The challenge of setting 'climate ready' ecological targets for environmental flow planning

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Abstract

Implementing environmental flows has emerged as a major restoration tool for addressing the impacts of hydrologic alteration in large river systems. The 'natural flow paradigm' has been a central guiding principle for determining important ecohydrological relationships. Yet, climate change and associated changes in rainfall run off relationships, seasonality of flows, disruptions to food webs and species life cycle cues mean these existing relationships will, in many circumstances, become obsolete. Revised thinking around setting ecological objectives is required to ensure restoration targets are achievable, particularly in regions where water scarcity is predicted to increase. Through this lens 'climate ready' targets are those that are robust to changing water availability or incorporate future adaptation options. Future objective setting should be based around the inclusion of changing climate and water availability, and the associated species and ecosystem vulnerabilities, and expected outcomes under different policy and adaptation options. This paper uses south eastern Australia as a case study region to review the extent to which current water management plans include climate considerations and adaptation in objective setting. Results show untested climate adaptation inclusions, and a general lack of acknowledgement of changing hydrological and ecological conditions in existing management plans. In response this paper presents a process for setting objectives so they can be considered 'climate ready'.

1 Introduction

Increasing global populations and the demand for freshwater is resulting in water scarcity across many parts of the globe (Bond et al. 2019; Vörösmarty et al. 2000). Regulation of rivers for human water use has left many rivers with altered hydrology and degraded ecology (Bunn 2016), which will be further impacted by climate change (Palmer et al. 2008; Smakhtin, Revenga & Döll 2004; Vörösmarty et al. 2010). In many regions, water resources are being managed to maintain or restore aspects of the natural flow regime in an effort to protect and restore the health of aquatic ecosystems by implementing environmental flows (elsewhere also referred to as environmental water (Arthington et al. 2018; Horne A et al. 2017)). Approaches to determining flow requirements for ecosystems are numerous, and reviews have outlined more than 200 recognised methods (Arthington et al. 2006; Nel et al. 2011; Poff et al. 1997; Tharme 2003). More recently, the challenges of assessing environmental flow requirements under a changing climate have been highlighted (Arthington et al. 2018). However, while there has been some discussion around the need for additional hydrological and ecological modelling to inform future environmental flow assessments (John et al. 2020; Tonkin et al. 2018), there has been little discussion of the likelihood of achieving the ecological restoration targets that have historically been formulated in environmental flow planning. This paper addresses this gap by examining the requirement for 'climate ready' targets, which we define as those identified as plausible and achievable under changing regimes of climate and water availability, and/or which incorporate vulnerability assessments and trade off options.

Clear objectives are considered an essential step in ecological restoration, as they enable managers to determine appropriate management strategies, prioritise funds, track performance, and adaptively update management actions over time (Wilson & Law 2016). As water scarcity becomes more commonplace, setting realistic and attainable objectives at the commencement of any water recovery project becomes essential to achieving the ecological outcomes earmarked for water reallocation. Current environmental flow objectives focus on flow dependent environmental assets and particularly include species or communities, habitats and ecological processes (Acreman & Dunbar 2004; Yarnell et al. 2015). Objectives can be determined by legislative requirements, local community values, a panel of expert scientists or a combination of all of these (Cottingham, Thoms & Quinn 2002; Horne AC et al. 2017).

Academic and grey literature outline many methods for setting objectives or goals in natural resource management (Edvardsson 2007; Gregory et al. 2012; Prober et al. 2018; Tear et al. 2005). For many decades the concept of 'SMART' goal setting (Specific, Measurable, Attainable, Realistic, Time bound) (Doran 1981) has been widely accepted including in the fields of ecological restoration, and conservation and water management. The concept of SMART goals is still very relevant in the face of climate change, especially in setting goals or targets that are realistic and attainable in a non-stationary environment.

Currently, there are few examples of widely accepted SMART objective setting techniques being applied within environmental flows studies (Acreman & Dunbar 2004), with objectives often being poorly defined, deliberately vague (Capon & Capon 2017; Wilson, Carwardine & Possingham 2009), or untested as to their feasibility; they are thus inadequate in terms of being Specific, Measurable, and (potentially) Attainable and Realistic. Further, flow assessments are often required by government agencies to be undertaken within short time frames and with limited budgets, and consequently are not conducive to setting long-term objectives due to time constraints on gathering and processing new data (Arthington et al. 2006; Mezger, De Stefano & del Tánago 2019).

Objective setting in environmental flow planning predominantly assumes the climate and environment is stationary with most goals defined based on some form of historic reference point – such as the restoration and/or rehabilitation of naturally abundant or endangered or iconic species and/or communities to a previous state (Dunlop, Parris & Ryan 2013; Hallett et al. 2013). Indeed most environmental flow methods are based on the assumption that ecosystem responses to flow regimes will remain the same in the future (Horne et al. 2019; Poff 2017; Tonkin et al. 2019). However, ecosystems are changing and recognition of this is needed in objective setting (Choi 2007; Hobbs & Harris 2001; Thompson et al. 2021). Further, there is currently little recognition of the impacts of climate change such as changing rainfall/runoff relationships and seasonality of flows and the impact of these on our ability to achieve existing objectives (the A and R in SMART). Increasing air and water temperatures will affect species physiology and ability to survive in situ, including growth rates and reproduction timing (Bunn 2016; Koehn et al. 2011). Bioclimatic envelope modelling suggests widespread geographic shifts and/or extinction of species due to water temperature changes and the exceedance of upper or lower thermal tolerance of species (Booth, Bond & Macreadie 2011; Comte & Olden 2017; Dawson et al. 2011; Dudgeon 2019). Extreme events (droughts and floods) will become more frequent and will play an important role in shaping species populations, composition and diversity and as the frequency of these events increases, there will be limited ability of species to recover between events (Harris et al. 2018; Shenton et al. 2012). Reduced water availability and more frequent droughts will lead to an increased number of streams becoming ephemeral and consequent habitat fragmentation. Reduction in overbank and high spring flows will impact floodplain vegetation, life cycle cues for various species and hinder transport of carbon to the river impacting aquatic food webs (Morrongiello et al. 2011). Most of these climate change impacts are currently given little, or no, consideration when determining the objectives associated with restoring environmental flows – both in terms of what the objectives should be, and whether they are feasible and/or robust to changes in water availability (Arthington et al. 2018).

It is now widely accepted that the climate is not stationary (Milly et al. 2008; Tonkin et al. 2019) and the current suite of environmental flow objectives aiming to restore conditions to an historic reference are unlikely to be achievable (Capon et al. 2018; Poff 2017; Prober et al. 2012; Thompson et al. 2021). This paper uses south eastern Australia as a case study to review the extent that current environmental water management plans include climate considerations and adaptation in objective setting. Results show untested climate adaptation inclusions, and a general lack of acknowledgement of changing hydrological and ecological conditions in existing management plans. To address the challenge of making environmental flow objectives 'climate ready'; that is, being robust to changing water availability, or incorporating climate adaptation options, we present a process for setting future objectives so they can include such considerations.

2 What does climate ready mean?

Existing environmental flow objectives may result in maladaptive outcomes under climate change as hydrological and ecological responses alter from our historic knowledge base (Capon & Capon 2017; Hansen & Hoffmam 2011). Setting management objectives that are relevant under future climate scenarios has been recommended by Dunlop, Parris and Ryan (2013). 'Climate ready' objectives, as referred to in this paper, are defined as objectives that include consideration of future changes in climate, flows and ecosystem response, and particularly include adaptations to these changes. Climate ready objectives link actions to future flow scenarios and ecosystem or species vulnerabilities and are informed by and provide benefit over a range of scenarios.

Several high level frameworks have been proposed for examining climate impacts. For example the IPCC has widely used the Exposure, Sensitivity and Adaptive capacity framework (Sharma & Ravindranath 2019). However this framework has been criticised for not sufficiently distinguishing between sensitivity and adaptability in predicting ecosystem outcomes (Fortini et al. 2013; Hinkel 2011; Juhola & Kruse 2015). Fortini and Schubert (2017) presented a modified framework that integrates ecological knowledge in predicting how species and ecosystems may respond to changing climate conditions. Here we suggest ecosystem adaptation responses based on the work of Boltz et al. (2019) and Morrongiello et al. (2011);

- **Persist/tolerate** - the ability of an existing ecosystem or species to maintain its function under changing conditions (Fortini & Schubert 2017). These are often generalist species.
    - Can a species persist/remain in situ and within its thermal tolerance limit?
    - Can a system return to the same ecological function after a recurring disturbance?
    - Is there enough area and spatial distribution of habitat refuge?
    - Are the tolerances to future scenarios know?
- **Adaptability** – enables the ecosystem to maintain its function regardless of the species it includes. Focusing water use on adaptation of ecological communities and processes rather

than historic reference states or specific species will ensure objectives are achievable (Capon et al. 2018; Hansen & Hoffmam 2011; Harris et al. 2006; Poff 2017; Prober & Dunlop 2011; Yarnell et al. 2015).

- How connected are landscapes to facilitate migration to new habitats?
- Is vegetation complex enough to allow adaptation and resilience?
- Are carbon and energy cycles able to continue?
- Can genetic diversity be retained?

- **Transformation/evolution** – this will establish ecosystems with new functions in novel circumstances. Given the rapid pace of climate change and inability of species to rapidly evolve many ecosystems will transform to a new state (Colloff et al. 2016; Fortini et al. 2013).
    - Are there obvious transformational pathways to a different community assembly?
    - Is assisted migration or translocation necessary?
    - Is it better to stock fish from hatcheries rather than promote spawning and recruitment in river/wetlands?
    - Is there a need to conserve species outside of the natural environment?

Examples of objectives incorporating climate adaptations that build on the three core species/ecosystem responses to climate change outlined above are proposed (Table 1). Ideally, inclusion of climate considerations into objectives would include detailed hydrological modelling of future scenarios along with vulnerability assessments, however where this technical information is not available the objectives in Table 1 allow for input of general climate change adaptations (Angeler et al. 2014; Foden et al. 2019; John et al. 2020).

3 Do water plans in south east Australia have climate ready objectives?

To determine the extent to which existing environmental flow plans for rivers in south east Australia can be considered 'climate ready', we evaluated a suite of documents against the recommended adaptation objectives (Table 1).

Throughout south east Australia climate change is already evident with average temperatures increasing between 0.6ºC to just over 1ºC since 1910 (Victorian Department of Environment 2019). Predicted future changes in temperature include a further increase in average, maximum and minimum temperatures of up to 0.7ºC by 2040 and 2.4ºC by 2070 (OEH 2014; Victorian Department of Environment 2019). Extreme hot days are also predicted to double by 2050, and winters will be warmer. Winter/spring rainfall has already declined by around 12% since the late 1990s, and warm season rainfall has increased. Future predictions suggest further rainfall reductions in spring by around 1 to 26% by 2040, and extreme rainfall events are likely to become more intense by the end of this century. Projected rainfall run off is expected to decrease by 5 to 40% by 2050, with three quarters of long term gauging stations in the MDB already displaying a decline in flow since 1970 (BOM & CSIRO 2020; Department of Environment et al. 2020).

3.1 The region

Inland south east Australia is dominated by the Murray Darling Basin (MDB), the most regulated river system in Australia. River regulation and water consumption in the MDB has resulted in overallocation of water for consumptive use and degraded riverine ecosystems (Grafton et al. 2014; Hart 2016; Horne A et al. 2017; Ladson & Finlayson 2002). In 2007 the Federal government passed the *Water Act 2007* which required the development of a strategic plan for river health (the Basin Plan) and set volumetric limits on how much water can be used for consumptive use and how much should be used to maintain ecological condition. The *Water Act 2007* enables the Australian Government to recover water for the environment in several ways (water buy backs, irrigation infrastructure upgrades) and provides ecological objectives for the use of the recovered water. Other parts of south east Australia included in this case study are those in southern Victoria, including rivers around Melbourne and river systems that end in estuary's or coastal lakes (e.g. Glenelg River, LaTrobe River).

3.2 Method

We reviewed a total of 422 riverine environmental flow objectives from 44 separate documents describing flow requirements for rivers in Victoria, southern New South Wales (NSW) and the Murray River in South Australia (SA). The objectives were assessed against the recommended climate adaptation objectives outlined in Table 1.

Documents reviewed were public documents obtained directly from the organisation or indirectly via the organisation's website. The documents analysed were environmental flow studies, annual watering plans or longer term (10 year) environmental water management plans from local, state and federal government agencies (e.g. Catchment Management Authorities, state governments, water holders, the Commonwealth Basin Plan). The longest time frame for the development of environmental flow objectives was associated with the draft NSW Long Term Water Plans, which set objectives outlining environmental outcomes and 5, 10 and 20 year targets for each objective, and a review of the plan every five years to evaluate the targets. The date range of the plans assessed was from 2010 to 2020, a date range we considered adequate to anticipate potential inclusion of climate change impacts. A list of documents assessed are provided in the supplementary material.

The analysis focused on specific documented objectives, and ignored visions and goals, which in most reports simply mirrored higher level policy goals and were generally too vague to evaluate against our specific criteria. Duplicate objectives stated in more than one document for the same system were identified and ignored to avoid double counting. This case study is chiefly focused on the southern MDB, but also includes objectives from southern Victorian catchments. Of the documents assessed, 60% were from the southern MDB and 40% were from southern Victoria. Not all climate adaptation objectives (Table 1) were relevant to all the existing objectives assessed e.g. where an existing objective was focused on physical habitat, the adaptation objective relevant to species diversity is not applicable.

3.3 Results

When assessing existing objectives against our recommended adaptation objectives, the existing objectives most frequently relied on persistence and adaptation strategies (Table 2 and Figure 1).

Within the persistence strategy, the recommendation most frequently met was that aimed at maintaining ecosystems rather than restoring them (3). Under this adaptation objective, many of the existing objectives aim to maintain populations of specific species, including threatened species, or maintain components of the environment to be in similar condition to a previous or current state. Further, based on a word search of the objectives, there has been a relative decline in the use of the words 'restore' and 'protect', and an increase in the use of 'maintain' suggesting a general recognition that restoring populations may no longer be possible. This is an important recognition by water managers however there is no specific mention in existing objectives that connects this change of focus to consideration of future climate or water availability, or if it is due to other considerations. The Murray Darling Basin Plan (2012), and NSW long term water plans (which link closely with the Basin Plan), include numerous objectives with the wording “protect and restore”, “increase the distribution and abundance” of fish, vegetation and waterbirds. It has been widely documented that the Basin Plan does not adequately address climate change (Alexandra 2017; Pittock, Williams & Grafton 2015; Young et al. 2011) and this is evidenced by the objectives assessed here. In the documents assessed for this case study there were seven occurrences of objectives from the Basin Plan stating ‘protect and restore’ compared with two occurrences of this wording in non Basin Plan documents.

From the adaptation response category, the two objectives met most often were those considering habitat diversity, conservation and connectivity (4), and those aiming to maintain a diversity of species (5); both categorised as adaptation response. The high frequency of objectives addressing habitat diversity, conservation and connectivity is a good start, however these objectives are very broad. Examples of objectives in this category include maintaining flow connectivity, improving vegetation zonation, and maintaining inset benches and other geomorphologic features. All these issues contribute to habitat connectivity or diversity. Consequently, this category is too general and does not contribute well to the discussion of climate ready objectives in existing environmental water management. For future use this recommended objective could be dedicated specifically to habitat functions.

Very few objectives specifically mention climate change or its impacts. A search for the words ‘climate change’ show it is mentioned just five times from the 422 objectives assessed. Overall, existing objectives provide some climate change adaptations as defined by response categories of Section 2, however this is commonly a result of generic wording rather than an explicit recognition of ecohydraulic relationship changes under climate change.

Of the objectives assessed, very few included proactive consideration of climate change adaptation (objectives that meet the transformation response). While most existing planning documents include some kind of adaptation response, many of the objectives did not specifically refer to climate change e.g. *Provide periodic opportunities for regeneration of riparian, floodplain and wetland plant species”* falls into the “maintain a diversity of species” adaptation category without recognition that floodplain and wetland watering will become more difficult under climate change. Without inclusion of vulnerability assessments and detailed hydrologic modelling that takes future flows into account, these type of objectives are unlikely to be feasible. None of the documents assessed in this case study included detailed hydrologic modelling of future flow and/or vulnerability assessments, and therefore had no evidence to support the ‘achievability’ of these objectives in a changed future.

There were few objectives in the transformation response group, such as encouraging the establishment of non locally native species to maintain ecosystem function, and there were zero objectives that considered active translocation of species to more suitable habitats. Translocation is more likely to be required for threatened or specialist species rather than for generalists or species able to disperse on their own. Transformation may seem radical and costly, but if not considered, current environmental water management may lead to maladaptation and increased environmental loss. Thoughtful decisions around transformation is the proactive response to an uncertain future. Further, if transformation actions are undertaken, it may alter objectives for environmental water use in a river system and can provide opportunities for co-design of visions and management strategies by riverine communities.

The remainder of this paper discusses the challenges of preparing the environmental water industry to develop climate ready ecological objectives and finally, we propose a process to enable this to happen.

4 What are the major challenges for incorporating climate change?

There have been high level discussions on the need to consider climate change in environmental flow objectives, yet the lack of guidance on how to implement this is hindering inclusion (Kiem, Austin & Verdon-Kidd 2016; Poff 2017). Most existing methods for determining objectives do not sufficiently address the challenges of an uncertain, non stationary future in terms of altered hydrology and ecology. Specific challenges that need to be considered to move the practice forward include: (1) Environmental flow assessment methods rarely incorporate climate scenarios or water availability outlooks (Horne et al. 2019; Shenton et al. 2012) making it hard to assess if their objectives are "Attainable" and "Realistic". (2) High level of uncertainty around ecological responses to climate change and water scarcity including a lack of species vulnerability assessments (3) The spatial scale of ecological change and decision making does not align well with site specific environmental flow objectives (4) Lack of guidance for objective setting to transition systems. Each of these issues in discussed in more detail below.

1. *Water availability under climate scenarios*

Current environmental flow assessments typically look at historic water availability with little consideration for long term future water availability or change. A challenge to include long term future water availability lies in the large knowledge gaps of climate change forecasting including how the climate will respond to future greenhouse emission levels, and the sequencing in global climate models of extreme events (Hallegatte et al. 2012). There is also much debate around downscaling methods, and the data and resources required to derive regionally relevant information.

There are also many knowledge gaps on the effect on local rainfall/run off (Saft et al. 2016), seasonality of flows, and water quality (Arora et al. 2017). It is perhaps these large uncertainties that has limited the incorporation of future scenarios and run off changes into objective setting. While scenarios have been used within decision making and environmental flow assessments (King & Brown 2010; King, Tharme & De Villiers 2000), they rarely link back to an assessment of the objectives under the SMART framework (particularly the Attainable and Realistic).

One potential approach to address this uncertainty in future outcomes and link back to the achievability of objectives is to include fit for purpose and commonly agreed hydrologic models using a range of stochastic data and narrative scenarios within environmental flow assessment methods (Horne et al, in prep, John et al, in prep). To demonstrate the potential ramifications of incorporating water availability scenarios, a recent study in the Goulburn River, Victoria (Australia) identified floodplain vegetation condition as a high priority objective and resulted in a recommendation for overbank flows. However, with the inclusion of climate change it was found that overbank flows would likely decrease by 12 – 36% under a moderate to high climate impact scenario, making this objective challenging to achieve without significant reoperation of the river (Horne et al, in prep). Using climate/rainfall runoff scenarios to inform decision making and objective setting should be included in future flow assessments.

2. *Uncertainty of ecosystem response to climate change*

There are many uncertainties around how species, communities and ecosystems will respond to hydrological change and their vulnerability to climate change which may be restricting the ability of water managers to develop climate ready objectives (Kiem, Austin & Verdon-Kidd 2016; Tonkin et al. 2018). Poff (2017) suggests future environmental flow management needs to include ecological vulnerability assessments (EVAs). EVAs examine the pressures climate change will have on a particular species or taxonomic group and assesses their sensitivity (the degree that a system is affected (adversely or beneficially) by climate change), exposure (nature, magnitude and rate of change to a species) and capacity to adapt (ability of a species or ecosystem to adjust to climate change and/or benefit from opportunities or to respond to the effects) (De Lange et al. 2010; Foden & Young 2016; Mastrandrea et al. 2010; Pielke Sr et al. 2012).

Vulnerability assessments can be undertaken at the species or ecosystem level, investigating different types of impact (e.g. decline in diversity or ecosystem function, to species extinction), at a range of spatial and temporal scales and can consider various climate change impacts such as direct climate response, to predicted land use change in response to climate impacts.

The three main methods for vulnerability assessments are:

1. Correlative approach – uses models to determine the correlation between a species distribution range and its historical climate requirements. This information is subsequently combined with future climate projections to predict areas of suitable climate for future distribution. These models are sometimes called niche-based or species distribution models.
2. Traits based approach – uses species biological characteristics to estimate their sensitivity and capacity to adapt to estimates of their exposure to climate change. The scores for sensitivity, adaptive capacity and exposure are then combined to determine the vulnerability of a species.
3. Mechanistic approaches – uses process based models and incorporates biological processes, thresholds and interactions to predict a species response to changing environmental conditions. These models can incorporate species longevity and fecundity, predation and competition, and changes in habitat suitability in response to climate change, along with land use change. (Foden & Young 2016)

There are pros and cons of each of these three methods and while interest in applying vulnerability assessments has increased in the last ten or so years (Foden et al. 2019), the method adopted will depend on available data and resources. Fortini et al. (2013) developed and tested a method to assess plant species vulnerability to climate change which could be adapted to other ecosystems. They focused on species responses to changes in habitat – specifically area, quality and distribution - under a changing climate. Four species responses included in the vulnerability assessment include tolerate, remain in microrefugia, migrate and evolutionary adaptation. These responses are commonly referred to as methods of adaptation in adaptation literature.

Although there are limitations and uncertainties involved with vulnerability assessments, the inclusion of species vulnerability assessments in future flows assessments would provide water managers with improved information to develop more robust objectives. Upscaling species vulnerability assessments to a guild or community level could then be translated to broader spatial scales. Combining climate/rainfall runoff scenarios and species vulnerability assessments would greatly reduce uncertainty for future flow assessments.

3. Spatial scale

Many flow assessments are conducted at the scale of individual river systems, and in some cases at even finer scales. However, life cycle requirements of flora and fauna require interconnectedness of flow regimes. Continuing to develop objectives restricted to a single river scale will not enable long term trade off evaluations to be made. Larger spatial scale planning will enable different river systems to be prioritised for certain life stages of species and habitat connectivity and linkage corridors between fragmented habitats (Hobbs & Norton 1996; Stein et al. 2013). Regional, or basin, spatial scale management, rather than local, will become a necessity to maintain ecosystem function, and increasingly important as water availability decreases and reduces the ability to target the same objective at multiple sites (Heller & Zavaleta 2009).

4. Acceptance to proactively manage intervention (transition the ecosystem)

One adaptation action that needs to be addressed in environmental flow assessments, but which is currently largely ignored is the option to actively manage the river system to a new state (Colloff et al. 2016; Thompson et al. 2021; West et al. 2009). This includes consideration of management actions such as translocation of species to new habitats, relying on stocking of species rather than self-sustaining populations, and conservation triage. This type of adaptation action recognises that under climate change, water resources will not be able to conserve all species at all locations and that environmental water can be used as a tool for ecological transformation rather than restoration. Proactively managing intervention ensures ecosystem functions are retained and aims to avoid system collapse (Lin & Petersen 2013). Although these types of actions seem extreme and costly now, without proactive adaptation the environmental, social and economic loss and cost to rivers, wetlands and local communities are likely to be higher (Boltz et al. 2019).

5 A process to develop climate ready environmental flow objectives

We propose a new process to develop ‘climate ready’ objectives that considers non-stationarity and attempts to addresses the four challenges discussed above (Figure 2). Under our proposed process objective setting should be iterative where objectives are informed by both the values and desires of community and scientists and required legislation. Community involvement is important for gaining legitimacy for environmental flows and ensuring local communities, including indigenous communities, are given a voice in the decision making process (Anderson et al. 2019; Pahl-Wostl et al. 2013). This will be increasingly important where objectives move towards adaptation and transformation, rather than maintaining or restoring existing condition.

Initial objectives, which can be based around ecosystem response adaptations as per Table 1 or developed independently, are tested against climate change scenarios, sequences of possible extreme events, predicted water use and vulnerability assessments to determine if the objectives are Achievable and Realistic in the long term. This is a crucial new step and addresses the challenges outlined in section 4. Due to the large uncertainty and constantly updated information around climate and associated ecological changes, setting objectives without the inclusion of the most up to date technical information may lead to unachievable and irrelevant objectives. While there are challenges of combining hydrology, ecology and climate science (John et al. 2020), there is a need to proactively manage riverine environments to enhance resilience and future transformation.

If the objectives cannot be met under possible futures, a trade off decision is required. The trade off decision will need to determine what measures will be acceptable (for community, government and the environment) to continue pursuing the desired objective, or when a revision of objectives is best.

This decision can be informed by climate adaptations such as: spatial considerations, the best use of future water and its availability, and ecosystem function and potential requirements to actively transition the ecosystem to new state. However, in making these trade off decisions each system will have different legacy issues and community values, resulting in potentially different decisions. This would be a new step in most environmental flows assessments and leads to a clear articulation of the decision making process when finalising objectives. With increased water scarcity under climate change, trade off decisions in environmental flow management will become standard practice in environmental flows assessments. Thompson et al. (2021) have developed a management decision framework where managers can “resist, accept or direct” actions in response to climate change. This could be combined with our proposed process to implement ‘climate ready’ actions developed in Figure 2.

Issues and examples that will need to be considered in trade off decisions will be many and complex (Table 3). Once trade off decisions are made, environmental flow objectives may need to be revised. When revising objectives, adaptation actions should be incorporated and focus on managing for diversity of functional groups, improving migration and reducing barriers to movement through the landscape, increasing the resilience of the system to cope with change, or actively promote change to a novel state (Table 1). It is only by going through this process in its entirety that objectives will be truly ‘climate ready’.

Incorporating these additional tasks for implementing climate ready objectives will initially significantly increase the complexity, time and resources required for determining environmental flow requirements, yet without doing so, water managers cannot make informed, proactive decisions and trade offs when managing riverine environments into the future. All objectives should be supported by the best available science (Horne A et al. 2017), monitoring data and should be updated regularly. The framework should be re-evaluated at short, regular time frames (e.g. five years) as new climate/water, and species information, along with monitoring data become available. Without including these considerations in objective setting, environmental flows are unlikely to be able to achieve the stated objectives, may lead to maladaptation and loss support from local riverine communities. However, where resources to implement the recommended framework are not available or where appropriate climate and hydrology scenarios, and species data are scarce, managers should consider incorporating adaptation and transformation objectives as a minimum (Table 1).

6 Conclusion

There is a need to establish clear best practice guidelines for managers, scientist and consultants involved in developing environmental flow restoration goals under a changing climate. It is clear that current environmental flow plans in south east Australia do not adequately include future climate and flow scenarios, and none have incorporated species or ecosystem vulnerability assessments. Most objectives assessed in the case study referred to current or historic states considered achievable in a stationary environment where relationships of the past will carry through to the future. However, under climate change objectives need to incorporate adaptations to new hydrological and ecological conditions by increasing ecosystem resilience and the ability to transform.

There remain critical knowledge gaps that are limiting the ability to adapt environmental water management to a non stationary future (Capon et al. 2018). A major weakness is the lack of future hydrologic modelling and vulnerability assessments that can help determine the ability of a species or ecosystem to withstand, or how it may change, in response to a changing climate and more frequent extreme events. By incorporating the latest available climate, flow and vulnerability scenarios, water managers will be better equipped to set objectives that are SMART and climate ready. Once this technical information is available more informed and transparent trade off decisions can be made and truly ‘climate ready’ objectives can be set. The need to make trade off decisions will only increase as competition for water and its availability shifts under climate change.

Equipping water managers with the most up to date tools and information to proactively manage water sustainability into an uncertain future is vital to achieve the desired ecological outcomes. The process proposed in this paper should be applied to catchment and basin wide environmental flow decisions and updated as new information becomes available. If this or a similar process is not adopted, future objectives will be inadequate in preparing and/or supporting river managers in achieving policy objectives.

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Table 1 – Adaptations for inclusion in climate ready ecological objectives

Possible inclusions in future environmental water objectives		Justification or intent
Persistence		
Maintain diversity of habitats; including refuges	1. Protect key ecosystem features e.g. buffer zones, structural complexity of vegetation, diversity of geomorphic features, protection of water quality	Many of these aspects are also relevant to adaptation, yet the ability to persist relies on 'protection' of these features in the landscape (West et al. 2009)
	2. Consider drought induced low flows or provision or maintenance of refuges (pool habitat for low flow/drought conditions)	Allows species to persist in situ during periods of drought (West et al. 2009)
	3. Seek to minimise losses rather than prevent change (e.g. uses maintain rather than restore/protect)	Aims to maintain ecosystems in the current state rather than aim for an historic reference point (Dunlop, Parris & Ryan 2013)
Adaptation		
Maintain habitat and ecological function; focus on population diversity and dynamics, carbon cycling	4. Consider and provide for habitat diversity, connectivity and/or conservation Encourage increased movement of species from one ecosystem to another (e.g. to new habitats within an acceptable thermal tolerance range)	Increased habitat diversity and connectivity improves resilience by enabling species to migrate to new locations with more tolerable climate and thermal tolerance zones, or adapt to changing conditions (Comte & Olden 2017; Fortini et al. 2013; Palmer et al. 2009)
	5. Maintain a diversity of species, without mention of specific species	Aiming for species diversity, rather than species specific conservation, the ecosystem can include species with similar functions rather than focusing on protection of endangered or highly vulnerable species
	6. Ensure carbon cycling and energy sources for aquatic and riparian productivity are maintained	Allows for continuation of some ecosystem function regardless of species/communities (Lin & Petersen 2013)

	7. Aim for high functional redundancy and diversity within an ecosystem	Encouraging large functional groups whereby one species can fill the void made by another species of similar function if extinction occurs
Transformation		
Actively promote change	8. Objectives that are flexible, and achievable, with changing water availability (e.g. they are achievable under flood and long term drought conditions)	Objectives need to be flexible to changing water availability and updated as climate and river flow scenarios become available
	9. Allow the establishment of locally non native species that preserve regional biodiversity or sustain ecological functions	Allows for potentially more suitable, climatically tolerant species to fill a gap after disturbances, and provides for the greatest diversity possible (e.g. stocking fish) (West et al. 2009)
	10. Consider ex situ conservation or active translocation of species to a new site	Species vulnerability assessments coupled with climate scenarios will reduce uncertainty around viability of species in certain locations. Incorporating this information into environmental flow assessments will help with trade off decisions regarding translocation and triage

Table 2: Assessment results comparing existing environmental flow planning documents against the recommended climate change adaptation objectives of Table 1. (See supplementary material for more detail).

Suggested objectives that incorporate climate change adaptations (from Table 1)		Number of objectives that meet this criterion	Number of objectives that could meet this criterion	Percent of objectives that could meet this criterion
Persistence - Aims to maintain habitats and features, including refuges				
1	Protect key ecosystem features that can support and underpin the overall system e.g. buffer zones, riparian areas incorporating drought tolerant plants, structural complexity of vegetation, protect nursery and spawning areas (West et al. 2009)	158	183	86% (n=183)

2	Considers drought induced low flows or provision or maintenance of refuge or pool habitat for low flow/drought conditions	11	33	33% (n=33)
3	Tries to minimise losses rather than prevent change (e.g. uses maintain rather than restore/protect)	182	230	79% (n=230)
Adaptation - Provides for improved migration and maintenance of ecological function				
4	Considers habitat diversity, connectivity and/or conservation	98	155	63% (n=155)
4	Encourages increased movement of species (e.g. to new habitats within an acceptable thermal tolerance range)	48	83	58% (n=83)
5	Aim to maintain a diversity of species, without mention of specific species	84	122	69% (n=122)
6	Ensure carbon cycling and energy sources for aquatic and riparian productivity are maintained	18	22	81% (n=22)
7	Aim for high functional redundancy and diversity within an ecosystem	19	41	46% (n=41)
Transformation – Objectives that actively promote change and/or are flexible to change				
8	Objectives that are flexible, and achievable, with changing water availability	9	15	60% (n=15)
9	Allow the establishment of locally non native species that maintain native biodiversity or ecosystem function in the overall region (West et al. 2009)	13	22	59% (n=22)
10	If there was any suggestion for ex situ conservation or active translocation	0	1	0% (n=1)

Table 3: Examples of trade off considerations given future scenarios in setting environmental flow objectives

Trade off considerations	**Example**
Are there alternate ways to achieve the objectives?	If the objective is to provide abundant recreational fish populations, can these be stocked fish rather than naturally spawned and recruited?
Where is the best use of environmental flows on a basin wide scale?	If the river and each tributary is delivering a flow component to achieve the same objective, can the same result be achieved by delivering water to just a limited number of rivers e.g. is fish spawning required in every tributary of a basin? Decisions need to be made for retaining a representative area of each ecosystem rather than trying to maintain all areas where water scarcity increases
Cost benefit to achieving the environmental objective	If the objective of delivering overbank flows requires levee construction or land acquisition on the floodplain, is the ecological benefit greater than economic and social cost?
Cost benefit to other water users	To achieve a desired environmental flow objective larger volumes of water may be required to be re-allocated from agricultural or other consumptive use. Are existing irrigation areas sustainable in the long term? Can urban communities recycle more water?
Sequencing of extreme events such as drought	Developing objectives for 2-5 consecutive dry years and/or 5 – 10 consecutive dry years will provide information on life cycle thresholds of species and allow decisions to be made on how long to provide water during periods of drought
Willingness of the community to transition to a new state	Where future conditions will not sustain the historical complement of species could an alternative suite of species deliver the same goods and/or services or ecological function, be acceptable to the community? Does the community invest money in maintaining the full suite of current species, including endangered species, or trade off some species to save others?
Revise objectives for the region	Are the objectives for restoration goals sustainable in the long term, or should objectives be aimed at ecosystem services?

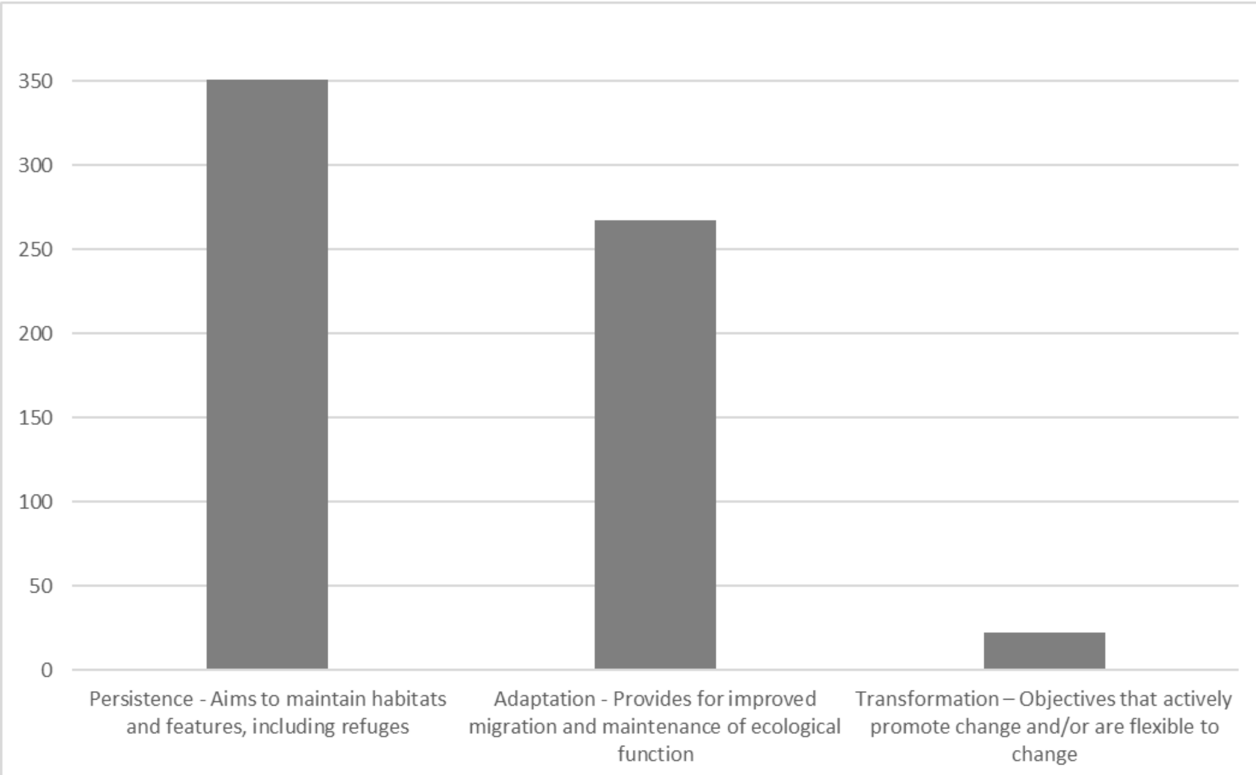

Figure 1: Number of existing flow objectives that meet the recommended climate change adaptation objectives

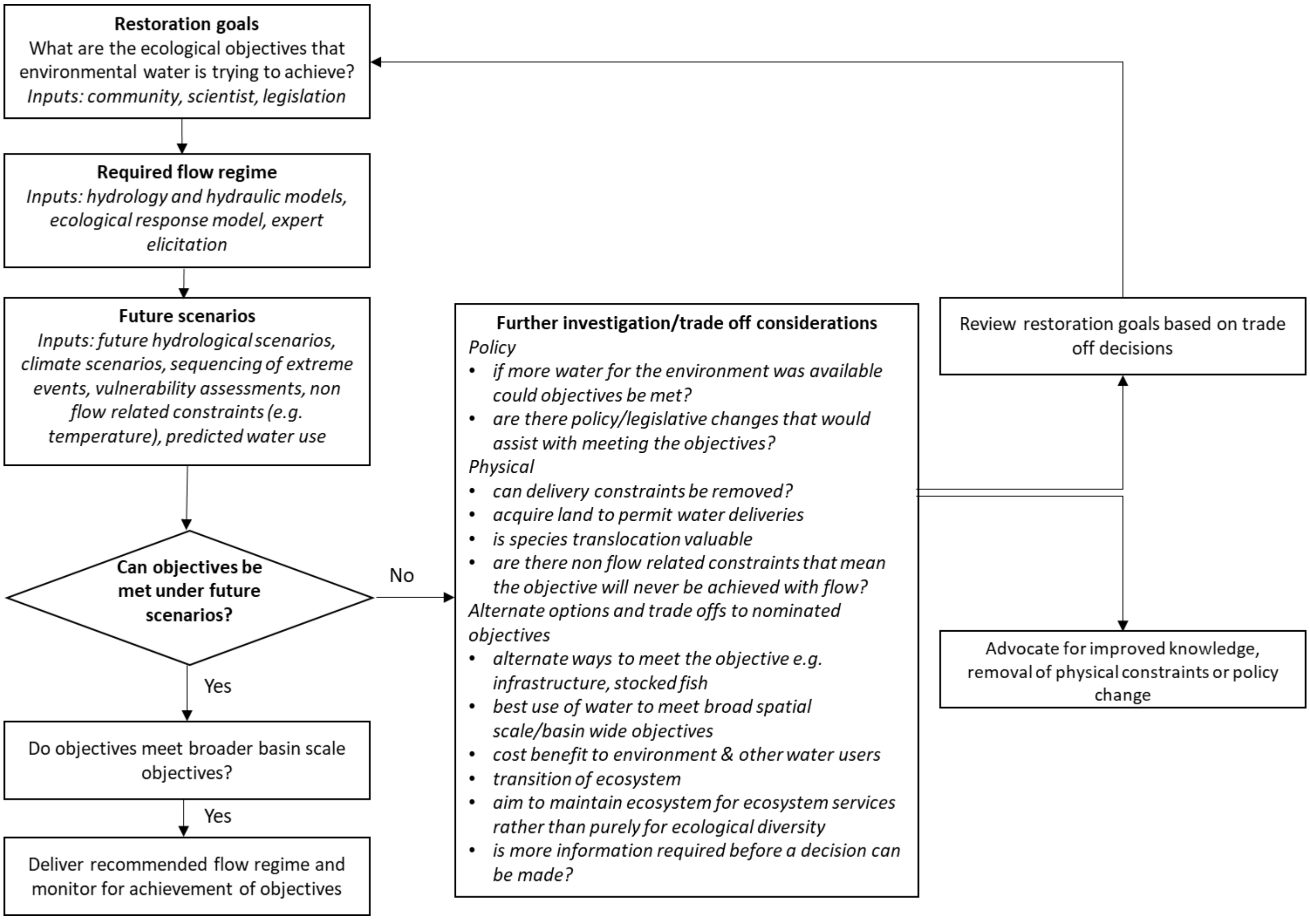

Figure 2 Process to establish climate ready objectives in future flow assessments

Supplementary Material

<u>List of plans analysed</u>

Victoria – non Murray Darling Basin

- Moorabool River Environmental Water Management Plan (EWMP) 2016
- Moorabool River Flows study 2015
- Moorabool River Seasonal Watering Proposal 2019/2020
- Upper Barwon River Seasonal Watering Proposal 2019/2020
- Upper Barwon Yarrowee Leigh Flows study 2019
- Glenelg River Seasonal Watering Proposal 2017/2018
- Glenelg River Seasonal Watering Proposal 2018/2019
- Upper and Mid Glenelg Flows study 2013
- Lower Glenelg Flows study 2018
- Glenelg River Environmental Water Management Plan (EWMP) 2016
- Tarago-Bunyip Environmental Water Management Plan (EWMP) 2017
- Werribee River Environmental Water Management Plan (EWMP) 2015
- Yarra River Flows study 2018
- Tarago and Bunyip Rivers Flows study 2018
- Cement Creek Flows study 2020
- Macalister River EWMP 2015
- LaTrobe River Seasonal Watering Proposal 2019/2020
- Thompson River Seasonal Watering Proposal 2019/2020

Victorian Murray Darling Basin

- Goulburn River Environmental Water Management Plan (EWMP) 2015
- Goulburn River Seasonal Watering Proposal 2019/2020
- Lower Goulburn River Flows study 2020 (draft)
- Broken River Environmental Water Management Plan (EWMP) 2013
- Broken Creek and Nine Mile Environmental Water Management Plan (EWMP) 2010
- Murray River Lock 6 - 10 Environmental Water Management Plan (EWMP) 2015
- Murray River Lock 5 Environmental Water Management Plan (EWMP) 2015
- Campaspe River Environmental Water Management Plan (EWMP) 2014
- Gunbower Creek and lagoon system Environmental Water Management Plan (EWMP) 2015
- Loddon River Environmental Water Management Plan (EWMP) and Flows study 2015
- Coliban River Environmental Water Management Plan (EWMP) 2015
- Birch (Bullarook) Creek Environmental Water Management Plan (EWMP) 2015
- Pyramid Creek Flows study 2015
- Serpentine Creek Flows 2014
- Ovens River EWMP 2015
- Wimmera Seasonal Watering Proposal 2018/2019

South Australia

- South Australia Murray River Environmental water plan 2018/2019
- South Australia Murray Darling Basin NRM Plan 2015
- River Murray Channel Environmental Water Requirements: Ecological Objectives and Targets 2014

New South Wales

- NSW Government River Flow objectives 1999 (12 overarching objectives for the protection or restoration of river health, ecology and biodiversity)
- Water Sharing Plan for the Lachlan Regulated River Water Source 2016
- Water Sharing Plan for the Murrumbidgee Regulated River Water Source 2016
- Murrumbidgee Long Term Water Plan 2019 (Draft)
- Murray-Lower Darling Long Term Water Plan 2019 (Draft)
- Lachlan Long Term Water Plan 2019 (Draft)

Commonwealth Government

- The Basin Plan 2012

Examples of existing objectives that include recommended climate change adaptations as per Table 1.

	Suggested objectives that incorporate climate change adaptations (from Table 1)	Number of existing objectives that meet this adaptation	Examples of existing objectives from case study documents
Persistence - Aims to maintain habitats and features, including refuges			
1	Protect key ecosystem features that can support and underpin the overall system e.g. buffer zones, riparian areas incorporating drought tolerant plants, structural complexity of vegetation, protect nursery and spawning areas (West et al. 2009)	158	"*Protect and restore the key species, habitat components and functions of the ecosystem by providing the hydrological environments required by indigenous plant and animal species and communities*" (Murray River Lock 6-10 EWMP 2015) "*Maintain or improve in-stream & riparian vegetation extent, structure & composition*" (Yarra River Flows study 2018) "*Trigger downstream spawning migration of adult catadromous and amphidromous fish*" (Moorabool River EWMP 2016) "*Provide flows cues by increasing water depth to promote downstream migration and spawning for Australian grayling, tupong and Australian bass*" (Macalister River EWMP 2015)
2	Considers drought induced low flows or provision or maintenance of refuge or pool habitat for low flow/drought conditions	11	"*Provide adequate water quality/habitat for fish refuge locations in dry periods*". (Wimmera SWP 2018/19) "*Protection of drought refuge plus dry spell breaking under climate change conditions*" (Broken and Nine Mile EWMP 2010)

			"*To protect refugia in order to support the long-term survival and resilience of water-dependent populations of native flora and fauna, including during drought to allow for subsequent re-colonisation beyond the refugia*". (The Basin Plan 2012) "*Flush pools to prevent water quality decline during low flows*" (Glenelg River SWP 2017-18)
3	Tries to minimise losses rather than prevent change (e.g. uses maintain rather than restore/protect)	182	"*Provide flow variability to maintain species diversity of fringing vegetation*" (Moorabool River EWMP 2016) "*Maintain high species richness and abundance of fish populations in the upper reaches*" (Werribee River EWMP 2015) "*Maintain current macroinvertebrate community (including benthic invertebrates, crayfish and mussels)*" (Cement Creek Flows 2020)
Adaptation - Provides for improved migration and maintenance of ecological function			
4	Considers habitat diversity, connectivity and/or conservation	98	"*Increase instream physical habitat diversity (e.g. shallow and deep water habitats)*" (Goulburn River EWMP 2015) "*Provide baseflow adequate to allow the persistence of aquatic macrophytes at the bank toe*." (Broken River EWMP 2013) "*Maintaining passage for migratory fish moving between the estuary and the upper reaches*" (Tarago-Bunyip EWMP 2017) "*Disturb the algae/bacteria/organic biofilm present on rock or wood debris to support macroinvertebrate communities*." (Wimmera SWP 2018/19) *"Create quality instream, floodplain and wetland habitat - regulation of DO, temp and salinity, provision of diverse wetted areas and geomorphic processes, control encroachment of terrestrial vegetation, appropriate rates of rise and fall*" (Murray-Lower Darling Long Term Water Plan 2019)
4	Encourages increased movement of species (e.g. to new habitats within an acceptable thermal tolerance range)	48	*"Maintaining a viable breeding population of platypus along Serpentine Creek that can disperse to tributaries and contribute to a larger regional metapopulation"* (Serpentine Creek Flows study 2014) "*Provide movement and dispersal opportunities for biota to complete lifecycles and disperse into new habitats lifecycles - within and between catchments - including migration for full life cycle, recolonisation following*

			disturbance, dispersal of eggs, larvae and seeds" (Murrumbidgee Long Term Watering plan 2019)
5	Aim to maintain a diversity of species, without mention of specific species	84	"*Maintain abundance, improve breeding and recruitment of macroinvertebrates as a food source for fish, frog and platypus populations*" (Upper Barwon River SWP 2019/20) "*Provide periodic opportunities for regeneration of riparian, floodplain and wetland plant species and improve in channel carbon availability*" (Goulburn River SWP 2019/20) "*Maintaining the full suite of native migratory and non-migratory fish species*" (Tarago-Bunyip EWMP 2017)
6	Ensure carbon cycling and energy sources for aquatic and riparian productivity are maintained	18	*Provide for the mobilisation of carbon and nutrients from the floodplain to the river to reduce the reliance of instream food webs on autochthonous productivity.* (River Murray Channel Environmental Water Requirements: Ecological Objectives and Targets 2014) *Protect and restore ecological community structure, species interactions and food webs that sustain water-dependent ecosystems, including by protecting and restoring energy, carbon and nutrient dynamics, primary production and respiration.* (The Basin Plan, 2012) *Support nutrient, carbon and sediment transport along channels and benches/banks, and between channels and floodplains/wetlands* (Murrumbidgee Long Term Water Plan, 2019)
7	Aim for high functional redundancy and diversity within an ecosystem	19	"*Maintain or improve condition, extent and diversity of emergent macrophyte vegetation to provide structural habitat and channel/lower bank stability to low and moderate flows.*" (Upper Barwon Rv SWP 2019/20) "*Maintain/increase diversity and productivity of macroinvertebrates and macroinvertebrate functional feeding groups"* (Campaspe River EWMP 2014)
Transformation – Objectives that actively promote change and/or are flexible to change			
8	Objectives that are flexible, and achievable, with changing water availability	9	"*Maintain water rats as a component of the system and accept their numbers will fluctuate between drought and non-drought conditions*" (Loddon River EWMP 2015) "*water-dependent ecosystems are resilient to climate change, climate variability and disturbances (for example, drought and fire)"* (The Basin Plan, 2012)

9	Allow the establishment of locally non native species that maintain native biodiversity or ecosystem function in the overall region (West et al. 2009)	13	This included objectives with generic terms such as: "*To protect, restore and enhance its ecological health, functioning, and biodiversity of the Werribee River*" (Werribee River EWMP 2015) "*Maintain/increase diversity and productivity of macroinvertebrates and macroinvertebrate functional feeding groups*" (Cement Creek flows study 2020) *"Maximise structural complexity and diversity of floodplain vegetation, including wetlands*" (Goulburn River flows study 2020)
10	If there was any suggestion for ex situ conservation or active translocation	0	There were no suggestions on active movement of species from one catchment to another or conservation of a species in a non natural setting