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Opportunities for water forecasts to inform water management decisions in the Murray–Darling Basin

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Contents

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The authors pay respect to the Traditional Owners and their Nations of the Murray−Darling Basin. We acknowledge their deep cultural, social, environmental, spiritual and economic connection to their lands and waters.

Executive summary

New and emerging water forecast products are becoming available that can support river operation decision-making in the Murray–Darling Basin (MDB), e.g., to manage natural and augmented high flow events for improved environmental water delivery. Project 8a of Theme 2 of the MD-WERP aims to demonstrate how ensemble water forecasts can inform river operations in the MDB. This report is the first deliverable for the project.

This report (i) summarises the opportunities for water forecasting to improve river operations and environmental water delivery in the MDB as identified by MDBA river operators and CEWO, and (ii) describes two case studies to demonstrate how these opportunities can be realised. The first case study is of an area in the southern MDB, while the second an area in the northern MDB.

The opportunities for water forecasts to improve river operations and environmental water delivery are based on a series of meetings with the MDBA, CEWO, QLD RDMW, QLD DES, BOM and SunWater. The two case studies proposed are based on the opportunities and seek to address the areas of greatest potential identified through the meetings.

The first study will support MDBA river operators to better characterise the risks related to river regulation decisions. Ensemble forecasts of unregulated tributary inflows, such as those currently produced by the BOM, will be integrated into models of regulated systems and tools to translate ensemble forecast products into assessments of system operation risks, e.g. chance of exceeding flood thresholds. Methods will be developed and demonstrated. The case study will focus on the upper Murray River between Hume Dam to Yarrawonga.

The second case study will demonstrate how forecasts can support CEWO to decide when to activate event-based mechanisms for supplementing environmental water delivery. The case study will focus on the Condamine-Balonne catchment in the northern MDB. The case study will prototype novel event-volume forecast products that can be derived by combining streamflow observations and existing BOM seasonal and 7-day streamflow forecast products, to produce products that can be directly related to CEWO decisions.

1 Introduction

River operations in the Murray–Darling Basin (MDB) have traditionally involved delivering water to entitlement holders, meeting minimum flow requirements and reducing flood impacts. Climate change and environmental watering requirements, e.g., within-bank freshes and overbank flows to inundate wetlands, are adding complexities to the problem. Particular challenges are due to the need to deliver environmental water at times of high natural flow coupled with the need to manage the risk of unintended inundation of private land and infrastructure. New and emerging water forecast products are becoming available that can support improved river operations, including the management of natural and augmented high flow events.

Project 8a of Theme 2 (T2.8a) of the Murray–Darling Water and Environment Research Program (MD-WERP) aims to demonstrate the value of ensemble water forecasts for river operation decision-making in the MDB. This is to be achieved through case studies in the southern and northern Basin and the development of new forecasting tools customised to the specific needs of river operators in the region. The results will provide new understanding of how probabilistic water forecasts can assist with river operations, particularly with quantifying and managing risks.

This report is the first deliverable for Project T2.8a. In this report, (i) we summarise the available opportunities for water forecasting in the MDB to improve river operations and (ii) based on the opportunities, propose two case studies for demonstrating the potential of water forecasts for informing river operation decisions.

Our understanding of the available opportunities is based on a series of meetings with key stakeholders, i.e., the Murray–Darling Basin Authority (MDBA), Commonwealth Environmental Water Office (CEWO), Queensland Department of Regional Development, Manufacturing and Water (QLD RDMW), Queensland Department of Environment and Science (QLD DES), Bureau of Meteorology (BOM) and SunWater. These agencies are involved with the day-to-day delivery of water allocations and environmental water and flood operations of dams in the MDB. They are also involved with the long-term planning of these activities. Thus, they are best placed to advise on the current state of water forecasting in the MDB and opportunities for improved operations with more accurate forecasts.

The meetings occurred from August to October 2021. Table 1.1 gives an overview of the meetings, their dates and key attendees and some explanatory notes.

Meeting 1 was with CEWO, who provided some background on environmental watering in both the southern and northern MDB. Meeting 3 followed from Meeting 1; it was also with CEWO and focused on the northern MDB. Meetings 5 and 6 followed from Meeting 3 and were with CEWO, again, and other stakeholders in the northern MDB; the meetings focused on the Condamine-Balonne catchment. The narrowing of our focus to the Condamine-Balonne from Meeting 3 to Meetings 5 and 6 was recommended by CEWO who advised that the catchment is an area of primary concern with several parties there having expressed interest in better water forecasts.

We focused on the southern MDB in Meetings 2 and 4. The meetings were with MDBA. In Meeting 2, we met with MDBA managers and modellers, who provided an overview of river operations, including environmental watering operations, in the region and how water forecasts may help overcome some of its challenges. In Meeting 4, we met with MDBA river operators charged with making the day-to-day decisions governing dam operations, who gave their perspectives on the matter.

Following this, in Chapter 2, we describe our understanding of the problem and give our recommendations for the southern MDB. We do the same for the northern MDB in Chapter 3.

Table 1.1 Six meetings to identify and discuss opportunities for improved river operations in the MDB with better water forecasting

NO	DATE	ORGANISATIONS REPRESENTED	PURPOSE OF MEETING
1	19-08-2021	CSIRO CEWO	To meet with CEWO to gain an overview of environmental watering in the northern and southern MDB and the role of water forecasts
2	01-09-2021	CSIRO MDBA CEWO	To meet with MDBA managers and modellers to gain an overview of MDBA river operations and decision-making in the southern MDB
3	09-09-2021	CSIRO CEWO	To meet with CEWO to gain a more in-depth understanding of environmental watering and its challenges in the northern MDB
4	07-10-2021	CSIRO MDBA	To meet with MDBA river operators to gain their perspectives on the need for more accurate water forecasts in the southern MDB
5	08-10-2021	CSIRO QLD RDMW BOM CEWO SunWater	To meet with various stakeholders to gain an overview of the current state of water forecasting in the Condamine-Balonne catchment in the northern MDB
6	21-10-2021	CSIRO CEWO QLD RDMW QLD DES BOM	To meet with various stakeholders to discuss on the need for more accurate water forecasts in the Condamine-Balonne catchment in the northern MDB

2 Findings and recommendations for the southern MDB

In this section, we present, for the southern MDB, our understanding of the opportunities for water forecasting (Section 2.1), a framework describing how water forecasts can support river operation decision-making (Section 2.2) and our proposed case study for MD-WERP (Section 2.3).

2.1 Opportunities for water forecasts to assist river operations decisions

Discussions with MDBA and CEWO identified three priority areas where water forecasts may improve river operations in the southern MDB.

2.1.1 Environmental water delivery

Inundation of riparian zones, including floodplains, plays a crucial role in recharging groundwater and wetlands, creating wildlife habitat, initiating fish and bird breeding events and replenishing soil nutrients. To realise these benefits, environmental watering in the southern MDB aims to induce controlled inundation of ecologically sensitive areas by controlling upstream dam releases of environmental water. For greater flood peaks and to conserve environmental water, dam releases of environmental water are ideally timed to coincide with natural high tributary inflows, which can be highly uncertain and difficult to predict. The problem is further complicated (i) by the different lag times from upstream dam releases and tributary inflows to target sites and (ii) by flow limits above which untargeted riparian areas are at risk of unintended inundation.

In the southern MDB, there is a desire to release environmental water from Hume Dam to combine with tributary inflows from Kiewa and Ovens Rivers to inundate downstream areas such as the Barmah-Millewa Forest. For this, the timeframes over which flows need to be predicted to support the Hume Dam releases are of the order of 5-10 days. Further downstream, delivery of environmental flow events is highly dependent on releases from Hume Dam and in addition, tributary inflows from Goulburn, Murrumbidgee and potentially Darling Rivers. The timeframes over which these flows need to be predicted to support decision-making related to the Hume Dam releases are of the order of 4-8 weeks.

The combination of unregulated inflows and regulated dam releases for delivering large environmental flows creates challenges in assessing risks and places operators in a space where risks are potentially higher than in traditional operations. There exist risks within the operational delivery of environmental flow events, e.g. (i) the risk of unintended inundation (from exceeding thresholds) and (ii) the risk of missing flow targets or durations (from not exceeding thresholds). There are also risks associated with the tactical planning of environmental flow events, particularly in assessing opportunities to make an environmental flow release, e.g., whether to coincide with an event early in a season (which may transpire to be the only opportunity in the season) or to hedge for a better opportunity later in the season (that may not materialise).

This highlights that risks exist over multiple time scales and need to be integrated when deciding environmental water release strategies. However, many of these risks are currently not quantified, which limits the ability of river operators to assess the trade-offs between competing objectives and/or risks. Ensemble forecasts of inflows for major unregulated tributaries along the Murray are available to assist in assessing the likelihood of tributary inflows. However, for river operators, the outstanding challenges are to: (i) integrate regulated dam release decisions with ensemble forecasts of tributary inflows to generate forecasts of flow at target sites; and (ii) transform ensemble forecasts of flow throughout the system to measures that reflect the risks that river operators are seeking to manage, i.e. chance of exceeding flow thresholds leading to unintended inundation.

2.1.2 Seasonal planning

In the southern MDB, planning of river operations is essential for the efficient delivery of water allocations and environmental water. Seasonal planning serves to identify the best means of achieving longer-term river operation goals — e.g., the transfer of water to support downstream demands and to manage the risks to achieving those goals, including the risk of delivery shortfalls. Current seasonal planning procedures use models operating at monthly time steps to lead times of 12 months and consider six future inflow and water availability scenarios. These scenarios are based on historical inflow sequences that characterise the chance of exceeding inflow thresholds, including an inflow sequence representing the lowest historical observations. However, recent experience has highlighted that flows can be lower than the lowest-on-record historical inflow sequence when catchments are dry and rainfall low. Climate change may increase the chance of this occurring and therefore more robust inflow sequences may be required. In addition, as a result of their monthly time steps, the current seasonal planning models are unable to provide insight into sub-monthly and shorter-term risks that can influence water availability to downstream users and potentially result in delivery shortfalls.

The current models are being migrated to the eWater Source platform, which operates at daily time steps and therefore offers the ability to assess sub-monthly risks. Source also offers more comprehensive and robust estimates of crop water demands and river system losses. However daily inflow sequences (as opposed to monthly sequences) of the major tributary inflows from Kiewa, Ovens and Goulburn Rivers are more challenging to obtain. Ideally the daily sequences would offer similar or better information than the monthly sequences used in the current monthly planning models.

In forecasting terminology, the current seasonal planning models use 'climatology' inflow sequences that reflect the historically observed system inflows and their associated exceedance probabilities. However, the chance that a given inflow sequence will occur at a particular time is dependent on the catchment conditions at that time and expected future climate. Therefore, the actual exceedance probabilities associated with an inflow sequence at a particular time may differ considerably from the climatological estimate. In extreme, particularly dry, conditions, the exceedance probabilities of the lowest-on-record inflow sequence are likely to be underestimated and therefore the risk of shortfalls also likely to be underestimated. By considering the current catchment conditions and future climate, inflow forecasts are likely to be sharper and more confident that the climatology inflow sequences, and therefore able to provide operators with a better reflection of the actual chance of shortfalls.

Forecasts to enable the use of the eWater Source platform for river seasonal planning are not currently available. There are several outstanding issues that would need to be addressed to enable the better characterisation of future inflows and risk of delivery shortfalls using Source. A critical feature of any multi-site forecast used for planning is that the forecast inflow sequences embed appropriate spatial and temporal correlation patterns so that flow accumulates appropriately along the river system. The climatology inflow sequences used by the current seasonal planning models implicitly embed these spatial and temporal patterns. However, while available forecasts do consider spatial and temporal patterns within a valley (e.g. within the Ovens or Kiewa River valleys), they currently do not capture between valley correlations (e.g. between Ovens and Kiewa River valley outflows). The use of eWater Source potentially adds an additional dimension to this problem of spatial and temporal patterns. Source internally computes crop water demands, and river system losses, which may also require climate sequences. Therefore, there would be a need to ensure that forecast inflows are appropriately correlated with the climate sequences used to compute the demands and losses.

2.1.3 Flood operations of major dams

The airspace in a dam is the unoccupied volume in the dam and is useful in times of high inflow as a buffer to retain all or part of the dam inflow for flood mitigation. A major challenge in dam airspace management is the foresight required to make effective decisions on when to draw down the dam in preparation of an upcoming flood depending on the future weather, which cannot be known with certainty. The problem is complicated by the fact that in many systems, the flood mitigation benefit of drawing down a dam need be balanced with the water supply benefit of filling it. Further, in all systems, spills from a dam need be carefully managed to minimise the risk of downstream flooding while ensuring the safety of the dam infrastructure. The risk of downstream flooding is not only influenced by the dam release but also downstream tributary flows. Therefore, in the management of airspace and flooding, river operators need to concurrently evaluate a number of risks relating to the cumulative dam inflow volumes and flow rates at downstream flood sensitive locations.

During times of flooding, MDBA actively manages the airspace of Hume Dam, and to a lesser extent Dartmouth Dam. To manage this airspace, MDBA currently uses models and what-if scenarios to assess possible situations and relies on mostly human intuition informed by weather forecasts and experience to assess risks. This current approach based on human judgement can be hard to justify in the face of scrutiny. One way to strengthen the current approach is to incorporate more quantitative assessments of risk, based on forecasts, to decision-making. However, there is currently limited means to undertake quantitative assessments of the risks involved.

Conceptually the outstanding challenges for river operators in flood operations are similar to those for the delivery of environmental water in that there is a need to (i) integrate regulated dam release decisions with ensemble forecasts of inflows and (ii) transform ensemble forecasts of flow throughout the system to measures that reflect the risks that river operators are seeking to manage, i.e. the chances of exceeding flood thresholds or leaving the dam level below full supply after a flood event. However, there are also differences in (i) some of the risks that need to be managed and (ii) the parts of the river system where forecasts are required, e.g. forecasts of dam inflows are essential for flood operations but not critical for environmental water delivery decisions.

2.2 Water forecasting for informing decisions

2.2.1 Current and extended application of water forecasts for decision-making

The full potential of water forecasts can only be realised when used to inform operational and/or planning decisions. Examples as described above include to guide real-time dam releases of environmental water, support planning of water allocations and environmental flow events, or direct dam airspace management for flood mitigation.

However, several challenges impede the full incorporation of water forecasts, in particular probabilistic ensemble forecasts, to existing decision-making: First, ensemble streamflow forecasts have only been available in the southern MDB for a relatively short time. Therefore, river planners and operators have had limited opportunity to understand their characteristics and performance under a wide range of conditions. Second, currently available water forecasts, e.g. the BOM 7-day Ensemble Streamflow Forecasting service, are only available for mostly unregulated tributaries, but not the regulated flow along the mainstem of the Murray, that is an amalgamation of upstream decisions and unregulated and regulated tributary inflows. As it is the flow along the mainstem that is usually of primary concern, the currently available forecasts are inadequate. Third, most current decision-making in the southern MDB is based on human experience and intuition. There is therefore limited scope to quantitively incorporate the probabilistic information of ensemble forecasts. In other words, current systems are restricted in their ability to make full use of ensemble forecasts when making decisions.

Water forecasts can quantitatively inform river operation and planning decisions in a range of ways beyond how they are currently used. Water forecasts can be used to characterise the risks associated with operational decisions and assess the likelihood of achieving river operation objectives in the face of uncertain future inflows. These risks can be characterised by (i) defining the dam release strategies required under a range of forecast inflow scenarios or for an inflow scenario with a particular exceedance probability, and/or (ii) describing the range of river system outcomes that may arise from an adopted dam release strategy under a range of forecast inflow scenarios. Where it is possible to define, in numerical terms, the river operation objectives, constraints (e.g. limits on flow or changes in flow) and appetite to risk, forecast-informed optimisation methods can be implemented to obtain recommended decision scenarios. These optimisation methods may be deployed in real-time or used off-line to define forecast-informed operating strategies or guidelines.

Figure 2.1 gives a graphical representation of extended approaches to using water forecasts for decision-making in the southern MDB and how they compare to the current state. In the current case, the decision-making is centred on human judgement, considering the problem objective and constraints and real-time forecasts of tributary inflows. In the extended approaches, the decision-making is also centred on human judgement but with three additional components to aid it, as follows: (i) an integrated ensemble forecasting model that is capable of forecasting the flow within the main channel of Murray River combining forecasts of unregulated tributary inflows and river regulation decisions, (ii) a model to translate forecasts from the integrated forecasting model to system operation risks (e.g. of exceeding flow thresholds or not meeting demands), and (iii) an optimisation model to quantitatively consolidate the complex mix of probabilities, risks, flow lags and limits and other critical factors to find the recommended decision scenarios.

The integrated forecasting model comes first and is independent of the other two components. For the Murray, this may be a version of the Source model in Section 2.1.2 that is currently being developed for seasonal planning. The model to translate forecasts of the Murray flow to risks follows from the integrated forecasting model and depends on it. The optimisation model comes last and wraps around the forecasting and forecast-to-risk models. We envisage the forecast-to-risk and optimisation models providing feedback to the human decision-maker, who then makes the final judgement on decisions. In this regard, the three additional components are not to replace human judgement, but to provide evidence to support decisions. Sound human judgment is still needed to critically evaluate the model results to detect unexpected errors and account for factors outside the scope of the models.

A key strength of these additional components is that they are quantitative, which makes them invulnerable to human biases and therefore more objective. They are also more systematic and focused than qualitative methods. Thus, incorporating them to current decision-making frameworks, that is mostly based on human judgement, will streamline processes and make the results more dependable and justifiable, and objective knowledge and data to learn from.

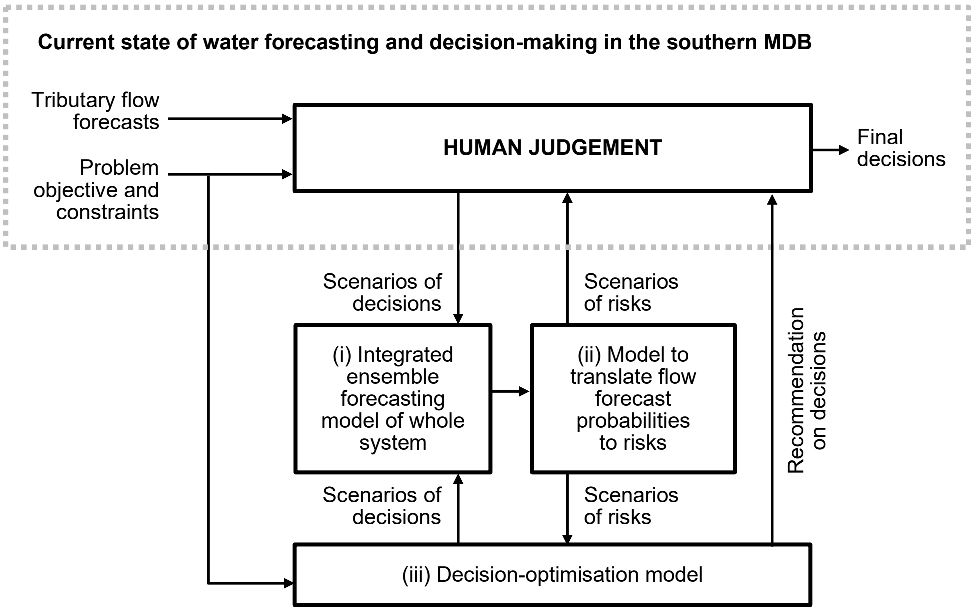

Figure 2.1 Extended application of water forecasting for river operation decision-making in the southern MDB and how it compares to the current state; the extended application contains an additional three components: (i) an integrated ensemble forecasting model, (ii) a model to translate forecasts to risks and (iii) a decision-optimisation model

2.2.2 Steps to extend the application of water forecasts for decision-making

To extend the application of water forecasts for decision-making is not straightforward. To do so requires developing new models, operationalising them and upskilling staff. Table 2.1 gives a summary of the key steps that would be involved in extending the application of water forecasts for decision-making, specifically they can be divided into four parts: (i) Part A to develop an integrated ensemble forecasting model of the system and a model to translate forecasts to risks, (ii) Part B to operationalise the two, (iii) Part C to develop a decision-making optimisation model and (iv) Part D to operationalise it.

Table 2.1 Steps to extend the application of water forecasts for river operations decision-making in the southern MDB and how they relate to the three additional components in Figure 2.1

PART	STEPS
A	**Development a forecasting model and a forecast-to-risk model** *In relation to components (i) and (ii) in Figure 2.1* - Define the problem specifications - Develop an integrated ensemble forecasting model - Evaluate the forecasting model performance - Develop a model to translate forecasts to risks
B	**Operationalise the forecasting and forecast-to-risk models** *In relation to components (i) and (ii) in Figure 2.1* - Operationalise and monitor the forecasting and forecast-to-risk models
C	**Develop an optimisation model** *In relation to component (iii) in Figure 2.1* - Develop a decision-making optimisation model
D	**Operationalise the optimisation model** *In relation to component (iii) in Figure 2.1* - Operationalise and monitor the optimisation model

Here, we present the steps linearly, for clarity. In reality, they need not occur in a linear fashion, but may overlap or run in parallel with each other. The steps are as follows:

- **Part A: To develop a forecasting model and a forecast-to-risk model**

  Define the problem specifications. The first step is to define the problem objective, e.g., to manage spills from a dam to create airspace for flood mitigation. Then, based on the problem objective, identify the type and locations of the streamflow forecasts required. Different problems require different forecast types and at different locations. For example, dam airspace management typically requires days ahead short-term hourly forecasts of the dam inflow while seasonal planning months ahead monthly forecasts of flow at various points throughout the system.

  Develop an integrated ensemble forecasting model. The next step is to develop an integrated ensemble forecasting model with the ability to forecast the different tributary flows concurrently, with each other and with the mainstem flow. This is to yield consistent ensemble forecasts with the right cross-correlations. This is also to give the model the ability to forecast the mainstem flow of the Murray that current models lack.

Evaluate the forecasting model performance. In this step, integrated forecasting model will be applied to generate hindcasts of the flows at the required locations and under various scenarios of upstream decisions. Then, hindcasts will be evaluated against historical observations. This is to assess the model performance and to give confidence to the modeller of its fitness for use. This is also to provide guidance on the effects of critical factors such as seasonality and forecast lead time.

Develop a model to translate forecasts to risks. To convert the ensemble forecasts from the integrated forecasting model to a useable form, a model to translate the forecast probabilities to risks of the system failing will be developed, e.g. risks of a flow a exceeding a flood threshold or of a dam overtopping, and the results organised in an easy-to-understand format.

- **Part B: To operationalise the forecasting and forecast-to-risk models**

  Operationalise and monitor the forecasting and forecast-to-risk models. This step is to operationalise the integrated forecasting and forecast-to-risk models to run in real-time. This will entail automating multiple workflows to (i) retrieve, check and store data, (ii) execute the models and (iii) organise the results in the desired format. It will also entail upskilling staff on how to use the models and interpret the results. Operationalising the models will enable generation of the required forecasts and risks in real-time and make available the models for scenario analysis of upstream decisions to aid in real-time decision-making. Once operational, ongoing monitoring of the models will be necessary to evaluate their efficacies under real conditions, and to identify and resolve technical difficulties.

- **Part C: To develop an optimisation model**

  Develop a decision-making optimisation model. The next step is to develop an optimisation model wrapped around the integrated forecasting and forecast-to-risk models to identify the best combination of decisions that maximises the system performance. The model will then be thoroughly tested on historical data to assess its performance and demonstrate its suitability for use.

- **Part D: To operationalise the optimisation model**

  Operationalise and monitor the optimisation model. Finally, the optimisation model will be operationalised alongside the integrated forecasting and forecast-to-risk models. This will require introducing new workflows including one to update the initial conditions of the model at every time step given the decisions of the previous time step. It will also require upskilling staff on how to use the model and evaluate its outputs. Operationalising the model will enable it to make real-time recommendations on decisions. Continuous monitoring of the operationalised optimisation model will be necessary to evaluate its performance and usefulness under real conditions.

2.3 Better understanding of operational risks in the southern Basin

For MD-WERP, we propose to implement, for a case study in the southern MDB, the four steps in Part A in Section 2.2. Doing so will establish the foundations for implementation of Parts B-D (Table 2.1). Our objectives are:

1. to demonstrate the value of ensemble water forecasting for river operations in a real application context
2. to demonstrate the use of forecasts to quantify risks
3. to provide a tool to assess the sensitivity of risks to decisions
4. to set the foundation for coupling forecasting with optimisation for improved real-life decision-making.

We propose to conduct the case study on the section of the Murray River between Hume Dam and Yarrawonga Weir, which forms the outlet of Lake Mulwala. We select this site for the following reasons:

- In the southern MDB, it is an area of primary interest with multiple competing stakeholders — including CEWO, the New South Wales Department of Planning, Industry and Environment (NSW DPIE) and irrigators. It can be challenging to balance between their interests.
- The flow lag times from Hume Dam and tributaries to Yarrawonga Weir are such that it is possible to forecast the inflow to Lake Mulwala fairly skilfully, and therefore, feasible to control the flow at Yarrawonga Weir by controlling the release from Hume Dam. The same cannot be said of locations further downstream on the Murray due to their longer lag times. Thus, this section of the Murray selected is best for our purposes.
- The river operation objectives and constraints for the area are well-established, i.e., its environmental watering goals are well-defined, as are its water supply requirements and flood limits. As described in Section 2.1.1, environmental water is released from Hume Dam to meet flow targets at Yarrawonga — for inundating downstream areas such as the Barmah-Millewa Forest — subject to flood limits at Doctors Point and downstream of Yarrawonga Weir. Water is also released from Hume Dam to supply Lake Mulwala, a major source of irrigation water.
- There are sufficient historical streamflow and rainfall data to calibrate and validate a hydrologic model of the system and from there, develop an integrated ensemble forecasting model to forecast the flows throughout the system. There are also sufficient retrospective global climate model (GCM) rainfall forecasts to produce retrospective flow forecasts to verify the outputs of the forecasting model, as well as available real-time GCM rainfall forecasts to produce real-time flow forecasts if so desired going forward.

To meet Objective 1. Specifically, we propose to develop and evaluate an integrated ensemble forecasting model of the system comprising the catchment of the section of the Murray River of concern including the catchments of Kiewa and Ovens Rivers. As part of this, we propose to investigate the potential of the Source operations model (from Section 2.1.2) as a means of integrating ensemble forecasts of tributary inflows with management decisions to generate ensemble forecasts of the flow along the mainstem of the Murray. To obtain the forecasts of tributary inflows, in particular of the inflows at key BOM forecast locations, we aim to leverage on another CSIRO project with the NSW DPIE which also involves generating ensemble flow forecasts for the same locations.

Further, we propose using the integrated forecasting model to forecast, up to 7-10 days ahead, the hourly inflow to Lake Mulwala and the hourly flow in the Murray downstream of Yarrawonga Weir as a function of the Hume Dam release and irrigation diversions from Lake Mulwala. This is to introduce ensemble water forecasting and its value by providing tangible examples of water forecasts for the system and with that, fulfill our Objective 1 above.

To meet Objectives 2 and 3. We also propose to develop a model to, from the forecasts from the forecasting model, forecast risks, in particular, the risks of water supply shortfall at Lake Mulwala, of the flow in the Murray downstream of Yarrawonga Weir exceeding flood limits and of it failing to meet environmental flow targets. This is to demonstrate the potential of water forecasts for forecasting risks and with that, fulfill our Objective 2. As the forecasts of the risks will be a function of upstream decisions, namely the Hume Dam release and diversions from Lake Mulwala, the forecast-to-risk model together with the integrated forecasting model will provide a means to assess the sensitivity of the risks to the decisions and with that fulfill our Objective 3.

To meet Objective 4. The results will be useful for real-time river operations, primarily, as explained in Section 2.2.1, for timing the Hume Dam release to synergise with the tributary inflows from Kiewa and Ovens Rivers to meet downstream water supply demands and environmental watering goals, while limiting the risks of unintended inundation of riparian areas. Better timing of the Hume Dam release will enable the greater conservation of water in Hume Dam and reduce the risk of flooding. The proposed work will yield a significantly improved understanding of the potential of ensemble water forecasts for real-time operations in the southern MDB and establish a foundation for combining forecasting with optimisation for even more powerful decision-making if so desired in the future. And with that, fulfill our Objective 4.

3 Findings and recommendations for the northern MDB

This section summarises our understanding of the some of the priority opportunities for water forecasts to be used for supporting environmental water management decisions in the northern MDB.

3.1 Opportunities for water forecasts to assist environmental watering decisions

Discussions with CEWO identified four priority opportunities where forecasts could have been used to inform environmental watering decisions or would be able to add value in the future. Two of these opportunities relate to the delivery of water into the Narran Lakes, while other opportunities relate to within valley delivery of environmental water and connectivity events across the entire northern Basin.

3.1.1 Delivery of water to Narran Lakes

Narran Lakes are series of ephemeral terminal wetlands in northern NSW. The lakes are an important site for bird breeding and are protected under the Ramsar Convention. Water enters the lakes from the Narran River. Near the Narran Lakes, the Balonne River is a braided stream with a wide floodplain and many channels. The Narran River is the eastern most anabranch of the Balonne River and flows over a course of nearly 300 km, southwest from Dirranbandi. For bird breeding events to be successful requires the lakes to be inundated for a period of at least 3 months. Such events can occur when at least 250 GL of water passes the St George stream gauge on the Balonne River.

The river system is only lightly regulated and therefore inundation of the Narran Lakes is dependent on natural flow events. Large flow events achieve the required inundation without any management intervention. For medium-sized natural events, particularly following dry spells, CEWO can use held environmental water to support water delivery to the Narran Lakes. However, CEWO held environmental water is insufficient to fully support a bird breeding event.

CEWO have the ability activate event-based mechanisms to augment their held environmental water. These event-based mechanisms involve paying irrigators not to extract water from the Balonne River, or to delay any extraction. Activation of such a mechanism requires time to introduce and communicate the necessary legal arrangements. Once the legal arrangements are in place, decisions to commence and cease the event-based mechanism are taken as the event unfolds. CEWO understand that there is value in activating event-based mechanisms when between 250 and 500 GL of flow is expected to pass the Balonne River stream gauge at St. George over a period of 6-8 weeks. Flow volumes smaller than 250 GL are insufficient to support bird breeding in the Narran Lakes, while when flow volumes are larger than 500 GL the Commonwealth environmental water holding is typically sufficient.

Decisions to introduce legal arrangements to enable activation of the event-based mechanisms are primarily driven by environmental demand, i.e., the need to support environmental objectives given recent history. Decisions to start and cease the event-based mechanisms are currently made with lead times of hours based on anticipated event flow volumes. However, ideally they could be made days to a week in advance, which would be possible if there were sufficient confidence in flow forecasts.

3.1.2 Maintaining the level of Narran Lakes during bird breeding events

Inundation events in the Narran Lakes can initiate bird-breeding events. Small flow events can result in inundation of the lakes but for periods that are insufficient for such events to complete, particularly if tributary rivers recede relatively quickly. Nonetheless, there is currently the ability to use held environmental water to augment flow during the recession of a larger event to extend the duration of an inundation event and allow for bird-breeding events to complete.

Decisions to use held environmental water to extend the duration of Narran Lakes inundation are conditional on the hydrograph receding to low levels and there being confidence that subsequent rises in the hydrograph are unlikely. While the observed hydrograph can be used to inform the first condition, forecasts can potentially provide information on expected future hydrograph rises.

3.1.3 Coordinated tributary flows to deliver water in the Darling past Bourke

The Barwon-Darling River periodically ceases to flow. Long periods of cease-to-flow conditions, such as those experienced in recent years, can result in degraded water quality in river pools which places stress on fish and other aquatic life. Therefore, environmental water can be used to create connectivity events that allow fish to move between pools and improve water quality.

CEWO seek to create connectivity events in the Barwon-Darling River by ensuring 30 GL of water flows past Bourke. The 30 GL flow volume has been estimated to be the minimum required for flow to reach Menindee. To date, two connectivity events have been achieved with different characteristics. The first, in 2018, used a combination of held, regulated environmental water from headwater storages and a natural flow event. The second connectivity event, in January 2021, combined new water sharing plan rules, that restricts extraction until 30 GL of water is forecast to pass Bourke for social, cultural and environmental outcomes, and held environmental water from Copeton and Pindari dams to ensure that flow in the Barwon-Darling reached Menindee.

These two examples highlight that there are multiple ways environmental objectives can be met using a combination of natural flow and dam releases from tributaries. Dams that supply regulated releases are in the catchment headwaters. These dam releases can take many days to travel to target locations. These releases are augmented by unregulated tributary inflows and runoff from intermediate catchments that may arise before, during or after the releases. Accurate forecasts of flow at target sites, such as Bourke, that combine the regulated and unregulated flows can potentially inform the management of dam releases, particularly if it is necessary to stop a release early or late.

3.1.4 Delivery of water within river valleys

CEWO seek to achieve many within-valley hydrological and ecological objectives in the Northern Basin with a limited amount of environmental water. Opportunities may exist to conserve environmental water or enhance environmental outcomes by including real-time forecasts in decision making on water orders. For example, to meet minimum flow targets, orders for regulated or unregulated water are often set and left unchanged for months. These orders could be adapted, based on forecasts of tributary inflows, so that environmental water holdings are conserved. At the other end of the spectrum, environmental water is used to protect, enhance or extend periods of high flow to facilitate inundation of wetlands and support their dependent ecosystems. Forecasts of flows through many Northern Basin river systems would assist in understanding how best to use the range of water entitlements available to CEWO, including the rate and timing of orders relative to natural unregulated inflow events.

3.2 Forecast services to support decision-making in the northern Basin

BOM routinely delivers seasonal forecasts of monthly streamflow volumes to lead times of three months and continuous forecasts to lead times of seven days for some unregulated stream gauges in northern Basin catchments. Seasonal forecasts are issued once a month, while the 7-day service issues ensemble forecast hydrographs every day that are designed for water resources management applications. However, these routine services exclude managed parts of the river systems that are of interest to CEWO. BOM also produces flood forecasts when flooding is anticipated, as part of its public safety obligations. The flood forecasting service extends into the regulated parts of the river systems of interest. This service is underpinned by event-based models that are designed to predict large flood-inducing streamflow events and have limited ability to make accurate predictions until rain has fallen and river levels have begun to rise.

Continuous forecasting of the full streamflow hydrograph in the northern Basin is challenging. Many of the streams within the northern Basin are intermittent or ephemeral with braided channels and therefore can be challenging to accurately model. Irrigation extractions in the region are supported by both regulated and unregulated flows and the precise timing, location and volume of extractions are not necessarily well understood. This means that calibrating and real-time updating of models needs to allow for incomplete knowledge of the river water balance. The methods used for forecasting flood events circumvent some of the challenges involved in forecasting the full hydrograph. Flood forecasting models are manually calibrated for each forecast event and during large events, the impact of extractions on river flow are a relatively small component of the water balance and can therefore be neglected. However, the flow events that CEWO are looking to augment may be associated with within-bank freshes, rather than flooding, and therefore flood forecasts may not be issued. In addition, for these smaller events, irrigation extractions are likely to be important component of the water balance and therefore need to be considered explicitly.

3.3 Toward forecast-informed operation of event-based mechanisms

We propose a case study to investigate how forecasts can support CEWO enacting event-based mechanisms for the delivery of environmental water in the Lower Balonne River.

Decisions relating to enacting event-based mechanisms in the Lower Balonne River are based on cumulative event flow volumes past the stream gauge at St George, particularly the exceedance of threshold volumes. Flow events that realise the threshold volumes of interest can be associated with flooding but can also result from within-bank high-flow freshes. No continuous forecasting service is currently available for this gauge; however, flood forecasts are made when flooding is imminent. Both seasonal and 7-day forecasts are available for nearby upstream gauges. Existing streamflow forecasting services do not produce products that can be directly used to inform CEWO decisions, but such products can potentially be derived from a combination of observed and forecast streamflow.

The case study therefore will seek to:

1. develop and deploy methods to derive forecast products from existing forecasting services that can directly inform CEWO decisions
2. characterise the performance of the derived forecast products and the lead times for which they are likely to add value to CEWO decisions
3. identify how the performance of forecasts can be improved to better inform CEWO decisions.

The anticipated derived forecast products will be in the form of forecasts of the probabilities of exceeding the minimum and maximum threshold volumes for activation of an event-based mechanism. Prior to the commencement of a flow event, forecasts will simply reflect the raw forecast probabilities of exceeding the flow volume thresholds over the forecast horizon. However, once the event has commenced, the forecast product will characterise the probabilities of the total event flow volume exceeding the thresholds based on the observed flow volume for the event to the forecast issue date combined with the forecast flow for the coming days. These volume forecasts will be regenerated daily using updates of flow observations and streamflow forecasts. The forecasts of event volumes exceeding thresholds can be informed by both the BOM 7-day and seasonal streamflow forecasts with the seasonal forecasts primarily providing context on the anticipated monthly conditions.

The approach to the case study will involve:

- Prototyping event volume forecast products and evaluating forecasts at a location(s) where existing BOM seasonal and 7-day streamflow forecast products are available.
- Establishing methods to provide forecasts for the St George gauge, possibly using forecasts for indicator locations, and evaluating the forecast performance.
- Experimental deployment of a forecast product generation system to produce forecasts in real-time.
- Investigating methods to make use of alternative forecast products that are available to improve forecast performance.

The forecast evaluation process will involve using retrospective forecasts to verify performance using traditional techniques, that assess the accuracy and reliability of forecasts, and also decisionoriented verification methods, which characterise whether forecast-informed decisions to activate and rescind event-based mechanisms could be made earlier and with more confidence than using simpler methods.

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