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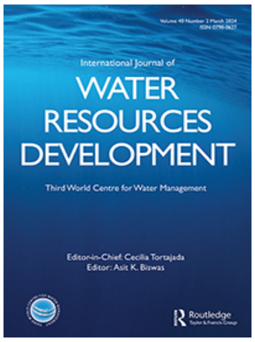

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Managing risks associated with environmental water delivery: a case study of the Goulburn River, Australia

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ABSTRACT
Effective environmental watering programmes improve the ecological conditions of river systems. This involves identifying and managing any significant risks that may hinder programme success. We undertook a qualitative study exploring how environmental water managers perceive and manage these risks while planning and delivering environmental water, using the Goulburn River, south-east Australia, as a case study. We developed a risk table detailing the progression of key risk events and how environmental water managers manage these. The findings highlight that many risk management strategies are tied to different organizations and water users, making it challenging to successfully deliver environmental water.

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Environmental water managers; risk framework; risk management; environmental water planning and delivery; qualitative data analysis; SDG 6: Clean water and sanitation

Introduction

Many river ecosystems are in decline due to extraction for consumptive demands coupled with the increasing threat from climate change. Environmental flows are one approach to address this, providing water for the environment to sustain or restore ecosystem health (Arthington & Balcombe, 2017). There are two main mechanisms through which environmental flows are provided: rules-based methods and active environmental water management (Horne et al., 2018, 2017). In the rules-based approach, the environmental flows are provided by placing conditions on other water users (e.g., by placing restrictions on water abstraction) or on water managers or storage operators to release flows from storage, or by implementing a limit on a total abstraction of the water (called a 'cap') from the system (Horne et al., 2018). Where environmental flows are provided through a legal right (termed here 'environmental water') that requires active management of this water (Arthington et al., 2018; O'Donnell & Garrick, 2017). With active environmental water management, environmental water managers (EWMs) are required to make ongoing

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decisions concerning how, when and where to use environmental water to achieve the best outcomes (Doolan et al., 2017; Horne et al., 2018). These decisions include planning and operational decisions such as deciding when to call water from storage, and which flow objectives to prioritize. There are risks associated with environmental water management and delivery, and how these risks are managed has a direct impact on the likely benefit achieved from the environmental water. This paper examines the perceived risks for environmental water planning and delivery from the perspective of EWMs, and how they are managed.

In the state of Victoria, Australia, environmental water is managed by multiple organizations. Environmental water holders own the water entitlement, catchment management authorities (CMAs) manage this water to benefit the environment, and water supply authorities (WSAs) deliver the water upon request from CMAs and environmental water holders. Environmental water holders may have broader interests than a single catchment, while CMAs and WSAs primarily focus on single catchments. Basin management agencies can also be involved in transboundary rivers (e.g., the Murray–Darling Basin Authority – MDBA). Collaborative arrangements across these multiple organizations remain a challenge for environmental water delivery, especially when these organizations' priorities do not align (Bischoff-Mattson & Lynch, 2017; Kirsch et al., 2022; Margerum & Robinson, 2015; Natural Capital Economics, 2017).

EWMs make a range of decisions in the active management of environmental water (Horne & O'Donnell, 2014). The decisions within the scope of this paper are planning and implementation decisions. Horne and O'Donnell (2014) categorize planning decisions into: (1) planning for environmental outcomes, involving setting objectives focusing on different environmental outcomes, such as to protect and restore water-dependant ecosystems and to improve water quality (CEWO, 2013); and (2) planning for environmental water use, involving different flow events and watering actions. In this paper, we focus on planning for environmental water use (referred to as 'planning' from here onward) as this is where dynamic decisions come into play. In contrast, planning for the environmental outcome is much more deliberative and will be the same for both rules-based and active environmental water management (Doolan et al., 2017). The implementation decisions involve sequencing watering actions for different flow objectives, making trade-offs to achieve targeted environmental outcomes when one objective may hinder other objectives, and liaising with environmental water holders and WSAs to deliver the water to the targeted environmental assets.

Environmental water management faces challenges due to factors such as climate change (Capon et al., 2018), competition for resources from different water users (Cai & Ringler, 2007), involvement of stakeholders with conflicting objectives (Conallin et al., 2017), and knowledge gaps (Bhuiyan, 2022). The increased frequency of extreme weather events associated with climate change significantly disrupts the planning and delivery of environmental water. In addition, a gradual shift to a scarcer water supply adds pressure to already stretched water resource systems (Capon et al., 2018), causing increased competition between different water users. A further challenge for environmental water delivery in Australia is its interaction with the delivery of consumptive water, as both compete for shared water resources and capacity within the delivery network (river and irrigation channels). When there are constraints in delivery capacity, consumptive water users are generally favoured by WSAs (DPIE EES, 2021; Meempatta et al., 2021). Since environmental water is a relatively new management instrument, our knowledge and understanding are rapidly changing. These various challenges are considered in terms of the risk they pose to the planning and delivery process. If not managed appropriately, these challenges lead to a risk of failing to improve river health, or even causing adverse effects by delaying or not delivering the planned environmental watering actions.

While there are empirical studies examining the frequency and severity of different risks affecting environmental water delivery (Alluvium, 2016; Peter Cottingham & Associates and SKM, 2011; Wood et al., 2021), there remains a knowledge gap regarding how EWMs perceive and manage these risk events in their planning and delivery decision-making process. Addressing these gaps could help contribute to policies around improving the efficacy of environmental water deliveries, and help to improve the representation of EWM decision-making in water resource models (WRMs). We undertook an exploratory qualitative study to examine how EWMs perceive and manage these risks while planning and delivering environmental water, using the Goulburn River, Australia, as a case study. It is worth mentioning that this work is being done as part of a larger project focusing on interactions in decision-making by EWMs, WSAs and irrigators.

Case study: Goulburn River, Australia

The Goulburn River is one of the largest tributaries to the Murray River, located in Taungurung and Yorta Yorta country in Northern Victoria. The river is 570 km long, extending from the Great Dividing Range near Woods Point to the Murray River in the north-west near Echuca (GB-CMA, 2005; VEWH, 2022). While the Goulburn River catchment is just 2% of the Murray–Darling Basin area, it contributes around 11% of the Basin's surface water (MDBA, 2021). The river is highly regulated by Lake Eildon (3334 GL) and further downstream by Goulburn Weir (26 GL), the latter of which serves as a major diversion point for irrigation water (DELWP, 2019; MDBA, 2021).

The Goulburn River joins as a tributary to the Murray River near the township of Echuca (Zampatti et al., 2015). The Barmah Choke (Barmah–Millewa forests) – located upstream of the confluence of the Goulburn and Murray rivers (Figure 1), is the major natural constraint on Murray River channel capacity, limiting the amount of water that can be transferred from the upper system storages to meet downstream demands. This means that the tributaries downstream of the Barmah Choke are important for meeting the mid- and lower Murray River water demands. Yarrawonga Weir divides the upper and mid-Murray River (Figure 1), and the water released from the weir is closely tied to the Barmah choke channel characteristics (MDBA, 2013). The pool formed by Torrumbarry Weir in the mid-Murray (Figure 1), is a major source to meet water demands in the Torrumbarry Irrigation Area by diverting water from the weir via National Channel. Lake Victoria – located in the lower Murray, is an off-river flow regulated lake that supports the consumptive and environmental water demands of the state of South Australia (MDBA, 2013) (Figure 1).

The Goulburn River provides water to consumptive users: agriculture, urban centres, industry, and recreational activities, and to key environmental assets in the region. The river and associated tributaries, floodplain and wetlands act as a conservation area for iconic and threatened species such as Murray cod, golden perch, trout cod, Macquarie perch, freshwater catfish, eastern egret and platypus (GB-CMA, 2022, 2014; VEWH, 2021).

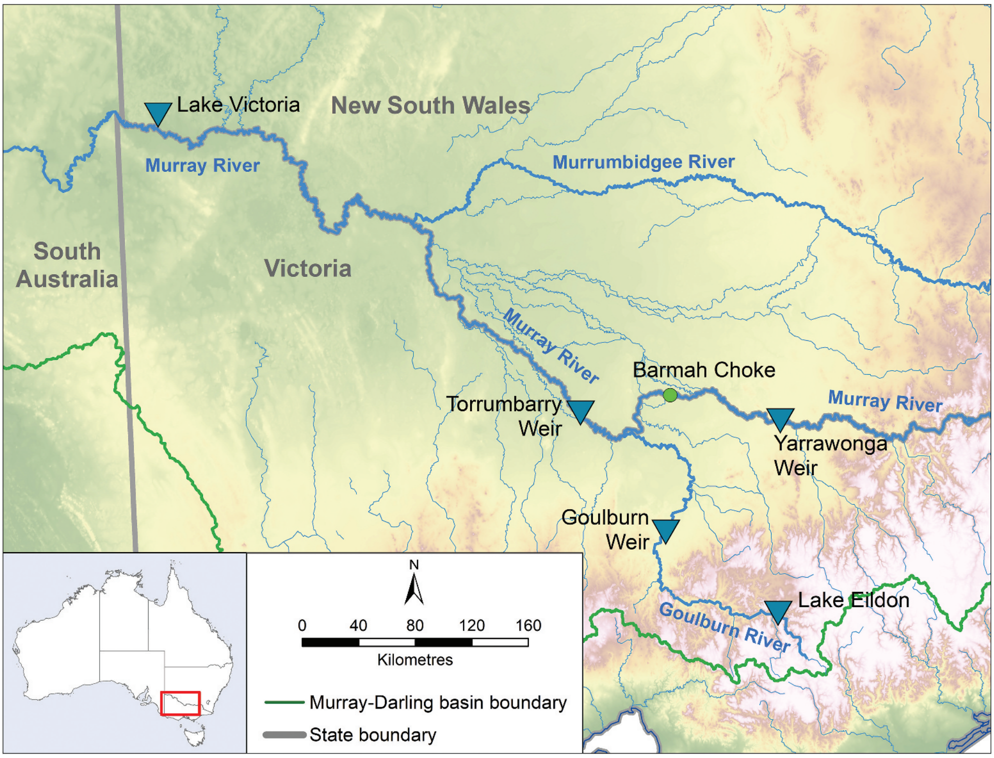

Figure 1. Case study area: Goulburn River catchments and some key locations along the Murray River in the Southern Murray–Darling Basin, Australia.

The Goulburn River is highly regulated primarily for the purpose of meeting irrigation demands (DELWP, 2017). This has resulted in changes in the seasonal flow patterns and a decline in several native species. The frequency and duration of overbank flows connecting floodplains covering 13,000 ha alongside the river have also been greatly reduced (DELWP, 2016, 2017). The Victorian Constraints Measures Program (Victorian CMP), a Victorian Government initiative, is currently underway, aimed at relaxing some of the constraints limiting overbank flows (DEECA, 2023a). However, the project is still in the feasibility stage to identify and manage third-party risks of overbank flows (i.e., flooding of private property and recreational areas). Once implemented, overbank flows are expected to provide significant improvements to the ecological values of the floodplains and wetlands of the Goulburn River (Horne et al., 2022). However, under current operating rules managers are not able to deliver overbank environmental flow events and all environmental water deliveries are targeted at delivering in-channel environmental outcomes.

The planning and delivery of environmental water in the region are undertaken in collaboration with several organizations (called *delivery partners*). The Goulburn–Broken Catchment Management Authority (GB-CMA) orders and manages environmental water delivery in the catchment, while EWMs in the GB-CMA actively manage the water by deciding the quantity and timing of the delivery and deciding priority watering actions. Goulburn–Murray Water (GMW) is the catchment’s rural WSA, and provides water delivery services in response to water order requests from water users in the region. The environmental water is owned as *water entitlements* (also called *water rights*) by environmental water holders in the catchment. The water holders in the catchment are primarily the Victoria Environmental Water Holder (VEWH), which owns the state's water entitlements; Commonwealth Environmental Water Holder (CEWH), which owns the federal government's water entitlements; and Murray–Darling Basin Authority (MDBA), which owns the entitlements as part of the Living Murray Initiative – a river restoration programme jointly funded by federal and state governments. The MDBA is also authorized to determine water allocation and manage water delivery in the Murray River in coordination with WSAs in Victoria, New South Wales and South Australia. The Department of Energy, Environment and Climate Action (DEECA) is the state government department responsible for designing and implementing policies, investments and programmes concerning environmental water management (DEECA, 2023b).

Methods

We conducted an exploratory qualitative study using the Goulburn River as a case study. There were two sources of data: (1) data collected from experts during and after semi-structured interviews (hereafter primary data); and (2) published reports or documents relevant to their decision-making and referred to in the primary data (hereafter documentary data). Semi-structured interviews allowed us to collect data on key themes of interest while allowing the interviewees to elaborate on their responses (Liamputtong & Serry, 2013). Documentary data were used to supplement the primary data and included available documents and databases from various secondary sources identified by experts as relevant to their decision-making (Kothari, 2004; Winter, 2019). The analysis of these data in this paper focussed on how EWMs manage the risks associated with environmental water planning and delivery in the Goulburn River catchment, thereby contributing to the broader project aim of understanding EWMs' decision-making behaviour.

Population and sampling

The population of interest was EWMs and WSAs operating in the case study catchment within the organizations GB-CMA, GMW and CEWH. The participants for the semi-structured interviews were selected using a purposive sampling strategy. The officials were selected based on their role and experience in the participating organizations, selecting those most able to share experiences and insights into the decision-making processes related to environmental water management. The officials selected from the participating organizations were decision-makers for environmental water delivery. The participants were identified (1) based on recommendations from experts in the water industry or (2) by contacting the organization to find a suitable candidate for the research. We used a snowball approach for further recruitment when the selected participants were not able to participate in the study. Participants were contacted by email regarding their availability, and were sent the plain language statements and interview questions ahead of the interview. In addition to interviews, participants were invited to share relevant documents.

Data collection

The data collection was conducted within a broader project aimed at gaining an in-depth understanding of the decision-making behaviour of participants in these organizations, while the data analysis for this study focuses on how these participants perceive and manage risks in their decision-making process. Interviews were guided by a set of open-ended questions, allowing the interviewer to spontaneously generate questions in the natural flow of the interview (see S1 in the supplemental data online). We followed up with the participants after the interview to obtain the documents identified as critical to their decision-making processes.

The collected data were grouped into primary data and documentary data. The primary data consisted of interview transcripts, notes taken during the interviews and the documents shared by the participants during and after the interviews. Though all interviews were recorded, the interviews towards the end of the data collection were conducted primarily to get answers to specific questions to validate the information obtained from the earlier participants. Hence transcriptions of these later interviews were not needed as their duration was short, instead only relevant quotes were transcribed. The documents shared by the participants consist of (1) file notes and operational logs prepared by EWMs during their decision-making and water delivery processes; and (2) email communications between the CMA and their water delivery partners or customers. The documentary data were published reports and journal papers recommended by the participants during the interview or referred to in their file notes. The documents as part of the primary data differ from that of documentary data, as these are shared by the participants and not published anywhere else. Primary data were the key source of data for this research, and the documentary data were used to understand the context and, in some cases, for better clarity on some of the information in the primary data.

Data analysis

Thematic analysis was used to analyse the primary and documentary data, a commonly used method in qualitative research for finding patterns or themes in the data (Hansen, 2006). All data collected were analysed together. After reading the data several times, we developed a coding/thematic framework around the key themes in the data and grouped the data under each theme. We analysed the data under each theme separately. The analysis was carried out using qualitative analysis software QSR NVivo 20.6.1.113. The results are presented in this paper with the relevant quotes from the primary data and citations from the documentary data to support the claims wherever necessary.

Results

A total of 71 documents were collected as part of the primary data from five participants across the three organizations, and 10 as part of documentary data (Table 1). The primary and documentary data included references to organizations beyond the three within which we did interviews; hence, they are also mentioned in this study where required. Most of the primary data comes from the documents shared by the participants after the interview (Table 1).

Table 1. Details of the primary and documentary data collected for the study.

Data types	Item	Count
Primary data	Notes taken during interviews with officials from the GB-CMA, GMW and CEWH	5
	Transcript of the interview recordings from the GB-CMA, GMW and CEWH	4
	File notes and operational logs shared by the GB-CMA related to their decision-making and water-delivery process	42
	Communication between GB-CMA and their stakeholders shared by the GB-CMA relevant to their decision-making process	20
	Total	**71**
Documentary data	Reports or publications relevant to the risks and risk management strategies associated with environmental water delivery in Goulburn	10
	Total	**82**

The thematic analysis was guided by the question: How do environmental water managers perceive and manage risks while planning and delivering environmental water? In order to answer this question, primary and documentary data were organized into themes based on different types of risk events. This meant that for each type of risk event, further analysis could be performed to explain how each risk was perceived and managed. Data were analysed this way because the perception and management of risk varied depending on the type of risk. We defined *risk* in this study context as a potential adverse event that affects the planning, delivery or outcome of the environmental watering actions. The primary data mention several such risks.

The meaning of the term *risk* used in the paper reflects its use by our interviewees and differs from traditional risk assessment terminologies. It is derived from the thematic analysis and hence does not necessarily fit the traditional definition related to likelihood and consequence. The term *risk* used in this paper somewhat aligns with the term *hazard* from the literature (Scheer et al., 2014); *hazard* is used as the potential for adverse effects. We used the term *risk* in this study solely because the term *hazard* did not appear in the data, whereas the term *risk* occurred several times in the context of potential adverse events associated with environmental watering. The terms *threats* and *consequences* as the causes and effects of the risk events broadly align with the literature, especially in the cases where they represent a risk in the 'bow-tie' method of risk assessment (Abdi et al., 2016; Jones & Israni, 2012). It is worth noting that our observation that EWMs did not mention the likelihood of risk events in their file notes defied our initial expectation of how they consider risks in their decision-making process.

The results were organized into a *risk table* (see Table S2 in the supplemental data online) centred around seven key risk events (Table 2) identified during the analysis. Each key risk event could be understood to include the following:

- The progression of the risk starting from *threats*, through the *key risk event* and to the consequences (Figure 2) from columns 1 to 5.
- Key drivers contributing to the risk events in column 6.
- Risk management strategies adopted or proposed by the GB-CMA in column 7.

The seven risk events identified in the risk table are listed in Table 2 with a brief description of each event.

The risk table includes additional columns for threat and consequence to clarify the pathway from *threat* to the *risk event* and onto consequence (Figure 2). An *indirect threat*

Table 2. Details of the key risk events listed in the risk table. The first three (risk events 1–3) are explained in further detail in the main body of this paper.

No.	Key risk events	Details
1	Risk to vegetation due to prolonged inundation from high flows	Seedling mortality occurs if high flow events occur within 6 weeks of spring fresh. Low flow is required after seed germination for early seedling establishment
2	Risk of not meeting the conditions required for coordinated water delivery to assist fish migration	There is a management goal to provide coordinated water delivery aiming to stimulate the migration of silver and golden perch fishes into the Goulburn from the Murray River
3	Risk of insufficient water or channel capacity to deliver environmental water	Risk of not having sufficient water to meet the environmental water demand in Goulburn or not having sufficient capacity in the channel to deliver it
4	Risk of creating uncertainty due to the difference between forecasted versus actual water demands and availability	Actual water demand and availability differ from what is planned, leading to modification or cancelling some of the planned environmental delivery
5	Risks from other water users and weather variability	Environmental water delivery in Goulburn was affected by demands from other water users and weather variability
6	Risk of getting an adverse outcome from planned water delivery	Risk of getting an adverse outcome for planned environmental delivery
7	Risk of not meeting intended environmental outcome	Risk of not meeting intended Goulburn environmental objective specified in the GB-CMA's annual seasonal watering proposal, even after successfully delivering planned environmental water due to unknown reasons

leads to a *direct threat*, which is the immediate cause of the risk event. The risk event causes an outcome (an *immediate consequence*), which leads to a *fundamental consequence* of concern. This is perhaps best demonstrated through the example in Figure 2. The indirect threat of unseasonably high volumes of consumptive inter-valley trade (IVT; water traded out of the Goulburn catchment for consumptive purposes in the Murray River) water being traded out of the system during summer, leads to a direct threat of failure to meet maximum low flow requirements for bank vegetation along the Goulburn River. This leads to a risk to bank vegetation due to prolonged inundation during the growing season. The immediate consequence of this risk event is a loss of vegetation and consequent bank erosion, and this will ultimately lead to the fundamental consequence of loss of community support for the environmental water programme.

The risk table also contains the *key drivers* that influence the different elements of the risk progression (in column 6) and the *management strategies* from EWMs (here, GB-CMA) to manage the risk event (in column 7). The drivers are identified based on their mention in the primary and documentary data under key risk event themes. The management strategies are a list of decisions that EWMs (1) currently undertake to manage different elements of the risk progression or (2) propose to adopt in the future and are formed based on the lessons learned from their past decisions. The scope of the decisions in this paper is limited to the management strategies listed in the risk table, which are discussed in detail in the subsequent sections and listed in Table S1 in the supplemental data online. The example section of Figure 2 lists these decisions in response to 'risks to vegetation due to prolonged inundation'. They include negotiating with the delivery partners to reduce the flow rate of IVT and delivering it as a series of pulses, monitoring vegetation

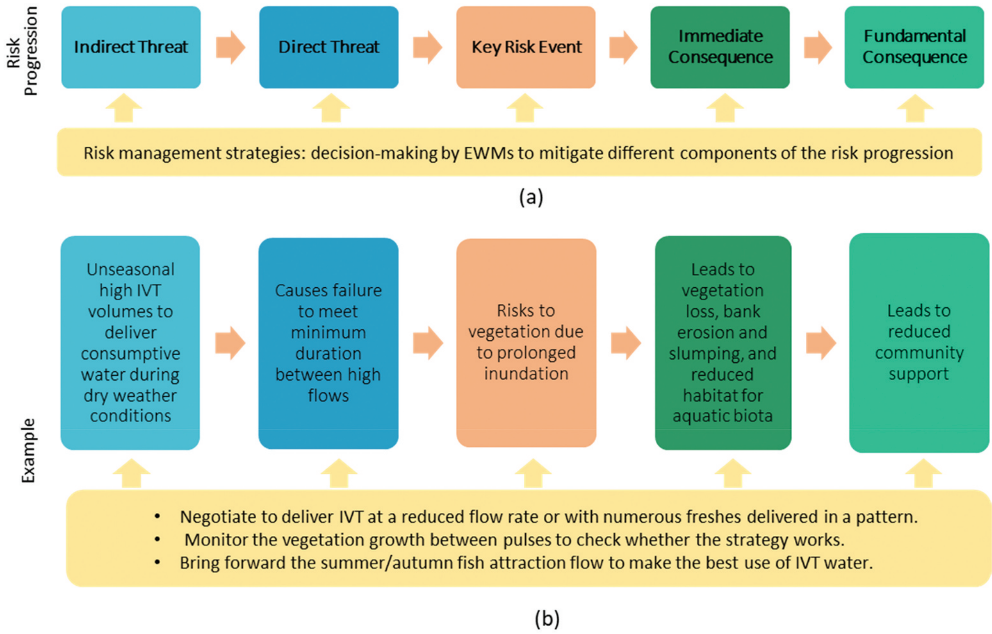

Figure 2. Risk progression organized in the risk table with one example from the table. (a) The key risk event proceeded with direct and indirect threats to the key risk event and is succeeded by immediate fundamental consequences from the key risk event. Management strategies affect each element of the risk progression. (b) An example of different elements of the risk progression and their management strategies for the key risk event – risk to vegetation due to prolonged inundation.

growth in response to these pulses and adjusting other planned freshes to minimize the damage to vegetation.

The three risk events most commonly discussed in the primary data were: (1) risks to vegetation from prolonged inundation, (2) the risk of not meeting conditions required for coordinated water delivery to assist fish migration, and (3) insufficient water or channel capacity for environmental water delivery (risks events 1–3) (Table 2). We discuss each of these key risk events with further details below, including relevant extracts from the risk table in Tables 3–5. Risk events 4–7 (Table 2) were less common in the data. They are included in the risk table (see Table S2 in the supplemental data online) but not described further here.

Risks to the vegetation due to prolonged riverbank inundation

The thematic analysis revealed that riverbank vegetation is threatened by prolonged inundation in summer during periods of high flows and not meeting a minimum duration between these high flows at the early stages of their seedling establishment. This is supported through the environmental flow assessment literature for the Goulburn River. Low flows are essential during summer and autumn seasons to support the growth of aquatic macrophytes – aquatic vegetation that grows in or near the water (Chee et al., 2009; EPA, 2022; Treadwell et al., 2021; Wood et al., 2021). Hence, periods of sustained high flows (more than 1000 ML/day in the Goulburn River) during summer are particularly

Table 3. Risks to vegetation due to prolonged inundation.

Indirect Threat (1)	Direct Threat (2)	Key Risk Event (3)	Immediate Consequence (4)	Fundamental Consequence (5)	Key Drivers (6)								Strategies used by GB-CMA to manage the risk event (7)
					Organisations								
					GB-CMA	GMW	CEWH	MDBA	VEWH	Weather factors	Water Market	Other water users	
Unseasonal high IVT volumes to deliver consumptive water during dry weather conditions					x	X		X		x	X	X	1. Negotiate to deliver IVT at a reduced flow rate or with numerous freshes delivered in a pattern. 2. Monitor the vegetation growth between pulses to check whether the strategy works. 3. Bring forward the summer/autumn fish attraction flow to make the best use of IVT water.
Regional-scale environmental water requirements require water delivery to Murray River in conflict with Goulburn priorities.	Causes failure to meet minimum duration between high flows	Risks to vegetation due to prolonged inundation	Leads to vegetation loss, bank erosion and slumping, and reduced habitat for aquatic biota	Leads to reduced community support	X	x	X		x	x			1. When splitting the delivery between environmental and consumptive IVTs, deliver a higher baseflow to accommodate environmental IVT before the consumptive IVT demand commences and modify the September fresh hydrograph to accommodate both IVTs. 2. Modify the start date of the spring fresh by not more than one week to meet Goulburn objective and, to some extent, mid and lower Murray objectives 3. Taking a firm position to not participate in regional watering actions that do not directly benefit Goulburn.
Spring or summer fresh delivered on already inundated riverbanks					X					x			1. If the winter fresh is fully delivered, reduce the two weeks duration of the September fresh (based on Roberts (2006), mentioned in the primary data) 2. Cancel the planned spring freshes if it is expected to lead to adverse outcomes for the vegetation.
Prolonged inundation due to high unseasonal flooding due to natural events										X			Coordinate with delivery partners to plan future events to minimise the damage caused by the prolonged inundation associated with high natural flow events.

Note: Columns 1–5 are risk progression with the key risk event at the centre (column 3) and threats (columns 1 and 2) and consequences (columns 4 and 5) on either side of the key risk event. Key drivers contributing to one or more of the elements of the risk progression are given in column 6, with different sizes for markers depending on the scale of contribution. Strategies used by the GB-CMA to manage different elements of the risk progression are given in column 7. Numbers are assigned to the columns to cross-reference in the main body of the paper.

Table 4. The risk of not meeting conditions required for coordinated water delivery to assist fish migration.

Indirect Threat (1)	Direct Threat (2)	Key Risk Event (3)	Immediate Consequence (4)	Fundamental Consequence (5)	Key Drivers (6)								Strategies used by GB-CMA to manage the risk event (7)
					Organisations					Weather factors	Water Market	Other water users	
					GB-CMA	GMW	CEWH	MDBA	VEWH				
Conflicting priorities between partner organisations	Causes delay in receiving feedback from partner organisations during the planning and execution stage				X	X	X	X	x	x		x	1. Early planning and communications with partners so that everyone is on board with the process. 2. When the partners' priorities conflict, negotiate to adjust the timing of their water deliveries. 3. Coordinate with other CMAs to align their planned freshes with the coordinated delivery.
High demand from consumptive water users during dry weather conditions or high natural flows during wet weather	Causes insufficient water or channel capacity to facilitate the coordinated delivery					X		X		X	x	X	1. Only proceed when there is enough capacity in the system for the delivery and for meeting demands from other users. 2. Use all available infrastructure to reserve water to meet irrigation demands during the coordinated delivery.
The predicted flows from the coordinated delivery could be higher than the expected flows in the Goulburn river	Causes flooding private properties or damages the riverbank vegetation	The risk of not meeting the conditions required for a coordinated water delivery	Leads to delaying or cancellation of the coordinated water delivery	Leads to insufficient cues triggering fish migration.	X	X	X	X	x				1. Send advice to the impacted irrigators that some potential high-flows 2. The impact on vegetation may not be eliminated if water managers proceed with the coordinated water delivery, other than to plan for vegetation recovery in the coming seasons. However, this is not a major threat as the impact is minimal since it is not a peak vegetation growing season
Weather conditions at the time of coordinated delivery can be different from forecasted weather conditions at the planning stage	Cause unexpected water demand from other water users when weather conditions are drier than forecasted.									X		X	Proceed with the coordinated delivery only if it is not severely compromised by the water demand of consumptive water users.
Higher priority watering actions will only proceed during dry weather conditions	Causes insufficient water to release from the Goulburn River to facilitate the fish migration.									X			Seek water holders for any environmental water available in Murray and top it with the Goulburn component.

Note: See the note to Table 3.

Table 5. Risk of insufficient water or channel capacity to meet the environmental water demand in Goulburn.

Indirect Threat (1)	Direct Threat (2)	Key Risk Event (3)	Immediate Consequence (4)	Fundamental Consequence (5)	Key Drivers (6)								Strategies used by GB-CMA to manage the risk event (7)
					Organisations								
					GB-CMA	GMW	CEWH	MDBA	VEWH	Weather factors	Water Market	Other water users	
Dry weather conditions increase IVT demand	Causes high unseasonal IVT delivery volumes in the channel	Insufficient water or channel capacity to meet the environmental water demands in Goulburn	Leads to a failure to meet priority environmental water objectives	Leads to a failure to meet community expectations and loss of support for environmental watering actions		x				X		X	1. Engage with the community to inform the drivers of the high flows, especially in dry conditions. 2. Negotiate with GMW to alter the volume and timing of the IVT deliveries to facilitate or act in place of environmental water delivery.
Capacity constraints at Barmah Choke restrict water delivery from the upper Murray during periods of high demand	Causes Goulburn River to supply Murray system environmental water demands				X		X	X	X				Discussion with all the environmental water holders and agreement to make sufficient water available to deliver a high baseflow.
Junction Wetlands at the confluence of the Murray and Murrumbidgee rivers require coordinated delivery from the Goulburn and Murrumbidgee rivers to build on the benefits of the natural freshes received in the previous season.	Causes Goulburn River to supply the coordinated watering action						X						Only support the coordinated watering action if it directly benefits the Goulburn.
Dry weather conditions cause low water allocation and higher consumptive demands in the Goulburn.	Low allocation causes not enough water to support Goulburn demand, and high consumptive demand causes insufficient channel capacity									X			1. Only meet the highest priority environmental watering objectives 2. Utilise IVT water delivery to provide a higher baseflow in summer 3. Communicate with the VEWH and CEWH to trade water into the Goulburn system for later in the year 4. Inform community members regarding possible watering actions and provide education regarding the need for environmental delivery in dry weather conditions.
The long-term trend of declining water availability due to climate change	Causes environmental demands to not be met in full in future									X			Carryover water to next season if water is available after meeting the current year's higher priority environmental objectives.

Note: See the note to Table 3.

damaging, as the littoral vegetation is actively growing during this time (Wood et al., 2021). In addition, at least five weeks of low flows following a high-flow event is also important to ensure that seedlings are well established and survive inundation by later summer/autumn flows (DELWP, 2022).

Based on the primary and documentary data, the direct threat leading to this risk event is a failure to meet the minimum duration of low flows between two high-flow events (Table 3). There are four indirect threats that cause this: (1) the delivery of consumptive IVTs from the Goulburn River to the Murray River; (2) the delivery of environmental IVT (similar to consumptive IVTs, i.e., water delivered from the Goulburn catchment for environmental purposes in the Murray River) from the Goulburn River to the Murray River; (3) the delivery of environmental water for the Goulburn River (if delivered as a high flow and by not meeting the minimum required interval between high-flow events); and (4) prolonged inundation due to flooding from natural events. The immediate consequences of lost vegetation due to unseasonal inundation are bank slumping, bank erosion and reduced habitat for aquatic biota (column 4), which has a fundamental consequence of increased reputational risk for the environmental water programme within the community (column 5). Therefore, in addition to failing to achieve the vegetation outcomes, the CMA also has to manage the reputational risks arising from the community falsely assuming that the adverse effects on the riverbanks from IVTs and high natural flow events are due to environmental water delivery.

> The CMA have previously had issues with bank slumping and local community concerns that environmental water caused this. The CMA and water holders have spent a lot of time and resources, including monitoring of bank slumping and erosion since 2012.(file notes, November 2018)

The consumptive IVT is the most frequently mentioned threat compared with the other three indirect threats. Consumptive IVT demands are higher during dry weather, causing the MDBA and GMW to negotiate the volume and timing of transfers as the Goulburn becomes a major source of water to meet the IVT demand. These transfers normally happen during naturally low flow conditions in summer when there is adequate capacity in the downstream storages (primarily in Lake Victoria) (Figure 2) to meet the South Australian demand. This high volume of consumptive IVT deliveries happens at the time of early seedling establishment of river bank vegetation, killing most of these seedlings. Unfortunately, WSAs do not get the flexibility to plan the deliveries at a time that minimizes the threat due to delivery capacity constraints in the lower Murray.

> The largest volume ever of IVT was delivered through the Goulburn River in summer/autumn 2018, and the lower banks were continuously inundated for approximately 98 days. Consequently, much of the fringing vegetation died along the entire lower Goulburn River, with some small sections remaining above the 2,500 ML/day level.(file notes, August 2018)

The threat from environmental IVT is due to the conflict in priorities between the regional and catchment-scale managers. While the priorities of these organizations complement each other in most cases, there are instances mentioned in primary data where the delivery of environmental water to meet the environmental demands of the lower and mid-Murray River pose risks to vegetation in the Goulburn River if delivered at specific times. For example, the CEWH's request to delay the spring fresh in the Goulburn for a couple of weeks to meet environmental water objectives in the mid-Murray River (from Torrumbarry to Wentworth) was not accepted by the CMA (but they did agree to delay by one week). The rationale was that postponing spring fresh for longer than one week would have shortened the gap in high flows between spring and summer freshes, creating a risk for Goulburn vegetation.

> There was discussion about the timing of the Goulburn spring pulse and whether a delay was possible to assist meeting some of the mid and lower Murray (environmental) objectives. I was prepared to delay the start date of the fresh by one week only. Rationale: the spring fresh is aimed at dispersing seed and enabling plants to grow and increase vigour, flower and produce seed. They cannot do this if there is not enough time between the fresh and subsequent high flows.(file notes, August 2018)

The thematic analysis of data revealed a range of strategies adopted by the GB-CMA to manage different elements of this key risk event (column 7). These strategies included negotiations with organizations outside of environmental water management to limit the consumptive IVT volume, negotiations with WSAs to restrict or change the delivery of consumptive water for the Goulburn River, and modifying the timing and peak flow of the planned environmental water deliveries. A recent example of negotiations with organizations outside of environmental water management is the CMA's lobbying of the state government to revise the trade rules to reduce the volume of IVT and timing of delivery to limit impacts on the environment.

> If more water was requested, the CMA would not be very supportive. The focus for 2018/19 is to build resilience into the lower and mid bank riparian vegetation, so it can cope with drought and flood in a sustainable and resilient way. Riparian vegetation is vital to a healthy functioning riverine environment by protecting the toe of the bank and preventing erosion, providing habitat and protection for macroinvertebrates and small bodied fish, providing carbon to aquatic food webs, and regulating stream temperature and water quality. Altering the timing and seasonality of flow in regulated rivers can encourage seed production and plant germination of different plants, ultimately resulting in a changed vegetation structure. (file notes, September 2018)

> The highest priority for delivery of the high-water volumes in 2019 is to pulse the flow to enable existing lower bank vegetation to recover, grow and withstand temporary inundation. Recovery of vegetation on the lower bank, will assist in future bank stabilization.(file notes, November 2018)

The risk of not meeting the conditions required for coordinated water delivery to assist fish migration

While each CMA is responsible for managing the environmental water in their respective catchment, where targeted environmental processes occur at a regional scale, coordination of flow events may be needed across several catchments (and therefore with multiple delivery partners). Interviews highlighted a prominent example of this, with the coordinated water delivery required between the Murray River (low flows) and the Goulburn River (high flows) to facilitate migration of juvenile (about 1.5 years old) silver and golden perch fishes from the Murray River to the Goulburn River to recruit into the local population (Koster et al., 2021; Zampatti et al., 2021).

> The CMA thought about these issues, knowing environmental water management has evolved from one river only viewpoint, to wider southern connected basin viewpoint and benefits (file notes, June 2017)

> A summer fish attractant/migration flow, targeting juvenile Golden and Silver perch, was included in the Goulburn Seasonal Watering Proposal (SWP) for 2016/17. At the time, details of this flow were still to be finalised. However, its inclusion in the SWP was to enable its delivery if sufficient water, operational details and field monitoring became available.(file notes, May 2017)

Managing water delivery in the Goulburn River alone will not help fish migration if there are inappropriate conditions in the Murray River to initiate this migration. For example, primary data (file notes, May 2017) specified the preferred water levels and corresponding flow rates at different locations in the Murray and Goulburn rivers to facilitate the fish migration from the Murray into the Goulburn. This is achieved by first varying the water level downstream of Torrumbarry Weir (Figure 2) on the Murray River to initiate the migration via fishways, and then adjusting the water levels upstream of Torrumbarry Weir timed to match high flows from the Goulburn River to facilitate fish migration into Goulburn River at the confluence of the Goulburn and Murray rivers (Figure 2).

The thematic analysis of primary and documentary data reveals the complexities associated with the coordinated deliveries to facilitate this fish migration (Table 4). The data highlight several discussions among delivery partners and frequently mention the direct threat of delay in receiving communication from the partner organizations caused by the indirect threat of conflicting priorities among organizations. For example, during the coordinated delivery planned in 2017, the file notes mentioned delays in MDBA staff responding to hydrograph suggestions because their attention was being directed towards managing spring flooding.

> This communication commenced in September, however due to spring floods MDBA resources where not available to provide feedback for a number of weeks.(file notes, May 2017)

> A new, and coordinated, watering action requires a lot of time in the planning stage prior to delivery and much communication between all interested parties.(file notes, May 2017)

During dry weather conditions there is an indirect threat that the Murray River will be already at capacity with water to meet consumptive demands from lower Murray water users, restricting the ability to manipulate the water levels in Murray River upstream of Torrumbarry Weir to facilitate the coordinated delivery. Natural flows in the Murray River during wet weather conditions can also reduce the capacity to deliver these coordinated conditions. Hence, if there is already a high flow in the Murray River upstream of the Torrumbarry Weir (either due to the water deliveries that are already committed or natural flows), water releases from the Goulburn River will not be adequate to provide sufficient cues for the fish to migrate into that system as there will be insufficient difference between flows in the two rivers.

There is also an indirect threat of discrepancies between the weather conditions at the time of coordinated delivery and weather conditions forecast during the planning stage, resulting in a direct threat of unexpected changes in water demand from other water users. This is because the actual water demands from consumptive users are not known at the time of planning the coordinated delivery, creating uncertainty regarding how these demands will influence the watering actions. For example, during the coordinated watering action in 2017, when there was high unexpected irrigation demand from the Torrumbarry Irrigation Area, the weir staff had to divert the water to irrigation flows instead of delivering flows to trigger the fish migration.

> An increase in irrigation demand in the Torrumbarry Irrigation Area on February 25, led to an increase in diversions from the National Channel. This was combined with increased irrigator diversions and an expected drop in Murray River flow due to operations. These factors meant that the ideal steady releases or river level rises were not met.(file notes, May 2017)

There is also an indirect threat of high volumes of water released from the Goulburn River as coordinated deliveries causing a direct threat of adverse impacts on some water users or environmental assets along the Goulburn River. This is because these high flows may flood private properties along the river or damage riverbank vegetation (columns 3 and 4). However, this impact on vegetation is not a major threat as it is not a peak vegetation growing season. The immediate consequence of this risk event is that the coordinated delivery may be delayed or cancelled (column 5), which has a fundamental consequence of not providing sufficient cues for fish migration (column 6). It is worth noting that despite the many variables to manage, the coordinated delivery provided enough cues in 2017 to trigger fish to migrate upstream into the Goulburn (file note, May 2017).

The thematic analysis of data revealed a range of management strategies by the GB-CMA to target each indirect threat (column 7). These management strategies are already in place or planned for future watering actions by the GB-CMA. Examples of management strategies that are already being used by the GB-CMA include negotiating with partner organizations to adjust the volume and timing of their priority watering actions to align with the targeted fish migration, and only proceeding with the water delivery when there is capacity in the Murray River (required low flow condition) to manipulate the water levels upstream of Torrumbarry Weir. An example of management strategies planned for future watering actions by the GB-CMA is to use Kow Swamp (Figure 2) and storages other than the Torrumbarry Weir to meet high irrigation demand from the Torrumbarry Irrigation Area. This would allow for low flow conditions and manipulation of water levels upstream of the Torrumbarry Weir.

> There is no specific requirement to coordinate a hydrograph in the Murray River, as the Goulburn design is based on the Murray running at near capacity. At the time of developing the hydrograph, this was believed to be the most likely scenario given the climate outlook was for hot and dry, and entitlements and water availability was good.(file notes, December 2017)

> Following discussions with GMW, it was noted that filling Kow Swamp and other Torrumbarry Irrigation Area storages prior to the event would have meant National Channel diversions could have been kept more constant throughout the event as there would have been more water in storages to meet irrigation demand. This is a learning that could be considered in future events.(file notes, May 2017)

Risk of insufficient water or channel capacity to meet the environmental water demand in the Goulburn

The risk of insufficient water to fulfil the environmental water demand and inadequate capacity in the delivery network to supply the requested environmental water were frequently discussed in both primary and documentary data (Table 5). We defined these two conditions as the risk of not meeting the *lower environmental threshold* and exceeding the *upper environmental threshold*, respectively. Not meeting the lower environmental threshold means not having adequate water in the system to meet the priority environmental watering actions, resulting in a failure to achieve the desired environmental outcomes. Exceeding the upper environmental threshold means that there is excessive water in the system to meet the environmental objectives, damaging some key environmental assets. For example, the high flow required for consumptive IVT delivery through the Goulburn River in summer crosses the upper environmental threshold needed to maintain vegetation.

Drier weather conditions are an indirect threat to this risk event, causing direct threats of both (1) not leaving sufficient water to fulfil priority environmental actions due to lower allocations, and hence not meeting the lower environmental threshold; and (2) high flows in the Goulburn River to meet the high consumptive demands within and outside the Goulburn River system (consumptive IVTs), and hence exceeding the upper environmental threshold. While the environmental water demands of instream river habitats may be satisfied with the consumptive water delivery (if delivered at a flow rate and during a season favourable to the habitats), this is not the case for watering actions required for wetlands and floodplains in the Goulburn River. This risk event leads to the immediate consequence of not meeting environmental objectives, resulting in a fundamental consequence of reduced community support for environmental watering actions. Failure to achieve the desired environmental outcome itself can be considered as a fundamental consequence of the cost of environmental water management.

> If irrigation demand in the Goulburn Murray irrigation district continues as it is, GMW are not confident they can deliver the entire fresh, and instead suggested the likely peak flow rate could be around 7,500 ML/day. This will depend on conditions at the time and irrigation demand. (file notes, September 2018)

High consumptive IVT demand is a direct threat to vegetation, as discussed in key risk event 1, above, as the high flow required to meet demand in summer exceeds the upper environmental threshold. The file notes discussed instances of using IVT deliveries to assist some of the freshes for Goulburn environmental water. However, there were concerns mentioned in the file notes that IVT demand can be unreliable and cease abruptly because of a change in demand, followed by the suggestions from EWMs to only proceed with delivering these freshes if there is a certainty about IVT demands. One consequence of the threat of high IVT delivery during summer is that the community can incorrectly assume that the high water in the river during summer is for environmental water delivery. The management strategy for GB-CMA is to communicate with community members on the drivers of the high flows, especially during dry conditions.

> If we commence the fresh and IVT drops off, it is likely this will occur because there is rainfall, which may then be able to be used to complete the fresh (with a small volume of environmental water to manage the recession if required and available). (file notes, December 2017)

> Sections of the community perceive (incorrectly) that high river flows are due to environmental releases in dry conditions, leading to a loss of support for watering activities. (Documentary Data, Seasonal Watering Proposal 2020; GB-CMA, 2020)

In addition to consumptive IVTs, albeit to a minor extent, environmental IVTs can also be a direct threat when using the Goulburn River to supply environmental water to the Murray River system. For example, the file notes refer to a request from the CEWH to deliver an August fresh to coordinate with environmental water delivered from the Murrumbidgee River (Figure 2) for water to break out into 'junction wetlands' at the confluence of the Murrumbidgee and Murray rivers. The rationale behind the CEWH's request was that these junction wetlands had received natural freshes the previous season, and the CEWH wanted to continue to support the wetlands. However, the EWMs in GB-CMA expressed their concern that delivering these freshes would not leave enough water to meet Goulburn's objectives later in the season, hence not meeting the lower environmental threshold. To manage these threats from environmental IVT demands, the EWMs decided not to support any deliveries that did not complement objectives for the Goulburn River (Table 5, column 7; see also Table S2 in the supplemental data online).

> the CMA concluded not to deliver an August pulse in the Goulburn River. Although environmental water delivery in the Goulburn (and southern basin) has evolved substantially since its inception, the Goulburn Broken CMA is charged with managing the river systems in the GB catchment, and consequently the Goulburn and Broken River/Creeks are the first priority in the delivery of environmental water. It was thought that water used in an August fresh can provide greater benefit to the Goulburn River if used at another time throughout the year e.g., a pre conditioning spawning pulse around October. (file notes, June 2017)

The CMA was also concerned if this water was used so early in the year, the planned winter fresh for 2018 may need to be modified, or unable to be fully delivered. And although a lower priority in the Goulburn SWP, a summer/autumn fresh to attract native fish into the river is also a priority that can be delivered if enough water is available.(file notes, June 2017)

The thematic analysis of data revealed a range of management strategies adopted by the GB-CMA to target each indirect threat (column 7). These strategies primarily involve meeting high-priority environmental demands, reducing the peak flow rate of the hydrograph to accommodate consumptive water delivery, negotiating with water holders to release a higher volume of water to meet the Goulburn demands, making use of IVT deliveries to deliver environmental freshes or baseflows where possible, and communicating early with community members regarding possible watering actions when there is limited availability of environmental water in dry weather conditions.

> There are other lower priorities but due to low water availability this year, the priorities mentioned above are likely to be the only ones delivered (with the exception of higher baseflows over summer using IVT).(file notes, December 2015)

> If modifications of deliveries are required due to lack of water later in the season, the 2018–19 winter fresh is likely to be modified to a smaller peak flow rate or shorter duration. (file notes, June 2019)

> This suggests, that without using environmental water, there will still not be enough water to deliver the full winter fresh. It might be worth discussing options with VEWH and CEWO (preceding organisation of CEWH) for trading water into the Goulburn system for later in the year, or modifying the proposed hydrograph of the winter fresh.(file notes, December 2017)

Discussion

The risk table provides a structure to show the progression of different risk events associated with the planning and delivery of environmental water. The research shows that many of the risk management strategies for EWMs require cooperation from different organizations and consumptive water users, making it challenging to successfully deliver environmental water. There are implications of these findings for operations, planning and water resource modelling.

Implications for operations

The risk table is a comprehensive guide to assist EWMs in their decision-making. It identifies key risk events, key drivers contributing to the risk event, and the management strategies they have used or listed in their documents to use in future. Contrary to empirical studies quantifying different risk events for each environmental asset (Alluvium, 2016; Peter Cottingham & Associates and SKM, 2011; Wood et al., 2021), this study sheds light on how EWMs manage risks in their day-to-day operations and how they negotiate with their partner organizations in planning environmental water deliveries.

Importance of gaining community support for environmental water deliveries

Loss of support from the community for environmental watering actions is a fundamental consequence of some key risk events. On certain occasions, EWMs also have to manage the consequence of the community falsely perceiving that adverse outcomes from consumptive deliveries are the result of environmental water deliveries. For example, the water delivery associated with the consumptive IVTs in summer can cause the community to falsely perceive that high-flows and associated adverse outcomes result from environmental water deliveries (see the key risk event 3 in the Results section). The risk table can be used to inform programmes to raise community awareness and increase engagement from community and partner organizations. In adaptive environmental water management, with changing management strategies in the wake of new knowledge, simultaneously engaging with the community members to discuss the benefit of environmental watering is essential to prevent misconceptions.

Shift in risk perception and management strategies with changes in circumstance

The risk perception of EWMs has changed as the nature of the associated threats changed. This shift in risk perceptions comes about because of (1) a change in the severity of the different elements of the risk progression, or (2) an improved understanding of the risk based on new evidence from scientific studies, experience or community input.

A prominent example of a shift in management strategies is associated with a change in EWMs' perception of consumptive IVT deliveries. In the early years of IVT deliveries

(2015–16), EWMs were using consumptive IVT deliveries to help meet environmental water deliveries. However, as the volume of IVTs grew, EWMs had concerns that consumptive IVT quantities were excessive and becoming a considerable threat to riverbank vegetation. The key reason for the changing attitude is the increase in the severity of the threat with rising IVT volumes. This shifted the management strategy from one of advising the GMW to top up the IVT delivery hydrograph to aid environmental outcomes, to instead taking a stance against excessive IVT deliveries.

Attitudes have also shifted over the role of environmental deliveries for local as opposed to regional environmental outcomes. The GB-CMA has shifted its position over time from using Goulburn water to assist wider basin outcomes, to now not supporting water delivery requests that do not simultaneously meet a direct Goulburn objective, or worse, that pose a risk to Goulburn environmental assets (see the key risk event 1 in the Results section for further details). Their rationale is that their primary objective as an organization was to support environmental assets in the Goulburn River. Sometimes, the Goulburn and mid-Murray environmental water objectives are incompatible; in that case, each organization works toward their own best interest.

Lack of probabilistic thinking on managing risks

The lack of any mention by the EWMs of the likelihood of occurrence or severity of the risk events defied our initial expectation on how they perceive and manage risks in planning and delivering environmental water. As EWM decision-making becomes increasingly dependent upon other water users and delivery partners, having mechanisms to quantify different risk events, especially those threats arising from other organizations, would be beneficial for better managing different elements of the risk progression. This approach would also help EWMs to discuss the reasoning behind certain watering decisions with community members by demonstrating why managing certain risk factors is of higher priority, especially for the cases where community interest does not align with the environmental watering actions. In addition, this approach would aid negotiations with the delivery partners, especially for risk events where the risk tolerance is very low.

A comparison with the decision-making of consumptive water users

While this paper focuses on the risk management strategies perceived and adopted by EWMs in their decision-making processes, there are some fundamental similarities and differences between the decision-making processes of EWMs and consumptive users in using their allocated water. In active environmental water management, EWMs decide when and where to use the allocated water to achieve the best ecological response. Irrigators also make similar decisions for their allocated water (Horne et al., 2018). These include options such as (1) deciding whether to trade water in the market instead of planting crops this season, and (2) if they decide to plant, then how much water to order for the crops planted. While the biophysical characteristics of the system (e.g., weather conditions) is a key driver contributing to some of the major risk events for both EWMs and consumptive water users, the results show that EWMs' decisions are also governed by the decisions made by other water users and WSAs, and are also concerned with public support. In contrast, irrigators are mainly concerned with environmental and market conditions when making water use decisions (Meempatta et al., 2019).

Since the same WSAs allocate and deliver water to both these water user groups (Meempatta et al., 2021), knowing what contributes to their stakeholders' decision-making in managing risks would help WSAs plan water allocation and delivery efficiently. This is also important when representing these water users and suppliers in the WRMs used to understand the system and plan for future interventions.

Implications for planning

When designing policy instruments for environmental water deliveries, the importance of acknowledging and specifying the role of various decision-makers and influencers is increasing as environmental water planning evolves from the catchment to a broader regional scale. While these cross-institutional arrangements are essential for successful environmental water outcomes (MDBA, 2019), this study shows that organizations with conflicting priorities are a significant threat to coordinated water delivery (see the key risk event 2 in the Results section). Additionally, existing governance structures in the Basin are complex and lack transparency across the organizations and government departments responsible for environmental water planning and delivery (Kirsch et al., 2022). Currently, EWMs have to spend a lot of time communicating with other delivery partners (Table 5, column 2), which can result in missing the ideal conditions for delivery. Since the primary purposes of each delivery partner differ, it is important to design policy instruments that clearly distinguish the roles of individual organizations responsible for managing the threats to any risk event.

We also acknowledge that many of the challenges are newly emerging, given that environmental water planning and delivery is a relatively new field (DPIE EES, 2021). Therefore, it is important to have provisions for reviewing the policy instruments as new challenges emerge. For example, despite the floodplains along the Goulburn River being identified as 'wetlands of national significance' (GB-CMA, 2014), and the delivery of overbank flows to these floodplains being identified as a priority for local stakeholders (Horne et al., 2020), none of the interviewees nor the file notes discussed this flow event or its associated risks. This may be because managed overbank flows are not allowed under the current operating rules. It would be interesting to see how recommendations from the Victorian Constraints Management Program (see the case study section above) to relax the restrictions on these flow events affect the resulting policy instruments, and how those policies acknowledge and specify the role of various decision-makers and influencers.

Since environmental water management is an evolving area, some management strategies considered best practices in the past have changed with improved knowledge of the systems and better understanding between different organizations (DPIE EES, 2021). EWMs revealed during the interviews that their management strategies are generally based on EWMs' individual knowledge of the system, which is based on their experience and not always formally recorded in operational plans. This management approach is inconsistent with the best principles of evidence-based environmental management (Keene & Pullin, 2011). We also observed that the way information is logged can differ among EWMs within the same organization. Hence there remains a need for a unified approach and policies in place to organize and synthesize new information so that it may be used to respond to new challenges that arise in planning and operation.

There needs to be an effort at the organizational level (the CMA in this case) to shift planning for environmental water deliveries from person dependent to policy/process dependent and evidence-based. If not, this will lead to the loss of institutional knowledge when EWMs change jobs (DPIE EES, 2021; Margerum & Robinson, 2015). A comprehensive document of management strategies for the key risk events, people or organizations responsible for managing these risks, and antecedent conditions required to initiate the management strategies would be helpful to create consistency in long-term environmental water management.

Implications for water resource modelling

There is an increasing focus in existing WRMs on finding optimal water allocations for different water users (Dobson et al., 2019; Hassanzadeh et al., 2016; Steinschneider et al., 2014). The optimal water allocation for environmental water is often unrealistic due to the constraints that exist for environmental water delivery. In addition, the current WRMs do not accurately represent the decision-making behaviour of the different human components of a water resources system (Meempatta et al., 2021). We need a realistic representation of environmental water delivery in WRMs, which considers the decision-making power of EWMs and their delivery partners and how they are influenced by various threats that lead to key risk events. A good approach would be to use bottom-up models that allow modelling of the decision-making behaviour of EWMs and their interactions with delivery partners and the surrounding environment. However, there is also a challenge with this approach, as we might overlook the basin-scale implications of environmental water releases and their outcome. Extending the survey to officials in other higher level organizations would help to identify solutions for water releases when there are conflicting priorities. The comprehensive risk table developed in this research could be a basis to help modellers better understand the decision-making of EWMs.

We acknowledge that it would be challenging to capture the impact of EWM decision-making on environmental water delivery using existing WRMs. The thematic analysis of our primary data reveals extensive communication between EWMs and their delivery partners during environmental water planning and delivery. There are also instances in the data where EWMs successfully negotiated with their delivery partners to modify water release patterns to minimize the risks to environmental assets (see the key risk event 2 in the Results section above). While communication is an inherent part of any policy delivery, what makes it particularly relevant in this context is that the EWMs need to negotiate with organizations that have different objectives, and that successful environmental water deliveries are increasingly dependent on these interactions. Hence EWMs cannot make rationally optimum decisions related to environmental delivery, and current WRMs do not adequately capture these complexities. While incorporating such complexities could be difficult for traditional WRM models, bottom-up models such as agent-based models have been shown to be an effective way to give autonomy to different participants in a modelled system.

Conclusions

Our research shows that many factors contributing to the key risks to environmental water delivery are challenging to control and require negotiations with partner organizations and action at the policy level to control the risks. The findings are currently being used to define attributes for EWMs as agents in bottom-up models (i.e., agent-based modelling).

To our knowledge, this is the first study to conduct in-depth research on how EWMs manage the risks associated with environmental water during the planning and delivery stage. While the scope of this study is to understand the risk perception of EWMs in the Goulburn River basin, there are also larger scale risks that need to be managed by higher level organizations that oversee water releases affecting other states and the Murray River. Extending the research to officials of these water holders and state and federal government departments would give us a better understanding of the severity of risks perceived by EWMs compared with those that occur at a basin scale. It would also be interesting to know how risk management in the Goulburn affects the catchments that are hydrologically connected to it (the Campaspe and Loddon rivers).

We would gain further insights into EWM's management of risks by testing the findings of this study in different river basins. While there will be aspects of the risk table unique to individual water resource systems, the results from this study likely apply to EWMs in other regions in Australia and elsewhere around the world. The state of Victoria, where the Goulburn River is located, has a network of CMAs whose primary interest is in protecting the environment. However, elsewhere in Australia and the world, the same organization that manages water for the environment may also manage water for consumptive purposes. This creates conflicting priorities within the same organization in addition to those identified here between different organizations. These conflicts could result in a new threat to several of the risk events identified here, which could be explored in further studies. It would also be interesting to see if we could generate a risk table universally applicable for all catchments in the Murray–Darling Basin, and to see how they are different for environmental water management in other developed and developing countries.

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Credit author statement

L.M.: conceptualization, investigation, methodology, data curation, formal analysis and writing – original draft preparation. J. A. W.: conceptualization, methodology, writing – review and editing, funding acquisition and supervision. A. C. H.: conceptualization, methodology, formal analysis, validation, writing – review and editing, and supervision. L. A. K.: conceptualization, methodology, writing – review and editing, and supervision. M. J. S.: conceptualization, writing – review, and supervision.

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