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Perhaps, perhaps, perhaps: Navigating uncertainty in environmental flow management

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Uncertainty can be an impediment to decision making and result in decision paralysis. In environmental flow management, system complexity and natural variability increase uncertainty. Climate change provides further uncertainty and can hinder decision making altogether. Environmental flow managers express reluctance to include climate change adaptation in planning due to large knowledge gaps in hydro-ecological relationships. We applied a hybrid method of hypothetical scenarios and closed ended questions within a survey to investigate ecological trade off decision making behaviours and cognitive processes of environmental flow managers. The scenarios provided were both similar to participants' past experiences, and others were entirely unprecedented and hence unfamiliar. We found managers were more confident making decisions in situations they are familiar with, and most managers show low levels of confidence in making trade off decisions under uncertain circumstances. When given a choice, the most common response to uncertainty was to gather additional information, however information is often unavailable or inaccessible–either it does not exist, or uncertainties are so great that decisions are deferred. Given future rainfall is likely to be different from the past, environmental flow managers must work to adopt robust decision making frameworks that will increase confidence in decision making by acknowledging uncertainties. This can be done through tools developed to address decision making under deep uncertainty. Adapting these tools and methods to environmental flow management will ensure managers can begin to consider likely, necessary future trade-offs in a more informed, transparent and robust manner and increase confidence in decision making under uncertainty.

KEYWORDS

environmental flow, uncertainty, decision making, climate change, adaptation

1 Introduction

"If you can't make your mind up, we'll never get started". Doris Day.

Without acknowledging uncertainties of the future, managers of environmental flows are effectively aiming to maintain a museum of the past. Environmental flows are an important tool in river health management, primarily used in regulated river systems (Arthington et al., 2018). Determination of environmental flows are typically guided by scientifically based flow assessments that develop recommendations for water delivery linked to specific ecological objectives (Tharme, 2003; Poff et al., 2017). Flow recommendations may include the magnitude, frequency or timing of water releases required to achieve a specific objective. Environmental water (used to deliver flow recommendations) is defined as all legally available water that can be used in a river system to provide environmental benefit such as protection of specific species, habitat maintenance or ecosystem function (Horne et al., 2017).

There is clear evidence that anthropogenic climate change is occurring, yet agreement on how to adapt environmental flow management is far from absolute. Environmental flow assessments (and recommendations) typically aim to restore ecosystems to an historic condition or protect them from further change and use historic flow regimes to make recommendations (Capon et al., 2018; Horne et al., 2022). However the past is not a good representation of the future and climate adaptation is required when determining flow objectives and recommendations for future environmental water (Judd et al., 2022). Under climate change, temperature and rainfall patterns are predicted to change along with rainfall run off relationships and streamflows (Saft et al., 2016). As these hydro-climatic changes occur, some current ecological relationships are unlikely to remain and consequently objectives are also unlikely to be achievable (Judd et al., 2022). Future water use and flow recommendations need to incorporate climate change adaptation (John et al., 2020). Yet, there are many known barriers to climate change adaptation, including insufficient staff and funding, lack of political leadership, backward looking legislative requirements, and uncertainty (Abunnasr et al., 2015; Kiem et al., 2016; Oberlack and Eisenack, 2018; Judd et al., 2023). Uncertainties include future greenhouse gas emissions; the direction, magnitude and intensity of change in response to emissions with large variances in predictions at particular geographic locations (Hallegatte et al., 2012; Shepherd et al., 2018). Managers of water for environmental flows (environmental water managers) cite uncertainty of hydrological and ecological systems' response to climate change as a major barrier to adaptation (Judd et al., 2023). Adaptation to climate change also suffers from considerable uncertainties regarding how social, economic and political systems will react (Kundzewicz et al., 2018).

Part of the role of environmental water managers is to prioritise flow recommendations based on flow assessments and antecedent conditions (Doolan et al., 2017). This 'active' management of water allows managers to determine how much and when to use water to achieve the desired ecological objectives. Management can include releasing water from dams to restore part of a flow regime or adding water releases to a natural flow to hit flow recommendations. Decisions to manage water are made in real time based on current ecological conditions, water availability and other constraints such as channel capacity or social/recreational requirements. At times flow recommendations for one component of the ecosystem (e.g., vegetation) may conflict with recommendations for another component (e.g. fish) and water managers will be required to make a trade off decision between two ecosystem components within the one system. In times of drought management tends to focus on maintaining drought refuges, avoiding species loss, and providing opportunities for ecosystem recovery once drought breaks (Doolan et al., 2017). In times of water scarcity, decision making is substantially more difficult as uncertainties in water availability and ecosystem response become more unknown and constrained.

Uncertainty in environmental flow management can be separated into nature and level. The nature of uncertainty relevant to the types of decisions environmental water managers must make are epistemic uncertainty and aleatoric uncertainty. Epistemic uncertainty arises due to a lack of knowledge or information about a phenomenon or process. This type of uncertainty can be reduced by gaining new knowledge or doing more research. Reducing uncertainty with new information can help increase confidence in decisions (Singh et al., 2020). Aleatoric uncertainty is defined as uncertainty that cannot be reduced by increasing knowledge due to the inherent variability and unpredictability of the phenomenon (Dewulf and Biesbroek, 2018; Singh et al., 2020). Both these sources of uncertainty will increase with climate change.

Levels of uncertainty have been defined by Kwakkel et al. (2010) as the "assignment of likelihood to things or events" with the likelihood able to be expressed either qualitatively or quantitatively. Kwakkel et al. (2010) identified four levels of uncertainty ranging from shallow uncertainty (level one) to recognised ignorance (level four). Following their definition environmental water management under climate change would fall into level three uncertainty. Level three is also referred to as 'deep uncertainty'. This is where alternative options can be specified but probability functions for the likelihood of alternatives cannot be determined, and an order ranking of alternatives is unknown or cannot be agreed on by experts or decision makers. Lempert et al. (2003) defines deep uncertainty as unknown or unagreeable boundaries surrounding the external context of a system, how the system works and where its boundaries lie, and the outcomes of interest from the system or their relative importance.

Both the nature and level of uncertainty impose impediments to making well informed decisions about future management of environmental water. The uncertainty surrounding climate change projections coupled with the natural variability and complexity of ecosystems means there will always be uncertainty in making environmental management decisions. Aleatoric uncertainty will always exist, and epistemic and deep uncertainty provide barriers to timely decision making if the uncertainties cannot be resolved. Herein lies the challenge for environmental water managers: there are uncertainties that will always exist, and others where a decision will need to be made prior to information becoming available. Understanding how water managers respond to such uncertainty will enable development of appropriate tools for planning and policy decisions to be made.

People respond to uncertainty in different ways as detailed by Lipshitz and Strauss (1997) and Pasquini et al. (2019). The three principal response categories to uncertainty are:

- Suppress - through complete denial, ignoring or distorting undesirable information, relying on intuition and taking a gamble. Additionally, fear of making the wrong choice can also result in avoidance of making a decision (Retief et al., 2013). Using traditional rational decision making approaches under climate change could be considered a form of suppression.
- Reduce - by collecting more information, deferring decision making, extrapolating from existing data, and shortening the time frames for decisions. However, deciding to collect more information should be an option employed with caution to

ensure it will add value, be available in time and change the decision outcome (Dietz, 2013).

- Acknowledge–often adopted when reducing uncertainty is not possible. This response involves preparing to confront potential risks under a chosen course of action, and may include incorporating reversible or no regret actions, or making an informed decision of the pros and cons. The use of multiple plausible futures or confidence intervals in data analysis also helps acknowledge uncertainty (Brugnach et al., 2008).

Lipshitz and Strauss (1997) undertook an empirical experiment and determined the following response strategies were used most frequently (in order); reduction, forestalling, assumption based reasoning, weighing pros and cons where there was difficulty choosing between alternatives, and suppression. They also note that different strategies were used in different situations e.g., assumption based reasoning was used where there was incomplete information and reduction was adopted where there was a lack of understanding. When people feel uncertain or a decision is difficult, the response can be to delay, avoid and/or be paralysed to make decisions (Weber et al., 2001; Höllermann and Evers, 2017). In a study by Doerner (1990) people's decision responses to maintaining or improving a complex and dynamic system were observed. Results showed common faults of people's decisions included failing to establish clear goals, treating a complex system as separate variables rather than an integrated system, and making decisions without checking the effects of these to other parts of the system. Doerner (1990) found even though participants had enough information they were not very adaptative in their thinking and devoted most of their time to problems they currently faced rather than looking to potential future problems or how their actions today may lead to future issues.

Decision making in water planning and policy has traditionally relied on rational and probabilistic methods to reduce uncertainty and optimise one preferred option (Haasnoot et al., 2013; Horne et al., 2016; Siders and Pierce, 2021). This approach follows a 'reduce uncertainty' principle where a set of possible actions are determined and compared through probability distribution functions, with the best performing option chosen to optimise a desired outcome (Citroen, 2011; Pasquini et al., 2019). This requires information such as averaged hydrological parameters, the likelihood of alternate states, how actions will combine to form outcomes and the benefit of one outcome over another (Polasky et al., 2011). During assessment of options this approach acknowledges uncertainties, but ultimately aims to maximise one particular outcome within the knowledge of some spread in performance (and uncertainty) amongst all options. The approach often employs data intensive mathematical models that follow generalised principles. They do not provide reasons for why or how a decision may deviate from the norm (Pasquini et al., 2019).

We know that river system dynamics–particularly under climate change–include significant aleatoric uncertainty, where these traditional approaches of 'reduction' can no longer be applied. Managers of environmental water and other natural resources express reluctance to include climate adaptation due to large knowledge gaps surrounding ecological and hydrological relationships (Stein et al., 2013, Judd et al., 2023). Although knowledge is improving, researchers suggest there is a clear need to increase understanding of flow ecology relationships (Thompson et al., 2019). Many models developed to predict biological responses to climate change ignore fundamental biological functions such as species interactions, demography (births, deaths, phenology etc) and evolutionary potential (Urban et al., 2016). Even when attempts are made to include this information in ecological models there is limited data due to funding constraints for long term monitoring programs. Further, the translation of global climate scenarios into meaningful and useful localised hydrological and ecological information for water supply remains a barrier (Kiem et al., 2016). Consequently, probability based decision methods that optimise for one solution will no longer be appropriate (Brugnach et al., 2008; Hallegatte, 2009; Polasky et al., 2011; Maier et al., 2016; Fletcher et al., 2017). Future planning needs to be either robust; include objectives or actions that can be achievable over a range of plausible futures, or dynamic; objectives and policies that are flexible and can change over time as new information becomes available. This causes further challenges for a technocratic industry where data and 'uncertainty reduction' for optimisation has always dominated thinking (Pahl-Wostl et al., 2013; McLoughlin et al., 2020).

This paper examines the readiness and response of environmental water managers to make ongoing decisions under uncertainty. A survey approach is adopted to challenge environmental water managers to make decisions in situations they are familiar with, and possible future scenarios. The data analysis links decision making in three hypotheses with the human responses of Pasquini et al. (2019) and Lipshitz and Strauss (1997). This study investigates the following three hypotheses:

H1: Environmental water staff have a high confidence in making ecological trade off decisions when situations are similar to their past lived experience (reduce)

H2: Environmental water staff are unwilling to make ecological trade off decisions when there is insufficient information (supress)

H3: Environmental water staff will be confident in making trade off decisions when provided with climate change information they consider to be important (acknowledge)

This study provides the first step in understanding how environmental water managers are making decisions, what type of information they consider important and how confident they feel making these decisions. By framing the managers response to uncertainty around 'acknowledge, reduce, suppress' we will be in a better position to support decision making under uncertainty and provide recommendations for future research, and development of methods or tools that enable increased confidence and ability of managers to make decisions in such situations. Bearing Doris Day's point in mind, we can help environmental water managers to make their mind up and get started despite not knowing with certainty.

2 Method

This research used a self administered online survey to measure how environmental water managers make decisions when faced with incomplete information (thereby introducing uncertainty). The questions were predominately a mix of behavioural and self assessment style questions including a combination of closed end

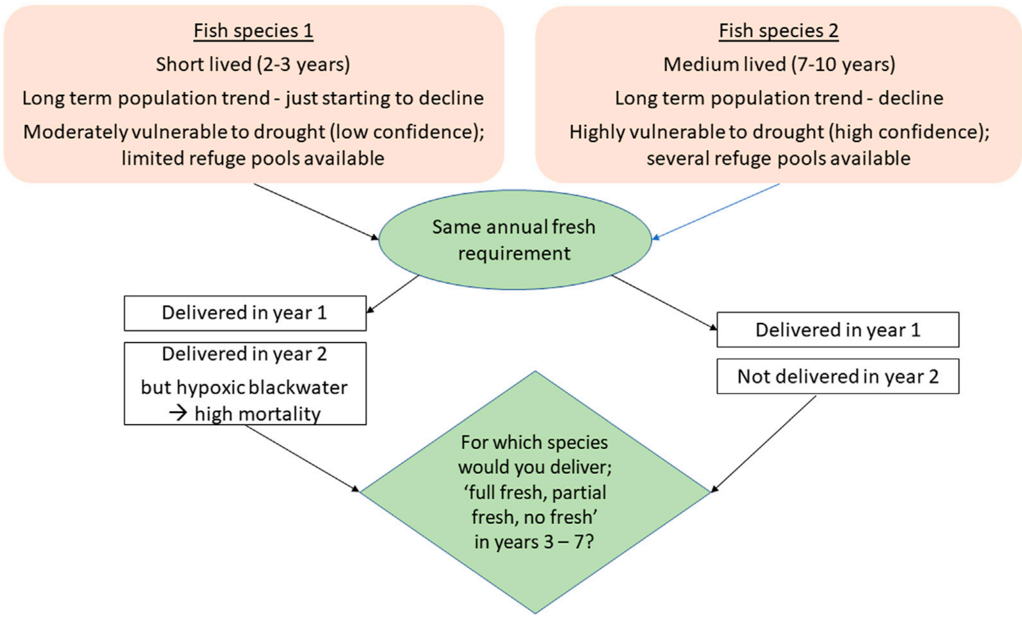

FIGURE 1
Hypothetical scenario (one) provided in the online survey for environmental water managers to measure trade off decision making response during a drought and in an uncertain situation.

questions and hypothetical scenarios (see Supplementary Material). Scenarios were presented as descriptive 'stories' which can be useful when decision making is required in uncertain conditions (Peterson et al., 2003). Scenarios can be based on past events or situations similar to existing conditions, they can be imagined and combined with climate change information, but importantly they should be plausible (Bryman, 2016; Shepherd et al., 2018).

The inclusion of imagined, hypothetical scenarios in this research allowed participants to improve their awareness of their decisions, think deeply about the scenarios provided, and demonstrate their current thinking and ideas. The survey scenarios were developed to determine how confident water managers were in situations they were familiar with, and likely future scenarios under a water scarce future to link back to hypotheses one to three.

The first scenario (Figure 1) asked participants to decide how they would use environmental water to support two different species located in different rivers of the same catchment during a drought with limited water. Historically water availability has been such that both species can be supported, but under this scenario there is restricted water availability and hence an ecological trade off decision is required between the two species. A drought scenario was chosen as there is a high likelihood that most participants have managed water during a drought, and it is a likely future scenario under climate change. Participants were asked to make a trade off decision between providing a full fresh, partial fresh or no fresh for one species *versus* the other. A fresh is defined as a short duration flow event greater than median flow and provides functions such as biological triggers for migration and/or spawning and physio chemical changes (DEPI, 2013). A full fresh was the recommended action for both species and benefits of a partial fresh were uncertain along with water trade and operational rules, broader population status including vulnerability and most recent antecedent conditions. This deliberate omission of certain information relates to hypothesis two; "staff are unwilling to make ecological trade off decisions when there is insufficient information". Questions about this scenario also linked to hypothesis one; "staff have high confidence in making ecological trade off decisions when situations are similar to their past lived experience" by testing whether participants have previously experienced a similar situation and their level of confidence in their water use decision.

In scenario two (Figure 2), participants were given information deemed important for decision making under climate change as identified by Judd et al., 2023. Information provided included species vulnerability assessments, temperature and water availability changes, drought refuge availability, extreme event frequency and habitat connectivity, species life span, social value and ecological function. The confidence levels of these projections were also provided. Considering the information provided participants were asked if they wanted to continue delivering water and pursuing the objective for the nominated species, despite climate data showing this species had a moderate to high level of vulnerability and survival looked unlikely. This scenario tests hypothesis three; "staff will be confident in making trade off decisions when provided with climate change information they consider to be important" and adds uncertainty in the moderate confidence levels provided for future conditions. This scenario enabled respondents to think about the types of decisions they will have to make more commonly in the future.

The survey was developed through an iterative process of review and pre-testing with a small number of environmental water managers. The online survey was developed in Question Pro (Inc) survey software and distributed by email to approximately 80–100 environmental water staff or researchers identified through purposive sampling (Gideon, 2012). The survey was distributed to staff working in government water management

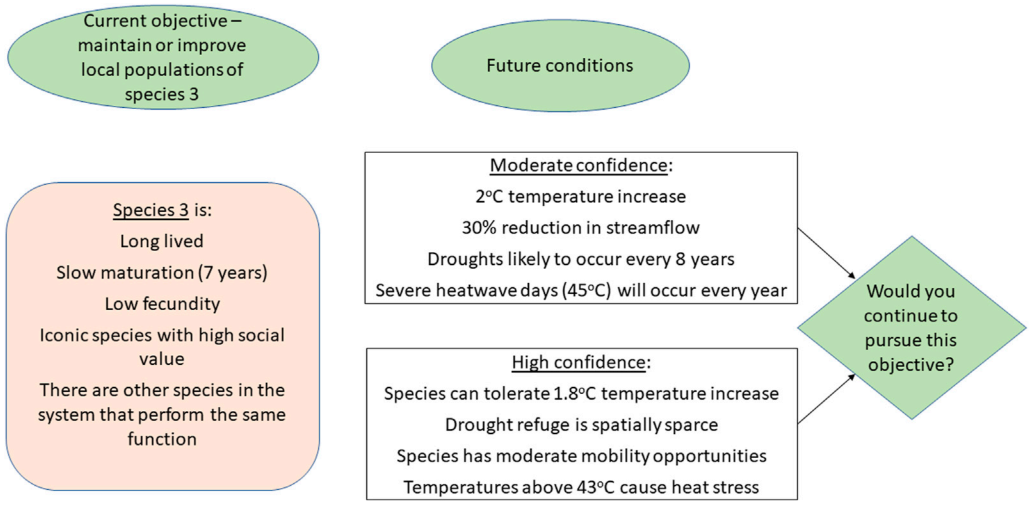

FIGURE 2
Hypothetical scenario (two) provided in the online survey for environmental water managers to measure their willingness to change objectives when provided with relevant climate change information.

agencies who are responsible for making decisions on the long term use of riverine environmental water throughout Australia, with a strong focus on the south east. Although researchers are not responsible for making decisions about water use and/or delivery, they are often approached by environmental water staff to help inform decision making. The survey was distributed in late January 2022 and open for approximately 6 weeks. This timing was chosen as it was thought staff would be returning to work after summer holidays and likely to have time available to complete the survey. Two reminder emails were sent to everyone on the distribution list at 4 weeks and just before the closing date. There were 25 completed responses and average completion time for the survey was 45 min.

The use of scenarios followed by specific survey questions meant data analysis could link to the study hypotheses. Questions in the survey that linked directly to the study hypotheses include "how confident are you with your decision" and "how closely does this reflect your own experience". Other questions used in the data analysis came from questions specifically asking the participants their perception of the amount/type of data provided for decision making, if there were specific pieces on information that assisted with their decision making, and if they found certain decisions difficult to make. Some of these questions were repeated with each scenario and additionally asked in a general manner. Questions asking the same question in different situations were collected and compared to provide results described here.

3 Results

3.1 Demographics and general response to uncertainty

There were 25 complete responses to the online survey encompassing a diversity of experience and training, and roles and responsibilities (Table 1). There were no partially completed survey responses.

Participants were asked about their general approach to decision making; how confident they are in making a decision with a lack of information and how they would go about making such a decision. Eight of the 25 participants had a very high or high level of confidence, while 14 had a medium level of confidence. Three had low confidence. Responses to how participants go about making a decision with uncertainty are shown in Figure 3. Linking the answers to Lipshitz and Strauss (1997) the overwhelmingly most common response was to reduce uncertainty by gaining additional information from experts or colleagues or drawing on a previous similar experience. An additional six of the 25 would delay their decision while reducing uncertainty by sourcing more information. Although fewer respondents aimed to acknowledge uncertainty by making reversible decisions a substantial number (14/25) still chose this option while some participants (7/25) chose to suppress uncertainty by relying on intuition.

3.2 Hypothesis 1—Environmental water managers have high confidence in making ecological trade off decisions when situations are similar to past lived experiences

Environmental water managers were found to be most confident in decision making when they feel the situation is similar to what they have previously experienced (Figure 4), however there was some spread in participant levels of confidence. This result is a common human response with much literature showing that personal experience, especially recent experiences, can be the most frequently drawn on source of information in decision making (Giehl et al., 2017; Ausden and Walsh, 2020; Page and Dilling, 2020; Kong et al., 2021). Two participants showed relatively very high or somewhat high levels of confidence without having been in a similar situation. Both these participants had more than 20 years' experience working in environmental water management.

Using drought as a previous experience aligns with the expectation that past droughts may provide a reasonable analogue for more permanent

TABLE 1 Participant demographics.

	n = 25	%		n = 25	%
Age			Trained as:		
22–32	2	8	Ecologist/biologist	14	56
33–44	12	48	Physical scientist	3	12
45–54	9	36	Engineer	3	12
55–65	2	8	Geographer	1	4
			Other (NRM, land/water manager)	4	16
Years of experience			Currently working as:		
0–4	6	24	Operational manager/officer	4	16
5–9	2	8	Strategic manager/officer	6	24
10–15	10	40	Both strategic and operational	10	40
16–20	4	16	Researcher	3	12
Longer than 20	3	12	Other (community engagement, project officer)	2	8

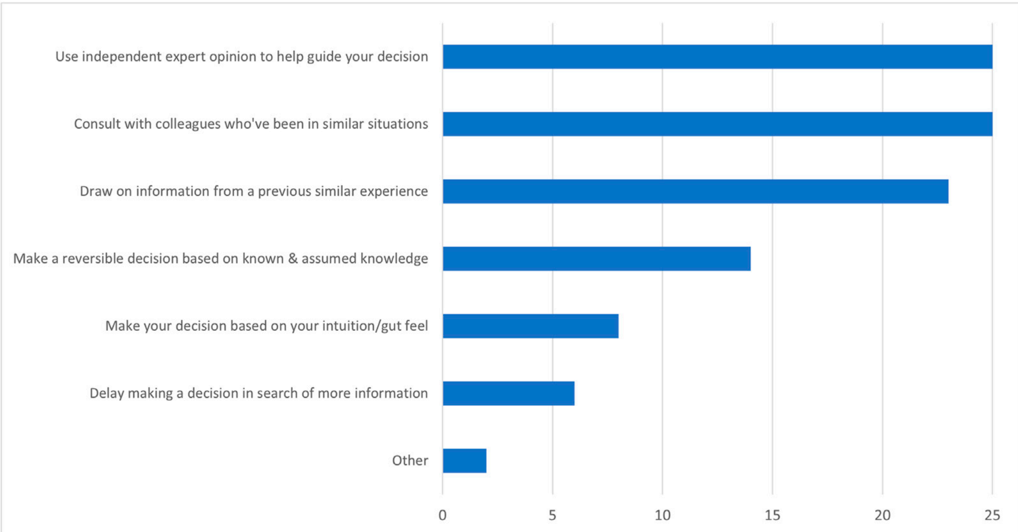

FIGURE 3
Online survey responses to a question asking how participants generally respond to decision making with uncertainty. Participants were Australian environmental flow managers (n = 25) responsible for making decisions on water use.

climate shifts in the region under investigation. These results show participants who had previously managed water during a drought were more confident in decision making than participants who had not managed during a drought (Figure 4). In fact four participants who had managed water during a drought indicated that scenario one was almost identical to an experience of their own management situations. This may also link to their level of confidence in similar situations as per the drought scenario one of the online survey, but the separation of managing water in a drought *versus* the total previous experience of these managers was not asked and hence cannot be concluded.

3.3 Hypothesis 2—Environmental water managers are unwilling to make ecological trade off decisions when there is insufficient information

Environmental water managers were found to be willing to make trade off decisions despite incomplete information (contrary to our hypothesis). Sixteen respondents (64%) chose to deliver a partial fresh with no certainty of the benefits this would provide to either species, while eight (32%) made the choice to only deliver water

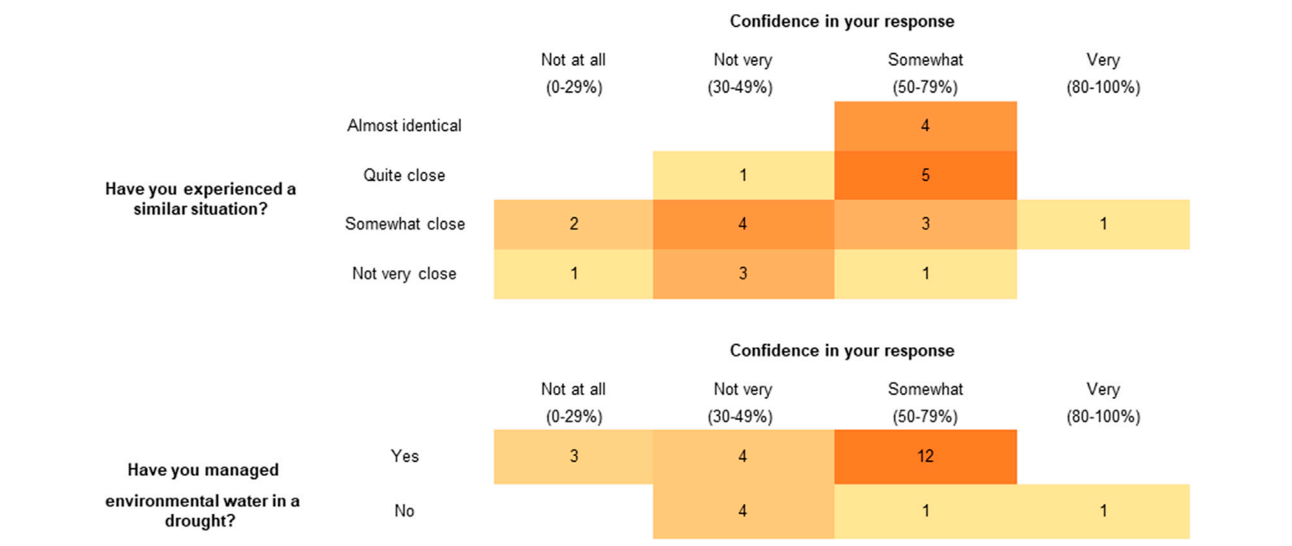

FIGURE 4
Participants' level of confidence in decision making in situations similar to their own experience and level of confidence for those who have managed water during drought conditions. Darker colours represent higher numbers of participant responses for this category.

when availability was such that a full fresh (as per recommendations) could be delivered.

Further, the same proportion of respondents decided to favour a higher value species despite the lower certainty of information. When asked how they would use water to support either one of two species or to try and balance water for both species, the shorter lived species with high social and ecological value and moderate, yet uncertain, vulnerability to drought was favoured over the longer lived species that was highly vulnerable and moderately valued. Seven respondents (~30%) chose to use water in a balanced way (i.e., alternating target species in alternate years) to aim for survival of both species showing a lack of willingness to 'give up' on a species and citing the lack of information as reason for their decision. The most critical pieces of information for all participants were species life span and water availability. When asked how long they would continue pursuing both these objectives given the information provided, the majority of participants said they would aim to reduce the uncertainty by gathering more information before 'giving up on one species' (Table 2).

These results show that approximately two thirds of participants are willing to make ecological trade off decisions when there is a lack of information and a level of uncertainty. However, 21 of the 25 participants agreed they found it difficult to make a decision for the following reasons: uncertainty of water availability now and in future years (including baseflows), uncertain benefits of a partial fresh for these specific species and the overall ecosystem, lack of detail on location and connection of other populations and refuges (e.g., how long will they retain water), and a lack of experience in making similar decisions. Results from the open ended question also show some participants were looking for information from contemporary monitoring data indicating the importance of up to date monitoring to some environmental water managers' decision making processes.

3.4 Hypothesis 3—Environmental water managers will be confident in making trade off decisions when provided climate change information deemed important

In general terms, the participants acknowledged and supported the need to prioritise sites, make trade offs and allow some sites to transition to a different structure, along with incorporating adaptation actions into environmental watering programs (Figure 5). There is also a large proportion of participants who are wanting to do this and not willing to wait for policy guidance, and as shown above believe the procurement of information will assist in this decision making.

However, the results also show that despite being willing to make adaptation decisions, participants are still challenged with how to go about making these decisions without complete information. Despite being provided the information previously deemed important for decision making (see Judd et al., 2023), a large portion of participants (10 or 40%) thought the information provided in the scenarios was not detailed enough. Another eleven agreed the information was useful with only three participants suggesting there was an overwhelming amount of information. Of the information provided, the most important or trigger pieces of information were species life span and sensitivity to temperature, species social value, the potential benefit this watering event may have on other components of the ecosystem (i.e., flow on effects to other species), frequency of drought and availability of refuges. Contrary to our hypothesis, provision of this information was not enough for managers to confidently change the management objective provided in this scenario. Nineteen of the 25 participants decided to continue to pursue the existing objective.

Clifford et al. (2020) found managers were opposed to ecosystem transformation due to a lack of confidence in climate projections,

TABLE 2 Participant responses to uncertainty for future water use.

Action	Count	Response to uncertainty
I would not stop delivering freshes for either species and lobby the government for increased environmental water entitlements	4	acknowledge
I would not stop delivering freshes for either species, however I would revise the relevant flows study	2	reduce
I would continue for 1–2 years while I seek expert opinion on issues such as climate change vulnerability and ecological function and then make a decision	17	reduce
I would continue for 1–2 years while I conduct a community survey to determine the community value of both species and then make a decision	1	acknowledge
Other (e.g., investigate complementary measures, prioritise and deliver for fish only)	2	suppress and acknowledge

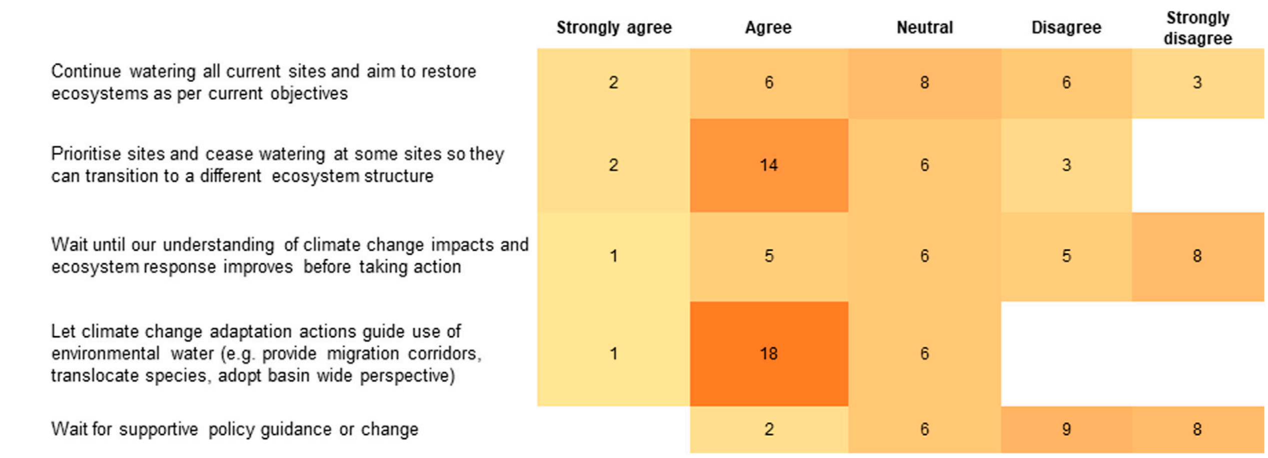

FIGURE 5
Participant agreement with suggested climate change management actions and adaptations. Participants used a Likert scale to select their level of agreement with each action. Darker colours represent higher numbers of responses for this action. All 25 participants provided their level of agreement to each management action.

while Azhoni et al. (2018) concluded a lack of confidence in climate information was as a barrier to adaptation. This also occurred in our study were some participants suggested they did not trust the provided climate change and vulnerability assessment information strongly enough to allow this to influence their decisions. As two participants said:

> *"Some thresholds and tolerance results from lab work are exceeded in natural systems and whilst they do cause impacts - they are not necessarily curtains"*

> *"Whilst the evidence shows the species cannot survive above 1.8°C annual average increase, I would view this with scepticism as similar research fails to take into account the potential for rare, but important genetic traits to influence selection."*

Nineteen (19) of the 25 respondents said they would continue pursuing a watering objective even when climate data showed significant vulnerability and unlikely survival. They sought more information in deciding whether to cease pursuing this objective as captured by this response:

> "Due to the uncertainty of the future, doing whatever is possible today to ensure survival of (the) species 'buys' time and provides motivation to look for ways to protect these species in the long term using alternative options"

4 Discussion

The results of the survey support one of the three hypotheses tested. Results show environmental water staff are not very confident in decision making when there is a lack of information with only one participant having greater than 80% confidence. These results show past experiences increase managers confidence in making ecological trade off decisions (hypothesis one). In decision making, past experiences are usually combined with a person's scientific knowledge but can also be subject to strong biases (Cook et al., 2010; Höllermann and Evers, 2017; Ausden and Walsh, 2020; Clifford et al., 2020). Further, the non stationarity of climate and weather experienced under climate change makes the past a poor reference point for the future, and one where past actions may not have the same outcome. As Helmrich and Chester (2020) emphasise, although a system has been shown to be resilient in the past, does not ensure its resilience in the future.

Using the past to inform future decisions can provide benefit if past decisions were the 'best' possible decisions. However, without clear monitoring each time a decision and action are taken, this will not be known. Adaptive management is one method to acknowledge this uncertainty and improve knowledge through testing hypotheses, implementing and monitoring actions, and adjusting future decisions and actions based on the results. Adaptive management is well acknowledged and included in environmental water management (Tonkin et al., 2020; Watts et al., 2020; Horne et al., 2022), but there can be lagged ecological feedbacks, and thresholds or tipping points may pass before managers are even aware. Other reasons also prohibit widespread adoption of adaptive management such as institutional risk aversion of looking like a 'failure' and insufficient resourcing, amongst others (Allan et al., 2008; Stults and Larsen, 2020).

Results from this research do not support hypothesis two which suggests managers would be unwilling to make a decision with insufficient information. In fact the results show environmental water managers are willing to adapt and make trade off decisions with a lack of information, but they find it difficult and would like an extensive list of additional information. The need to reduce uncertainty is a common response by people and organisations and can lead to the believe that improvement in information will be a solution to their decision problem. However, the improvement in information or science may not always be accessible, in a format reachable to practitioners or available in a timely manner. According to Ryder et al. (2010) providing knowledge from research for decision making is difficult due to misalignment of academic and manager's requirements, including different questions from practitioners and researchers, research timeframes are too slow for practitioners and different personal or organisational goals (Ryder et al., 2010). There can also be difficulty for practitioners to access research information along with different views on legitimacy of information, while recommendations provided by researchers can be perceived as irrelevant or impractical in practice (Cook et al., 2013; Dilling et al., 2015).

These results show even when provided with climate change information, water managers were reluctant to change objectives, rebutting hypothesis three. Under climate change, improvement in currently available science is simply not sufficient. Knowledge of future greenhouse gas emissions, and the direction, timing and severity of changes is unavailable. How this will change soil moisture capacity and rainfall runoff relationships is largely unknown. Human behavioural change and the complexity of ecosystem responses to these changes is also unknown (Stults and Larsen, 2020). Consequently, consideration of time and money invested in searching for more information needs to be weighed against the benefits extra information will provide. It is pointless to delay a decision if the new knowledge is not available and/or will not improve a decision outcome. This also makes it vitally important to ensure any additional research and/or monitoring is addressing well thought out endpoints to capture information important for long term decision making and the uncertainty of hydro-climatic change and consequent ecological responses.

To assist decision making the use of adaptation decision frameworks such as the expanded "resistance-resilience-transformation" or "resist-accept-direct" as per St-Laurent et al. (2021) and Thompson et al. (2021) respectively can be useful for environmental water managers. These frameworks aim to assist decision making under climate change by offering options for management actions; namely resisting change, accepting and adapting to change or transforming systems to a new state. These decision frameworks are useful to inform which adaptation path to follow but fail to acknowledge uncertainty. Several methods that do acknowledge uncertainty are already available and should be adopted by environmental water managers. Firstly, scenario planning provides managers with multiple possible future scenarios to consider. For example, the scenarios prepared for this research could be modified based on the results of this study and presented at a workshop of environmental water managers and other stakeholders. The scenarios can highlight parameters and inclusion of information deemed of high importance to managers in their decision making process (Kong et al., 2021). Each scenario can be as complex or simple as required and incorporate non flow and social or economic related constraints. Scenarios should be supported by real data and include the main concerns and uncertainties, significant driving factors and the plausible changes in those factors (Wodak and Neale, 2015; Shepherd et al., 2018; Gray et al., 2020). Numerous scenarios can be presented in a workshop yet there is no assumption on the likelihood of any particular scenario occurring. The workshops do not require specialist technical skills (other than a facilitator) thereby keeping costs low, with scenarios 'tested' prior to a workshop to ensure their feasibility and realism. Scenario planning workshops can include a large number of stakeholders and allow managers to think about events outside their own experience, and consider what type of policy/strategic decisions are required under a range of possible futures (Wodak and Neale, 2015; Shepherd et al., 2018). Fact sheets can be sent out prior to the workshop to ensure all participants have the same base level of information (Serrao-Neumann et al., 2019). Scenario planning workshops can challenge managers assumptions and improve knowledge of complex and dynamic issues.

Secondly, another option is to adopt robust and adaptive methods that have been developed specifically to deal with deep uncertainty. These are innovative methods for environmental water managers and can assist by providing information on long term policy and strategic direction to inform issues such as setting achievable ecological objectives. All such methods principally test system vulnerabilities across multiple scenarios to determine where the objective, or policy, fails. By testing objectives through a wide range of future conditions and 'stress testing' a system until the point of failure, the method delivers robust decisions rather than optimising for one ideal solution (i.e., robust being where performance is insensitive to which future may occur (Maier et al., 2016)). These methods aim to achieve a 'satisfactory' outcome under multiple scenarios rather than optimise one preferred option. Other methods aim to ensure performance is flexible enough depending on what future outcome may occur allowing for changes of approach if things 'fail' (Maier et al., 2016; Lawrence et al., 2018). Examples of these methods include; Robust Decision Making and Multi Objective Robust Decision

Making (Lempert et al., 2003; Lempert and Groves, 2010; Herman et al., 2014), Info-Gap analysis (Ben-Haim, 2006), Adaptation Pathways and Dynamic Adaptation Policy Pathways (Haasnoot et al., 2013). There are pros and cons in all these methods and reviews have been provided by Matrosov et al. (2013), Kwakkel et al. (2016), Bosomworth et al. (2017) and Bartholomew and Kwakkel (2020). One consideration when using, or adapting, these methods to environmental flow management is the requirement of potentially new data (e.g., vulnerability assessments), but the results of this study have shown managers are willing to make decisions in the absence of information/data. Therefore, perhaps the need for additional information is not as important as providing managers with tools and experiences to increase their confidence and ability to make decisions under uncertainty.

We will briefly review Robust Decision Making (RDM) as we consider this a suitable initial method to test vulnerabilities of existing environmental water ecological objectives and policies and can support subsequent implementation of other methods. The results from this study support the trialling of such methods as environmental water managers have shown they are able to make decisions under uncertainty and willing to test new methods of decision making. This method could be used to support long term decision making and objective setting as proposed in scenario two of this study. RDM allows analysts to propose an objective and stress test, or evaluate its vulnerabilities, across a range of plausible futures (Radke et al., 2017). For environmental water plausible futures may include those such as climate change scenarios (e.g., RCPs), response of species or communities including distribution models and vulnerability assessments, changes in water availability, trade and water quality, occurrence of disturbance events (e.g., drought, hypoxic blackwater) and change in land use. RDM allows managers to determine under what conditions the existing objectives or strategy performs well or fails, and what conditions affect performance. This would be ideal for testing vulnerabilities of existing environmental water goals under a range of possible futures. Alternative combinations of problems and uncertainties allow iterative assessments of scenarios to achieve satisfactory performance over a range of futures. Scenario two provided in this research could be tested in a RDM model to determine if and/or when to cease delivering environmental water to support the species identified by the objective, or in scenario one by running the options through numerous scenarios available in RDM which would indicate when different volumes of water can support both species, or when one will not survive under different water availability scenarios. Using RDM results of the scenarios will provide trade off curves that compare alternate strategies for achieving the goals identified by participants in this research and assist in making informed trade off decisions so environmental water managers can achieve the best bang for their environmental water buck. RDM outputs can also show where system 'tipping points' or vulnerabilities are, which can then be used in other methods such as Adaptation Pathways. While there are a number of academic examples of applying the RDM method to water resource management (Matrosov et al., 2013; Singh et al., 2015), RDM is currently not widely used or accepted in testing/setting objectives or policy (Jensen and Wu, 2016). This may be due to the following downsides of RDM; the model is data intensive, requires large computing capacity, and often needs specialist skills to run, analyse and interpret the results all of which make it expensive to execute (Jensen and Wu, 2016; Shi et al., 2019). Despite these challenges testing this method with environmental water use under climate change uncertainty would allow managers to consider future plausible hydrological and ecological changes and assist them in becoming more confident in their future decision making.

This research specifically focused on participants' decisions regarding ecological trade offs, and deliberately omitted other factors in environmental water decision making (e.g., recreational use, socio-economic or political influences). The study acknowledges managers' decisions may be different for reasons other than those investigated here and people make decisions based on a combination of their personal values and judgement, experience, organisational values, risk perception, political influence, availability of resourcing, and chances of success (Dietz, 2013; Mukherjee et al., 2018; Moallemi et al., 2020). Hence incorporation of climate change adaptations and the ultimate decision to implement adaptations will be affected by all these factors, along with geographic, legacy, economic and political differences, resulting in potentially different choices from managers in similar situations (O'Brien, 2009; Maani, 2013; Hagerman and Satterfield, 2014; Clifford et al., 2022).

It is also acknowledged that the methodology and data collected in this research have limitations. The data was gained from a small, purposive sample and cannot be generalised to the entire population of environmental water managers (Walter, 2019). Participation was voluntary so it is likely that participants are environmental water staff interested in climate change, and therefore likely to skew results to higher climate change interest than the whole population representing a level of sampling bias (Bryman, 2016). An additional limitation is the lack of opportunity for participants to request clarifications or explanations, especially when using scenarios, in online surveys (Walliman, 2015). Despite these limitations, this exploratory study acknowledges existing limitations of addressing uncertainty and provides research into new ways of embracing uncertainty in aquatic ecosystem management.

5 Conclusion

This research has shown that environmental water managers display all three responses to uncertainty (suppression, reduction and acknowledgement) with a large focus on reduction. The results highlight managers' hesitancy in making decisions without full information. As climate change becomes embedded into legislative and strategic requirements of businesses and governments, the ability to incorporate adaptations despite these uncertainties becomes fundamental. However, environmental water managers will ultimately need to have conversations about if, or when, they cease managing waterways for certain species or communities, with or without what is deemed sufficient information. To ignore the need for such radical shifts will mean, in some cases, management becomes focused on unachievable ecological goals (Campbell et al., 2021; Judd et al., 2022). As well as failing to achieve those goals, such actions would be a poor use of a shared resource, would likely lead to loss of community support for environmental water, and may be maladaptative by reducing the likelihood of achieving other goals (environmental or otherwise). With the range of methods available to support decision making under deep uncertainty, environmental water managers have options to support decisions that can incorporate uncertainty and assist in water planning options and management decisions.

The results of this paper demonstrate that significant effort is still required to adopt decision making frameworks in environmental water management that are robust and well suited to handling the high levels of uncertainty associated with the future. Trialling methods for decision making under deep uncertainty will empower managers to acknowledge uncertainty, increase confidence, inform decision making and support conversations on future ecological objectives. Prior to widespread adoption (if deemed appropriate), less intensive options should be adopted immediately; such as scenario planning, climate change vulnerability assessments, use of adaptation decision frameworks and inclusion of reversible or low regret decisions. We acknowledge that all decision making is contextual, so we encourage managers to determine which method, or ideally range of methods, is best suited for their decision situation and employ the appropriate steps to get started.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by La Trobe University Human Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

Author contributions

MJ developed methods and performed data collection and analysis and prepared the manuscript. AH and NB reviewed methods and contributed to manuscript revision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1074896/full#supplementary-material

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