River Murray 2022-23 Flood Review

FINAL REPORT

February 2024

alluvium

Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Melissa Barton. This piece was commissioned by Alluvium and tells our story of caring for Country, through different forms of waterbodies, from creeklines to coastlines. The artwork depicts people linked by journey lines, sharing stories, understanding and learning to care for Country and the waterways within.

Erratum

An error in Figure 9 has been corrected. The orange line in the chart depicts Hume Dam inflow and the blue line shows Hume Dam releases. The labels were previously reversed in error and have now been updated in the Figure.

This report has been prepared by Alluvium Consulting Australia Pty Ltd for Murray-Darling Basin Authority under the contract titled 'River Murray 2022-23 flood review'.

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Cover image: abstract river image, Shutterstock

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Table of abbreviations

Abbreviation	Explanation
Agreement	The Murray-Darling Basin Agreement (Schedule 1 to the Water Act)
AIDR	Australian Institute for Disaster Resilience
Authority	Murray-Darling Basin Authority (the board; used for statutory items)
BOC	Basin Officials Committee
The Basin	Murray-Darling Basin
Basin States	The Basin States are South Australia, Victoria, New South Wales, the Australian Capital Territory and Queensland.
The Bureau	Bureau of Meteorology
CCM	Crisis Communications Manager
CCP	Crisis Communications Plan
CMEP	Communication, Media and Engagement Plan
DEECA	Department of Energy, Environment and Climate Action (Victoria)
DEW	Department of Environment and Water (South Australia)
DPE	Department of Planning and Environment (NSW; former name)
DSEP	Dam Safety Emergency Plan
EAP	Emergency Action Plan
EWN	Early Warning Network
FOM	Flood Operations Manuals
FSL	Full Supply Level
GL/d	Gigalitres per day (a measure of the rate of flow)
GMW	Goulburn Murray Water
IRORG	Independent River Operations Review Group
MDBA	Murray-Darling Basin Authority (the organisation; see Authority above)
ML/d	Megalitres per day (a measure of the rate of flow)
NSW	New South Wales
RMO	River Murray Operations
ROWS	Software used by MDBA for River Operation Warning System
SA	South Australia
SCA	State Constructing Authority
SES	State Emergency Services
SMOM	'Source' Murray Operation Model
TFWS	Total Flood Warning System
URBS	Unified River Basin Simulator
VMFRP	Victorian Murray Floodplain Restoration Project
Water Act	*Water Act 2007* (Cth)

Executive Summary

This is the final report of Alluvium's independent review of the Murray-Darling Basin Authority's (**MDBA**'s) technical operations, governance and communication of the River Murray 2022-23 flood event. The review arose from Basin Officials Committee (**BOC**) discussions in 2023 as to the circumstances of the River Murray 2022-23 flooding and the agency response. Alluvium was engaged by the MDBA to undertake a review of the communication, governance, and technical information and systems relevant to the 2022-23 flooding and to prepare a report covering all aspects of the review. This includes:

1. Formal governance arrangements documenting roles and responsibilities within the management of the 2022-23 flood.
2. Communication linkages and content effectiveness both within the defined governance and with the broader community.
3. The collection, generation and communication of technical information including hydrologic data, flow and river height forecasts.
4. Collaboration between the MDBA and related agencies (Bureau of Meteorology (**the Bureau**)), state departments and river operators, councils, and State Emergency Services (**SES**)).

Alluvium was not asked to review the performance of other agencies and was mindful to support the MDBA in its ongoing collaboration between relevant agencies, including those interviewed in this review. Agencies interviewed for this review have been provided with the opportunity to review key points from those interviews for inclusion in the final report where relevant. Additionally, Alluvium was not asked to review the river infrastructure operational decisions made by the MDBA, and other river operators, during the 2022-23 floods, nor the objectives, outcomes or policy set by the BOC under the Murray-Darling Basin Agreement (**the Agreement**).

The below table provides a summary of the key findings and recommendations of this review. These should be read and considered in the context of the full review and report.

Table 1. Summary of the findings and recommendations of this review.

	Finding	Recommendation
General	**F1:** The MDBA operated the major storages during the flooding period as set out in the requirements prescribed by the Basin Officials Committee (BOC). Overall, stakeholders and landholder groups expressed positive sentiments about the MDBA's engagement efforts during the 2022-23 flood event, which constituted significant improvements in engagement and information exchange.	No recommendation
Governance , communication and collaboration	**F2:** The arrangements between the MDBA and the Bureau during the 2022-23 flood events were found to be functional and highly collaborative. Both the Bureau and the MDBA were working within their roles and responsibilities. However, once peak flows passed downstream of Yarrawonga Weir, the agreed guidelines between the MDBA and the Bureau did not provide guidance for further collaboration to support flow forecasts (while it is noted that collaboration did occur).	**R1:** It is recommended that the Bureau and the MDBA expand their guidelines to include an appropriately flexible collaboration process to support flow forecasting in future events, including collaboration with other agencies where appropriate. A potential example is the "Inter-agency forecasting and flood warning collaboration meetings" described in the flood warning operational protocol developed between the Bureau, the MDBA and South Australian agencies in 2023.

	Finding	Recommendation
	This arrangement transitioned later in 2023 (after the flooding) to incorporate changes to the service level agreement between the Bureau and the South Australian Government, which includes forecast locations in the River Murray in SA.	
	F3: The MDBA's Flood Operations Manuals (**FOMs**) have been in draft form for a substantial period of time. The draft manual for the Hume Dam viewed as part of this review is well advanced, and the Independent River Operations Review Group (**IRORG**) noted in their review that the manuals have been independently functionally reviewed. **F4:** The MDBA maintains a regular formal program of training and accrediting its staff. However, wider simulations involving other agencies occurs less frequently.	**R2:** It is recommended that the FOMs be updated to include appropriate learnings from the 2022-23 flooding period, and the FOMs be finalised and formally approved as a matter of urgency. **R3:** Consideration should also be given to undertaking regular simulated flood operations exercises involving other appropriate agencies to build and maintain communication and collaborative relationships.
	F5: The historic practice of providing flow forecasts at the South Australian border during flooding periods is an important role for the MDBA that is not recognised as a requirement in formal governance arrangements.	**R4:** To reflect the value and importance of this work, it is recommended that the provision of flow modelling to the Bureau and South Australian government by the MDBA is incorporated as a requirement within the Objectives and Outcomes for MDBA river operations set by the BOC each year (MDBA 2022).
	F6: The Hume Dam surcharge policy is not recognised in formal governance arrangements. **F7:** It is not clear whether the surcharge limits could be increased following further investigation or works.	**R5**: The Hume Dam surcharge policy should be formally agreed and adopted by the MDBA for the effective management of the Hume Dam during periods of high inflows. The policy could also be incorporated into the BOC's Objectives and Outcomes document. **R6:** The MDBA should consider formally adopting an approach to optimising the Hume Dam surcharge policy against the general objectives and outcomes set by the BOC each year, in particular, those set out in sub-sections (2), (3), and (4) of Section 4 of the Objectives and Outcomes (MDBA 2022).
	F8: Interviews indicated that landholders below the Hume Dam are seeking information with more focus on the outlook for potential releases from the Hume Dam under different weather scenarios.	**R7:** The MDBA could review the content of briefings and consider the use of video briefings compared to the distribution of more targeted information products on information sought by landholders (see also recommendation R12 below on flow forecasting).
	F9: Interviews indicate that landholders along the River Murray system below the Hume Dam and the Yarrawonga Weir remain dissatisfied with flood operations strategies and airspace strategy, as well as related communications and consultation.	**R8:** The MDBA should give consideration to ongoing and transparent information sharing on the strategies for flood operations and airspace, combined with an elevated level of information in the lead up to (and following)

	Finding	Recommendation
		potential flooding periods. Information should be shared as: • Information that is generally available • More prominent information in the lead up to flood events, and • Post-flood publication of information about what had occurred.
Information and systems	**F10:** Accurate measurement of rare high flow events presented challenges to forecasting river flows and public communication.	**R9:** The MDBA (in collaboration with the Basin States[1] and the Bureau) investigate opportunities to improve real-time flow measurement and reporting where possible, including addressing known issues at some flow gauging stations, and use of new technologies such as drones and remote sensing. **R10:** The MDBA should consider opportunities to provide additional information that can assist landholders to be as prepared as possible during floods. This also links with recommendation R12. **R11:** The MDBA (in collaboration with the Basin States and the Bureau) consider how flow measurement uncertainties at very high flow rates could be better communicated, including via the "River Murray Data" website.
	F11: The MDBA has developed an upgraded 'Source' Murray Operations Model (**SMOM**), which was able to provide the Bureau and South Australian government agencies with valuable guidance for the forecasting of river flows downstream of the major storages.	**R12:** It is recommended that the MDBA develop and document internal processes for SMOM operations during flood events, to support an enduring and predictable level of support and communication with partner agencies.
	F12: Interviews indicate that a number of stakeholders, particularly landholders downstream of the Hume Dam, see significant benefits in receiving river flow forecasts that show a range of scenarios, and increased notice of releases from the Hume Dam. In recognition of the many challenges in rainfall and flood flow forecasting, there was a willingness to receive forecasts that are more probabilistic, or indicate a range of potential outcomes, to enable advice to be provided earlier in advance of the releases.	**R13:** The MDBA consider the feasibility, costs, benefits and risks, of providing information about possible scenarios for storage releases and river flows, in collaboration with the Bureau

[1] The Basin States are South Australia, Victoria, New South Wales, the Australian Capital Territory and Queensland.

	Finding	Recommendation
Operational infrastructure	**F13:** There is ageing infrastructure on the River Murray floodplain that may be at risk of failure during larger flood events, some of which supports the normal operation of the River Murray system (specifically the Mildura Weir, Lake Victoria and surrounding infrastructure).	**R14:** The MDBA, in collaboration with other asset-managers, should undertake a review of the condition of ageing floodplain infrastructure relevant to the MDBA's river operations to assess the risk of future failures during floods, and the consequences of those failures. Such a review would address the general objective and outcomes in subsection 4(3) of the Objectives and Outcomes set by the BOC (MDBA 2022). This risk assessment should also have regard for the impacts of climate change on the future likelihood and consequence of severe flood events.

1 Introduction

1.1 Climate context and flooding overview

Australia experienced its ninth highest annual rainfall in 2022, according to historical records, with rainfall across the country 26 percent above the 30-year average of the 1961-1990 period, according to the Bureau of Meteorology (the Bureau)(2022). In south-eastern Australia, above average rainfall, and the timing of this rainfall, resulted in significant flooding across much of the Murray-Darling Basin (the Basin).

Throughout 2022, eastern Australia experienced repeated episodes of heavy rainfall and widespread flooding due to several climate drivers (Bureau, 2023b). La Niña, which causes wetter than average conditions over eastern and northern Australia, was present during the summer of 2021–22, weakened in autumn, but re-emerged in early spring and lasted until the end of 2022. A negative Indian Ocean Dipole, which also favours more rainfall over southern and central Australia, developed in winter and persisted until spring (MDBA, 2024a). Additionally, a positive phase of the Southern Annular Mode, which shifts westerly winds and storm systems further south, dominated from mid-autumn onwards. As a result of these factors, water storages across the country were high for most of 2022.

The 2022-23 River Murray flood event occurred between October 2022 and February 2023, as a result of continued heavy rain and multiple flood events (MDBA, 2024a) in the river and its major tributaries.[2][3]

The 2022 floods led to one of the most devastating events in Victoria's history for communities along the northern Victorian river system of the Campaspe, Goulburn and the River Murray, including the towns of Shepparton, Rochester and Echuca (NEMA, 2022). At Echuca, the River Murray rose slightly higher than 1993 levels (VICSES, 2022). Emergency warnings and evacuation orders were issued for Swan Hill (Victoria); however, Swan Hill's levees were able to contain the water within the river. In the same period, major flooding was also occurring in the Murrumbidgee and Lachlan Rivers, and along the Barwon-Darling River. The floodwaters isolated the NSW town of Moulamein on the Edward River and caused major road closures and evacuation of residents.

In the lower River Murray, the river height exceeded the historical 1974 floods at the Mildura Weir. Further downstream, the flood events of 2022-23 are regarded as the worst flood events in almost 70 years for South Australia, with daily flows near Renmark peaking at 186,000 ML per day on 20 December 2022 (SA DEW, 2023). The event caused flooding to an unprecedented number of homes, properties, businesses, and infrastructure, and affected 4,000 hectares of agricultural land and 3,500 private residents (SA DEW, 2023). In South Australia, between Christmas 2022 and early January 2023, the River Murray progressively peaked in towns including Renmark, Waikerie, Swan Reach and Murray Bridge. Numerous flood levees failed along the Murray in South Australia, affecting communities near Renmark, where the peak was similar to the flood level that occurred in 1931. The State Emergency Services (SES) rescued three people from floodwaters near Renmark. The River Murray was closed to all non-essential activity from the South Australian border to Wellington. The flooding affected communities downstream from Loxton and Berri to Mannum and Lake Alexandrina (SA DEW, 2023).

[2] For consistency, the authors have referred to the river throughout as the River Murray, except for organisational names and quotes. It is recognised that both governments and stakeholders use both the constructions 'River Murray' and 'Murray River' and the official geographical name varies between states. In addition, the authors recognise that First Nations have always had Indigenous names for the river in their own languages.

[3] The term River Murray system is used to refer to the connected system of the River Murray with its anabranch system, such as the Edward River, Niemur River and Wakool River.

1.2 Review objectives

Scope

This Review arose from the Basin Officials Committee (**BOC**) discussions in 2023 as to the circumstances of the 2022-23 River Murray flooding and the multi-agency response. The scope for this Review of River Murray Floods is provided in Attachment 1[4]

The scope of this flood review report is tightly focussed on the role that the MDBA played in managing the 2022-23 flood event as part of a multi-agency emergency response.[5]

The Murray-Darling Basin Authority (MDBA) engaged Alluvium Consulting Australia (Alluvium) with Paul Simpson and Garry Smith to undertake a review of the communication, governance, and technical information and systems and prepare a report covering all aspects of the review.[6] This includes:

1. Formal governance arrangements documenting roles and responsibilities within management of the 2022-23 flood.
2. Communication linkages and content effectiveness both within the defined governance and within the broader community.
3. The collection, generation and communication of technical information including hydrologic data, weather forecasts, flow and river height forecasts.
4. Collaboration between the MDBA and related agencies (Bureau of Meteorology, state departments and river operators, councils, and State Emergency Services).

Specifically, Alluvium was asked to investigate:

- Information collection system performance
- Modelling system performance
- Technical collaboration opportunities.

In conducting this Review, the MDBA has requested Alluvium consider the following questions and inputs:

1. What should have happened (i.e. what do the governance arrangements require)? **Addressed in Sections 2 and 3.**
2. What actually happened (how did the event unfold from both a governance and information and systems perspective)? **Addressed in Sections 4 and 5.**
3. Identify any differences between the governance arrangements and reality in both the governance and technical fields. **Addressed in Sections 4, 5 and 6**.
4. Agencies and stakeholders relevant to this Review be offered the opportunity to be interviewed for and to review summaries of the engagement. **Addressed in Section 6**
5. Provide findings and recommendations for both governance and information and systems workstreams. **Addressed in Section 7.**
6. Commonwealth and Basin States[7] had the opportunity to review this report as part of consideration by BOC and subsidiary River Murray Committees[8].

Out of scope

Alluvium was not asked to review the performance of other agencies and was mindful to support the MDBA in its ongoing collaboration between relevant agencies, including those interviewed in this review.

[4] References to the Review that is the subject of this report are capitalised.
[5] This review refers to the '2022-23 flood event', but it is recognised that the flooding involved several peak flow events – see Chapter 5.
[6] The authors use the abbreviation MDBA to refer to the organisation, while the term Authority for the 'board' of the organisation, for example when referring to (or quoting) statutory obligations.
[7] The Basin States are South Australia, Victoria, New South Wales, the Australian Capital Territory and Queensland.
[8] River Murray Operations Committee and Water Liaison Working Group. While Basin government agencies had the opportunity to review the report and provide comments, the report remains an independent review by Alluvium and partners.

Additionally, Alluvium was not asked to review the river infrastructure operational decisions made by the MDBA and other river operators during the 2022-23 floods, nor the broader objectives, outcomes or policy set by the BOC under the Murray-Darling Basin Agreement (**the Agreement**).

1.3 Methodology

The purpose of this Review is to review and report roles and responsibilities as relevant to the 2022-23 flood event, report on agency and stakeholder engagement, provide an analysis of the information and systems used during the event, review the sequence of events, governance and communications and synthesise outcomes.

The Review and this report have been informed by a review of literature (relating to both governance and technical information and protocols). In particular, the MDBA prepared two reports; a *Post flood report* that records the 2022-23 series of flood events and MDBA's operational actions at its three main structures at which flood operations occurs (MDBA 2024a), and a *Flood forecast report* describing the application of the MDBA's SMOM to simulate potential flows along the River Murray to the South Australian border (MDBA 2024b). In addition, the 2023 review of MDBA's river operations by the Independent River Operations Review Group (IRORG) has also been an important source of information.

This information was complemented by interviews, with a view to assessing if stakeholders received timely and appropriate information during the 2022-23 flood events, including by:

1. engaging with external agencies including state river operators[9], the Bureau, SES, and local councils to assess the functionality and timeliness of information provided by the MDBA, and
2. engaging and seeking feedback from community stakeholders downstream of major storages through existing representative groups.

Project stages

The project involved five key stages (Figure 1), including inception and planning, targeted agency, and stakeholder engagement, delivering a draft report to BOC, delivering the final report to the MDBA.

Figure 1. *Project stages*

Workstream 1: Governance and communication

Workstream 1 involved reviewing and examining formal governance and communications arrangements and documenting roles and responsibilities within management of the 2022-23 flood event across the River Murray System.

[9] Under the Murray-Darling Basin Agreement, state river operators are also designated as 'State Constructing Authorities' (SCAs) for operations and asset maintenance of certain works on the River Murray. The MDBA makes the operational decisions for the River Murray.

As part of this workstream, Alluvium assessed governance, roles and responsibilities during the 2022-23 flood events. As well as reviewing existing documentation (publicly available, and from MDBA and agencies), the project team relied on the agency engagement to explore:

- how the MDBA and other agency parties interacted, communicated, managed and shared data and information such as warnings during floods,
- how data and information was shared more broadly with the community, and
- whether data and information was fit for the purposes of agencies and the broader community, with a focus on local government and floodplain residents.

Alluvium worked with the MDBA to identify relevant agency and community stakeholders (see Table 2, below) and the best method and design for engagement.

Targeted agency engagement
Engagement with relevant agency stakeholders was conducted via a series of targeted interviews. The purpose of these interviews was to document and align common and different understandings and procedures of flood event data sharing, governance, communications, and arrangements. The interviews were also aimed at identifying potential knowledge gaps for the purposes of making recommendations to improve multi-agency and jurisdictional responses to future transboundary river flood events.

Targeted community engagement
The purpose of these interviews was to understand from affected stakeholders the timeliness and utility of MDBA's provision of information during the flood event (and at critical or material times leading up to it) and the opportunities to improve for future purposes.

Table 2. Engagement with MDBA, relevant agencies and stakeholders.

Organisation	Team	Comments
MDBA	River Operators Modelling Group	Interview 01/11/2023 Interview 07/11/2023
	Andrew Reynolds, Executive Director River Management	Interview 02/11/2023
Bureau of Meteorology		Interview 23/11/2023
WaterNSW		Interview 11/12/2023
NSW DPE Water[10]		Opted out of interview
Goulburn Murray Water		Interview 15/12/2023
Department of Energy, Environment and Climate Action (DEECA) Victoria		Interview 15/12/2023
Murray River Group of Councils (Victorian councils)		Interview 11/01/2024
Department for Environment and Water (DEW) South Australia		Interview 17/11/2023
SA Water		Interview 10/01/2024
Murray River Action Group		Interview 01/12/2023
Murray River Strategy Group		Interview 12/01/2024
SES NSW		Interview 11/12/2023
SES Victoria		Interview 16/01/2024

NOTE: The Riverina and Murray Joint Organisation of NSW councils were contacted and provided opportunity for interview(s). However, an interview was not able to be scheduled within the project timeframe.

[10]From 1 January 2024 this agency is now known as the NSW Department of Climate Change, Energy, the Environment and Water.

Workstream 2: Information and system operations

Workstream 2 involved reviewing available technical information and existing systems, including investigating the performance of information collection and modelling systems between the MDBA and other water authorities. Workstream 2 involved a high-level consideration of the management limitations and opportunities for the MDBA to improve collaboration and information sharing during flood events.

Alluvium also assessed the antecedent conditions and the airspace management in the River Murray storages as part of this project stage. This included utilising publicly available data and examining MDBA's own data to assess and characterise the extent, duration and pattern of the 2022-23 flood event.

Alluvium's scope did not include review of infrastructure operation decisions (including airspace and release decisions), rather a review of the suitability of information, governance and communications in informing those decisions and in communicating flood events. The following matters have been included in this investigation:

- whether the data systems were fit for the purpose of the decision making,
- assessing available technical information to establish the flood event sequence, and
- review of monitoring, modelling and data system performance.

2 The River Murray system

The River Murray receives inflows from across the Murray-Darling Basin and is the longest river in Australia. The headwaters of the River Murray rise in the alpine areas of south-east Australia, and flow across NSW, Victoria and south-eastern South Australia, reaching the sea in the Great Australian Bight (Figure 2).

The flows in the River Murray and its major tributaries are regulated by dams, weirs and locks which are managed to provide water for urban water supply, irrigation, the environment and, in the lower reaches, for navigation. The regulated River Murray system extends from the major dams in its headwaters to the barrages at the Murray Mouth, with flows in major tributaries also managed as separate but connected regulated river systems. The River Murray regulated system from the Dartmouth Dam to the South Australian border is managed by the MDBA on behalf of the governments of the Commonwealth, New South Wales (NSW), South Australia (SA) and Victoria.

The MDBA as river operator manages and takes operational decisions for the dams, weirs, and locks along the River Murray system from the Dartmouth Dam to Lake Victoria. The MDBA directs river operations in the River Murray system in accordance with objectives and outcomes set by the BOC (MDBA 2022). Directions from the MDBA are implemented on site by the relevant State Constructing Authorities (SCAs).

There are three main structures that require operational flood management. These are the two major storages at the Hume Dam and the Dartmouth Dam, and the Yarrawonga Weir. Other structures such as Lake Victoria and other weirs and locks along the River Murray generally have no capacity to affect flood flows.

2.1 The Dartmouth Dam

Primary function – water conservation

The Dartmouth Dam on the Mitta Mitta River has a capacity of 3,856 GL and provides longer-term storage for the regulated River Murray system. The MDBA oversees the operation of the Dartmouth Dam, capable of holding up to 40% of the River Murray system's total storage capacity. The MDBA manages the Dartmouth Dam in accordance with Objectives and Outcomes set by the BOC, (MDBA, 2023), with a primary role of water conservation and meeting downstream supply demands. Goulburn-Murray Water is the SCA for the Dartmouth Dam.

The Dartmouth Dam provides a 'back up' reservoir to supplement the Hume Dam. The Dartmouth Reservoir has a large capacity compared to average inflows, which means this storage takes relatively longer periods to fill.

Transfers of water from the Dartmouth Dam to the Hume Dam are undertaken based on 'harmony operations' that balance and seek to equalise the risk of spill between the two reservoirs. Harmony operations take into account forecasts of downstream demands and the limited release capacity from the Dartmouth Dam using hydrological modelling.[11]

2.2 The Hume Dam

Primary function – water conservation

The Hume Dam has a capacity of 3,005 GL and is the major operating storage of the River Muray regulated river system. This storage also receives water from the Dartmouth Dam and from the Snowy Mountains Hydro-electric Scheme. The Dam operations are managed by the MDBA, with WaterNSW (as the SCA) being responsible for day-to-day operation and maintenance. It operates to supply water to provide the target flows to SA set out in the Agreement, and to meet Victorian and NSW requirements. The storage typically receives the majority of its inflows during the winter-spring season and is usually drawn down to meet water demands during summer and autumn each year.

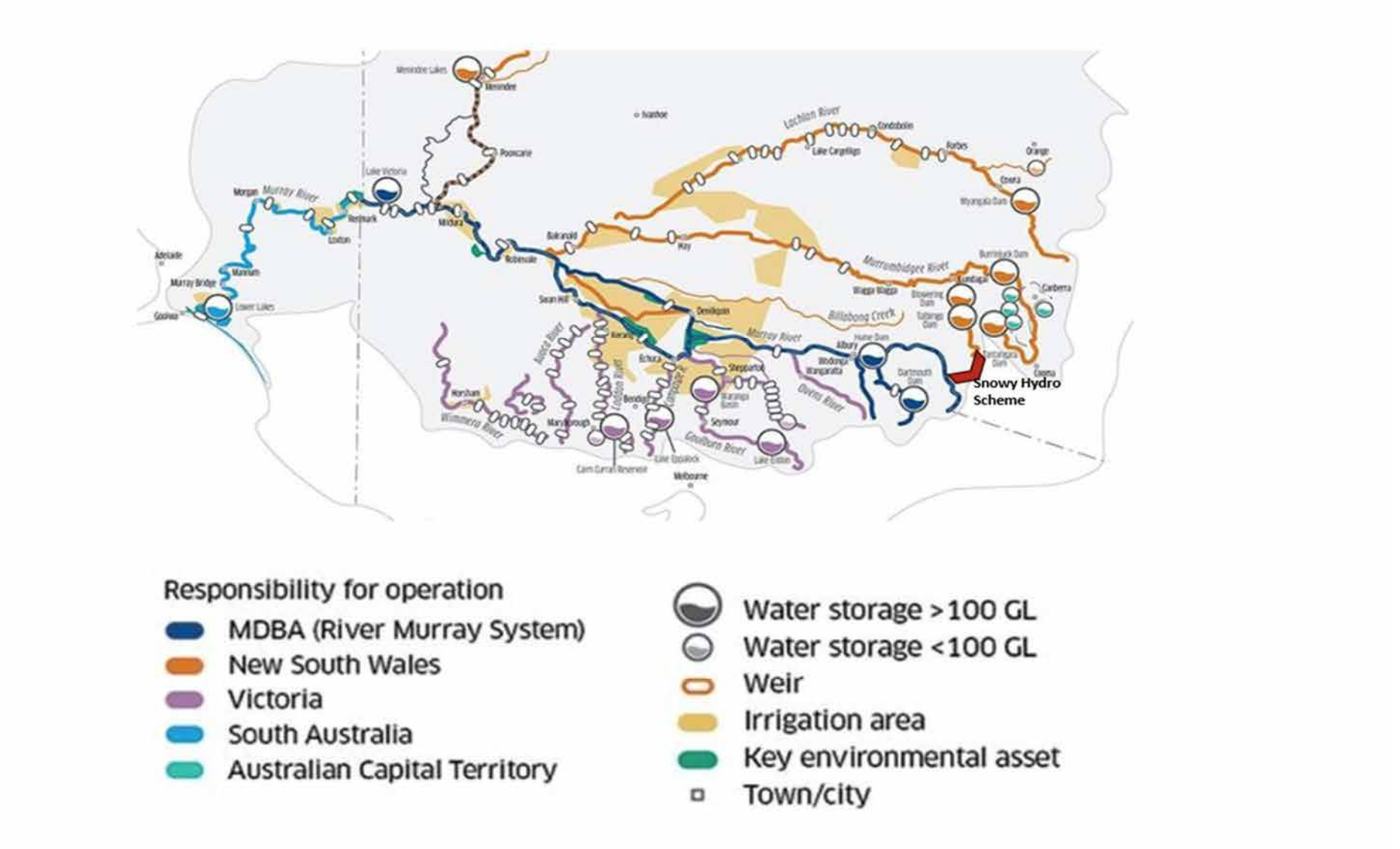

Figure 2. *Regulated River Murray System (Source: MDBA website)*

Besides its primary function of conserving water and supplying the system, the Hume Dam provides other benefits including flood mitigation. During flood operations, the airspace in the Dam is managed to reduce risks from floods to downstream under an airspace policy[12] where pre-releases from storage can be made prior to potential major inflow events to create airspace. However, airspace can only be created to the extent that there is a very high likelihood that the storage will refill prior to the onset of downstream water demands.

2.3 Yarrawonga Weir

Primary function – diversion of irrigation water and water conservation

The Yarrawonga Weir is the largest weir on the River Murray, with a capacity of 117 GL. Its main purpose is to raise the water level to enable the diversion of water from the River Murray to the irrigation channels of Mulwala Canal (NSW) and Yarrawonga Main Channel (Victoria). Out of the 10 gates on the northern and southern structures, the 2 northern gates are only operated during floods with flows larger than 60,000 ML/day. Due to limited pool capacity, during a flood event the weir operation mainly serves to ensure peak inflows are passed without local impacts. Lowering the pool ahead of flood events via 'pre-releasing' helps to minimise the risk of any increase to peak flows, but provides no material reduction to downstream flooding. Goulburn-Murray Water is the SCA for the Yarrawonga Weir.

2.4 The Snowy Scheme

The Snowy Scheme (operated by Snowy Hydro Limited) is a hydro-electric scheme in the NSW Snowy Mountains that stores water from the upper reaches of the Snowy, Murrumbidgee, and Murray rivers and makes releases for power generation and water supply to the Murray and Murrumbidgee Rivers. The Snowy Scheme has a series of power stations and tunnels leading to the Tumut River in the Murrumbidgee Valley and to the Murray Valley along the Geehi and Swampy Plains Rivers. Releases from the Snowy Scheme's Murray development flow into the River Murray above the Hume Dam, providing 1,036 GL for use along the River Murray in 2022-23[13].

There is little capacity for the Snowy Scheme to be used to reduce flows from the Geehi River, as the main trans-mountain tunnel between the Snowy River and the Geehi River only flows westward, and there is limited storage capacity in the small storages on either side of the two Murray power stations or at the bottom of the system on the Swampy Plains River.

Whilst not prescribed in the Snowy Water Licence, Snowy Hydro Limited have undertaken to ensure that peak releases out of the Murray Development at Khancoban Dam are not larger than those that would naturally have occurred during periods where downstream flooding is occurring[14].

2.5 River Murray from Yarrawonga to South Australia

The MDBA directs operations on the River Murray to the South Australian Border. During flood events, flows in the River Murray between Yarrawonga and the South Australian border are impacted by major tributary flows from both NSW and Victoria (including the Goulburn, Campaspe, Loddon and Avoca rivers from Victoria and the Murrumbidgee, the Edward-Wakool and the Lower Darling rivers from NSW). There are a range of locks and weirs in this reach that are managed by the SCAs[15], including WaterNSW, Goulburn Murray Water and SA Water.

Beyond the South Australian border, river operational decisions are made by the South Australian Department for Environment and Water (**DEW**), while SA Water operates weirs, locks and structures in the South Australian River Murray. SA Water is the SCA for structures in southwest NSW including, Lake Victoria and Locks 7, 8 and 9.

[12] Objectives and outcomes document (MDBA 2023), Specific objectives and outcome 2.6, see Hume Dam subsection under Section 4.2
[13] Snowy Scheme Annual Water Operating Report for 2022-23 (https://www.snowyhydro.com.au/wp-content/uploads/2023/04/SH2068_Water-report.pdf)
[14] https://www.snowyhydro.com.au/generation/water/
[15] Under the Murray-Darling Basin Agreement, Schedule 1 to the *Water Act 2007* (Cth)

Lake Victoria is a large and shallow water body that can store up to 677 gigalitres of water. It spans over an area of 12,200 hectares and has an average depth of around 5.5 metres. The lake is an important water storage used to regulate the flow in the River Murray system to South Australia. Lock 9 is about 60 km downstream from the confluence of the Murray and Darling rivers, and the Lock 9 weir pool on the River Murray enables diversions into Lake Victoria via Frenchmans Creek. Water stored in Lake Victoria can be returned to the River Murray below Lock 7 via the Rufus River.

Operationally, Lake Victoria plays a crucial role in regulating the supply of water to SA. The Agreement specifies the amounts of water that SA is entitled to receive each month. When the River Murray is not able to deliver sufficient water from upstream sources, Lake Victoria can be used to compensate for the shortfall. Conversely, when there is excess water coming from upstream, Lake Victoria can be used to store water for later release. However, operation of Lake Victoria has very little capacity to affect flood flows.

2.6 Managing the River Murray system during floods

The primary objective of most major storages in the Basin is to conserve water for future water supply, and to have the storage as close to full as possible following any inflow events, prior to downstream demands for water commencing again (MDBA 2022). Most major storages can provide significant flood mitigation even when they are nearly full. This can be achieved by maintaining storage releases below the inflows and allowing the storage level to rise above the sill of its spillway, which takes time and allows the storage to exceed its full supply level (surcharging) for a period of time, which temporarily stores significant volumes of water. This has the effect of delaying the release of water and reducing the peak release rate required. Delays can help allow downstream tributary inflows to peak first and begin to recede before the higher releases from the storage occur. This is the strategy that is applied at the Dartmouth Dam. Some storages have gates which can be used to store water above the full supply level for limited periods of time before additional downstream releases are required.

This delaying effect can also be achieved or enhanced by creating airspace ahead of inflow events. Some storages in other river systems, have a dedicated airspace that is maintained for flood mitigation, although many do not. However, even without a dedicated portion of the storage being reserved for flood mitigation, a similar effect can be achieved by a temporary or variable airspace strategy. Airspace can be created at times when the storage is close to full and there is a high probability of further inflows by pre-releasing water from storage. This can be undertaken based on seasonal conditions (e.g. ahead of winter inflows), based on the recession of current inflows as conditions become drier, or (where there is sufficient travel time to reach the storage) based on forecast inflows to a storage. A temporary airspace strategy is applied at the Hume Dam. The Yarrawonga Weir has a much smaller storage capacity than the Hume Dam and the Dartmouth Dam, and has been designed primarily to divert water into the Yarrawonga Main Channel in Victoria, and the Mulwala Canal in NSW. This storage normally provides the ability to adjust in-channel flows when the river is under regulated conditions. During smaller inflows from tributaries, the Yarrawonga Weir can help capture flows for later use.

The weirs and locks along the River Murray system below Yarrawonga have no significant capacity to affect flood flows. Their gates are usually removed to protect the structures and allow flood flows to pass unimpeded. Most structures require preparation in advance of flood flows, to physically remove them from the river.

The Mildura Weir is a unique structure in Australia, as it is the only trestle weir in the country. It consists of 24 steel trestles, each weighing about 11 tonnes, that have to be lifted out of the river by a winch. The trestles also have to slide along tracks on the riverbed and the weir (GMW, 2024). This makes the removal and reinstatement of the weir a lengthy and complex process, which can affect the community. Goulburn-Murray Water (GMW) is the SCA for the Mildura Weir. The weir pool is essential for the town water supply of local water utilities. The age of the structure and the post-flood conditions, such as debris and sand deposition on the concrete ramp and tracks, can also pose challenges for reinstating the trestles. To ensure this occurs in a timely manner, the MDBA river operators provide advice to GMW and the local water utilities on the timing of approaching high flows and the receding limb of the flood, noting the significant lag time between upstream rainfall and flows travelling further downstream.

The MDBA river operators have a historic practice of continuing to provide forecasts of flows at the South Australian border during high flow and flood periods to the South Australian government agencies.

3 Roles and responsibilities of state and federal agencies in flood events

3.1 Overview of roles and responsibilities

Many government agencies and organisations at the state and Commonwealth levels contribute to responding to floods in Australia (Figure 3). The Total Flood Warning System (TFWS) shown in Attachment 4, is a concept promoted by the Australian government and is widely applied for the period immediately before and during flood events (AIDR, 2022). The network of agencies involved in River Murray flood operations and communication under the TFWS roles and responsibilities at both the Commonwealth and state (NSW, South Australia, and Victoria) levels are summarised in Table 3.

At the Commonwealth level, there are at least two agencies involved in flood risk management: the Bureau and the MDBA. Across the three states, the Review identified multiple key agencies responsible for the oversight of flood risk management: five in NSW, ten in South Australia, and eight in Victoria. Not all agencies always play a role in floods, and not all were captured as relevant to the River Murray 2022-23 flood event (i.e. the flood central to this Review), or the response, for the purposes of this Review.

States take different approaches to describing flood operations and communications, however, each state's local councils, government bodies, water management authorities, emergency response teams and community play an integral role in flood risk management (Table 3).

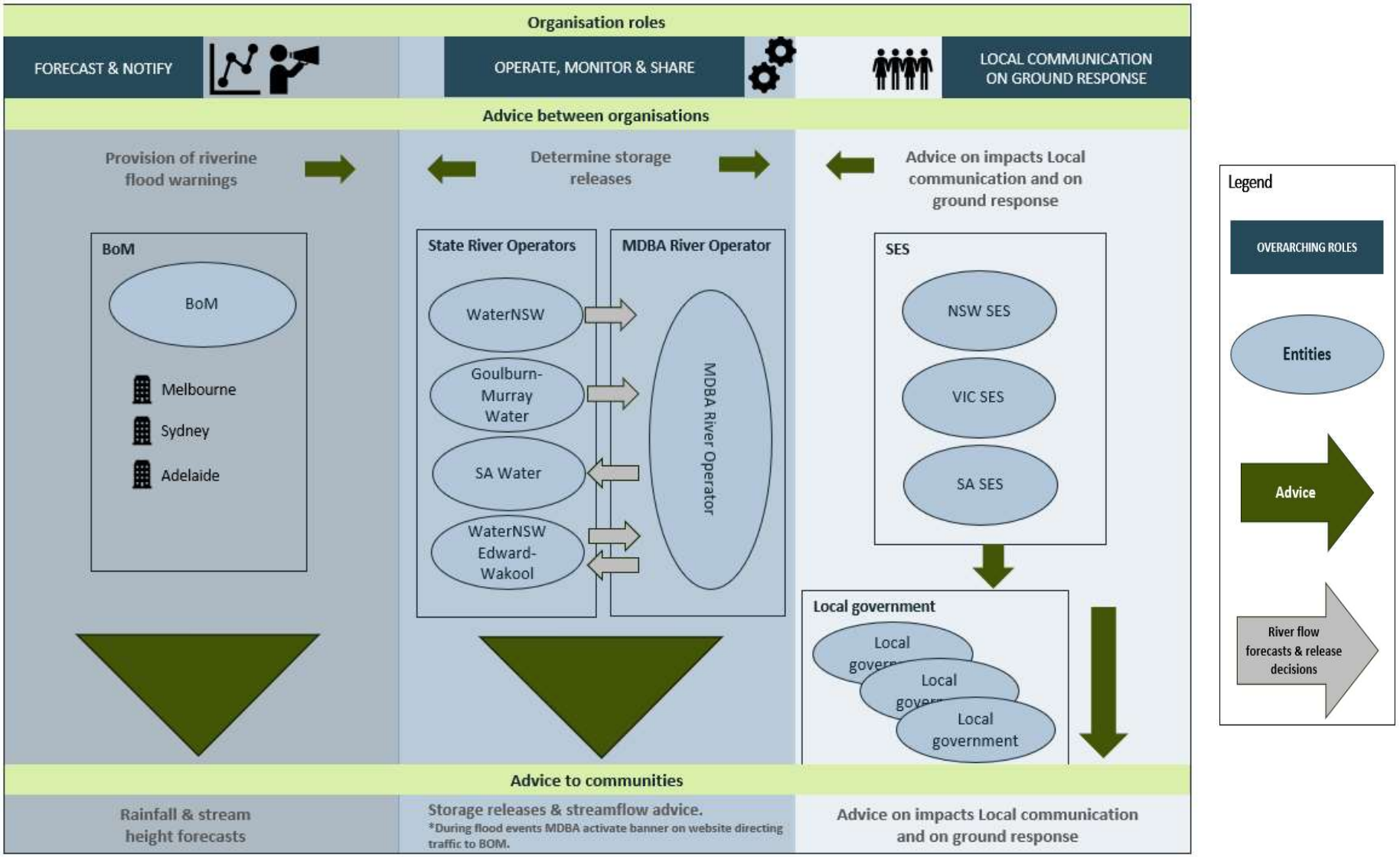

Figure 3. *Roles and responsibilities of the Bureau, river operators, and SES during flood operations*

Table 3. Roles and responsibilities of Commonwealth and State agencies during floods.

State	Agency	Roles and responsibilities as relevant to the River Murray and 2022-23 flood event
Commonwealth		
	The Bureau	Responsible for the provision of weather (including flood) forecasting and climate data.
	MDBA	River operator (River Murray to SA border)[16] managing major storages
New South Wales		
	WaterNSW	River operator managing the Menindee Lakes and flows within the Edward-Wakool River system SCA at the Hume Dam, Menindee Lakes and selected locks and weirs
	Local Government	Implement local road closures, Operate local infrastructure, and provide community support
	NSW SES	Lead agency for flood response in NSW, provision of public information, supporting evacuations, rescues, and protection of property from further damage. Prepares communities through planning and education.
	Police and other emergency services	Support SES and local councils where required, including support for road closures, evacuations and other emergency actions
South Australia		
	SA Water	SA Water maintains and operates significant water infrastructure in SA that has a primary or secondary flood mitigation function. SCA at Lake Victoria and all locks and weirs along the River Murray downstream of Lock 10 (Wentworth)
	Local Government	Implement local road closures, operate local infrastructure and provide community support Provisions of flood monitoring services and community awareness programs
	DEW	Flood forecasting[17] Operates infrastructure that provides flood protection.
	South Australian SES (SA SES)	Flood control agency and establishes efficient emergency response systems.
	Police and other emergency services	Support SES and local councils where required, including support for road closures, evacuations and other emergency actions
Victoria		
	Goulburn Murray Water	SCA at the Dartmouth Dam, Yarrawonga Weir and selected locks and weirs.
	Local government	Implement local road closures, and Operate local infrastructure Facilitate emergency management planning and provide relief and recovery support for affected communities.
	Victoria SES (VICSES)	Lead agency for flood response in Victoria, provision of public information, supporting evacuations, rescues, and protection of property from further damage. Prepares communities through planning and education.

[16] This is part of the joint venture arrangement between the states and Commonwealth that manages the River Murray system, and is described in Section 4.1

[17] This role transferred to Bureau for flows greater than 100,000 megalitres per day in October 2023 (see Section 3.2).

State	Agency	Roles and responsibilities as relevant to the River Murray and 2022-23 flood event
	DEECA	Support agency to VICSES for floods, with custodianship and management of Victoria's flood data base and intelligence platform.
	Police and other emergency services	Support SES and local councils where required, including support for road closures, evacuations and other emergency actions
	Emergency Management Commissioner	Coordination, ensuring effective control arrangements are established and consequence management.

3.2 Bureau of Meteorology

The Bureau provides climate and flood warnings across Australia and are responsible for providing public flood warnings under the Meteorology Act (1955) (Bureau, 2018b). The Bureau uses the terminology of minor, moderate and major flood levels that are developed and maintained by the local community, councils and the SES to classify the severity of expected flooding at locations along rivers (Bureau, 2018a). The Bureau delivers a national flood forecasting and warning service. This includes the forecasts downstream of the Hume Dam and forecasts and flood warnings for upstream of the Hume Dam.

When forecast rainfall suggests that a flood event is possible, the Bureau will issue a Flood Watch or a Flood Warning.

- Flood watch: A Flood Watch includes forecast rainfall totals, and also identification of the catchments that are at risk of flooding. A Flood Watch can be issued up to four days in advance of expected flooding. They are updated at least daily and finalised once all areas are covered by Flood Warnings or the risk of flooding has passed.

- Flood warning: When conditions mean that flooding is probable for a particular location, the Bureau issues a Flood Warning. Flood Warnings typically include a prediction of likely river height at a locality and the flood classification (see Table 4), and where data are available, may indicate the expected duration of flood conditions.

The Bureau's riverine flood warnings cover larger rivers that take more than six hours to respond to rainfall. The reason these rivers are treated differently is that the longer lead time enables a different response. The Bureau can work with other government partners to collect data, run prediction models, interpret flood mapping and determine potential consequences, as well as issue and communicate warnings.

However, in the case of flash floods, these typically happen so quickly that there isn't time to run these processes. While the Bureau do not warn for flash floods, they do provide forecasts and warnings for severe weather conditions and potential heavy rainfall that can cause flash flooding. In the case of flash floods, the Bureau's response is different, and the best warning advice comes in the form of a Severe Weather Warning (Bureau, 2023a).

Flood classifications are utilised by the Bureau, SES and the emergency services, using a three-tiered scheme that classifies flooding as minor, moderate or major at key river height stations, defined by expected impacts (Table 4) associated with various water levels (Bureau, 2023a). In addition, warnings are also issued when there are flows forecast that are likely to affect private pump installations and livestock along rivers.

As an example of the flood classifications process, in NSW these are proposed by NSW SES in consultation with the local community based on the impacts and consequences of flooding and are forwarded to the Flood Warning Consultative Committee for approval and adoption (NSW SES, 2019). These heights are used by the Bureau to forecast and predict flooding. The NSW SES uses these heights to warn the public and advise them on any consequences along with public safety information.

Table 4. Flood classification definitions of the Bureau of Meteorology

Flood classification	Definition
Minor Flooding	Causes inconvenience. Low-lying areas next to water courses are inundated. Minor roads may be closed and low-level bridges submerged. In urban areas inundation may affect some backyards and buildings below the floor level as well as bicycle and pedestrian paths. In rural areas removal of stock and equipment may be required.
Moderate Flooding	In addition to the above, the area of inundation is more substantial. Main traffic routes may be affected. Some buildings may be affected above the floor level. Evacuation of flood affected areas may be required. In rural areas removal of stock is required.
Major Flooding	In addition to the above, extensive rural areas and/or urban areas are inundated. Many buildings may be affected above the floor level. Properties and towns are likely to be isolated and major rail and traffic routes closed. Evacuation of flood affected areas may be required. Utility services may be impacted.

Once flood warnings have been issued by the Bureau, key stakeholders and agencies are notified including the SES, Police, relevant state agencies, local radio and community media outlets to help spread the message.

As a result of inputs from models, flood warnings are generated by the Bureau for relevant locations, as one flood event can result in different severities of flooding depending on local infrastructure e.g., "moderate" at one location and "minor" at another. These warnings are adaptable and customisable, and have a qualitative indication of confidence (e.g., 'may' or 'very likely'), to help users interpret the warning.

Service Level Specifications

The Bureau has developed a Service Level Specification with each state and territory across Australia that sets out the agreed services it will provide, and the support expected from each state's agencies. The Bureau's Service Level Specifications are consistent with the TFWS as defined in the Australian Emergency Manuals Series, Manual 21 Flood Warning (AIDR, 2009). The TFWS recognises that an effective flood warning service is multi-faceted in nature, and its development and operation includes multiple agencies each with specialised roles to play. The service level specifications identify the Bureau's role in the TFWS and its interaction with other stakeholders. This ensures that both the Bureau and other stakeholders are aware of how the Bureau supports each of the relevant components of the TFWS. More information on the TFWS is provided in Attachment 4.

The 'Service Level Specification for Flood Forecasting and Warning Services' reports focus exclusively on riverine flooding caused by rainfall, where typical rain-to-flood times are six hours or more. The nature of services covered by the reports include routine catchment monitoring and river height prediction activities necessary for operation of the TFWS, as well as issuing and publishing warning and data products. Each year the Service Level Specification reports are consulted, reviewed, and if needed updated.

During the 2022-23 flooding period the Service Level Specifications for NSW (Bureau, 2013a), Victoria (Bureau, 2013b), and SA (Bureau, 2013c and 2023d) were very similar in nature, the main difference being that along the River Murray there are only forecasting locations in NSW and Victoria, and not in SA (as set out in Appendix 2 of each document). Consequently, the Bureau did not have a lead role in the provision of riverine flood forecasting or warnings for the River Murray in South Australia, and the DEW led forecasting and the SA SES provided warnings.

In 2023, after the 2022-23 flooding, an agreement was reached between SA and the Bureau for flood forecasting services to be provided at forecasting locations along the River Murray in SA (Bureau, 2023), following a long period of review and negotiations. These new specifications indicate that flood predictions are provided by the DEW when minor flooding may be influenced by river operations.

3.3 State Emergency Services

The SES is a volunteer-based organisation in each state with responsibilities to provide emergency assistance during floods and storms, as well as assisting full-time emergency services during major disasters. The SES undertakes a range of actions to strengthen the community's capacity to prevent, prepare, and respond to flood events. This includes coordinating and assisting, other government services, and, in major flooding, undertaking evacuations and rural search and rescue operations if required.

The SES, in consultation with the Bureau and local communities, identifies the river heights at relevant locations that correspond to minor, moderate and major flood impact classifications (Bureau, 2023), taking into account the local knowledge of infrastructure and community impacts during a flood event. The SES publish online Flood Bulletins for their local area. These bulletins use the Bureau flood warnings to provide locally meaningful information about the impact of flooding on infrastructure such as major road closures, loss of utilities, and areas subject to flooding that may experience isolation. The SES also have a flood intelligence system that assesses flood information for the flood type and severity, collects information on the communities at risk of flooding and the extent of the impact and shares flood data with supporting agencies and local sources. This system assists the SES with community warnings, emergency planning and decision making.

The SES is involved in three critical phases of a flood event: pre-impact, impact, and post-impact. The pre-impact phase begins as soon as the SES receive information from the Bureau regarding potential for significant flooding. During the pre-impact phase the SES undertake strategic planning for the response; this includes establishing coordination arrangements, and emergency management teams. During the impact phase the SES conducts state operations. This includes operating a command centre, briefing emergency services on flood operations, issuing community warning and information, assisting councils, coordinating agriculture and animal services, and providing operational updates to all relevant agencies. The post-impact phase includes supporting post-impact data collection, establishing an information service for the community and recovery arrangements and providing immediate welfare for evacuees.

3.4 River operators and their statutory duties

The operation of most major regulated river systems is undertaken by state-owned corporations that operate under each state's legislation. For the River Murray, the MDBA's River Management branch operates the regulated River Murray system on behalf of the three states and the Commonwealth. Regulated tributary rivers to the River Murray within each state, and the River Murray itself downstream of the South Australian border, are managed by the respective state river operators: WaterNSW (NSW), Goulburn-Murray Water (Victoria) and the South Australian DEW and SA Water. As previously noted, while MDBA takes river operational decisions and issues river operation directions, the actual operation of works to give effect to these directions is undertaken by the relevant SCA for each structure.

River operators manage the operation of major storages and weirs that regulate river flows to provide water for licensed water users, predominantly for irrigation, but also including environmental water deliveries, town water supplies, as well as domestic and stock supply for landholders along the rivers. River operators generally have statutory powers and obligations and manage each river system in accordance with plans developed by each state. The MDBA's operation of the River Murray system is managed in accordance with the Agreement, as set out in Schedule 1 of the *Water Act 2007* (the Water Act). The Agreement sets out the broad arrangements for the management of the River Murray system by the MDBA on behalf of NSW, Victoria, SA and the Commonwealth.

River operators provide advice to the public regarding flows in regulated river systems throughout the year, with the exception of any periods when flood flows occur, where the Bureau provides public flood warnings. However, river operators are responsible for managing releases from dams and weirs during flood events in accordance with the relevant statutory requirements.

Operation of the River Murray is managed at the highest level by the Murray-Darling Basin Ministerial Council. Below the Council, authority for policy and management lies with the BOC, which approves the Objectives and Outcomes for the management of the River Murray system (MDBA 2023). The operations group within the MDBA manages the operation of the regulated River Murray system to the South Australian border to meet these requirements on behalf of the states, with MDBA's directions implemented by the SCA.

The DEW and SA Water manage River Murray flows within South Australia. Importantly, South Australian agencies rely on forecasts of flows at South Australian border made by the MDBA. During periods of flooding, the South Australian agencies have also taken MDBA's flow forecasts into account when making operational decisions and public warnings.

3.5 Basin States: Hydrometric services

The measurement of water levels and flows along rivers is fundamental to river management, and particularly for flood forecasting and warning. Flows and water levels in rivers are recorded using flow gauging stations situated along rivers. Typically, these gauging stations directly measure the depth of water at the site, and a relationship (or "rating") is developed between the water depth and the flow at that site by measuring flows at discrete points in time using specialised equipment and techniques. Maintaining equipment, ratings for each gauging station, and making the recorded data available is undertaken by teams of hydrographic specialists in each state. During flood events, where flows can be higher than any previously measured (or there has been a significant period since any flows of similar magnitude have previously been measured), taking flow measurements is important for ensuring that the ratings at each site remain accurate at high flows. High flows and associated debris can also damage equipment, and hydrographic teams play an important role in ensuring that the Bureau and river operators have reliable and timely information.

In the states of NSW, Victoria and South Australia, most water data in the River Murray is being monitored and recorded continuously, or at short intervals, by flow gauges and transmitted to central databases where it is disseminated as operational data. Key water quantity parameters recorded include water level in metres, discharge or flow rate in megalitres per day and storage volume in gigalitres (also presented as the proportion or percentage (%) of storage capacity). Some monitoring stations may also record water quality parameters such as salinity, temperature, acidity/alkalinity (pH), and dissolved oxygen levels. In most circumstances, water quality and quantity information is made publicly available shortly after being recorded as operational data, with quality-assured data added to the long-term archive and made available later.

Each state is responsible for the provision of hydrometric services. The state agencies responsible for the provision of hydrometric services also provide data to the MDBA for river operation and forecasting purposes.

Under the *Intergovernmental Agreement on the Provision of Bureau of Meteorology Hazard Services to the States and Territories* (2018, Intergovernmental Agreement), states and territories including Basin States have agreed to provide the Bureau with relevant information that is in their possession or control in order to discharge its responsibilities. The Intergovernmental Agreement resolved that the Bureau has responsibility for the provision of forecasting and warning services for Riverine Flooding in all States and Territories except for Port Phillip and Westernport catchments and the Lower Murray (Bureau, 2018a).

The detail of these arrangements varies between jurisdictions and is described in separate Data Sharing Agreements established for each jurisdiction between the Bureau and agencies providing data. Refer to Attachment 4 for further details about national data-sharing arrangements.

Information technology services are increasingly important to ensure the flow of data from gauging stations into the computer systems used to forecast flows occurs quickly and reliably.

In the southern Basin including the River Murray system, the state agencies responsible for maintaining hydrometric services including flow data collection from the river gauging stations are:

- WaterNSW for River Murray and northern tributaries
- DEECA, for River Murray and southern tributaries
- DEW for River Murray within South Australia

3.6 Local Government

Local government and utilities manage infrastructure associated with town supply and storm water systems during floods to prevent damage to infrastructure, reduce flooding where possible and coordinate local services.

The national arrangements (Bureau, 2018b) set out local government roles including contributing to the real-time flood warning data network either directly or through local cooperative programs with other agencies. It also sets other key local government roles such as flood preparedness activities and response planning, providing assistance to the Bureau with the interpretation of flood predictions into local impacts and with local warning dissemination in accordance with jurisdictional emergency management arrangements. In addition, under the national arrangements local governments in collaboration with State agencies and supported by the Bureau, are required to implement and operate flash flood warning systems.

Local government provides support to state agencies for flood emergency management (DPE, 2023), which includes the development and implementation of local flood plans and local emergency management plans. Other activities, where councils may support state agencies during floods involve:

- Provision of up-to-date flood intelligence and supporting information
- Identification and protection of critical public utilities
- Identification of critical public assets such as emergency evacuation centres and access routes, and
- Operation of flood mitigation works (levees and flood gates) and assistance with community road closures.

Local government, with support from state agencies, is generally required to undertake flood risk management in council service areas. They are also responsible for planning and reporting related to funding, maintenance and operational costs associated with flood mitigation assets such as levees and flood warning systems. (DPE, 2023, DECCA, 2022, DEW, 2021). Under formal arrangements, local governments are also accountable for maintaining a management framework for flood mitigation infrastructure (DECCA, 2022).

4 MDBA flood operations

The centrality of the MDBA to the focus of this Review and the technical operations of the 2022-23 River Murray flood warrant a separate section describing the MDBA's flood operations beyond the general roles and responsibilities of state and Commonwealth agencies described in the previous chapter.

4.1 Statutory and policy framework

The River Management branch of the MDBA undertakes the management of the River Murray system on behalf of Victoria, NSW, South Australia, and the Commonwealth Government (Figure 4).

The MDBA has a statutory framework that includes legislation (specifically the Water Act includes the Agreement at Schedule 1), and subordinate instruments (the BOC requirements, objectives and outcomes (MDBA 2022)), which require a number of plans and procedures that the MDBA has developed.

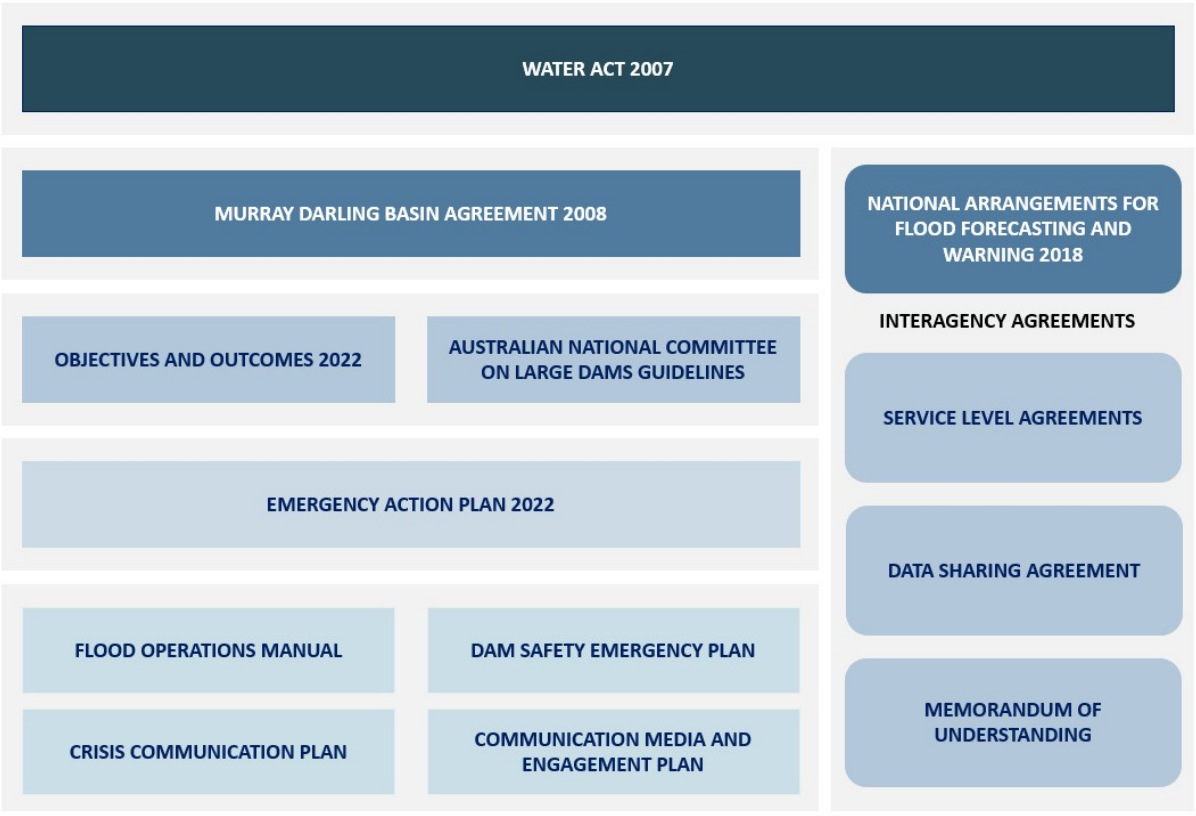

Figure 4. *Statutory and policy framework relevant to MDBA flood operations, technical and data matters, governance and communication*

Water Act and Agreement

The long-standing Agreement sets out the arrangements agreed between NSW, Victoria, SA and the Commonwealth for the management of the River Murray system, and became Schedule 1 of the Water Act in 2007. Under the Agreement, the MDBA has responsibilities relating to River Murray system operations and asset management. Key responsibilities relating to the operation of structures come from clauses 26, 30, 31, 61, 66, 68 and 98 of the Agreement.

- Clause 26 establishes the powers and functions of BOC, including responsibility for high level decision making in relation to river operations, and setting objectives and outcomes to be achieved by the Authority in relation to river operations.[18]
- Clause 30 requires that the Authority carry out its functions in relation to river operations in accordance with objectives and outcomes specified in the document approved under clause 31.
- Clause 31 requires that BOC must annually approve, and may from time to time amend, a document which specifies the objectives and outcomes to be achieved by the Authority in carrying out the Authority's functions in relation to river operations (see MDBA 2022).
- Clause 61 provides for the Authority to 'give directions, as required to give effect to the corporate plan and asset management plan or to give effect to a decision of Ministerial Council under sub-clause 29(3), to ensure the efficient construction, operation, maintenance and required performance of any work'.
- Clause 66 allows the Authority to 'determine procedures for the operation of works' and clause 68 requires Contracting Governments to operate a work 'in accordance with any procedures determined by the Authority under clause 66'.
- Clause 98 states that the Authority 'may give directions for the release of water from upper River Murray storages and water must be released in accordance with any such directions'.

Basin Officials Committee requirements

The three states along the River Murray have codified the general objectives and outcomes that the MDBA must achieve when performing its river operations functions, as well as a range of specific objectives and outcomes for particular operational activities, individual river reaches, or river management assets managed by the MDBA. These objectives and outcomes are set out in *Objectives and outcomes for river operations in the River Murray System* (Objectives and Outcomes) approved by BOC each year (MDBA 2022).

The key objectives that relate to flood operations are set out in section 4(3)(b)(iv), which contains three general objectives for MDBA operated assets that the asset operator is required to target and prioritise during storage airspace management and flood operations:

1. protect the structural integrity and safety of the dam; then
2. maximise water availability (i.e., fill the storage to at least 99% of capacity prior to any ensuing drawdown to meet downstream needs); and then
3. subject to the foregoing items, limit flood damage to downstream communities and increase benefits to the environment and public amenity.

There are three main assets for which the MDBA has flood operations responsibility: the Dartmouth Dam, the Hume Dam, and the Yarrawonga Weir.

Most other works within the regulated River Murray system do not involve operational decisions that affect river flows significantly during floods. However, most structures do require a structural operational response to floods. For example, at the Torrumbarry Weir (only) the gates are lifted clear during higher flows. Other weirs and locks for navigation must be removed from the river ahead of peak flood flows and reinstalled following floods. Flood operations at the Menindee Lakes are managed by WaterNSW.

The Objectives and Outcomes provides that the objective to maximise water availability is a higher priority than limiting flood damage to downstream (MDBA 2022). However, when the major storages are near full and large inflows are occurring, the downstream demand for water is low and the recession of inflows under drier conditions will typically take a number of weeks, during which time the storage can be refilled. Under these conditions, storage release decisions at the height of flood operations are strongly influenced by the need to manage storage safety and minimise flooding impacts when moderate to major flood inflows are occurring at the storage.

[18] As noted earlier, the authors have used the abbreviation MDBA to refer to the organisation, but have retained the term Authority when referring to the 'board' such as with statutory obligations.

The MDBA (2023) also sets out general objectives for communications and information management, including that the MDBA:

- keeps all stakeholders with an interest in the MDBA's river operations well informed of its plans and activities;
- acts transparently; and
- is accountable for its actions in accordance with the Agreement.

MDBA Emergency Action Plan

Section 9(3) of the objectives and outcomes (MDBA 2022) requires the MDBA to have and maintain an Emergency Action Plan (**EAP**). The River Murray system EAP (MDBA, 2023d) details roles and responsibilities of MDBA staff (see Attachment 3), resourcing and training requirements in relation to the systems, operations and assets during River Murray system emergencies. The EAP also sets out procedures and guides communication and information flow for the systems and operations during an event. Although the MDBA's area of responsibility is primarily to pass floods or water for the environment downstream, the MDBA's FOM detail site specific triggers, guidance on flood alert levels and extreme flood event procedures and operations. The EAP does not intend to detail how an event is managed or controlled. Table 5 lists the alert levels triggered during a flood event. A Yellow Alert level of flood does not activate the EAP. However, the EAP may be activated during a declared or highly likely emergency occurrence at a River Murray Operations (**RMO**) asset or in the River Murray system. Activation of Dam Safety Emergency Plan (**DSEP**) at a major structure may also activate the EAP.

Table 5. MDBA EAP Triggers for flood emergency (Source, MDBA 2023a)

MDBA EAP Alert Level	Flood Status
Yellow	Elevated risk of an Amber flood alert being activated.
Amber	Severe or extreme flooding threating to overtop town levees or reach record levels.
Red	Severe or extreme flooding occurring. Risk of major structural failure at a storage occurring.

While the MDBA's priorities relating to RMO asset safety and limiting flood damage to downstream communities are set out in the Objectives and Outcomes and FOM, the EAP details processes for internal decision-making arrangements and information dissemination during an emergency. Additionally, it specifies the obligations to train personnel, and the requirement to keep records and undertake post event reporting.

For most flood events at MDBA storages, the EAP is unlikely to be triggered. It is only triggered when nearing flood of record or the structural integrity of the storage is at risk. The MDBA have advised that this plan was in place during the period of flooding, but the circumstances did not warrant its enlivenment. The MDBA has also advised that the EAP is currently under review.

Dam Safety Emergency Plan

A DSEP is prepared by the relevant SCA (Section 4.2) for each asset. A DSEP and an EAP operate concurrently. In the event of an emergency, storage operations need to be conducted in accordance with relevant DSEP conditions. DSEP activation is among the triggers for activating an EAP action response.

A DSEP's activation is generally concentrated around structural safety or risk of structural failure during emergency events such as extreme floods. The role of the EAP is broader, in that it gets triggered if the events are likely to impact downstream communities, regardless of structural risk of failure. Appendix A of the EAP details the structures and the location of revised DSEP copies held by the MDBA, as well as major RMO structures, contracting governments and responsible SCAs.

Compared to an EAP, the DSEPs contain detailed action responses relevant to each site. It provides the site operators and responsible incident controllers with a structured response, where the respective incident controller at site may direct operations of the storage consistent with relevant DSEP requirements. However,

where time allows, the incident controller may seek MDBA's advice prior to carrying out an action, and where changes are actioned, reasonable steps should be taken to advise the MDBA of the changes.

Crisis Communications Plan and Communication Media and Engagement Plan

The Crisis Communications Plan (CCP) (MDBA, 2018) supports the MDBA's communication functions during a crisis event. The CCP sits below other crisis event operational manuals and management plans such as EAP and FOM. It details the MDBA's response procedure and a practical reference guide, for prompt and effective management of a potential crisis, including those requiring coordinated multi-agency and cross-jurisdictional response (MDBA, 2018).

While the MDBA and cross-jurisdictional agencies carry out flood management operations under the guidance of various documents, the CCP outlines how flood-related crisis communications are activated including:

- Triggers – such as significant forecast rain events and high dam levels or MDBA River Murray advice of anticipated significant flood operations
- Lead agency – for managing crisis communications (the Bureau and SES) as well as MDBA lead roles, if required
- Roles and responsibilities for MDBA staff – specific to five key roles:
    - Crisis Communications Manager (CCM) – operational briefings and media statement update and distribution
    - External communications officer – manages stakeholder engagements and communications
    - Media liaison officer – manages and coordinates media inquiries and monitoring and support the CCM
    - Content coordinator – distribution of flood content through MDBA's social media, review, and update of other flood related content
    - Internal communications officer – development and distribution of information content and support to internal staff and stakeholders
- Stakeholders – including primary (the Bureau, SES, SCA, state water authorities, Ministers and local councils) and secondary (government departments, members of parliament, MDBA staff), and other external stakeholders.

In the event of crisis such as a flood, a crisis communication channel map detailed in the CCP can be used to guide communication activities related to stakeholder engagement, communications, media and internal communication.

The CCP also sets out provisions for MDBA's incident responses including communications functions to be evaluated in terms of effectiveness and to identify potential improvements such as a post incident the review and update of the plan.

To meet the communication and information management objectives set out in the Objectives and Outcomes Procedures section 4(6)(a) (MDBA 2022), it is current practice for the MDBA to prepare a Communication, Media and Engagement Plan (CMEP) that outlines MDBA's activities related to communication, media and engagement during flooding events. These plans define the communication and engagement approach that MDBA will adopt in partnership with other agencies pre-flood event and once a flood event has been declared. The plans also identify stakeholders such as federal and state agencies and representatives, landowners, and local government, as well as key message themes for MDBA's public messaging.

The CMEP put in place for the 2022-23 flooding period provides an outline of the MDBA's planned activities once the Dartmouth and the Hume reservoirs reach 80 percent of full capacity and the operators have a high confidence of the storage filling and spilling. This includes activities and definitions before and during floods, such as dam pre-releases and the impact on downstream river channels as well as keeping communities and stakeholders informed of high dam inflows. The CMEP also establishes pre-flood communication and engagement approaches and activities in partnership with other agencies to ensure proactive information sharing with key stakeholders and communities about flood risk management. The CMEP procedures during the flood are triggered by the flow conditions that exceed channel capacity at key locations downstream of the dams. Downstream of the Hume Dam, 25,000 ML per day at Doctors Point (near Albury) is the trigger for WaterNSW's Early Warning Network (EWN) to issue its flood warning notifications. Any proactive MDBA

engagement with the community during this stage is generally done in partnership with the Bureau, WaterNSW and GMW. This involves providing the communities impacted by flows downstream of the Hume Dam to Yarrawonga Weir with briefings as required, led by the Executive Director, River Management or Director River Murray Operations.

The CMEP sets out that the MDBA would establish a communication and engagement program when the Hume Dam reaches 95% full and contact will be established with key media teams within the primary stakeholder group. At this stage, flows above 25,000 ML per day at Doctors Point also triggers regular briefing updates when required, where the Bureau and the SES play a more active role in communicating to the public. Once the Hume Dam is in flood, the CMEP requires the MDBA to provide support to other organisations. During this phase the MDBA establishes internal lines of communication and holds daily meetings to discuss and finalise talking points and a copy of the daily situational reports is circulated internally. The MDBA's objective in the CMEP is to provide public messaging about dam safety, respond to any media inquiries and publish key flood messages about flood preparedness on the MDBA's official media outlets, including directing the public to SES, WaterNSW and the Bureau websites.

The communication plan for the Dartmouth Dam outlines a slightly different approach to that of the Hume Dam, whereby the pre-flood phase releases are restricted to the channel capacity for the Mitta Mitta River of 10,000 ML per day. When the Dartmouth is likely to enter flood operations, it triggers the MDBA's proactive communication and media activities under the CMEP. This phase involves publishing flooding risk reminders and promotion via a range of internal and emergency services provider media and communication channels including e-newsletters and social media. Additionally, the MDBA invites key stakeholders downstream of the Dartmouth Dam to weekly briefings held for the Hume Dam, and the media team become the point of contact for advice, including flow advice.

4.2 MDBA operational procedures

River operations team

The MDBA river operations team is based in its Canberra and Mildura offices and maintains continuous river operations management every day using a team of trained river operators. The team is led by a Director of River Operations.

Flood Operations Duty Operators are rostered on for one or more structures depending on conditions and are responsible for issuing instructions to staff at these structures. A Flood Operations Officer may also be rostered on to provide administrative and/or technical support if required. They are overseen by a Manager of Flood Operations.

Staff must undergo appropriate training and be endorsed by the Executive Director River Management to undertake each role. At the commencement of the 2022-23 flooding period, the MDBA had:

- Four staff endorsed by the Executive Director River Management to undertake the role of Manager of Flood Operations, including the Director, River Murray Operations who is the default Manger of Flood Operations. Three of these staff were also endorsed to undertake the role of Flood Operations Duty Officer.
- Ten staff were endorsed as Flood Operations Duty Operators within the river operations team
- Three additional experienced staff from outside the river operations team were endorsed Flood Operations Duty Operators, and
- a further three staff were endorsed to undertake the role of Flood Operations Officer

During flood events, one or more Flood Operations Duty Operators are rostered on duty, and there is always one Manager Flood Operations on duty. Regular internal briefings are provided to the Senior Director of River Operations and the Executive Director River Management; however, the Manager of Flood Operations has the delegation to approve most operational decisions.

The Flood Operations Duty Operators liaise closely with the Bureau to consider potential inflows and downstream flooding risks, and any other relevant factors, to set releases based on the strategy that best

mitigates flood inflows without endangering the structure or taking undue risk of not subsequently being able to refill the storage. These decisions are then communicated to staff at the relevant storage, as well as the Bureau. The Bureau uses the decisions to issue the forecasts which is then also communicated to SES and other appropriate agencies.

The MDBA conducts regular flood operations training events to maintain operator proficiencies, and there is a formal training program that staff must complete to become an endorsed Duty Operator or a Manager, Flood Operations. The list of endorsed staff for flood operations is updated by the Executive Director River Management annually.

Operations and flood manuals

The MDBA has prepared a draft River Operations Manual and a set of four draft FOM to set out the procedures for operations staff during normal river operations and during flood operations (including pre-releases). This includes a draft FOM for each of the Dartmouth Dam, the Hume Dam, and the Yarrawonga Weir, as well as an overall Flood Management Manual. The flood manuals set out requirements and guidelines for flood operations and also refer to a number of technical documents that describe how to use specific software such as the “flood sheets" (see *Data and systems* subsection below).

This set of flood manuals had a draft status during the 2022-23 flooding period, and the MDBA has advised that they are planned to be finalised in 2024.

State Constructing Authorities

Each structure along the River Murray was constructed and is operated by state agencies as SCAs. The SCAs have a responsibility to maintain and operate each structure in accordance with an asset agreement or other arrangement made with the MDBA, to give effect to the Agreement. Goulburn-Murray Water is the constructing authority for the Dartmouth Dam and the Yarrawonga Weir, and WaterNSW is the constructing authority for the Hume Dam.

Under arrangements with the MDBA, each works or structure has its own emergency procedures, including the operation of the works during floods if communication with MDBA river operators is not possible. In general, the emergency procedure during floods requires that releases are set based on observed inflows at the works to ensure the safety of the structure, although local operators are to follow the last received instructions from the MDBA river operators if local conditions allow.

Data and systems

The MDBA receives the majority of its data and information from state agencies in NSW, Victoria, and SA to support its river operations activities. This includes:

- flow, storage and rainfall data directly from state agencies that manage their hydrometric services
- water orders, and metered diversions by licensed water users, and
- other hydrometric information such as the rating tables that relate the measured water levels to flows at flow gauging stations and the results of individual field flow measurements made by hydrographic teams.

The MDBA also receives data and information on storage volumes and releases made from the Snowy Scheme to the River Murray. Operational data and information is provided daily, and other data and information on the Snowy Scheme operations is provided on a fortnightly or monthly basis.

The MDBA has arrangements in place to automatically update data from the databases maintained by state agencies, with the frequency of updates able to be increased as needed. Normally, the MDBA updates most data on a daily basis, but this can be increased if required during flood operations to an hourly basis for most information. These data collation activities are generally for MDBA purposes only, and the Bureau has similar arrangements in place with the relevant agencies in each jurisdiction.

This data is used in several operational models and decision support systems that the MDBA uses to inform its operational decisions at the dams and weirs along the regulated river system:

- Typically the data is used in the MDBA's spreadsheet-based daily operations decision support system, which is similar (although more complex) to those used by the states to manage their regulated river systems across the Basin.
- The SMOM, primarily developed to support regulated river operation and delivery of environmental flows has shown during the 2022-23 flood period that it is able to provide useful flow forecasts during floods.
- For flood operations, a spreadsheet decision support system has been developed for each storage that allows river operators to carry out scenario analyses that route predicted flows down to the storage from upstream river flow gauges, assess changes in river flows, and trial potential tributary inflow scenarios. These "flood sheets" can operate on an hourly basis or using longer timesteps to suit the available data and conditions.
- The MDBA also has a Unified River Basin Simulator (URBS) rainfall runoff hydrologic model configured to simulate flows from the upper Murray catchments above the Hume Dam. This model is typically only used during flood operations to simulate the potential inflows to the Hume Dam from observed or forecast rainfall. The Bureau also use URBS models in the upper Murray catchment and elsewhere.
- The MDBA's implementation of the Flood Early Warning System or river operation warnings system (known as ROWS)[19], provides data integration, management and visualisation targeted at flood forecasters, reservoir operators and operational managers in the water sector. The ROWS Software also hosts the URBS model that receives and provides rainfall forecast visualisation for a range of global weather models.

The MDBA has a dedicated operations services team that provides support for the data collection process and internal systems. This is an important service given that the MDBA receives data from a number of agencies across three states and the Commonwealth.

The Dartmouth Dam

The Dartmouth Dam is primarily operated to conserve inflows and make releases to supplement the Hume Dam to meet the downstream water requirements of each state. Due to limited channel capacity downstream, during normal operations the Dam can release up to 3.4m at the Tallandoon gauge downstream of the storage. Updates to the rating post the 2022-23 flood now indicate that a 3.4m river height translates to a gauge reading of 11,100 ML per day, however at the time of the flood, this was rated as 10,000 ML per day. This channel capacity also applies to airspace management (pre-releases).

The Dartmouth Dam's spillway design is such that the storage can be surcharged beyond the full supply level, as water passes over the spillway crest. This has both the benefit of reducing the downstream flood peak and delaying the releases during large flood events.

The MDBA estimates the transition to very dry conditions by using historic data to assess the serially correlated minimum inflows. This is a statistical correlation of historic inflow data over a period of months (from the time of the assessment) with recently observed inflows to assess the minimum future storage inflows that could be expected with very high confidence. This method aims to balance the objectives of airspace management and water conservation that are specified in the Objectives and Outcomes (MDBA 2022).

The Objectives and Outcomes also require the MDBA to plan the airspace management at the Dartmouth Dam to not reduce the available airspace in the Hume Reservoir below the adopted target level.

The Hume Dam

The Hume Dam is primarily operated to conserve inflows and make releases to meet the downstream water requirements of each state, up to a maximum release rate for normal operations of 25,000 ML per day at the Doctors Point flow gauge downstream of the storage.

However, when the storage is forecast to spill, the MDBA can make "pre-releases" to provide temporary airspace to mitigate any high inflows that might occur before downstream demands are forecast to exceed inflows. The Hume Dam has a gated spillway, although its normal full supply level requires the use of these gates

[19] The Flood Early Warning System (FEWS) by DELFT

to provide additional storage above the spillway sill. However, the Hume Dam is normally operated to avoid allowing the storage to exceed its normal full supply level during flooding periods. Whilst not a requirement of the Objectives and Outcomes, the MDBA has advised that a temporary surcharge policy has been progressively developed in consultation with WaterNSW since the Hume Dam safety incident in 1996. The policy allows for a surcharge of up to 50 GL above the full supply level if there is a risk to life or of flows arising from dam releases overtopping the Albury levees, and to not exceed a four-day period of this surcharge (Surcharge Policy, 2021).

An airspace management strategy for the Hume Dam is set out in the Objectives and Outcomes, where a temporary airspace can be targeted when the storage is close to full (typically during the winter-spring period) by making pre-releases when conditions permit. The target airspace must be based on the assumption that, in the potential scenario of a transition to very dry conditions, the Hume Reservoir should be effectively full (99 percent of the total capacity at FSL) when downstream demands exceed inflows. The MDBA estimate the transition to very dry conditions by using historic data to assess the serially correlated minimum inflows. This is a statistical correlation of historic inflow data over a period of months (from the time of the assessment) with recently observed inflows to assess the minimum future storage inflows that could be expected with very high confidence. This approach is intended to strike a balance between the objectives for airspace management and water conservation set in the Objectives and Outcomes.

The Objectives and Outcomes also requires the MDBA to constrain any airspace targeted at the Hume Dam within the range of 30 GL to 386 GL which is equivalent to between 0.15 m to 2.0 m below Full Supply Level.

Yarrawonga Weir

The Yarrawonga Weir's main function is to supply water for irrigation and other uses to the Mulwala Canal and the Yarrawonga Channel by diverting it from Lake Mulwala through the offtake regulators. The Yarrawonga Weir has a much smaller capacity than the major storages and only has a small influence on flows during larger floods. However, the operation of the Yarrawonga Weir must also ensure that timely adjustments to downstream releases are made as inflows change to avoid unwanted inundation around the weir pool (Lake Mulwala). The Kiewa and Ovens Rivers flow into the River Murray between the Hume Dam and the Yarrawonga Weir and can contribute large inflows at times.

Forecasting flows to South Australia

The MDBA undertake forecasting of the flows to SA (at the border) regularly during normal river operations, and they have advised that this has also previously been undertaken during flood events.

Prior to the 2016 floods, this was undertaken with the MDBA's spreadsheet-based daily operations decision support system, which relied heavily on operator expertise and experience. In practice it was often difficult to provide reasonable forecasts of flow peaks at the South Australian border until a flow peak at Euston had occurred. This point is downstream of most major tributary inflows and downstream of the complex interaction between the multiple river channels and the floodplain in the Murray, Edward (Kolety) and Wakool Rivers.

In the smaller flooding events of 2016, an early version of the SMOM was trialled to forecast flows to South Australia, and this showed that there was potential for SMOM to provide better forecasts of flows.

In the 2022 flooding events, the latest version of SMOM was used to forecast flows to South Australia.

Agreed guidelines between the Bureau and the MDBA on providing flood advice

The Bureau and MDBA have agreed to a set of guidelines to ensure that the public receive consistent and timely advice on current flood warnings and predictions along the River Murray (MDBA 2021). These guidelines were originally agreed in 1994 and have been reviewed several times since then, with the latest review in September 2017.

The Guidelines set out a number of arrangements, such as triggers for each organisation to initiate contact with the other, and for the exchange and use of information during flood events, including the following:

- When the Hume Dam reaches 80%, or the Dartmouth Dam 90%, the MDBA is to contact the Bureau, and where a storage operation is likely to cause flow at or above minor flood levels, MDBA will initiate a discussion with the Bureau to liaise on planned storage operation and releases.

- The MDBA is to contact the Bureau if there is going to be a change to the release rate or the flood operational strategy from the Hume Dam, and to update messages on the WaterNSW EWN.
- The Bureau is to use expected or actual releases from the Hume Dam provided by the MDBA to develop warnings for Albury and downstream.
- In case there is a loss of communications between the Bureau and the MDBA duty operator, the guidelines set out alternate contact arrangements, including the MDBA Senior Director of River Operations, and then the WaterNSW Hume Dam duty operator.

The guidelines also include triggers for contacting and advising other organisations, including NSW and Victorian SES, and state river operators (including in their capacity as SCAs), and also on the timing of public advice from the Bureau. In particular, flood warnings for major floods at Albury may need to be issued on a 3 – 6 hourly basis.[20] Once flood-producing rain has eased, the guidelines note that the Bureau will usually issue flood warnings for the River Murray on a daily basis.

Agreed guidelines between the Bureau, South Australia and the MDBA on providing flood advice

An inter-agency operational communications protocol has been developed to accompany the changes to the service level agreement between the Bureau and the South Australian Government. The parties to this agreement include the Bureau, DEW, SA SES, SA Water, and the MDBA. The current version is an agreement in principle, and the protocol is intended to be finalised following an inter-agency desktop exercise which will be held in 2024.

A high-level summary of the roles and responsibilities post-transition in 2023 for the 15 forecast locations in the River Murray in SA, is shown in Table 6 below. Of note, the protocol also provides for inter-agency forecasting and flood warning collaboration meetings that involve all parties to the protocol.

Table 6: Lead prediction and warning agency in South Australia, for different flow rates and flood classifications

<table>
<tr><th>Flow to SA (GL/day)</th><th>Townships</th><th>Shack Areas only</th><th>Predictions in SA</th><th>Bureau Warnings</th><th>SA SES</th></tr>
<tr><td>>200</td><td>Major Flood</td><td>Major Flood</td><td rowspan="2">The Bureau</td><td rowspan="3">Yes</td><td rowspan="4">Impact messaging for affected localities.
Call to action</td></tr>
<tr><td>130 – 200</td><td>Moderate Flood</td><td>Moderate Flood</td></tr>
<tr><td>100 – 130</td><td>Minor Flood</td><td>Minor Flood</td></tr>
<tr><td>60 – 100</td><td>High Flow</td><td>Minor Flood</td><td rowspan="2">DEW</td></tr>
<tr><td>40 – 60</td><td colspan="2">High Flow</td><td>No</td></tr>
<tr><td><40</td><td colspan="5">Normal Flow Range, no warnings</td></tr>
</table>

[20] The guidelines note that the SES needs at least 12 hours warning, preferably starting in daylight hours, if evacuations in and around Albury are necessary.

5 MDBA operations during the 2022-23 flood events

This section details the MDBA's flood operations during the 2022-23 flood events.

5.1 2022–23 period of flooding

Between August and December 2022 repeated rainfall events on already relatively wet catchments across south-eastern Australia produced a series of flooding events across most of the Basin. In the upper Murray catchments, high flows persisted over a three-month period, culminating in two major flood events in early November (see Figure 5).

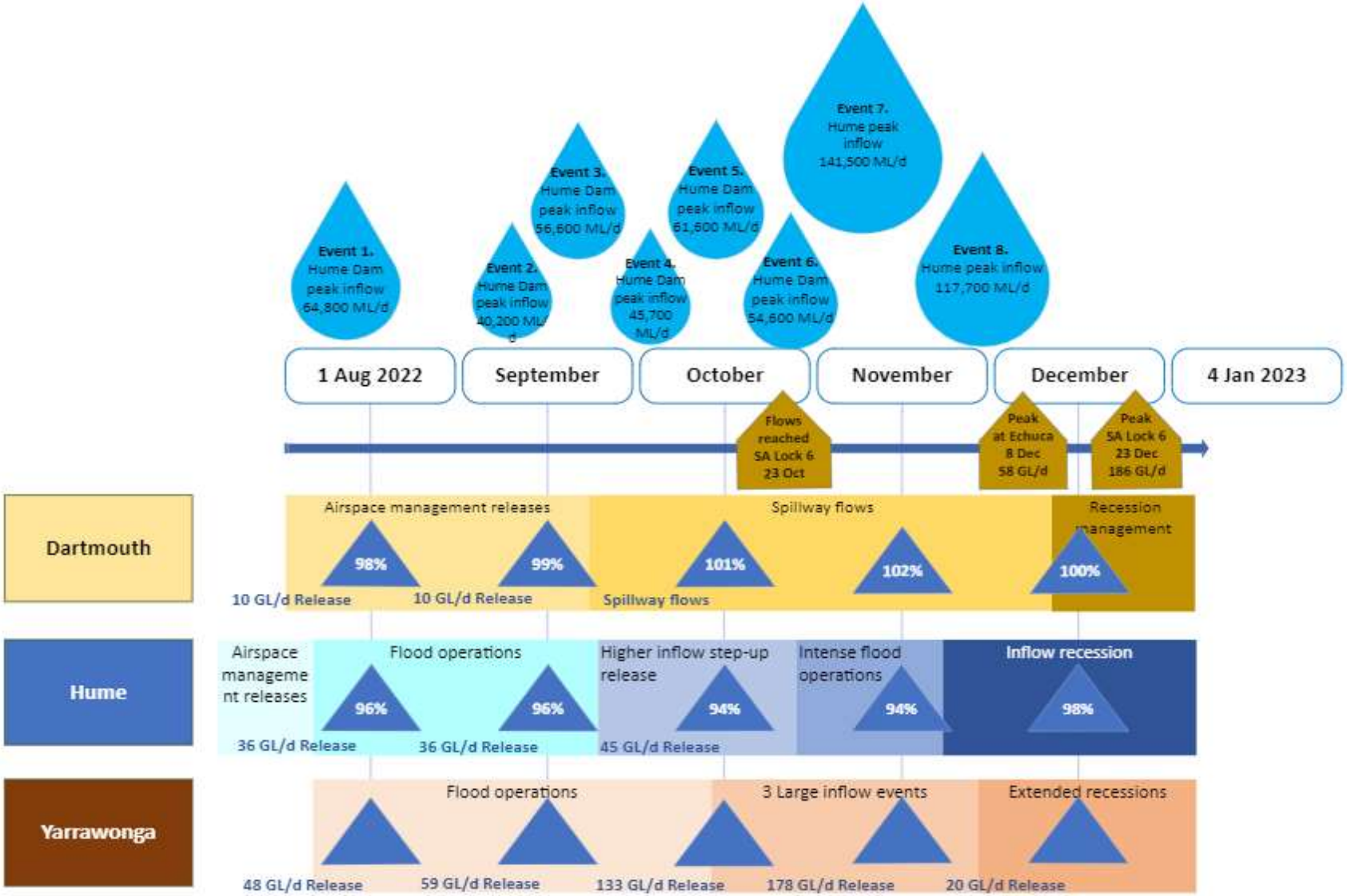

Figure 5 *Overview of flood events across the River Murray System.*

The period of major flooding along the River Murray between October 2022 and January 2023 was notable in that it occurred at the end of an extremely wet period across south-eastern Australia. Flood inflows in the upper Murray catchments occurred simultaneously with, or shortly after major flooding in NSW and Victorian tributaries in the southern connected Basin, and major flooding flows were already occurring along the Barwon-Darling system from most rivers in the northern Basin. In particular:

- Major flooding occurred in the Goulburn, Campaspe and Loddon rivers in Victoria, with inflows to Lake Eppalock on the Campaspe River reaching a new historic maximum, and possibly the largest flood peak since 1974 occurring on the Goulburn River at Shepparton in mid-October,
- Major flooding occurred in the Murrumbidgee River simultaneously with the timing of the major inflows in the upper Murray catchment,
- Major flooding occurred in valleys across northern NSW and Queensland over the period from September to November 2022, resulting in major flooding along the Barwon-Darling River concurrently with the floods in the southern Basin,
- Although not resulting in major inflows to other rivers, major flooding occurred simultaneously in the Lachlan River in NSW, and
- Major flooding occurred in northern NSW coastal catchments (outside the Basin, while calling on national or statewide resources of some agencies).

In South Australia, this River Murray 2022-23 flood event was the largest since 1956, and the third highest River Murray flood ever recorded in South Australia, with an unprecedented number of impacted homes, shacks businesses and infrastructure.

The flow rate at the South Australian/Victoria border peaked at 186,000 megalitres per day on 22 December 2022, the largest flood peak since 1956, with approximately 4,000 hectares of agricultural land and 3,500 private residences affected over the course of the event in SA (SA DEW, 2023).

5.2 Weather forecast and the antecedent catchment conditions.

The 2020 to 2022 period was particularly wet in south-eastern Australia, with three wet La Nina periods occurring in three consecutive years.

During the 2022-23 water year the southern Basin and the River Murray catchment experienced significant rainfall events over August to November period. This was after south-eastern Australia had received average to above average rainfall in the preceding water years (Figure 6).

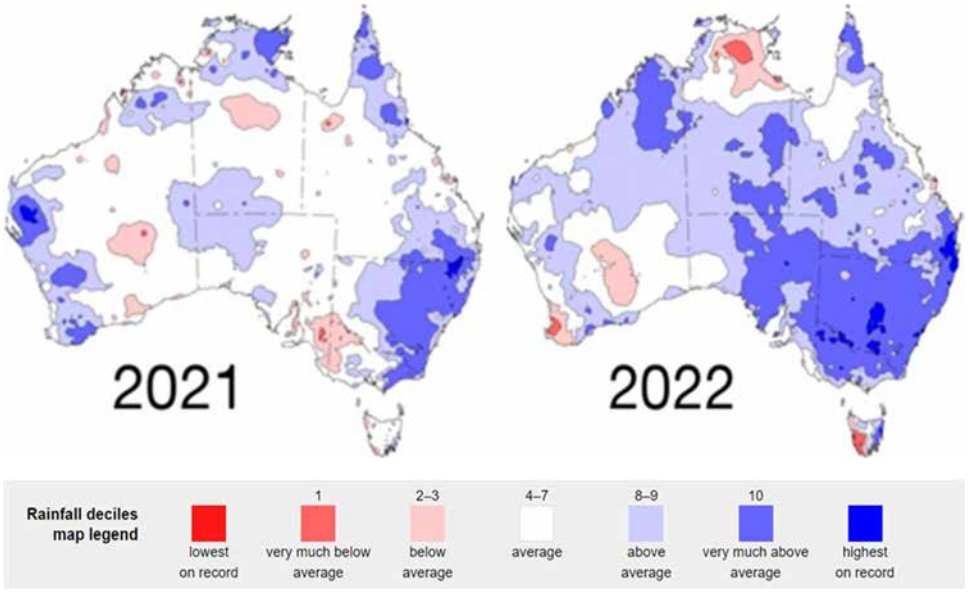

Figure 6. *Australian rainfall decile maps, showing average to above average rainfall in the Murray Darling Basin (Bureau, 2022)*

The wetter conditions had resulted in most storages across the Basin having reached full supply level by May 2022, with 90% water available across the whole of Basin storages (Figure 7).

The Bureau's winter 2022 outlook showed a strong signal indicating the return of La Nina. Over 100 mm of rainfall across the upper Murray catchment in early August 2022 resulted in the commencement of airspace management at the Dartmouth Dam and at the Hume Dam, and the transition to flood operations. The wet conditions persisted over a three-month period to December 2022, driving some of the highest observed tributary inflows across the southern Basin.

The two major inflow events to the MDBA storages in the upper River Murray occurred following approximately five months of continuous pre-release operations at the Hume Dam.

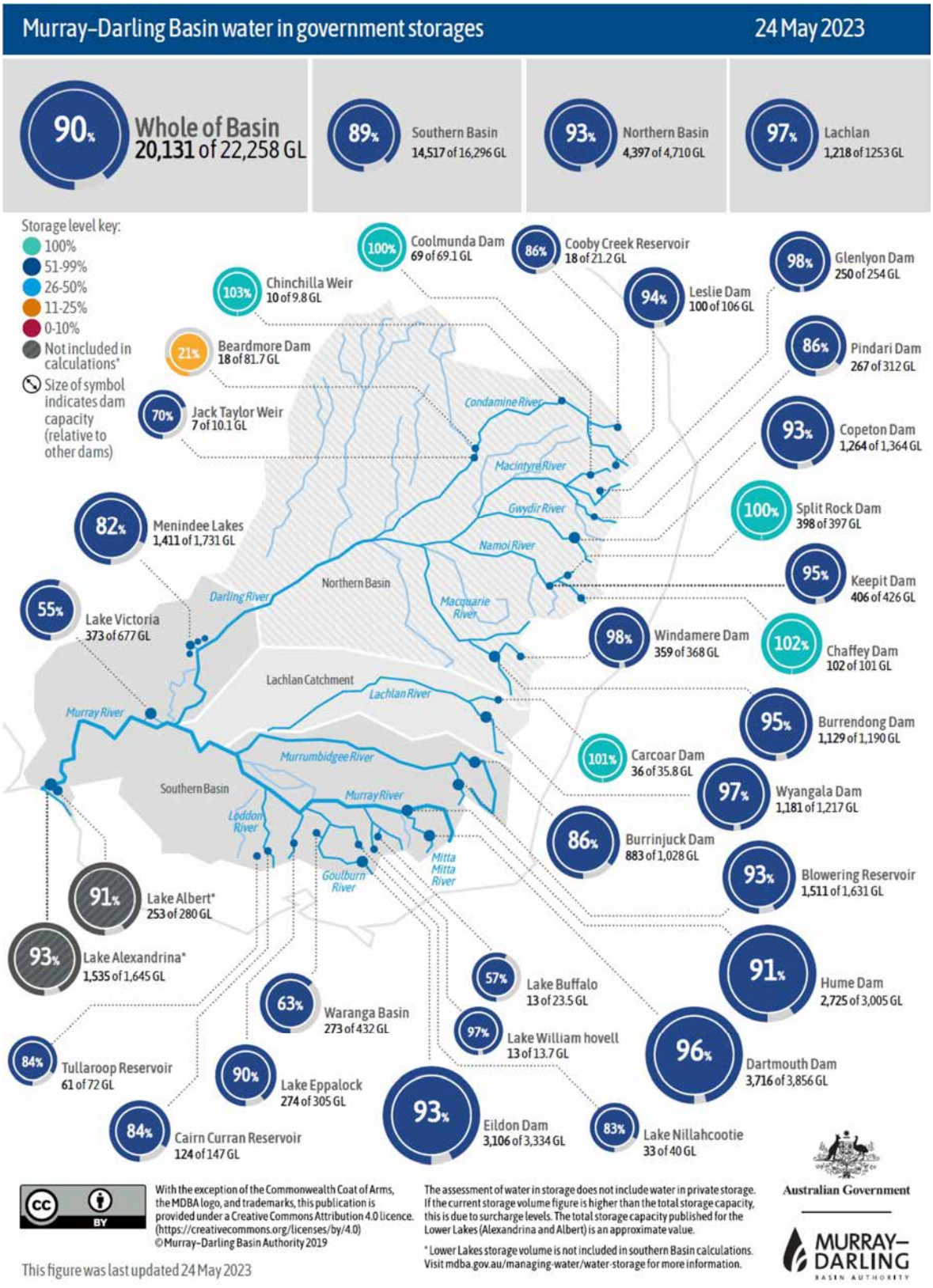

Figure 7. *Storage levels across the MDB, May 2022 (Source, MDBA, 2023)*

5.3 MDBA flood operations during the 2022-23 flood events

MDBA flood operations superseded the previous environmental releases in early August with the onset of higher rainfall (MDBA, 2024a). The MDBA commenced regular briefings with the Bureau that expanded to include the Goulburn river operator (GMW) and Murrumbidgee/Edward-Wakool river operator (WaterNSW) as the Bureau input to rainfall events became important across the southern Basin, and tributary inflows to the Murray increased. As catchment conditions became increasingly wet and larger rainfall events were forecast, the briefings with the Bureau were expanded to include SES and undertaken more frequently during the major inflow events (MDBA, 2024a).

Information exchange with the Bureau increased during the August to November period to facilitate use of the Bureau rainfall forecast products (such as gridded rainfall), and allow collaboration on catchment modelling to provide more information on potential inflows to the major storages. This also involved MDBA's Duty Operators calling the Bureau on a regular basis to speak with the meteorologists about the forecast.

The Dartmouth Dam

During the 2022-23 flood events at the Dartmouth Dam, the MDBA was able to achieve dam safety and water conservation, managing fourteen inflow events (Figure 8) within the three operational phases of:

1. **1 August – 22 September**: delayed filling and avoided spillway flows through airspace management releases.
2. **September 22 – 14 December**: flood attenuation and mitigation through spillway flows to reduce downstream impact.
3. **14 December – 4 January**: conservation of water after the airspace management release.

The MDBA was able to achieve the third flood operation objective, by limiting flood damage to downstream communities during Aug-Oct 2022 and by reducing the impact of inflow events through mitigating large flood peaks as shown in Table 7.

Table 7. The Dartmouth Dam peak inflow and outflow during the 2022-23 flood event and operation phases (Source: MDBA, 2024a).

Event	Inflow peak (ML/day)	Outflow peak (ML/day)	Flood operations
1	24,000	~10,000	Pre-releases increased to 4,000 ML/day and then to 10,000 ML/day at Tallandoon
2	16,500	~7,500	Air space management releases remained steady to maintain flows at Tallandoon below 10,000 ML/day channel capacity, until the storage reached FSL.
3	14,500	~6,800	
4	16,500	~7,000	
5	12,500	~7,500	
6	17,200	~8,500	FSL was reached and flows over the spillway commenced
7	17,800	~5,600	Heavy rainfall across the upper catchment resulted in spillway flowing across late Sept to late Oct 2022. Mitta Mitta River at Colemans reached over 22,000 ML/day, due to spillway flows minor flood level was exceeded at Tallandoon (15,200 ML/day) from mid Oct to late Nov 2022, including 8 days of moderate flood level in early and mid Nov.
8	11,500	~7,200	
9	17,000	~9,000	
10	16,000	~9,700	
11	24,000	~10,000	
12		~16,800	
13	36,000	~22,000	
14	15,500	~16,800	

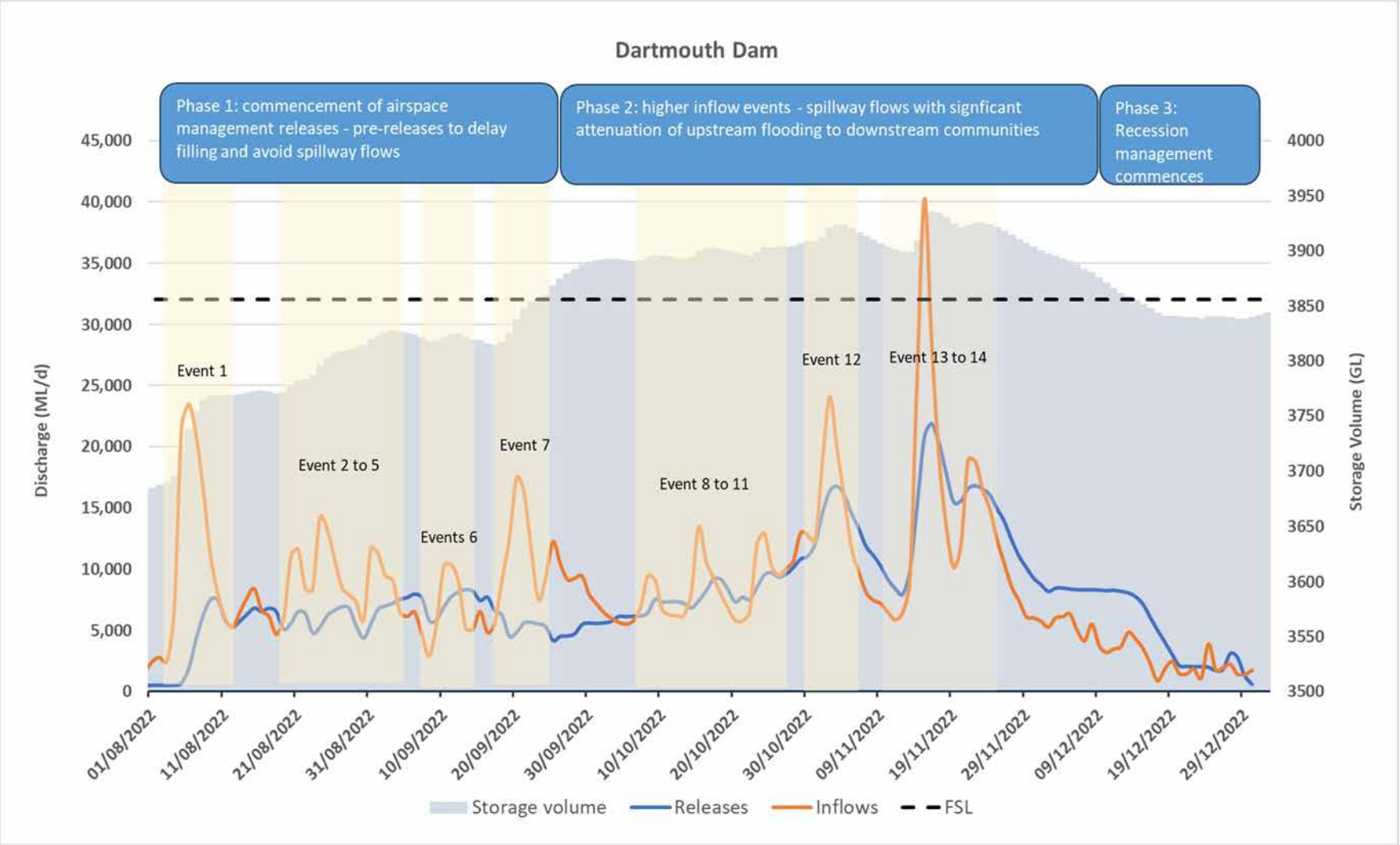

Figure 8. *Hydrograph of the Dartmouth Dam peak storage inflows and releases in ML/day and storage volume in GL. The Full Supply Level (FSL) for the Hume Dam is shown in dotted line on the horizontal axis of the hydrograph.*

Throughout the 2022-23 flood events and phases, the MDBA operated the Dartmouth Dam in accordance with sub-clause 4(3) of the Objectives and Outcomes (MDBA 2022). Both while managing the airspace in the Dam and during the spillway events, the MDBA operated the Dam safely and liaised with relevant agencies to mitigate flood risks to downstream of the Dam.

The Hume Dam

In the lead up to the 2022-23 flood events and due to air space management of the Dam, the MDBA was able to achieve water conservation and mitigate the inflow peaks and safely operate the Dam during eight inflow events within the four operational phases (Figure 9 and Table 8):

1. 5 August – 18 September: increased releases to manage airspace.
2. September 19 – 28 October: airspace maintenance through increased releases to manage higher inflow (~530 GL) events.
3. 29 October – 20 November: management of two major inflow events (~850 GL) through higher releases of up to 95,000 ML per day that limited downstream flooding to moderate flood levels in Albury during most of November.[21]
4. 20 November – 4 January: reducing releases post-flood operation to ensure the storage returned to effective FSL.

Table 8. The Hume Dam peak inflow and outflow during the 2022-23 flood event and operation phases (Source: MDBA 2024a).

Event	Inflow peak (ML/day)	Outflow peak (ML/day)	Inflow volume (GL)	Flood operations
1	64,800	36,000	500	Pre-releases increased from 15,000 to 35,0000 ML/day via spillway, an airspace of around 100 – 150 GL was maintained in case of further events.
2	40,200	35,000	275	
3	56,600	48,000	530	Pre-releases increased periodically from 35,000 to 50,0000 ML/day via spillway to increase airspace to 150-200 GL
4	45,700	41,000	300	
5	61,600	45,000	300	
6	54,600	43,000	470	
7	141,500	75,000	850	Release to mitigate peak inflow.
8	117,700	95,000	670	Pre-release to increase airspace ahead of peak inflow.

Release decisions during all inflow events took into account the forecasts of rainfall and inflows provided by the Bureau. During the most intense phase of flood operations, frequent collaboration with the Bureau occurred to assess potential inflows to the Hume Dam. The MDBA reported that clearing conditions following event seven allowed the available storage airspace to be almost fully utilised.

[21] Releases from Hume Dam combined with local downstream inflows to produce flows that exceeded the major flood level at Albury (Doctors Point flow gauging station) for approximately 6 hours during the second major inflow event.

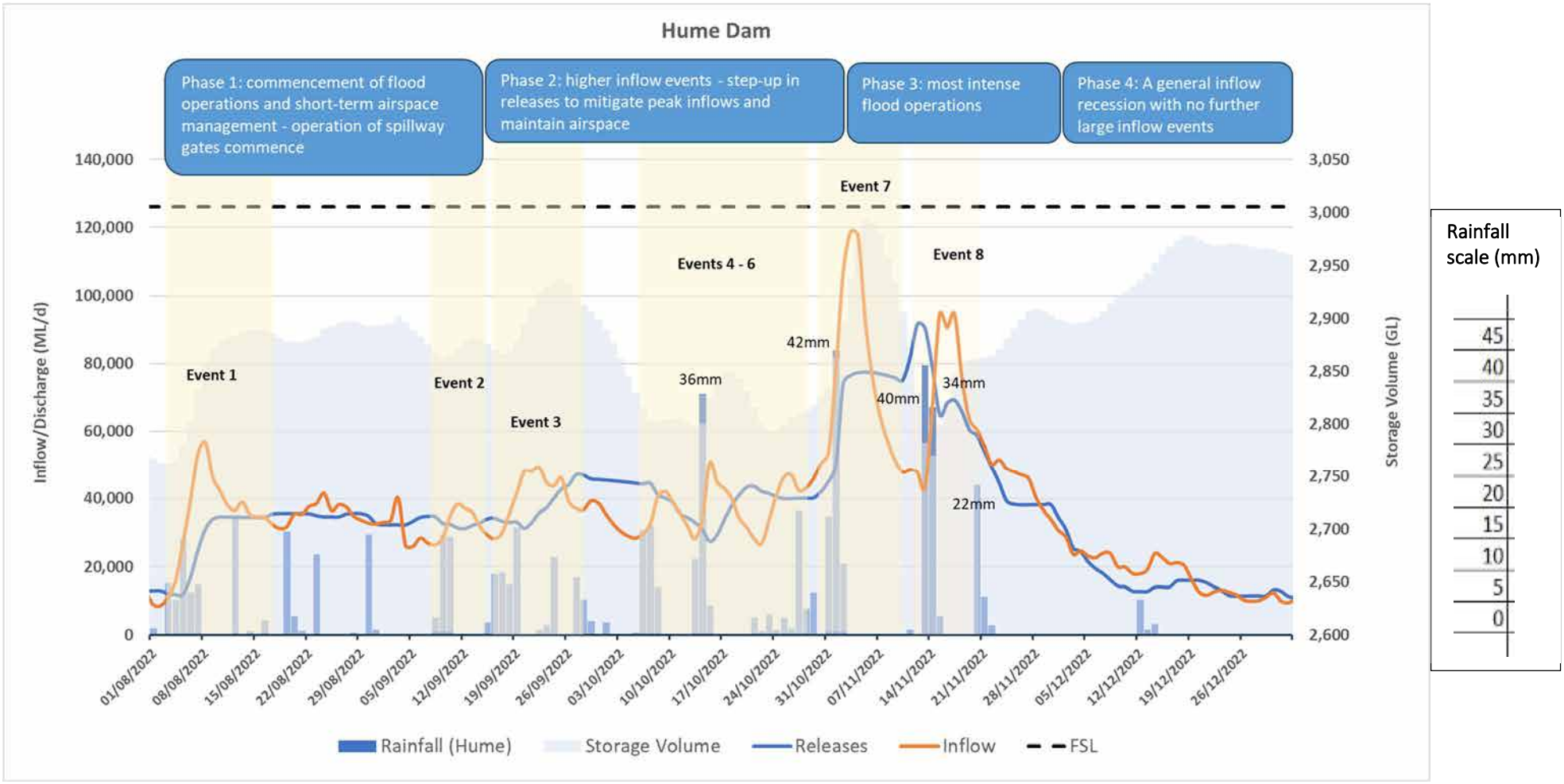

Figure 9. *Hydrograph of peak storage inflows and releases at the Hume Dam in ML/day, and the Hume Dam storage volume in GL during the River Murray 2022-23 flood events depicted for 1 August 2022 to 4 January 2023.The Full Supply Level (FSL) for the Hume Dam is shown in dotted line on the horizontal axis of the hydrograph. Rainfall at the Hume Dam is shown as vertical dark blue bars, with a rainfall scale (mm) shown to the right of the hydrograph. Storage volume at the Hume Dam is the light blue background continuous bar graph.*

Shortly following event seven, it became clear that another significant rainfall event was likely and high releases were maintained to regain airspace in the storage. However, there was uncertainty in the rainfall forecasts due to prevailing climatic conditions, and there was potential for severe rainfall and flooding to occur. As a consequence, releases were increased to what became the peak release of the flooding period to increase the airspace in the storage. These releases were reduced with the onset of significant local rainfall to prevent major flooding from occurring downstream in Albury. The rainfall in the upper Murray catchment was subsequently less than expected, with more severe rainfall and flooding occurring instead further to the north in the Lachlan catchment.

Throughout the flood operation events, the MDBA operated the Hume Dam in accordance with sub-clause 4(3) of the Objectives and Outcomes (MDBA 2022). The MDBA, while managing the airspace during the 2022-23 flood events, operated the Dam safely and liaised with relevant agencies to mitigate flood risks to downstream of the Dam.

The Snowy Scheme has no formal limits on releases from the Snowy-Murray development during floods, but Snowy Hydro Limited has publicly stated that it will ensure releases do not exceed the flows that would have naturally occurred (had the Snowy Scheme not been in place). Whilst no advice has been provided regarding the flows that would naturally have occurred during the 2022-23 flood event on the Geehi River, the peak flow at Khancoban (just downstream of the lowest storage on the Snowy-Murray development) was approximately 15% of the peak flow into the Hume Dam in events seven and eight.

The Yarrawonga Weir

The storage at the Yarrawonga Weir experienced significant flood operations from August 2022 to January 2023, following a period of high releases that reached about 28,000 ML per day in June. The weir pool remained within the agreed operating range for the duration of the flood. The flow stayed above 50,000 ML per day for 108 days and more than 9,300 GL of water was discharged through the storage, of which over 3,500 GL came from the Kiewa and Ovens rivers (Figure 10).

The river section downstream of the Yarrawonga Weir experienced moderate flooding of 6.7 m (about 97,500 ML per day) for three days in October and for nearly three weeks in November (see Table 1Table 9). The water level reached its highest point of 7.79 m on November 16, which was close to the major flooding threshold of 7.8 m (around 182,000 ML per day). The flood situation gradually improved from November 30, 2022, until the end of the flood operations on January 4, 2023. Table 9 summarises the inflow events and flood operation for the Yarrawonga Weir.

Table 9. The Yarrawonga Weir peak inflow and outflow during the 2022-23 flood event and operation phases (Source: MDBA 2024a).

Event	Inflow peak (ML/day)	Outflow peak (ML/day)	Flood operations
1	74,000	71,000	Commencement of flood operations and short-term airspace management from 5 August to 12 October, with releases remaining above 50,000 ML/day
2	134,900	133,000	Peak inflows from three large successive events reached 134,900 ML/day, 126,450 ML/day and 184,800 ML/day respectively. Peak releases were 132,000 ML/day, 126,000 ML/day and 178,000 ML/day respectively. Releases resulted in flows downstream of the weir exceeded moderate flood levels for up to 23 days.
3	126,450	126,000	
4	184,800	178,000	

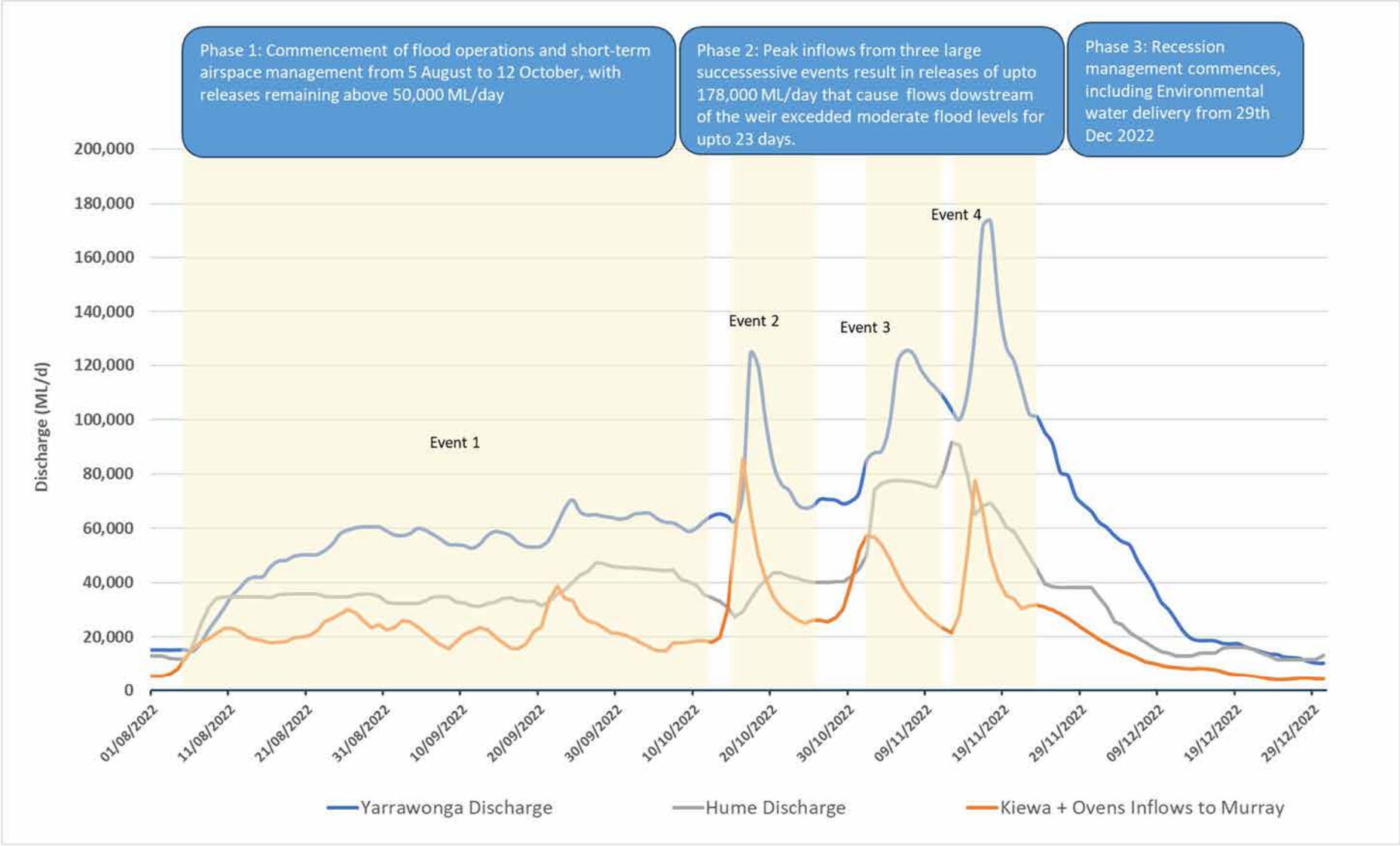

Figure 10. *Hydrograph of storage inflows and releases at Yarrawonga Weir during the 2022-23 flood events*

Mid to Lower River Murray

Below the Yarrawonga Weir, MDBA river operators have little control over flood flows, since the capacity of weirs along the River Murray is too small to significantly affect such large river flows. The normal practice is to remove each weir from the river ahead of high flows to avoid exacerbating flooding and to avoid damage from debris carried by the flood waters. The Torrumbarry Weir has gates which are raised clear. Likewise, the inlet and outlet maximum release rates at Lake Victoria Ta-Ru do not have sufficient capacity to affect moderate or major flooding.

The main role of the MDBA river operators in the Mid to Lower River Murray is to:

- forecast flows along the river to ensure that weirs are managed to safely pass the flood flows (including timely removal (or lifting for the Torrumbarry Weir) of the weir gates from the river),
- provide advice to the Bureau to support its forecasting of flows and issuing of flood warnings, and
- provide advice to the South Australian government regarding the forecast flows at the South Australian border (and also to the Bureau as of October 2023).

In the Mid to Lower River Murray, flows are affected by a number of physical features:

- a number of major tributaries enter, including the Goulburn, Campaspe and Loddon Rivers from Victoria, and the Murrumbidgee and Darling Rivers from NSW,
- a significant portion of the River Murray flows into the Edward-Kolety River system on the NSW side of the river, with further outflows from the Edward River into the Wakool River and a number of other rivers and creeks before flows in these river systems return to the River Murray, and
- a number of large floodplain wetland and forest complexes that fill with water along the River Murray, from the Barmah-Millewa forests downstream of Yarrawonga Weir to the Lindsay-Wallpolla wetland complexes near the South Australian border.

Major tributary inflows, as well as the complex interaction between the multiple river channels and the floodplain in the Murray, Edward-Kolety and Wakool Rivers affect river flows during flood events and must be taken into account when forecasting flows. During the 2022-23 flooding along the River Murray, major flooding also occurred on the major NSW and Victorian tributaries, including on:

- the Goulburn, Campaspe and Loddon Rivers in mid-October,
- the Murrumbidgee River in early November 2022, and
- along the Barwon-Darling River system over a period of four months between September 2022 and January 2023.

As flows exceed the capacity of the river channel, they flow onto the floodplain and spread into the landscape. This helps to attenuate (reduce) peak flows as they travel downstream, and not all water that flows into the river from tributaries will reach the end of the River Murray system. The degree to which the floodplain wetlands and forest affect river flows depends on the peak flow rate and conditions on the floodplain, including how much water was already on the floodplain from previous rainfall and high river flows. The Edward-Wakool system and the River Murray and associated forests can interconnect at many places, and it is difficult to gauge flows in this area, as flows move across the floodplain around the gauging stations and between the main river channels.

For example, it was reported that the very large inflows from the Goulburn River resulted in the River Murray flowing “backward” upstream for some distance. This affected the flows measured at the Barmah flow gauging station, and also forced additional flows overbank from the River Murray and into the Barmah-Millewa forest. This is in addition to the more typical increase in overbank flows downstream of the confluence of the Murray and Goulburn Rivers into the Gunbower forest, the Koondrook-Perricoota forest and subsequently into the Wakool River system. Such large inflows from the Goulburn River also force a higher proportion of the River Murray flows into the Edward-Kolety system. The complexity of the river system in this area makes flow measurement and forecasting of flows challenging.

The relationships used to convert the continuously measured water levels to flows rely on flow measurements taken by hydrographers to provide an accurate conversion. As the flood inflows from major tributary rivers accumulated along the River Murray, the resulting flows were often higher than any previously measured flows since the 1970s or, in South Australia, since the historic 1956 floods. As a consequence, the relationships being used to convert such high water levels to flows had not been able to be verified for decades, and there was significant uncertainty regarding the accuracy of flows being reported at many flow gauging stations.

The flows recorded at key flow gauging stations along the River Murray and at the end of major tributary rivers are shown in Figure 11. Flow gauging stations between Yarrawonga and Euston have not been shown as they each only represent a portion of the flows that subsequently rejoin further downstream. The combined effect of major tributary inflows and the inundation of large floodplain wetland and forest areas can be seen at Euston, where river flows peaked in early December at over 200,000 ML per day.

Figure 11shows that there were high inflows from all major tributaries, however, the flooding flows from the Goulburn River were particularly significant. End of system flows in the Goulburn River are thought to be under-estimated during the 2022-23 floods. Satellite imagery showed that flows in the lower Goulburn River bypassed the gauge at McCoy's Bridge to an extent.

Impacts on River Murray system infrastructure

The primary water management infrastructure in the River Murray was generally able to pass the flood flows without significant impacts. At the Torrumbarry Weir, the peak flood flows exceeded the highest recorded flows at the new weir structure (completed in 1996) and the local DSEP was triggered. No issues were recorded, but activation of the DSEP provided for additional monitoring to be undertaken.

The 2022-23 flood events posed some operational difficulties for the Mildura Weir, especially when it came to safely restoring the weir after the flood waters receded (trestles were removed in September 2022 and reinstated in February 2023, (GMW 2023)). In addition to the usual lengthy manual process to reinstate the weir, following the 2022-23 flood event there was a delay due to the need to clear flood debris and sand from the concrete ramp and trestle tracks. This resulted in a delay in restoring the weir, which lowered the water level in the weir pool below the normal operating level. There were also elements of communication uncertainty between river operators, SCAs and stakeholders. This happened during a time of high irrigation water demand and recreational boating activity, which raised some concerns among the community and uncertainty about irrigation supplies, town water supply and navigation. While noting these are issues of concern that may have impacts in the community, the Reviewers' understanding is that there is no specific obligation to maintain the weir pool level.

There is also a significant amount of infrastructure on the River Murray system floodplain, including levees, channels and regulators. Some of this floodplain infrastructure is only of significance during floods and, in some cases is quite old and not subject to regular maintenance. There are two reported instances during the 2022-23 flood event where Murray floodplain levees failed, and another instance in the lower Goulburn was noted by some of the stakeholders in interviews. One of the two Murray floodplain levee failures was at Lock 9, where a levee on the north bank failed and a section of forested floodplain was inundated as the peak flood flows were approaching. This subsequently led to uncontrolled inflows to Frenchmans Creek (the main inlet channel for Lake Victoria), requiring the bulkheads to be closed at the regulator at Lake Victoria. The additional flows also resulted in a second levee failure on the south side of the inlet channel, closer to Lake Victoria, resulting in further inundation of the local floodplain, and the need for repairs before further water could be stored in Lake Victoria. The floodplain inundation also impeded access to the areas needing repair, and delayed completion of repair works for several months. Lake Victoria was not full at the time of the levee failures, and it appears fortunate that there was no subsequent loss of resource.

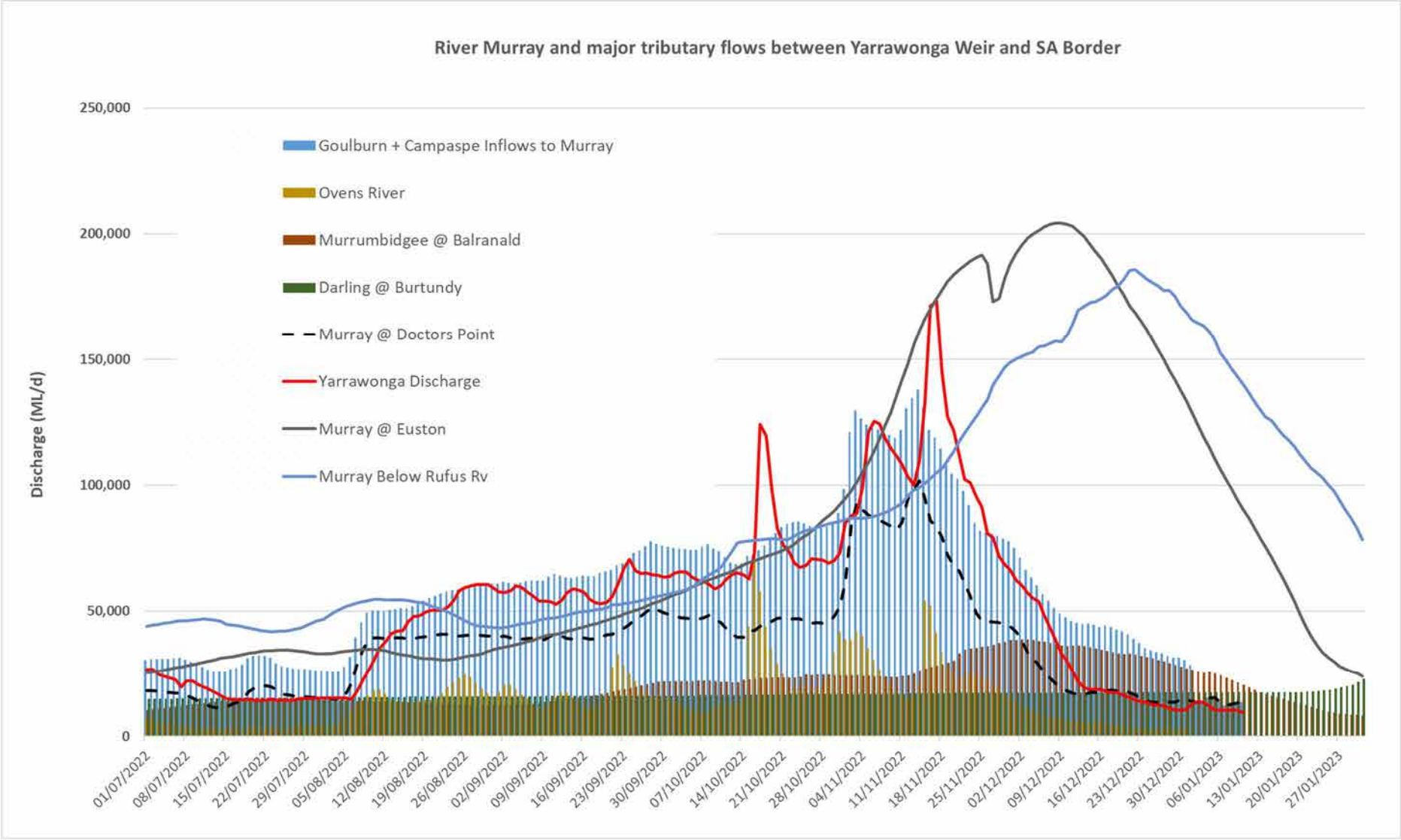

Figure 11. *Hydrograph of releases downstream of Yarrawonga and inflow contributions from the major River Murray tributaries*

Modelling of River Murray flows below Yarrawonga

All jurisdictions in the Basin have developed hydrologic models of their major regulated river systems for long-term planning and other purposes and, in many valleys, have transitioned to the 'Source' modelling platform, which has been adopted as Australia's national hydrological modelling platform[22]. Likewise, the MDBA (on behalf of the NSW, Victorian and South Australian governments) has implemented a Source Model for the Murray regulated river system, referred to as the Source Murray Model.

For a number of years, the MDBA has been developing a version of its existing Source Murray Model that has been configured for operational use, referred to as the SMOM. This is a daily-step hydrologic model with a representation of the River Murray system that is based on the MDBA's established Source Murray Model, with some simplifications through removing functionality that is not required in an operations model (such as water allocations and accounting). Some additional functionality has also been added relevant to operations and forecasting. This model can route flows along the River Murray system and includes inflows from major tributaries, and provides a simplified representation of some of the major floodplain wetland and forest systems, which are the dominant hydrologic influences within the regulated river system, rather than catchment rainfall-runoff modelling.

In recent years, the SMOM has been used to provide forecasts of flows to the South Australian border during higher flows along the River Murray over periods of up to a few months for operational purposes. These purposes have included advice for environmental water managers and assessing potential water supply requirements under a range of potential climate conditions. An earlier version of SMOM was first used to trial forecasting of flows during the 2016 flood events.

The 2022-23 flooding period provided an opportunity to use the latest version of SMOM during much higher flows than are experienced during normal river operations or environmental flows. The model was updated and run daily during the entire flood period from 17 October until late December, and less frequently until the end of January 2023. The MDBA has subsequently documented the results of this trial (MDBA 2024b).

A number of changes were made to the model during the period of flooding, primarily to bring across additional representation of floodplain wetlands from the SMM into SMOM, including for the Hattah Lakes and the Wallpolla Island (near Wentworth).

The primary objective was to test the ability of SMOM to provide useful forecasts of flows in the River Murray at the South Australian border, which is a role that the MDBA has historically undertaken as part of its river operations (including during flooding periods). Table 10 shows the modelled flows at the South Australian border and the difference to the observed peak flow (last line in Table 10).

Table 10 shows that early modelling of the peak flow at the South Australian border increased as additional rainfall and further inflows occurred. After the majority of the rain had fallen across the southern connected Basin (approximately mid-November) the peak flow was overpredicted with a later peak timing than eventuated. However, as the flood progressed, these predictions improved as the peak passed critical gauges that provided feedback on the SMOM performance (MDBA, 2024b). From early December 2022 there was:

- limited change in the forecast timing of the peak, overpredicting by 3-4 days consistently until the peak arrived, and
- limited change in the peak flow rate, as forecast peak flows were below 200,000 ML per day 23 days before the eventual peak of 188,000 ML per day on 22/12/2022.

[22] https://ewater.org.au/about-us/nhms/

Table 10. Performance of modelled flows at the South Australian border (Source: MDBA 2024b).

Forecast date	Modelled Peak flow (ML/d)	Modelled Peak Date	Peak flow (%) diff (Modelled peak - actual peak) / actual peak	Peak date difference (days)
1/10/2022	81,645	16/11/2022	-56.5%	-36
21/10/2022	126,179	30/11/2022	-32.7%	-22
24/10/2022	129,806	1/12/2022	-30.8%	-21
28/10/2022	148,210	1/12/2022	-21.0%	-21
1/11/2022	135,203	3/12/2022	-27.9%	-19
3/11/2022	165,338	3/12/2022	-11.9%	-19
8/11/2022	169,339	6/12/2022	-9.7%	-16
10/11/2022	164,839	7/12/2022	-12.1%	-15
14/11/2022	203,062	5/01/2023	8.2%	14
21/11/2022	201,835	31/12/2022	7.6%	9
28/11/2022	205,108	31/12/2022	9.3%	9
5/12/2022	199,015	25/12/2022	6.1%	3
12/12/2022	198,356	25/12/2022	5.7%	3
19/12/2022	189,453	26/12/2022	1.0%	4
23/12/2022	187,594	22/12/2022	0.0%	0

Modelling of Floodplain inundation

The inclusion into SMOM during the 2022-23 flooding event of the SMM's representation of several floodplain wetlands in several locations helped improve the modelling of flows. This involved including the Hattah Lakes and the Lindsay-Wallpolla floodplain near the South Australian border that were not previously included in the SMOM. Adapting the representation of The Living Murray icon sites and the Victorian Murray Floodplain Restoration Project (VMFRP) will improve the usefulness of SMOM during flood flows.

Sentinel imagery was available during the period of flooding, and was able to provide insights into the flooding behaviour at key locations, which helped to diagnose discrepancies between flow measurement stations and modelled flows. This, in turn, supported modelled results (e.g. where some flows were bypassing flow gauging stations), provided opportunities to adjust the model during the flooding period, or identified future improvements that would improve model performance at very high flows.

The use of satellite imagery[23] during the flood event provided useful insights into the behaviour of water on the floodplain, including:

- flow breakouts that were by-passing some flow gauging stations
- antecedent conditions in floodplain wetlands, forests, and lakes, and
- the effect of levee failures.

In one case, a levee that normally prevented inundation of the Lake Caringay near Euston had failed, and the filling of the lake explained the short-term dip in flows measured at the downstream flow gauging station at Euston.

Tributary inflow modelling

The MDBA has limited to no modelling of the flows in the major tributary regulated rivers within its models. The MDBA normally requests advice from the state agencies as needed, including model outputs and/or operational forecasts made by state river operators. The main tributaries below Yarrawonga are the Goulburn, Campaspe and Loddon Rivers, and Broken Creek in Victoria, and the Murrumbidgee and Darling Rivers, and Billabong Creek in NSW. Most of these tributaries also had major flooding occurring and provided a significant proportion of the total flows in the mid and lower River Murray during the period of flooding. Accordingly, these inputs to the

[23] Imagery from the Copernicus Sentinel 2 satellites program was used.

modelling of flows along the Murray in SMOM have a significant influence on the usefulness of the modelled flows further along the River Murray as forecasts.

During this use of SMOM, the MDBA generally used advice on potential inflows from tributaries from relevant state river operators as tributary inflow forecasts for use in SMOM. This advice was not sought every day, and MDBA river operators revised state advice between receiving updates. The MDBA has advised that these forecasts of tributary inflows were initially a significant source of uncertainty in modelling of flows with SMOM. As the tributary inflows peaked and flows moved downstream, the uncertainty in modelled flows further downstream at the South Australian border significantly reduced.

The MDBA has noted that improvements in tributary inflow forecasts would provide greater confidence in the model outputs. In locations where significant river flow data is not captured by the gauge, instead flowing onto the floodplains, some estimates of this provided by state authorities, or represented explicitly in the SMOM, would improve forecasts in the River Murray.

It is also noted that there are also significant resourcing challenges for state river operators in forecasting flows during major floods in tributary systems, when concurrent flooding across a number of river systems occurs within a state.

Forecasting flows in South Australia

During the 2022-23 flooding period DEW undertook flood forecasting and predictions of flood levels for River Murray in SA. There are no major tributary inflows to the River Murray in SA, and DEW staff indicated that the historical practice has been to use the MDBA's forecast of flows to the South Australian border, and assume that as flow magnitude continue, these flows move through SA with only minor attenuation. For the prediction of flood levels and potential inundation, DEW used a combination of historic flow data and modelled flood levels and inundation maps from the hydraulic model of the South Australian River Murray[24]. The hydraulic modelling for inundation maps was undertaken in 2014 and was used to produce inundation maps at various flow intervals. Information from these maps were then adjusted to account for variations in flow conditions during the 2022-23 flood, as they emerged.

While some hydraulic modelling was undertaken during the event in specific areas (for example, to inform levee works at Renmark) using newer model builds developed for other Murray projects by DEW, re-running the original flood model (extending from near the SA border to Wellington) during the event was considered to be of limited value. This was due to the time required to upgrade the model to the current software version and the long run time of the model itself. Further, changes in the historic flow-level relationships (which the 2014 model was calibrated to) became evident in the weeks before the peak in river flows.

DEW have a 'Source' model for the SA River Murray, based on the MDBA's 'Source' model. However, it was not calibrated for floods, in particular, travel time. The SA River Murray reach is unusual because in flood it transitions from being a series of relatively flat pools with the water level controlled by the weirs, to behaving more like a typical river at higher flows when the structures are removed. This means that during low flow (regulated) conditions, the travel time for a flow peak from the SA border to the mouth is approximately 1 week, but at higher flows when weir structures are removed, the travel time is longer (e.g. around 3 weeks at 100,000 megalitres per day). However, at even higher flows the travel time has been observed to decrease (the 2022-23 event took approximately 2.5 weeks, and the 1956 flood was more rapid again). As a consequence, DEW largely relied on historical travel times. The peak flow advice provided by DEW was used by local councils to conduct levee improvement works.

DEW and MDBA exchanged flow forecasts at the border in graph format during weekly meetings through the flooding period. MDBA forecasts typically included a plausible upper and lower bound of forecast flow, to provide some representation of the uncertainty in the modelled flow at the South Australian border.

From November 2022, DEW provided a range of flow estimates to reflect uncertainty in flood extents. DEW advised that, ultimately, the observed flow peaks were within the flow forecast range provided. Water level

[24] This model has been developed using the widely used MIKE FLOOD software by the Danish Hydraulics Institute (DHI)

predictions (provided as a range) were updated as the peak moved through SA using modelled water levels as a starting point and applying variations as observed during the event.

As was the case for the MDBA and the Bureau above the South Australian border, uncertainty in flow measurement at these very high flows complicated flood forecasting. DEW advised that ensuring this uncertainty was recognised proved challenging at times, and there were some instances where a level of precision in flow measurement was assumed that was inappropriate. During the 2022-23 flood events DEW observed that there were some variations in water levels of observed vs predicted or expected, due to geomorphological processes and rivers changing over time, and noted that there had been changes to the floodplain landscape that affected inundation compared to previous similar events.

5.4 Inter-agency communication and data provision

The extended period of wet conditions leading up to the 2022-23 period of flooding resulted in the early commencement of communications between the MDBA, the Bureau and state agencies.

MDBA and the Bureau

The MDBA and the Bureau staff indicated that there was a high degree of communication between agencies, from officer-to-officer personal communications through to more formal briefings and exchanges of data. Due to the very wet conditions, communication between the organisations commenced well ahead of major flood events. The MDBA initiated "inflow briefings" with the Bureau early in the flooding period that were held approximately two to three days before forecast rainfall events to discuss rainfall forecasts and potential flows and responses at the major storages. The frequency of inflow briefings increased to two- to three-day intervals at the peak of the flooding. Following these briefings, and responding to observed increases in flows, the MDBA would:

- make release decisions for each major storage,
- publish changes in dam releases via WaterNSW's EWN, and
- have a follow-up discussion with the Bureau to confirm the MDBA's release strategy and current actions.

The MDBA and the Bureau also shared results from rainfall-runoff modelling, with each having URBS models of the Murray catchment above the Hume Dam. These results were taken into account by the MDBA when setting releases from the Hume Dam. This largely accords with the requirements of the agreed *guidelines between the Bureau and the MDBA on providing flood advice*. (MDBA, 2017)

Prior to the flooding period, the MDBA had been undertaking weekly "River Murray flow" briefings with environmental water managers and the South Australian agencies regarding likely flows along the River Murray and into South Australia. As the objective of releases from the Hume Dam shifted from environmental water deliveries to pre-releases for managing airspace, the participants at these briefings transitioned to include the Bureau with the South Australian government (DEW) rather than environmental water managers. This was expanded to include WaterNSW river operators when flooding was occurring through the Edward Wakool system. It was at these briefings that MDBA commenced presenting the modelling produced using SMOM, including the modelled forecast flows at downstream locations to the South Australian border. These briefings arose as a result of interaction between staff at the respective agencies, indicating that cooperative relationships were in place. However, interviews with agency staff indicated there was support for formalising these arrangements to some degree as a safeguard in case of future increased movement of staff.

In discussions with the MDBA and the Bureau, it was noted that the latest rating tables for flow gauging stations were not being transferred from state hydrometric agencies to the Bureau as part of the automated data-sharing arrangements currently in place. Refer to Attachment 4 for further details about data-sharing arrangements.

From discussions with the MDBA river operators and modelling team, it is clear that there is a strong collaborative relationship between the MDBA, the Bureau and the state river operators, and that the MDBA plays an active role in keeping the Bureau informed of MDBA's operational arrangements and readily exchanges information during flood operations. Both parties noted that the widespread adoption of video conferencing

has enabled more regular and productive collaboration and helped build relationships and trust between agencies.

MDBA and SES

The SES conducted "incident control" briefings with the Bureau and other emergency services to discuss flood warnings and inform their on-ground actions and public communications. In NSW, the MDBA did not participate in the incident control briefings or the more local emergency management committees but provided "semi-official" flow advice to senior local SES personnel managing the floods in the Murray Valley. This advice was described as complementing the overarching advice from the Bureau to the NSW SES, and was greatly valued by the local senior SES.

All agencies indicated that, as flooding moved further along the River Murray system, the MDBA, NSW SES, Victorian SES, WaterNSW, and GMW were in frequent contact to deal with the challenges in understanding the complex flood pathways and the effects on flow gauges. The MDBA was also invited to attend some Emergency Management Team briefings held by the Victorian SES in Mildura, which included staff from the Bureau, SES, state water operators and other agencies with local knowledge of river flows, such as CMAs in Victoria. These meetings were used to provide information to the Bureau about likely flooding and impacts, and to develop consistent public messaging.

Other communication

In addition to the regular direct communication between duty flood operators and SCA staff at storages, locks, and weirs, the MDBA produced regular "situational update" reports during the flooding period. The primary objective of the situational updates is to support and improve efficiency and robustness in the flow of information from the MDBA river operations team to SCA staff at storages, locks, and weirs on the current state of flood operations and the plan and strategy going forward. The MDBA river operators noted that these were also useful for updating the broader MDBA management team and the Bureau.

State river operators and water policy and management agencies also noted that there were briefings provided to the members of the Water Liaison Work Group[25] that kept agencies well informed throughout the flooding period.

The MDBA and state river operators indicated that flow forecasts from the regulated state tributary rivers were provided as required during the flooding period. It was noted that these were initially subject to considerable uncertainty until inflows into each tributary river system peaked, and also that the scale of flooding that had not been seen for many decades.

The Bureau, the SES, and state agencies all praised the MDBA operations team during interviews for providing a high level of informal advice during the flooding period. In particular, NSW SES and SCA staff indicated that discussions with river operators helped to facilitate forward planning for their activities (e.g. removal of weirs and closing regulators) ahead of public warnings issued by the Bureau.

5.5 How was the event communicated

Overview

Outside of flooding periods, river operators are the primary source of information on river flows and forecasts. As flows are forecast to approach minor flood levels, the Bureau takes responsibility for flow forecasting. In NSW and Victoria, the Bureau has the primary obligations for issuing public flood warnings and forecast river heights, which is then disseminated by the SES together with a description of potential local impacts. In SA in 2022 this role was undertaken by DEW (flow and river height forecasting) and SA SES (public flood warnings). Following agreement with the Bureau in October 2023, the Bureau will undertake this role for flows at the South Australian border in excess of 100,000 megalitres per day.

[25] A working group convened by the MDBA that meets regularly to provide technical oversight of regulated river operations in the River Murray system.

Following the transition of flow forecasting and public communication roles to other agencies during flooding periods, the MDBA still maintains a role to provide key information during flooding periods, including:

- public announcements regarding changes in storage releases, including via WaterNSW's EWN (for the Hume Dam),
- near-real time hydrometric data, providing access to water heights and flows at gauging stations, dams, locks and weirs information that are normally available on the MDBA website, and
- storage and river flow data as part of their business-as-usual process in their River Murray weekly reports.[26]

MDBA communications

Ahead of the 2022-23 flooding period, the MDBA prepared a communication, media and engagement plan (the plan) that outlined MDBA's activities related to communication, media and engagement during flooding events (MDBA, 2023b). The plan reflects key lessons from previous flood events, and outlines storage volume triggers and associated communication objectives, and actions that would be undertaken (

).

Table 11. MDBA communication, Media and Engagement Plan objectives.

Event stage	Objectives
Pre flood (Hume Dam >80%, wet conditions)	• In partnership with other relevant agencies (Bureau of Meteorology, WaterNSW, Goulburn Murray Water and the SES), the MDBA's role is to keep stakeholders informed and remind impacted communities about how the Hume Dam is managed at times of high inflows and during a flood event.
During flood (Doctors Point flows > 25,000 <ML/d)	• Raise awareness of where audiences need to go for up-to-date weather, river height and emergency services information (including EWN) amplifying existing messages from responsible agencies. • Ensure messages are consistent and accurate, where possible and within the MDBA's control. • When the MDBA does communicate regarding the Hume dam operations and pre-releases, it is coordinated and joined up with other involved agencies and point-in-time is clearly articulated. • Raise awareness of the ongoing safe management of the Hume Dam by the MDBA

The plan also sets out a range of activities that were subsequently undertaken during the flooding period, including:

- Media statements when required on flood operations and pre-releases, distributed to media and regular briefing attendees including social media (Facebook and Twitter[27] – to target media outlets primarily)
- Community information activities (advertisements in local newspapers)
- Talking points for executive, other state and Commonwealth agencies, Ministers' offices, and MDBA engagement staff (for their 1800 number)
- Amplify relevant messages from the Bureau, SES and relevant agencies during business hours, and
- Publish a precis of the stakeholder briefings on mdba.gov.au – and promote via social media.

[26] https://www.mdba.gov.au/publications-and-data/data-and-dashboards/river-murray-weekly-reports
[27] Now known as X

In addition to these activities, a number of stakeholders praised the MDBA during interviews for additional activities, including ad-hoc advice from MDBA staff, and regular radio interviews undertaken by the MDBA's Executive Director of River Management during the flooding period.

Public Briefings

Landholders and organisations operating immediately below major storages are most impacted by large changes in release rates, and the MDBA has a history of engagement with these stakeholders.

For the first time during a flooding period, the MDBA planned and delivered weekly public briefings during the flooding period with stakeholders downstream of the Hume Dam (including the Murray River Action Group) to inform interested stakeholders in the River Murray system operation, primarily regarding the Hume Dam releases. These briefings were video conferences chaired by the Executive Director of River Management and were generally jointly held with Bureau and SES representatives.

Stakeholders invited to these briefings included the Australian Government Minister for Water's office, state and federal Members of Parliament and Senators' offices, state and federal government agencies, the Murray River Action Group (MRAG), the Murray-Darling Association (MDA), and local government. A precis of the information presented was subsequently provided to attendees for distribution, and published on the MDBA website.

An interview for this Review was carried out with MRAG, which represents landholders along the River Murray downstream of the Hume Dam to around Yarrawonga. MRAG indicated that the briefings by MDBA were welcomed by landholders, as well as additional informal advice provided by MDBA river operators. Despite this, MRAG indicated that it felt there was too much emphasis was placed on events that had occurred over the period since the previous briefing, and they sought a greater emphasis on forecasts of what could happen. MRAG conceded that forecasts would necessarily be uncertain and subject to highly uncertain weather conditions but felt that even indicative advice would be particularly helpful for landholders as they sought to prepare for flooding.

New South Wales agencies noted that there was interest in briefings from stakeholders below Yarrawonga and in the Edward-Wakool areas. This raises an issue about the extent to which such briefings can be offered more widely, noting the resourcing efforts required during flooding periods, and the need to ensure public messaging remains consistent.

Operational flow and height data

The MDBA (and state agencies) continued to provide operational height and flow data for flow gauging stations along the River Murray system as close as possible to real-time via its "River Murray data" website during the flooding period. The MDBA included advice and links on its website to the Bureau and SES for the latest advice on flood warnings and forecast river heights. The MDBA also continued to use the WaterNSW EWN[28] to provide advice on the Hume Dam releases during floods, under guidelines agreed with the Bureau.

All Basin States and the Bureau also have similar near real-time data websites, which provide a valuable and well-used resource for a wide range of stakeholders. The Bureau's National Arrangements for Flood Forecasting and Warning includes the principles that have guided the establishment of current national arrangements (Section 4.1). One of these principles is *Free near real-time access to rainfall, stream level and stream flow observations are to be provided to the Australian community.* Refer to Attachment 4 for further details about the National Arrangements.

Many agencies and stakeholders indicated that this data was a particularly valuable resource during flooding periods to understand what was happening near them. Some stakeholders indicated that they rely on this information to the extent that missing information for key sites can affect their ability to respond to high flows. There is a large number of river and storage gauges that supply information into the MDBA's "River Murray data" website, and data for most of the river gauging stations was supplied through the flooding period.

[28] http://www.waternsw.com.au/supply/visit/hume-dam#tabs-4

However, during floods water can reach much higher velocities and contain large debris that can damage equipment, and a number of issues were reported, as noted below.

Equipment failure and site issues.

- A few flow gauges near the Hume Dam were reported to have issues, affecting local landholders' awareness of coming flows. This included the flow gauging station on the Kiewa River (near Bandiana) that provides important warning for local landholders, where there is reported to be a history of data unavailability during high flows. The MDBA has advised that this Kiewa River gauge can be impacted by backwater from high flows in the River Murray, which means that the rating table is invalid when backwater occurs.
- The river gauge at Tocumwal also suffered equipment failure during the flooding period.
- In SA, several river gauges were sited on pontoons with tethering lines that were not long enough to cope with the peak water levels, and had to be removed to avoid being submerged as water levels rose.

Ratings errors and bypass at high flows

- In many cases, river flows were higher than any previously gauged at some flow gauging stations since the 1970s or 1950s (depending on location) and there was considerable uncertainty regarding the measured flows. This issue impacted the Bureau and MDBA's ability to model and forecast flows.
- This uncertainty was not apparent on the MDBA River Murray Data website and was difficult to communicate to the public more generally.
- Another issue that arises when very high flows occur is that some of the flow can travel around the river gauge site. This occurred where the Goulburn River joined the River Murray, and at locations in the Edward-Wakool system.

6 What we heard

As part of this Review, Alluvium interviewed state and federal agencies, local governments and landholder representatives with various degrees of involvement in responding to the River Murray 2022-23 flood events. The MDBA attended a subset of these meetings. Throughout the interviews, a wide range of issues were raised, which have been discussed in the body of this report. Other issues that were also highlighted through stakeholder engagements fit into one of the main themes listed in Table 12.

Main Themes

Seventeen separate interviews were conducted with government agencies or stakeholder groups to understand their experiences and interactions with the MDBA during the flooding period. A wide range of feedback was provided.

Table 12. Main themes raised during interviews

Theme	Feedback	Stakeholder group
Communication & coordination	Communication and coordination by MDBA was well conducted.	All
	Public briefings could have been more forecast focussed.	Landholders
	Operational decisions and rationale for airspace and releases from the Hume Dam were not sufficiently communicated to the public below Yarrawonga.	WaterNSW, Landholders
River Murray data website	An important source of information that is relied upon.	All
	Concern that some key flow gauges were unavailable or inaccurate during floods due to previously known issues.	Landholders
Flow monitoring accuracy and infrastructure	River flow rating table inaccuracies during the flood event presented significant challenges to agencies including the Bureau modellers and state agencies alike.	Landholders, local government, agencies
	There are different height datums used between river gauges managed by NSW and Victoria.	SES, local government.
Roles and responsibilities	Understanding roles during flooding periods across agencies was complex and not always clear	SES, local government.
Technical collaboration	Improved collaboration for River Murray tributary inflow information to be better incorporated into the forecast of dam releases	All
	Better understanding of “on the ground” conditions in the River Murray system by the river operators	Agencies, landholders, local government.

Themes raised out of scope for this Review

During the interviews, state and federal agencies, local governments and landholders, also provided feedback on a range of other issues related to the themes outlined in Table 13. These issues are out of scope for this Review, but are recorded here for future improvements and lessons learned exercises.

Table 13. Main themes raised during interviews

Theme	Feedback	Stakeholder group
Airspace Management and Dam Operation	Concerns that airspace in the Hume Dam is not targeted sufficiently, and that existing airspace limits could be increased in years where climate drivers indicated that wet conditions were more likely. • WaterNSW reported significant community enquiries about the flood management strategy adopted by the MDBA at the Hume Dam, with concerns raised about airspace operations that may be exacerbated by an absence of public information • WaterNSW noted the approach taken in NSW valleys during the flooding period to use "airspace advisory panels" to explain the strategies being adopted at the major storages as the flooding unfolded.	Landholders
	Operational policy to be reviewed to take into account antecedent conditions and consider different means of operation during extreme conditions such as the 2022-23 flood events	Landholders, local government
Flood Forecasting	Expectations that information about potential peak flows along the River Murray could have been forecasted earlier (landholders, local govt, agencies).	Landholders, local government agencies
Landscape changes	Landscape changes on the floodplain had occurred in the decades since flooding at this level last occurred. Instances where inundation did not occur as expected. In some instances, levees have been constructed that might potentially alter local flood behaviour.	Landholders, local government agencies

Theme	Feedback	Stakeholder group
Water management policy	Some stakeholders believed that current water management rules, changes in water user behaviour, and some aspects of the Basin Plan are contributing to generally higher storage volumes, which is exacerbating the impact of floods.	Landholders
Flood Mitigation Infrastructure	A number of issues were reported with levees, including responsibility for maintenance, whether levees have been constructed with authorisations or approvals, and the need for coordination of levee approvals beyond local government.	Agencies, local government, MDBA.
	The operation of regulators on some effluent creeks can affect local flooding, and responsibility is not clear.	Local government
Future Opportunities	Opportunity for improved use of technology to make better river flow predictions and better river operations during large flood events	Local government. landholders
	Challenges with providing information about local flooding impacts – e.g. period of time since floods of this magnitude last occurred, getting arrangements in place to provide and disseminate local knowledge.	SES, local government.

7 Findings and recommendations

In making findings and recommendations, Alluvium has also considered and, where appropriate, built upon the previous findings and recommendations made by reporting prepared by the MDBA (2024a and 2024b), and the independent review of the MDBA's river operations during 2022-23 undertaken by the IRORG (2023)[29]. These findings and recommendations are summarised in Attachment 2.

7.1 General findings

The 2022-23 flooding period saw the largest floods seen in many decades, and the MDBA successfully conducted its flood operations in challenging circumstances. Flood operations at the Hume and the Dartmouth Dams provided significant mitigation of peak inflow rates during the flooding period, and the modelling and analysis work undertaken by the MDBA provided important guidance for the Bureau and other agencies. Interviews across agencies and stakeholders indicated that the MDBA staff supported collaborative and cooperative arrangements with a large number of agencies across three states, as well as conducting a high level of engagement with stakeholders immediately downstream of the major storages.

> **Finding (F1):** The MDBA operated the major storages during the flooding period as set out in the requirements prescribed by the BOC.
>
> Overall, stakeholders and landholder groups expressed positive sentiments about the MDBA's engagement efforts during the 2022-23 flood event, which constituted significant improvements in engagement and information exchange.

This was also the finding of the IRORG as part of their review of the MDBA's river operations during 2022-23 (see Attachment 2).

7.2 Governance, communication and collaboration arrangements

Bureau and MDBA guidelines

The Bureau and MDBA have internal guidelines on providing flood advice, which were agreed in 2017 (initially established in 1994 and subsequently updated). These guidelines set out the conditions during which the MDBA is required to initiate contact with the Bureau offices during a predicted flood event along the River Murray. However, these arrangements are focussed around the flood operations at the major storages managed by the MDBA, and do not provide guidance on interactions between the organisations as the flooding proceeds along the River Murray system below the Hume Dam and the Yarrawonga Weir. An inter-agency operational communications protocol has been developed to accompany the changes to the service level agreement between the Bureau and the South Australian Government. The parties to this agreement include the Bureau, DEW, SA SES, SA Water, and the MDBA.

The complex challenges faced in flood forecasting along the River Murray during such large floods resulted in the collaboration of a number of agencies, including the MDBA and the Bureau. The strong relationships and willingness to collaborate between organisations enabled this to occur. However, some agencies noted that the transition from normal arrangements (MDBA providing flow forecasts) to the collaborative arrangements to support flow forecasts by the Bureau was somewhat cumbersome.

> **Finding (F2):** The arrangements between the MDBA and the Bureau during the 2022-23 flood events were found to be functional and highly collaborative. Both the Bureau and the MDBA were working within their roles and responsibilities. However, once peak flows passed downstream of the Yarrawonga Weir, the agreed guidelines between the MDBA and the Bureau did not provide guidance for further collaboration to support flow forecasts (while it is noted that collaboration did occur). This arrangement transitioned later in 2023 (after the flooding) to incorporate changes to the service level

[29] IRORG annual reports are published on the MDBA website: https://www.mdba.gov.au/publications-and-data/publications/river-murray-system-annual-summaries-and-reviews-river

agreement between the Bureau and the South Australian Government, which includes forecast locations in the River Murray in SA.

Recommendation (R1): It is recommended that the Bureau and the MDBA expand their guidelines to include an appropriately flexible collaboration process to support flow forecasting in future events, including collaboration with other agencies where appropriate. A potential example is the "Inter-agency forecasting and flood warning collaboration meetings" described in the flood warning operational protocol developed between the Bureau, the MDBA and South Australian agencies in 2023.

MDBA flood operations procedures

There can be many decades between floods of similar magnitude to the 2022-23 floods, making it a challenge to maintain capabilities and resourcing. The MDBA has developed considerable resources and capabilities for managing floods, and it will continue to be important to maintain this resourcing of well-trained staff and well-developed procedures in place. Flood operations manuals play a central role in ensuring that river operations organisations maintain critical knowledge over time, and to support staff during floods. It is important that flood operations guidelines are clearly and fully documented, and that there is clear approval in place to operate to them.

Regular training and flood simulation exercises play a central role in ensuring that staff capabilities are maintained over time.

Finding (F3): The MDBA's FOMs have been in draft form for a substantial period of time. The draft manual for the Hume Dam viewed as part of this Review is well advanced, and IRORG noted in their review that the manuals have been independently functionally reviewed.

Recommendation (R2): It is recommended that the FOMs be updated to include appropriate learnings from the 2022-23 flooding period, and the FOM be finalised and formally approved as a matter of urgency.

Finding (F4): The MDBA maintains a regular formal program of training and accrediting its staff. However, wider simulations involving other agencies occur less frequently.

Recommendation (R3): Consideration should also be given to undertaking regular simulated flood operations exercises involving other appropriate agencies to build and maintain communication and collaborative relationships.

MDBA flow forecasting

The MDBA has historically provided flow forecasts at the South Australian border (referred to as "QSA") during flooding periods to South Australian government agencies. The SMOM modelling proved to be a valuable input to the Bureau's flood forecasting effort during the 2022-23 flooding period. The SMOM is increasingly being used as part of normal regulated river operations, and was enhanced (using elements from the MDBA's 'Source' planning model) during the flooding period to better account for the behaviour of floodplain flows through major wetlands and forests. As the implementation of relaxed flow constraints under the Basin Plan continues, the capabilities of SMOM during periods of high flow (above normal regulated flows, and below minor flood level) will likely increase. This ongoing development of SMOM over time will likely increase its value as an input to flood forecasting.

Finding (F5): The historic practice of providing flow forecasts at the South Australian border during flooding periods is an important role for the MDBA that is not recognised as a requirement in formal governance arrangements.

Recommendation (R4): To reflect the value and importance of this work, it is recommended that the provision of flow modelling to the Bureau and South Australian government by the MDBA is incorporated as a requirement within the Objectives and Outcomes for MDBA river operations set by the BOC each year (MDBA 2022).

The Hume Dam surcharge policy

Following the dam safety incident in 1996, when movement occurred in the embankment to the south of the main structure, WaterNSW (as the SCA for the Hume Dam) had advised that operating to minimise the risk of surcharge is preferable from a dam safety perspective (MDBA, 2023c) The MDBA, in collaboration with WaterNSW, has progressively developed a surcharge policy as well as adopting rules (such as a specific filling target of 99% in the Objectives and Outcomes) and improved forecasting tools and approval processes.

The policy provides for limited surcharging (25cm above the normal full supply level, representing approximately 50 GL of additional water storage) in limited circumstances such as risk to human life, or to avoid overtopping nearby levees protecting Albury.

> **Finding (F6):** The Hume Dam surcharge policy is not recognised in formal governance arrangements.
>
> **Finding (F7):** It is not clear whether the surcharge limits could be increased following further investigation or works.
>
> **Recommendation (R5):** The Hume Dam surcharge policy should be formally agreed and adopted by the MDBA for the effective management of the Hume Dam during periods of high inflows. The policy could also be incorporated into the BOC's Objectives and Outcomes document.
>
> **Recommendation (R6):** The MDBA should consider formally adopting an approach to optimise the Hume Dam surcharge policy against the general objectives and Outcomes set by the BOC each year, in particular, those set out in sub-sections (2), (3), and (4) of Section 4 of the Objectives and Outcomes (MDBA 2022).

Public engagement

During the 2022-23 flooding period, the MDBA, the Bureau, and state SES undertook regular briefings (via video conference) on the Hume Dam flood operations with landholders downstream of the Hume Dam. This is an innovative new approach led by the MDBA, and represented a significant commitment of resources during this period. Landholders below the Hume Dam and other key stakeholders were supportive of this engagement by the MDBA. However, some landholders would like these briefings to extend beyond the explanation of recent events to also cover outlook and storage release scenarios (see Finding F12 and Recommendation R13).

> **Finding (F8):** Interviews indicated that landholders below the Hume Dam are seeking information with more focus on the outlook for potential releases from the Hume Dam under different weather scenarios.
>
> **Recommendation (R7):** The MDBA could review the content of briefings and consider the use of video briefings compared to the distribution of more targeted information products on information sought by landholders (see also recommendation R13 below on flow forecasting).

The NSW submission to the 2022-23 IRORG review and interviews with WaterNSW and landholders noted that landholders and water user representatives below the Yarrawonga Weir were not involved in briefings by the MDBA. Interviews indicated that these stakeholders, similarly to those below the Hume Dam, have concerns about airspace policy and management at the Hume Dam. Underlying these concerns is that opportunities to improve flood mitigation using storages can potentially affect water resource security. These concerns are beyond the scope of this Review. However, during interviews WaterNSW noted that it undertook a consultation program in other NSW valleys during the 2022-23 flooding period that addressed its airspace operations and flood response strategy at major storages (including the trade-offs with water resources security). The MDBA could consider whether a similar approach would provide greater transparency for a range of stakeholders.

> **Finding (F9):** Interviews indicate that landholders along the River Murray system below the Hume Dam and the Yarrawonga Weir remain dissatisfied with flood operations strategies and airspace strategy, as well as related communications and consultation.
>
> **Recommendation (R8)**: The MDBA should give consideration to ongoing and transparent information sharing on the strategies for flood operations and airspace, combined with an elevated level of

information in the lead up to (and following) potential flooding periods. Information should be shared as:

- Information that is generally available
- More prominent information in the lead up to flood events, and
- Post-flood publication of information about what had occurred.

7.3 Information and systems

Flow measurement during floods

Flow measurement in rivers relies on the use of observed relationships between water height and flow (referred to as ratings). The extremely high flows observed during the 2022-23 flooding period have not been observed for many decades, if at all, and there is insufficient information to develop good ratings. In addition, changes in floodplain conditions can accumulate over the many decades between floods of this magnitude, meaning that a rating that was appropriate in the 1970s or 1950s may no longer be appropriate. Very large floods also result in some flows that bypass river gauges on the floodplain.

Conversely, the MDBA and water managers in each state publish largely unchecked near-real-time data from the flow gauging network in each river valley, and interviews indicated that this is an important and much-used source of information during flooding periods. Landholders downstream of the Hume Dam indicated a small number of flow gauging stations that were important for them during high flows and floods had pre-existing measurement issues that had not been addressed. Some issues were also noted in South Australia, and the IRORG review noted that the South Australian government has already commenced a project to make flow gauging stations more flood resilient.

Near-real-time data from the River Murray flow gauging network is published (in part at least) by each state and the Bureau, as well as MDBA's River Murray Data website. Some stakeholders noted that there were some differences between data on these sites, possibly related to the time during the day that data is reported, or the use of daily averages compared to observed data at a certain point in time. It was also noted that there are different height datums used to report flow heights between states. Whilst beyond the scope of this Review, it is noted that this issue could be considered further by the MDBA in collaboration with the states and the Bureau.

Governments should always be looking to improve the availability of information to better support communities during flooding and other extreme events. However, floods are powerful natural events, and there will always be a risk that some or all flow information may not be available in some instances during these events. It is unlikely that safeguards against all possible contingencies can be put in place. In addition to other measures to manage this risk, information could be developed to assist landholders along the River Murray to plan for such contingencies (or to improve planning and preparation landholders already undertake).

Finding (F10): Accurate measurement of rare high flow events presented challenges to forecasting river flows and public communication.

Recommendation (R9): The MDBA (in collaboration with Basin States and the Bureau) investigate opportunities to improve real-time flow measurement and reporting where possible, including addressing known issues at some flow gauging stations, and use of new technologies such as drones and remote sensing.

Recommendation (R10): The MDBA should consider opportunities to provide additional information that can assist landholders to be as prepared as possible during floods. This also links with recommendation R12.

Some examples include; the use of remote sensing to confirm when flows are bypassing flow gauging stations undertaken by the MDBA during the 2022-23 flooding period, and there is work underway between the MDBA and the Inspector General for Water Compliance (IGWC) to consider techniques to assist in compliance monitoring and assessing floodplain harvesting take.

Recommendation (R11): The MDBA (in collaboration with the Basin States and the Bureau) consider how flow measurement uncertainties at very high flow rates could be better communicated, including via the "River Murray Data" website.

Source Murray Operations Model

The SMOM has proven to be a valuable tool in informing flood operations and response, and its ongoing development and application should continue to be supported.

Finding (F11): The MDBA has developed an upgraded SMOM, which was able to provide the Bureau and South Australian government agencies with valuable guidance for the forecasting of river flows downstream of the major storages.

Recommendation (R12): It is recommended that the MDBA develop and document internal processes for SMOM operations during flood events, to support an enduring and predictable level of support and communication with partner agencies.

This will help to ensure consistency of approach, and ensure sufficient appropriately trained staff are available during large flood events, and arrangements with state river operators to inform appropriate inflow forecasts from the major regulated tributary rivers.

Forecasts of dam releases and flood flows

Forecasting inflows to the Hume Dam and the subsequent releases is a complex and challenging task driven by highly uncertain weather conditions that are themselves difficult to forecast. However, it is apparent that there is an expectation held by some stakeholders that flood forecasting can be improved. Stakeholders downstream of the Hume Dam pointed to the increased understanding and reporting of ocean climate drivers such as La Nina/El Nino[30], and the potential for these to be taken into account.

Further downstream from the Hume Dam, flow measurement along the River Murray during floods proved challenging, complicating the task of modelling and forecasting flows. The application of new technology, including the SMOM and remote sensing undertaken by the MDBA, indicated that forecasting of flood flows will continue to improve.

Finding (F12): Interviews indicate that a number of stakeholders, particularly landholders downstream of the Hume Dam, see significant benefits in receiving river flow forecasts that show a range of scenarios, and increased notice of releases from the Hume Dam. In recognition of the many challenges in rainfall and flood flow forecasting, there was a willingness to receive forecasts that are more probabilistic, or indicate a range of potential outcomes, to enable advice to be provided earlier in advance of the releases.

Recommendation (R13): The MDBA consider the feasibility, costs, benefits and risks, of providing information about possible scenarios for storage releases and river flows, in collaboration with the Bureau.

However, even if feasible, providing more complex forecasts and warnings will likely require consideration of appropriate education to support the use of such forecasts to ensure that they are useful and are not misunderstood or misused.

7.4 Operational infrastructure

The primary water management infrastructure in the River Murray was generally able to pass the flood flows without significant impacts. However, there is also a significant amount of infrastructure on the floodplain, some of which is relevant to regulated river operations. Levees along Lake Victoria inlet channel at Frenchmans

[30] Bureau climate driver descriptions and current conditions can be found at: http://www.bom.gov.au/climate/enso/

Creek and around the Lock 9 weir pool failed during the flooding period, and were difficult to repair for an extended period due to inundation of access tracks and work areas.

Much of the infrastructure at and around Lake Victoria was constructed before World War II, and the failure of levees at Lock 9 and along the inlet channel could potentially have resulted in a loss of resource if the inlet channel to Lake Victoria was unavailable for an extended period. During interviews, SA Water indicated that they are preparing a detailed account of the events in this area during the flooding period.

The timely post-flood reinstatement of the Mildura Weir was an issue significant to river operations governance and to communication with the community and stakeholders that rely on the pool level. The manual handling required to reinstate the trestles takes substantial time and resources and requires careful management of a range of safety risks. Displaced sand that had deposited on the trestle track during the flood extended the time taken to reinstate the weir and resulted in the river level dropping below normal pool level as the flood receded. In terms of the Wentworth Shire, Mildura township, Lower Murray Water and those irrigators who draw water from the weir pool, this presented a risk to their supply. Upgrading or replacing this ageing infrastructure is likely to assist this community's resilience post flood, noting that there will be a range of issues to consider in developing a business case.

Failure of levees was reported at a number of other locations along the River Murray floodplain that affected flows and inundation, although no reports of impacts to public infrastructure or people were noted to this Review. The potential for ageing floodplain levees and associated risks is a wider issue that involves multiple jurisdictions and agencies, and that has previously been noted, including as part of the constraints relaxation program.

> **Finding (F13):** There is ageing infrastructure on the River Murray floodplain that may be at risk of failure during larger flood events, some of which supports the normal operation of the River Murray system (specifically the Mildura Weir, Lake Victoria and surrounding infrastructure).
>
> **Recommendation (R14):** The MDBA, in collaboration with other asset-managers, should undertake a review of the condition of ageing floodplain infrastructure relevant to the MDBA's river operations to assess the risk of future failures during floods, and the consequences of those failures. Such a review would address the general objective and outcomes in subsection 4(3) of the Objectives and Outcomes set by the BOC (MDBA 2022). This risk assessment should also have regard for the impacts of climate change on the future likelihood and consequence of severe flood events.

7.5 Summary of findings and recommendations

Table 14 provides a summary of the key findings and recommendations of this Review. These should be read and considered in the context of the full review and report.

Table 14. Summary of the findings and recommendations of this Review.

	Finding	Recommendation
General	**F1:** The MDBA operated the major storages during the flooding period as set out in the requirements prescribed by the Basin Officials Committee (BOC). Overall, stakeholders and landholder groups expressed positive sentiments about the MDBA's engagement efforts during the 2022-23 flood event, which constituted significant improvements in engagement and information exchange.	No recommendation
Governance , communication and collaboration	**F2:** The arrangements between the MDBA and the Bureau during the 2022-23 flood events were found to be functional and highly collaborative. Both the Bureau and the MDBA were working within their roles and responsibilities. However, once peak flows passed downstream of Yarrawonga Weir, the agreed guidelines between the MDBA and the Bureau did not provide guidance for further collaboration to support flow forecasts (while it is noted that collaboration did occur). This arrangement transitioned later in 2023 (after the flooding) to incorporate changes to the service level agreement between the Bureau and the South Australian Government, which includes forecast locations in the River Murray in SA.	**R1:** It is recommended that the Bureau and the MDBA expand their guidelines to include an appropriately flexible collaboration process to support flow forecasting in future events, including collaboration with other agencies where appropriate. A potential example is the "Inter-agency forecasting and flood warning collaboration meetings" described in the flood warning operational protocol developed between the Bureau, the MDBA and South Australian agencies in 2023.
	F3: The MDBA's FOMs have been in draft form for a substantial period of time. The draft FOM for the Hume Dam viewed as part of this review is well advanced, and the Independent River Operations Review Group (**IRORG**) noted in their review that the FOMs have been independently functionally reviewed. **F4:** The MDBA maintains a regular formal program of training and accrediting its staff. However, wider simulations involving other agencies occurs less frequently.	**R2:** It is recommended that the FOMs be updated to include appropriate learnings from the 2022-23 flooding period, and the FOM be finalised and formally approved as a matter of urgency. **R3:** Consideration should also be given to undertaking regular simulated flood operations exercises involving other appropriate agencies to build and maintain communication and collaborative relationships.
	F5: The historic practice of providing flow forecasts at the South Australian border during flooding periods is an important role for the MDBA that is not recognised as a requirement in formal governance arrangements.	**R4:** To reflect the value and importance of this work, it is recommended that the provision of flow modelling to the Bureau and South Australian government by the MDBA is incorporated as a requirement within the Objectives and Outcomes for MDBA river operations set by the BOC each year (MDBA 2022).
	F6: The Hume Dam surcharge policy is not recognised in formal governance arrangements.	**R5**: The Hume Dam surcharge policy should be formally agreed and adopted by the MDBA for the effective management of the Hume Dam during periods of high inflows. The policy

	Finding	Recommendation
	F7: It is not clear whether the surcharge limits could be increased following further investigation or works.	could also be incorporated into the BOC's Objectives and Outcomes document. **R6:** The MDBA should consider formally adopting an approach to optimising the Hume Dam surcharge policy against the general objectives and outcomes set by the BOC each year, in particular, those set out in sub-sections (2), (3), and (4) of Section 4 of the Objectives and Outcomes (MDBA 2022).
	F8: Interviews indicated that landholders below the Hume Dam are seeking information with more focus on the outlook for potential releases from the Hume Dam under different weather scenarios.	**R7:** The MDBA could review the content of briefings and consider the use of video briefings compared to the distribution of more targeted information products on information sought by landholders (see also recommendation R12 below on flow forecasting).
	F9: Interviews indicate that landholders along the River Murray system below the Hume Dam and the Yarrawonga Weir remain dissatisfied with flood operations strategies and airspace strategy, as well as related communications and consultation.	**R8:** The MDBA should give consideration to ongoing and transparent information sharing on the strategies for flood operations and airspace, combined with an elevated level of information in the lead up to (and following) potential flooding periods. Information should be shared as: • Information that is generally available • More prominent information in the lead up to flood events, and • Post-flood publication of information about what had occurred.
Information and systems	**F10:** Accurate measurement of rare high flow events presented challenges to forecasting river flows and public communication.	**R9:** The MDBA (in collaboration with the Basin States and the Bureau) investigate opportunities to improve real-time flow measurement and reporting where possible, including addressing known issues at some flow gauging stations, and use of new technologies such as drones and remote sensing. **R10:** The MDBA should consider opportunities to provide additional information that can assist landholders to be as prepared as possible during floods. This also links with recommendation R12. **R11:** The MDBA (in collaboration with the Basin States and the Bureau) consider how flow measurement uncertainties at very high flow rates could be better communicated, including via the "Murray River data" website.
	F11: The MDBA has developed an upgraded 'Source' Murray Operations Model (SMOM), which was able to provide the Bureau and South Australian government agencies with valuable guidance for the forecasting of river flows downstream of the major storages.	**R12:** It is recommended that the MDBA develop and document internal processes for SMOM operations during flood events, to support an enduring and predictable level of support and communication with partner agencies.

	Finding	Recommendation
	F12: Interviews indicate that a number of stakeholders, particularly landholders downstream of the Hume Dam, see significant benefits in receiving river flow forecasts that show a range of scenarios, and increased notice of releases from the Hume Dam. In recognition of the many challenges in rainfall and flood flow forecasting, there was a willingness to receive forecasts that are more probabilistic, or indicate a range of potential outcomes, to enable advice to be provided earlier in advance of the releases.	**R13:** The MDBA consider the feasibility, costs, benefits and risks, of providing information about possible scenarios for storage releases and river flows, in collaboration with the Bureau
Operational infrastructure	**F13:** There is ageing infrastructure on the River Murray floodplain that may be at risk of failure during larger flood events, some of which supports the normal operation of the River Murray system (specifically the Mildura Weir, Lake Victoria and surrounding infrastructure).	**R14:** The MDBA, in collaboration with other asset-managers, should undertake a review of the condition of ageing floodplain infrastructure relevant to the MDBA's river operations to assess the risk of future failures during floods, and the consequences of those failures. Such a review would address the general objective and outcomes in subsection 4(3) of the Objectives and Outcomes set by the BOC (MDBA 2022). This risk assessment should also have regard for the impacts of climate change on the future likelihood and consequence of severe flood events.

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Attachment 1: Scope of flood review

OBJECTIVES

The Modernising Murray River Systems program of study will identify opportunities to improve water security for all water users and mitigate the impacts of floods and droughts on communities and the environment.

The 2022-23 Flood Review study will examine the effectiveness of flood operations by the MDBA, specifically flood forecasting, data and communication during the recent widespread flooding in the River Murray and make recommendations on opportunities to enhance flood management in future events.

SCOPE

The study will inform its work and gather data through consultation with partner governments, state constructing authorities, information service providers, emergency services, local government, environmental water holders and key community stakeholder groups.

Review of the effectiveness of MDBA's operations, flood forecasting, data and communication during the 2022-23 flood event

Undertake a review of the 2022-23 flood event at the River Murray System scale to identify, evaluate and recommend opportunities to further improve flood forecasting, data and communication as they relate to MDBA's management of the flood.

They study will consider:

- The effectiveness of the system-wide gauging network for measurement of streamflow and rainfall, particularly upstream of the Hume and within the tributaries of the system as well as flows within the River Murray at high water levels and flow rates.
- The effectiveness of existing flood modelling capacity and whether new technologies might improve flood modelling and forecasting (e.g. Real time calibration of models from remote sensing imagery of flood extents, etc.)
- The accuracy of underlying data in flood models including river bathymetry and catchment representations (e.g., LiDAR digital terrain models)
- The effectiveness of critical infrastructure in flood management including supporting recovery post flood and recommencement of normal activity
- The effectiveness of communication of flood related data to flood management agencies and the public.

The Review will be mindful of the various inquiries being undertaken by the states into the event and as much as possible not interfere with the working of these reviews. Finding from these state-based reviews where relevant to the shared management of the Murray will be incorporated into the finding from this review.

Review of MDBA's role in managing the 2022-23 flood event

The scope of this 2022-23 Flood Review is tightly focussed on the role that the MDBA played in managing the 2022-23 flood event as part of a multi-agency emergency response. In particular, the communication, governance, and technical information and systems. This included:

1. Formal governance arrangements documenting roles and responsibilities within management of the 2022-23 flood.
2. Communication linkages and content effectiveness both within the defined governance and within the broader community.
3. The collection, generation and communication of technical information including hydrologic data, weather forecasts, flow and river height forecasts.

4. Collaboration between the MDBA and related agencies (Bureau of Meteorology, state departments and river operators, councils, and State Emergency Services).

Specifically, to investigate:

- Information collection system performance
- Modelling system performance
- Technical collaboration opportunities.

In conducting this Review, the MDBA requests the consideration of the following questions and inputs:

1. What should have happened (i.e. what do the governance arrangements require?)
2. What actually happened (how did the event unfold from both a governance and information and systems perspective)?
3. Identify any differences between the governance arrangements and reality in both the governance and technical fields.
4. Provide findings and recommendations for both governance and information and systems workstreams.
5. Agencies and stakeholders relevant to this Review be offered the opportunity to review summaries of the engagement.
6. Commonwealth and Basin States will have the opportunity to review this report as part of consideration by BOC and subsidiary River Murray committees.[31]

Out of scope

The following are out of scope for this Review:

1. The performance of other agencies, while being mindful to support the MDBA in its ongoing collaboration between relevant agencies, including those interviewed in this Review.
2. The scope does not include a review of the river infrastructure operational decisions made by the MDBA and other river operators during the 2022-23 floods, nor the broader objectives, outcomes or policies set by the BOC under the Murray-Darling Basin Agreement.

Attachment 2: MDBA Reports 2024

Three other reviews have been conducted into the 2022-23 River Murray flood event, two from the MDBA and one from IRORG. Together, these reports made the following recommendations, which Alluvium supports based on this independent Review.

Summary of learning and improvement from the MDBA (2024a) Flood Review Report

The MDBA (2024a) Flood Review Report provides information for learning and improvement for future flood operations and incorporates recommendations from the 2021-22 flood report where relevant. A summary of the areas where learning and improvements were made include:

A. Preparation and Training for flood operations
B. Data systems during flood operations
C. Tools that underpin flood operations
D. Collaborative partnerships in flood operations
E. Communication systems in flood operations
F. Workgroup sustainability during flood operations
G. Documentation and record-keeping during the flood operations

Improvements from the MDBA (2024b) Flood Forecast Report

The MDBA have also made recommendations in their Flood forecast report (MDBA, 2024b), to improve the SMOM data and information inputs and outputs and methodology for an improved and representative model performance:

- Improving the process for creating or obtaining tributary inflows. Improvements to inflow forecasts are likely to come as advice from the relevant state authority.
- Standardising a method to consistently producing and report on a range of flow scenarios.
- Adapting representations of The Living Murray icon sites and VMFRP sites from the SMM for the SMOM. This would improve flood modelling as well as provide functionality for environmental water holders.
- Recalibrating selected reach representations given the new data available at elevated flow rates. For example, improvements to the Boundary Bend anabranch and Darling Anabranch representations could reduce the uncertainty experienced in forecasts during the 2022 flood.

Recommendations from the Independent River Operations Review Group 2023

The IRORG is an independent group of experts that review the MDBA's river operations each year to ensure that BOC's requirements set out in the Objectives and Outcomes (MDBA 2022) have been complied with, and to consider whether further improvements could be made. In 2023 IRORG made a number of observations and recommendations in relation to the flooding period.[32]

Main Report

- Under general Objectives and Outcomes 4(3) (RMO Assets) IRORG noted that
    - Many of the River Murray monitoring stations in SA (operated on behalf of the joint venture) were not designed to be operable at very high flow/flood river levels and were removed for three months during the worst of the flooding, with only a small number left in-river recording continuous water levels throughout the event. A project to make the stations more flood resilient is underway.

[32] IRORG annual reports are published on the MDBA website: https://www.mdba.gov.au/publications-and-data/publications/river-murray-system-annual-summaries-and-reviews-river

- No emergencies occurred during 2022-23 at RMO assets but Torrumbarry Dam Safety Emergency Plan was triggered to ensure detailed surveillance and monitoring due to highest record flows for that structure (MDBA's EAP was not activated due to the low associated risk).

- In 2022-23, flood operations extended from August 2022 – January 2023 at the Dartmouth and Hume storages, and the Yarrawonga Weir. The MDBA managed floods at storages in accordance with the criteria and priorities set out in the Objectives and Outcomes document and provided significant flood mitigation benefits where possible.

- IRORG was encouraged to learn that the MDBA expects the SMOM to be the primary operational planning tool for the River Murray system for the 2024-25 water year.

- As a result of concerted efforts by expert modelling staff, significant improvements were made to the SMOM. This enabled high quality forecast of flows into SA to be provided in a timely manner to guide flood preparations work by communities.

Complementary Report

- Of the two highest priority past recommendations that have not been addressed, one is the completion of the flood manuals.

    - "The delay in the completion of flood manuals deserves a special comment. The Authority initiated a review of its flood operations manuals for major storages some time ago (2017). This review is not yet completed. Since then, an expert functional review has been undertaken on the Hume manual and has found that it was fit for purpose and met the industry standards. However, a legal review is currently in progress, and has been for two years. The Authority remains exposed on this deficiency."

    - "The Authority initiated a review of its flood operations manuals for major storages some time ago. This review is not yet completed, although IRORG was advised during its 2017 review that the revised flood manuals are at a near-final draft status"

    - Action as reported by the MDBA in September 2023:

        - "An expert functional review has been undertaken on the Hume manual and found that the manual was fit for purpose and met the industry standards. A legal review is currently in progress.

        - An advanced draft of the Yarrawonga flood manual has been prepared and is waiting for internal review. Drafting the Dartmouth flood manual is close to completion."

Attachment 3: Roles and responsibilities defined in the River Murray System Emergency Action Plan Version 5.2

The MDBA's River Murray System Emergency Action Plan (EAP) defines specific roles and responsibilities. These roles come into existence once the EAP is triggered and act in conjunction with the existing senior management roles within the MDBA, which forms the Emergency Management Team (EMT). The EAP further specifies about the responsibilities related to emergency events that:

"Whilst this EAP specifies responsibilities pertaining to emergency events in the River Murray system, actions under this EAP must be in accordance with any instrument of delegation provided under section 199 of the Water Act (2007), or under the powers granted to the MDBA by Ministerial Council under clause 29(3) of the Agreement."

Attachment 4: Total Flood Warning System and the National Arrangements for Flood Forecasting, Warning and data sharing

Total Flood Warning System

The Australian Institute for Disaster Resilience (AIDR) has produced resources including the Australian Disaster Resilience Handbook Collection to guide on national principles and practices for disaster resilience (AIDR, 2022). In 2022, AIDR produced the Application of the Total Warning System to Flood: *Companion to Flood Emergency Planning for Disaster Resilience (2020) and Public Information and Warnings (2021)* Handbook (the handbook). The guidelines in the handbook include warning systems related to riverine and flash flooding with emphasis on the development and application of flood monitoring, predictions, and intelligence. The handbook complements products developed by AIDR about warning construction, communication and review (*Public Information and Warnings,2021*), and nationally consistent warning levels, hazard icons and calls to action (*Australian Warning System, 2021*).

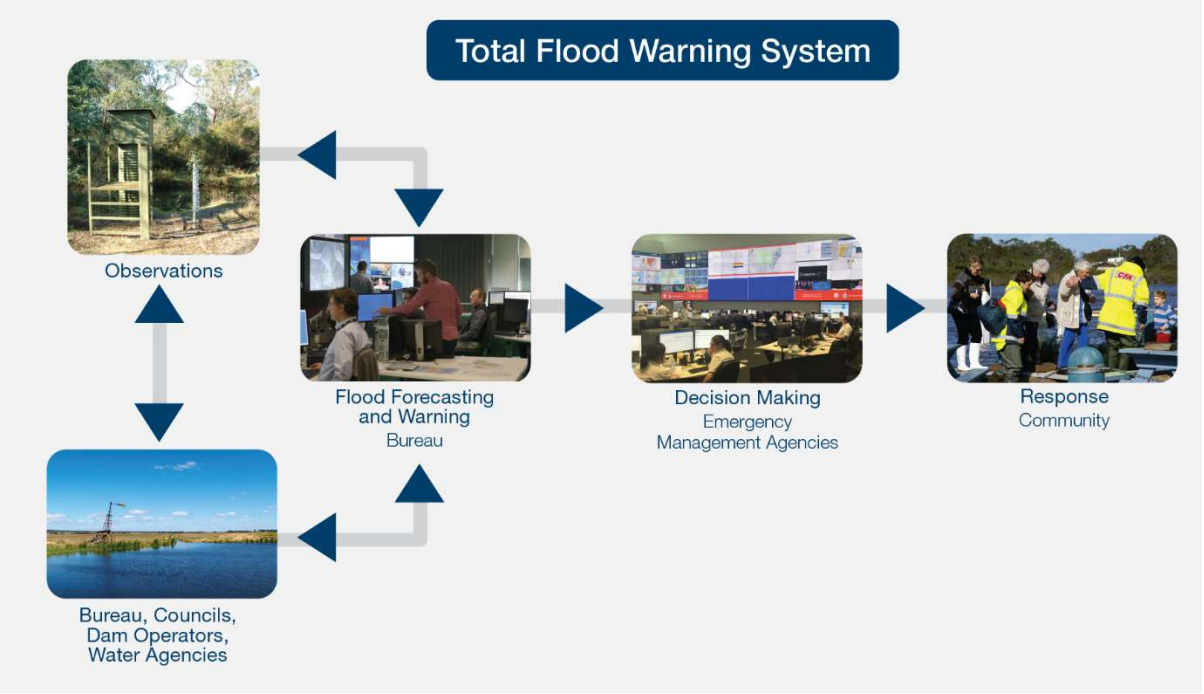
Concept diagram – Total Flood Warning System (sourced from AIDR, 2022).

The application of Total Flood Warning System (TFWS), consists of the nine elements described below and as presented in the concept diagram:

1. Situational awareness – continuous attention to and connection with the past, current and emerging situation (e.g. weather system)
2. Building community resilience to flooding – Community preparedness and engagement to understand and act on flood warnings and flood systems.
3. Organisational readiness to warn – Accountable organisations (within TFWS) to have sufficient capability and capacity to understand their roles.

4. Flood warning and prediction – Advice on affected catchment, expected flood classification, stream heights and timing, to understand flood severity and timing.
5. Interpretation: using flood intelligence – Public communication of floods through flood markers, historical pictures, maps and information on potential inundation extent.
6. Message construction – Explanatory messages on current and predicted flood including when, where and how it will affect the communities and the actions they can take.
7. Communication – The use of communication channels for communicating flood warnings.
8. Community response – Strengthening community response through flood awareness engagement, and
9. Continuous review and improvement – Using appropriate indicators to review flood warning performance.

The handbook also provides guidelines on the considerations for developing a flood warning system, that defines the need, priority and feasibility of a fit-for-purpose flood warning system and investigates its scope, intent and limitations to be considered when designing the system. It also includes critical considerations for defining and building flood warning systems such as consulting the community during the design phase, system review and documentation, predictive modelling, and setting up flood warning monitoring infrastructure and local community systems.



Total Flood Warning System process diagram (Source Bureau website).

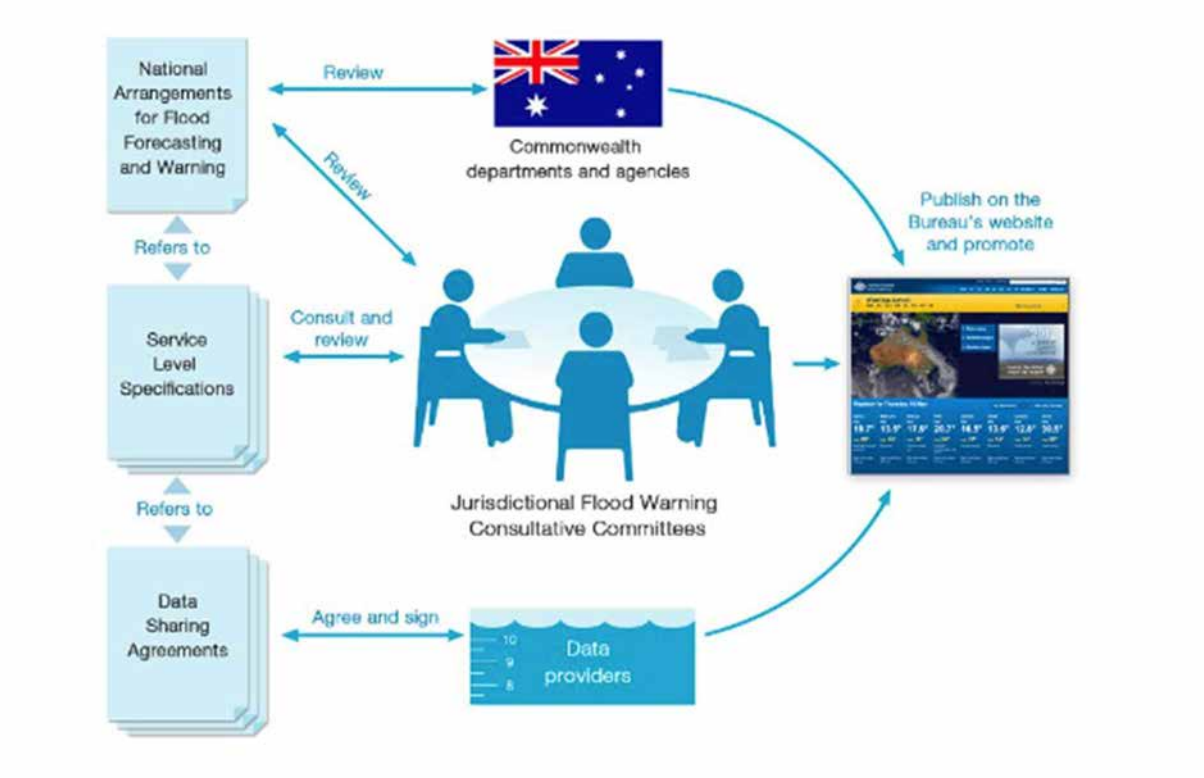
The National Arrangements for flood forecasting, warning and data sharing

The National Arrangements for Flood Forecasting and Warning (Bureau 2018b) details the roles and responsibilities for flood warning services, also affirmed by *the Intergovernmental Agreement on the Provision of Bureau of Meteorology Hazard Services to the States and Territories* (Bureau, 2018a). These are further reflected in the Flood Warning Consultative Committees membership which service jurisdictions across Australia. The Bureau provides flood forecasting and warning services in each Australian state and territory as part of the TFWS in partnership with emergency management agencies, government departments responsible for water management, water authorities and local councils.

The process diagram below illustrates the aspects related to flood forecasting and warning, which includes weather observations, dam operator information, modelling likely scenarios, decision-making and response. While the Bureau has flood monitoring and predicting responsibilities, the work closely with state and territory

and local governments as well as SES to interpret the data and communicate the key messages to the community. As part of this process the Bureau may issue a flood watch or a flood warning.

The National Arrangements document (Bureau, 2018b) defines the Bureau as the lead national agency, responsible for flood forecasting and warning and formalises its regulatory implementation for all levels of government to play a part in the arrangements. With a primary focus on improving clarity and detail of flood warning policy and practice. The Bureau also publishes two other documents, the Service Level Specifications (SLS) and the Data Sharing Agreements (DSA). While SLS details the services provided by each State/Territory including areas served, forecast locations and the levels of service, DSA describes arrangements for supporting flood warning and forecasting operations through the provision of near real-time data.



Formalising flood forecasting and warning service levels and arrangements (adopted from BOM, 2018a)