Resilient Landscapes
National Environmental Science Program

Indigenous cultural and ecological values of the Donnelly River

Part A: Interim hydro-socio-ecological conceptual model and knowledge gaps from desktop review.

Caroline Canham, Leah Beesley, Fiona Freestone, Thiaggo C. Tayer, Samantha Setterfield & Michael Douglas

The University of Western Australia

Creative Commons licence

Cataloguing data

This publication (and any material sourced from it) should be attributed as: Caroline Canham[1], Leah Beesley[1], Fiona Freestone[1], Thiaggo de Castro Tayer[1], Samantha Setterfield[1], Michael Douglas[1] (2024). *Indigenous cultural and ecological values of the Donnelly River and their water requirements. Part A: Interim hydro-socio-ecological conceptual model and knowledge gaps from desktop review*, The University of Western Australia, Perth, WA. Report to the Resilient Landscapes Hub of the Australian Government's National Environmental Science Program. November 2024. CC BY 4.0.

This publication is available at https://nesplandscapes.edu.au/resources/

The Resilient Landscapes Hub is funded by the Australian Government under the National Environmental Science Program. The hub is hosted by The University of Western Australia.

Disclaimer

Acknowledgements

We thank Adrian Goodreid, Adam Green, Katherine Mahar, Joanne Mannering, Tim Storer, Ashley Ramsey, Simon Pinnington and Kelli O'Neill from the Western Australian Department of Water and Environmental Regulation for their expert advice.

We thank Stephen van Leeuwen for his expert advice and guidance.

Acknowledgement of Country

We acknowledge the Traditional Owners of Country throughout Australia and their continuing connection to and stewardship of land, sea and community. We pay our respects to them and their cultures and to their Ancestors, Elders and future leaders. Our Indigenous research partnerships are a valued and respected component of National Environmental Science Program research.

Contents

Tables

Figures

Executive summary

This report is the first for *Project 3.5: Ecological and Indigenous values of south-western Australian rivers*, funded by the Australian Government's National Environmental Science Program (NESP) Resilient Landscapes Hub. Project 3.5 aims to deliver targeted research on rivers in the south-west of Western Australia (SWWA) to support water management that protects ecological and Indigenous values. The research catchment is the Donnelly River which is considered a priority system for research by the Western Australian Government's water managers.

This report presents an interim hydro-socio-ecological (HSE) conceptual model and associated principles and considerations for water managers. We have previously developed an HSE model for WA's Fitzroy River in tropical northern Australia, and this is the first test of whether the model is applicable to rivers in other regions.

The specific aims of this report are to:

- Aim 1. Apply the HSE model approach to the Donnelly River and use this to underpin a set of principles and considerations for water managers seeking to protect ecological and cultural values.
- Aim 2. Determine the transferability of the model between the Fitzroy River to the Donnelly River.
- Aim 3. Summarise relevant information on the Indigenous cultural values and flow-ecology for the Donnelly River.
- Aim 4. Identify key knowledge gaps and areas for future research.

To address these aims the report is structured as follows:
Part A - Report

- Background information on the Donnelly River and its management.
- Conceptual HSE model and principles for water planning.
- Summary of the information supporting the HSE model and principles.
- Discussion on transferability of the HSE model from the Fitzroy to the Donnelly River.
- Identify key knowledge gaps to inform research needs.

Part B – Supplementary Information

- Literature review of Indigenous cultural values and water dependent ecological assets of the Donnelly River which underpins Part A.

We found that the HSE conceptual model approach developed for the Fitzroy River was broadly transferable to the Donnelly River, with the underlying relationships between flow and biota and Indigenous water rights and values applicable in both systems. Principles relating to Indigenous rights, values, knowledge and government principles were unchanged from the original model. These principles are supported by international and national agreements and academic publications, which apply to water management across Australia.

Principles relating to flow-ecology and related Indigenous values were underpinned by flow components, identified from the river's hydrograph. Although the Donnelly and the Fitzroy Rivers are very different with respect to climate, catchment size, dominant vegetation type, and aquatic species, they both experience highly seasonal rainfall and flow. The 4 key flow components identified for the Donnelly River, therefore aligned with the flows in the HSE model developed for the Fitzroy River: groundwater / low flows; within bank flows; overbank flows; and, recessional flows (Douglas et al., 2019). Using the HSE model we identified the ecological and Indigenous values that these flows support, which informed our principles and considerations for water managers.

Our literature review found that there was limited peer-reviewed and published information on Indigenous cultural values and flow-ecology relationships for the Donnelly River. The HSE model and principles were therefore informed by literature drawn from other systems. Knowledge gaps relating to Indigenous cultural values will not be determined until after consultation with the Karri Karrak Aboriginal Corporation’s Cultural Advice Committee. For ecological values priority knowledge gaps related to better describing the distribution of biota (including riparian and aquatic plants, fish and crayfish) and quantifying the link between species and flow. There are also key knowledge gaps relating to biophysical values, primarily the location of dry season pools and groundwater needed to support them, as well as the duration of connecting flows.

In Part B of this report, we review the discoverable literature for Indigenous cultural and ecological values of the Donnelly River. Further information is provided in Part B.

1 Introduction

1.1 Introducing NESP Project 3.5: Ecological and Indigenous values of south-western Australian rivers

This report is the first for Project 3.5: Ecological and Indigenous values of south-western Australian rivers, funded by the Australian Government's National Environmental Science Program (NESP) Resilient Landscapes Hub. The project will undertake targeted research on rivers in south-west Western Australia (SWWA) to support water management decision-making that protects ecological and Indigenous values. The Donnelly River is considered a priority system for research by water planners from the Western Australian Government and is the current focus of this project.

We apply an approach that was successfully developed for the Fitzroy River in the Kimberley region of northern Australia (Douglas et al., 2019, Beesley et al., 2021a). To support decisions that protect freshwater ecological and Indigenous cultural values we developed:

Hydro-socio-ecological (HSE) conceptual model of the linkages between key flow components and ecological and Indigenous values, showing how a reduction in flows would impact these values.

Principles and considerations for water managers to protect ecological and Indigenous cultural values and for more inclusive water management. The principles and considerations are based on the HSE model.

Table of evidence summarising the evidence that supports the HSE model and principles and recommendations. To identify knowledge gaps, evidence was categorised by spatial scale: local, regional and elsewhere.

These outputs provided a framework used by managers to develop water-planning rules for the Fitzroy River (Department of Water and Environmental Regulation, 2020, Department of Water and Environmental Regulation, 2023a, Department of Water and Environmental Regulation, 2023b). For example, government water planners used the principles and considerations (Douglas et al., 2019), in a discussion paper on water management in the Fitzroy catchment (Department of Water and Environmental Regulation, 2020). Following the discussion paper, the recently announced (October 2023) policy positions for the Fitzroy River include no further surface water take, which protects many freshwater ecological and cultural values, and includes engagement with Traditional Owners (Department of Water and Environmental Regulation, 2023b).

The approach applied to WA's Fitzroy River also guided research questions, with the original HSE model and supporting table of evidence (based on existing information) highlighting key knowledge gaps. Targeted research then addressed these knowledge gaps and the HSE model was updated, directly showing the contribution of research and increasing the certainty of the model (Beesley et al., 2021a).

This approach provides a robust framework for better consideration of ecological and Indigenous values in water-management decisions. We therefore decided to use the same approach, and assess the transferability of a HSE model developed for the Fitzroy River in the Kimberley region (Douglas et al., 2019) to the Donnelly River in SWWA.

1.2 Report aims and structure

The research presented in this report had 4 aims:

- Aim 1. To apply the HSE model approach to the Donnelly River, and use this to develop principles and considerations for water managers seeking to protect ecological and Indigenous cultural values.
- Aim 2. To determine the transferability of the model between the Fitzroy River to the Donnelly River.
- Aim 3. To summarise available information on the Indigenous cultural values and flow-ecology for the Donnelly River, and from elsewhere, if required.
- Aim 4. To identify key knowledge gaps and areas for future research.

To address these aims the report is structured as follows:

Part A - Report

- Background information on the Donnelly River and its management setting.
- Conceptual hydro-socio-ecological model and principles for water planning.
- Summary of the information supporting the HSE model and principles.
- Discussion on transferability of the HSE model from the Fitzroy to the Donnelly River.
- Identify key knowledge gaps to inform research.

Part B – Supplementary Information

- Literature review of Indigenous cultural values and water dependent ecological assets of the Donnelly River which underpins Part A.

Information from Parts A and B of the current report will be used to determine key knowledge gaps, which will guide research projects undertaken as part of NESP RLH Project 3.5 (as summarised in Figure 1).

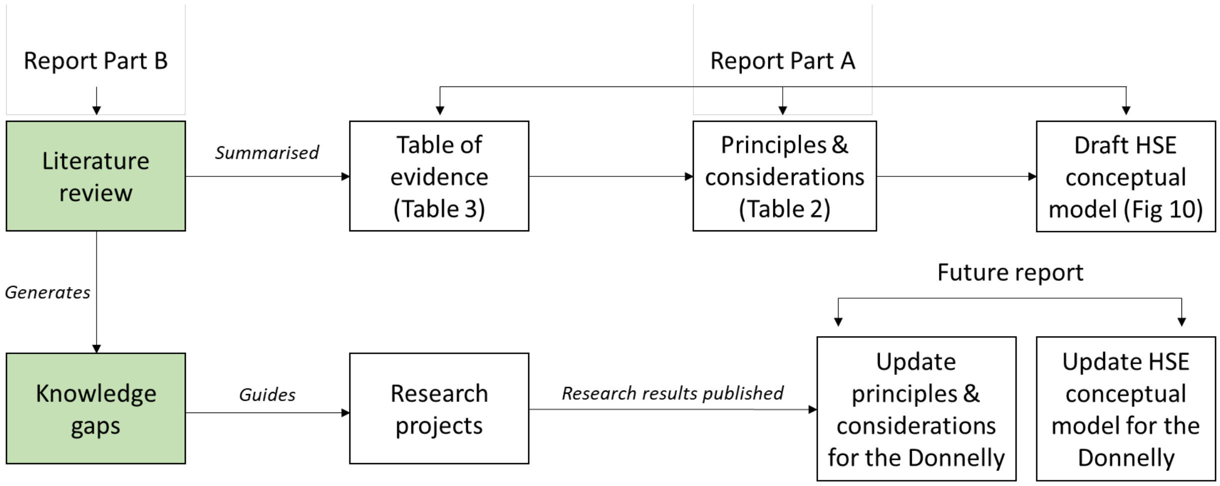

Figure 1. Workflow showing the components of the current report (Parts A and B) and how they inform on-going work.

1.3 The need for protection of ecological and Indigenous freshwater values

River systems across Australia face multiple threatening processes, including climate change, water extraction, altered land use and alien species (Dudgeon et al., 2006, Vörösmarty et al., 2010). The Australian Government has developed *Australia's strategy for nature 2019–2030*, to help meet United Nations Sustainable Development Goals, and the global targets to reduce threats to biodiversity set out in the Kunming-Montreal Global Biodiversity Framework (Commonweath of Australia, 2019). The Strategy recognises the importance of aquatic biodiversity, and that it is threatened by "the impacts of changed frequency, magnitude and intensity of floods and droughts, water quality and the condition of habitats fringing rivers and streams" (Commonweath of Australia, 2019). Objective 8 of the Strategy states that there needs to be "explicit consideration of environmental flow requirements" in water planning and decisions. Objective 7 notes the importance of "explicit consideration of climate change adaptation and resilience, including in the management of species and ecosystems that are vulnerable to climate change". Protecting river flows is thus recognised as a critical part of meeting international and national obligations to protect biodiversity.

South-west Western Australia (SWWA) is considered a biodiversity hotspot, that is, it is a region that has an exceptional concentration of endemic species that are undergoing exceptional habitat loss (Myers et al., 2000). Due to extensive land clearing for agriculture, most rivers in SWWA have been affected by dryland salinisation (Kay et al., 2001, Morgan et al., 2003) and all have been affected by the impacts of a drying climate (Silberstein et al., 2012). As freshwater availability declines in the region (Petrone et al., 2010, McFarlane et al., 2020), there is an increasing need to understand the importance of surface and groundwater flows for aquatic and riparian biota to inform water planning and management decisions that protect biodiversity values.

Indigenous cultural knowledge and values are crucial to the management and protection of rivers, as identified in the Samuel review of the Environment Protection and Biodiversity Conservation Act (EPBC) Act (2020) and in the Productivity Commission's National Water Reform inquiry (2020). Rivers and the life they support are central to Indigenous culture (Australian Government, 2017). As part of the National Water Initiative, a module has been produced to guide water management that supports "Indigenous social, spiritual and customary objectives" (Australian Government, 2017). Indigenous organisations from the Murray-Darling Basin and northern Australia have also developed a guide for water managers that details how to describe, manage and monitor cultural flows (MacKenzie et al., 2017). However, there are few examples of Indigenous values being appropriately and effectively incorporated in water planning and policy in Western Australia.

2 Introducing the Donnelly River

2.1 Location

The Donnelly River catchment in SWWA is considered a priority system by WA's Department of Water and Environmental Regulation (DWER) and is the focus of NESP Project 3.5. The Donnelly River system is situated within the forested region of SWWA, in the South-West Boojarah region of the Bibulman (Pibelmen) Noongar Nation.

The Donnelly River is a relatively small catchment at 1,727 km^2 located approximately 250 km south of Perth. The catchment lies predominantly within the Warren (WAR) Interim Biogeographic Regionalisation for Australia (IBRA) bioregion, with the top northeast of the catchment in the Jarrah Forest IBRA bioregion (Figure 2).

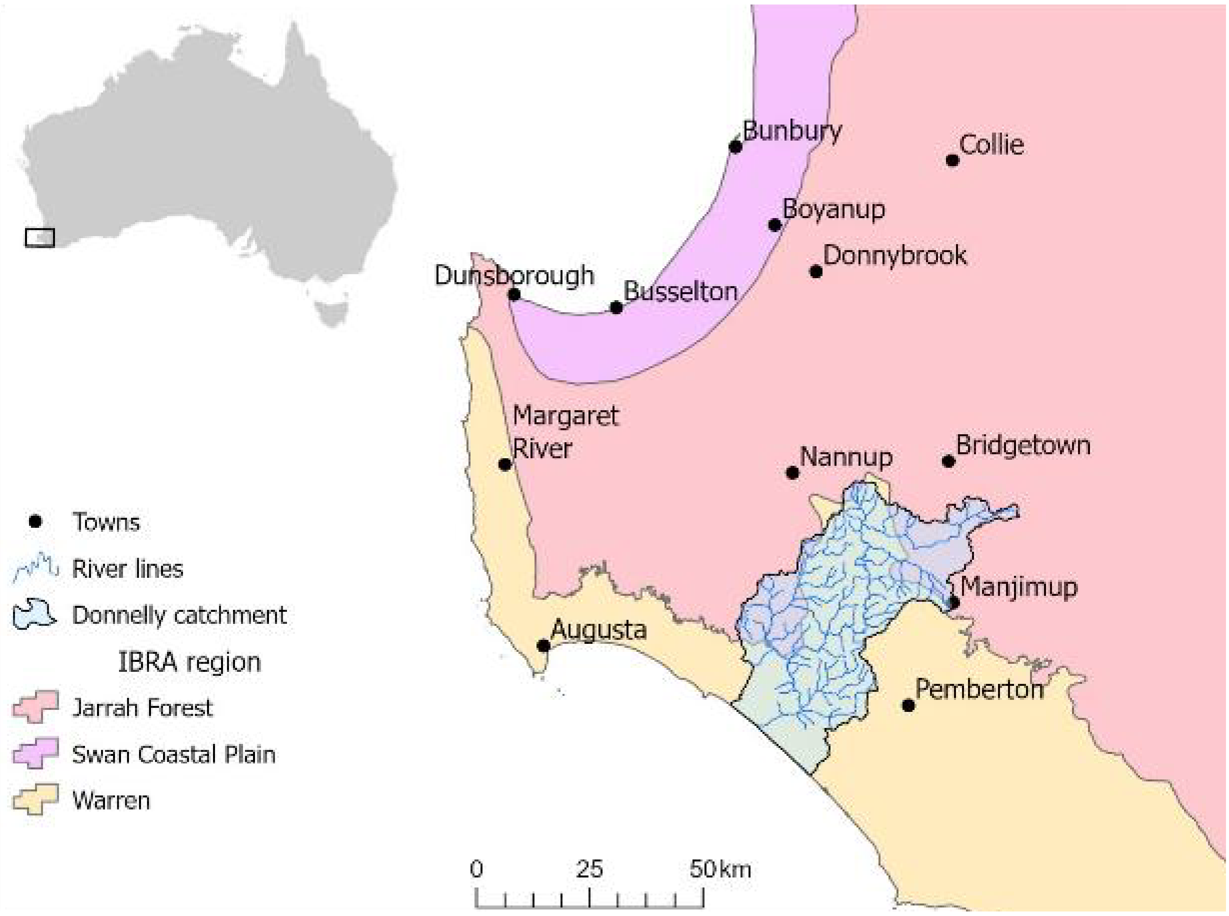

Figure 2. Map of the location of the Donnelly catchment and Interim Biogeographic Regionalisation for Australia (IBRA) subregions.

The Donnelly catchment is mainly forested. State forests cover 46 % (798 km^2) of the catchment and have historically been managed for the production of Jarrah (*Eucalyptus marginata*), Karri (*E. diversicolor*) and Marri (*Corymbia calophylla*) timber. National parks cover 31 % (537 km^2) of the catchment. The upper part of the catchment is mostly cleared for agriculture. Associated with agricultural production, there are many large dams that capture and store surface runoff (Figure 3).

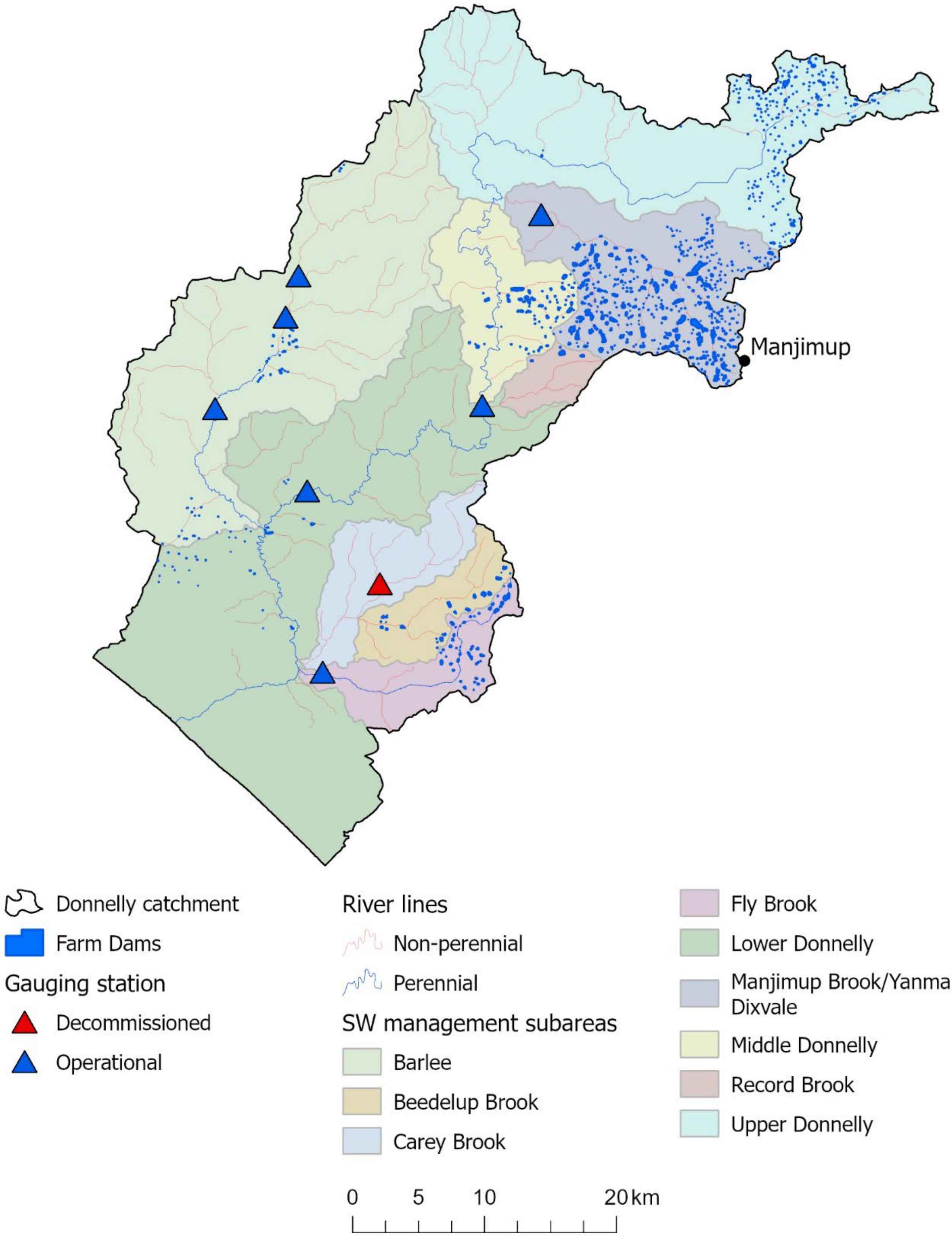

Figure 3. Donnelly River catchment showing the location of farm dams, management sub-areas and the location of gauging stations.

2.2 A freshwater refuge in a drying climate

The Donnelly River catchment may be considered a refuge for freshwater-dependent biota in the region, as it is largely unimpacted by salinity and has perennial reaches. The riverine environment of the Donnelly catchment supports a range of aquatic and riparian ecological assets and values. The aquatic biota includes 12 fish species, nine of which are endemic to the rivers of SWWA (Morgan and Beatty, 2008), with two listed as threatened under the Commonwealth *Environment Protection and*

Biodiversity Conservation Act (1999) (Table 1). Another species, the Western Mud Minnow (*Galaxiella munda*), is currently under consideration for listing. Riparian vegetation is likely important to the listed terrestrial marsupial species quokka (*Setonix brachyurus*) and western ringtail possum (*Pseudocheirus occidentalis*) (Table 1).

Table 1. Threatened species that occur in the riverine environment of the Donnelly River catchment. Threatened status as listed under the Commonwealth EPBC Act (1999). *Galaxiella nigrostriata* is shown in grey as it is most likely to occur in non-flowing habitats, i.e., wetlands low in the catchment. Species are listed from most to least threatened for the different habitat types.

Species	Common name	Threatened status	Habitat
Galaxiella nigrostriata	Black-striped dwarf galaxias	Endangered	Aquatic
Galaxiella munda	Western dwarf galaxias/ western mud minnow	Currently under consideration	Aquatic
Nannatherina balstoni	Balston’s pygmy perch	Vulnerable	Aquatic
Westralunio carteri	Carter’s mussel	Vulnerable	Aquatic
Pseudocheirus occidentalis	Western ringtail possum	Critically endangered	Riparian & terrestrial
Setonix brachyurus	Quokka	Vulnerable	Riparian & terrestrial

Carey Brook and Fly Brook are two major tributaries to the Donnelly River and are significant as they are classified as “stable winter baseflow”, which indicates a perennial stream or river with the majority of runoff occurring in winter (Kennard et al., 2010). It is notable that these two tributaries of the Donnelly River were two of only 14 reaches found to be perennial in the 136 reaches in WA assessed by Kennard et al. (2010), highlighting how uncommon this flow type is in Western Australia. In SWWA, the majority of rivers have intermittent flow, with reaches classified as “predictable winter intermittent” or “predictable winter highly intermittent” (Kennard et al., 2010). In a drying climate these perennial reaches may be important refuges for aquatic biota (Robson et al., 2013).

A drying climate: declining rainfall and increasing temperature

Freshwater values in SWWA are threatened by a drying climate, with rainfall declining and temperature increasing since the 1970s (McFarlane et al., 2012). For the Donnelly catchment, mean annual rainfall has reduced from 1066 mm between 1916 to 1969 to 816 mm between 2000-2022

(Manjimup gauge, station number 9573) (Figure 4). This represents a 23 % decline compared to the 1916-1968 average (Figure 4).

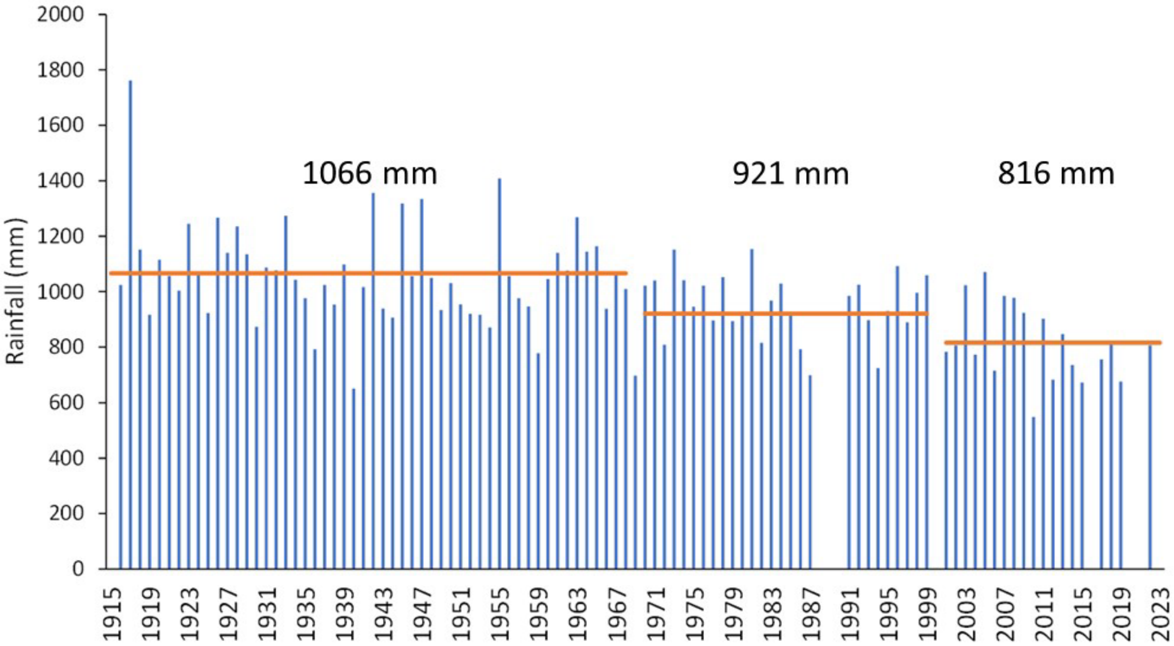

Figure 4. Annual rainfall in Manjimup from 1915 to 2022. Yellow lines indicate the mean annual rainfall from 1916-1969 and 1970-1999 and 2000-2023, showing a decline in rainfall. Data are from Manjimup gauge (No. 9573). Years with no data show where annual rainfall data were incomplete, and are therefore not shown.

The decline in rainfall is more pronounced for winter rainfall (May to July). Hope and Ganter (2010) found that average winter rainfall for 2000-2007 was 44 % less than the average for 1910-1968 (at the Wilgarrup gauge station number 9619, 11 km from Manjimup). To update this assessment, we summarised more recent rainfall data at both the Wilgarrup and Manjimup stations. We found that winter rainfall has decreased by an average of 29 % for the period of 2000-2023 compared to 1916-1968 at the Manjimup station. We found a similar decline at the Wilgarrup gauge, with an average of 31 % less winter rainfall for the period 2000-2023 compared to 1910-1968. For the period 2000 - 2015 (inclusive) data were missing for 10 years at the Wilgarrup station, and these years were excluded from the analysis. Data were incomplete for 1990 and 2020 at the Manjimup station and were also excluded.

Drivers of rainfall decline in coastal areas, including the Donnelly catchment, have been linked to changes in global circulation (Hope and Ganter, 2010), although there is evidence that the greater southwest corner has also experienced similar drought cycles in the past 700 years (as inferred from paleoclimate and tree ring records (O'Donnell et al., 2021)).

The drying climate has been exacerbated by an increase in air temperature, with the mean maximum annual temperature for the hottest months, of December to March, increasing from 25.8 °C (1937-1975) to 26.5 °C (1975-2022) at Manjimup. Similarly, minimum temperatures have increased from 9.3 °C to 10.1 °C for the same time periods (Manjimup gauge 009573).

A drying climate: decreasing streamflow in the Donnelly River catchment

Streamflow in the main channel of the Donnelly River has declined markedly in recent decades. For example, at the Strickland gauge (No. 608151) mean annual discharge was 140 GL/year (+/- 27 GL) from 1952 to the end of 1959, which increased to 163 GL/year (+/- 18) during the 1960's, when rainfall was higher (Figure 5). In comparison, the mean annual average streamflow for the decade from 2010 was ~75% lower, at 41 GL/year (+/-10 GL).

Future streamflow (years 2022-2059) for the Donnelly River was predicted to decline by approximately 40% of recent historical streamflow, as modelled under a range of climate scenarios (2001-2020) (Hughes and Wang, 2022). There was a high degree of variability in these estimates, reflecting the variability in future climate estimates, although all indicate continued drying. The calibration of the streamflow model was also limited by the availability of gauged streamflow data and information on site characteristics, and more information is required to improve model estimates of future streamflow for the Donnelly River (Hughes and Wang, 2022). Declines in streamflow have been attributed to a decrease in groundwater levels, which has resulted in reduced groundwater contributions to stream and saturated overland flow (Kinal and Stoneman, 2012).

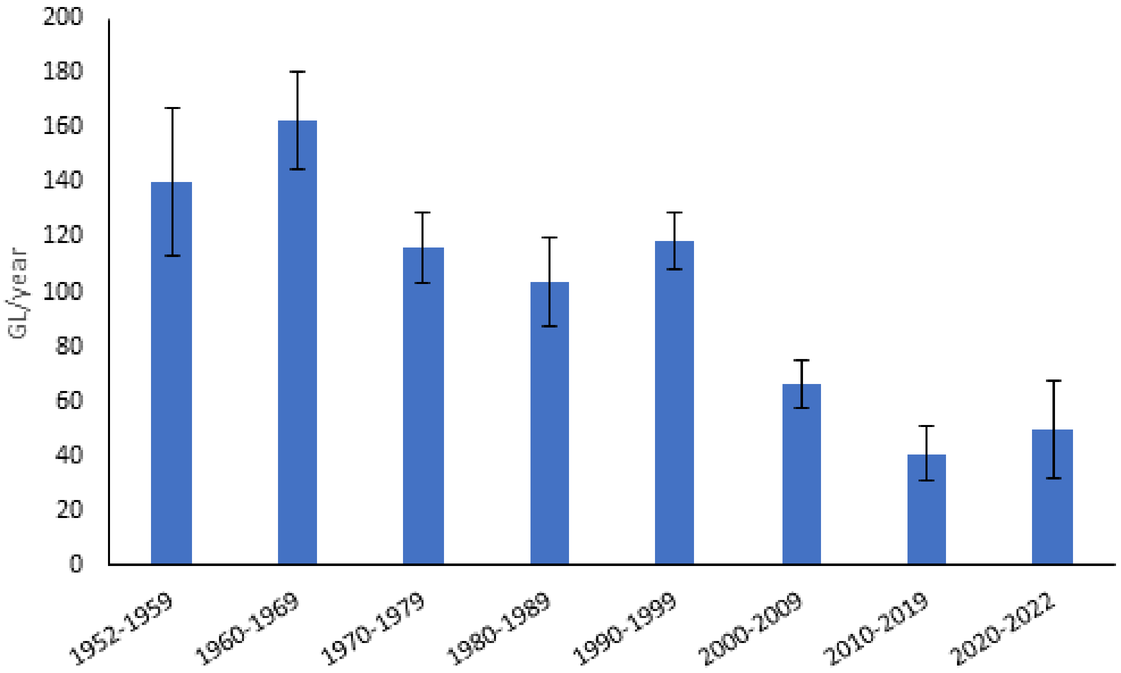

Figure 5. Mean annual streamflow discharge by decade at the Strickland gauge (no. 608151) on the Donnelly River. Values are the mean +/- SE, n = 10 for each decadal increment, except 1952-1959 (n=8) and 2020-2022 (n=3).

2.3 Management setting

Native title and Indigenous water

The Donnelly River is on Bibbulmen Noongar Country (Figure 6).

Figure 6. Map of Bibbulmen (Pibelmun) Country source:
https://www.boodjar.sis.uwa.edu.au/language-region-pibelmen

The South West Noongar Native Title Settlement (the Settlement) involves approximately 30,000 Noongar people and covers approximately 200,000 km^2 (National Native Title Tribunal, 2018). The Donnelly catchment is in the South West Boojarah #2 Indigenous Land Use Agreement (ILUA), one of six ILUAs in the Settlement, which formally commenced in February 2021 (Karri Karrak Aboriginal Corporation, 2023b). The Karri Karrak Aboriginal Corporation is the regional corporation for the South West Boojarah region, which includes Wardandi, Bibulmen/Piblemen and Kaneang Noongar language or dialectal groups (Karri Karrak Aboriginal Corporation, 2023a).

Freshwater is central to Indigenous peoples' being and culture, but since colonisation water management decisions have historically been made without Indigenous peoples' counsel (Moggridge and Thompson, 2021). The United Nations Declaration on the Rights of Indigenous Peoples, of which Australia is a signatory, includes the following:

- Article 25 – Indigenous peoples have the right to maintain and strengthen their distinctive spiritual relationship with their traditionally owned or otherwise occupied and used lands, territories, waters and coastal seas and other resources and to uphold their responsibilities to future generations in this regard.

- Article 32.2 – States shall consult and cooperate in good faith with the Indigenous peoples concerned through their own representative institutions in order to obtain their free and informed consent prior to the approval of any project affecting their lands or territories and other resources, particularly in connection with the development, utilization or exploitation of mineral, water or other resources.

The National Water Initiative is a national water management framework, which included the establishment of a Committee on Aboriginal Water Interests (CAWI) as part of the renewal and water reform process (Green and Moggridge, 2021). At the State-level, DWER formed an Aboriginal Water and Environment Advisory Group at the end of 2022 (West Australian Government, 2022).

Water planning

In WA, water allocation planning and licensing is the responsibility of the DWER and is implemented under the Rights in Water and Irrigation Act (RIWI Act 1914). In SWWA different allocation plans exist for surface and groundwater resources. A surface water allocation plan for the combined Warren-Donnelly catchment was prepared in 2012, and a water allocation statement for the Donnelly was released in 2018 in response to the proposed Southern Forest Irrigation Scheme. The scheme as proposed did not occur, but there is on-going interest in further development of irrigated agriculture in the catchment. A new surface water plan for the Warren-Donnelly catchment is currently in preparation. Groundwater is managed under the South West Groundwater Areas Allocation Plan 2009, which was evaluated in 2012 and 2015. The focus of the current report is to inform surface water planning; however, groundwater sources are mentioned when pertinent.

The Donnelly River catchment is divided into nine subareas (Figure 3), and each subarea has an allocation limit, i.e. an annual volume of surface water that is available for consumptive use (Government of Western Australia, 2012b). The allocation limit includes water that is available for licensing, water that is exempt from allocation and water that is reserved for future public water supply. It does not include water to be left in the river (Government of Western Australia, 2012c). DWER allocate water within the allocation limit for each subarea via licensing and water resource monitoring. Investigations and licence compliance monitoring are also undertaken by DWER. Under the *RIWI Act 1914*, provision must be made for the protection of river ecosystems and the environment associated with water resources (Government of Western Australia, 2012c). Environmental water requirements for the Warren-Donnelly planning area are currently informed by studies on the Lefroy River, a tributary to the Warren River (Donohue et al., 2009). Although Donohue et al. (2009) had clear flow requirements to meet stated flow-ecology objectives, there is limited data to support these, in particular the transferability of findings to other reaches and catchments.

The upper and middle parts of the Donnelly catchment, around Manjimup, have cleared areas that are Priority Agricultural Management Areas under the Shire's Local Planning Scheme (Government of Western Australia, 2012a). Water resource development occurs predominantly in these locations including the Manjimup Brook/Yanmah-Dixvale (which is fully allocated) and Middle Donnelly subareas. The irrigated agriculture industry is the largest user of water in the Warren-Donnelly area (Government of Western Australia, 2012c). Typically, farm dams are built as gully dams, intercepting stream flow and storing water for summer irrigation when crop water demand is highest in the Mediterranean-type climate. Recently there has been interest in progressing the Southern Forest

Irrigation Scheme, which planned to take water from the Donnelly River and store it in a dam on Record Brook, a tributary of the Donnelly. Water would then be distributed by a pipeline through parts of the Donnelly and Warren Catchments. However, it is likely that there will be insufficient water available to meet the requirements of the scheme under future climatic conditions (Hughes and Wang, 2022). Historically, there has been interest in developing the Donnelly River as a source for the Integrated Water Supply Scheme that supplies the southwest, including Perth (McFarlane, 2005), and there remains interest in developing the Donnelly River and its tributaries for agriculture. The Barlee, Carey and Record Brook subareas (Figure 3) are managed as state forest, and to date there has been minimal water development in these locations (Government of Western Australia, 2012c).

3 Interim HSE model and principles

A conceptual model can guide water management decisions by showing the linkages between flow and specific values, from which it can be inferred how values will be impacted by a change in flow. The authors previously developed a conceptual model for the Fitzroy River in the Kimberley region of northern Australia (Douglas et al., 2019). A key aim of the model was to show both Indigenous and ecological values in relation to river flow, which is encompassed as a "hydro-socio-ecological" (HSE) model. The HSE model and the accompanying principles and considerations demonstrated a framework for better consideration of ecological and Indigenous values in water resource management. In the current study we applied the HSE model and principles to the Donnelly River. We outline the following:

- Key flow components for the Donnelly River
- Key habitats of the Donnelly River
- The HSE model
- Principles and considerations for water planning
- Evidence supporting the links between flow and ecological and Indigenous cultural values

3.1 Flow components

The HSE model started with a hydrograph showing average flows for the river, from which key flow components (i.e. the timing and magnitude of particular flows) were identified. Defining the flow components is an important step in determining ecological water requirements, with different flow components providing specific ecological roles or functions because of their different timing and magnitude (Poff et al., 1997, Bunn and Arthington, 2002). For example, overbank flood flows inundate the riparian zone and can recharge the alluvial aquifer and act as an environmental filter by preventing the establishment of terrestrial species. Within bank or active channel flows maintain longitudinal connectivity and facilitate fish passage.

Flow in the Donnelly River is highly seasonal, with low or no flows from January until late May, and peak flows in August (Figure 7). We identified four key flow components, following the HSE model developed for the Fitzroy River in northern Australia (Douglas et al., 2019):

- groundwater / low flows
- within bank flows
- overbank flows
- recessional flows

Although the Donnelly River and the Fitzroy River are very different systems with respect to climate, catchment size, dominant vegetation type, and aquatic species; however, both experience highly seasonal rainfall and flow. The main channel of the Donnelly River is "predictable winter intermittent", whereas the Fitzroy River is "predictable summer highly intermittent" (Kennard et al., 2010). Thus, we found that the flow components were broadly transferable, although the timing (i.e. high flows occur in winter in the Donnelly, but in summer in the Fitzroy), magnitude (much larger flood flows in the Fitzroy), and interannual variability differed between the two systems. The flow components identified in the current report also broadly agree with those characterised by DWER in their “Generalised Ecological-Flow Model for South-West Western Australia (DWER Healthy Rivers South-west, 2023). Notable differences are that we use a broad category of “within-bank flows” which includes the freshening, active channel and early season flows characterised in the DWER conceptual model.

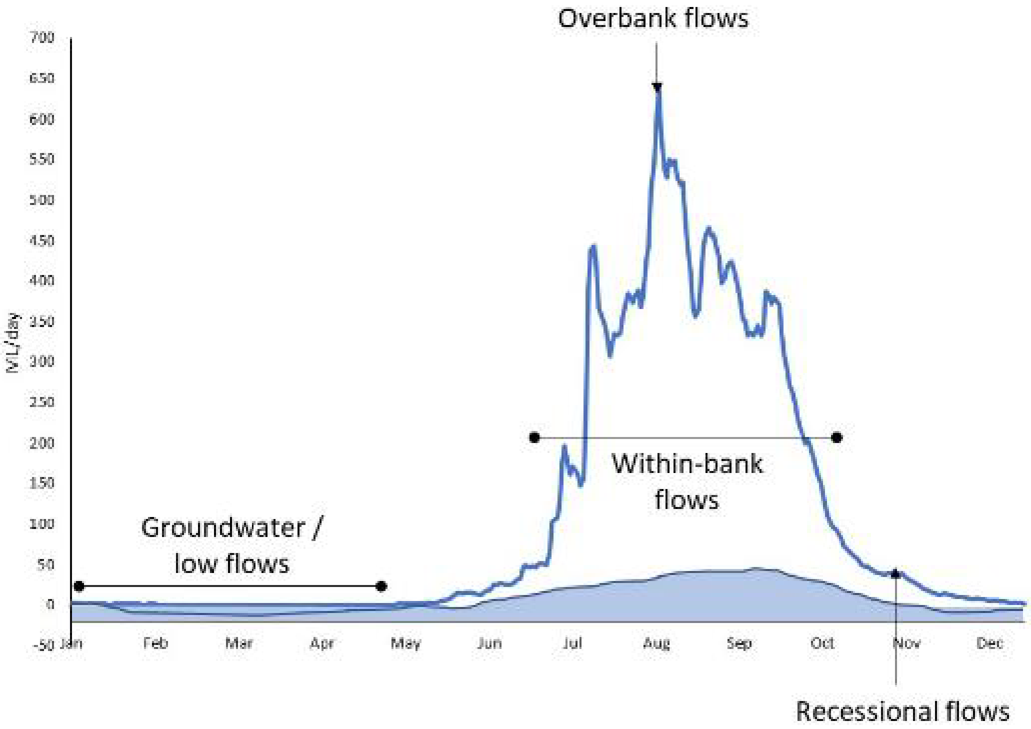

Figure 7. Hydrograph from the Donnelly River with four key flow components; groundwater/low flows, within-bank flows, overbank flows and recessional flows. Streamflow data are the mean from 2010-2022 at the Strickland Gauge. Flow components are illustrative only, it has not been confirmed that the daily flow rate (ML/day) corresponds with overbank flows.

Groundwater / low flows

The groundwater/low flow (also termed baseflow) component refers to the dry season in the hydrological cycle where flow in the river is sustained by groundwater (Allan, 1995). Depending on the amount of upwelling groundwater, the river may continue to flow (perennial reaches), albeit at a low level, or may stop flowing and dry down (intermittent reaches). In intermittent reaches, the unconfined groundwater table may sit below the soil surface.

The low rainfall season in the Donnelly River catchment occurs between December to May, when there is limited (~20% annual total) rainfall. It is thought that groundwater input from deep confined water sources varies across the catchment according to faults and upwelling. Perennial reaches occur lower in the catchment, such as downstream of the Strickland Gauge in the main channel, and in the lower sections of Barlee and Carey Brooks, which are significant tributaries. In these perennial reaches, the stream flow remains constant, albeit low. In the remainder of the catchment, especially the tributaries in the upper part of the catchment, the river ceases to flow from approximately January to late May. The upper part of the catchment (main channel and tributaries) dry completely, but downstream the main channel contracts to a series of refuge pools. Sections of the channel may receive regional groundwater (i.e., where fractured rocks exist along fault lines), which may support large refuge pools, although this is not currently well understood.

Within-bank flows

Within-bank flows refer to flows associated with rainfall during the wet season and are contained in the channel of the main river stem or tributary. Within bank flows occur regularly and maintain channel form (which is also referred to as the ‘active channel’), where the majority of scour and deposition occurs (Boulton et al., 2014). In the Donnelly River, within-bank flows occur from May to the end of November, when winter rain provides consistent surface and subsurface water inputs which mean that flow continues between rain events.

Although within-bank flows are contained within the channel, these flows may vary considerably in size. An important distinction is bankfull flows, which are flows that fill to the top of the riverbank (DWER Healthy Rivers South-west, 2023). These flows may be short in duration, typically occurring after large rainfall events during winter. Within bank flows can recharge alluvial groundwater in losing reaches, i.e. where river water downwells (Brunner et al., 2011).

Overbank flows

Flows that overtop the banks of the channel are referred to as spates, overbank or flood flows (Boulton et al., 2014, Gordon et al., 2004). Overbank flows occur after significant rainfall during the winter and may not occur every year. In the Donnelly River, overbank flows are most likely to occur in winter following large rainfall events. Overbank flows can be important for recharging the alluvial aquifer, although evidence for this is predominantly from arid systems (Dahan et al., 2008) and coastal alluvium aquifers (Rojas et al., 2018). More information is required to understand surface water – groundwater interactions for the Donnelly River.

Recessional flows

We use the term ‘recessional flows’ to refer to the period at the end of the winter when flows are declining, i.e., the protracted falling limb of the hydrograph. Although technically a within-bank flow, recessional flows are defined separately given their ecological significance. The rate and duration of recessional flows is important, as they cue the movement and provide passage for species to travel to dry season refugial pools. In the Donnelly River recessional flows occur in October and November (Figure 7).

Antecedent and future flows

Antecedent flows refer to flows that occurred in previous years, which influence the ecological condition and function under current conditions (Beesley et al., 2014, Leigh, 2013). Although the Donnelly River receives relatively regular winter flows, the magnitude of flows vary among years. After a series of low rainfall years, it takes longer for the catchment to ‘wet up’ sufficiently for flows to occur, and pools that are present most years may not occur. Long-term drying trends are impacting flows in the Donnelly River. Modelling suggests that flows in the Donnelly River could decrease by up to 40% of the mean streamflow for the 2001-2020 (Hughes and Wang, 2022). There is high variability with these model predictions due to uncertainty of the magnitude of change that is expected, however, continued drying is highly likely (Hughes and Wang, 2022).

3.2 Habitats

Including riverine habitats is helpful when conceptualising how altered flows may impact river values because changes to biota often manifest through a habitat intermediary. For the Donnelly River, we chose to limit our conceptual model to habitats we consider prominent within the system. Thus, we include:

- river channel
- riparian zone
- aquifer/spring
- estuary

Floodplain wetlands are captured inside 'riparian zone' in recognition that the Donnelly River does not have an extensive floodplain system. The small size of the Donnelly River floodplain is common for many coastal Australian rivers (Thoms et al., 2016). Given the surface water planning context of our research we focus on habitats shaped largely by riverine flow – thus groundwater dependent wetlands with limited connection to the river (e.g., Scott Coastal Plain) are omitted from our model.

Definitions of riverine habitats vary among authors; the definitions we use are provided below.

River channel

This refers to the channel created by flow, including the main river stem and its tributaries, and includes both the active and bankfull channel. In the high rainfall period, when there is a high degree of longitudinal connectivity (i.e. flow inundates and connects large lengths of the river channel), the main channel may be considered as one unit. However, in summer and autumn the Donnelly River may be further divided into perennial and intermittent channels.

Perennial channel

This refers to river channels that typically retain year-round flow (Allan, 1995). In the Donnelly River, this habitat occurs in the lower portion of the main stem of the river downstream of the Strickland gauge, as well as the lower portion of Barlee, Carey and Fly Brook (Figure 3). It is likely that these channels maintain perennial flow due to groundwater upwelling associated with the Darling Fault, although research to confirm this is ongoing. In the dry period of summer and autumn, perennial channels have distinct mesohabitats, with a system of pools connected by run/riffles zones (Figure 9).

Intermittent channel and dry-season refugia

This refers to tributary streams (e.g. brooks, gullies) and river channels that generally cease to flow during the dry season, contracting to either a completely dry channel or a series of refugial pools (Allan, 1995) (Figure 8 & Figure 9). Strictly speaking, channels that are not perennial can be classified along a continuum in accordance with their predictability and duration of filling, i.e. seasonal, intermittent, episodic and ephemeral (Boulton et al., 2014), but here we refer to all of them as intermittent. In the Donnelly, intermittent channels exist in the upper portion of the river's main stem, in key tributaries (e.g. Barlee, Carey and Fly Brooks), as well as other smaller tributaries in the upper catchment (Figure 3).

In intermittent channels, surface water contracts down to pools that persist through summer which may act as dry-season refugia for aquatic biota (Magoulick and Kobza, 2003a). These pools may be supported by groundwater or may be surface water retained in a topographically deeper part of the channel.

Figure 8. An example of a refuge pool: Tom Rd 4 which is in the Upper Donnelly sub-region. Photo: WA DWER.

Riparian zone

The riparian zone is the interface between the aquatic and terrestrial environment and includes the riverbank, areas regularly flooded by river water, or areas with a high alluvial water table (Naiman and Décamps, 1997). Definitions for the riparian zone differ among researchers, but it is generally delineated by ground elevation, flow regime and the composition of vegetation. The riparian zone can include the broader floodplain which includes areas that receive seasonal flooding as well as oxbow lakes (Naiman and Décamps, 1997). Therefore, our definition of the riparian zone includes the floodplain (areas that are periodically inundated by river water) and wetlands that are connected to the main channel of the river during large flows.

Aquifers and springs

The term ‘aquifer’ refers to water-bearing sediment or rock and can be categorised as alluvial or confined. Alluvial aquifers refer to water stored in unconsolidated surface sediments (e.g., gravel, sand, silt) deposited by the river (Schwartz and Franklin, 2003). These aquifers are typically found below riverbeds and in riverbanks and are recharged by direct infiltration of rainfall, overland flows and river water (Ali et al., 2012, Dahan et al., 2008). A confined aquifer is an aquifer that is confined between two less permeable geologic layers (aquitards) (Freeze and Cherry, 1979). Water from these aquifers reaches the surface if the aquifers are under pressure (termed artesian conditions) and the rock above them contains fractures (Freeze and Cherry, 1979). A spring is the term given to locations where confined aquifers reach the surface at a particular point (rather than a diffuse connection).

It is likely that the Donnelly River receives water from both alluvial and confined aquifers, with further research required to quantify these sources. Water from aquifers upwells in the channel of several of the rivers’ tributaries including Barlee Brook and sustains their perennial flow. Water from confined aquifers may also maintain permanent refugial pools in intermittent reaches of the river’s main stem. The rivers springs and aquifers are likely to support stygofauna.

Estuary

This refers to the lower reaches of the river that abut the ocean and are influenced by the high tide, such that freshwater mixes with sea water. This habitat is included in our conceptual model, as it is influenced by freshwater flows and because at least one diadromous species of fish, the lamprey *Geotria australis*, inhabits the Donnelly River. However, we did not undertake a focussed literature review of this habitat (in Part B) as wholly freshwater environments were the focus of our study.

Lacustrine/Palustrine Wetlands

This refers to vegetated waterbodies on the Scott Coastal Plain that are non-riverine systems, i.e. they are fed predominantly by rainwater but also receive some upward leakage from the confined aquifers below them (Leederville or Yarragadee) (CSIRO, 2009). They include lakes, swamps, bogs, soaks and springs. In the Donnelly Catchment the Ginglilup – Jasper wetland system includes Lake Jasper, Lake Wilson and Lake Smith. This habitat is considered beyond the scope of this document.

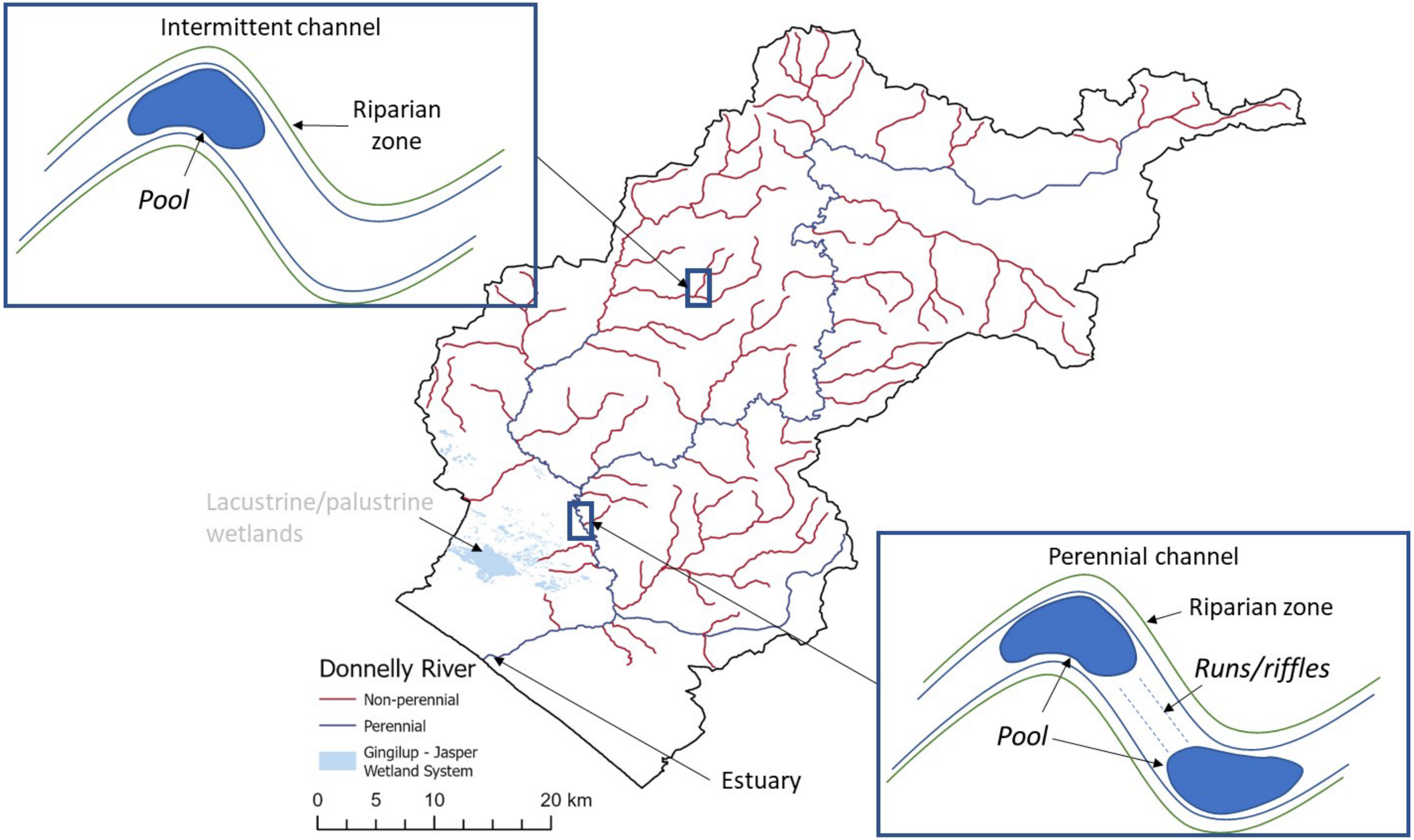

Figure 9. The Donnelly River catchment showing riverine habitats: the river channel which can be further defined as intermittent or perennial channels. Insets show the riparian zone, as well as pool and run/riffle mesohabitats. Lacustrine/palustrine wetlands on the Scott Coastal Plain are shown in grey and are an important part of the landscape but are not within the scope of our review.

3.3 HSE model

Our HSE model highlights the likely impact of reduced flow on the Indigenous cultural and ecological values of the Donnelly River, by showing mechanistic links between flow components and the values they support (Figure 10). The numbers in the diagram link to management considerations presented in Table 1. The supporting evidence is summarised in Table 3, which includes statements supporting the linkage and an indication of the spatial region the information comes from, i.e., the Donnelly River, rivers in the Warren Bioregion or elsewhere. The literature review that underpins the supporting table of evidence is in Part B of this report.

Our HSE model for the Donnelly River was centred on four key flow components: 1) groundwater and low flows during a hot, dry summer, 2) within bank flows, including bankfull flows, (3) overbank flows after significant rain events in the cool wet seasons, and (4) recessional flows as seasons transition from wet to dry. The flow components are also recognised by Noongar people. For example, during *Bunuru*, or the second summer (February-March), low season flows were important as freshwater foods (as well as seafood) were a major part of the diet at this time (BOM, 2016). *Makuru* (winter) is when waterways and catchments started to fill and is when people started to move inland (BOM, 2016).

For each flow component we indicate how a reduction in flow could impact hydrology and physical habitats, and as a result, impact water dependent biota and ecological processes. We also highlight impacts that affect values of Indigenous people (based on the available literature). Some of the knowledge behind these predictions arises from the Donnelly, but other information comes from the Warren Bioregion or further afield (Table 3). We briefly summarise this knowledge below, using information only from the Donnelly River, Warren Bioregion and elsewhere in SWWA (antecedent flows excluded).

Within-bank flows fill previously depleted river channels and seasonal tributaries. They allow native fish and freshwater crayfish, such as gilgies and marron, to spread along the river and to colonise seasonally-inundated tributary habitats (Beatty et al., 2014). Seasonal tributaries are important nurseries for many fish and crayfish, particularly those that breed during winter (which is most) (Koenders and Horwitz, 2006, Beatty et al., 2014). This means that reductions in within-bank flows are likely to lead to a decline in fish and crayfish recruitment. The importance of these flows to the production of fish and crayfish mean that the availability of bush tucker, which is important to Noongar people (BOM, 2016), is likely to decline if within-bank flows decline. Within bank flowsstructure macroinvertebrate assemblages (Growns and Davis, 1994) and deliver nutrients to the estuary (Congdon and McComb, 1980) which likely support estuarine fish production. Thus, declines in these flows will have system-wide consequences. Within-bank flows play an important role for in the completion of the lamprey’s life cycle, as they likely assist the downstream migration of juvenile lamprey to the ocean (Potter et al., 1979) and attract adult lamprey into the estuary by distributing pheromones emitted by larval lamprey into the ocean (Miller et al., 2021, Potter et al., 1983). Thus, reductions in these flows may impact this species whose WA conservation status is Priority 3 (poorly-known).

Overbank, or flood flows, are important for the maintenance of riparian vegetation. Obligate riparian species, such as *Eucalyptus rudis* subsp. *rudis*, are associated with periods of inundation (White et al., 2021), and may be negatively impacted by a reduction in the frequency and duration of over-bank flows. *Eucalyptus rudis* subsp. *rudis* (*moitch* in Noongar) is a culturally important tree used for bush medicine, bush tucker and its leaves may be used for bedding (Hansen and Horsfall, 2016, Hansen and Horsfall, 2019). Thus, changes to overbank flows may reduce the availability of bush tucker and medicine. Overbank flows also deliver water to wetlands situated in the riparian zone and prevent the exposure of their soils, preventing the formation of Acid Sulphate Soils (Koenders and Horwitz, 2006). Riparian vegetation and wetlands are important for frogs, birds and many mammals, particularly quokkas and water rats (rakali) especially during the hot summer months (Yeatman et al., 2016, Speldewinde et al., 2013, Abbott and Burrows, 1999, Bain et al., 2019). By supporting riparian vegetation these flows assist many terrestrial species, such as frogs, mammals (quokkas, rakali), and birds (Abbott and Burrows, 1999).

Recessional flows are the transition between the high flows of the wet season and the low flows of summer. These flows allow fish to move along the river and between tributaries and the main channel to seek permanent pools or river reaches that can provide them with refuge during the dry summer months (Beatty et al., 2014). Recessional flows are also likely important for the freshwater cobbler, a species that migrates upstream during spring (Sept, Oct) (Beesley et al., 2019) prior to summer late spring/summer spawning.

As conditions dry further, recessional flows and **low flows** in summer and autumn trigger burrowing behaviour in crayfish and mussels (an EPBC listed species) (Koenders and Horwitz, 2006, Lymbery et al., 2021) and shape the distribution and assemblage structure of aquatic fauna (Klunzinger et al., 2015, Pennifold et al., 2017, Morgan and Beatty, 2008, Morrissy, 1978, Benson et al., 2019) (Figure 10, Table 3). Low flows structure macroinvertebrate assemblages (Pennifold et al., 2017), and are important for the maintenance of macrophytes (Paice et al., 2017). Perennial reaches sustained by low flows are particularly important as dry season refugia for aquatic biota (i.e., mussels, crayfish, fish) (Beatty et al., 2006). In the Donnelly River, refugia may be maintained by upwelling of groundwater, which is thought to discharge from the Yarragadee Formation directly into the river (De Silva, 2004), although more information is needed to understand where this occurs. Inputs of cool, deep groundwater can help to dilute water quality issues associated with land use change (e.g., salinity) (Morgan et al., 2003, Beatty et al., 2006, Beatty and Morgan, 2010), and is important in perennial reaches for larval lampreys (Morgan and Beatty, 2008). Noongar people recognise that connectivity exists between surface water and groundwater (such as the Yarragadee aquifer), and that changes in regional groundwater may impact water in the river (Goode, n.d. p52). Groundwater is also important in sustaining riparian vegetation and the biota that it supports, including frogs, rakali and quokkas (Yeatman et al., 2016, De Tores et al., 2007, Speldewinde et al., 2013, Bain et al., 2019).

The HSE model shows the impact of altered hydrology on ecological and some Indigenous cultural values, however, this mechanistic approach does not fully represent the diverse range of connections that Indigenous people have with the river (Douglas et al., 2019). Some of these connections are illustrated by quotes from Noongar people, recorded in reports from the Warren Region (in relation to the Blackwood River and the Yarragadee Aquifer). Water is of central importance: “water has sacred, religious significance. Water is fundamental to life, our heritage and our culture” (Goode, n.d.). Noongar people recognise and value the importance of both groundwater and surface water: “water is the life of the system and is all interconnected, spiritually holistically, all interconnected. All water bodies are a culturally significant site to Nyungars, this includes groundwater” (Goode, n.d.).

Stewardship of freshwater resources is also recognised, with water managed so as to not “deny other species the use of water”. The quotes shown in the model relate to freshwater places in the Warren Region, however, more research is required to represent the Indigenous cultural values of the Donnelly River.

Finally, the HSE model is encircled by the key social factors and conditions that affect water allocation planning. This outer ring represents the institutional arrangements that govern water management decisions (Douglas et al., 2019), including Indigenous customary governance arrangements and custodial responsibilities, in addition to state and federal government policies and processes (Douglas et al., 2019).

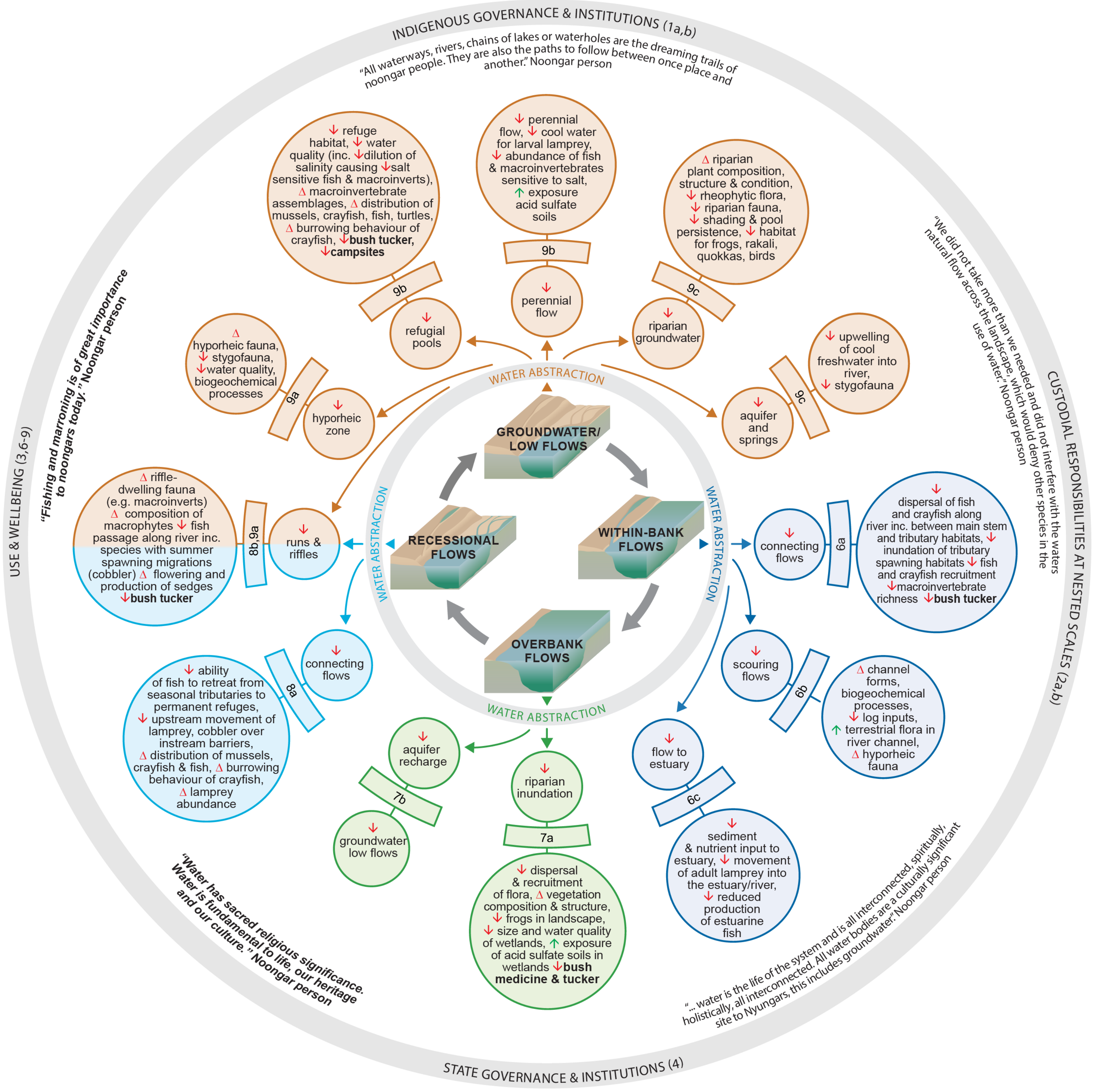

Figure 10. The interim hydro-socio-ecological model for the riverine environments of the Donnelly River. The model is centered on four flow phases and potential impacts of abstraction during each flow phase are colour coded: groundwater / low flows = orange; within-bank flows = dark blue; overbank flows = green; and recessional flows = light blue. Small inner circles describe impacts on hydrology and physical habitats, and large outer circles describe impacts on habitat availability and quality, water-dependent biota, and ecological processes. Impacts of particular interest to Indigenous people are in bold. Dual colouration indicates that a habitat may be affected by changes during two flow phases. Predicted responses to water abstraction are depicted with a red downward arrow or delta (indicating a decrease or change, respectively). The statements in italics illustrate Indigenous understanding of hydro-socio-cultural relationships with quotes from Goode (n.d.). The outer circle encompasses the key social factors and conditions that affect water allocation planning (Douglas et al., 2019). The numbering in rectangular boxes (in bold type) relates to the principles and key considerations in Table 2. Note that "bush tucker" is the local term for plants and animals that are harvested.

3.4 Principles and considerations for water management

The HSE model and table of evidence was used to inform a series of principles and considerations for water managers (Table 2 with table of evidence in Table 3 and supporting literature review in Part B of this report). Principles 1-3 state that water planning should “recognise the legitimacy and diversity of Indigenous rights, interests, knowledge and responsibilities and their governance principles and structures” (Douglas et al., 2019). **Principle 1** acknowledges that “Indigenous water rights, values, knowledge and government principles have been overlooked in Australian water policy and planning practice…” To address this, we suggest two considerations. The first states that “Indigenous communities and institutions should be engaged early, appropriately, consistently and as partners rather than stakeholders in water planning and policy” (Douglas et al., 2019). The second consideration relates to government and Indigenous institutions negotiating formal rules for the joint management of natural resources. **Principle 2** and its consideration relate to Indigenous participation in water planning processes, highlighting that planning processes need to enable Indigenous participation at different scales (e.g., individual places, a catchment, Native Title areas). **Principle 3** and its consideration note the need for policy to enable Traditional Owners to use water for economic, social and cultural development.

Principles 4 and 5 relate to uncertainty, and contend that water planning should acknowledge gaps, uncertainties, and limitations, and that it can draw on diverse knowledge systems to understand water requirements and potential impacts. **Principle 4** highlights that there are multiple world views, and that water planning should include Indigenous knowledges. **Principle 5** emphasises that for almost all systems knowledge of the impacts of water development is incomplete and/or contested. For the Donnelly River, we found that there was limited information available to determine impacts on ecological and Indigenous cultural values. We therefore recommend that “knowledge gaps are made explicit and that the limitations of transferability from other locations is acknowledged in water planning decisions.”

Principles 6-9 focussed on key flow components and the hydrological and ecological processes they support. Each flow component was represented by a principle with key considerations that highlight key hydrological, cultural, or ecological values supported by the flow. For example, **Principle 6** highlights the importance of within-bank flows for longitudinal connectivity, which is important for the ecology of the river. To address this principle, water planning is encouraged to consider how alteration of within-bank flows will affect longitudinal connectivity and the movement of biota, as well as the effect on channel geomorphology if scouring flows are reduced. For the Donnelly River we have highlighted that changes to within-bank flows can impact the movement of animals between the main channel and tributaries, as there is evidence from the neighbouring Blackwood River that this is likely to be important (Beatty et al., 2014). The river and longitudinal connectivity is important for Noongar people, embodying the Waugal and providing fish and crayfish harvest. In other systems Traditional Owners have identified that high velocity wet season flow-pulses are important for cleaning river country (Barber and Woodward, 2018, Toussaint et al., 2001) and sustaining Indigenous fisheries (Jackson et al., 2012a, Davis et al., 2011, Toussaint, 2008), although we have not found evidence for this in our literature review for the Donnelly River.

Principle 7 emphasises the importance of overbank flows, which maintain riparian habitats, including the floodplain and wetlands that connect to the river. We highlight that the maintenance of these habitats is important as they support aquatic and terrestrial diversity distinct from the main river channel. Overbank flows are of particular importance to riparian vegetation, dependent on a high degree of water availability and flood events that promote recruitment. These flows support riparian plant species that are used by Noongar people. Overbank flows also provide lateral connectivity between the river and riparian zone, including the floodplain and wetlands that connect to the river. Thus, water decisions that alter overbank flows should consider the impact on riparian vegetation and habitats that connect to the river in large flows.

Principle 8 relates to recessional flows, with considerations for how alterations to recessional flows may impact longitudinal connectivity, and thus the passage of biota. Of particular consideration is how recessional flows allow for the movement of fish (e.g., cobbler, adult lamprey) along the river (Beatty et al., 2010, Potter et al., 1983) and from intermittent tributaries to the main channel (Beatty et al., 2014). These flows also influence the amount of different instream habitats available which can determine the abundance and distribution of aquatic biota, such as larval lamprey (Potter et al., 1986).

Principle 9 highlights the importance of groundwater for providing low flows (or baseflows), which maintain important freshwater habitats during hot, dry summer and autumn months. Low flows are important for the persistence and productivity of emergent macrophytes (sedges, rushes) (Froend and McComb, 1994, Paice et al., 2017). Groundwater flows are important to Noongar people. Groundwater is currently managed as a separate water resource in the Donnelly catchment; however, water planning should consider how alteration of groundwater levels will impact flow in the river. The maintenance of perennial reaches and dry season refugial pools is of particular consideration for the Donnelly, which has experienced a marked reduction in flows over recent decades. Other considerations are the maintenance of key habitats including run/riffles, riparian groundwater and hyporheic habitat.

Principle 10 emphasises the importance of antecedent flows, and the need to consider lag effects and long-term cycles when making water planning decisions. For instance, flow over previous years shapes the abundance and distribution of individuals of any species across the catchment and this, together with a species' life history strategy and migratory capacity, influence how a population responds to current flows. For example, consistent flows may trigger dispersal and a boom in abundance of a given fish species, but population growth may be severely reduced if previous years have been so dry that the species has been extirpated from much of the catchment and relegated to refuge pools in the lower reaches. Given the high likelihood that reduced rainfall and flows will continue in the Donnelly, planning decisions should consider how a drying climate will exacerbate the stress associated with water resource development.

In summary, the principles and considerations provide a systematic outline of key hydro-socio-ecological components for the Donnelly River. Importantly, much of the knowledge that currently underpins these principles does not arise directly from the Donnelly River, coming instead from other rivers in the Warren Bioregion or further afield, i.e., elsewhere in SWWA or beyond (Table 3).

Table 2. Hydro-socio-ecological principles and key considerations for water planning for the riverine environments of the Donnelly River.

Hydro-socio-ecological principle	Key considerations for water planning
1. Indigenous water rights, values, knowledge and governance principles have been overlooked in Australian water policy and planning practice, affecting both the equity of access to water and the fairness of water planning and management processes. Joint planning and management should be based on recognition of the legitimacy of Indigenous customary law and modes of water governance and should aim for fair outcomes in water distributions and decision-making.	*1a - Indigenous communities and institutions should be engaged early, appropriately, consistently and as rights holders rather than stakeholders in water planning and policy;* *1b - Agreements between government and Indigenous governance institutions should be negotiated to formalise rules for joint management.*
2. Indigenous people have custodial responsibilities at nested scales: place-based responsibilities (e.g. an individual's strong custodial ties to a significant place), at the scale of Native Title areas, as well as larger scales that include the whole catchment. A multi-scalar approach to participatory planning and evaluation is therefore needed.	*2. Water planning should consider supporting mechanisms that enable effective Indigenous participation in all phases of the planning process. This will include enabling Indigenous people to evaluate information relevant to water planning across multiple scales, including Native Title areas, and to be fully involved in the management decisions flowing from water plans (e.g. licensing and monitoring).*
3. Indigenous people have the right to use water for their economic, social and cultural development.	*3. Water law and policy needs to enable Traditional Owners to fully realise this right, which is based in international guidelines (United Nations Declaration on the Rights of Indigenous Peoples) and includes protecting the means of subsistence and the cultural heritage of water bodies as well as advancing economic opportunities.*
4. Planning occurs in settings where there are multiple world views and many different ways of relating to water.	*4. Water planning should draw on diverse knowledges of flow relationships, water requirements and socio-economic and environmental impacts, including Indigenous knowledges.*
5. The knowledge of impacts from water resource development is incomplete and/or contested.	*5. Knowledge gaps and uncertainty should be made explicit and the limitations of transferability from other locations must be acknowledged. Planning processes should establish the means to source the best available evidence and mechanisms to include both scientific and Indigenous knowledge.*

Hydro-socio-ecological principle	Key considerations for water planning
6. Within-bank flows promote longitudinal connectivity and are important for the ecology of the river and its estuary. Connectivity is valued in and for itself by Traditional Owners and the high-velocity flow-pulses are also valued, particularly for their ability to clean the river country and sustain Indigenous fisheries.⁺	*6. Water planning should consider how the alteration of within-bank flows during the wet season will affect:* *(a) connectivity along the entire length of the river channel and the passage of animals along the length of the river, including movement between the river channel and tributaries, and to and from the estuary* *(b) the frequency and magnitude of scouring flows that clean the river, maintain within-channel geomorphic complexity (pools, bars, riffles) and prevent siltation of hyporheic sediments* *(c) deliver nutrients to the estuary that increases the productivity of the estuary and the biota that use it*.*
7. Overbank (flood) flows facilitate lateral connectivity, maintaining the health of the riparian zone including the alluvial aquifer, and wetlands that connect to the river in high flows, which support aquatic and terrestrial biodiversity that is distinct from the main river channel. The riparian zone and wetlands supported by river water and the life they support are highly valued by Traditional Owners.⁺	*7. Water planning should consider how the alteration of over-bank flows will affect:* *(a) connectivity between the river and its riparian zone, adjacent wetlands, and recharge of the alluvial aquifer,* *(b) dispersal and recruitment of riparian vegetation and surface water inputs to riparian plants.*
8. Recessional flows facilitate the movement of animals to refuges. Maintenance of these habitats supports important ecological processes and particular species and places that are important to Traditional Owners.⁺	*8. Water planning should consider how the alteration of recessional flows during the dry season will affect:* *(a) connectivity along the entire length of the river channel and the passage of animals along the length of the river, including movement from intermittent tributaries to the main channel, and to and from the estuary,* *(b) the availability and quality of shallow, fast-flowing habitats (i.e. runs/riffle)*
9. Groundwater provides low flows during the low rainfall period, which are important in maintaining perennial reaches, runs/riffles, hyporheic habitat and refugial pools. It also supports riparian zones (including wetlands) and springs/subterranean habitats. Some of these places and processes (groundwater flow) are of high significance to Traditional Owners.	*9. Water planning should consider how the alteration of groundwater resources will affect:* *(a) the availability and quality of shallow, fast-flowing habitats (i.e. runs/riffle) and the extent and quality of hyporheic habitat* *(b) the size, number, quality of refugial dry season pools, particularly historically perennial reaches and pools* *(c) the condition and composition of riparian vegetation reliant on groundwater.*

Hydro-socio-ecological principle	Key considerations for water planning
10. Past and future hydrological conditions over a range of temporal scales have an important influence over the ecology of the system.	*10. Water planning should take into account:* *(a) how hydrological conditions in previous years will influence water available in the current year* *(b) how a drying climate will place additional stress on freshwater ecological values on top of water resource development.*

⁺ Limited published/discoverable evidence available to support Indigenous values

* Potentially important but beyond the scope of the literature review

3.5 Supporting evidence

Our review of the literature is reported in the accompanying “Part B: literature review” and is summarised in Table 3 below. In general, there was extremely limited information available for the Donnelly River, particularly in relation to Indigenous cultural values. Evidence for high-level Indigenous water rights, governance, custodial responsibilities, and knowledge systems is drawn primarily from international and national agreements and academic publications (Table 3). Information relating to Indigenous perspectives on freshwater and river flows, and the plants and animals they support was drawn from reports about the Blackwood River and the Yarragadee aquifer. These reports included insight into the spiritual connection and custodianship for Noongar people and freshwater places, and quotes highlighted the importance of fishing and marroning. There are good resources on Noongar Bush Tucker (Hansen and Horsfall, 2019) and Bush Medicine (Hansen and Horsfall, 2016), but there is limited information specific to the Donnelly River and neighbouring catchments. There is a key knowledge gap for place-based information for the Donnelly River and the Indigenous cultural values that the river flows support.

At the local scale, for the Donnelly River there was information relating to flow-ecology for lampreys (Potter et al., 1986), macroinvertebrates (Growns and Davis, 1994), and mussels (Klunzinger et al., 2015) (note the Klunzinger et al. 2015 study extended beyond the Donnelly). Information on the ecological values of the Donnelly River was broadly limited to species distributions, with relatively little targeted information on flow-ecology (as outlined in Part B of the report). We could find no information for the Donnelly River about scouring within-bank flows, overbank flows in the riparian zone, recessional flows in the main channel, and groundwater and the riparian zone, hyporheic zone, and aquifer and springs and the ecological values they support (Table 3). We were also unable to find any information about the influence of antecedent flow conditions on ecological values.

At the regional scale (Warren Bioregion), considerably more knowledge existed about flow-ecology. There was information on the importance of flow to crayfish and fish movement and recruitment, and to hyporheic invertebrates, the inundation requirements of some riparian trees and their recruitment, and terrestrial animals. Information was also available about the capacity of groundwater to dilute the effects of secondary salinisation instream and promote flow perenniality. At this broader spatial scale, information gaps still remained about the water requirements to maintain riparian tree communities and aquatic plants. There were also gaps in knowledge for antecedent flows, aquifer and spring biota as well as the importance of groundwater to riparian vegetation.

Considerable flow-ecology information exists at the ‘elsewhere’ scale; most is from Australia but some of it also comes from overseas. The information that is most transferable to the Donnelly is likely that from other SWWA rivers (shown underlined in Table 3). This knowledge reinforces that flow influences the movement and recruitment of fish, burrowing behaviour in crayfish and mussels, recruitment in crayfish and structures macroinvertebrate assemblages. The influence of flow on ecosystem function, such as energy sources sustaining the food web, ecosystem metabolism and leaf litter breakdown remains unclear.

Key knowledge gaps from Table 3 are identified and summarised in section 5.

Table 3. Sources of information used to construct the interim conceptual model of potential water resource development impacts on ecological values in the riverine environments of the Donnelly River and the Principles and Key Considerations for water planning. Information has been grouped according to spatial proximity to the study river. Literature cited supports each statement. Evidence for Indigenous values is shown in italicised font and ecological evidence in normal font. Evidence from the Donnelly and Warren River bioregion was the result of a comprehensive literature search; evidence from elsewhere was pursued in the absence of local evidence and for the ecological literature is illustrative only – note information from elsewhere in southwest Western Australia is underlined. A description of Principles/Considerations 1 to 10 is provided in section 4.4. The full literature review is available in Part B of the report.

Principle/ Consideration	Flow component	Hydrology & Physical Habitats	Donnelly River (local)	Warren IBRA (regional)	Elsewhere (remote)
1	**NA**	**NA**	No literature found	No literature found	• *State water regimes are failing to recognise and respect Aboriginal water rights and to redress historical legacies of exclusion and discrimination in access to water* (Taylor et al., 2016, Hartwig et al., 2018, Tan and Jackson, 2013, Weir, 2011). • *Water governance needs further research, policy development and law reform to address equity of Indigenous access to water* (Jackson, 2006). • *Formal agreements between parties (including governments and indigenous bodies) is a mechanism to recognise legitimacy of Indigenous modes of governance* (Jackson, 2019).
2	**NA**	**NA**	No literature found	No literature found	• *Indigenous peoples have a distinct stake in water governance and management and do not see themselves as '"mere" stakeholders'* (Tan et al., 2012, O'Bryan, 2019). • *Water planning must be negotiated with explicit consideration of people-place relationships* (Ayre and Mackenzie, 2013). • *Indigenous-grounded methodologies and Indigenous-led research is needed to integrate Indigenous water knowledge into society and policy* (Moggridge and Thompson, 2021).
3	**NA**	**NA**	No literature found	No literature found	• *The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) asserts that Indigenous peoples "have the right to freely pursue their economic, social and cultural development" (Article 3) and to "maintain and strengthen their distinctive spiritual relationship with their traditionally owned or otherwise occupied and used lands, territories, waters and coastal seas and other resources and to uphold their responsibilities to future generations in this regard" (Article 25).* • *The First People's Water Engagement Council's advice to the National Water Commission included clear statements about the need for Aboriginal water allocation for both cultural and economic development (2012).* • *A module to the National Water Initiative recognises the role of water in improving Indigenous economic outcomes (Australian Government, 2017).*
4	**NA**	**NA**	No literature found	No literature found	• *Water planning should rely on the best available scientific knowledge and Indigenous knowledge* [National Water Initiative, see also (Taylor et al., 2016)].
5	**NA**	**NA**	No literature found	No literature found	• *National Water Initiative* – see above. • *In other water planning contexts in Australia, especially in cases involving groundwater, research has revealed widespread misunderstanding of the implications of water extraction, and highlighted the importance of public communication and explanation of the information upon which planning was based (Jackson et al., 2012b).*
6a	**Within-bank flows**	**River-channel habitat/ depth**	• Promote macroinvertebrate species richness, especially where flow velocity is high (Growns and Davis, 1994, Pennifold and Pinder, 2011).	• Promote or cue the movement of fish, including movement into tributary spawning habitats during winter (Beatty et al., 2014, Allen et al., 2020, Allen, 2016). • Promote the upstream movement of adult lamprey over barriers (Potter et al., 1983). • Inundate seasonal tributaries which are important breeding habitat for fish and crayfish (Koenders and Horwitz, 2006, Beatty et al., 2014). • Promote or cue the movement of gilgies into seasonally flowing tributaries during winter to lay eggs in burrows (Beatty et al., 2006, Koenders and Horwitz, 2006). • Deliver nutrients to the estuary (Congdon and McComb, 1980).	• Facilitate the dispersal of potamodromous fish along the length of the river and the recolonization of tributary habitats (Pusey et al., 2018, Bishop and Forbes, 1991), which supports food web connectivity (Jardine et al., 2012). • Promote connectivity along the river, which likely assists the migration of juvenile lamprey to the ocean (Miller et al., 2021). • Displace fish downstream (Beesley et al 2019) • Provide spawning and rearing habitat for many fish species (Stanford and Ward, 1993). • Increase recruitment success of marron (De Graaf et al., 2010, Nickoll, 1996). • Potentially alter the faunal assemblage in the hyporheic zone (Trayler and Davis, 1998). • Influence the rate of nutrient processing (Bernal et al., 2015).

Principle/ Consideration	Flow component	Hydrology & Physical Habitats	Donnelly River (local)	Warren IBRA (regional)	Elsewhere (remote)
				• *Embody the Waugal (Goode and Irvine, 2006).* • *Trap migrating fish using wooden traps (Goode and Irvine, 2006, Dortch and Gardner, 1976).* • *Provide harvest for Noongar people, due to their role in promoting production of fish and crayfish (Goode, n.d.).*	• *Makuru (winter) is when waterways and catchments started to fill and is when people started to move inland* (BOM, 2016).
6b	**Within-bank flows**	**Scouring flows**	• No literature found (although search focussed on biota not physical processes)	• May impact hyporheic fauna (Trayler and Davis, 1998). • *Embody the Waugal (Goode and Irvine, 2006).*	• Maintain geomorphic units (pools, bars, benches, riffles) by bed scour (Boulton et al., 2017, Poff et al., 1997, Cluett, 2005). • Contribute large woody debris (trees) into the river to provide habitat for fish (Pettit et al., 2013, Pusey and Arthington, 2003). • Push debris downstream and remove instream macrophyte beds (Boulton et al., 2017). • Remove fine sediment from the bed of the river (Cluett, 2005), promoting vertical connectivity (i.e. interaction between surface and subsurface waters) in areas with course substrate (e.g. grave) that promote biogeochemical processes (Brunke and Gonser, 1997). • Remove terrestrial flora from the main channel (Cluett, 2005). • May (Paul et al., 2006, Niu and Dudgeon, 2011), or may not, influence leaf litter breakdown (Middleton, 2015); however the majority of breakdown occurs at this time (Bunn, 1988)
6c	**Within-bank flows**	**Estuary**	• Likely associated with the movement of adults into the estuary as this occurs during winter months, i.e. July/August (Potter et al., 1983).	• Promote the movement of adult lamprey into the estuary (Potter et al., 1983). • Likely facilitate the migration of juvenile lamprey to the ocean (Potter et al., 1979). • Deliver nutrients to the estuary (Congdon and McComb, 1980) • *Embody the Waugal (Goode and Irvine, 2006).*	• Transport sediment and nutrients from upper catchment to the lowland section of the river and into the estuary (Burford et al., 2016). • Promote the migration of adult lamprey into the estuary as they distribute pheromones produced by larval lamprey into the ocean (Sorensen and Vrieze, 2003, Miller et al., 2021).
7a	**Overbank flows**	**Riparian zone**	• No literature found	• Influence woody plant species distribution (White et al., 2021). • Influence the recruitment of *Eucalyptus rudis* and *Melaleuca rhaphiophylla* (Pettit and Froend, 2001a). • Influence plant species richness, shrub cover, and exotic species abundance (Pettit and Froend, 2001b). • Create terrestrial habitat which supports increased frog abundance and a different vertebrate assemblage than non-riparian areas during warm months (Yeatman et al., 2016). • Create a terrestrial habitat that supports quokkas (Bain et al., 2019). • Inundate wetlands reducing exposure of Acid Sulphate Soils (Koenders and Horwitz, 2006).	• Influence the survival and recruitment of riparian vegetation (Naiman and Décamps, 1997, Jansson et al., 2019). • Sustain the water quality of wetlands situated close to the river (Ward et al., 2002, Jolly et al., 2008). • Maintain wetland size which influences fish condition, recruitment (Balcombe, 2007) and abundance (Beesley et al., 2014). • Maximise regional species richness by supporting different species to the terrestrial landscape (Sabo et al., 2005). • Create a terrestrial habitat that supports mammals, including Rikali (Speldewinde et al., 2013) and birds (Abbott and Burrows, 1999). • Facilitate transfer of nutrient and organic matter between instream and riparian environment (see synthesis by Thoms and Sheldon, 2002). • May recharge the alluvial aquifer (Dahan et al., 2008, Rojas et al., 2018). • *Support Eucalyptus rudis which is important for bush medicine, bush tucker and for bedding* (Hansen and Horsfall, 2019, White et al., 2021). • *Support other riparian plants that are used as bush medicine, bush tucker and have other camp site uses* (Hansen and Horsfall 2016, 2019).
8a	**Recessional flows**	**Connecting flows**	• Influence the abundance of larval lampreys (Potter et al., 1986).	• May cue the movement of fish from intermittent tributary habitats back to main channel habitats (Beatty et al., 2014). • Promote the upstream movement of adult lamprey over barriers (Potter et al., 1983). • Maintain depths that allow passage of fish along the river, especially freshwater cobbler (Beatty et al., 2010). • *Embody the Waugal (Goode and Irvine, 2006).*	• Promote the upstream spawning migrations of certain fish species, such as the freshwater cobbler, as it allows them to cross barriers (Beesley et al., 2019). • *Reveal the location of mussels (bush tucker)* (Dortch, 1974).
8b, 9a	**Recessional flows/ Low flows/ groundwater**	**Run/ riffles**	• No literature found	• Maintain depths that allow passage of fish along the river, especially freshwater cobbler (Beatty et al., 2010). • *Embody the Waugal (Goode and Irvine, 2006).* • *Trap migrating fish using wooden traps (Goode and Irvine, 2006, Dortch and Gardner, 1976).*	• Increase movement of fish along the length of the river, including assisting the upstream spawning migration of freshwater cobbler (Beesley et al 2019). • Determine phenology and above ground productivity of sedges and rushes (Froend and McComb, 1994). • Influence the composition and abundance of macrophytes (Paice et al., 2017). • Provide "regeneration niche" for aquatic macrophytes (Nicol and Ganf, 2000).
9b	**Low flows/ groundwater**	**Refugial pools**	• Drive flow perenniality which influences the distribution of Carter's mussel (Klunzinger et al., 2015) and certain native fish	• Dilute the effects of secondary salinisation and promote the occurrence of salt intolerant fish species (Beatty et al., 2010, Morgan et al., 2003, Beatty et al., 2006), mussels (Benson et al., 2019), and macroinvertebrates (Beatty and Morgan, 2010).	• Provide a deep cool-water habitat that acts as a refuge (place of high survival) for aquatic biota without a drought-resistant life stage, such as fish and many invertebrates (Erskine et al., 2005, Grossman et al., 1998, Arthington et al., 2005, Dekar and Magoulick, 2007). • Important habitat for freshwater turtles (Cogger, 2015).

Principle/ Consideration	**Flow component**	**Hydrology & Physical Habitats**	**Donnelly River (local)**	**Warren IBRA (regional)**	**Elsewhere (remote)**
			(Morgan and Beatty, 2008, DWER, HRP). • Shape macroinvertebrate assemblages, particularly turnover among sites (Pennifold et al., 2017)	• Create a summer refuge for fish (Beatty et al., 2006). • Influence burrowing behaviour in crayfish (Koenders and Horwitz, 2006). • Increase flow perenniality which influences the distribution of crayfish species (Morrissy 1978; Austin & Knott 1996; Beatty et al. 2006) and mussels (Klunzinger et al. 2015; Benson et al. 2019). • Facilitate the settling of juvenile mussels from a fish host into the sediment (Klunzinger et al., 2013). • *Campsite locations when travelling through the landscape and sites to harvest fish and crayfish (Goode, n.d.).* • *Provide harvest for Noongar people (fish, crayfish and plants) (Goode and Irvine, 2006).*	• Prevent pool shrinkage and associated deterioration of water quality (e.g. temperature increases, oxygen decreases) (Leigh, 2013). • Limit fish mortality associated with declining water quality (Townsend, 1994, Townsend et al., 1992). • Influence the ability of gilgies to survive waterbody drying (Emery-Butcher, 2023). • Influence burrowing behaviour in mussels (Lymbery et al., 2021). • Increase movement of fish along the length of the river, including assisting the upstream spawning migration of freshwater cobbler (Beesley et al 2019). • Limit reductions in fish growth and condition associated with pool shrinkage and water quality decline (Balcombe et al., 2012, Magoulick and Kobza, 2003a, Beesley et al., 2021b). • Reduce negative interactions such as competition and predation pressure, as well as reduce the risk of disease and parasite transmission (Magoulick and Kobza, 2003b, Zaret and Rand, 1971, Marcogliese, 2008, Maceda-Veiga et al., 2009, Medeiros and Maltchik, 1999). • May (Datry et al., 2011), or may not, influence leaf litter breakdown (Carey et al., 2021). • May slow leaf litter breakdown if they dilute instream nutrient concentrations (Middleton, 2015). • Inundate iron-rich soils, which if exposed could release acid sulphate (Koenders and Horwitz, 2006). • Creates stable flow that sustains aquatic life and provides nutrients to support the aquatic food web (Stanford and Ward, 1993, Boulton and Hancock, 2006). • Determine phenology and above ground productivity of sedges and rushes (Froend and McComb, 1994). • Influence the composition and abundance of macrophytes (Paice et al., 2017). • *Freshwater foods a major part of the diet during Bunuru, or the second summer.* (BOM, 2016).
9c	**Recessional flows & Low flows**	**Hyporheic zone**	No literature found.	• Increased current velocity may reduce hyporheic invertebrate richness in deeper riverbed sediments (Trayler and Davis, 1998).	• Promote downwelling of surface water into the hyporheic zone providing food and habitat for stygofauna (Boulton, 1993, Boulton et al., 2010). • Create critical habitat for stygofauna (Boulton, 2007, Daltry et al., 2007). • Cool surface water (Boulton, 2007). • Create a hotspot of biogeochemical transformations that alters nutrient levels and cleans the water (Boulton, 2007, Boulton and Hancock, 2006, Boulton et al., 2010, Grimm and Fisher, 1984). • Provide sub-surface connectivity of flows along the river and vertical connectivity between surface-water and groundwater (Boulton et al., 2017).
9d	**Low/flows Groundwater**	**Perennial flow**	• Provide cool water that support larval lampreys (Morgan and Beatty, 2008) which are filter feeders.	• Support perennial streamflow (Strategen, 2006). • Support vulnerable fish species, such as Balston's Pygmy Perch which are highly sensitive to salt (Beatty et al., 2006). • Prevent exposure of Acid Sulphate Soils (Koenders and Horwitz, 2006).	• May provide nutrients (energy) that support the food web (Holmes, 2000). • Reduce the temperature of instream water affecting the rate of ecosystem processes (Holmes, 2000).
9e	**Groundwater**	**Riparian groundwater**	• Supports riparian vegetation whose shade and organic matter supports larval lampreys (Potter et al., 1986).	• Support riparian vegetation which provides habitat for frogs in *the Helioporous* and *Crinia* genus (Yeatman et al., 2016).	• Groundwater level shapes the water vulnerability of individual plants (Canham et al., 2009, Pfautsch et al., 2015). • Supports riparian vegetation which provides habitat for mammals including water rats (Speldewinde et al., 2013) and quokkas (Bain et al., 2019, De Tores et al., 2007). • Supports complex vegetation preferred by freshwater turtles (Whatmore, 2023).
9f	**Groundwater**	**Aquifer and springs**	No literature found	No literature found	• Provide habitat for stygofauna (Boulton, 2000). • Contribute to perennial flow (Saunders et al., 2001). • May provide ancient carbon that contributes to the aquatic food web (Mazumder et al., 2019).
10	**Antecedent and future flows**	**All habitats**	No literature found	No literature found.	• Influence marron recruitment (De Graaf et al., 2010).

3.6 Transferability of HSE model and principles and considerations: from the Fitzroy to the Donnelly River

A key aim was to assess the transferability of our model (i.e. the HSE conceptual model and principles and considerations) from the Fitzroy River in northern Australia to the Donnelly River in SWWA. We found that the approach was broadly transferable, with the underlying relationships between flow and biota and Indigenous governance, water rights and values applicable across systems.

Principles 1-5, which relate to Indigenous rights, values, knowledge and government principles were unchanged from the original model. These principles are supported by international and national agreements and academic publications, which are applicable to water management across Australia; however, in the Fitzroy there was also local evidence supporting these principles (Douglas et al., 2019).

Principles 5-10 are underpinned by flow components, identified from the hydrograph for the system. The flow components for the Donnelly River were broadly similar to those in the Fitzroy, despite the differences between the systems. The similarity in the flow components is due to both systems having broadly intermittent flow regimes (although there are significant perennial reaches in the Donnelly River) with highly seasonal rainfall and streamflow patterns. However, the seasons are reversed between the systems, with the Donnelly River experiencing high flows in the cool, wet winter and spring months, compared with the Fitzroy, where high flows occur in hot summer months. The magnitude of flow also differed, with the Donnelly experiencing a median peak flow of 864 ML day^{-1} compared with 116,121 ML day^{-1} for the Fitzroy. Despite these differences, the broad flow components of within-bank, overbank, recessional, low / groundwater, and antecedent flows were determined to be applicable to the Donnelly River.

There were some differences in habitats between the Donnelly and Fitzroy Rivers; as the Donnelly is a much smaller system with smaller flows, it does not have the same extensive floodplain system (including floodrunners, billabongs and floodplain wetlands) as the Fitzroy. Therefore, for the conceptualisation of the Donnelly we did not highlight these habitats. Instead, wetlands that are supported by river water are incorporated into the principles and considerations relating to overbank and groundwater flows that support the riparian zone.

Some additional changes were made to the model to increase clarity, to highlight issues relevant to the Donnelly and due to increased knowledge and experience of the authors. Key changes were:

- Principle 7 now includes the importance of overbank flows for recharging the alluvial aquifer.
- Principle 8 was reworded to highlight that recessional flows are important for the movement of animals to refuges. The associated considerations were changed to reflect this, with 8b (the composition and condition of riparian vegetation reliant on surface water from the channel) removed from the new model.
- Considerations 8d (size number and quality of refugial pools) and 8e (extent and quality of hyporheic habitat) were removed from the new model, but remain included in considerations 9a and 9b. This change was made to highlight the importance of groundwater for these values.
- Principle 10 was reworded, replacing the term “antecedent” with past and future hydrological conditions. Consideration 10b (how a drying climate will place additional stress

on freshwater ecological values on top of water resource development) was added to highlight the significance of the drying climate being experienced in SWWA.

Overall, there were minimal changes made to the original model when applying it to the Donnelly River. The underlying concepts of Indigenous water values, rights and governance, and the flow-ecology principles are broadly applicable across the two distinct systems.

4 Key knowledge gaps and research needs

Our literature review and supporting table of evidence identified key knowledge gaps in the discoverable literature for Indigenous cultural and ecological values for the Donnelly River ( ).

4.1 Limited information on Indigenous cultural values

Supporting evidence for Indigenous customary arrangements and custodial responsibilities was primarily drawn from national and international sources. We found that there are currently very few documents discussing Indigenous water management in SWWA (Table 3). The implementation of the South West Native Title Settlement, and the establishment of the Karri Karrak Aboriginal Corporation in 2021 provides a path towards greater self-determination and governance of Noongar boodja including water resources.

Our review also highlighted knowledge gaps in relation to place-based river and flow-related cultural values for the Donnelly River (Table 3). Instead, information was available from reports from the Blackwood catchment and Yarragadee aquifer in the Warren Bioregion. It is important to stress that our review is desktop only and that further consultation and collaboration with cultural knowledge holders is required to appropriately represent these values. Until such collaboration has taken place, we will refrain from speculating further about these knowledge gaps.

4.2 Limited information on environmental water requirements

Our literature review revealed that quantitative flow-ecology relationships require more research in the Donnelly River.

The water requirements for riparian vegetation are not well described or quantified for the Donnelly River, although there is information on the relationship between rainfall, inundation and the distribution of riparian tree species (Table 3). However, the transferability of these relationships to the Donnelly River is uncertain given the distribution of riparian trees has not been recorded. For aquatic plants, the distribution of species in the Donnelly River is unknown and the flow requirements for species in SWWA has not been quantified.

The ecological importance of riparian vegetation is understudied in SWWA. Riparian trees and aquatic plants are likely to provide important functions to the river, including shading and cooling of water, bank stabilisation, and log and leaf inputs, but this is supported by only one study in the Donnelly catchment and few others in SWWA (Table 3). The importance of riparian vegetation as habitat for threatened species such as quokkas and western ring-tailed possums has not been quantified in SWWA, and understanding these relationships is critical to manage flows that protect both vegetation and terrestrial species.

For riverine fish more information was available, however most flow-ecology knowledge was inferred from patterns in species distribution. There was limited information on the causal linkages between flow and ecological values, including linkages between flow and habitat, and habitat and species.

Quantification of flow-ecology linkages is necessary if robust predictions are to be made about the impacts of reduced flow. Such knowledge should assist managers to better predict the implications of water management rules and climate change. It may also assist managers to set hydrologic targets or thresholds that trigger management actions.

Flow-ecology linkages require relevant biophysical data, for example the location of pools, or the duration of flow. For the Donnelly River and SWWA more broadly, the location of refuge pools has not been mapped. There is also a gap in the knowledge relating to the relative importance of groundwater, in particular regional groundwater for the maintenance of refuge pools. A better understanding of the flows and habitats is necessary to inform water management that protect ecological values.

4.3 What next: Priority knowledge gaps

Priority knowledge gaps for further research were determined by reviewing the knowledge gaps identified in the literature review in Part B of this report. We highlight knowledge gaps that have limited transferable information from elsewhere and where a direct link to management actions could be identified.

Priority knowledge gaps for Indigenous water values are to be determined following consultation with the Karri Karrak Aboriginal Corporation’s Cultural Advice Committee.

Priority knowledge gaps are described in Table 4.

Table 4. Summary of knowledge gaps identified in the literature review.

	Knowledge gap	Reasoning for prioritisation	
		Transferable information from elsewhere?	**Link to water management**
Indigenous cultural water requirements			
Cultural water values	Information on cultural values of aquatic animals and riparian and aquatic plants, and the flows required to maintain them.	The specific knowledge gaps and advice on transferability and links to manage will not be determined until after consultation with the Karri Karrak Cultural Advice Committee.	
Ecological values			
Riparian vegetation	Distribution of woody species and assemblage of riparian vegetation along the Donnelly River.	Key tree species from the Warren have been classified as obligate or facultative riparian, but there is no data showing if these species occur on the Donnelly and where they are distributed.	Riparian trees currently not included in EWRs. Information on distribution in relation to relative flows may be incorporated in future ecological water requirements.
	The distribution of aquatic plants and the flow requirements for species occurrence.	No information on distribution of riparian aquatic plants and their flow requirements for SWWA.	The distribution of aquatic plants is necessary to identify and protect the flows required to sustain them.
Riverine fish	Distribution of fish species, including threatened species, in the Donnelly River.	Currently limited data on the distribution of species, particularly threatened species.	Species distribution is necessary to identify and protect the flows required to sustain them.
	The link between environmental variables (pool depth, river km, habitat etc) and fish presence and/or abundance.	The link between environmental variables, particularly pool depth, and fish has not been quantified for SWWA.	Depth thresholds for each species are necessary to provide flows that protect dry season refugia.

	Knowledge gap	Reasoning for prioritisation	
	The dispersal capacity of different fish species, and the length of flow connectivity needed to facilitate fish movement.	The dispersal capacity for native fish has not been quantified for SWWA.	Understanding the speed at which fish move is necessary to provide flows that allow sufficient connectivity between refugia. It can also inform the spatial placement of refuges across the riverine landscape.
Biophysical values			
Refuge pools	The location of dry season refugia pools.	The location of pools has not been mapped for the Donnelly, or SWWA.	The location of pools and their physical attributes is a critical step in identifying and protecting the flows required to sustain them.
Streamflow	Duration of connectivity in the upper part of the Donnelly catchment (which includes habitat for threatened fish species).	There is no published information on the duration of connectivity for the Donnelly River. Some information has been collected by DWER.	Quantifying the duration of connectivity is necessary to provide flows that allow for fish dispersal.
Hydrogeology	Locations of groundwater upwelling (particularly regional groundwater) that support perennial reaches / pools.	Some new recent information as part of a PhD project. Sites do not include the upper part of the catchment.	Quantifying groundwater contributions to pools is necessary to protect groundwater levels to maintain pools.

References

ABBOTT, I. & BURROWS, N. 1999. Biodiversity conservation in the forests and associated vegetation types of southwest Western Australia. *Australian Forestry,* 62**,** 27-32.

ALI, R., MCFARLANE, D., VARMA, S., DAWES, W., EMELYANOVA, I., HODGSON, G. & CHARLES, S. 2012. Potential climate change impacts on groundwater resources of south-western Australia. *Journal of Hydrology,* 475**,** 456-472.

ALLAN, J. D. 1995. *Stream ecology: structure and function of running waters,* London, UK, Chapman & Hall.

ALLEN, M. 2016. *Barriers to fish migration in drying climates: contributions from south-western Australia.* Murdoch University.

ALLEN, M. G., MORGAN, D. L., CLOSE, P. G. & BEATTY, S. J. 2020. Too little but not too late? Biology of a recently discovered and imperilled freshwater fish in a drying temperate region and comparison with sympatric fishes. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 30**,** 1412-1423.

ARTHINGTON, A. H., BALCOMBE, S. R., WILSON, G. A., THOMS, M. C. & MARSHALL, J. 2005. Spatial and temporal variation in fish-assemblage structure in isolated waterholes during the 2001 dry season of an arid-zone floodplain river, Cooper Creek, Australia. *Marine and Freshwater Research,* 56**,** 25-35.

AUSTRALIAN GOVERNMENT 2017. Engaging Indigenous peoples in water planning and management. *Module to the National Water Initiative (NWI) policy guidelines for water planning and management. .* Canberra, Australia: Commonwealth of Australia.

AYRE, M. & MACKENZIE, J. 2013. “Unwritten, unsaid, just known”: the role of Indigenous knowledge(s) in water planning in Australia. *Local Environment,* 18**,** 753-768.

BAIN, K., WAYNE, A. F. & BENCINI, R. 2019. Spatial ecology of the quokka (*Setonix brachyurus*) in the southern forests of Western Australia: implications for the maintenance, or restoration, of functional metapopulations. *Australian Mammalogy,* 42**,** 38-47.

BALCOMBE, S. R., BUNN, S.E., ARTHINGTON, A.H., FAWCETT, J.H., MCKENZIE-SMITH, F.J., WRIGHT, A. 2007. Fish larvae, growth and biomass relationships in an Australian arid zone river: links between floodplains and waterholes. *Freshwater Biology,* 52**,** 2385-2398.

BALCOMBE, S. R., LOBEGEIGER, J. S., MARSHALL, S. M., MARSHALL, J. C., LY, D. & JONES, D. N. 2012. Fish body condition and recruitment success reflect antecedent flows in an Australian dryland river. *Fisheries Science,* 78**,** 841-847.

BARBER, M. & WOODWARD, E. 2018. Indigenous water values, rights, interests and development objectives in the Fitzroy catchment. *July.* https://doi. *org/10.25919/5b86ed8acd71b.*

BEATTY, S., MORGAN, D. & MCALEER, F. 2006. Migration patterns of the fish and crayfish fauna of the Blackwood River. *In:* BEATTY, S. (ed.) *Fish and freshwater crayfish communities of the Blackwood River: migrations, ecology and the influence of surface and groundwater.* Western Australia: Mudoch University.

BEATTY, S. J. & MORGAN, D. L. 2010. Teleosts, agnathans and macroinvertebrates as bioindicators of ecological health in a south-western Australian river. *Journal of the Royal Society of Western Australia,* 93**,** 65-79.

BEATTY, S. J., MORGAN, D. L. & LYMBERY, A. J. 2014. Implications of climate change for potamodromous fishes. *Global Change Biology,* 20**,** 1794-1807.

BEATTY, S. J., MORGAN, D. L., MCALEER, F. J. & RAMSAY, A. R. 2010. Groundwater contribution to baseflow maintains habitat connectivity for Tandanus bostocki (Teleostei: Plotosidae) in a south-western Australian river. *Ecology of Freshwater Fish,* 19**,** 595-608.

BEESLEY, L., CANHAM, C. A., DOUGLAS, M., SETTERFIELD, S. A., FREESTONE, F. L., KEOGH, C. S., KENNARD, M., LOOMES, R., PUSEY, B. & BURROWS, R. 2021a. Environmental water needs of Western Australia's Fitzroy River. . Perth, Western Australia: The University of Western Australia.

BEESLEY, L., CLOSE, P. G., GWINN, D. C., LONG, M., MOROZ, M., KOSTER, W. M. & STORER, T. 2019. Flow-mediated movement of freshwater catfish, Tandanus bostocki, in a regulated semi-urban river, to inform environmental water releases. *Ecology of Freshwater Fish,* 28**,** 434-445.

BEESLEY, L. S., GWINN, D. C., PRICE, A., KING, A. J., GAWNE, B., KOEHN, J. D. & NIELSEN, D. L. 2014. Juvenile fish response to wetland inundation: how antecedent conditions can inform environmental flow policies for native fish. *Journal of Applied Ecology,* 51**,** 1613-1621.

BEESLEY, L. S., PUSEY, B. J., DOUGLAS, M. M., KEOGH, C. S., KENNARD, M. J., CANHAM, C. A., CLOSE, P. G., DOBBS, R. J. & SETTERFIELD, S. A. 2021b. When and where are catfish fat fish? Hydro-ecological determinants of energy reserves in the fork-tailed catfish, Neoarius graeffei, in an intermittent tropical river. *Freshwater Biology,* 66**,** 1211-1224.

BENSON, J. A., CLOSE, P. G., STEWART, B. A. & LYMBERY, A. J. 2019. Freshwater tributaries provide refuge and recolonization opportunities for mussels following salinity reversal. *Science of the Total Environment,* 683**,** 231-239.

BERNAL, S., LUPON, A., RIBOT, M., SABATER, F. & MARTÍ, E. 2015. Riparian and in-stream controls on nutrient concentrations and fluxes in a headwater forested stream. *Biogeosciences,* 12**,** 1941-1954.

BISHOP, K. & FORBES, M. 1991. The freshwater fishes of northern Australia. *In:* HAYNES, C. S., RIDPATH, M. G. & WILLIAMS, M. A. (eds.) *Monsoonal Australia: landscape, ecology and man in the northern lowlands.* Rotterdam: A.A. Balkema.

BOM. 2016. *Indigneous Weather Knowledge* [Online]. South West Aboriginal Land and Sea Council: Bureau of Meterology. Available: http://www.bom.gov.au/iwk/calendars/nyoongar.shtml [Accessed].

BOULTON, A. 1993. Stream ecology and surface-hyporheic hydrologic exchange: Implications, techniques and limitations. *Marine and Freshwater Research,* 44**,** 553-564.

BOULTON, A., BROCK, M., ROBSON, B., RYDER, D., CHAMBERS, J. & DAVIS, J. 2014. *Australian freshwater ecology: processes and management*, John Wiley & Sons.

BOULTON, A. J. 2000. The subsurface macrofauna. *Streams and ground waters***,** 337-361.

BOULTON, A. J. 2007. Hyporheic rehabilitation in rivers: restoring vertical connectivity. *Freshwater Biology,* 52**,** 632-650.

BOULTON, A. J., DATRY, T., KASAHARA, T., MUTZ, M. & STANFORD, J. A. 2010. Ecology and management of the hyporheic zone: stream–groundwater interactions of running waters and their floodplains. *Journal of the North American Benthological Society,* 29**,** 26-40.

BOULTON, A. J. & HANCOCK, P. J. 2006. Rivers as groundwater-dependent ecosystems: a review of degrees of dependency, riverine processes and management implications. *Australian Journal of Botany,* 54**,** 133-144.

BOULTON, A. J., ROLLS, R. J., JAEGER, K. L. & DATRY, T. 2017. Hydrological connectivity in intermittent rivers and ephemeral streams. *Intermittent Rivers and Ephemeral Streams.* Elsevier.

BRUNKE, M. & GONSER, T. 1997. The ecological significance of exchange processes between rivers and groundwater. *Freshwater Biology,* 37**,** 1-33.

BRUNNER, P., COOK, P. G. & SIMMONS, C. T. 2011. Disconnected surface water and groundwater: fom theory to practice. *Groundwater,* 49**,** 460-467.

BUNN, S. E. 1988. Processing of leaf litter in a northern jarrah forest stream, Western Australia: I. Seasonal differences. *Hydrobiologia,* 162**,** 201-210.

BUNN, S. E. & ARTHINGTON, A. H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental management,* 30**,** 492-507.

BURFORD, M. A., VALDEZ, D., CURWEN, G., FAGGOTTER, S. J., WARD, D. P. & BRIEN, K. O. 2016. Inundation of saline supratidal mudflats provides an important source of carbon and nutrients in an aquatic system. *Marine Ecology Progress Series,* 545**,** 21-33.

CANHAM, C. A., FROEND, R. H. & STOCK, W. D. 2009. Water stress vulnerability of four Banksia species in contrasting ecohydrological habitats on the Gnangara Mound, Western Australia. *Plant, Cell & Environment,* 32**,** 64-72.

CAREY, N., CHESTER, E. T. & ROBSON, B. J. 2021. Flow regime change alters shredder identity but not leaf litter decomposition in headwater streams affected by severe, permanent drying. *Freshwater Biology,* 66**,** 1813-1830.

CLUETT, L. 2005. The role of flooding in morphological changes in the regulated Lower Ord River in tropical northwestern Australia. *River Research and Applications,* 21**,** 215-227.

COGGER, H. G. 2015. Reptiles and amphibians of Australia. CSIRO Publishing.

COMMONWEATH OF AUSTRALIA 2019. Australia's strategy for nature 2019-2030. Canberra, Australia: Commonweath of Australia.

CONGDON, R. A. & MCCOMB, A. J. 1980. Nutrient Pools of an Estuarine Ecosystem--The Blackwood River Estuary in South-Western Australia. *The Journal of Ecology***,** 287-313.

CSIRO 2009. Groundwater yields in south-west Western Australia. *A report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project.* Canberra, Australia: CSIRO Water for a Healthy Countr Flagship.

DAHAN, O., TATARSKY, B., ENZEL, Y., KULLS, C., SEELY, M. & BENITO, G. 2008. Dynamics of Flood Water Infiltration and Ground Water Recharge in Hyperarid Desert. *Groundwater,* 46**,** 450-461.

DALTRY, T., LARNED, S. T. & SCARSBROOK, M. R. 2007. Responses of hyporheic invertebrate assemblages to large-scale variation in flow permanence and surface–subsurface exchange. *Freshwater Biology,* 52**,** 1452-1462.

DATRY, T., CORTI, R., CLARET, C. & PHILIPPE, M. 2011. Flow intermittence controls leaf litter breakdown in a French temporary alluvial river: the “drying memory”. *Aquatic Sciences,* 73**,** 471-483.

DAVIS, J., STREET, M., MALO, H., CHEREL, I. & WOODWARD, E. 2011. Mingayooroo—Manyi Waranggiri Yarrangi: Gooniyandi Seasons (Calendar), Margaret River, Fitzroy Valley, Western Australia. Darwin: CSIRO Ecosystem Sciences.

DE GRAAF, M., BEATTY, S. & MOLONY, B. M. 2010. *Evaluation of the recreational marron fishery against environmental change and human interaction*, Western Australian Fisheries and Marine Research Laboratories.

DE SILVA, J. 2004. Hydrogeology of the Pemberton-Irwin Inlet 1:250000 sheet. Report HM 8. *Hydrogeological map explanatory notes series.* Western Australia: Department of Environment.

DE TORES, P. J., HAYWARD, M. T., DILLON, M. J. & BRAZELL, R. I. 2007. Review of the distribution, causes for the decline and recommendations for management of the quokka, *Setonix brachyurus* (Macropodidae: Marsupialia), an endemic macropodid marsupial from south-west Western Australia. *Conservation Science Western Australia,* 6**,** 13-73.

DEKAR, M. P. & MAGOULICK, D. D. 2007. Factors affecting fish assemblage structure during seasonal stream drying. *Ecology of Freshwater Fish,* 16**,** 335-342.

DEPARTMENT OF WATER AND ENVIRONMENTAL REGULATION 2020. Managing water in the Fitzroy River Catchment: Discussion paper for stakeholder consultation. Joondalup, Western Australia.

DEPARTMENT OF WATER AND ENVIRONMENTAL REGULATION 2023a. Ecological water requirements of water-dependent ecosystems in the Fitzroy water planning area. *Environmental water report series. Report no. 34.* Joondalup, Western Australia.

DEPARTMENT OF WATER AND ENVIRONMENTAL REGULATION 2023b. Water allocation planning in the Fitzroy: Policy Position Paper. Joondalup, Western Australia.

DONOHUE, R., MOULDEN, B., BENNETT, K. & GREEN, A. 2009. Ecological Water Requirements for Lefroy Brook. Western Australia: Department of Water, Government of Western Australia.

DORTCH, C. E. 1974. A twelve thousand year old occupation floor in Devil's Lair, Western Australia. *Mankind,* 9**,** 195-205.

DORTCH, C. E. & GARDNER, G. 1976. Archeological investigations in the Northcliffe district, Western Australia. *Records of the Western Australian Museum.*

DOUGLAS, M. M., JACKSON, S., CANHAM, C. A., LABORDE, S., BEESLEY, L., KENNARD, M. J., PUSEY, B. J., LOOMES, R. & SETTERFIELD, S. A. 2019. Conceptualizing Hydro-socio-ecological Relationships to Enable More Integrated and Inclusive Water Allocation Planning. *One Earth,* 1**,** 361-373.

DUDGEON, D., ARTHINGTON, A. H., GESSNER, M. O., KAWABATA, Z.-I., KNOWLER, D. J., LÉVÊQUE, C., NAIMAN, R. J., PRIEUR-RICHARD, A.-H., SOTO, D., STIASSNY, M. L. J. & SULLIVAN, C. A. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews,* 81**,** 163-182.

DWER. HRP. *Healthy River Program* [Online]. Department of Water and Environmental Regulation, WA government. [Accessed].

DWER HEALTHY RIVERS SOUTH-WEST. 2023. *Ecological water requirements* [Online]. online: Government of Western Australia. Available: https://rivers.dwer.wa.gov.au/overview/management/ecological-water-requirements/ [Accessed].

EMERY-BUTCHER, H. E. 2023. *Effects of climate drying on endemic freshwater macrocrustacean persistence in south-western Australia.* Murdoch University.

ERSKINE, W. D., SAYNOR, M. J., ERSKINE, L., EVANS, K. G. & MOLIERE, D. R. 2005. A preliminary typology of Australian tropical rivers and implications for fish community ecology. *Marine and Freshwater Research,* 56**,** 253-267.

FREEZE, A. R. & CHERRY, J. A. 1979. *Groundwater,* New Jersey, USA, Prentice-Hall, Inc.

FROEND, R. H. & MCCOMB, A. J. 1994. Distribution, productivity and reproductive phenology of emergent macrophytes in relation to water regimes at wetlands of south-western Australia. *Marine and Freshwater Research,* 45**,** 1491-1508.

GOODE, B. n.d. Southwest Yarragadee Blackwood groundwater area: Aboriginal cultural values survey. Dunsborough, Western Australia: Prepared for WA Department of Environmental Protection Water and Rivers Commission.

GOODE, B. & IRVINE, C. 2006. A survey of Aboriginal social water requirements for the southern Blackwood plateau and the Scott Coastal Plain southwest, Western Australia. Dunsborough, Western Australia: Prepared for WA Department of Environment.

GORDON, N. D., MCMAHON, T. A., FINLAYSON, B. L., GIPPEL, C. J. & NATHAN, R. J. 2004. *Stream hydrology: an introduction for ecologists*, John Wiley and Sons.

GOVERNMENT OF WESTERN AUSTRALIA 2012a. Shire of Manjimup local planning scheme No. 4. *In:* DEPARTMENT OF PLANNING, L. A. H. (ed.). Perth, Western Australia: Government of Western Australia.

GOVERNMENT OF WESTERN AUSTRALIA 2012b. Warren-Donnelly surface water allocation plan. *In:* WATER, D. O. (ed.). Perth, Australia: Government of Western Australia.

GOVERNMENT OF WESTERN AUSTRALIA 2012c. Warren-Donnelly surface water allocation plan methods report. *In:* WATER, D. O. (ed.). Perth, Western Australia: Government of Western Australia.

GREEN, J. & MOGGRIDGE, B. J. 2021. Australia state of the environment 2021: inland water. Independent report to the Australian Government Minister for the Environment. Canberra: Commonwealth of Australia.

GRIMM, N. B. & FISHER, S. G. 1984. Exchange between interstitial and surface water: Implications for stream metabolism and nutrient cycling. *Hydrobiologia,* 111**,** 219-228.

GROSSMAN, G. D., RATAJCZAK, R. E., CRAWFORD, M. & FREEMAN, M. C. 1998. Assemblage organization in stream fishes: effects of environmental variation and interspecific interactions. *Ecological Monographs,* 68**,** 395-420.

GROWNS, I. O. & DAVIS, J. A. 1994. Longitudinal changes in near-bed flows and macroinvertebrate communities in a Western Australian stream. *Journal of the North American Benthological Society,* 13**,** 417-438.

HANSEN, V. & HORSFALL, J. 2016. *Noongar bush medicine: Medicinal plants of the south-west of Western Australia,* Crawley, Western Australia, UWA Publishing.

HANSEN, V. & HORSFALL, J. 2019. *Noongar bush tucker: Bush food plants and fungi of the south-west of Western Australia,* Crawley, Western Australia, UWA Publishing.

HARTWIG, L., JACKSON, S. & OSBORNE, N. 2018. Recognition of Barkandji water rights in Australian settler-colonial water regimes. *Resources,* 7**,** 16.

HOLMES, R. M. 2000. The importance of ground water to stream ecosystem function. *Streams and ground waters.* Elsevier.

HOPE, P. & GANTER, C. Recent and projected rainfall trends in south-west Australia and the associated shifts in weather systems. Managing climate change: papers from the Greenhouse 2009 Conference, 2010. CSIRO, 53-63.

HUGHES, J. & WANG, B. 2022. Future climate streamflow estimation in the Donnelly River catchment. *Prepared for: Department of Primary Industries and Regional Development, Western Australia.* Canberra Australia: CSIRO Land and Water.

JACKSON, S. 2006. Compartmentalising Culture: the articulation and consideration of Indigenous values in water resource management. *Australian Geographer,* 37**,** 19-31.

JACKSON, S. 2019. Building trust and establishing legitimacy across scientific, water management and Indigenous cultures. *Australasian Journal of Water Resources,* 23**,** 14-23.

JACKSON, S., FINN, M. & FEATHERSTON, P. 2012a. Aquatic resource use by Indigenous Australians in two tropical river catchments: the Fitzroy River and Daly River. *Human Ecology,* 40**,** 893-908.

JACKSON, S., TAN, P.-L. & NOLAN, S. 2012b. Tools to enhance public participation and confidence in the development of the Howard East aquifer water plan, Northern Territory. *Journal of Hydrology,* 474**,** 22-28.

JANSSON, R., STRÖM, L. & NILSSON, C. 2019. Smaller future floods imply less habitat for riparian plants along a boreal river. *Ecological Applications,* 29**,** e01977.

JARDINE, T., PUSEY, B., HAMILTON, S., PETTIT, N., DAVIES, P., DOUGLAS, M., SINNAMON, V., HALLIDAY, I. & BUNN, S. 2012. Fish mediate high food web connectivity in the lower reaches of a tropical floodplain river. *Oecologia,* 168**,** 829-838.

JOLLY, I. D., MCEWAN, K. L. & HOLLAND, K. L. 2008. A review of groundwater–surface water interactions in arid/semi-arid wetlands and the consequences of salinity for wetland ecology. *Ecohydrology,* 1**,** 43-58.

KARRI KARRAK ABORIGINAL CORPORATION. 2023a. *About us* [Online]. Available: https://karrikarrak.org.au/about-us [Accessed 1 September 2023].

KARRI KARRAK ABORIGINAL CORPORATION. 2023b. *The South West Native Title Settlement* [Online]. Available: https://karrikarrak.org.au/settlement [Accessed 7 September 2023].

KAY, W. R., HALSE, S. A., SCANLON, M. D. & SMITH, M. J. 2001. Distribution and environmental tolerances of aquatic macroinvertebrate families in the agricultural zone of southwestern Australia. *Journal of the North American Benthological Society,* 20**,** 182-199.

KENNARD, M. J., PUSEY, B. J., OLDEN, J. D., MACKAY, S. J., STEIN, J. L. & MARSH, N. 2010. Classification of natural flow regimes in Australia to support environmental flow management. *Freshwater biology,* 55**,** 171-193.

KINAL, J. & STONEMAN, G. L. 2012. Disconnection of groundwater from surface water causes a fundamental change in hydrology in a forested catchment in south-western Australia. *Journal of Hydrology,* 472**,** 14-24.

KLUNZINGER, M. W., BEATTY, S. J., MORGAN, D. L., PINDER, A. M. & LYMBERY, A. J. 2015. Range decline and conservation status of Westralunio carteri Iredale, 1934 (Bivalvia: Hyriidae) from south-western Australia. *Australian Journal of Zoology,* 63**,** 127-135.

KLUNZINGER, M. W., THOMSON, G. J., BEATTY, S. J., MORGAN, D. L. & LYMBERY, A. J. 2013. Morphological and morphometrical description of the glochidia of Westralunio carteri Iredale, 1934 (Bivalvia: Unionoida: Hyriidae). *Molluscan Research,* 33**,** 104-109.

KOENDERS, A. & HORWITZ, P. 2006. Crayfish burrowing activity in the region of the Yarragadee discharge zone, Blackwood River. *In:* BEATTY, S. (ed.) *Fish and freshwater crayfish communities of the Blackwood River: migrations, ecology and the influence of surface and groundwater.* Western Australia: Murdoch University.

LEIGH, C. 2013. Dry-season changes in macroinvertebrate assemblages of highly seasonal rivers: responses to low flow, no flow and antecedent hydrology. *Hydrobiologia,* 703**,** 95-112.

LYMBERY, A. J., MA, L., LYMBERY, S. J., KLUNZINGER, M. W., BEATTY, S. J. & MORGAN, D. L. 2021. Burrowing behavior protects a threatened freshwater mussel in drying rivers. *Hydrobiologia,* 848**,** 3141-3152.

MACEDA-VEIGA, A., SALVADÓ, H., VINYOLES, D. & DE SOSTOA, A. 2009. Outbreaks of *Ichthyophthirius multifiliis* in redtail barbs *Barbus haasi* in a Mediterranean stream during drought. *Journal of Aquatic Animal Health,* 21**,** 189-194.

MACKENZIE, J., BUTCHER, R., GIPPEL, C., COTTINGHAM, P., BROWN, R., WANGANEEN, K., KLOEDEN, T. & MEARA, T. 2017. Cultural flows: a guide for water managers. Australia.

MAGOULICK, D. D. & KOBZA, R. M. 2003a. The role of refugia for fishes during drought: a review and synthesis. *Freshwater Biology,* 48**,** 1186-1198.

MAGOULICK, D. D. & KOBZA, R. M. 2003b. The role of refugia for fishes during drought: a review and synthesis. *Freshwater Biology,* 48**,** 1186-1198.

MARCOGLIESE, D. 2008. The impact of climate change on the parasites and infectious diseases of aquatic animals. *Rev Sci Tech,* 27**,** 467-484.

MAZUMDER, D., SAINTILAN, N., HOLLINS, S., MEREDITH, K., JACOBSEN, G., KOBAYASHI, T. & WEN, L. 2019. Carbon uptake in surface water food webs fed by palaeogroundwater. *Journal of Geophysical Research: Biogeosciences,* 124**,** 1171-1180.

MCFARLANE, D. 2005. Context report on south west water resources for: expert panel examining kimberley water supply options. *Client report to WA Government.* Canberra, Australia: CSIRO Water for a Healthy Country.

MCFARLANE, D., GEORGE, R., RUPRECHT, J., CHARLES, S. & HODGSON, G. 2020. Runoff and groundwater responses to climate change in South West Australia. *Journal of the Royal Society of Western Australia,* 103**,** 9-27.

MCFARLANE, D., STONE, R., MARTENS, S., THOMAS, J., SILBERSTEIN, R., ALI, R. & HODGSON, G. 2012. Climate change impacts on water yields and demands in south-western Australia. *Journal of Hydrology,* 475**,** 488-498.

MEDEIROS, E. S. F. & MALTCHIK, L. 1999. The effects of hydrological disturbance on the intensity of infestation of *Lernaea cyprinacea* in an intermittent stream fish community. *Journal of Arid Environments,* 43**,** 351-356.

MIDDLETON, J. A. 2015. *The 'urban stream syndrome' in a flat sandy landscape: hydrologic stress, riparian buffers, and nutrients drive stream integrity.* Batchelor of Science (hons), The University of Western Australia.

MILLER, A. K., BAKER, C., KITSON, J. C., YICK, J. L., MANQUEL, P. E. I., ALEXANDER, A. & GEMMELL, N. J. 2021. The Southern Hemisphere lampreys (Geotriidae and Mordaciidae). *Reviews in Fish Biology and Fisheries,* 31**,** 201-232.

MOGGRIDGE, B. J. & THOMPSON, R. M. 2021. Cultural value of water and western water management: an Australian Indigenous perspective. *Australasian Journal of Water Resources,* 25**,** 4-14.

MORGAN, D. L. & BEATTY, S. J. 2008. The Donnelly River catchment: an important refuge for all of south-western Australia's endemic freshwater fishes and the Pouched Lamprey (Geotria australis). *Western Australian Naturalist,* 26**,** 112-127.

MORGAN, D. L., THORBURN, D. C. & GILL, H. S. 2003. Salinization of southwestern Western Australian rivers and the implications for the inland fish fauna-the Blackwood River, a case study. *Pacific Conservation Biology,* 9**,** 161-171.

MORRISSY, N. M. 1978. past and present distribution of marrow, cherax tenuimanus (Smith), in Western Australia.

MYERS, N., MITTERMEIER, R. A., MITTERMEIER, C. G., DA FONSECA, G. A. B. & KENT, J. 2000. Biodiversity hotspots for conservation priorities. *Nature,* 403**,** 853-858.

NAIMAN, R., J. & DÉCAMPS, H. 1997. The Ecology of Interfaces: Riparian Zones. *Annual Review of Ecology and Systematics,* 28**,** 621-658.

NATIONAL NATIVE TITLE TRIBUNAL 2018. South West Boojarah #2 Indigenous Land Use Agreement (ILUA) (WI2017/013). *In:* COMMONWEATH OF AUSTRALIA (ed.).

NICKOLL, R. 1996. An investigation into the use of the freshwater crayfish marron (cherax tenuimanus) as a flagship for the restoration of the Blackwood River.

NICOL, J. M. & GANF, G. G. 2000. Water regimes, seedling recruitment and establishment in three wetland plant species. *Marine and Freshwater Research,* 51**,** 305-309.

NIU, S. Q. & DUDGEON, D. 2011. The influence of flow and season upon leaf-litter breakdown in monsoonal Hong Kong streams. *Hydrobiologia,* 663**,** 205-215.

O'BRYAN, K. 2019. *Indigenous rights and water resource management: not just another stakeholder,* Abingdon, UK, Routledge.

O'DONNELL, A. J., MCCAW, W. L., COOK, E. R. & GRIERSON, P. F. 2021. Megadroughts and pluvials in southwest Australia: 1350–2017 CE. *Climate Dynamics,* 57**,** 1817-1831.

PAICE, R. L., CHAMBERS, J. M. & ROBSON, B. J. 2017. Native submerged macrophyte distribution in seasonally-flowing, south-western Australian streams in relation to stream condition. *Aquatic Sciences,* 79**,** 171-185.

PAUL, M. J., MEYER, J. L. & COUCH, C. A. 2006. Leaf breakdown in streams differing in catchment land use. *Freshwater Biology,* 51**,** 1684-1695.

PENNIFOLD, M. & PINDER, A. M. 2011. South-West forest stream biodiversity monitoring, Forest Management Plan 2004-2013: key performance indicator 20. *In:* CONSERVATION, D. O. E. A. (ed.). Perth, Western Australia.

PENNIFOLD, M. G., WILLIAMS, K. J., PINDER, A. M., HARWOOD, T. D., MANION, G. & FERRIER, S. 2017. Whole-landscape modelling of compositional turnover in aquatic invertebrates informs conservation gap analysis: An example from south-western Australia. *Freshwater Biology,* 62**,** 1359-1376.

PETRONE, K. C., HUGHES, J. D., VAN NIEL, T. G. & SILBERSTEIN, R. P. 2010. Streamflow decline in southwestern Australia, 1950–2008. *Geophysical Research Letters,* 37.

PETTIT, N. E. & FROEND, R. H. 2001a. Availability of seed for recruitment of riparian vegetation: a comparison of a tropical and a temperate river ecosystem in Australia. *Australian Journal of Botany,* 49**,** 515-528.

PETTIT, N. E. & FROEND, R. H. 2001b. Variability in flood disturbance and the impact on riparian tree recruitment in two contrasting river systems. *Wetlands Ecology and Management,* 9**,** 13-25.

PETTIT, N. E., WARFE, D. M., KENNARD, M. J., PUSEY, B. J., DAVIES, P. M. & DOUGLAS, M. M. 2013. Dynamics of in-stream wood and its importance as fish habitat in a large tropical floodplain river. *River Research and Applications,* 29**,** 864-875.

PFAUTSCH, S., DODSON, W., MADDEN, S. & ADAMS, M. A. 2015. Assessing the impact of large-scale water table modifications on riparian trees: a case study from Australia. *Ecohydrology,* 8**,** 642-651.

POFF, N. L., ALLAN, J. D., BAIN, M. B., KARR, J. R., PRESTEGAARD, K. L., RICHTER, B. D., SPARKS, R. E. & STROMBERG, J. C. 1997. The natural flow regime. *Bioscience,* 47**,** 769-784.

POTTER, I. C., HILLIARD, R. W., BIRD, D. J. & MACEY, D. J. 1983. Quantitative data on morphology and organ weights during the protracted spawning-run period of the Southern Hemisphere lamprey Geotria australis. *Journal of Zoology,* 200**,** 1-20.

POTTER, I. C., HILLIARD, R. W., BRADLEY, J. S. & MCKAY, R. J. 1986. The influence of environmental variables on the density of larval lampreys in different seasons. *Oecologia,* 70**,** 433-440.

POTTER, I. C., PRINCE, P. A. & CROXALL, J. P. 1979. Data on the adult marine and migratory phases in the life cycle of the southern hemisphere lamprey, Geotria australis Gray. *Environmental Biology of Fishes,* 4**,** 65-69.

PUSEY, B. J. & ARTHINGTON, A. H. 2003. Importance of the riparian zone to the conservation and management of freshwater fish: a review. *Marine and freshwater Research,* 54**,** 1-16.

PUSEY, B. J., KENNARD, M. J., DOUGLAS, M. & ALLSOP, Q. 2018. Fish assemblage dynamics in an intermittent river of the northern Australian wet–dry tropics. *Ecology of Freshwater Fish,* 27**,** 78-88.

ROBSON, B. J., CHESTER, E. T., ALLEN, M., BEATTY, S., CHAMBERS, J. M., CLOSE, P., COOK, B., CUMMINGS, C. R., DAVIES, P. M. & LESTER, R. E. 2013. Novel methods for managing freshwater refuges against climate change in southern Australia.

ROJAS, R., COMMANDER, P., MCFARLANE, D., ALI, R., DAWES, W., BARRON, O., HODGSON, G. & CHARLES, S. 2018. Groundwater Resource Assessment and Conceptualization in the Pilbara Region, Western Australia. *Earth Systems and Environment,* 2**,** 345-365.

SABO, J. L., SPONSELLER, R., DIXON, M., GADE, K., HARMS, T., HEFFERNAN, J., JANI, A., KATZ, G., SOYKAN, C. & WATTS, J. 2005. Riparian zones increase regional species richness by harboring different, not more, species. *Ecology,* 86**,** 56-62.

SAUNDERS, K. S., MAYES, K. B., JURGENSEN, T. A., TRUNGALE, J. F., KLEINSASSER, L. J., AZIZ, K., FIELDS, J. R. & MOSS, R. E. 2001. An evaluation of spring flows to support the upper San Marcos River spring ecosystem, Hays County, Texas. *Texas Parks and Wildlife Department. River Studies Report*.

SCHWARTZ, F. W. & FRANKLIN, W. 2003. *Fundamentals of groundwater*.

SILBERSTEIN, R. P., ARYAL, S. K., DURRANT, J., PEARCEY, M., BRACCIA, M., CHARLES, S. P., BONIECKA, L., HODGSON, G. A., BARI, M. A. & VINEY, N. R. 2012. Climate change and runoff in south-western Australia. *Journal of Hydrology,* 475**,** 441-455.

SORENSEN, P. W. & VRIEZE, L. A. 2003. The chemical ecology and potential application of the sea lamprey migratory pheromone. *Journal of Great Lakes Research,* 29**,** 66-84.

SPELDEWINDE, P. C., CLOSE, P., WEYBURY, M. & COMER, S. 2013. Habitat preference of the Australian water rat *Hydromys chrysogaster* in a coastal wetland and stream, Two Peoples Bay, south-western Australia. *Australian Mammalogy,* 35**,** 188-194.

STANFORD, J. A. & WARD, J. V. 1993. An ecosystem perspective on alluvial rivers: connectivity and the hyporheic corridor. *Journal of the North American Benthological Society,* 12**,** 48-60.

STRATEGEN 2006. *South West Yarragadee Water Supply Development: Sustainability Evaluation/environmental Review & Management Programme: Executive Summary*, Strategen.

TAN, P.-L., BOWMER, K. H. & MACKENZIE, J. 2012. Deliberative tools for meeting the challenges of water planning in Australia. *Journal of Hydrology,* 474**,** 2-10.

TAN, P. & JACKSON, S. 2013. Impossible Dreaming–does Australia’s water law and policy fulfil indigenous aspirations. . *Environmental Planning and Law Journal,* 30**,** 132-49.

TAYLOR, K. S., MOGGRIDGE, B. J. & POELINA, A. 2016. Australian Indigenous Water Policy and the impacts of the ever-changing political cycle. . *Australasian Journal of Water Resources,* 20**,** 132-47.

THOMS, M. C., PARSONS, M. & SOUTHWELL, M. 2016. The physical template of Australia's rivers. *In:* CAPON, S. J., JAMES, C., REID, M. (ed.) *Vegetation of Australian riverine landscapes: Biology, ecology and management.* Victoria, Australia: CSIRO Publishing.

THOMS, M. C. & SHELDON, F. 2002. An ecosystem approach for determining environmental water allocations in Australian dryland river systems: the role of geomorphology. *Geomorphology,* 47**,** 153-168.

TOUSSAINT, S. 2008. Kimberley friction: Complex attachments to water-places in Northern Australia. *Oceania,* 78**,** 46-61.

TOUSSAINT, S., SULLIVAN, P., YU, S. & MULARTY, M. 2001. Fitzroy valley indigenous cultural values study (a preliminary assessment). *Perth: Water and Rivers Commission*.

TOWNSEND, S. A. 1994. The occurrence of natural fish kills, and their causes, in the Darwin-Katherine-Jabiru region of northern Australia. *SIL Communications, 1953-1996,* 24**,** 197-205.

TOWNSEND, S. A., BOLAND, K. T. & WRIGLEY, T. J. 1992. Factors contributing to a fish kill in the Australian wet/dry tropics. *Water Research,* 26**,** 1039-1044.

TRAYLER, K. M. & DAVIS, J. A. 1998. Forestry impacts and the vertical distribution of stream invertebrates in south-western Australia. *Freshwater Biology,* 40**,** 331-342.

VÖRÖSMARTY, C. J., MCINTYRE, P. B., GESSNER, M. O., DUDGEON, D., PRUSEVICH, A., GREEN, P., GLIDDEN, S., BUNN, S. E., SULLIVAN, C. A., LIERMANN, C. R. & DAVIES, P. M. 2010. Global threats to human water security and river biodiversity. *Nature,* 467**,** 555-561.

WARD, J. V., TOCKNER, K., ARSCOTT, D. B. & CLARET, C. 2002. Riverine landscape diversity. *Freshwater Biology,* 47**,** 517-539.

WEIR, J. K. 2011. Water planning and dispossession. *In:* CONNELL, D. & GRAFTON, R. (eds.) *In Basin futures: water reform in the Murray-Darling Basin.*

WEST AUSTRALIAN GOVERNMENT. 2022. *Aboriginal water and environment advisory group* [Online]. Perth, Western Australia: West Australian Government. Available: https://www.wa.gov.au/service/environment/environment-information-services/aboriginal-water-and-environment-advisory-group [Accessed].

WHATMORE, L. 2023. *Movement and habitat use of captively-reared southwestern snake-necked turtle (Chelodina oblonga) hatchlings.* Murdoch University.

WHITE, H. A., SCOTT, J. K. & DIDHAM, R. K. 2021. Evidence of Range Shifts in Riparian Plant Assemblages in Response to Multidecadal Streamflow Declines. *Frontiers in Ecology and Evolution,* 9.

YEATMAN, G. J., WAYNE, A. F., MILLS, H. R. & PRINCE, J. 2016. It's not all about the creeks: protection of multiple habitats will improve biodiversity conservation in a eucalypt forest. *Australian Journal of Zoology,* 64**,** 292-301.

ZARET, T. M. & RAND, A. S. 1971. Competition in tropical stream fishes: support for the competitive exclusion principle. *Ecology,* 52**,** 336-342.