Pine Dam

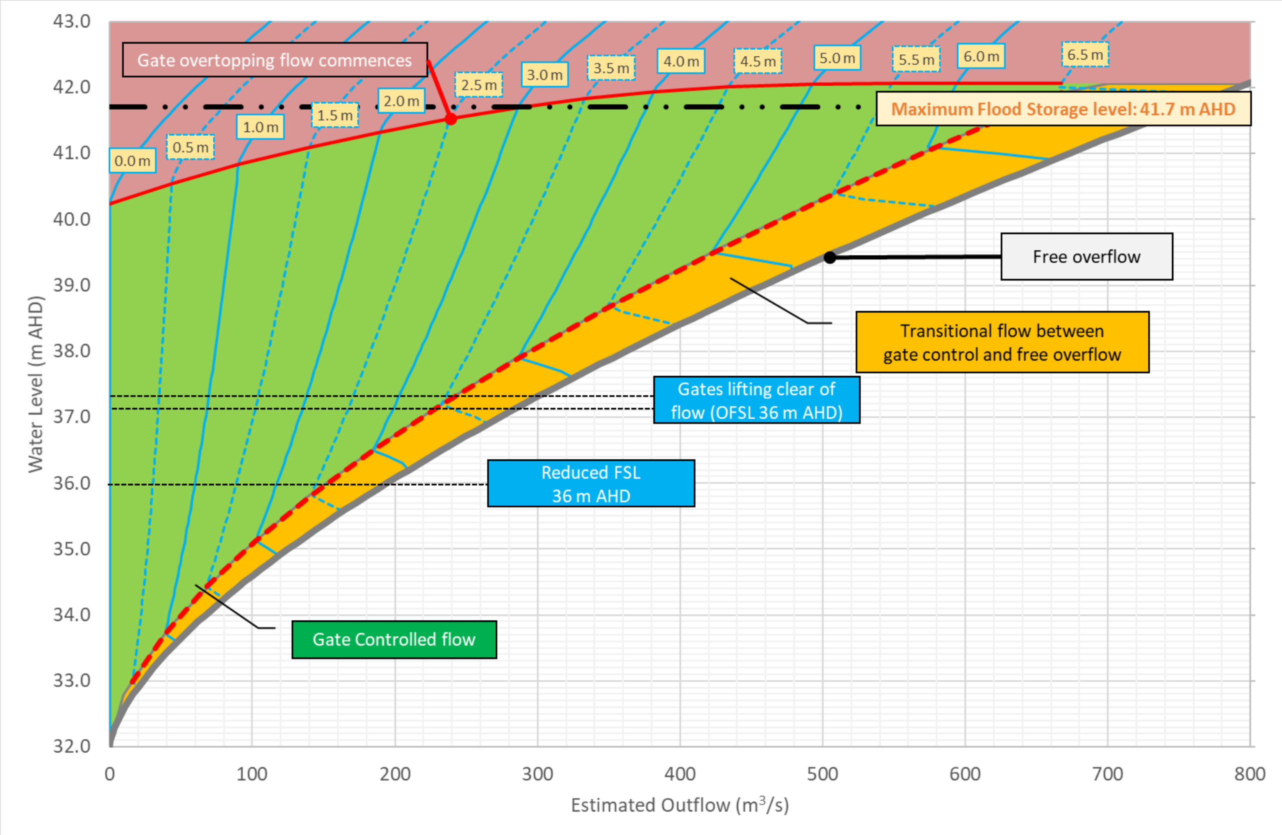


Table B.2 Individual gate rating colour codes

Colour	Estimated hydraulic control regime
(green)	Gate controlled (orifice flow)
(white)	Free overflow (gate is above the flow)
(orange)	Transitional flow (transitional between gate control and free overflow, flow conditions could be unstable)
(pink)	Flow overtopping gate (includes flow under the gate when gate setting is greater than 0 metres)

The hydraulic control regime at higher levels has been estimated using available studies. Actual hydraulic control regime may differ to those shown below.

Table B.3 Individual gate rating at North Pine Dam

	Outflow in m³/s														
Water Level (m AHD)	Gate Setting (metres)														
	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	Fully open
32.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32.1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
32.2	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2
32.3	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4
32.4	0	6	6	6	6	6	6	6	6	6	6	6	6	6	6
32.5	0	8	8	8	8	8	8	8	8	8	8	8	8	8	8
32.6	0	11	11	11	11	11	11	11	11	11	11	11	11	11	11
32.7	0	13	13	13	13	13	13	13	13	13	13	13	13	13	13
32.8	0	16	16	16	16	16	16	16	16	16	16	16	16	16	16
32.9	0	20	20	20	20	20	20	20	20	20	20	20	20	20	20
33.0	0	16	23	23	23	23	23	23	23	23	23	23	23	23	23
33.1	0	16	27	27	27	27	27	27	27	27	27	27	27	27	27
33.2	0	17	31	31	31	31	31	31	31	31	31	31	31	31	31
33.3	0	18	35	35	35	35	35	35	35	35	35	35	35	35	35
33.4	0	18	39	39	39	39	39	39	39	39	39	39	39	39	39
33.5	0	19	43	43	43	43	43	43	43	43	43	43	43	43	43
33.6	0	20	46	48	48	48	48	48	48	48	48	48	48	48	48
33.7	0	20	40	52	52	52	52	52	52	52	52	52	52	52	52
33.8	0	21	40	57	57	57	57	57	57	57	57	57	57	57	57
33.9	0	21	41	62	62	62	62	62	62	62	62	62	62	62	62
34.0	0	22	42	67	67	67	67	67	67	67	67	67	67	67	67
34.1	0	22	43	72	72	72	72	72	72	72	72	72	72	72	72
34.2	0	23	44	78	78	78	78	78	78	78	78	78	78	78	78
34.3	0	23	45	77	83	83	83	83	83	83	83	83	83	83	83
34.4	0	24	46	70	89	89	89	89	89	89	89	89	89	89	89
34.5	0	24	47	69	95	95	95	95	95	95	95	95	95	95	95
34.6	0	25	48	70	100	100	100	100	100	100	100	100	100	100	100
34.7	0	25	49	72	106	106	106	106	106	106	106	106	106	106	106
34.8	0	26	50	73	113	113	113	113	113	113	113	113	113	113	113
34.9	0	26	51	75	119	119	119	119	119	119	119	119	119	119	119
35.0	0	26	52	76	112	125	125	125	125	125	125	125	125	125	125
35.1	0	27	52	77	104	132	132	132	132	132	132	132	132	132	132
35.2	0	27	53	79	103	138	138	138	138	138	138	138	138	138	138
35.3	0	28	54	80	105	145	145	145	145	145	145	145	145	145	145
35.4	0	28	55	81	107	152	152	152	152	152	152	152	152	152	152
35.5	0	28	56	83	109	158	158	158	158	158	158	158	158	158	158
35.6	0	29	57	84	111	161	165	165	165	165	165	165	165	165	165
35.7	0	29	57	85	112	152	173	173	173	173	173	173	173	173	173
35.8	0	30	58	87	114	143	180	180	180	180	180	180	180	180	180
35.9	0	30	59	88	116	143	187	187	187	187	187	187	187	187	187
36.0	0	30	60	89	117	145	194	194	194	194	194	194	194	194	194
36.1	0	31	61	90	119	147	202	202	202	202	202	202	202	202	202
36.2	0	31	61	91	121	149	209	209	209	209	209	209	209	209	209
36.3	0	31	62	93	122	151	205	217	217	217	217	217	217	217	217
36.4	0	32	63	94	124	153	195	225	225	225	225	225	225	225	225
36.5	0	32	64	95	125	155	184	233	233	233	233	233	233	233	233
36.6	0	32	64	96	127	157	187	241	241	241	241	241	241	241	241
36.7	0	33	65	97	129	159	189	249	249	249	249	249	249	249	249
36.8	0	33	66	98	130	161	191	257	257	257	257	257	257	257	257
36.9	0	33	67	100	132	163	194	265	265	265	265	265	265	265	265
37.0	0	34	67	101	133	165	196	256	274	274	274	274	274	274	274
37.1	0	34	68	102	135	167	198	244	282	282	282	282	282	282	282
37.2	0	34	69	103	136	169	200	233	291	291	291	291	291	291	291
37.3	0	35	69	104	138	170	203	235	299	299	299	299	299	299	299
37.4	0	35	70	105	139	172	205	238	308	308	308	308	308	308	308
37.5	0	35	71	106	141	174	207	240	317	317	317	317	317	317	317
37.6	0	36	71	107	142	176	209	243	325	325	325	325	325	325	325
37.7	0	36	72	108	143	178	211	245	317	334	334	334	334	334	334

Water Level (m AHD)	Outflow in m^3/s														
	Gate Setting (metres)														
	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	Fully open
37.8	0	36	73	109	145	179	213	248	301	343	343	343	343	343	343
37.9	0	36	73	110	146	181	215	250	286	353	353	353	353	353	353
38.0	0	37	74	111	148	183	217	252	289	362	362	362	362	362	362
38.1	0	37	75	112	149	185	220	255	292	371	371	371	371	371	371
38.2	0	37	75	113	150	186	222	257	294	380	380	380	380	380	380
38.3	0	38	76	114	152	188	224	259	297	390	390	390	390	390	390
38.4	0	38	76	115	153	190	226	262	299	398	399	399	399	399	399
38.5	0	38	77	116	155	192	228	264	302	378	409	409	409	409	409
38.6	0	38	78	117	156	193	230	266	305	358	419	419	419	419	419
38.7	0	39	78	118	157	195	232	268	307	349	428	428	428	428	428
38.8	0	39	79	119	159	197	234	271	310	352	438	438	438	438	438
38.9	0	39	79	120	160	198	236	273	312	355	448	448	448	448	448
39.0	0	39	80	121	161	200	237	275	315	358	458	458	458	458	458
39.1	0	40	81	122	162	201	239	277	317	361	468	468	468	468	468
39.2	0	40	81	123	164	203	241	280	320	363	478	478	478	478	478
39.3	0	40	82	124	165	205	243	282	322	366	478	488	488	488	488
39.4	0	41	82	125	166	206	245	284	324	369	450	499	499	499	499
39.5	0	41	83	126	168	208	247	286	327	371	423	509	509	509	509
39.6	0	41	84	127	169	209	249	288	329	374	425	519	519	519	519
39.7	0	41	84	128	170	211	251	290	332	377	428	530	530	530	530
39.8	0	42	85	129	171	213	253	292	334	379	431	541	541	541	541
39.9	0	42	85	129	173	214	254	295	336	382	434	551	551	551	551
40.0	0	42	86	130	174	216	256	297	339	384	437	562	562	562	562
40.1	0	42	86	131	175	217	258	299	341	387	440	573	573	573	573
40.2	0	43	87	132	176	219	260	301	343	390	443	577	584	584	584
40.3	1	43	87	133	178	220	262	303	346	392	446	529	595	595	595
40.4	2	43	88	134	179	222	264	305	348	395	448	507	606	606	606
40.5	4	43	89	135	180	223	265	307	350	397	451	510	617	617	617
40.6	7	44	89	136	181	225	267	309	352	400	454	512	628	628	628
40.7	9	46	90	136	182	226	269	311	355	402	457	515	639	639	639
40.8	12	48	90	137	184	228	271	313	357	405	460	518	650	650	650
40.9	15	51	91	138	185	229	272	315	359	407	462	520	662	662	662
41.0	19	53	94	139	186	231	274	317	361	410	465	523	625	673	673
41.1	22	57	96	140	187	232	276	319	364	412	468	525	574	684	684
41.2	26	60	99	142	188	234	278	321	366	414	470	528	576	696	696
41.3	30	63	102	145	189	235	279	323	368	417	473	530	578	708	708
41.4	34	67	106	148	191	237	281	325	370	419	476	532	580	719	719
41.5	38	71	109	151	194	238	283	327	372	422	478	535	582	731	731
41.6	42	75	113	155	197	240	284	329	374	424	481	537	584	743	743
41.7	46	79	117	159	201	243	286	331	377	426	484	540	586	755	755
41.8	51	84	121	163	205	247	289	333	379	429	486	542	588	767	767
41.9	55	88	126	167	209	251	293	335	381	431	489	545	590	779	779
42.0	60	93	130	171	213	255	296	339	384	433	492	547	593	666	791
42.1	65	97	135	176	218	259	301	343	387	437	495	550	595	668	803
42.2	70	102	139	180	222	264	305	347	391	441	499	553	598	672	817
42.3	75	107	144	185	227	269	310	352	396	445	503	558	602	675	831
42.4	80	112	149	190	232	273	315	356	401	450	508	562	606	680	846
42.5	85	117	154	195	237	279	320	361	406	455	513	567	611	684	861
42.6	91	122	160	200	242	284	325	367	411	460	519	572	616	689	865
42.7	96	128	165	206	248	289	330	372	416	466	524	578	621	694	868
42.8	101	133	170	211	253	295	336	377	422	471	530	583	626	699	869
42.9	107	139	176	217	259	300	341	383	427	477	536	589	631	705	869
43.0	113	144	181	222	264	306	347	389	433	483	542	595	637	710	869
43.1	118	150	187	228	270	312	353	395	439	489	548	601	642	716	879
43.2	124	156	193	234	276	318	359	401	445	495	555	607	648	721	888
43.3	130	161	199	240	282	324	365	407	452	502	561	613	654	727	896
43.4	136	167	205	246	288	330	371	413	458	508	568	619	660	733	904
43.5	142	173	211	252	294	336	378	420	464	515	575	626	666	740	910
43.6	148	179	217	258	301	343	384	426	471	521	581	633	673	746	917
43.7	154	186	223	264	307	349	391	433	478	528	588	639	679	752	923

Water Level (m AHD)	Outflow in m^3/s														
	Gate Setting (metres)														
	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	Fully open
43.8	161	192	229	271	313	356	397	439	484	535	595	646	685	759	929
43.9	167	198	236	277	320	362	404	446	491	542	603	653	692	765	935
44.0	173	205	242	284	327	369	411	453	498	549	610	660	699	772	941
44.1	180	211	249	290	333	376	417	460	505	556	617	667	705	779	947
44.2	186	217	255	297	340	382	424	467	512	564	625	674	712	785	954
44.3	193	224	262	304	347	389	431	474	520	571	632	682	719	792	960
44.4	200	231	268	311	354	396	439	481	527	578	640	689	726	799	966
44.5	206	237	275	317	361	404	446	489	534	586	648	697	733	806	972
44.6	213	244	282	324	368	411	453	496	542	593	655	704	740	814	978
44.7	220	251	289	331	375	418	460	503	549	601	663	712	748	821	984
44.8	227	258	296	338	382	425	468	511	557	609	671	719	755	828	990
44.9	234	265	303	346	389	433	475	519	565	617	679	727	762	835	996
45.0	241	272	310	353	397	440	483	526	572	625	687	735	770	843	1002

Figure B.2 North Pine Dam total outflow rating for various OFSLs when applying gate openings presented in Appendix C

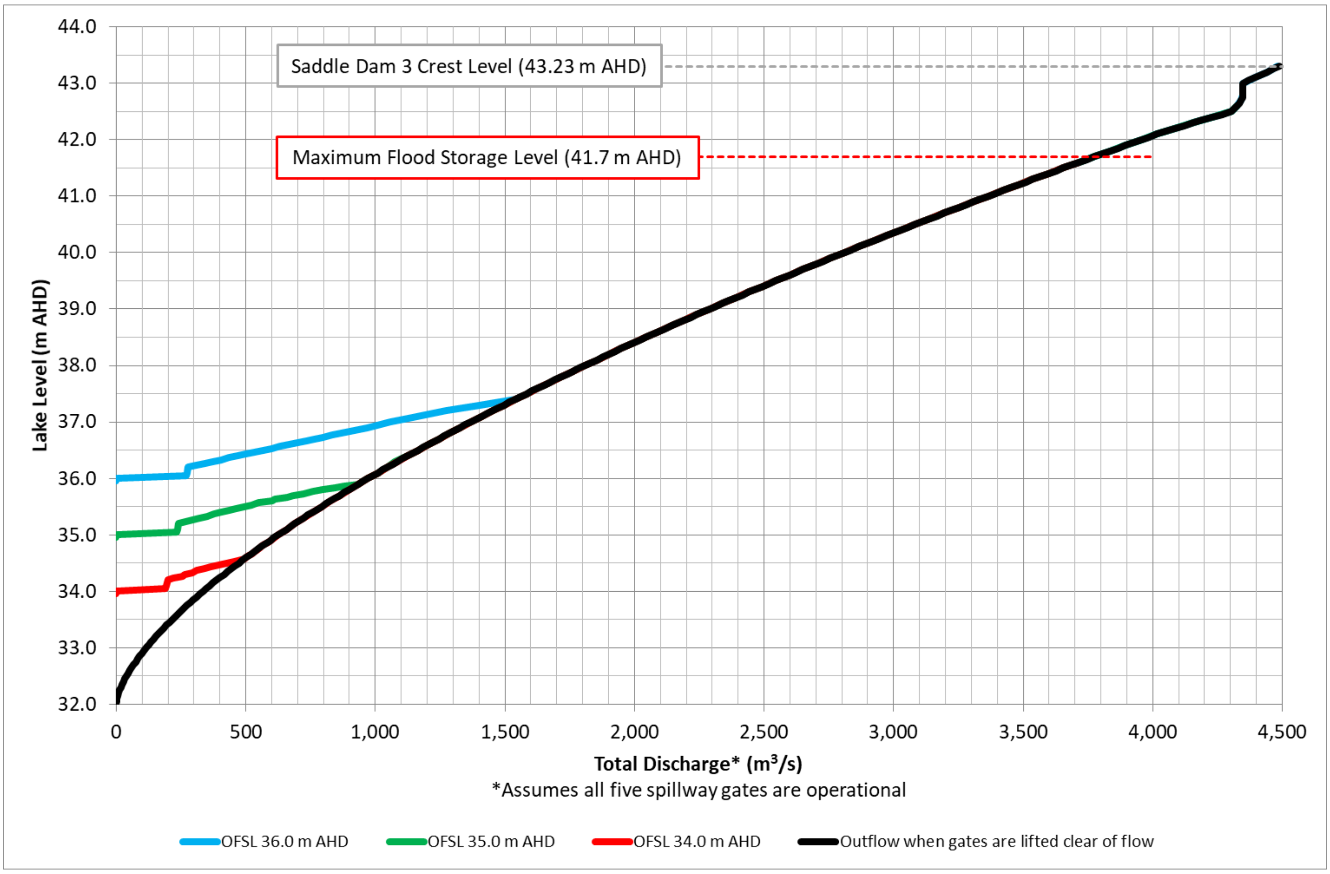


Table B.4 North Pine Dam total outflow rating for various OFSLs when applying Appendix C

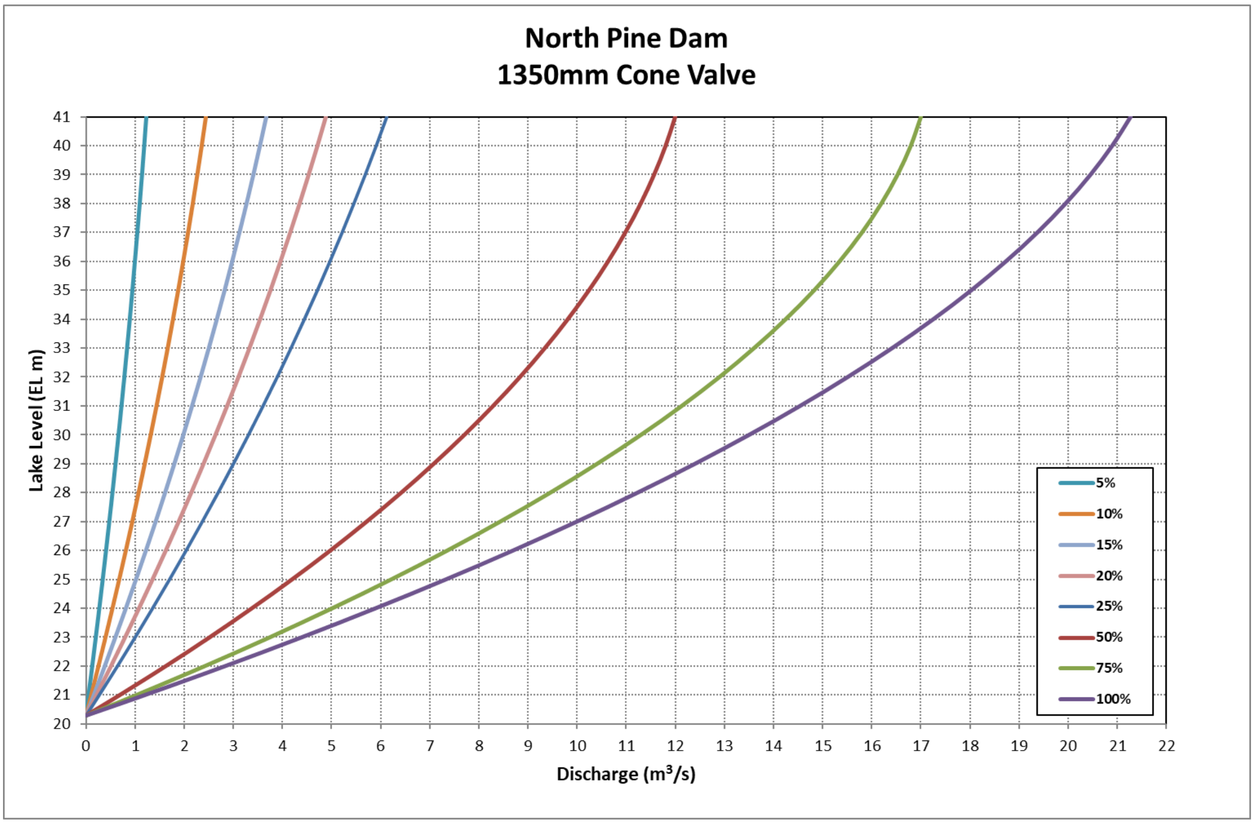
Lake Level (m AHD)	Operational FSL (m AHD)		
	36.0	35.0	34.0
34.0			0
34.1			194
34.2			198
34.3			263
34.4			339
34.5			425
34.6			502
34.7			532
34.8			563
34.9			594
35.0		0	626
35.1		237	658
35.2		241	691
35.3		322	724
35.4		405	758
35.5		491	792
35.6		603	827
35.7		682	863
35.8		796	899
35.9		935	935
36.0	0	972	972
36.1	273	1,009	1,009
36.2	277	1,047	1,047
36.3	371	1,074	1,086
36.4	467	1,125	1,125
36.5	565	1,164	1,164
36.6	665	1,204	1,204
36.7	764	1,244	1,244
36.8	865	1,285	1,285
36.9	968	1,326	1,326
37.0	1,057	1,368	1,368
37.1	1,159	1,410	1,410
37.2	1,272	1,453	1,453
37.3	1,399	1,496	1,496
37.4	1,539	1,539	1,539
37.5	1,583	1,583	1,583
37.6	1,627	1,627	1,627
37.7	1,672	1,672	1,672
37.8	1,717	1,717	1,717
37.9	1,763	1,763	1,763
38.0	1,809	1,809	1,809
38.1	1,855	1,855	1,855
38.2	1,902	1,902	1,902
38.3	1,949	1,949	1,949
38.4	1,997	1,997	1,997
38.5	2,044	2,044	2,044
38.6	2,093	2,093	2,093
38.7	2,142	2,142	2,142
38.8	2,191	2,191	2,191
38.9	2,240	2,240	2,240
39.0	2,290	2,290	2,290
39.1	2,340	2,340	2,340
39.2	2,391	2,391	2,391
39.3	2,442	2,442	2,442
39.4	2,494	2,494	2,494
39.5	2,545	2,545	2,545
39.6	2,597	2,597	2,597
39.7	2,650	2,650	2,650
39.8	2,703	2,703	2,703
39.9	2,756	2,756	2,756
40.0	2,810	2,810	2,810
40.1	2,864	2,864	2,864
40.2	2,918	2,918	2,918
40.3	2,973	2,973	2,973
40.4	3,028	3,028	3,028
40.5	3,083	3,083	3,083
40.6	3,139	3,139	3,139
40.7	3,195	3,195	3,195
40.8	3,251	3,251	3,251
40.9	3,308	3,308	3,308
41.0	3,365	3,365	3,365
41.1	3,422	3,422	3,422
41.2	3,480	3,480	3,480
41.3	3,538	3,538	3,538
41.4	3,597	3,597	3,597
41.5	3,655	3,655	3,655
41.6	3,714	3,714	3,714
41.7	3,774	3,774	3,774
41.8	3,833	3,833	3,833
41.9	3,894	3,894	3,894
42.0	3,954	3,954	3,954
42.1	4,016	4,016	4,016
42.2	4,084	4,084	4,084

Blue values represent outflow when all gates are lifted clear of flow
Black values represent outflow when one or more gates are controlling flow

Table B.5 1350mm Cone Valve Settings

Lake Level	Opening (%)								Opening (%)							
	5	10	15	20	25	50	75	100	5	10	15	20	25	50	75	100
m AHD	Valve Discharge (m^3/s)								Valve Discharge (ML/d)							
20.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0	0
21.0	0.1	0.1	0.2	0.2	0.3	0.7	1.0	1.2	5	9	14	18	23	59	87	102
22.0	0.1	0.3	0.4	0.5	0.6	1.6	2.4	2.8	11	22	33	44	55	139	208	243
23.0	0.2	0.4	0.6	0.8	1.0	2.5	3.7	4.4	17	34	52	69	86	217	323	379
24.0	0.3	0.5	0.8	1.1	1.3	3.4	5.0	5.9	23	47	70	93	117	291	432	508
25.0	0.3	0.7	1.0	1.4	1.7	4.2	6.2	7.3	29	59	88	117	146	362	536	632
26.0	0.4	0.8	1.2	1.6	2.0	5.0	7.4	8.7	35	70	105	140	176	429	635	751
27.0	0.5	0.9	1.4	1.9	2.4	5.7	8.4	10.0	41	82	122	163	204	493	729	863
28.0	0.5	1.1	1.6	2.1	2.7	6.4	9.5	11.2	46	93	139	185	232	554	817	970
29.0	0.6	1.2	1.8	2.4	3.0	7.1	10.4	12.4	52	104	155	207	259	611	899	1,071
30.0	0.7	1.3	2.0	2.6	3.3	7.7	11.3	13.5	57	114	171	228	285	665	976	1,166
31.0	0.7	1.4	2.2	2.9	3.6	8.3	12.1	14.5	62	124	186	249	311	716	1,048	1,256
32.0	0.8	1.6	2.3	3.1	3.9	8.8	12.9	15.5	67	134	201	269	336	763	1,115	1,340
33.0	0.8	1.7	2.5	3.3	4.2	9.3	13.6	16.4	72	144	216	288	360	807	1,176	1,418
34.0	0.9	1.8	2.7	3.6	4.4	9.8	14.2	17.3	77	153	230	307	383	847	1,231	1,491
35.0	0.9	1.9	2.8	3.8	4.7	10.2	14.8	18.0	81	162	244	325	406	884	1,281	1,558
36.0	1.0	2.0	3.0	4.0	5.0	10.6	15.3	18.7	86	171	257	343	428	918	1,326	1,619
37.0	1.0	2.1	3.1	4.2	5.2	11.0	15.8	19.4	90	180	270	360	450	949	1,366	1,674
38.0	1.1	2.2	3.3	4.4	5.4	11.3	16.2	19.9	94	188	282	376	470	976	1,400	1,724
39.0	1.1	2.3	3.4	4.5	5.7	11.6	16.5	20.5	98	196	294	392	490	999	1,428	1,768
40.0	1.2	2.4	3.5	4.7	5.9	11.8	16.8	20.9	102	204	306	408	510	1,020	1,452	1,806
41.0	1.2	2.4	3.7	4.9	6.1	12.0	17.0	21.3	106	211	317	423	528	1,036	1,469	1,838

Figure B.3 1350mm Cone Valve Rating



APPENDIX C

DAM OPERATOR - LOSS OF COMMUNICATIONS

Appendix C — Dam Operator – Loss of Communications

Table C.1 Gate settings relative to Operational Full Supply Level

Level relative to OFSL	Gate A	Gate B	Gate C	Gate D	Gate E	Total Openings	Dam release rates for range of Operational FSL (m AHD)		
							36.0	35.0	34.0
m	m	m	m	m	m	m	m^3/s	m^3/s	m^3/s
Below OFSL	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
OFSL	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
+0.05	1.0	0.5	1.0	1.0	1.0	4.5	272	235	191
+0.10	1.0	0.5	1.0	1.0	1.0	4.5	273	237	194
+0.20	1.0	0.5	1.0	1.0	1.0	4.5	277	241	198
+0.23	1.0	1.0	1.0	1.0	1.0	5.0	308	268	221
+0.27	1.0	1.0	1.5	1.0	1.0	5.5	340	295	257
+0.30	1.0	1.0	2.0	1.0	1.0	6.0	371	322	263
+0.33	1.0	1.0	2.0	1.0	1.5	6.5	403	349	295
+0.37	1.0	1.0	2.0	1.0	2.0	7.0	435	377	311
+0.40	1.5	1.0	2.0	1.0	2.0	7.5	467	405	339
+0.43	2.0	1.0	2.0	1.0	2.0	8.0	499	433	364
+0.47	2.0	1.0	2.0	1.5	2.0	8.5	533	463	393
+0.50	2.0	1.0	2.0	2.0	2.0	9.0	565	491	425
+0.53	2.0	1.5	2.0	2.0	2.0	9.5	599	520	455
+0.57	2.0	2.0	2.0	2.0	2.0	10.0	633	550	494
+0.60	2.0	2.0	2.5	2.0	2.0	10.5	665	603	502
+0.63	2.0	2.0	3.0	2.0	2.0	11.0	697	612	511
+0.67	2.0	2.0	3.0	2.0	2.5	11.5	731	660	523
+0.70	2.0	2.0	3.0	2.0	3.0	12.0	764	682	532
+0.73	2.5	2.0	3.0	2.0	3.0	12.5	797	724	541
+0.77	3.0	2.0	3.0	2.0	3.0	13.0	832	760	554
+0.80	3.0	2.0	3.0	2.5	3.0	13.5	865	796	563
+0.83	3.0	2.0	3.0	3.0	3.0	14.0	899	842	572
+0.87	3.0	2.5	3.0	3.0	3.0	14.5	934	881	584
+0.90	3.0	3.0	3.0	3.0	3.0	15.0	968	935	594
+1.00	3.0	3.0	Lift clear	3.0	3.0	16.0	1,057	972	626

APPENDIX C

DAM OPERATOR - LOSS OF COMMUNICATIONS

Level relative to OFSL	Gate A	Gate B	Gate C	Gate D	Gate E	Total Openings	Dam release rates for range of Operational FSL (m AHD)		
							36.0	35.0	34.0
m	m	m	m	m	m	m	m^3/s	m^3/s	m^3/s
+1.10	3.0	3.0	Lift clear	3.0	**Lift clear**	17.0	1,159	1,009	658
+1.20	**Lift clear**	3.0	Lift clear	3.0	Lift clear	18.0	1,272	1,047	691
+1.30	Lift clear	3.0	Lift clear	**Lift clear**	Lift clear	19.0	1,399	1,074	724
+1.40	Lift clear	**Lift clear**	Lift clear	Lift clear	Lift clear	20.0	1,539	1,125	758
+1.50	Lift clear	Lift clear	Lift clear	Lift clear	Lift clear	25.0	1,583	1,164	792
+1.60	Lift clear	Lift clear	Lift clear	Lift clear	Lift clear	30.0	1,627	1,204	827
+1.70	Lift clear	Lift clear	Lift clear	Lift clear	Lift clear	35.0	1,672	1,244	863
+1.80	**Fully open**	**Fully open**	**Fully open**	**Fully open**	**Fully open**	**35.0**	1,717	1,285	899

Blue numbers indicate change in gate setting from previous setting (for an increasing water level).

(green)	Gates lifting clear of flow. Monitor flow conditions on-site and lift gate clear of flow if unusual turbulence or vibrations are observed.
(pink)	Gates are clear of flow. Move gate to a fully open position as soon as practical.

Appendix D— North Pine Dam – Guidance on Radial Gates and Equipment Operations

D.1 Radial Gate operation – general considerations

The radial gates are sequentially labelled from A to E from right to left looking in the downstream direction. Plans of the Dam and spillway are contained in Section 4.

The roller-bucket dissipation basin is designed to dissipate the energy of the spillway discharge.

D.2 Radial Gate operating equipment

There are five 12.2-metre-wide by 8.6-metre-high radial gates that control the spillway. Each of the five radial gates is connected to two operating winches driven by a single electrically driven gear unit. The gates are raised or lowered by two wire ropes wound around each winch drum and connected by two rope equalisers to lifting lugs on each side of the upstream face of the gate.

The spillway gates at the Dam are raised and lowered using electric motor driven winches. These motors are normally powered from the mains electric supply. In the event of a failure of the mains supply, a standby diesel generator automatically cuts in to maintain electric supply. An additional diesel-powered generator is available on request from a local hire company. This unit is leased on standby for the wet season each year and will supply the electrical needs for the Dam.

The Dam also has a hydraulic gate opening system, comprising of a trailer mounted power-pack, permanently fixed hydraulic pipe-work and hydraulic motors mounted at the winch controls under the service deck. In the event of total failure of the electrical system, this would be the preferred option for gate operations.

Review of the Dam hydrology has shown that extreme events can submerge the five radial gate electric winch motors that are located on platforms beneath the bridge deck forming the Dam crest. During such an event, the electric winch motors would not operate and the winches would not be accessible. The hydraulic system is designed to be operable when submerged or above the water level.

If required under Flood Operations Strategy Procedure 1c in Section 13, it is physically possible to open each radial gate in under 15 minutes. Up to five radial gates can be operated simultaneously, subject to personnel resources to maintain surveillance on gates.

While the radial gates have been designed to withstand some overtopping, it should be avoided if possible. Key Lake Levels impacting the operation of the radial gates are as follows:

Table D.1 Key Lake Levels for radial gate operation at North Pine Dam

Lake Level (m AHD)	Impact on radial gate operation
40.2	Top of closed radial gate. Gates will be overtopped above this level.
41.1	Winch room floor level. Impacts access to radial gate switch gear
41.6	Radial gate electric switch gear. Gates should be operated hydraulically above this level.
41.7	Maximum Flood Storage Level.

D.3 No free fall of the Radial Gates

Under no circumstances are the radial gates allowed to free fall.

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.

D.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 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.

D.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.

D.6 Bulkhead gate operating limitations

The bulkhead gate should not be used to control discharge in an emergency situation where a radial gate is inoperable.

The bulkhead gate is not to be used for flood regulation or inserted under flow conditions.

D.7 Equipment malfunction

Normal gate operation is by means of external mains supply electric power. 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.

D.7.1 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.

In the event of total failure of the electrical system, the trailed mounted power-pack and use of the hydraulic gate opening system would be the preferred option for gate operations.

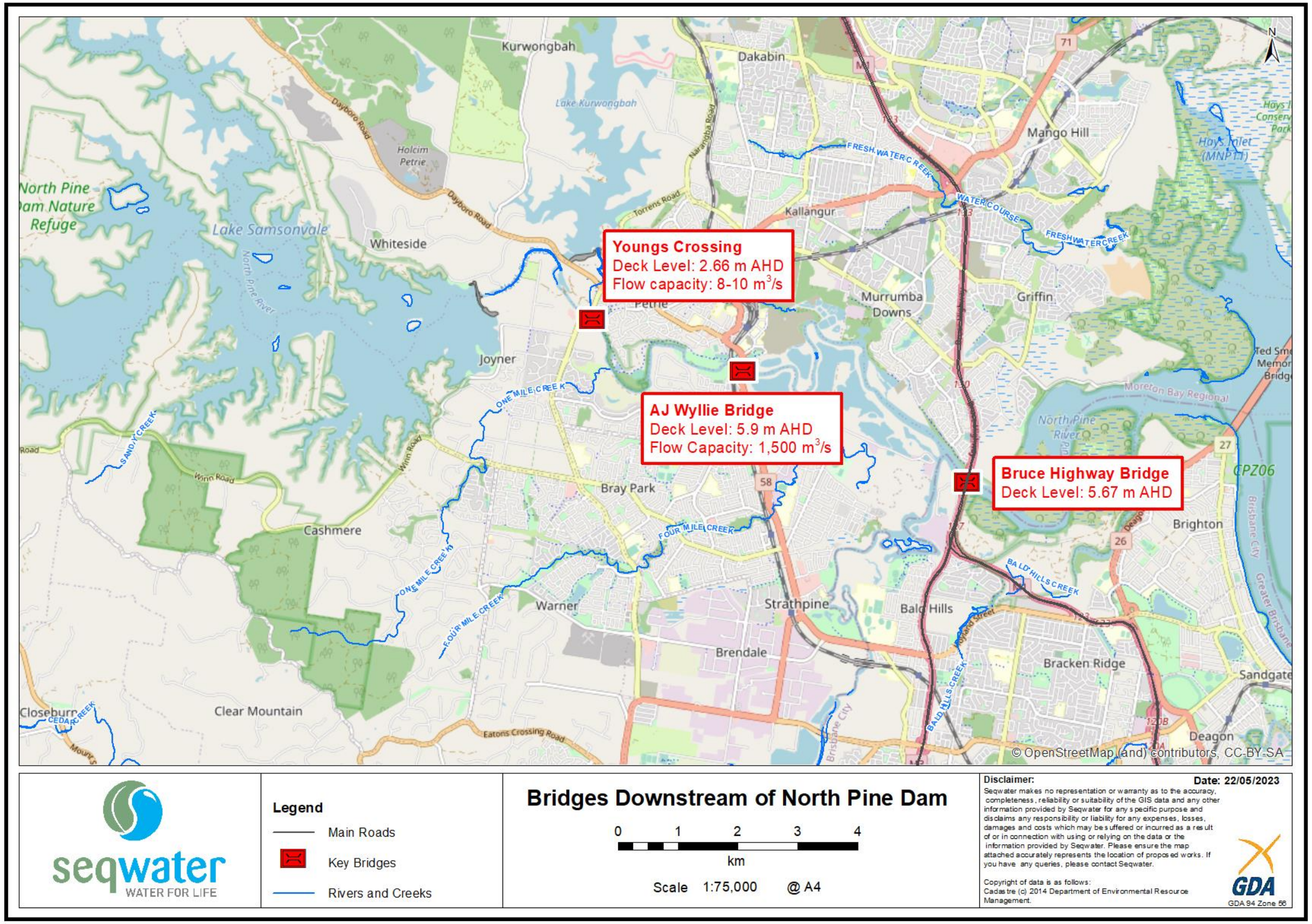
D.7.2 Fouling of Radial Gate lifting gear

The lifting tackle consists of lifting lugs, wire ropes and winch drums. Debris may be collected on the wire ropes that may in turn foul the winching mechanism. This may result in jamming of the wire rope or in uneven lifting, both of which may cause the radial gate to jam. The lifting gear should be checked for debris prior to each operation of the gates.

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

Appendix E — Bridges Downstream Impacted by Floods

Figure E.1 Bridges downstream of North Pine Dam



Appendix F— Hydrologic Investigations

Table F.1 Key data from historical floods

Event	FSL (for flood event)	Peak Height	Peak Inflow	Inflow Volume	Peak Outflow
	m AHD	m AHD	m^3/s	ML	m^3/s
Apr-88	39.6	40.06	790	178,000	630
Apr-89	39.6	n/a	1,150	95,000	990
Feb-99	39.6	39.84	1,180	117,000	80
Apr-09	39.6	36.6	790	34,000	0
May-09	39.6	39.9	1,220	91,000	330
Feb-10	39.6	39.92	510	70,000	360
Oct-10	39.6	40.11	1,000	68,000	910
Early Dec-10	39.6	39.78	440	21,000	330
Mid Dec-10	39.6	39.78	290	46,000	270
Jan-11	39.6	41.11	3,480	208,000	2,850
Jan-12	39.6	39.95	850	71,000	630
Jan-13	38.4	39.8	1,650	101,000	840
Feb-13	38.4	39.75	630	108,000	490
Apr-14	39.6	39.58	240	5,800	0
May-15	38.5	38.72	890	29,800	305
Mar-18	38.6	38.66	70	9,200	140
Mar-20	36.0	36.12	90	4,180	240
08-Dec-21	36.0	36.05	30	2,300	120
09-Dec-21	36.0	36.21	410	15,400	370
01-Jan-22	36.0	36.09	110	2,800	120
09-Jan-22	36.0	36.15	60	6,000	180
Late Jan-22	36.0	36.13	80	3,800	180
Early Feb-22	36.0	36.12	210	6,500	210
Feb-22	36.0	37.39	1,700	281,300	1,530
Early May-22	36.0	36.48	690	132,300	530
Late May-22	36.0	36.09	50	10,800	120
Jul-22	36.0	36.13	50	2,900	90
Oct-22	36.0	36.1	180	15,000	120

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

G.1 Overview

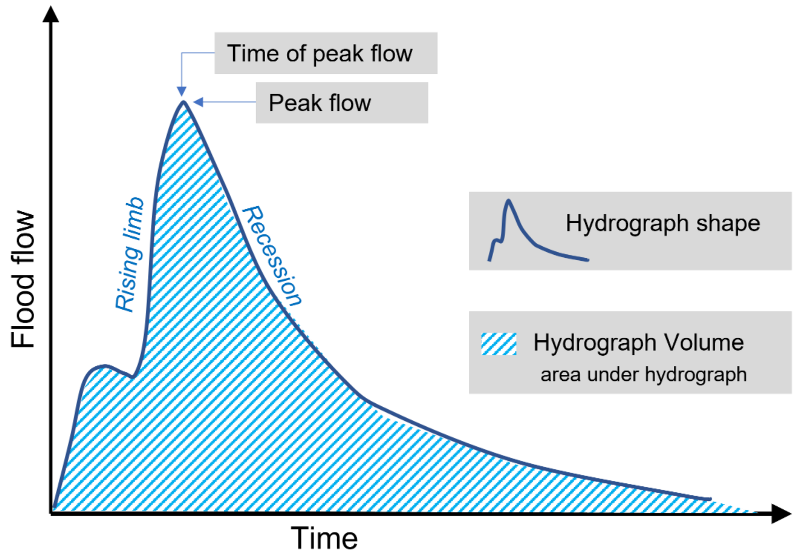
This Appendix contains content on:

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

G.2 Characteristics of a flow hydrograph

Figure G.1 below illustrates important characteristics of catchment flow hydrographs.

Figure G.1 Important characteristics of catchment flow hydrograph



The Procedures in this Manual[32] 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 G.3.

Experience[33] 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. Multiple aspects of the definition of rainfall over the catchment that are important include:

[32] Apart from the Procedures in Section 14.3, which apply when communication is lost with the Flood Operations Centre.

[33] Experience in hydrological simulations for model calibration, in past real-time flood operations, and in simulated flood exercises.

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 North Pine Dam catchment is shown in Figure G.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 North Pine Dam catchment is shown in Figure G.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).

d. An example of spatial variation of accumulated rainfall totals over the North Pine Dam catchment is shown in Figure G.4.

Reliable rainfall definition for the aspects described above is necessary to produce reliable flow hydrographs for catchments upstream and downstream of the Dam that can affect the decision making.

Figure G.2 Example catchment average rainfall (15 minute rainfall intervals) over North Pine Dam catchment (March 2021)

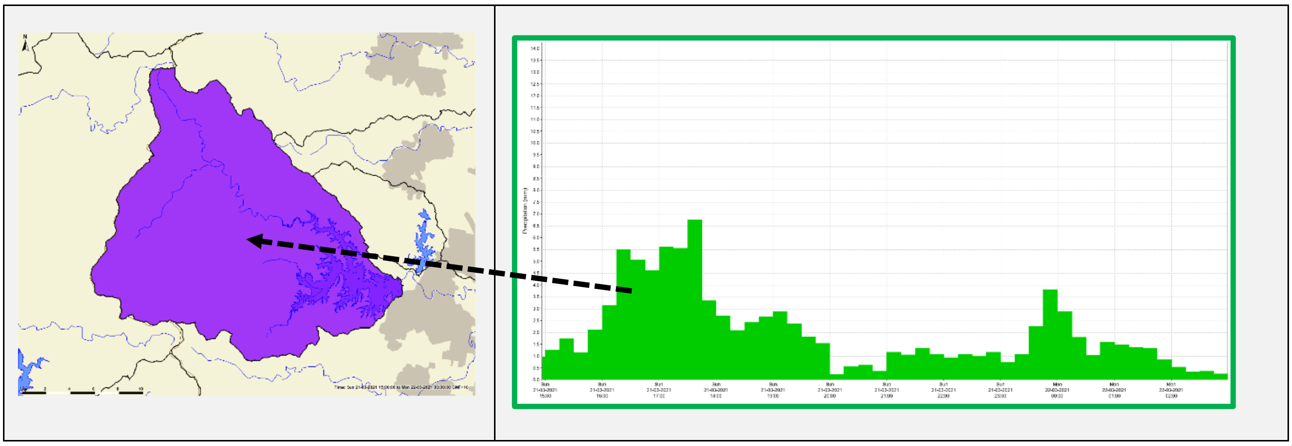


Figure G.3 Example variation of temporal pattern (15 minute rainfall intervals) in different parts of North Pine Dam catchment (March 2021)

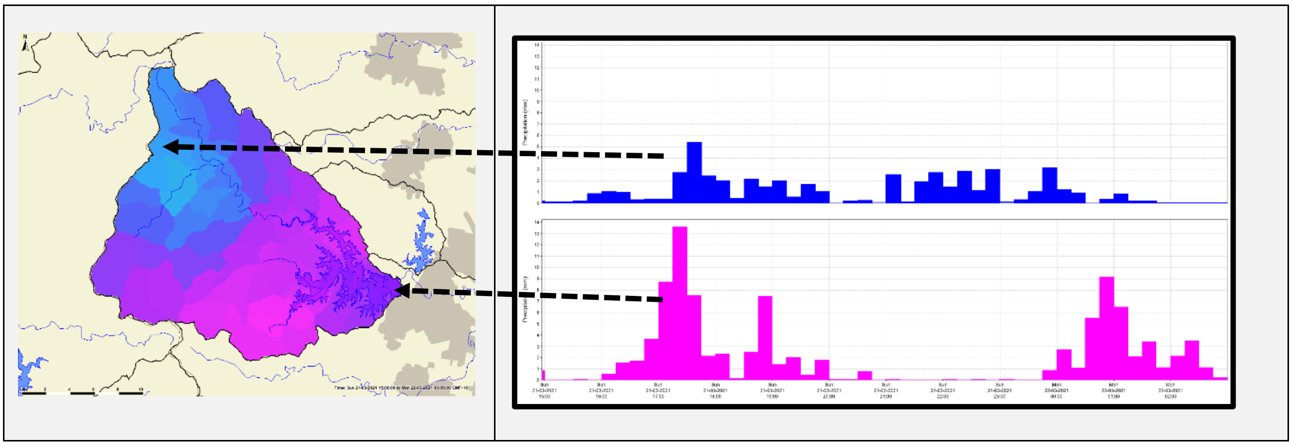
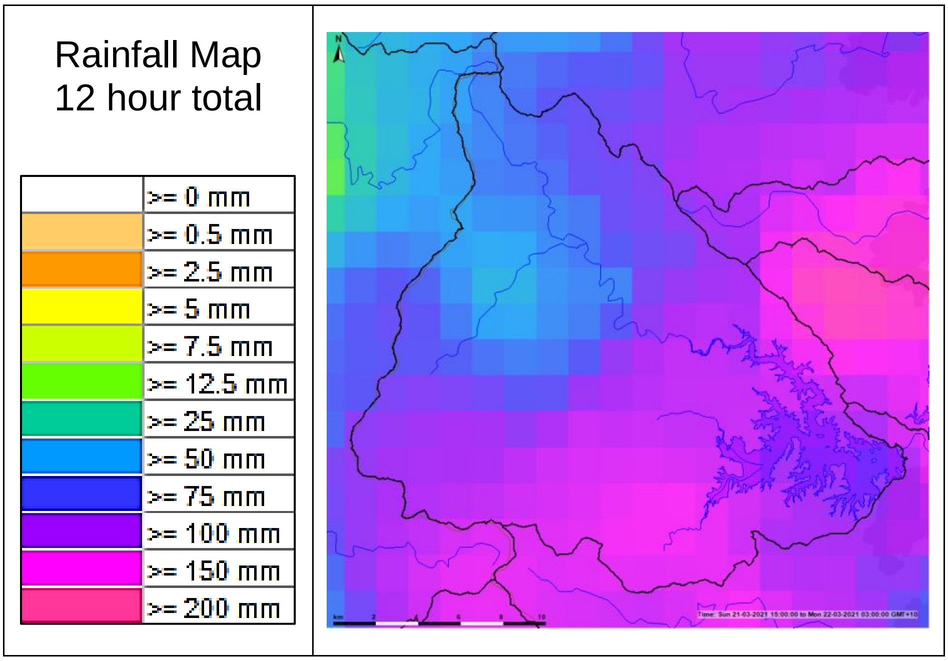


Figure G.4 Example spatial variation of 12 hour rainfall total over North Pine Dam catchment (March 2021)



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 5.3.

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).

G.3 Requirements for reliable flow hydrographs to develop a Release Plan

Sufficiently reliable definition of the catchment flow hydrograph for the dam inflow is 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:

- The total inflow volume constrains the ability to release water when the Actual Lake Level is below OFSL. The Release Plan must always demonstrate that the Water Supply Compartment will be full at the end of the Flood Event (that is, the Lake Level will be returned to OFSL).
- The predicted inflow rate and change of rate over time (this means the shape of the hydrograph) affects the predicted Lake Level response to the Release Plan. Unreliable definition of the hydrograph shape can materially impact the predicted Lake Level.
- The Predicted Event Peak inflow rate is an important release constraint in some of the Procedures to achieve the Objective to mitigate downstream flooding. If the Predicted Event Peak inflow rate used as the basis of the Release Plan is unreliable, it is possible that peak outflow will exceed the actual peak inflow for the Flood Event and exacerbate (rather than mitigate) flooding.

G.4 Forecasting flow hydrographs with Rain on Ground

Forecasting with Rain on Ground provides reliable definition of rainfall for the dam catchments and downstream 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 H.4). Vulnerability to risks of not achieving the Objectives with use of uncertain Rainfall Forecasts is described in Appendix H.5.

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 the Dam catchment where the inflow hydrograph is 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 latency34 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. Even though the North Pine Dam catchment can respond quickly to rainfall, 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 North Pine Dam can often be predicted 4 to 6 hours before it occurs. Reliable prediction of the inflow peak before it occurs can allow releases to commence earlier and provides better opportunity to mitigate the peak outflow.
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 Compartment of the Dam is full at the end of the Flood Event.

The main limitation of forecasting catchment flows with Rain on Ground is that the lead time is limited to around 4 to 6 hours.

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 H.

[34] 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 H— Additional information on Rainfall Forecasts

H.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:

- H.2 Overview of the Australian Digital Forecast Database (ADFD) product
- H.3 General matters of uncertainty in rainfall forecasts
- H.4 Impact of rainfall forecast uncertainty on catchment flow hydrographs
- H.5 Summary of potential benefits risks and vulnerabilities in quantitatively using rainfall forecasts

The second part of this appendix has following more detailed technical content:

- H.6 Limitations of benefits to prevent structural failure of the Dam
- H.7 Risks to ensuring the Water Supply Compartment is full at the end of a Flood Event
- H.8 Potential benefits and risks to mitigate downstream flooding
- H.9 Potential benefits and risks for environmental impacts
- H.10 Further technical information on the Australian Digital Forecast Database (ADFD) product
- H.11 International research on errors in location of heavy rainfall in rainfall forecasts

H.2 Overview of the Australian Digital Forecast Database (ADFD)

For this Manual, the current routine BPF is the Australian Digital Forecast Database[35] (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[36]. 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 H.10.

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 Mt Glorious occurs, it does not mean that high end of the rainfall forecast at the Dam will occur, and the location of the Dam may only get the middle range or low end of the rainfall forecast.

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

[36] http://www.bom.gov.au/weather-services/about/forecasts/australian-digital-forecast-database.shtml

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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 H.10).

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 G).

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.

H.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 the North Pine Dam catchment 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 H.11 summarises research on location errors.
   The dimensions of the North Pine Dam catchment are smaller than the common magnitude of location error in Rainfall Forecasts.
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[37] 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[38] 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

[37] 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

[38] Handbook of Hydrometeorological Ensemble Forecasting (2019): https://www.springer.com/gp/book/9783642399244

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 H.2 and H.11.

H.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 G.

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[39]. 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 H.11 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 North Pine Dam catchment. It can also make a difference between heavy rainfall occurring upstream or downstream of the Dam.

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.

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, 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 11.2).

[39] The Bureau's 7-day streamflow forecasts are not available for North Pine Dam catchment 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.

APPENDIX H (ADDITIONAL INFORMATION ON RAINFALL FORECASTS)

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.

H.5 Summary of potential benefits risks and vulnerabilities in quantitative use of 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).

These risks arise because developing a Release Plan for the Dam involves balancing the rate of inflow with the rate of release (and change in inflow and release rates over time – 'the inflow and outflow hydrographs'). The balance between the inflow and outflow rate over time determines the predicted Lake Level. Uncertainties in one or multiple characteristics of the forecasted catchment inflow hydrograph (e.g. inflow volume, inflow rate, timing and magnitude of the Predicted Event Peak inflow rate) can have adverse consequences. Risks of adverse consequences are not readily assessable in a real-time Flood Event as the uncertainty is undefined[40]. If an adverse consequence from use of Rainfall Forecast in an early stage of a Flood Event prior Release Plans does emerge later in the Flood Event it may be too late to intervene to mitigate adverse impacts of prior releases[41].

Benefits are also possible for some Objectives for the flood operations if catchment flow hydrographs derived from Rainfall Forecasts do produce a reasonably reliable definition of the true future flow hydrograph. The potential benefits versus risks may not be balanced and may also vary for the unique circumstances of the specific Flood Event.

Table H.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.

[40] With future advances in ensemble streamflow forecasting (in a form suitable for flood operations decisions making) it may be possible to define uncertainty in real-time. There are significant complexities in decision making for dam operations with ensemble catchment flow forecasts. Tested methods for dam operation decision making with ensemble flow forecasts do not currently exist for North Pine Dam.

[41] Examples include excessive releases below OFSL based on over-forecast of the volume of inflows resulting in being unable to fill the Water Supply Compartment, or high releases based on over-estimation of the Predicted Peak inflow resulting in releases exceeding actual peak inflow (flood amplification).

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Table H.1 Potential benefits and risks to each specific Objective for North Pine Dam flood operations

Objective	Potential benefits and risks of quantitative use of Rainfall Forecast
Prevent structural failure of the Dam.	**Potential benefit:** Forecasts may suggest a need for higher releases in order to reduce the Predicted Future Peak Lake Level. In limited situations (very extreme Flood Events) incorporating the Rainfall Forecast into the catchment flow hydrograph used to develop the Release Plan may potentially avoid exceeding the Maximum Flood Storage Level. The benefit for this Objective will often be limited (described further in Section H.6). **Risk:** Minimal to no risk.
Ensure the Water Supply Compartment of the Dam is full at the completion 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 a 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. Forecasts may suggest a need for higher releases early in the Flood Event which may then reduce the peak outflow at the peak of Flood Event. **Risk:** Higher flooding downstream. Releases could exceed actual peak inflow if the Predicted Event Peak inflow is too high. This means the flood will not have been mitigated and increases the flood impact. Duration of inundation of Youngs Crossing will be longer if releases start earlier based on forecasts which will increase disruption to transport.
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 releases to exceed 300 m^3/s is higher if Rainfall Forecasts are used when the Predicted Event Peak inflows are greater than actual inflows. Potential false Flood Event indications resulting in initiation of flood releases that are not necessary (due to over-estimated inflows) could result in unnecessary fish stranding impacts.

Summary of vulnerabilities to risks and opportunities for potential benefits with use of Rainfall Forecasts

On balance, the greatest vulnerability to the Objectives arising from quantitative use of Rainfall Forecasts to develop Release Plans are situations where the forecast rainfall is over-predicted in the Dam catchment. These situations can compromise multiple Objectives in a single Flood Event – water supply security may be impacted, peak outflow may exceed peak inflow and traffic disruption may increase. Occurrences of Rainfall Forecasts being higher than actual rainfall for the North Pine Dam catchment are common.

H.6 Limitations of benefits of use of Rainfall Forecasts to prevent the structural failure of the Dam

For the Objective to prevent the structural failure of the Dam there are theoretical benefits and relatively no risks in using catchment flows derived with Rainfall Forecasts for this specific Objective. An accurate Rainfall Forecast may offer guidance to make higher releases solely focussed on the Objective for the structural safety of the Dam (ignoring consideration of other Objectives). High releases to reduce the risk of exceeding the Maximum Flood Storage Level would only occur rarely. The probability of exceeding the Maximum Flood Storage Level is extremely low and requires a very extreme rainfall event to reach this level (refer Section 10.3). The skill of Rainfall Forecasts is unknown at such extreme rainfall intensities.

The practical benefit of using Rainfall Forecasts to potentially avoid exceeding the Maximum Flood Storage Level in a very extreme Flood Event is likely to be limited because of the limited range of spillway radial gate operations in this Manual. The Procedures in this Manual will ordinarily achieve fully open spillway radial gates around 1.4 metres above OFSL (when the OFSL is at 36 m AHD) or at lower levels. The spillway radial gates will be fully open at least 4.3 metres below the Maximum Flood Storage Level. In situations where the spillway radial gates are fully open for the majority of a very extreme Flood Event, the use of Rainfall Forecasts provides no or insignificant practical benefit because no further steps can be taken to increase the release rate. An example of an extreme flood event is described further below to demonstrate the benefits to reduce the peak Lake Level in an extreme flood is likely to be limited to a very narrow range of floods.

If a Temporary FSL below 36 m AHD is in place, the Procedures achieve fully open spillway radial gates at lower levels, further reducing the potential benefit. If one or more spillway radial gates is inoperable the Procedures will achieve full opening of the operable spillway radial gates earlier and at a lower level.

Example of extreme flood that could reach the North Pine Dam Maximum Flood Storage Level (41.7 m AHD)

An extreme Flood Event that could reach the Maximum Flood Storage Level in North Pine Dam (41.7 m AHD) is described for contrasting scenarios of the flood operation of the Dam. 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.

This extreme event example flood has 1,490 mm catchment average rainfall in 36 hours over the total North Pine Dam catchment. The inflow volume is approximately 510,000 ML and the peak inflow into North Pine Dam is approximately 7,100 m^3/s.

The chart in Figure H.1 shows the inflow hydrograph and the North Pine Dam Lake Level and outflow hydrographs to demonstrate the influence of the spillway capacity in an extreme event. Three scenarios are presented for the North Pine Dam Lake Level and outflow hydrographs that represent:

- Scenario 1: The blue lines represent the Lake Level and outflow for simulated application of the Loss of Communications Procedures in this Manual (Section 14) with OFSL at 36.0 m AHD, and initial Lake Level at OFSL. If communications are not lost the use of the FFS to forecast inflow with the Procedures in Section 13 the Release Plans aim to release earlier and higher releases than the Loss of Communication Procedures and produce a lower peak outflow. For simplicity this example uses the releases with the Loss of Communication Procedures to show a baseline peak Lake Level that does not consider rainfall forecasts;
- Scenario 2: The green lines represent the simulated Lake Level and outflow 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 (36.0 m AHD);
- Scenario 3: The red lines represent the simulated Lake Level and outflow 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 34.0 m AHD (equivalent to 31,000 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.

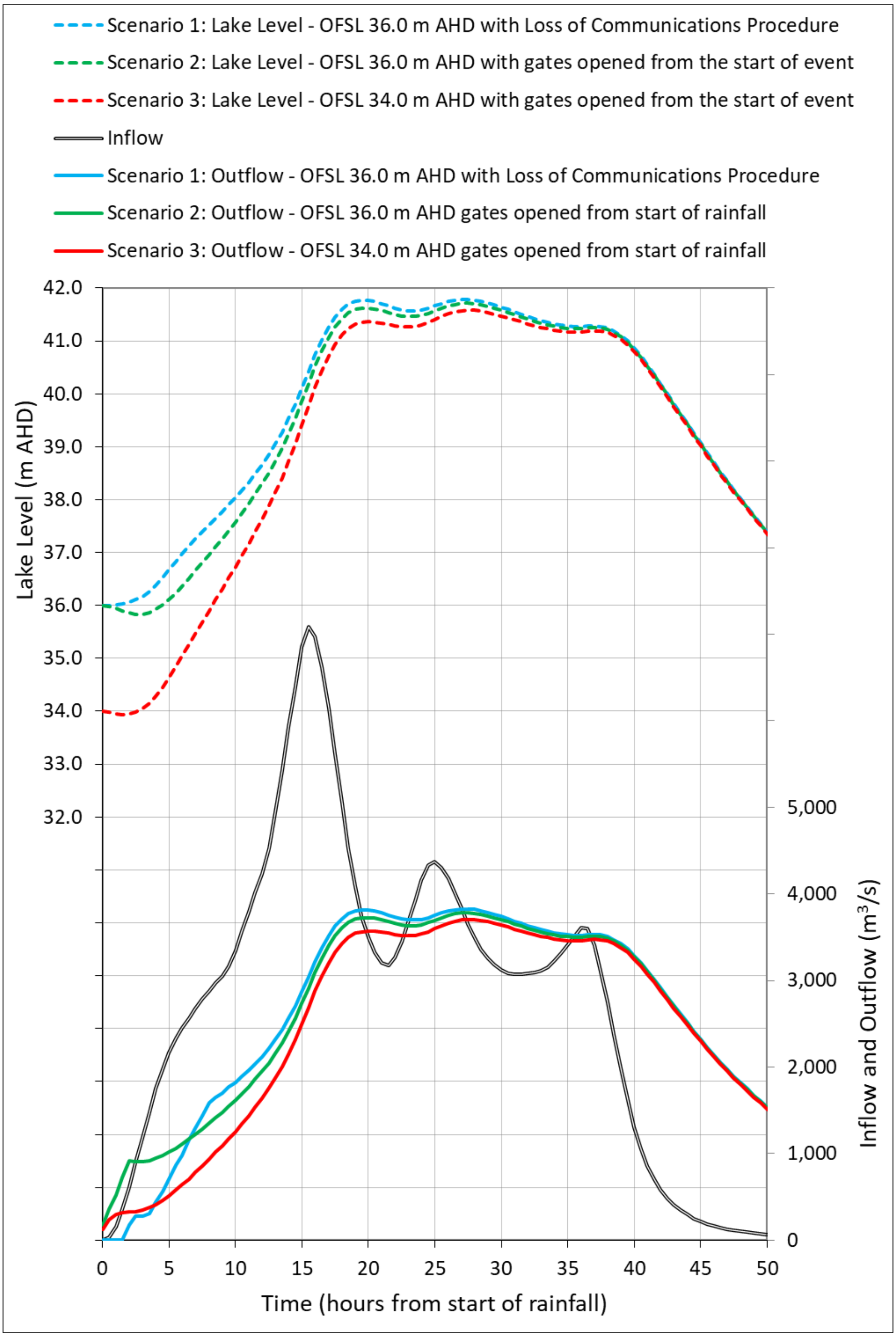
It is important to note that second and third hypothetical scenarios are conceptual and have only been included for demonstration purposes. It should not be interpreted that rainfall forecasts have sufficient reliability for such scenarios to occur. For clarity the second and third scenarios above are not in accordance with the Procedures in the Manual – they are simply hypothetical scenarios to demonstrate limitations to benefits of very high early releases for very extreme floods.

In all the above scenarios the simulations assume a maximum achievable rate of 6 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 H.2 presents key time points and information for these scenarios and should be read with reference to Figure H.1. Value differences stated in the table for the hypothetical scenarios are compared to the baseline scenario (no account for forecasts and applying the Loss of Communication procedures).

Table H.2 Scenario Comparison (refer Figure H.1 for chart)

Scenario	Scenario 1: Loss of Communications (Rain on Ground)	Scenario 2: Rainfall forecast influences immediate opening of spillway gates	Scenario 3: Lowered initial lake level and rainfall forecasts influences immediate opening of spillway gates
Initial lake level (m AHD)	36.00	36.00	34.00
Time to lift gates clear of flow	8 hours	2 hours	1.5 hours
Time spillway gates fully open	11 hours	6 hours	6 hours
Time to reach 40.6 m AHD	41 hours	41 hours	41 hours
Time to reach 41.7 m AHD	26 hours	29 hours	
Peak lake level (m AHD)	41.79	41.71 (0.08 m lower)	41.58 (0.21 m lower)
Time of peak lake level	28 hours	28 hours	28 hours

Figure H.1 North Pine Dam extreme flood example (rainfall event 1,490mm in 36 hours)



The simulated outflow and Lake Level hydrographs for the three scenarios for this example very extreme Flood Event demonstrate that:

- Scenario 2: A reduction in water level of 0.08 m is achieved by opening the gates immediately at the onset of rainfall;

- Scenario 3: A reduction in water level of 0.21 m is achieved by reducing the OFSL by 2.0 m and opening the gates immediately at the onset of rainfall.

In this specific example for a flood that slightly exceeds 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.

H.7 Risks to ensuring the Water Supply Compartment is 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 Dam 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. 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.

H.8 Potential benefits and risks to mitigate downstream flooding

The potential benefits and risks for the Objective to mitigate downstream flooding, specifically to mitigate (reduce) the peak outflow will be sensitive to the forecasted hydrograph inflow volume and timing and magnitude of the Predicted Event Peak inflow derived with Rainfall Forecasts. Possible variations include:

a. The greatest risk of increased downstream flooding will be in situations when the Predicted Event Peak inflow derived using Rainfall Forecasts is substantially higher than the actual peak inflow for the Flood Event. If the Predicted Event Peak inflow rate is overestimated, the peak outflow could exceed actual peak inflow for the Flood Event. This means the Dam will not have mitigated the Flood Event.
b. The potential benefit of decreased downstream flooding will arise if the Predicted Event Peak inflow rate does not exceed the actual peak inflow rate. In these circumstances, it is less likely that the peak outflow will exceed the peak inflow rate (meaning the Dam will have mitigated the Flood Event).

In real-time operations the actual peak inflow for the Flood Event is not known until after it occurs. This means that prior to the peak inflow occurring it is not known whether the Predicted Event Peak inflow rate will exceed the actual peak inflow rate. The balance of the potential benefit and risk for the Objective to mitigate downstream flooding is highly vulnerable to the accuracy of the inflow hydrographs derived from Rainfall Forecasts. The uncertainties in Rainfall Forecasts described in Appendix H.4 are particularly relevant for this vulnerability. The prevalence of location error for the areal position and extent of heavy localised rainfall in forecasts increases the risk that the Rainfall Forecast will not result in a reasonable prediction of the peak inflow rate.

H.9 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.

There is some risk of causing unnecessary fish stranding impacts near the North Pine 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.

H.10 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 H.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 North Pine Dam catchment.

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 North Pine Dam which is influenced by catchment flow hydrographs upstream of the Dam.

H.11 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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