Government of **Western Australia**
Department of **Water and Environmental Regulation**

Ecological water requirements of water-dependent ecosystems in the Fitzroy water planning area

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Acknowledgement of Country

The Department of Water and Environmental Regulation acknowledges the Traditional Owners and custodians of the Fitzroy water planning area and their deep and continuing connection to the land and waters of the region.

We pay our respects to Elders past and present, and to all members of the Aboriginal communities in the plan area and their cultures. We acknowledge that Traditional Owners have been custodians of Country for countless generations and that water is integral to life.

We recognise that the ‘living waters’ of the Fitzroy River are the centre of life and diversity in the Kimberley and that water places such as springs, river pools and floodplain wetlands are important places to Traditional Owners and Aboriginal people. These places are captured in our description of water-dependent habitats, and we acknowledge that continued connection to water places is fundamental to the health, spirit, culture, and community of the people of the Fitzroy water planning area.

We embrace the spirit of reconciliation, and we seek to listen, learn, and build strong partnerships with genuine opportunities for Aboriginal people throughout our business.

The Fitzroy River and its tributaries is known by several names across its many nations, including the Martuwarra. To respect these differences in language we have not used dual naming in this report.

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Summary

This report is one of several that will support water allocation planning in the Fitzroy.

This report builds on the *Environmental and heritage values and the importance of water in the Fitzroy* (values report; DWER 2023a). The values report described the environmental and heritage values listed under legislation, policy and guidance, which are dependent on water (surface and/or groundwater). This report then considered the available information, including newly published data, to describe water-dependent ecosystems (habitats), important species (e.g. Freshwater sawfish, silver-leafed Melaleuca), and the current understanding of how they are supported by surface and/or groundwater.

This report contains two parts. Part A summarises relevant background information and considers the components of the water regime (surface and groundwater) important to water-dependent habitats and the species they support. Part B establishes the hydro-ecological outcomes for each water-dependent habitat.

For each outcome, we present new science from the Fitzroy, and other relevant information, to describe the surface and/or groundwater conditions (e.g. pool depth, flow volume) required to meet the hydro-ecological outcomes. These are the ecological water requirements (EWRs).

There are twenty hydro-ecological outcomes spread across the four main parts of the water regime previously described by the University of Western Australia (UWA)/ National Environmental Science Program (NESP) (Douglas et al. 2019):

- within bank flows during the wet season
- overbank flows during the wet season
- recessional flows at the end of the wet season
- low flows/groundwater inputs during the dry season and dry years.

For eleven of these outcomes, we have evidence to describe EWRs. Some of these apply to a specific location only. Others use evidence from targeted investigation that can be applied to habitats elsewhere in the Fitzroy water planning area. For the remaining hydro-ecological outcomes, there is not enough evidence to define EWRs. For these, we present the information that is available and recommend future work that, if it occurs, can be used to develop EWRs at a local scale.

A summary of the hydro-ecological outcomes and ecological water requirements is presented in Chapter 10 at the end of this report along with the type of further work that could occur to describe the nine qualitative EWRs.

There is a growing body of work being driven by Aboriginal people on cultural science, knowledge and values across the Fitzroy River catchment. We acknowledge the importance and uniqueness of this work which provides greater depth to our understanding of the catchment’s ecological values.

The cultural science and values studies, projects and records comprise knowledge held by Traditional Owners, and it is not appropriate or respectful for us to present their material in this report. Such knowledge should be considered in conjunction with this report to gain an integrated understanding of places, people and spirit that need to be protected from the impacts of water use.

1 Introduction

1.1 Purpose of this document

Water allocation planning

The Department of Water and Environmental Regulation (the department) is responsible for regulating and managing Western Australia's water resources for sustainable productive use. In areas of high demand or interest in water, we develop water allocation plans. This report is one of several that informs the water allocation planning process in the Fitzroy.

The Fitzroy water planning area covers the Fitzroy River catchment extending north-west to also capture the extent of the Grant Group and Poole Sandstone aquifers.

This report builds on the *Environmental and heritage values and the importance of water in the Fitzroy* (DWER 2023a) (values report). The values report described the environmental and heritage values listed under legislation, policy and guidance, which are dependent on water (surface and/or groundwater). It then considered the available information, including newly published data, to describe water-dependent ecosystems (habitats), important species, and the current understanding of how they are supported by surface and/or groundwater (Figure 1).

In this report we consider the components of the water regime (surface and/or groundwater) important to water-dependent habitats and the species they support to define hydro-ecological outcomes. Then, using new science from the Fitzroy and other relevant information, we describe the surface and/or groundwater conditions (e.g. pool depth, flow volume) required to meet the hydro-ecological outcomes. These are the ecological water requirements (EWRs).

Ecological water requirements are the water regimes required to maintain ecological values of water-dependent ecosystems at a low level of risk (Water and Rivers Commission 2000). They are a key component of the water allocation process, which also considers social and cultural values of water and the consumptive demand.

The focus of recent studies in the Fitzroy water planning area was on ecosystems associated with the Lower Fitzroy River from Fitzroy Crossing downstream to Willare. This work provides evidence to inform EWRs to meet eleven hydro-ecological outcomes relevant to flow or groundwater depths in the Lower Fitzroy River. Types of evidence gathered in these studies include river flow to meet the hydro-ecological outcomes for river pool and off-channel wetland habitats on the Lower Fitzroy River, and vegetation within its riparian and floodplain zone.

The broader plan area remains largely unstudied but we have some information on groundwater, springs, cave and aquifer ecosystems and King Sound. This information is not enough to describe quantitative EWRs to meet the hydro-ecological outcomes for these habitats. For these, we present the information that is available and recommend future work that, if it occurs, can be used to develop EWRs at a local scale.

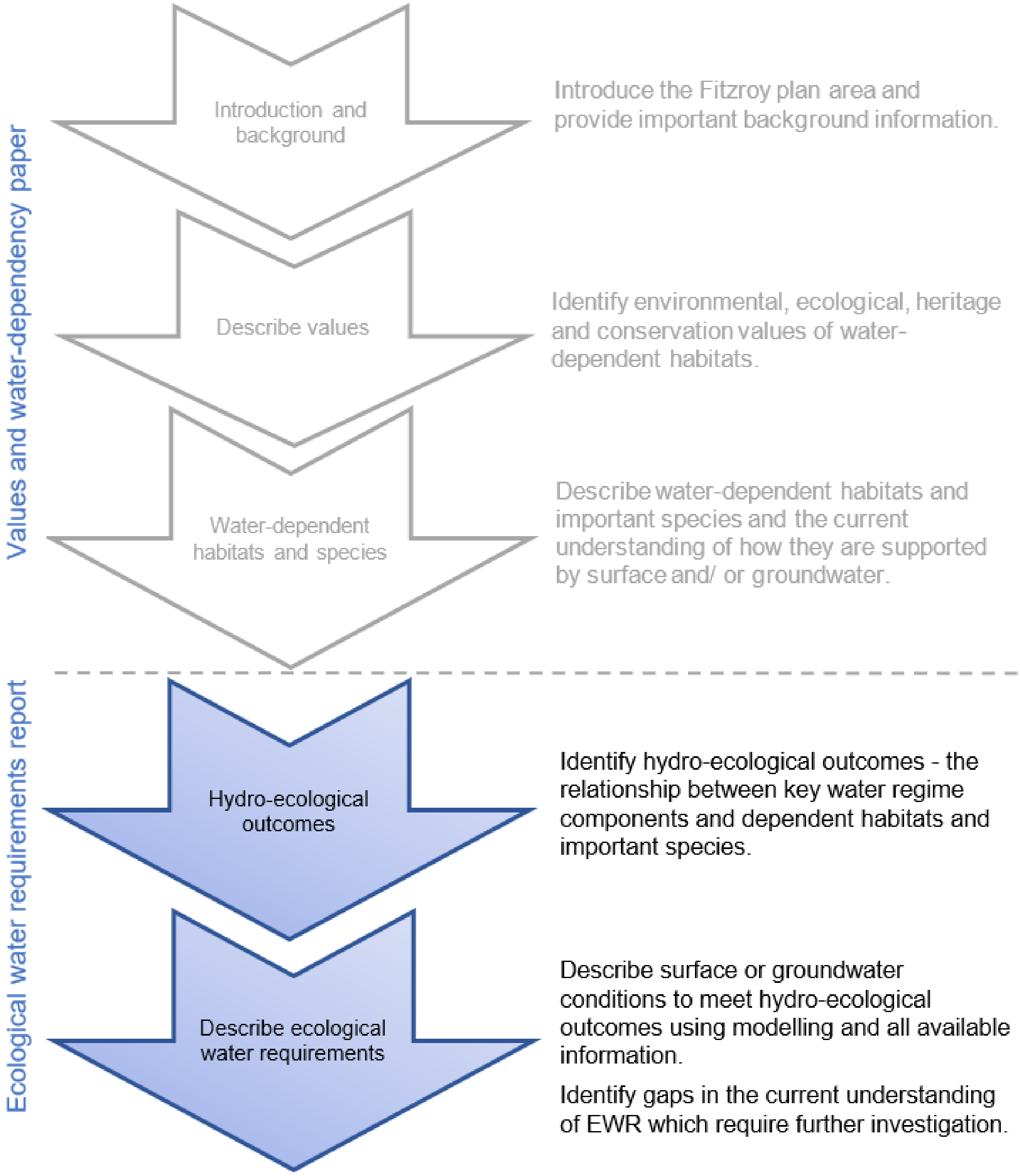

Figure 1 Ecological water requirement process for the Fitzroy water planning area

Limitations of this document

The ecological water requirements (EWRs) described here are largely based on a range of investigations undertaken in and around the lower Fitzroy River in recent years. However, as these studies focused mostly on requirements of aquatic fauna and vegetation, we sourced information on other ecological components of the river and broader catchment from similar river systems of northern Australia. These river systems included the Ord River in the Kimberley, the Daly River in the Northern Territory, and the Flinders, Gilbert and Mitchell rivers in northern Queensland.

There is also limited Fitzroy-specific information on groundwater-fed springs, cave and aquifer ecosystems and King Sound. We have also sourced information from other regions to describe EWRs for these ecosystems.

It is important to acknowledge that this report draws on evidence from published scientific journals and reports to inform the hydro-ecological outcomes and their EWRs. There exists, in traditional and customary knowledge, a depth of understanding and integrated knowledge of the complex interconnections between land, water and Country that sustains these ecosystems. This knowledge comes from relationships with land, water, and Country over countless generations. It may inform additional hydro-ecological outcomes and EWRs and should be considered in conjunction with the information in this report to gain an integrated understanding how the take and use of water can impact water-dependent ecosystems.

This document does not describe water requirements to support cultural values of the river. Traditional Owners are the custodians of their culture and cultural values and have knowledge that can inform cultural water requirements and the risk of impact from the take and use of water. For this reason, Traditional Owners should be consulted as part of any water development.

Complementary management

This ecological water requirements report is intended to support water allocation planning. It can be used to understand available information and can help inform investigations to support future water licence applications. The report does not address the wider range of management issues that may occur in the future from changes in water use activities in the Fitzroy. These issues include direct impacts of irrigated agriculture and pastoral activities, such as clearing and further impacts of stock on riverbanks and vegetation. Impacts from increased nutrient inputs to aquatic ecosystems, the use of herbicides and pesticides, ongoing impacts of the failed Camballin Irrigation Scheme and road crossings are also not addressed here.

Part A – Background information and approach

In Part A of this report, we summarise relevant background information and the important water habitats of the Fitzroy water planning area. We then present the approach taken to describe the water regimes required to protect these important habitats and species.

2 Background

2.1 Fitzroy water planning area

The Fitzroy water planning area covers 103,000 km^2 incorporating the Fitzroy River catchment (94,000 km^2) and the known extent of the Grant Poole aquifer which extends along the Lennard Shelf to the north (**Error! Reference source not found.**)(DWER 2023b).

The Fitzroy River originates in the Durack and Wunaamin-Miliwundi (formerly King Leopold) ranges in the Central Kimberley and flows approximately 730 km west into King Sound near Derby.

Between King Sound and Fitzroy Crossing (300 km upstream) the Fitzroy River is characterised by a flat and wide floodplain. During the summer wet season, the river can often extend 15 km across the floodplain over the alluvial sediments which cover more than 4,000 km^2 of the catchment.

Following the 2023 flood event the floodplain was about 40 km wide at Camballin (DWER 2023c). The upper catchment is characterised by bedrock, with minor localised aquifers, which constrains most smaller rivers and tributaries in the area.

The ecological water requirement work presented in this report focuses on the river and floodplain of the lower Fitzroy River from Fitzroy Crossing to Willare.

2.2 Ecology

As described in the values report (DWER 2023a), the Fitzroy River, its floodplain and tributaries provide important habitat for a diverse array of vegetation, flora and fauna.

During the wet season, flows connect river pools and recharge the alluvial aquifer before moving downstream to the estuary and King Sound. Larger flows connect the river to its floodplain, filling off-channel wetlands and creek lines and at times inundating the floodplain proper. During the long, dry seasons, groundwater-fed river pools and wetlands provide refugia for fish and other fauna. Groundwater also supports aquifer and subterranean ecosystems that contain stygofauna and springs.

The distribution of many species in the Fitzroy water planning area is uncertain due to a lack of systematic surveys and the challenge of accessing some parts of the catchment. There may also be high levels of cryptic diversity in that species exist that are morphologically indistinguishable from each other but are genetically different and incapable of interbreeding.

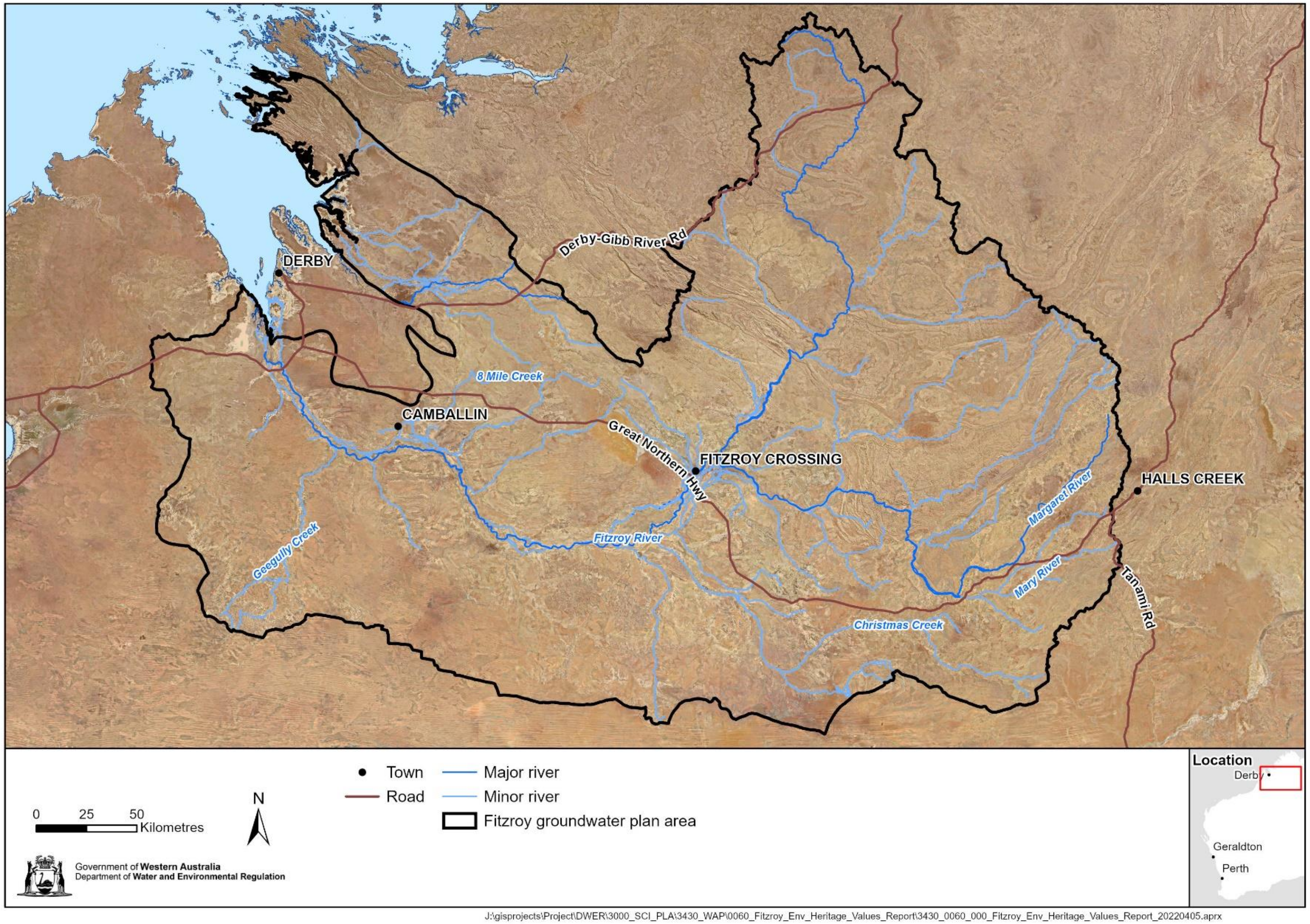

Figure 2 Fitzroy water planning area

Vegetation and flora

In the wet-dry tropics, the obvious green strips of riparian vegetation stand out against a sparsely vegetated savanna landscape. Floodplain vegetation also stands out; however, it tends to be less dense. Both riparian and floodplain species are well adapted to the flooding regimes and groundwater dynamics that occur in these areas.

Groundwater-dependent vegetation includes species that require groundwater at any stage of their life cycle to maintain their condition or persist in a particular location. Riparian and floodplain vegetation communities are often groundwater-dependent but can also use surface and soil water. Other vegetation communities, such as those associated with springs, also use groundwater.

The Fitzroy water planning area supports a diverse range of flora. Of these, 137 species are threatened and/or priority listed, including aquatic plants and cryptogams (lichens, liverworts and mosses).[1] The flora of highest conservation significance is *Pandanus spiralis* var. *flammeus,* which is listed as 'endangered' under the *Environment and Biodiversity Conservation Act 1999 (Cth)* and the *Biodiversity Conservation Act 2016 (WA)*. The Department of Conservation, Biodiversity and Attractions (DBCA) lists the remaining species as 'priority' (Western Australian Herbarium 1998-2022 Florabase). See the values report (DWER 2023a) for more information on listed flora.

Many of the known species of flora of the floodplain area are widespread in similar habitats across northern Australia. Others are recognised as significant because they are restricted to a small area of habitat, or have cultural significance (e.g. *Barringtonia acutangula* – Freshwater mangrove) or ecological significance (e.g. *Melaleuca argentea and M. leucadendra* – Silver and green leafed melaleucas). In many cases the distribution of significant tree species defines a landscape and a habitat visually, if not ecologically (e.g. *Eucalyptus microtheca* – Coolibah and *E. camaldulensis* - River red gum).

Fauna

The Fitzroy River, its tributaries and wetlands support 40 native fish species. Of these, 25 are freshwater species and 15 are estuarine or marine but may spend part of their lives in freshwater environments (Shelley et al. 2018). The number of freshwater species is higher than the number found in the Pilbara (12) and South West (10), but similar to other large northern Australian rivers, possibly due to catchment size (Morgan et al. 2004).

The distribution and richness of species vary between the lower (27), middle (22) and upper (17) reaches of the Fitzroy River and are different again across the tributaries. This variation is likely due to the diversity of habitat types and reduced access of estuarine species to the river's headwaters (Morgan et al. 2004).

[1] P1 – 57, P2 – 21, P3 – 52, P4 – 5; WA Herbarium

Fish that utilise both freshwater and estuarine marine habitats (diadromous species) include the high conservation value Freshwater sawfish (*Pristis pristis*), Dwarf sawfish (*Pristis clavata*) and Northern river shark (*Glyphis garricki*) and the commercially valuable and recreationally and culturally important Barramundi (*Lates calcarifer*) and Bull shark (*Carcharhinus leucas*).

Mammals, both native and introduced, also rely directly on the river for water and for the riparian habitat it supports. Native species include the Northern quoll (*Dasyurus hallucatus*), Ghost bat (*Macroderma gigas*) and Water rat (*Hydromys chrysogaster*). Cattle are the most prominent introduced species, but pigs, camels, donkeys, horses, cats, foxes and wild dogs are also common.

The river and its floodplain provide habitat for many birds, including more than 30 migratory species such as the Curlew sandpiper (*Calidris ferruginea*) and Greater sand plover (*Charadrius leschenaultia*). The Camballin floodplain is of particular importance to these species. Riparian habitat supports species including the Purple-crowned fairy-wren (*Malurus coronatus coronatus*) and Peregrine falcon (*Falco peregrinus*).

The iconic Saltwater crocodile (*Crocodylus porosus*) and Freshwater crocodile (*Crocodylus johnstoni)* rely on river pools and wetlands that persist during the dry season, along with other reptiles such as the Long-necked turtle (*Chelodina rugosa*).

The *Environmental and heritage values and the importance of water in the Fitzroy* report (DWER 2023a) provides lists of flora and fauna species protected under environmental legislation, policy or guidance.

Threatened and priority ecological communities

The values report (DWER 2023a) lists the threatened and priority ecological communities (TECs/ PECs) that occur across the Fitzroy water planning area. Many of these are water-dependent.

2.3 Climate

Climate of the Fitzroy River catchment and recent trends

The Fitzroy River experiences a semi-arid to arid monsoonal climate with large seasonal and year-to-year rainfall variations. Most rain falls in the wet season from November to April. High evaporation and dry conditions are prevalent from May to October. These patterns are reflected in streamflow data with river flows high in the wet season and little to no flow over the dry season.

Long-term records show that since the 1960s annual rainfall has generally increased. Yet low rainfall years still occur – as seen in the very dry 2018–19 wet season (**Error! Reference source not found.**). Soil moisture, runoff and evapotranspiration have also increased in recent years (Bureau of Meteorology 2022).

Climate change is being experienced now and must be a fundamental part of water planning and associated decision-making.

Traditional Owners have told us that the seasons are changing, plants and animals are behaving differently, and sacred water places are under threat. Traditional knowledge needs to be part of the water planning process, both to understand what is happening on Country, and to develop solutions to the problems that climate change presents.

Climate change and its potential effect on ecosystems and values

Much work is being done to understand how the climate might change into the future and the implications for water resources in Western Australia. In 2015 the Bureau of Meteorology (BoM) and the CSIRO[2] released national climate projections for Australia.

These climate projections draw on global climate models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Specific information for Western Australia was summarised in *Western Australian climate projections: summary* (DWER 2021).

The Bureau then developed a suite of national climate change projections, providing water resource managers with local-scale data to use in water resource investigations (Srikanthan et al. 2022a). Climate change information for the Fitzroy water planning area, which is in the Monsoonal North natural resource management (NRM) region of Western Australia, is reported in *Monsoonal North – national hydrological projections assessment report* (Srikanthan et al. 2022b) and summarised below.

[2] Commonwealth Scientific and Industrial Research Organisation

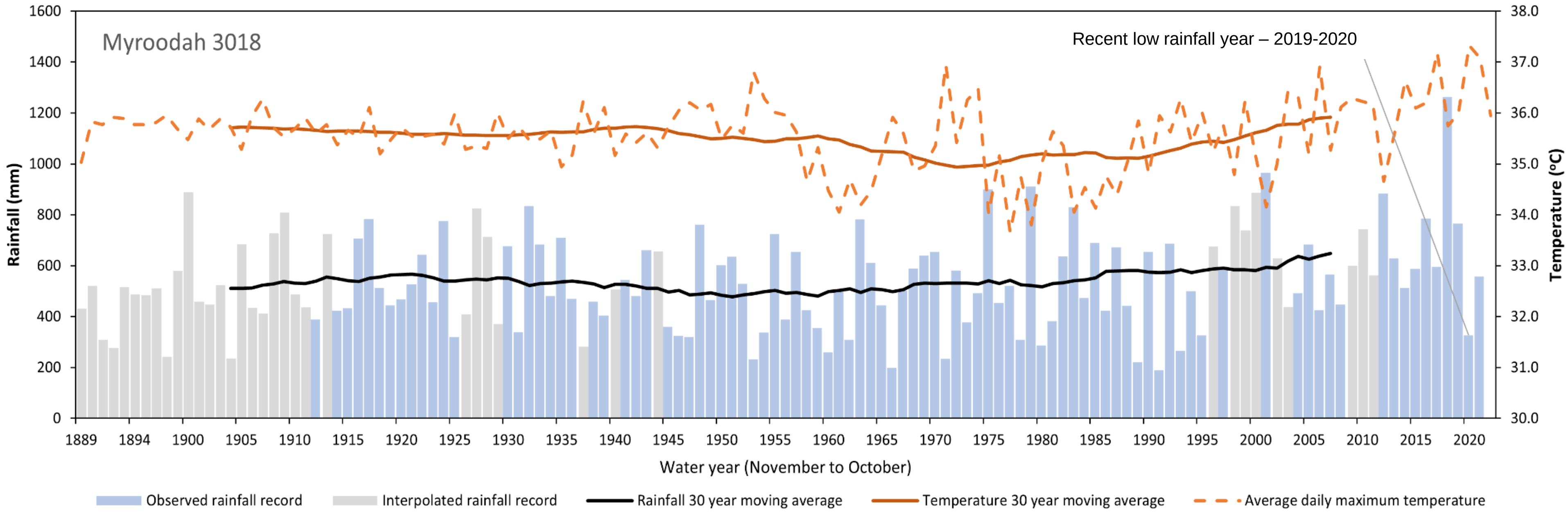

Figure 3 Long-term rainfall recorded on Myroodah Station, near the Fitzroy River (BoM site 3018)

Projections for the Monsoonal North region in Western Australia show:

- low confidence in projected changes in rainfall, which means that it may increase, or it may decrease
- high confidence that when rain falls, the intensity of heavy rainfall events will increase, and tropical cyclones – although projected to be fewer – will be more intense
- a projected increase in temperature and evaporation with more days of extreme heat temperatures over 35°C
- high confidence that sea levels will rise, and more frequent sea-level extremes will occur.

These changes may also influence crop water demands, as well as inflow, recharge and evaporation from open waterbodies, including persistent river pools and shallow groundwater.

In addition, these changes may affect the intensity of fire and influence the timing of the flowering and fruiting of plants, and animal migration. Sea-level rise may impact freshwater ecosystems that exist along the coastline of the King Sound

2.4 Hydrogeology

The Fitzroy water planning area comprises the sedimentary aquifers in the Fitzroy Trough and Lennard Shelf of the Canning Basin in the west and the fractured rock aquifers of the King Leopold and Halls Creek Orogens in the east (Figure 4).

The aquifers in the study area comprise (from youngest to oldest):

- Alluvial aquifer (regional aquifer)
- Canning-Broome aquifer (regional aquifer; however, only locally found in the south-west of the plan area)
- Canning-Wallal Sandstone aquifer (regional aquifer, found mainly in the south-west of the plan area)
- Canning-Erskine aquifer (regional aquifer; however, only locally found in the west of the plan area)
- Liveringa Group aquifer (regional aquifer, but can also be an aquitard)
- Noonkanbah Formation (aquitard with localised low-yielding, variable quality aquifers)
- Grant Group and Poole Sandstone aquifer (regional aquifer)
- Devonian Reef aquifer (regional aquifer)
- Fractured Rock aquifer (regional aquifer).

Alluvial aquifer

The Alluvial aquifer refers to all mapped alluvial deposits within the Canning Basin extent of the Fitzroy water planning area. It is a shallow water table aquifer that underlies and borders the lower Fitzroy, Lennard and Margaret rivers and some major tributaries.

The alluvium around the Fitzroy River is an extensive unconfined aquifer covering around 3,200 km^2 and can be up to 30 m thick (Lindsay & Commander 2005).

Groundwater recharge is from a combination of rainfall, floodwater from the Fitzroy and Margaret rivers and throughflow from regional aquifers such as the Poole Sandstone or Grant Group. Depth to groundwater varies but is generally shallow. Monitoring from recent investigations recorded water levels between 3 and 7 m below ground level (mbgl) around Camballin and 9 to 16 mbgl around Fitzroy Crossing (DWER 2023b).

The Alluvial aquifer is likely to be highly connected with the overlying rivers and other surface water bodies and will be supporting ecosystems, particularly during the dry season. It can also be connected to or facilitate discharge from underlying aquifers. Recent groundwater investigations support previous findings (Lindsay & Commander 2005) of strong inter-connectivity between the alluvial aquifer and the Fitzroy and Margaret rivers. This connectivity can be seasonably variable, with the river system acting either as a gaining or leasing stream depending on local surface water levels.

Canning-Broome aquifer

The Canning-Broome Sandstone aquifer is a minor unconfined aquifer system in the Fitzroy water planning area that comprises minor isolated outcrops. It may support groundwater-dependent ecosystems where it is shallow, but it is not in hydraulic connection with the Fitzroy River (DWER 2023a).

Canning Wallal Sandstone aquifer

The Wallal Sandstone aquifer is a high-yielding regional aquifer found mainly in the south-west and north-west areas of the Fitzroy water planning area (Taylor et al. 2018).

Recharge is likely to be via infiltration from rainfall during the wet season. In the area south of Camballin, there is evidence that the Canning-Wallal is in hydraulic connection with and is contributing flow to the Fitzroy River (DWER 2023b).

The aquifer is likely to be in hydraulic connection with the Fitzroy River and Alluvial aquifer, particularly in the area upstream of Willare Bridge.

Canning-Erskine aquifer

The Canning Erskine aquifer is an unconfined aquifer present as a small deposit on Myroodah Station. It is hydraulically separated from underlying aquifers by the Blina Shale. While only one deposit is mapped, the Canning Erskine aquifer may also be in other areas where the Blina Shale is currently mapped. Recharge is likely by direct infiltration from rainfall.

The Canning Erskine aquifer may support groundwater-dependent ecosystems where it is shallow, but it is not in hydraulic connection with the Fitzroy River (DWER 2023b).

Liveringa Group

The Liveringa Group is present at shallow depths throughout the sedimentary basin. While it is a significant regional aquifer, it has variable quality and in some areas functions as an aquitard. Where the Liveringa Group is an aquifer, it is typically low-yielding with marginal to brackish groundwater quality (DWER 2023b), although this finding is based on limited information as relatively few bores are drilled into the aquifer (Taylor et al. 2018).

Recharge is from either direct infiltration of rainfall in the wet season, leakage from the overlying Fitzroy alluvial aquifer, or in some areas, directly from the Fitzroy River (i.e. through Le Lievre Swamp near Camballin). In an area downstream from Fitzroy Crossing, the Liveringa aquifer likely discharges into the Fitzroy River. This discharge is caused by groundwater flow from the aquifer meeting the lower-permeability mudstones of the Noonkanbah Formation and being forced upwards towards the river (Harrington & Harrington 2015).

Noonkanbah Formation

The Noonkanbah Formation is generally a regional aquitard, although there are a few low-yielding, brackish-to-saline bores in the unit (Lindsay & Commander 2005). The formation is present across most of the Fitzroy water planning area, although not in the north-east and south-west portions.

Recent work shows the Noonkanbah Formation is shallower in some areas of the Fitzroy water planning area than was thought in previous conceptualisations, with several shallow bores intersecting the unit where it was not expected to be present (DWER 2023b). Little is known about the hydraulic properties of this aquifer. Existing information suggests it generally has very low hydraulic conductivity and will effectively separate aquifers unless conduits such as faults are evident (DWER 2023b).

Grant Group and Poole Sandstone aquifers

The Grant Group and Poole Sandstone are hydraulically connected and are managed together as a single aquifer for groundwater licencing purposes. This is a regionally extensive, major aquifer that is confined at depth and unconfined where it outcrops along the length of the Lennard Shelf, as well as in major anticlinal structural features in the Fitzroy Trough and around Camballin and Noonkanbah (Figure 4).

Where the Grant Poole aquifer is deeper or confined, faults can act as pathways for groundwater to flow, either to the surface or to the shallow alluvial aquifer, as noted in the area between Fitzroy Crossing and Noonkanbah (Harrington et al. 2011; DWER 2023b).

Groundwater recharge to the Grant Poole Sandstone aquifer is from direct infiltration of rainfall, leakage from overlying aquifers and regional aquifer throughflow. Groundwater flow is from east to west, potentially with some flow towards the Fitzroy River between Fitzroy Crossing and Noonkanbah (Taylor et al. 2018).

The Grant Poole Sandstone aquifer is likely to be in hydraulic connection with the Fitzroy River and Alluvial aquifer, particularly in the area near Fitzroy Crossing.

Devonian Reef aquifer

The Devonian Reef is a limestone aquifer which can be up to 2,000 m thick (DWER 2023b). It contains fresh groundwater, is regionally extensive and outcrops in the eastern part of the Fitzroy water planning area, with notable outcrops at Geikie Gorge, Windjana Gorge, Tunnel Creek and the Mimbi Caves (DWER 2023b) (Figure 4). Groundwater recharge is mainly through direct infiltration of rainfall but, as the aquifer has karstic features, this is likely to be highly variable (DWER 2023b).

Groundwater flows from the Devonian Reef aquifers appear to be strongly connected to both the Fitzroy and Margaret rivers, as well as the Grant Poole and Alluvial aquifers.

Fractured rock aquifers

Fractured rock aquifers, formed within basement-rock formations (Haig 2009) cover much of the north-eastern part of the Fitzroy water planning area (Figure 4). Groundwater recharge is rainfall-dependent and will only occur directly where fractured, jointed and weathered zones are exposed to rainfall (Haig 2009). The rocks contain very little groundwater outside of these zones.

Where shallow surficial aquifers exist within these formations, they are likely to support water-dependent ecosystems.

Groundwater interaction with the Fitzroy River

The lower Fitzroy River has possible interaction with groundwater across much of its extent. There is evidence of interaction between the Fitzroy River and its floodplain with the Devonian Reef and Grant-Poole aquifers on Bunuba and Gooniyandi Country near Fitzroy Crossing; the Liveringa aquifer on Yi-Martuwarra Ngurrara and Gooniyandi Country; the Grant-Poole aquifer near Noonkanbah; and the Canning-Wallal near Camballin on Nyikina Mangala Country (DWER 2023a).

During the wet season, flooding is likely to recharge the alluvial aquifer and the underlying regional aquifers where they are connected to the alluvial aquifer. During the dry season it is possible that persistent river pools and wetlands are sustained by groundwater from the underlying regional aquifers.

Groundwater interaction with the Fitzroy River is discussed further in Section 5.1.

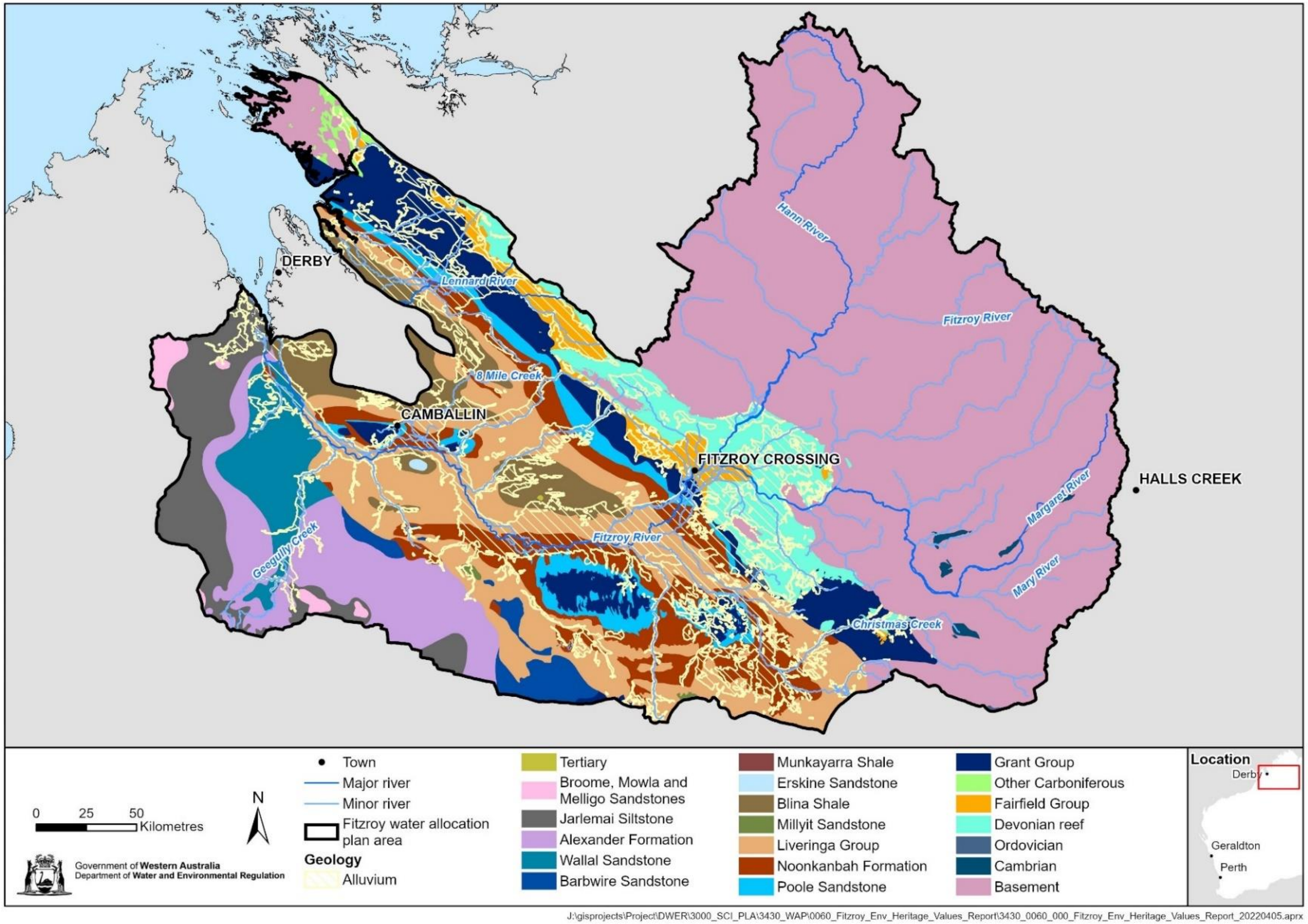

Figure 4 Surface geology in the Fitzroy water planning area

2.4 Hydrology

Flow in the Fitzroy River is highly variable, both between years and throughout the year. The wet season occurs from November to April with more than 90 per cent of streamflow occurring in the three months from January to March. Streamflow in the headwater catchments ceases relatively soon after the end of the wet season. On the floodplain, high flows during the wet season can contribute to the recharge of the sandy floodplain soil which subsequently discharges to the river during the dry season (DWER 2023b).

The river has an average annual flow of about 9,120 GL (1999–2020) measured at Fitzroy Barrage (station 802003). However, flows modelled by CSIRO over a 125-year period (1890–2015) show a lower average of 6,500 GL (Hughes et al. 2017). These volumes are the largest of any river in Western Australia, and at least 10 times larger than any river in the South West. Total measured annual flow has ranged from 676 GL in 2019 to 27,646 GL in 2011 (DWER 2023c).

At present we have 13 gauging stations operating along the river and its tributaries, which provides good spatial coverage of streamflow across the catchment (Table 1). A number of these stations are on the main channel of the Fitzroy River – Willare (802008), Looma (802007), Fitzroy Barrage (802003), Noonkanbah (802006) and Fitzroy Crossing (802055) (Figure 5). Flow data recorded here has formed a key part of the hydrological assessment in this report.

Other gauged systems within the catchment include Hann River (Philips Range: 802213) and Leopold River (Mt Winfred: 802202). Lennard River (803122), which is beyond the Fitzroy River catchment, also falls within the plan area.

As part of the Northern Australian Water Resource Assessment (NAWRA) project, the CSIRO developed a two-dimensional hydrodynamic model for the Fitzroy River floodplain (Karim et al. 2018). The model simulates the movement and depth of water within the river and across the floodplain. To show the variability of inundation extent and duration under different flow conditions, we contracted the CSIRO to run three selected years representative of a below-average flow ~3,000 GL (2012–13), an average flow ~8,800 GL (2005–06) and a high flow ~21,600 GL (1999–2000) (DWER 2023c). These model results were considered in this report.

In late 2022 and early 2023 an unprecedented flooding event hit the Fitzroy River catchment. This event exceeded all events previously recorded by up to 4 m. The maximum streamflow discharge for the January 2023 event is still under investigation, but we expect it has exceeded the 1 in 100 (1%) Annual Exceedance Probability (AEP) flood along the entire length of the lower Fitzroy River. The flooding on the Margaret River at the same time was just below the previous maximum levels observed in the 1980s and 1990s and the expected probability has been estimated at 1 in 20 AEP. The inundation extent for the January 2023 event was mapped using radar satellite technology.

The event destroyed the Great Northern Highway road bridge at Fitzroy Crossing and flooded more than 250 properties in the town and other communities along the river and its tributaries. Some components of our streamflow monitoring network were damaged. At Camballin the floodplain was about 40 km wide, and houses previously not flooded above floor level were inundated by up to two metres.

The flood also caused significant erosion and sedimentation of river channels and floodplain areas. The extent of changes to the river, such as the position and depth of river pools, will become clearer as time progresses. The long-term implications of this flooding event to people, communities and the environment are significant and will also become apparent overtime.

Camballin Barrage (Fitzroy Barrage)

The Camballin Barrage (commonly called the Fitzroy Barrage) is the largest ‘built’ structure on the Fitzroy River that impedes the flow of water (Figure 5). It was built across the main channel near Camballin in the 1950s as part of a now-abandoned irrigation scheme. River crossings at Myroodah Crossing and Noonkanbah also impede flow but to a much lesser extent.

The barrage has changed the annual flooding pattern of the river (AECOM et al. 2009), exacerbating downstream erosion and channelisation (Toussaint et al. 2001). It also acts as a barrier to migratory species, including Cherabin, Freshwater sawfish and Barramundi (Morgan et al. 2016).

Fitzroy Barrage gauging station (802003) measures the low flows in the main channel better than the Looma gauging station because of the hydraulics of the barrage (802007). This is because road crossings, weirs — such as the barrage – and natural rock bars provide stable low-flow controls, which define the river level at which flow downstream ceases (DWER 2023c). The over-bank or floodplain flow is best measured at Looma because of the containment of the overbank flow.

Table 1 Streamflow information at DWER monitoring locations and statistics for annual flow at each streamflow gauging station (1999 to 2020)

River	Streamflow gauging station	Statistics for annual flow (GL)			
		Minimum	Median	Average	Maximum
Hann	Phillips Range (802213)	18	1,034	1,051	4,217
Fitzroy	Dimond Gorge (802137)	158	3,577	3,404	11,445
Leopold	Mt Winfred (802202)	68	874	861	2,957
Margaret	Margaret Gorge (802156)	154	1,286	1,289	3,768
Margaret	Me No Savvy (802198)	150	729	754	1,899
Christmas Creek	Christmas Creek (802005)	42	271	278	1,171
Margaret	Mt Krauss (802203)	463	2,808	2,736	8,506
My Wynne Creek	Ellendale (802004)	0.75	19	25	89
Fitzroy	Fitzroy Crossing (802055)	509	6,007	6,111	18,573
Fitzroy	Noonkanbah (802006)	544	7,290	7,086	22,778
Fitzroy	Fitzroy Barrage (802003)	676	9,078	8,888	27,523
Fitzroy	Looma (802007)	570	8,412	8,567	27,821
Fitzroy	Willare (802008)	643	7,221	7,206	20,246

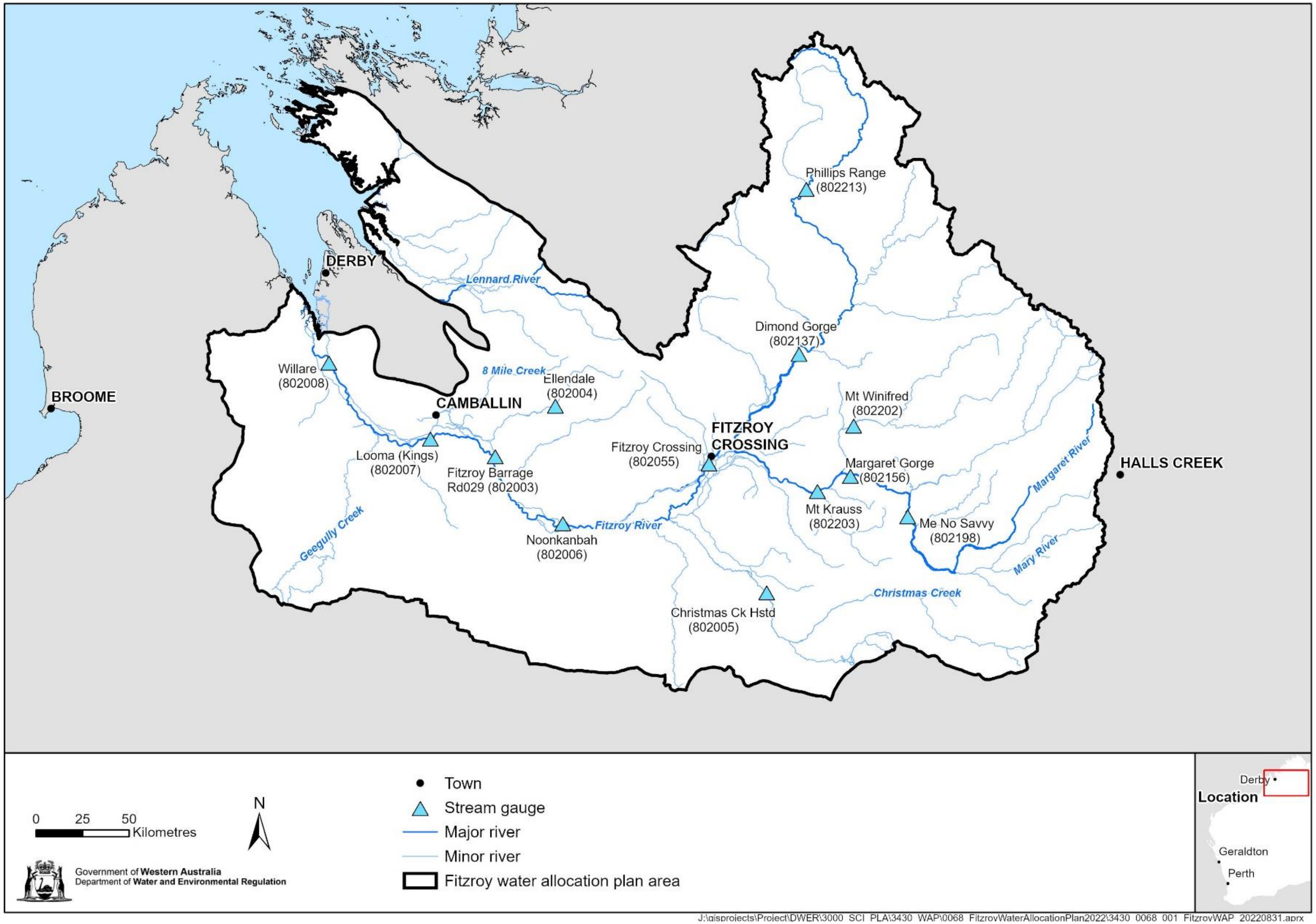

Figure 5 Location of river gauging stations, Camballin/Fitzroy Barrage and major tributaries

3 Relevant research

National Environmental Science Program (2016-2021) – Northern Hub at UWA and Griffith University

The department worked with the National Environmental Science Program (NESP) on the Environmental Water Needs of the Fitzroy River project. The project provided new information that has informed the ecological water requirements of riparian and floodplain vegetation and aquatic ecosystems including:

- vegetation distribution and composition in relation to flood inundation (Freestone et al. 2021; Brauhart 2021; Canham et al. 2021a; Freestone et al. 2022)
- potential groundwater sources of riparian and floodplain tree species (Canham et al. 2021b)
- functional traits of plants that affect how they tolerate different degrees of water availability (Canham et al. 2022)
- functioning of riverine and spring food webs (Beesley et al. 2020; Burrows et al. 2020; Tayer 2023)
- habitat use and distribution of Cherabin (*Macrobrachium spinipes*) (Beesley et al. 2023)
- hydro-ecology of the Fork-tailed catfish (*Neoarius graeffei*) (Beesley et al. 2021a)
- critical pool depth thresholds to predict fish species occurrence and richness in river pools and off-channel wetlands (Gwinn et al. in prep)
- importance of river-floodplain connectivity for floodplain fish assemblages (Pratt et al in prep) and for the growth and survival of bony bream (*Nematalosa erebi*) (Pratt et al. in prep)
- indigenous understandings of river flows and their dependencies (Douglas et al. 2019; Milgin et al. 2020; Laborde & Jackson 2021; 2022).

This research focussed on the lower Fitzroy River, between Fitzroy Crossing and Willare Bridge, and did not consider the water requirements for biota in the upper part of the river system. The studies completed prior to 2023 are summarised in the supporting report, *Environmental and heritage values and the importance of water in the Fitzroy*. The findings of these studies have informed our ecological water requirements work for fish, Cherabin, food webs and riparian and floodplain vegetation.

Centre for Sustainable Aquatic Ecosystems at Murdoch University

The Centre for Sustainable Aquatic Ecosystems at Murdoch University has been studying the EPBC Act-listed Freshwater sawfish (*Pristis pristis)* in the Fitzroy River since 2002. They have also studied other species including Barramundi (*Lates calcarifer*), smaller fish, sharks and Cherabin (*Macrobrachium spinipes*) along with water quality information to define food webs and map the overall distribution of all Fitzroy species at 70 sites across the catchment (Morgan et al. 2004). This work provided a lot of published information including:

- fishes of the Fitzroy River Catchment (Morgan et al. 2004) and broader Kimberley region (Morgan et al. 2011a)
- food webs of fishes of the Fitzroy River (Thorburn et al. 2014)
- ecology of Freshwater sawfish and Dwarf sawfish (*Pristis clavata*) (Thorburn et al. 2007; Whitty et al. 2009; Whitty et al. 2017)
- population genetics of Freshwater sawfish (Phillips et al. 2009; Phillips et al. 2017)
- predation of Freshwater sawfish (Morgan et al. 2017) and sawfish parasites in the Fitzroy River (Morgan et al. 2010)
- effect of increasing temperatures and energy limitations on metabolic rates of Bull sharks (*Carcharhinus leucas*) and Freshwater sawfish (Lear et al. 2020a)
- population structure of Northern river sharks (*Glyphis garricki*) (Feutry et al. 2020) and the importance of the Fitzroy River (Morgan et al. 2011b).

Working with the Nyikina-Mangala rangers each dry season from 2008 to 2019, the Murdoch team fitted up to 32 individual sawfish, from two permanent pools on the main channel, with acoustic tags, and monitored their movements continuously for several months (Whitty et al. 2017). The study’s objective was to understand the habitat preferences of differently aged sawfish across the dry season.

The team conducted a similar study of the movement patterns of the EPBC Act-listed Dwarf sawfish (*Pristis clavata*) in the Fitzroy estuary and King Sound in 2015–2016 (Morgan et al. 2021). Results from this work and data from historical catches between 2002 and 2016 were also collated to describe population dynamics of this species.

The team has also monitored Freshwater sawfish in Uralla/Snake Creek since 2008 and assessed the impacts of barriers on sawfish migration in the Fitzroy, Ord and Ashburton rivers (Morgan et al. 2016).

While undertaking sawfish surveys, the Murdoch team collected data on a broad range of other species including Barramundi, smaller fish, sharks and Cherabin as well as information on water quality. We directed funds to the team to analyse and report on some of this previously unpublished additional data to help inform our ecological water requirements for the Fitzroy water planning area.

The recent work has provided important published information specific to the Fitzroy, including:

- variability in fish ecology in dry season pools (Lear et al. 2020b; Lear et al. 2023)
- effects of hydrology and climate on Barramundi recruitment and growth (Morrongeiollo et al. 2020; Roberts et al. 2021)

- daily and seasonal movement of Freshwater and Dwarf sawfish between different habitats (Whitty et al. 2009; Whitty et al. 2017; Morgan et al. 2021)
- sawfish recruitment requirements (Lear et al. 2019; Morgan et al. 2021)
- factors affecting the loss of body condition in Freshwater sawfish over the dry season (Lear et al. 2021)
- relationship between flood magnitude and water quality in dry season pools (Gleiss et al. 2021).

The findings of these studies are discussed in the supporting report *Environmental and heritage values and the Importance of Water in the Fitzroy* (DWER 2023a) and findings were used in this report to inform our ecological water requirements work.

Department of Water and Environmental Regulation

The department investigated groundwater in the Fitzroy Valley through the state-funded Water for Food program, the federally funded Northern Australia Water Resource Assessment (NAWRA) Program (CSIRO), and our own State Groundwater Investigation Program (SGIP) from 2015–2018 (DWER 2023b).

Under the Water for Food program, we installed groundwater monitoring, exploration and production bores north of the river across Mt Anderson, Brooking Springs and Kimberley Downs pastoral stations to determine the prospectivity of the Poole Sandstone and Grant Group aquifers in this region. We also installed bores within the Darlngunaya and Bungardi Aboriginal communities on Bunuba Country. These bores are all located west of Fitzroy Crossing in the lower Fitzroy River catchment area.

Through the SGIP we sampled existing bores and river pools in the Fitzroy Valley and installed groundwater monitoring bores (LF series bores) closer to the river (DWER 2023b). In addition, Geoscience Australia conducted airborne electro-magnetic (AEM) surveys. This work was part of a comprehensive water resource investigation to map the extent and salinity of alluvial aquifers and provide greater knowledge of deeper geological structures.

The SGIP built on existing departmental research along the river between Willare and Fitzroy Crossing and consolidated our knowledge of groundwater resources and their links to water-dependent ecological, social and cultural values of the river.

The outcomes of this work are detailed in the supporting report *Fitzroy Valley groundwater investigations, 2015–2018, Kimberley, WA* (DWER 2023b) and summarised in the *Environmental and heritage values and the Importance of Water in the Fitzroy* (DWER 2023a).

In 2016, the department developed a two-dimensional Hec-Ras model using a 1 m digital elevation model (DEM) covering the river from 12 km upstream and 19 km downstream of the Camballin Barrage. The model was used to understand the accuracy of the water depth to flow relationships (flow rating curve) at the barrage and increase the certainty of flow measurements. The outcomes of this work are detailed in Greening et al. (2019).

Northern Australia Water Resource Assessment program

In recognition of some of the challenges and opportunities facing northern communities and primary producers, the Australian Government engaged the CSIRO to assess the opportunities for water and agricultural development in Northern Australia.

Three models of the Fitzroy were developed: catchment scale flow and flood models and a regional-scale groundwater model. The catchment and flood models were used in describing ecological water requirements in this report. The regional-scale groundwater model was developed mainly for use as a communication tool.

The models incorporated existing ecological data, hydrological and hydrogeological data as well as Indigenous water values. Barber & Woodward (2017) consulted with Traditional Owners during the Indigenous water values studies to discuss values, rights, interests and aspirations with respect to water and irrigated agricultural development in the Fitzroy River catchment.

4 Approach to describing ecological water requirements

In this section we summarise the water-dependent habitats of the Fitzroy water planning area and the listed and important species they support (Section 4.1; Table 2). We then outline the approach taken to describe the water regimes required to protect these important habitats and species. These are the ecological water requirements (Section 4.2; EWR).

4.1 Water-dependent habitats and their values

Water-dependent habitats or ecosystems are those parts of the environment where the species composition and natural ecological processes are determined by the permanent or temporary presence of flowing or standing water (ARMCANZ & ANZECC 1996). This includes both ground and surface water.

The *Environmental and heritage values and the importance of water in the Fitzroy* report (DWER 2023a; values report) identifies five broad water-dependent habitats across the Fitzroy water planning area for which we have described EWR in this report:

- river pools and off-channel wetlands – see in Chapter 5
- riparian and floodplain vegetation – see in Chapter 6
- springs – see in Chapter 7
- aquifer and subterranean ecosystems – see in Chapter 8
- estuarine and near shore marine ecosystems – see in Chapter 9.

Identifying the water regimes to maintain habitats such as river pools and off-channel wetlands (Figure 6) should also support the species and ecological communities that rely on them. Each habitat is presented in Table 2 along with their species and communities that are listed under state and federal legislation or are otherwise ecologically, culturally or socially important. Further information on these habitats and the species and communities associated with them can be found in relevant sections of the values report (DWER 2023a).

Persistent river pools and off-channel wetlands are critical habitat for flora and fauna during the dry season and support high ecological and cultural values (DWER 2023a). The persistence of these habitats is determined by river flows and connectivity during the wet season and potentially groundwater inputs during the dry season. Although they support several listed fauna species (Table 2), river pools and wetlands protect many other species and are important in supporting biodiversity, food webs and indigenous harvest.

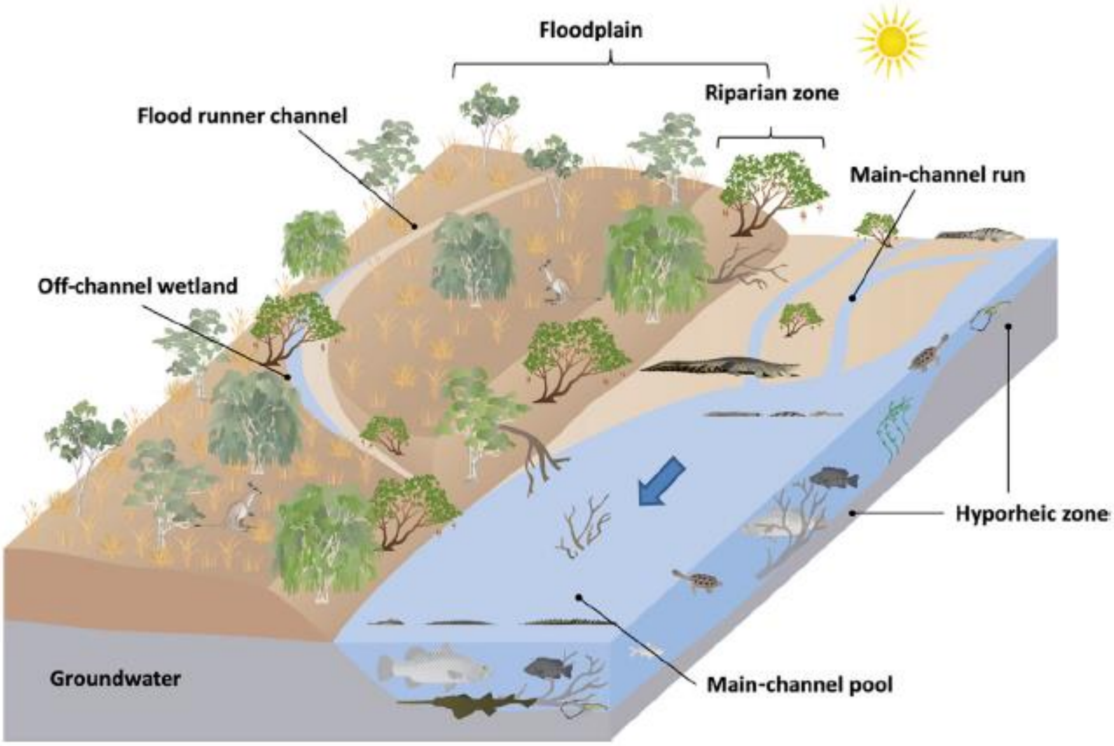

Figure 6 Water-dependent habitats of the Fitzroy River (Douglas et al. 2019)

Narrow zones of riparian vegetation fringe the Fitzroy River's main channel and larger tributaries (Figure 6). Healthy riparian vegetation is important to river health and provides a relatively productive ecosystem in an arid environment (Douglas et al. 2005; van Dam et al. 2005).

Floodplain vegetation extends from the main channel and riparian zone outwards across much of the flat, open floodplain area and along off-channel wetlands. A vegetation distribution model developed by UWA/ NESP (Canham et al. 2021) showed that species distribution reflects the area inundated during flooding and the frequency of high-flow events. Depth to groundwater in areas that overlay shallow aquifers is also important but is a lesser driver of distribution than inundation (Eamus et al. 2006).

In the semi-arid environment of the Fitzroy water planning area, groundwater-fed springs are critically important sources of water supporting terrestrial fauna and aquatic and riparian habitat. They are often important places to Traditional Owners and are also important sources of water to pastoralists. Several of the 400+ springs mapped in the Fitzroy water planning area are listed in Threatened Ecological Communities (TECs) (DWER 2023d).

Subterranean fauna inhabit a range of aquifer types. In the Fitzroy water planning area, the Grant Poole, Devonian Reef, Canning-Erskine, Canning-Broome, Canning-Wallal aquifers and Alluvial aquifers potentially host stygofauna (DWER 2023a). Some of these also support listed TECs. Careful management of groundwater levels in these aquifers is needed to maintain subterranean fauna habitat.

The hyporheic zone (Figure 6), at the interface of surface water and groundwater on the bottom of a river pool or wetland, also supports fauna and some flora, which on the Fitzroy are likely to inhabit water in pore spaces between sand grains.

Maintaining the connectivity of flow from the Fitzroy River to its estuary and broader King Sound should provide the freshwater inputs needed to support habitats including salt flats, mangroves and seagrass along with a large number of high conservation marine and avian fauna species (DWER 2023a).

Table 2 Habitats, the listed and important species and communities they support and relevant sections in the values report (DWER 2023a)

Habitat and listed or important species	DWER 2023a
River pools	Sections 6 & 8.1
Listed species	
• Freshwater sawfish (*Pristis pristis*)	Section 9.2
• Prince Regent hardyhead *(Craterocephalus lentiginosus)*	
• Greenways grunter *(Hannia greenwayi)*	
• Water rat, rakali (*Hydromys chrysogaster*)	
• Freshwater crocodile (*Crocodylus johnstoni)*	
• Saltwater crocodile *(Crocodylus porosus)*	
• Freshwater whipray (*Himantura chaophraya*),	
• Northern river shark (*Glyphis garricki*)	
Ecologically, culturally and socially important species	
• Barramundi (*Lates calcarifer*)	Section 9.3
• Cherabin (*Macrobrachium spinipes*)	Section 9.4
• Fork-tailed catfish (*Neoarius graeffei)*	Section 9.5
• Bony bream (*Nematolosa erebi*)	
Off-channel wetlands	Sections 6 & 8.2
Listed species	
• Water lily (*Nymphoides beaglensis)*	
• *Nymphaea kimberleyensis*	
• *Utricularia muelleri*	
• 27 internationally listed migratory birds	
Ecologically, culturally and socially important species	
• Fork-tailed catfish (*Neoarius graeffei)*	Section 9.4
• Bony bream (*Nematolosa erebi*)	
• Cherabin (*Macrobrachium spinipes*)	
• Freshwater crocodile (*Crocodylus johnstoni)*	Section 9.5
Riparian and floodplain vegetation	Sections 6 & 8.3
Listed species	
• *Cayratia cardiophylla*	
• *Corchorus fitzroyensis*	
• *Cullen candidum*	
• *Gomphrena cucullata*	
• *Pandanus aquaticus*	
• *Thespidium basiflorum*	
• Purple-crowned fairy-wren (*Malurus coronatus coronatus* (western species)	
• Red goshawk (*Erythrotriorchis radiatus*)	
• Gouldian finch (*Erythrura gouldiae*)	

Habitat and listed or important species	DWER 2023a
• Australian painted snipe (*Rostratula australis*)	
• Northern masked owl (*Tyto novaehollandiae kimberli)*	
• Northern quoll (*Dasyurus hallucatus*)	
• Northern leaf-nosed bat (*Hipposideros stenotisis*)	
• Water rat, rakali (*Hydromys chrysogaster*)	
<u>Listed Priority ecological communities (PECs)</u>	
• Vegetation association 67	
• Vegetation association 759	
• Vegetation association 1271	
<u>Ecologically, culturally and/or socially important species</u>	
• Freshwater mangrove (*Barringtonia acutangula*)	Section 9.6
• Silver melaleuca (*Melaleuca argentea*	Section 9.7
• Green melaleuca (*Melaleuca leucadendra*)	Section 9.7
• River gum (*Eucalyptus camaldulensis)*	
• Coolibah (*Eucalyptus microtheca)*	Section 9.8
Springs	Sections 6 & 8.4
<u>Listed Threatened ecological communities (TECs) and species</u>	
• Big Springs TEC	
• Organic mound springs of north Kimberley TEC	
• Edgar Range Pandanus (*Pandanus spiralis* var. *flammeus)*	
• *Pilsbrycharopa tumida* (land snail)	
Aquifer and subterranean ecosystems	Sections 6 & 8.5
<u>Listed Priority ecological communities (PECs)</u>	
• Napier range cave invertebrate community	
• Invertebrate community of Tunnel Creek	
• Invertebrate assemblages of the cliff foot springs around Devonian reef system	
Estuarine and near-shore marine ecosystems (King Sound)	Sections 6 & 8.6
<u>Listed species</u>	
• Northern river shark (*Glyphis garricki)*	
• Freshwater sawfish *(Pristis pristis)*	Section 9.2
• Dwarf sawfish *(Pristis clavata)*	
• Narrow sawfish *(Anoxypristis cuspidate)*	
• Green sawfish (*Prisits zijsron*)	
• Green turtle (*Chelonia mydas*)	
• Loggerhead turtle (*Caretta caretta)*	
• Flatback turtle (*Natator depressus*)	
• 36 migratory bird species	
<u>Ecologically, culturally and/or socially important habitats</u>	
• mangroves	
• salt flats	
• mud flats	
• seagrass	

4.2 Hydro-ecological outcomes and ecological water requirements

Hydro-ecological outcomes

In this report we describe hydro-ecological outcomes – the key elements of the natural water regime that are necessary to maintain the relationship between water and dependent habitats and species.

UWA/NESP described the key elements of the Fitzroy River's water regime as (Douglas et al. 2019):

- wiithin-bank flows during the wet season
- over-bank flows during the wet season
- recessional flows at the end of wet season
- groundwater inputs and low flows during the dry season and dry years
- flows from previous wet seasons – antecedent conditions.

These are shown in Figure 7 along with a hydrograph depicting the annual water regime.

Hydro-ecological outcomes clearly describe the link between a habitat or species and the water regime component that supports it. In this report, where a habitat or species relies on multiple components, we have described multiple outcomes. Summaries of the key scientific information we used to derive each outcome are described in chapters 5 to 9.

Ecological water requirements

In this report, ecological water requirements are the water flows, river pool/ wetland depths and/ or groundwater levels/pressure required to meet the hydro-ecological outcomes. Ecological water requirements include elements of quantity and quality of surface and/or groundwater which apply over space and time. They aim to define the intrinsic requirement a species or ecosystem has for water and not external factors unrelated to their water needs and health (Richardson et al. 2011a). This involves identifying those parts of the natural water regime that are most important for the persistence of critical ecosystem features and processes and to support the life cycle requirements of fauna.

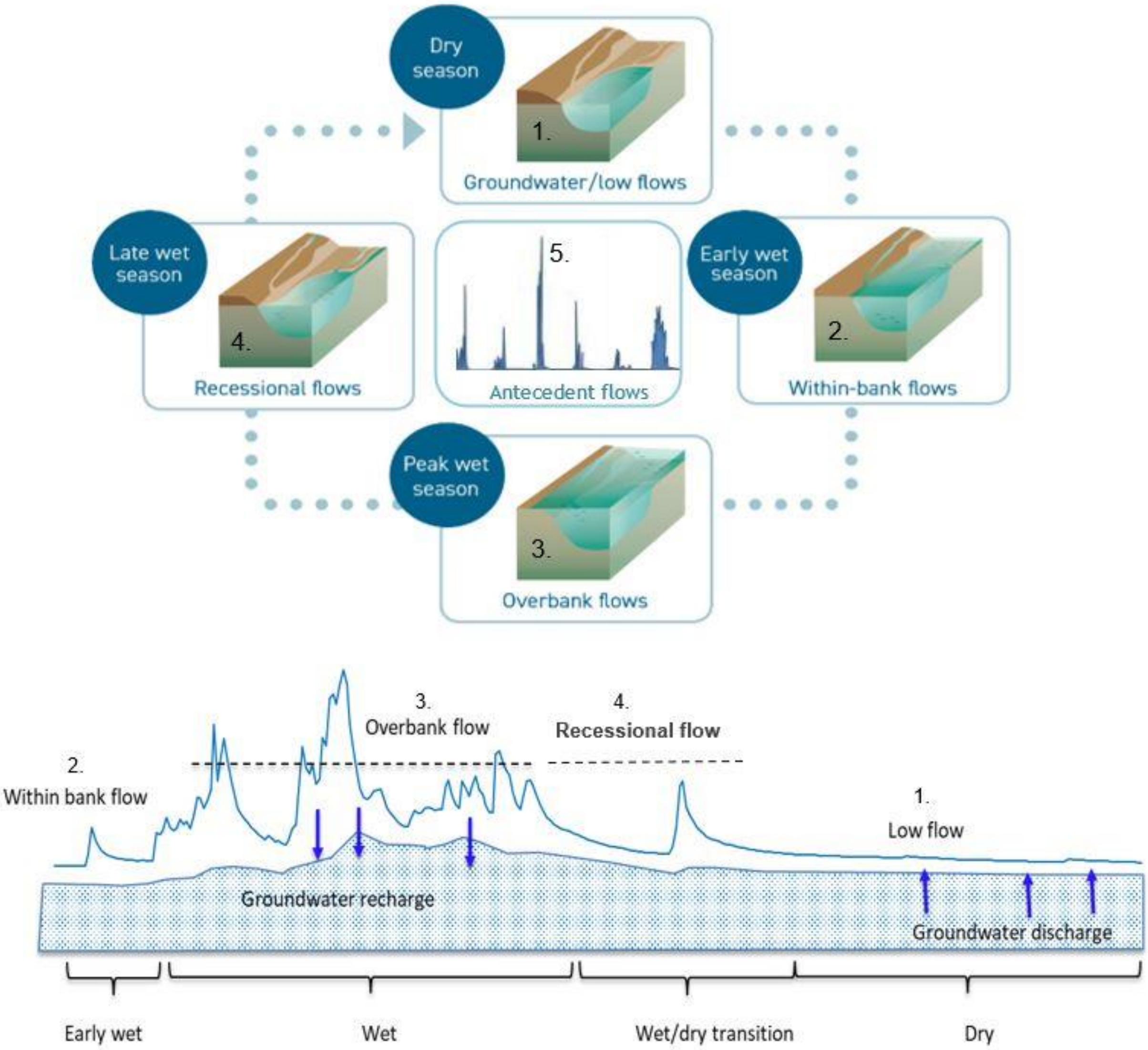

Figure 7 Water regime components of the Fitzroy River (adapted from Douglas et al. 2019)

Ecological water requirements can be based on targeted and specific research on a species or ecosystem or can be qualitative statements based on best available information (Richardson et al. 2011b). Researchers have been active in the lower Fitzroy River catchment in recent years, and we now have a better understanding of the water requirements of some species and habitats. However, the vast area of the catchment and the richness and abundance of water-dependent species and habitats mean data is still relatively limited. In these cases, we have described qualitative EWRs or recommended further regional or local scale work that would be required to inform a quantitative EWR.

We have focused on the findings of recent ecological studies specific to the lower Fitzroy River to describe EWRs. Where local data is not available or of sufficient detail, we have widened our scope to include studies from northern Australia and to other regions if needed. Some EWRs are presented as a flow volume or a river pool/

wetland depth, while others are qualitative and require that the current variability in annual flow regimes, water quality or water depths be maintained. We also identify further work needed to quantify the less-specific ecological water requirements.

The EWRs for broad habitat types are outlined in Chapters 5 to 9 and can be used to inform a water level, water flow, water quality, date or other parameter that indicates that the environmental outcome for water resources is being achieved in relation to a proposed activity associated with a water licence.

The hydro-ecological outcomes and ecological water requirements are summarised in Chapter 10 at the end of this report along with the type of further work that could occur to describe the nine qualitative EWRs.

Part B – Hydro-ecological outcomes and ecological water requirements for water-dependent habitats

In Part B of this report, we present the hydro-ecological outcomes relevant for each of the five water-dependent habitats described in Part A. For eleven hydro-ecological outcomes we present the information that is available to describe an ecological water requirement (EWR). For the remaining hydro-ecological outcomes, there is not enough evidence to define EWRs. For these, we present the information that is available and recommend future work that, if it occurs, can be used to develop EWRs at a local scale.

5 River pool and off-channel wetland habitats

River pools are found along the Fitzroy River, major tributaries and other, smaller rivers in the catchment. Off-channel wetlands are located in flood-runner channels - distributary creeks that carry wet season flows out onto the floodplain and drain excess water back into the river (Beesley et al. 2020) or in low lying basins on the Fitzroy's floodplain (Beesley et al. 2023) (Figure 8).

River pools and off-channel wetlands of the Fitzroy River are critical habitats for freshwater and diadromous[3] fish species, Cherabin, waterbirds, frogs, and reptiles during the dry season. Many pools and wetlands also support high ecological and cultural values (DWER 2023a) (Table 2). The persistence of these habitats is largely determined by river flows and connectivity between the river and its floodplain during the wet season and groundwater inputs during the dry season.

Recent studies in the lower Fitzroy River have provided information on important species including Freshwater sawfish (*Pristis pristis*), Barramundi (*Lates calcarifer)*, Fork-tailed catfish (*Neoarius graeffei*), Bony bream (*Nematalosa erebi*) and Cherabin (*Macrobrachium spinipes*). In the following sections we consider available information on these important species to describe the hydro-ecological outcomes and ecological water requirements for river pools and off-channel/floodplain wetlands. This information is presented in greater detail in the *Environmental and heritage values and the importance of water in the Fitzroy* report (DWER 2023a).

[3] Diadromous species are those that migrate between fresh and saltwater habitats.

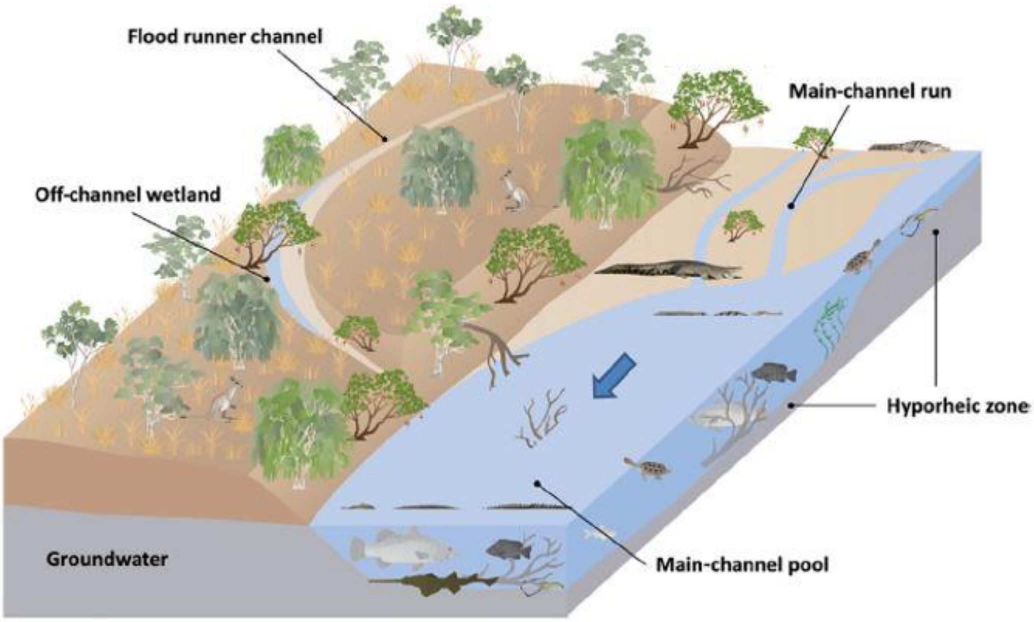

Figure 8 River pool and off-channel habitats of the Fitzroy River (adapted from Douglas et al. 2019)

5.1 Dry season and dry years

This section describes the ecological water requirements for river pools and off-channel wetlands in dry years (as defined above) and across annual dry seasons (May 31st – November 1st) (Figure 9).

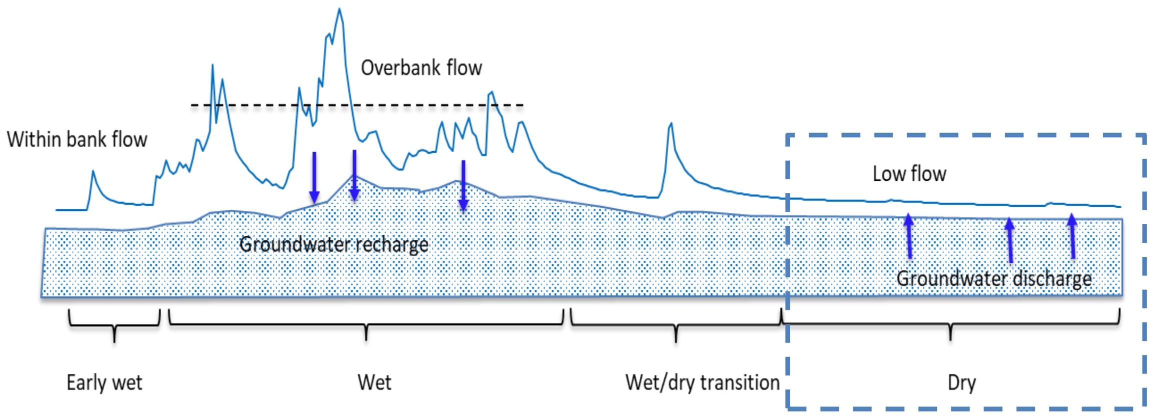

Figure 9 Dry season water regime components important to river pools and off-channel wetlands

A Deep river pool habitat

The values report (DWER 2023a) explained the importance of river pools that persist during the dry season providing important refuge habitat and sustaining populations of fish and other fauna. Large, deep pools are particularly important, providing critical habitat in the protracted dry season that follows a low-flow year. Deep pools can be considered as those that are deeper than the annual evaporation rate of approximately two metres (DWER 2023b).

Hydro-ecological outcome

The Fitzroy River provides a high-value nursery for the threatened Freshwater sawfish (*Pristis pristis*) (Morgan et al. 2011b; Pollino et al. 2018) and protection of its habitat is a high priority for our water resource management.

In the values report (DWER 2023a), we summarise the life history of the Freshwater sawfish along with its habitat and dietary needs. During the dry season, Freshwater sawfish occupy deep pools and runs near large woody debris during the day and then move into shallow water in glides, pool edges and runs at night to feed (Whitty et al. 2017).

Juvenile Freshwater sawfish are large-bodied in comparison to many freshwater species. Protecting the deep pools that support sawfish during the dry season is likely to also protect the habitat of other co-occurring large-bodied fish, freshwater crocodiles (*Crocodylus johnstoni*), saltwater crocodiles (*Crocodylus porosus*) and river sharks. As smaller-bodied fish also inhabit deep main channel pools (Gwinn et al. in prep), along with Cherabin, turtles and macroinvertebrates, protecting deep pools for sawfish should also protect these species.

Maintaining deep river pools as habitat for Freshwater sawfish also maintains the shallow water in glides, pool edges and runs connected to deep river pools. These areas are particularly important to the abundant small and medium-sized fish and Cherabin that also forage in shallow water at night (Lear et al. 2023).

The hydro-ecological outcome for deep river pools is:

A Water depth in deep river pools and connected foraging habitat is maintained during the dry season and low-flow years to protect Freshwater sawfish.

Ecological water requirement

The Freshwater Fish Group at Murdoch University investigated the habitat use and movement of juvenile Freshwater sawfish (Whitty et al. 2017). The researchers used acoustic transmitters and pressure sensors fitted to 16 sawfish to track their movement and depth through the study area. This monitoring was undertaken hourly over several months of each dry season from 2008 to 2019. The study was undertaken in two river pools: Camballin Pool, downstream of the Camballin Barrage and Myroodah Pool, below Myroodah Crossing. Depth contours of the pools were measured in the late dry season of 2017, and they were found to be up to 5.5 m deep (Lear et al. 2021).

Sawfish were found to occupy the cooler parts of deep pools near large woody debris during the day, but moved out into shallow water in glides, pool edges and runs at night to feed (Whitty et al. 2017). It was also noted that the mean relative abundances of sawfish prey species, Cherabin (*Macrobrachium spinipes*), Bony bream (*Nematalosa erebi*) and Fork-tailed/ lesser salmon catfish (*Neoarius graeffei*), were significantly greater within the shallow water environments at night than during the day (Whitty et al. 2017).

The findings of the study were reinforced by Gleiss et al (2017) who attached accelerometers[4] to 24 sawfish in 2011 (16 in the early dry and 8 in the late dry) and examined daily movements. They found that during the late dry season, when pools were thermally stratified, individuals rested in cool depths during the day and were active in shallow warmer depths during the night. Resting in cooler water when not active is thought to reduce metabolic rates (conserve energy) and possibly reduce the likelihood of predation by crocodiles and sharks (Gleiss et al. 2017).

The Whitty et al. (2017) tagging study discussed above provided scientific information about depths at which sawfish rested in deep river pool habitats. It indicated that sawfish were recorded at mean depths of up to 3 m during the day (Figure 10). This finding provided the basis for identifying a dry season minimum pool depth to meet this hydro-ecological outcome.

The depth data comprises mean values pooled across individuals, times (August to November) and sites (Camballin and Myroodah pools). Individual sawfish were at times recorded at depths greater than 3 m (Whitty et al. 2017). Using this data, we have identified a minimum pool depth of 4 m as the ecological water requirement. This may vary naturally, and the pools may get shallower towards the end of the dry season.

Surface water and groundwater connection will likely play an important role in the meeting of this ecological water requirement. Groundwater input during the dry season (May 1st – October 31st) and any late wet season flows is critical to sustain deep permanent river pools. Maintaining a depth of 4 m in main channel pools should also ensure shallow runs and glides at the ends of the pools are available for sawfish foraging.

[4] Animal attached device that provides data on movement, behaviour or physiology.

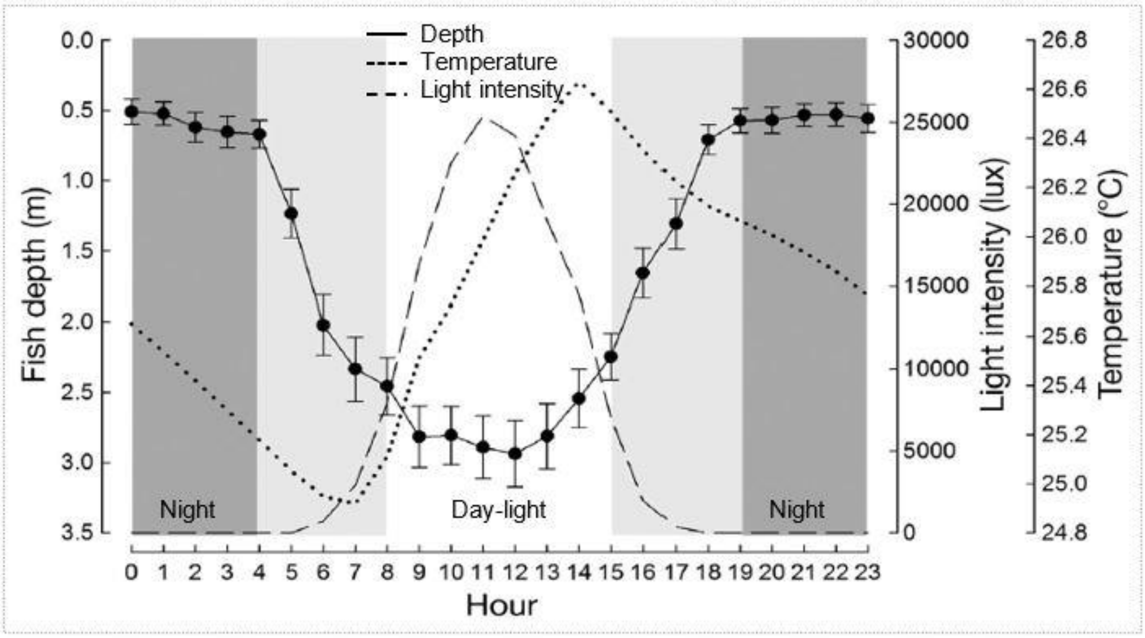

Figure 10 Mean and SE (Std error) hourly depths of two river pools supporting Freshwater sawfish during the dry season (from Whitty et al. 2017)

> Ecological water requirement to maintain deep river pool habitat (Hydro-ecological outcome A) during the dry season:
>
> - maintain a water depth of 4 m in Camballin and Myroodah pools for as long as possible during the dry season
> - protect all natural flows between May 1st and October 31st.

Further work

The ecological water requirement for hydro-ecological outcome A is based on information from two large river pools, the Camballin and Myroodah pools. Local ecological water requirement studies may be required to define the local conditions required to maintain deep river pool habitat to support Freshwater sawfish in other pools on the Fitzroy River and major tributaries.

B River pool and off-channel wetland habitats

The values report (DWER 2023a) explained that all river pools and wetlands that persist during the dry season provide important refuge habitat and sustain populations of fish and other aquatic fauna.

Hydro-ecological outcome

Depth of river pools and wetlands

The values report (DWER 2023a) highlighted the importance of Barramundi (*Lates calcarifer*) to cultural, recreational and commercial fishing in the Fitzroy River catchment. As a migratory species, Barramundi spawn near the river mouth and juveniles move upstream to spend their first years in freshwater habitats (Pollino et al. 2018). Permanent deep pools in the main river are important habitat in the dry season and during dry years. Although also a large-bodied species, Barramundi have a broader distribution than Freshwater sawfish and are also found in tributaries. They can inhabit pools that are shallower than those required by Freshwater sawfish. As a long-lived species (c.a. 20 yrs) Barramundi are a long-term measure of ecosystem health (Burford et al. 2021).

Fork-tailed catfish (*Neoarius graeffei*) is a medium-bodied species (generally <45 cm) in comparison to the larger-bodied Barramundi and Freshwater sawfish. They are an important indigenous harvest species along with smaller fish such as the Western sooty grunter (*Hephaestus jenkinsi*).

Other smaller species including Bony bream (*Nematolosa erebi*) are used as bait for indigenous harvest (Jackson 2015) and are important prey species for larger fish. Bony bream represents up to 30 per cent of the total fish catch on the Fitzroy (Lear et al. 2020a; Lear et al. 2023). These smaller species are found both in river pools and off-channel wetlands (Beesley et al. 2020; Lear et al. 2020a).

<u>Water quality</u>

Water quality, especially the characteristics of turbidity, dissolved oxygen and temperature, is an important driver of aquatic ecosystem health, particularly in dry season refugial pools supporting fish and other aquatic fauna (Pusey & Kath 2015). Available information suggests water quality in pools of the lower Fitzroy River downstream of the Barrage is relatively pristine and stable across dry seasons irrespective of wet season flows (Gleiss et al. 2021). However, stratification of the water column can be an issue in dry-season pools that have stopped flowing. Stratification occurs when the surface layer of water is warmed by the sun and becomes less dense than the water below it. The lower layer gets progressively cooler and heavier, making it difficult for the layers to mix (by wind). Due to the lack of mixing, dissolved oxygen in the lower layer is not replenished and is depleted by microbes, potentially leading to fish kills (Gleiss et al. 2021).

It is important that there is a diversity of river pool and off-channel wetland habitats available to sustain fish throughout the dry season. The depth of river pools and wetlands and the quality of water they hold are important during dry years where there is limited flooding to replenish or flush river pool and wetland habitats.

The hydro-ecological outcome for river pool and off-channel wetland habitats is:

> **B Water depth and water quality in river pools and off-channel wetland habitat is maintained during the dry season and dry years to support a diversity of fish species.**

Ecological water requirement

Depth of river pools and wetlands

UWA/NESP researchers investigated the abundance of 21 fish species in the lower Fitzroy and Margaret rivers and their floodplains, by surveying 22 river channel and 39 off-channel wetland sites. Sites were sampled over a four-year period (2018–2021) with some sampled multiple times; a total of 121 site survey events took place (Gwinn et al. in prep).

They found the likelihood of a certain fish species being present in a river pool or wetland depended primarily on water depth but was also affected by habitat complexity and turbidity (Gwinn et al. in prep). Taking these factors into consideration, modelling indicated that ensuring that water depth stays above 1.4 m in river pools at the end of the dry is ideal to support Barramundi.

The UWA/NESP study found that medium-bodied species such as the Fork-tailed catfish, Western sooty grunter and Bony bream do not require as deep water as do Barramundi. For these species a water depth above 0.9, 0.8 and 0.4 m in river pools at the end of the dry is sufficient to support these species respectively (Gwinn et al. in prep). In floodplain wetlands, depths of 0.5, 0.8, and 0.5 m respectively are needed.

UWA/NESP researchers also ran a simulation study considering variations in pool habitat complexity and turbidity across the landscape. This study revealed that a minimum depth of 1.5 m in river pools at the end of the dry season would ensure that more than 88 percent of these pools would contain all of the 21 fish species examined (Gwinn et al. in prep). This finding indicates that preventing permanent river pools from falling below a depth of 1.5 m will protect most species in the river channel (note sawfish, whipray and eels were not included in this analysis). In previous studies of large Pilbara rivers, a depth of 1.5 m has also been found to maintain large-bodied fish (van Dam et al. 2005; DoW 2012).

The simulation study found that a minimum depth of 1.1 m in floodplain wetlands at the end of the dry would ensure that more than 88 per cent of these pools would contain all floodplain fish species examined (Gwinn et al. in prep).

In other research (Crook et al. 2016; Crook et al. 2019) it was found that individual Barramundi commonly returned to the same refugial river pools at the end of each wet, even when there was potential habitat much closer to their wet season activity areas (Crook et al. 2019). This finding supports the importance of maintaining persistent river pools throughout the catchment.

Water quality

Murdoch University analysed 12 years of historical data to determine how fish respond to variable conditions in dry season pools and wetlands (Lear et al. 2020a). They sampled water quality in two 2–3 km long river pools downstream of Myroodah Crossing and upstream of Camballin Barrage – over three dry seasons between July 2017 and November 2019 (Gleiss et al. 2021). The flows during the wet seasons varied greatly where 2017/2018 had some of the largest flows on record, 2019–2020 had some of the lowest, and 2018–2019 was considered intermediate (Gleiss et al.

2021). This analysis allowed water quality in the dry season to be considered against a diverse range of preceding wet season flows.

Results showed only minor changes in most water quality parameters between years despite drastic differences in the flow of the preceding wet seasons. The exception was dissolved oxygen, which was low and close to hypoxic following the high flow year of 2017. These low oxygen levels were believed to be a result of water depth rather than nutrient input as the water column thermally stratified in deeper areas of pools (>4 m) and biological use lead to depleted oxygen levels (Gleiss et al. 2021).

Loggers deployed in the deepest part of Myroodah Pool in the dry season of 2019–2020 (August–November) recorded a range of 20–34°C at the top of the pool and 20–31°C at the bottom (Gleiss et al. 2021) (Table 3). Longer term logger data (January 2017 to November 2019) showed little variation in minimum and maximum temperatures between years despite significant differences in preceding wet season flows (Gleiss et al. 2021).

Results also showed surface water, in the upper 1.5 m of the water column, can heat by up to 3°C during the daylight hours before cooling overnight (Gleiss et al. 2021). This indicates that sufficient pool depth is required to provide cool water refuges for species, particularly late in the dry season.

A pilot study by UWA/NESP in October 2017 found that dissolved oxygen and temperature decreased with depth in river pools (Beesley et al. 2018). Water temperature was measured at 5 to 12 sites (61 replicates), using a water quality meter (YSI datasonde). They recorded an average temperature of 34.5°C at the top of the water column and 30°C at the bottom. Shallows runs were 37°C but cooler in areas of groundwater input: 29–32°C (Beesley et al. 2018) (Table 3).

During fish surveys in late 2019, UWA/NESP researchers found that oxygen had fallen to 2.0 mg/L at one site following early wet season rains (Beesley pers comm). Several species of fish that had been collected several months earlier were missing and there were clear signs of an algal outbreak. This suggests that early rains had caused an inflush of nutrients which had created a water quality issue and led to a localised fish kill. Such an event has commonly been reported across northern Australia (Townsend et al 1994).

Tayer (2023) sampled water quality using a YSI datasonde in four pools on the lower Fitzroy across the dry seasons of 2019 and 2020. Average DO values ranged between 7.07 and 10.41 mg/L and average temperature from 27.4 to 29.3°C and was similar in the four pools.

Burrows & Butler (2012) analysed temperature data from 6,000 records for 32 species from across northern Australia (data collected prior to 2010). They found that across all records, the mean temperature recorded was 25°C and the maximum was 43°C (Table 3). In a laboratory they then ran temperature tolerance experiments, testing 383 individuals from seven fish and four crustacean species from northern Queensland Rivers. These were non-lethal tests from which the subjects quickly recovered. Across all the species tested, the overall critical maximum temperature was 39.3°C, with a range from 33.5–41.8°C (Burrows & Butler 2012). Barramundi were the most tolerant species tested.

Water temperature was recorded in 20 pools in the Gilbert and Flinders rivers catchment in northern Queensland between September–October 2012 and May 2013 (Waltham et al. 2013). Average daily temperatures were found to be quite similar across sites, rising from around 22°C in September up to 32°C in December 2012. Pool depth had only a small influence on daily average temperatures; however, shallower pools had much larger daily fluctuations. Waltham et al. (2013) undertook further analysis of available data and identified a preferred water temperature threshold of 31°C and a maximum threshold of 33.5°C for fish species of northern Queensland rivers.

Available information suggests water quality and water temperature in pools of the lower Fitzroy River downstream of the barrage is stable across dry seasons irrespective of wet season flows (Gleiss et al. 2021) and that pool depth is the main driver of water temperature and dissolved oxygen. Table 3 presents a summary of available temperature records.

Table 3 Summary of available river pool temperatures in northern Australian rivers

Location	**Fitzroy**			**Flinders and Gilbert (Qld)**	**Northern Australia**
Study	Beesley et al (2018)	Gleiss et al (2021)	Tayer (2023)	Burrows & Butler (2012)	Waltham et al (2013)
Study period	Oct 2017	Jan 2017 to Nov 2019	Aug to Oct 2019, Sept 2020	Sep/Oct 2012 to May 2013	Review of data pre-2010
No. pools (replicates)	2 (61)	2 (?)	4 (57)	20	multiple
Average temp (°C) • surface • bottom • pool	 34.5 30 -	 20-34 20-31 -	 - - 27.4-29.3	 - - 22-32	 - - 25
Max pool temp (°C)	-	-	33.8	-	43
Threshold (°C) • preferred • maximum	 - -	 - -	 - -	 - 39.3	 31 33.5

The ecological water requirement to maintain river pools and wetlands for fish during the dry season (Hydro-ecological outcome B):

- barramundi – 1.4 m water depth in river pools
- medium-bodied fish (i.e. Fork-tailed catfish, Bony bream and Western sooty grunter) – 0.9 m water depth in pools, 0.8 m water depth in floodplain wetlands
- water depth above 1.5 m in river pools and 1.1 m in wetlands to maintain a diversity of fish.

Further work

Further regional scale assessment is required to determine the depth of refuge pools at the end of the dry season. UWA/NESP's work shows there is a link between pool maximum depth and pool length and width (Beesley pers comm.). Remote sensing could be used to map the length and width of each pool at the end of the dry season and estimate the maximum depth of each pool. Those pools found to be naturally deeper than 1.5 m would be regarded as important refuges and the depth EWR could be applied to maintain them.

Once deep refuge pools are identified, further work using an appropriately designed and rated hydrological model may determine minimum flows required to maintain river pool depth to sustain fish diversity and water quality.

Ongoing water quality monitoring programs would also detect high temperature and low oxygen conditions in deep pools. Investigation into how water quality conditions influence the physiological and behavioural responses of fish may lead to an understanding of temperature and dissolved oxygen tolerances and critical thresholds for fish species. This may assist in furthering our understanding of how climate change may impact the resilience of aquatic species and ecosystems. Other potential influences such as predatory birds, may also need to be considered.

C Groundwater to support river pools and off-channel wetland habitat

The values report (DWER 2023a) explained the importance of river pools and off-channel wetlands that persist during the dry season. Long-term groundwater discharge to the river maintains baseflow and persistent pools and wetlands (Harrington & Harrington 2016; Taylor et al. 2018), often for multiple years after flooding, providing important habitat for fish and other fauna (Pollino et al. 2018).

Hydro-ecological outcome

Many of the pools on the Fitzroy River and some of the larger tributaries, along with numerous off-channel wetlands, are likely supported by groundwater inputs for at least part of the year (DWER 2023b; Tayer 2023). In a small, targeted study Tayer (2023) found larger pools had more substantial groundwater inputs than smaller pools. Inputs can be from the Alluvial aquifer, various regional aquifers (Wallal, Liveringa, Grant Poole, Devonian Reef) or in combination (section 2.4).

However, while persistent river pools typically indicate groundwater discharge, their presence is not by itself definitive evidence. For example, deep pools (deeper than the annual evaporation rate of approximately 2 m) may persist through a dry year without additional inflows (DWER 2023b).

The hydro-ecological outcome for groundwater-dependent pools and wetlands is:

> **C The natural pressure and water levels in aquifers maintains groundwater discharge to river pools and wetlands throughout the year.**

Ecological water requirement

In some areas we have strong evidence of the relationship between groundwater discharge to river pools and wetlands (described below). However, it is impractical to define a quantitative ecological water requirement for the piezometric pressure and water levels of all aquifers that maintain groundwater discharge to rivers and wetlands throughout the catchment.

To investigate the interaction between the river and groundwater, the department undertook intensive sampling of surface and groundwater in 2016 and 2017, to identify reaches of the Fitzroy River where surface–groundwater interaction was occurring (DWER 2023b). Data were assessed through:

- hydrograph analysis from stream flow gauging stations and nearby groundwater bores
- river chemistry, radon and helium-4 sampling conducted in June 2017.

Results showed significant groundwater inputs to river pools from numerous regional aquifers as well as the Alluvial aquifer. It should be noted that although the Alluvial aquifer has some connection with the river over its full length, it is also supported by the regional aquifers in some areas. Figure 11 shows which aquifers are the most dominant in terms of groundwater input into various reaches of the Fitzroy and Margaret rivers.

Figure 11 shows an interpretation of the possible dry season interaction between groundwater and surface water, in different zones along the Fitzroy River from east to west. These zones are summarised below, and further information is available in DWER 2023b:

- Devonian Reef zone: likely interactions between Devonian Reef aquifer and the river, recharge and discharge are equally likely
- Fairfield Group zone: possible groundwater discharge, source aquifer not determined but likely from the Fairfield Group (Devonian Reef aquifer)
- Grant Group and Poole Sandstone zone: likely groundwater discharge, from the Grant Poole and Alluvial aquifers
- Noonkanbah zone 2: no evidence to suggest significant interaction between surface water and groundwater
- Liveringa zone 3: likely groundwater discharge, from the Liveringa aquifer

- Noonkanbah zone: likely groundwater discharge, from the Grant Poole and Alluvial aquifers
- Liveringa zone 2: likely recharge to the Alluvial aquifer from the river. Possible groundwater discharge, likely from the Alluvial aquifer
- Noonkanbah-Liveringa zone: possible groundwater discharge, source aquifer not determined
- Liveringa zone 1: possible groundwater discharge, source aquifer not determined
- Wallal zone: likely groundwater discharge, from the Wallal and Alluvial aquifers.

Investigations into the groundwater-dependence of river pools in the Noonkanbah zone (Figure 11) were further supported by a targeted investigation of environmental tracers in regional groundwater and surface water (Tayer 2023).

Further work

Further studies on surface and groundwater interaction would increase our understanding of ecological water requirements for specific reaches of the Fitzroy River and its tributaries. A development that proposes to use water from the Alluvial or connected regional aquifers may need to establish these local scale EWRs, likely by using baseline data from appropriate groundwater monitoring bores and water levels in river pools and wetlands.

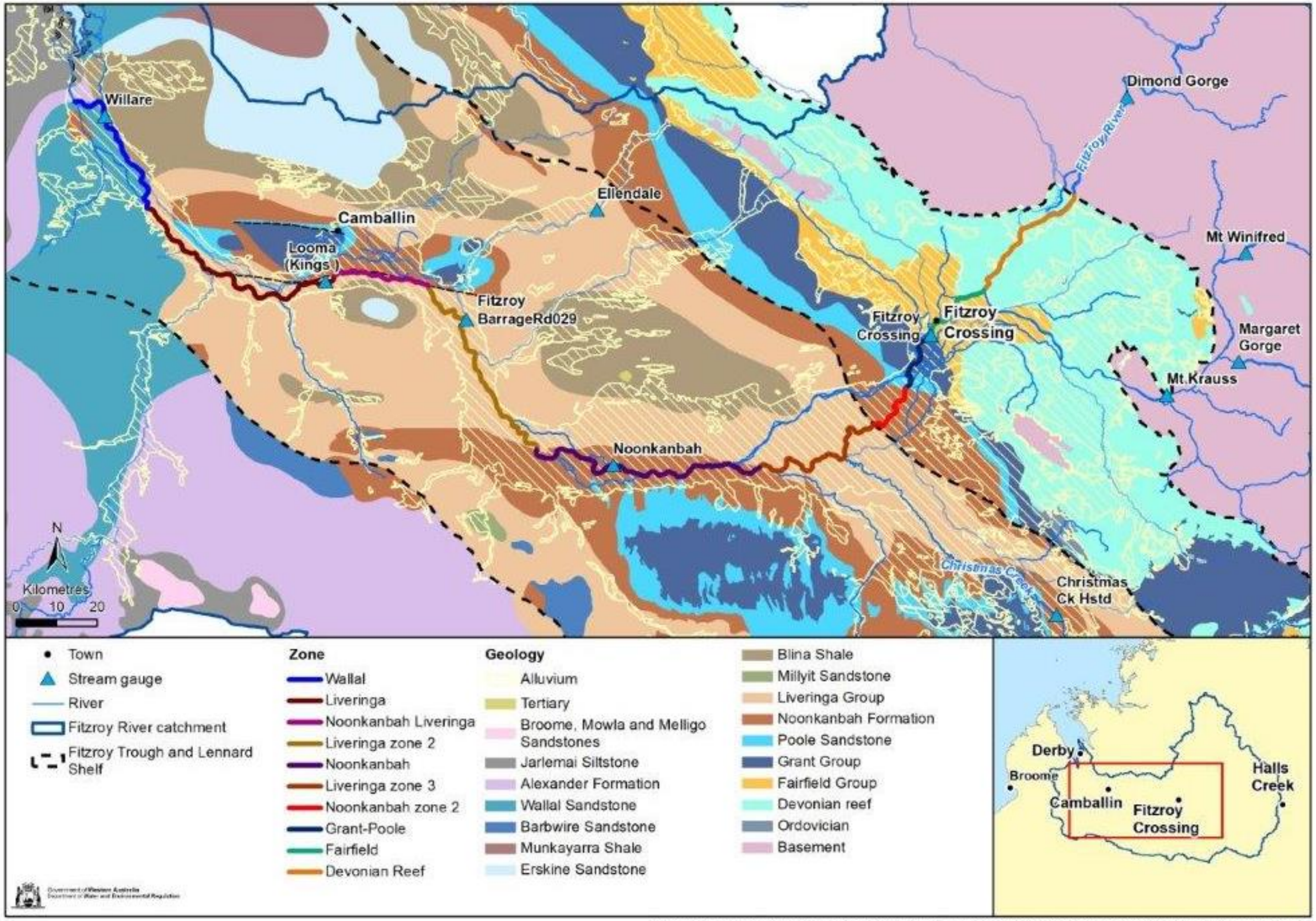

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Figure 11 Zones of groundwater and surface water connectivity on the Fitzroy and Margaret rivers

5.2 Wet season

This section describes the ecological water requirements for river pools and off-channel wetlands across the within-bank and overbank flow components of the wet season water regime (early November to end of May) (Figure 12).

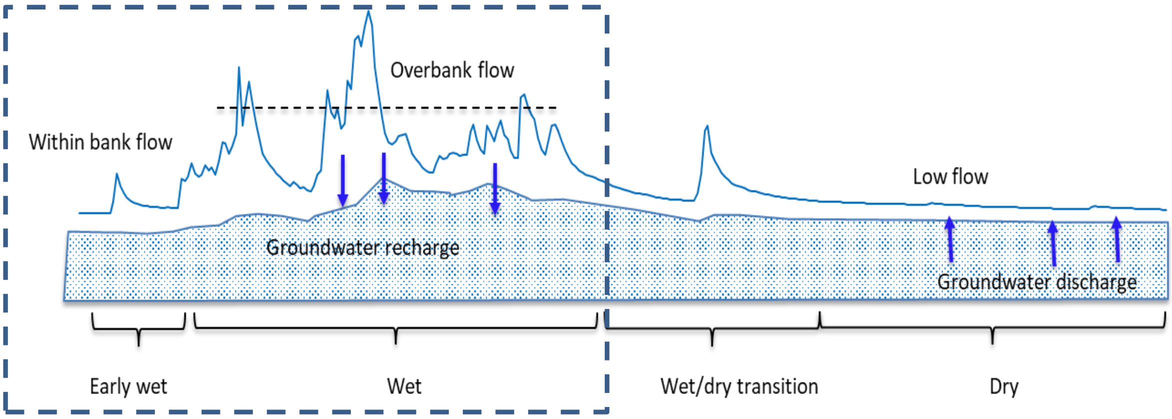

Figure 12 Wet season water regime components

D River pool connectivity

The values report (DWER 2023a) explained the importance of within-bank flows in reconnecting river pools along the lower Fitzroy River during the early wet season. Aboriginal people of the river have long recognised the importance of these early flows, or ‘warramba’, in cleaning out the river (Toussaint et al. 2001).

Hydro-ecological outcome

The Fitzroy River generally starts to flow in early November. The first flush flows, also known as freshening flows, are important as they:

- support recruitment of wet season spawners including Cherabin (*Macrobrachium spinipes*), the fork-tailed catfish (*Neoarius graeffei),* Western sooty grunter (*Hephaestus jenkinsi*), Barramundi (*Lates calcarifer*) and Freshwater sawfish (*Pristis* pristis) (Lear et al. 2023)
- reduce estuarine salinity – typically hypersaline in the late dry season and stressful for the plants and animals (Burford et al. 2021)
- allow fauna to move out of refugial river pools and disperse up and down the main channel (Douglas et al. 2019)
- reduce the risk of fish kills early in the season (Beesley pers. comm)
- clean out water that has persisted in pools over the dry season (Burford et al. 2021)
- flush high concentrations of nutrients into the estuary and King Sound increasing their productivity (Baldwin et al. 2016).

Cherabin are described as perennial wet-season spawners (Lear et al. 2023). The species is amphidromous, releasing larvae **Error! Reference source not found.**in freshwater reaches of the Fitzroy during the wet season and relying on flood pulses to carry larvae back into estuarine/brackish waters where they develop (Novak et al. 2015, Novak et al. 2017). Post-larval young then migrate upstream (Novak et al. 2017).

A UWA/NESP study sampled Cherabin across a 350 km reach of the Fitzroy River's main channel and floodplain pools in the dry seasons of 2018 and 2019 (Beesley et al. 2023). Although the findings supported an estuarine nursery and amphidromous life history, small individuals were also collected in the main channel late in the dry season, suggesting some level of within-river recruitment (Beesley et al. 2023).

A study on the Daly River in the wet-dry tropics of the Northern Territory found that Cherabin reproduction was restricted to the wet-season months of November to April, followed by a recruitment pulse three to four months later during the early dry season (Novak et al. 2015). Length, body condition and relative abundances peaked for both sexes immediately after the wet season, before declining throughout the dry season.

Unlike other *Macrobrachium* species in similar rivers, the abundance of females increased along the entire length of the Daly River during the reproductive season and reproductive effort occurred far upstream, over a restricted time period (Novak et al. 2015). This result highlights the importance of maintaining river connectivity for the reproductive success of this species and further recruitment into upstream reaches.

The hydro-ecological outcome for early wet season river pool connectivity is:

> **D A series of freshening flows reconnects the river through to the King Sound, cleaning out river pools and supporting movement and recruitment of aquatic fauna.**

Ecological water requirement

To determine the flow required as first flush or freshening flows, we considered hydrological modelling of river connectivity (DWER 2023c; Greening et al. 2018). The modelling focused on pools up and downstream of the Looma gauging station (802007) and used a digital elevation model (DEM) (Figure 13) to model different flows and determine degrees of pool connectivity.

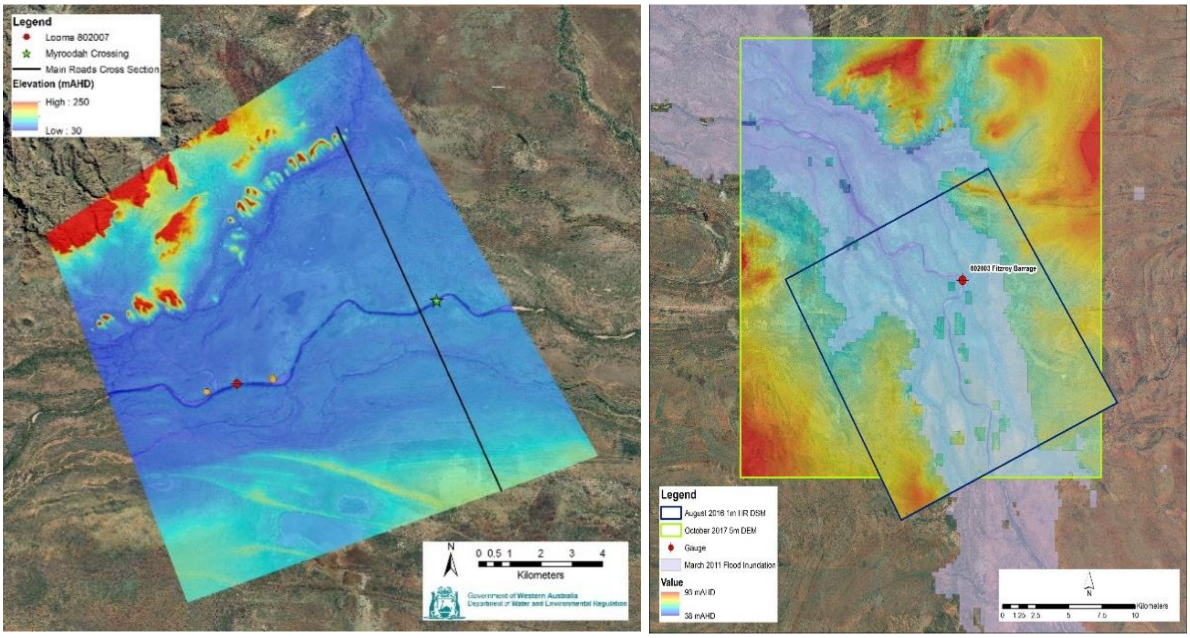

Figure 13 Extent of Looma (left) and Fitzroy (Camballin) Barrage (right) digital elevation models (DEMs)

Where good connectivity was detected, we identified the corresponding flows at the Fitzroy Barrage gauging station (802003) (43 km upstream of Looma) and calculated the cumulative flow (first flush) needed to connect pools after the dry season. A similar assessment was undertaken using a second DEM of the Camballin Barrage to ensure pools were connected downstream at this flow (Figure 14).

Good connectivity was found to occur where cumulative flow was above 1,500 GL (Figure 14). This volume is equivalent to the 10th percentile annual flow (meaning 90 per cent of annual flows in the observation period are larger than this flow) over the long-term modelled flow period (1890 to 2015) and is considered a very low annual flow. Observed flow recorded at the Fitzroy Barrage gauging station shows four years of very low flow were recorded between 1991–1992 and 2020–2021. Figure 15 shows total annual river flow at the barrage over this period highlighting the years under 1,500 GL. It also shows what proportion of flow this would equate to in years with varying total flows.

Figure 14 Pool connectivity upstream and downstream of the Fitzroy (Camballin) Barrage at no flow (left) and 1,500 GL (cumulative)(right)

A cumulative flow volume of 1,500 GL, measured at the Fitzroy Barrage gauging station within the wet season (November 1st to April 30th), is needed to provide freshening flows and to reconnect the river. This may occur early in the wet season or later if the start of the season is delayed. In years when annual flow is less than 1,500 GL,100 per cent of all river flow is required to connect the river, replenish river pools and sustain aquatic habitat.

> Ecological water requirements to provide freshening flows and connect river pools in the early wet season (Hydro-ecological outcome D):
>
> - a cumulative volume of 1,500 GL measured at the Fitzroy Barrage gauging station from November 1st.

Further work

Further regional scale assessment is required to determine the river flow volumes needed to connect river pools upstream of the Camballin Barrage and on major tributaries.

A local ecological water requirement study and baseline data can be used to establish flow to sustain connectivity between pools within a specified reach/study area.

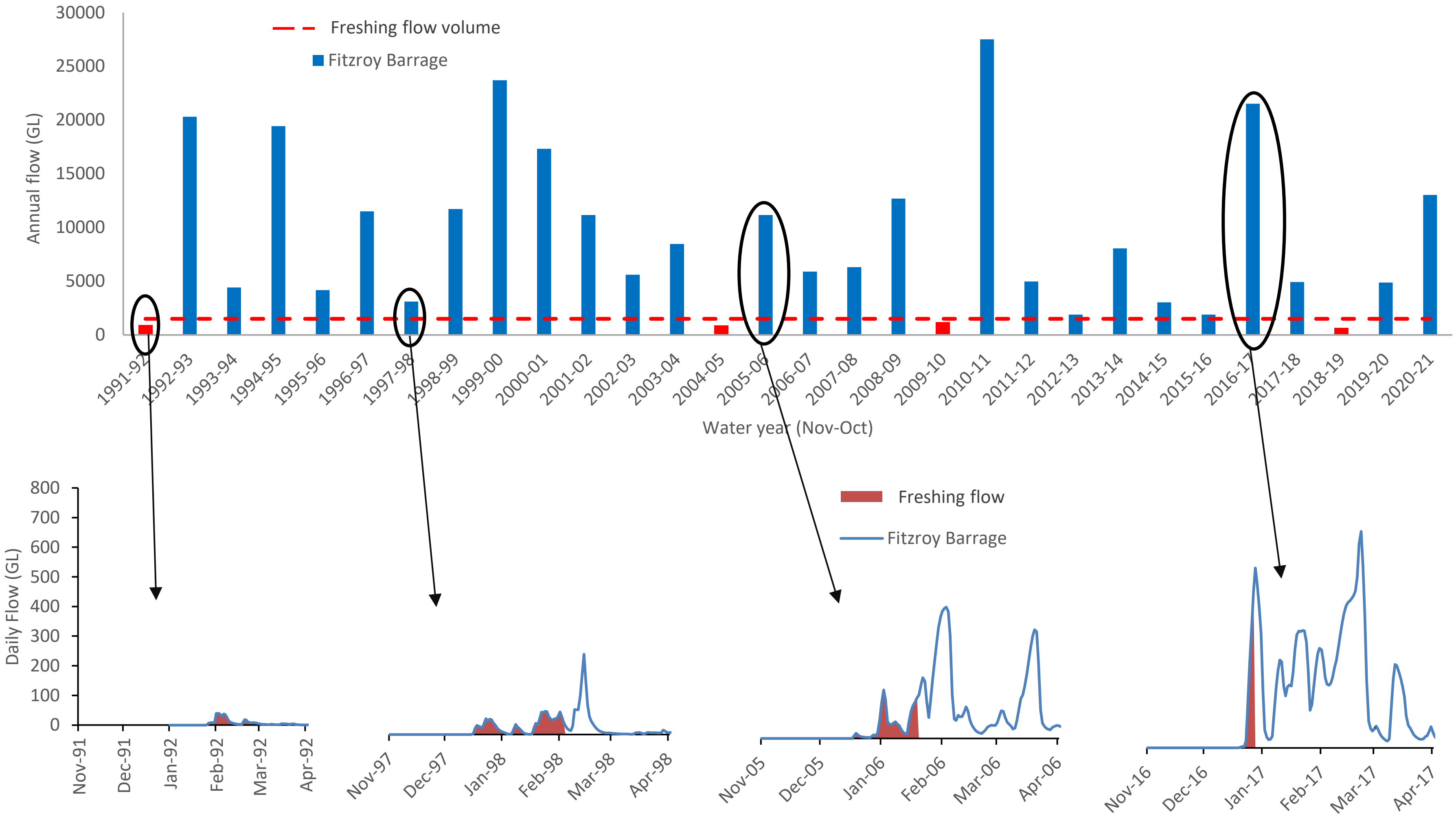

Figure 15 Annual flow at the Barrage from 1991–2021, highlighting freshening flows under 1,500 GL and how this would look in years with varying total flows

E Flow over permanent obstacles in the river

The Camballin Barrage was built across the main channel of the Fitzroy River at Camballin in the 1950s as part of a now abandoned irrigation scheme. The barrage has caused detrimental changes to annual flooding of the river (AECOM et al. 2009) and acts as a barrier to fish including Freshwater sawfish and Barramundi. There are also less substantial barriers at Myroodah Crossing where Myroodah Rd crosses the main river approximately 38 km downstream of Camballin and at Kalyeeda Crossing near Noonkanbah that may act as barriers to fish passage during low flows.

Hydro-ecological outcome

The Camballin Barrage is thought to prevent the movement of Freshwater sawfish up and down the main channel for up to nine months of the year (Morgan et al. 2016). However, it is also possible that sawfish bypass the barrage by moving into Uralla-Snake Creek (Morgan 2019).

The movement of other species, including predators such as Barramundi and Bull sharks, and prey species such as Bony bream and Catfish, is also impeded (Morgan et al. 2005; Morgan et al. 2011c; Morgan et al. 2016). Large, species such as Bull sharks and Freshwater sawfish, are also known to become stranded in shallow pools under the lip of the infrastructure.

The barrage also causes:

- disruption to cultural life of local communities (Morgan et al. 2005)
- a bottleneck at the base of the barrage exposing fish to elevated predation (Morgan et al. 2005)
- increased pressure on fish populations from recreational fishing (Morgan et al. 2005).

The hydro-ecological outcome for movement of fauna over permanent obstacles is:

> **E Flows of varying depths to allow fish passage over permanent obstacles on the Fitzroy River.**

Ecological water requirement

Researchers from the Freshwater Fish Group at Murdoch University have carried out studies to determine what impact the presence of the Camballin Barrage and Myroodah Crossing has on the migration of Freshwater sawfish and other fish species (Morgan et al. 2005; Morgan et al. 2011c; Morgan et al. 2016). Flows and stage heights (river height) at Myroodah Crossing were related to those at the barrage because there is no gauging station at Myroodah Crossing.

The stage height of the top of the barrage is 10.27 mRL (relative level). It is submerged, but still influences river flow at 10.87 mRL (0.60 m deep). It is completely flooded/ drowned out and has no influence on flow at 11.87 mRL (1.60 m deep) (AECOM et al. 2009) (Table 4).

Researchers found that all fish can pass over the barrage when it is drowned out (1.60 m deep) (Morgan et al. 2011c). Freshwater sawfish could move over the barrage when the water level was 11.10 mRL (0.83 m deep) and over Myroodah Crossing when stage height – measured at the barrage – was 10.70 mRL (0.43 m deep at Camballin Barrage) (Table 4). Some large, strong-swimming fish species, such as Barramundi and Bull sharks, may be able to pass when the barrage is submerged at 10.87 mRL (0.60 m deep). When levels fall below 10.35 mRL, exposed sand bars form natural barriers up and downstream of the barrage, preventing any movement of fish up and down the river (Morgan et al. 2011c).

The department converted 11.10 mRL – required for Freshwater sawfish – to an instantaneous daily flow threshold measured at the Fitzroy Barrage gauging station (Table 4). We then modelled the annual duration of these flows over a 16-year period. Outputs showed that during most wet seasons, passage of Freshwater sawfish was possible for 77 days, ceasing in April in the majority of years.

Table 4 Water levels and flows important for fish passage over the barrage and Myroodah Crossing

Water level at barrage (mRL)	Water depth over barrage (m)	Flow at Fitzroy Barrage gauging station (GL/day)	Description	Function
12.60	2.33	50	-	All fish can pass over Myroodah
11.87	1.60	30	barrage drowned out	All fish can pass over barrage
11.10	0.83	12	-	Sawfish observed moving over barrage
10.87	0.60	7.5	barrage submerged	Some large fish species can pass barrage
10.70	0.43	4.5	Myroodah submerged	Sawfish can pass over Myroodah
10.27	0	0	Height of barrage	No movement over barrage

Ecological water requirement to allow fish passage over permanent obstacles in the river (Hydro-ecological outcome E):

- Camballin Barrage
  - all fish species – 1.60 m deep
  - Freshwater sawfish – 0.83 m deep
  - Barramundi and Bull sharks – 0.60 m deep
- Myroodah Crossing (depth measured at Camballin Barrage)
  - Freshwater sawfish – 0.43 m deep
  - all fish species – 2.33 m deep

Further work

Kalyeeda Crossing near Noonkanbah may also act as a barrier to fish passage during low flow. If required in the future, a local ecological water requirement study may be undertaken to determine the minimum water depth required to enable fish passage at Kalyeeda Crossing and the corresponding flows measured at Noonkanbah gauging station.

F River and flood-runner channel connectivity

The values report (DWER 2023a) described the importance of small-to-moderate flows early in the wet season. These connect pools along the length of the river allowing fish and Cherabin to move up and down the main channel. These flows also start to fill flood-runner channels, the distributary creeks that connect the river to off-channel wetlands (Figure 8). They support the movement of fish and Cherabin on and off the floodplain (Beesley et al. 2021b) and help drain excess water back into the river (Beesley et al. 2020).

Hydro-ecological outcome

Uralla Creek is a large flood-runner that runs parallel to the main channel of the Fitzroy connecting the river to off-channel wetlands including Snake Creek, Six Mile Creek, Upper Liveringa Pool and wetlands of the Camballin Floodplain. It flows during the wet season from water which diverts naturally from the river via a modified off-take point at the Camballin Barrage.

Murdoch University researchers sampled fish in Uralla Creek annually from 2008 to 2021 (except 2011) and in the main river intermittently from 2004 to 2021. They assessed the effect of habitat, variations in annual flow and other factors on fish recruitment and community structure (Lear et al. 2023). They considered an annual flow, measured at the Willare gauging station, of <2,000 GL as low, 2,000-7,000 GL as moderate and >10,000 GL as high (there were no flows between 7,000 and 10,000 GL included in the study period).

Results showed that habitat type was the strongest driver of abundance, diversity and richness of fish. However, further investigations into annual flow variations found species diversity was higher in Uralla Creek in low or moderate flow years than in high-flow years (Lear et al. 2023), possibly due to increasing difficulty in catching fish in deeper water.

UWA/NESP sampled fish in 24 river pools on the Fitzroy and Margaret rivers and 17 off-channel wetlands during the dry season from 2017 to 2019 (NESP unpublished data). Data showed differences in species richness between the two habitat types, with an average of 18 species recorded for the river pool sites and 13 for off-channel wetlands.

The hydro-ecological outcome for early wet season river connectivity is:

> **F River pools and flood-runner channels are connected along the river during the wet season, supporting the movement of and providing habitat for aquatic fauna.**

Ecological water requirement

To identify flows that connect the river with flood-runners and off-channel wetlands, the department used a wetness index derived from satellite imagery (normalised difference water index) to compare the physical presence of water in a representative section of the river between Looma and Willare gauging stations, at various flow rates (Figure 16). The wetness index showed good connectivity of river pools at flow rates above 1.6 GL/ day and some connectivity with flood runner pools and off-channel wetlands between 2.8 and 3.1 GL/ day measured at the Fitzroy Barrage gauging station.

To translate our hydro-ecological outcome into a measurable flow rate, we ran a HEC-RAS model at Camballin Pool and confirmed that a daily flow of 3 GL, measured at the Fitzroy Barrage gauging station (802003), will connect river pools downstream of the barrage towards Willare and start to fill flood-runner channels. This flow rate will also maintain the depth of Camballin Pool at 4 m (see Hydro-ecological outcome A) (Figure 17).

However, Pratt et al. (in prep.) found that the classification of flow events based on discharge or river stage height alone might not fully support the connectivity of the Fitzroy River with its flood runners. Given the flashy nature of flow in the Fitzroy, they postulate that the duration of connectivity is also important. For example, an EWR as described above might connect pools and flood runners for only a short period of time, not allowing passage for aquatic fauna to/from the flood runners and up and down the river. The addition of a flow duration metric (e.g. flow of 3 GL >10 days), might ensure that these flows provide adequate time for biological exchange.

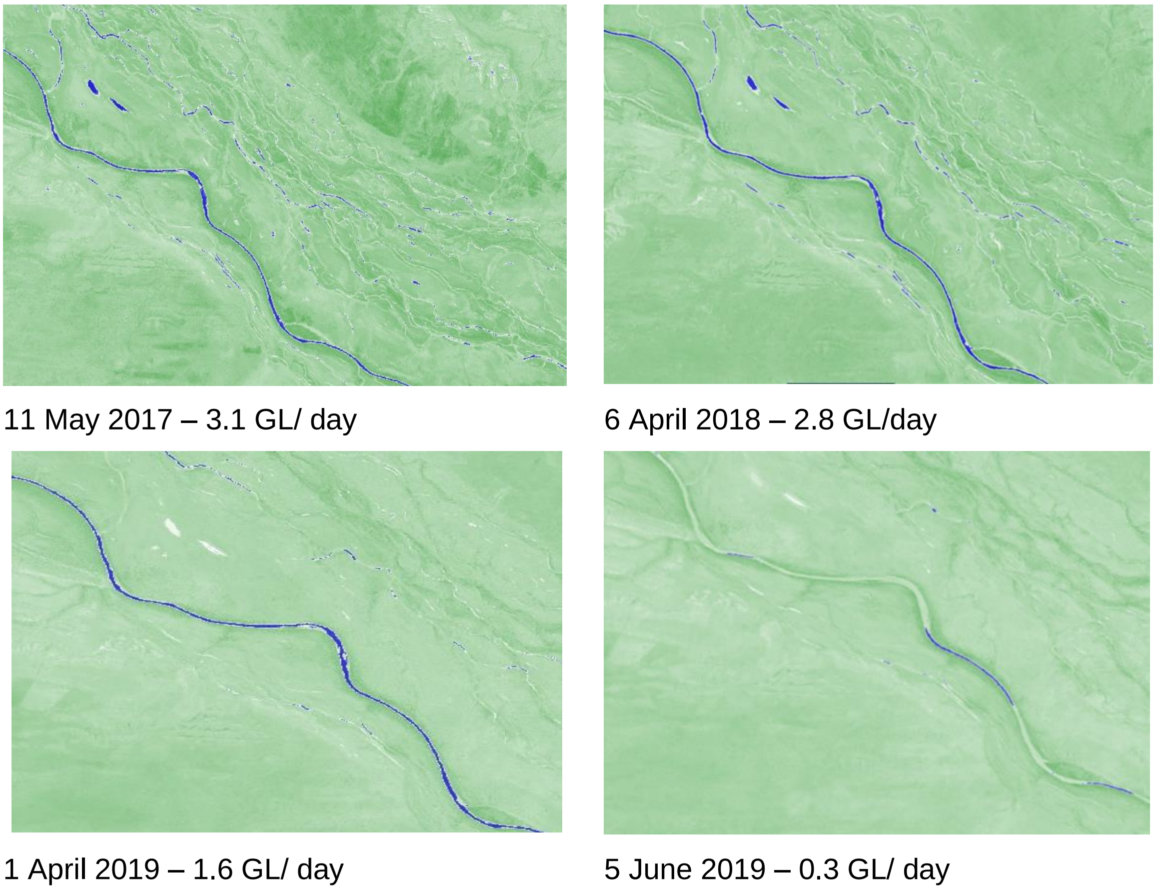

Figure 16 Presence of water downstream of Looma gauging station at various flow rates measured at the Fitzroy Barrage gauging station

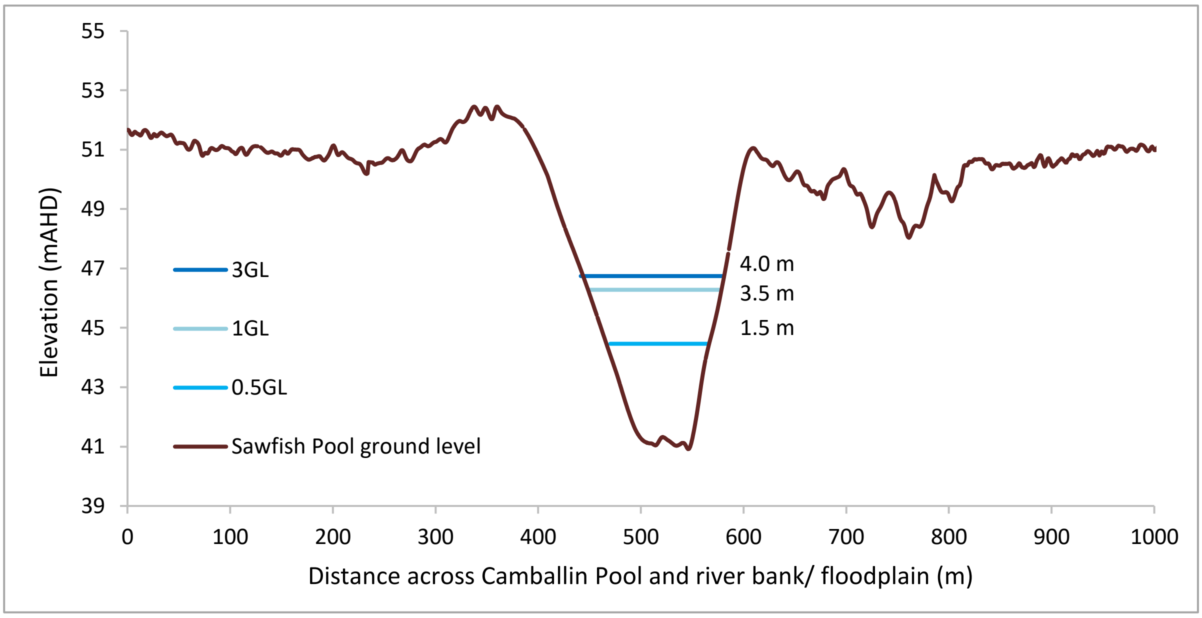

Figure 17 Modelled depth of Camballin Pool under different flow rates

> Ecological water requirement to reconnect river pools and flood-runner channels (Hydro-ecological outcome F):
>
> – daily flow of 3 GL, measured at the Fitzroy Barrage gauging station during the early wet season

Further work

Further regional scale assessment could determine flow volumes required to connect river pools and flood-runner channels upstream of the barrage and on large tributaries. This assessment may be possible using frequently updated satellite imagery.

Local ecological water requirements studies and baseline data can be used to establish the flows required to deliver connectivity between individual flood-runners or those within a specified reach/study area.

G River and floodplain connectivity

The values report (DWER 2023a) explained the complex and variable nature of connectivity between the river and its floodplain. Large overbank flows inundate the floodplain and recharge off-channel wetlands, providing important breeding, foraging and refuge habitat for fish, Cherabin and other aquatic fauna during the wet season.

Hydro-ecological outcome

Over-bank flows in the lower Fitzroy River, large enough to connect the river to its floodplain, only occur briefly each wet season, and typically last for less than three weeks (Jardine et al. 2012). These flows are important to:

- transfer nutrients, carbon (Burford & Faggotter 2021) and algal biofilm energy (Beesley et al. 2020) from the floodplain to the main channel and estuary as the floodplain drains
- the movement of fish and other fauna between the river and floodplain wetlands (Lear et al. 2020a; Lear et al. 2021; Pratt et al. in prep.)
- crucial feeding, breeding and/ or nursery habitats for many fauna species including Barramundi (Burford & Faggotter 2021), Catfish, Bony bream (Pratt et al. in prep) and Cherabin (Beesley et al. 2023)
- feeding and breeding habitat for wetland birds, frogs, turtles, crocodiles and other semi-aquatic species (Finlayson et al. 2006).

Bony bream (*Nematalosa erebi*) are an important food source for Barramundi, Freshwater sawfish and waterbirds, and are also an important bait fish (Pratt et al. in prep). This freshwater fish species is a habitat generalist and is widely distributed in Australia. UWA/ NESP researchers studied growth and survival rates of young-of-year Bony bream on the main channel and floodplain wetlands of the lower Fitzroy over a four-year period (2018-2021) (Pratt et al. in prep.).

They modelled the influence of food, temperature, habitat and flooding on growth rates, finding that maximum growth of Bony bream on the floodplain was almost double that in river pools. The higher growth was strongly related to the much higher availability of zooplankton as a food source – 70 times greater in floodplain habitats (Pratt et al. in prep.). Floodplain habitats with clear, low-turbidity water supported the highest biomass of zooplankton.

The study concluded that the optimal growth rate in clear-water floodplain habitats could lead to a 20-fold increase in the survival of sexually mature fish compared to main channel habitats. The Fitzroy floodplain is often only inundated for a short period of time each wet season. Although these flows are likely to still be beneficial to growth rates of Bony bream, higher or longer wet seasons show a greater benefit (Pratt et al. in prep). The hydro-ecological outcome for river and off-channel wetland connectivity is:

G Occasional high flows connect river pools to floodplain habitats during the wet season, transferring nutrients and energy and connecting feeding, breeding and nursery habitat for fauna.

Ecological water requirement

To understand the extent of natural variability in river and floodplain connectivity from wet season to wet season, we overlaid CSIRO's surface water model (Sims et al. 2018) with wetland mapping for the Fitzroy River floodplain to determine the number of wetlands inundated in representative wet (2000), medium (2006) and dry (2013) years (Figure 18). Wetlands were mapped at a scale of 1:100,000 and are unlikely to include all wetlands on the Fitzroy River floodplain. The model showed 391 wetlands were inundated in a wet year, 322 in a medium year and 94 in a dry year.

The model provided a tool to assess persistence of surface water in off-channel wetlands and indicated which wetlands may be inundated from year to year. The results clearly showed that a significantly smaller number of wetlands are inundated in a dry year in comparison to average and wet years.

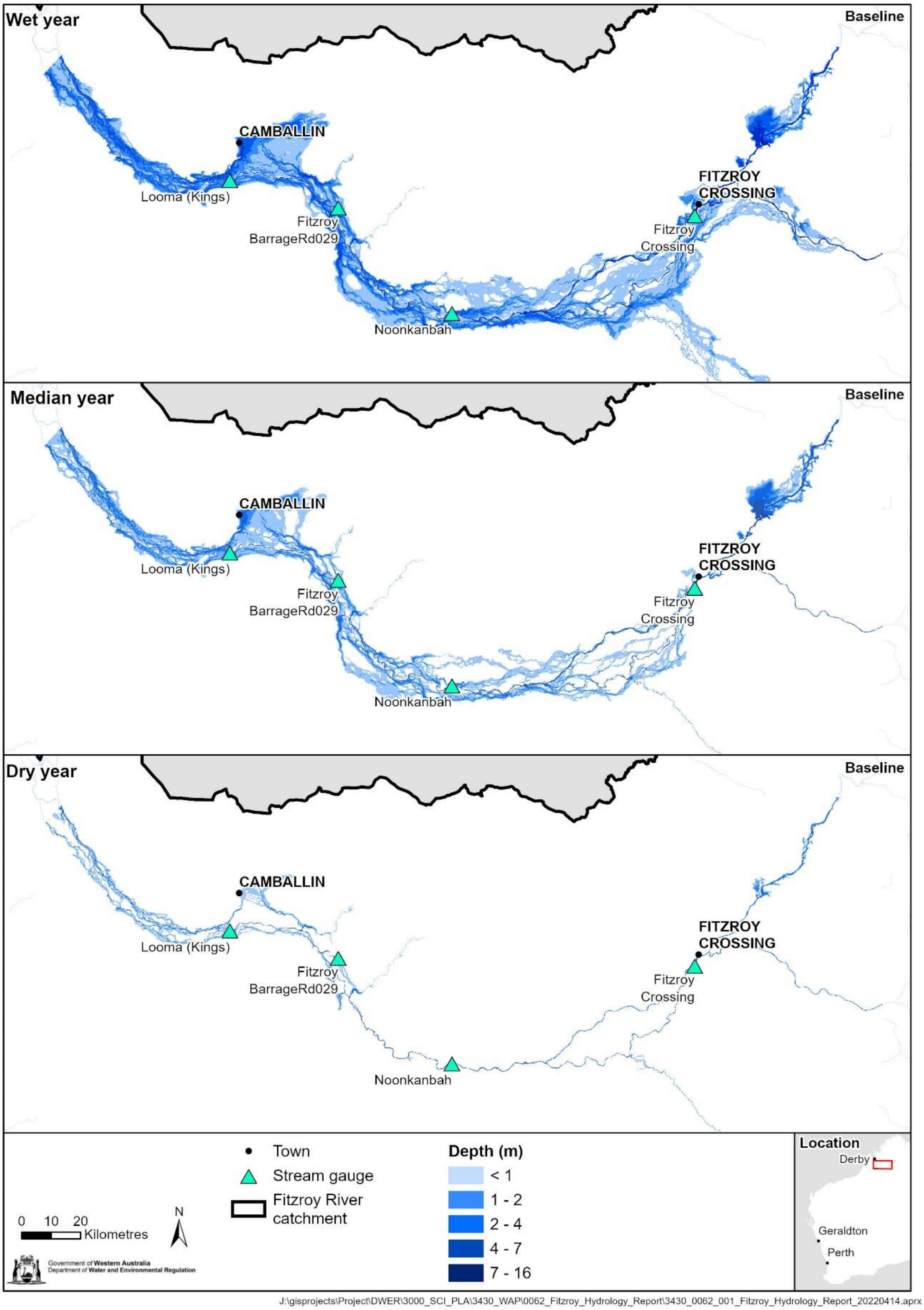

Figure 18 Modelled extent of off-channel wetland inundation in wet/high, average/median and dry/low years

It is reasonable to expect that wetland ecosystems are adapted to the natural variation of flooding that occurs within the Fitzroy River floodplain. However, further information is required to inform ecological water requirements in terms of the flow required to connect the river to floodplain habitats.

Further work

Development and pastoral activities that take or use water on the floodplain, as well as climate change, have the potential to accelerate the drying of wetlands. Rather than develop an ecological water requirement, this hydro-ecological outcome can be met by implementing management to avoid or minimise the risk an activity may have on the connectivity between the river and floodplain habitats. Management strategies can include implementing best-practice land management in pastoral activities and considering the risk of water development impacting the water regime supporting off-channel wetlands.

This mapping exercise did not consider the health or condition of the wetlands or their habitat value. Vegetation condition assessment and flora and fauna surveys should form part of the investigations supporting any water development that has the potential to cause a change in the water regime supporting off-channel wetlands.

H River and estuary connectivity

The values report (DWER 2023a) explained the importance of large flows that connect the river to the estuary and King Sound for recruitment of fish, including the conservation listed Freshwater sawfish, Cherabin (see hydro-ecological outcome D) and iconic Barramundi.

Hydro-ecological outcome

The Freshwater sawfish has a marine and a freshwater phase. Pupping happens in estuaries and river mouths with females birthing up to 12 young. During most wet seasons, juveniles move into the main channel of the Fitzroy River and out into flood runner channels (Whitty et al. 2017). However, successful recruitment events, as indicated by a high number of larger juveniles caught in freshwater pools, are much less frequent (Lear et al. 2019). In fact, the long-term monitoring program run by Murdoch University recorded recruitment success in only 3 out of 17 years between 2002 and 2018.

These recruitment events, in 2008–2009, 2010–2011 and 2016–2017, corresponded to the three highest flow years in the 17-year period (Lear et al. 2019). It was also noted that during the most successful recruitment years of 2010–2011 and 2016–2017, two large flood pulses occurred.

Barramundi also require occasional high-level flows for successful recruitment. A recent study by the University of Melbourne and the La Trobe, Murdoch and Charles Darwin universities (Morrongeiollo et al. 2020; Roberts et al. 2021) analysed ‘growth rings’ in otoliths (ear stones) of 310 fish caught in the Fitzroy River between 2001–2004 to determine fish age and reveal the flow years where most fish were spawned.

The study found that fish varied in age between 2 to 18 years and that most fish collected in the river were spawned during years with high wet-season flow followed by relatively high-flow dry seasons with short no-flow duration (Morrongeiollo et al. 2020).

The hydro-ecological outcome for river pool and estuary connectivity is:

> **H Occasional, very high flows that support Freshwater sawfish and Barramundi recruitment during the wet season.**

Ecological water requirement

Lear et al. (2019) used statistical modelling to determine which high-flow metrics were the best predictor of Freshwater sawfish recruitment events. They determined this to be a river height/depth of 8.1 m (discharge rate of 175 GL/day), maintained at the Willare gauging station (802008) for longer than 8 days (Lear et al. 2019). However, appreciable recruitment only occurs when 8.1 m is exceeded for 14 or more days.

Figure 19**Error! Reference source not found.** shows the duration of high-flow events from 1998–1999 to 2018–2019. Although 1998–1999, 1999–2000 and 2000–2001 were classified as high-flow years, sawfish surveys did not start until 2002. It is, however, likely that successful recruitment occurred in these three years (Lear pers. Comm).

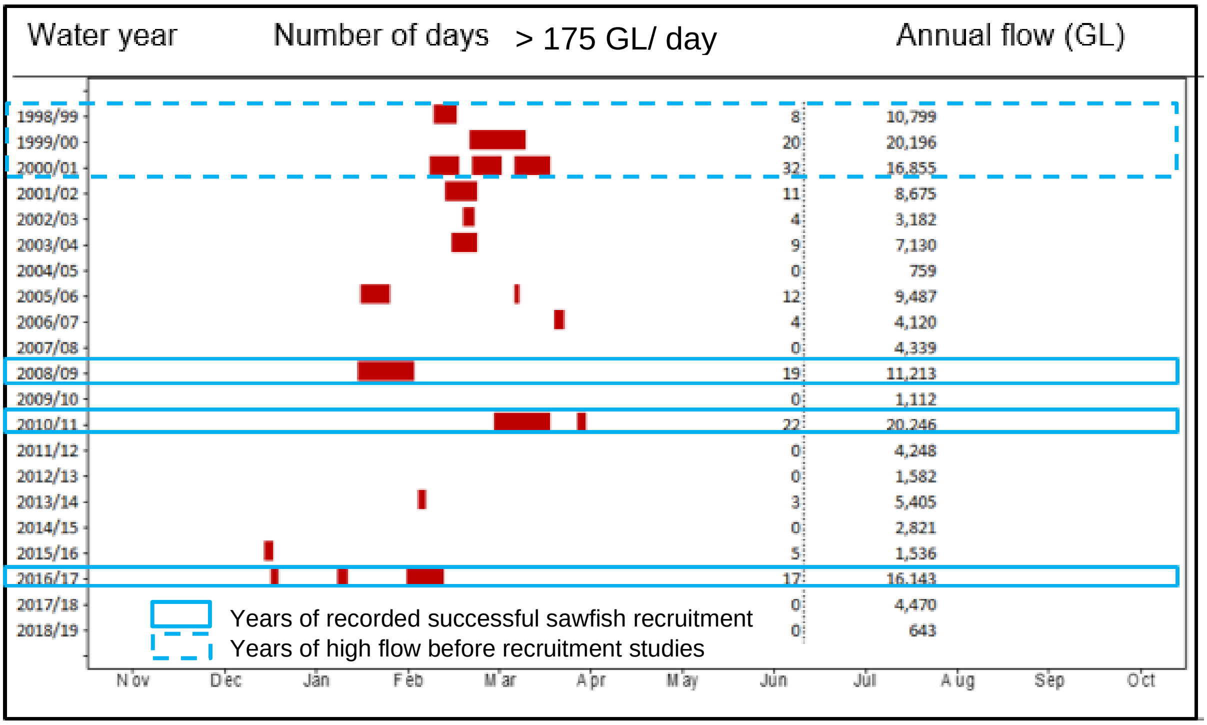

Figure 19 Duration of 'high-flow' conditions suitable for sawfish in days each year from 1998–1999 to 2018–2019 measured at Willare gauging station (802008)

The flow to meet this outcome is 175 GL/day (8.1 m river height/depth) for 14 days measured at Willare in any given wet season (not every wet season). Both Sawfish and Barramundi require occasional flows of this level (possibly 1 in 4 years) for successful or enhanced recruitment.

> Ecological water requirement to provide occasional very high-level flows to support Freshwater sawfish and Barramundi recruitment (Hydro-ecological outcome H):
>
> - 175 GL/day (8.1 m river height) for 14 days measured at Willare gauging station in any given wet season (not every wet season)

Further work

As high-flow years were recorded in 5 out of 20 years, we may set the high-flow requirement as a 1 in 4-year event. However, further regional scale assessment is required to determine if this is hydrologically appropriate given the variation in annual flows in the Fitzroy River.

I Scouring flows

A scouring flow is a short-duration, high-discharge event that is usually associated with periods of heavy rainfall. The values report (DWER 2023a) explained that scouring flows are important in maintaining existing channel morphology (pools, bars, riffles) and support large flushes of nutrients into King Sound (Storey et al. 2001; McJannet et al. 2009).

Hydro-ecological outcome

High-volume flows help maintain pool depth and water quality by removing accumulated sediment and detrital material that can fill pools and make them unsuitable as habitat and for fishing (Storey et al. 2001; Pollino et al. 2018; McJannet et al. 2009). Pig-faced turtles (*Carettochelys insculpta*) in the Daly River Northern Territory rely on scouring flows to rework and clean sandbanks needed as nesting sites (Erskine et al. 2003). In the absence of the high flows that change channel morphology, in-stream habitat complexity (pools, bars, riffles) can be lost.

Scouring flows also prevent the build-up of vegetation and large wood (logs) on the riverbed or the river mouth (Trayler et al. 2003) and reduce the abundance and cover of weed species (Storey et al. 2001). Although very high flows can destroy riparian vegetation, they are not common. Years with smaller scouring flows allow the development of the existing trees and the recruitment of younger individuals, thereby providing a diversity of habitat and resilience in riparian vegetation communities.

The hydro-ecological outcome for scouring flows is:

I Occasional, short-duration, very high flows scour river pools, bars, and riffles to maintain channel morphology, providing a diversity of aquatic habitat.

Ecological water requirement

The frequency and magnitude of scouring flows needed to scour the Fitzroy River are yet to be specifically described. However, the occasional very high-level flows are needed for successful Freshwater sawfish and Barramundi recruitment (Outcome H) (Lear et al. 2019) and are likely to have also resulted in scouring of river reaches along the lower Fitzroy River. The high-level flow was modelled as 175 GL/day for 14 days in any given wet season. Although, it is physically probable that short duration events would also result in sufficient scouring to support this requirement.

> Ecological water requirement to maintain scouring flows (Hydro-ecological outcome I):
>
> - 175 GL/day (8.1 m river height) for 14 days measured at Willare gauging station in any given wet season (not every wet season)

Further work

Further regional scale assessment could confirm that flow at a magnitude of 175 GL for 14 days is sufficient to scour river reaches along the lower Fitzroy River or may determine that shorter duration and lower magnitude flows delivers the same hydro-ecological outcome.

A local ecological water requirement study and baseline data can be used to define scouring flows within a specified reach/ study area. These data could provide an ecological water requirement for river reaches upstream of the Camballin Barrage or on major tributaries.

5.3 End of wet season

This section describes the ecological water requirements for river pools and off-channel wetlands towards the end of the wet season (Figure 20) and the importance of flows from previous wet seasons.

J Recessional flows

Other hydro-ecological outcomes related to wet-season flows have discussed connectivity between river pools (Outcome D), between the river and flood-runner channels (Outcome F), and between the river and the broader floodplain (Outcome G). Flows at the end of the wet season (Figure 20) are equally important.

The values report (DWER 2023a) explained that the duration of within-bank flows at the end of wet season is an important determinant of the recruitment and growth rate of fish species in the Fitzroy River (Lear et al. 2020b).

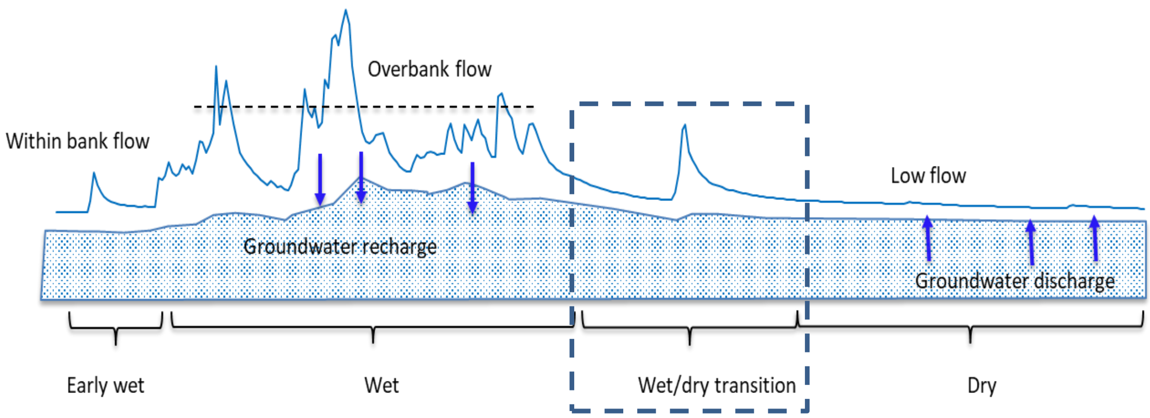

Figure 20 End of wet season (transition to dry) water regime components

Hydro-ecological outcome

Recessional flows towards the end of the wet season trigger juvenile Cherabin (*Macrobrachium spinipes*) to migrate up the river. End-of-season flows also signal Freshwater sawfish (*Pristis pristis*) and Barramundi (*Lates calcarifer*) to move out of floodplain wetlands and into deep, persistent river pools on the main channel and large tributaries.

The duration of within-bank flows at the end of wet season also appears to be an important determinant of the recruitment and growth rate of other fish species in the Fitzroy River (Lear et al. 2020b). Studies in other northern Australian rivers also indicate that recessional flows maintain soil moisture that supports seed germination and growth of riparian and floodplain vegetation (Pettit & Froend 2001; McLean 2014).

<u>Cherabin</u>

The values report (DWER 2023a) described the importance of Cherabin to indigenous harvest and recreational fishing in the Fitzroy, and as a critical part of the diet for Barramundi and Freshwater sawfish.

Cherabin larvae develop in estuarine/brackish waters before post-larval young migrate upstream in the two months following the end of the wet season (generally April and May) (Novak et al. 2017). The velocity of these recessional flows is lower than earlier wet season flows, allowing Cherabin to safely move through the main river and, in some instances, out into nearby off-channel wetlands to avoid predation.

Although there is currently little data on Cherabin migration in the Fitzroy, there is anecdotal evidence that they move upstream and climb the wall of the barrage towards the end of each wet season (ABC Kimberley, 19th February 2019; Luke Donovan pers. comm April 2023). This evidence is supported by studies on the Daly River, a large unregulated system in the Northern Territory, which found that the greatest movement of young Cherabin occurred in April and May, highlighting the importance of recessional flows (Novak et al. 2015; Novak et al. 2017).

Freshwater sawfish and Barramundi

The values report (DWER 2023a) explained that the Fitzroy River and its estuary provide a critical nursery for the Freshwater sawfish (*Pristis pristis*).

Flows at the end of the wet season signal juvenile Freshwater sawfish and Barramundi to move from the floodplains back into the main channel. Research by Crook et al. (2019) in the Northern Territory found Barramundi commonly return to the same river pools each year, even when potential habitat is available much closer to their wet-season habitats. If flows are too low, sawfish can become stranded in drying floodplain wetlands and may perish.

The hydro-ecological outcome for recessional flows is:

J Recessional flows at the end of the wet season support fish and Cherabin migration to refuge habitats.

Ecological water requirements

The magnitude and timing of recessional flows that signal migration of fish and Cherabin are not specifically described for the Fitzroy River. However, there is sufficient understanding of the life history of Cherabin, Freshwater sawfish and Barramundi to understand the importance of recessional flows.

We assessed river flow data from the Fitzroy Barrage gauging station to determine the timing of recessional flows on the Fitzroy. Results showed:

- 20 per cent occurs in December and January (early season flows)
- 75 per cent of the flow occurs in February and March (peak flows)
- 5 per cent occurs in April and May (recessional flows) (Figure 21).

These results clearly show that recessional flows at the end of the wet season predominately occur in April and May, coinciding with the observed migration of Cherabin in other unregulated northern rivers (Novak et al. 2015; Novak et al. 2017).

The drought conditions of the 2019 wet season (lowest recorded since 1992) led to early recessional flows, and Cherabin were observed climbing over the barrage on 19 February 2019 (Beesley et al. 2023). They were observed again on 6 April 2020 after a higher-than-average wet season and in February 2023 after record flooding.

Flow depth was unavailable for the 2023 event as the gauging station was damaged in the floods; however, we considered the depth of flow over the barrage recorded on those dates in 2019 and 2020 (0.05 and 0.55 m respectively) as representative of depths that allow Cherabin to climb over the barrage and move upstream into refuge habitats.

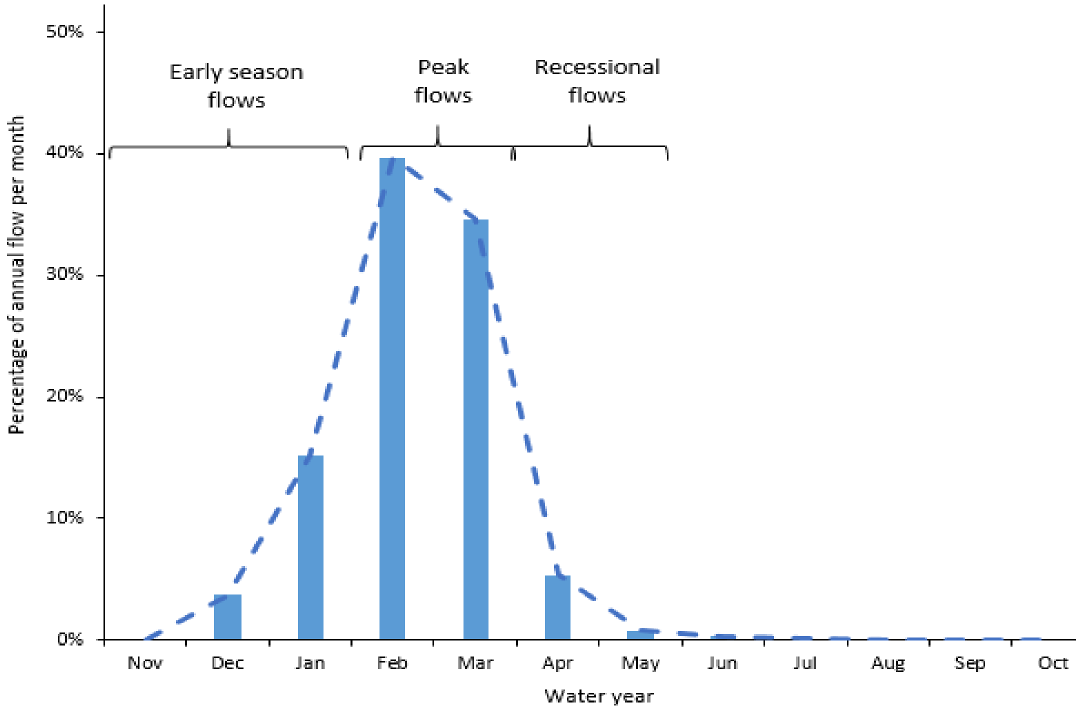

Figure 21 Average annual distribution of flow at the barrage (1992-2019)

Researchers from the Freshwater Fish Group at Murdoch University determined that Barramundi and other large-bodied fish species can move over the barrage when flows are 0.60 m deep (Morgan et al. 2011c) (See Hydro-ecological linkage E, Table 4).

Ecological water requirement to maintain recessional flows to support fish and Cherabin migration to refuge habitats (Hydro-ecological outcome J):

- Cherabin: 0.05 m – 0.55 m depth of water flow over the Camballin Barrage
- large-bodied fish species: 0.60 m depth of water flow over the barrage
- other fish species: maintain all flows during April and May.

Further work

The ecological water requirements described here focus on flows over the Camballin Barrage, as the largest impediment to movement of aquatic fauna on the Fitzroy River. However, a local ecological water requirements study and baseline data can be used to determine flows required in upstream reaches of the Fitzroy River and major tributaries to support migration of fish and Cherabin to dry season refuges. Further work is also required to describe the range of end-of-wet season flows under which Cherabin can traverse the barrage wall.

K Preceding wet season flows (antecedent conditions)

The values report (DWER 2023a) explained that the river flow from the preceding wet season, or antecedent flow conditions, has an influence on aquatic ecosystems in the following dry season. This effect includes all flow conditions, from very low (<1,500 GL) to very high (>20, 000 GL).

Hydro-ecological outcome

In the Fitzroy researchers from UWA/NESP found Fork-tailed catfish have their greatest fat reserves in years following moderate-to-high wet-season flows (2008–2009 and 2018–2019) and smaller reserves in a year that followed a very low-flow wet-season (2019–2020) (Beesley et al. 2021a). Sufficient fat reserves allow catfish to survive the dry season when food is less available. When fat stores are depleted. fish can have lower reproductive output or defer reproduction for an entire year. or they may even die (Beesley et al. 2021b). They also found that in a low-flow year (2019–2020) the number of fish species in flood-runner pools was lower than following wetter years (2008–2009 and 2018–2019) (Beesley et al. 2021b).

Murdoch University's long-term Fitzroy fish dataset (2008–2019) suggests if successive very dry years occur, populations of wet-season spawning fish diminish (Lear et al. 2020a; Lear et al. 2023). Conversely, successive very wet years may negatively impact dry-season spawners. Either scenario could result in fish species assemblages being dominated by one type of spawner. Based on natural breakpoints in wet season discharge volumes over this period, Lear et al. (2020a; 2023) considered low volume as <2,000 GL, medium volume 2,000 – 6,500 GL and high volume >10,000 GL.

Lear et al. (2021) also examined the Murdoch University dataset to describe how the severity in cycles of intermittent drought and magnitude of wet season flooding affects growth of Freshwater sawfish in the Fitzroy. They found that sawfish lost body condition throughout the dry season in all years of the study (2008–2019). This finding indicates that regardless of wet season volume, sawfish use more energy than they can acquire through feeding. However, body condition was significantly lower in dry seasons following low-volume wet seasons. This finding suggested sawfish are less resilient to the prolonged energy-limited periods in these years. Lear et al. (2021) suggested the lower resilience is likely due to lower food resource availability related to lower-volume wet seasons.

Research on estuaries in the Gulf of Carpentaria found that successive poor wet seasons reduce the area of aquatic habitats, negatively impacting recruitment, growth and survival of Barramundi (Burford et al. 2021). Barramundi and other species using estuaries were also found to be most sensitive to changes in river flow during and immediately after successive years of below average (median) flow (Burford et al. 2021).

A study of macroinvertebrates in five Northern Territory rivers found that antecedent flow characteristics of the most recent dry and wet seasons influenced community structure (Leigh 2013) and that short, wet seasons may reduce macroinvertebrate resistance and resilience to extended dry seasons (Leigh 2013; Leigh et al. 2015). Results also suggested that increased occurrence of extreme events, such as floods and droughts, will change water quality, habitat availability and connectivity (Leigh et al. 2015).

Antecedent conditions also shape populations of Magpie geese, Saltwater crocodiles, turtles, and some snakes due to influences on recruitment and survival of juveniles (Bayliss 1989, Fukuda and Saalfeld 2014, Doody et al 2003, Shine and Brown 2008).

The hydro-ecological outcome for preceding wet season flows is:

> **K Within bank and overbank flows from preceding wet season(s) should be considered to identify the likelihood of cumulative impacts from successive poor wet seasons.**

Ecological water requirement

Very large wet seasons, for example as occurred during 2010–2011 (Figure 22) and extensive flood events such as the recent record high flow of 2022–2023, cannot be predicted, controlled, diverted or managed. However, it is possible to consider the impact that a very low-flow wet season can have on the next dry season.

As outlined in hydro-ecological outcome D, a very low-flow year is defined as having a cumulative flow of less than 1,500 GL between 1 November and 30 April at Fitzroy Barrage gauging station. This volume is equivalent to the 10th percentile flow over the long-term modelled flow period (1890 to 2015).

Although four years of very low flow (<1,500 GL) were recorded at the barrage between 1991–1992 to 2020–2021, none of these were consecutive (Figure 22). However, between 2012–2013 and 2015–2016 the average annual flow was ~3,700 GL with two years below 2,000 GL and a third below 3,000 GL. Flows under 3,000 GL are considered low-flow years.

There is evidence that consecutive low-flow years may negatively impact the diversity and abundance of aquatic fauna, particularly in off-channel wetlands and creeks (Lear et al. 2020a; Lear et al. 2023). However, further information is required to identify a trend or demonstrate the impact of extended dry conditions on the flora and fauna of the Fitzroy River.

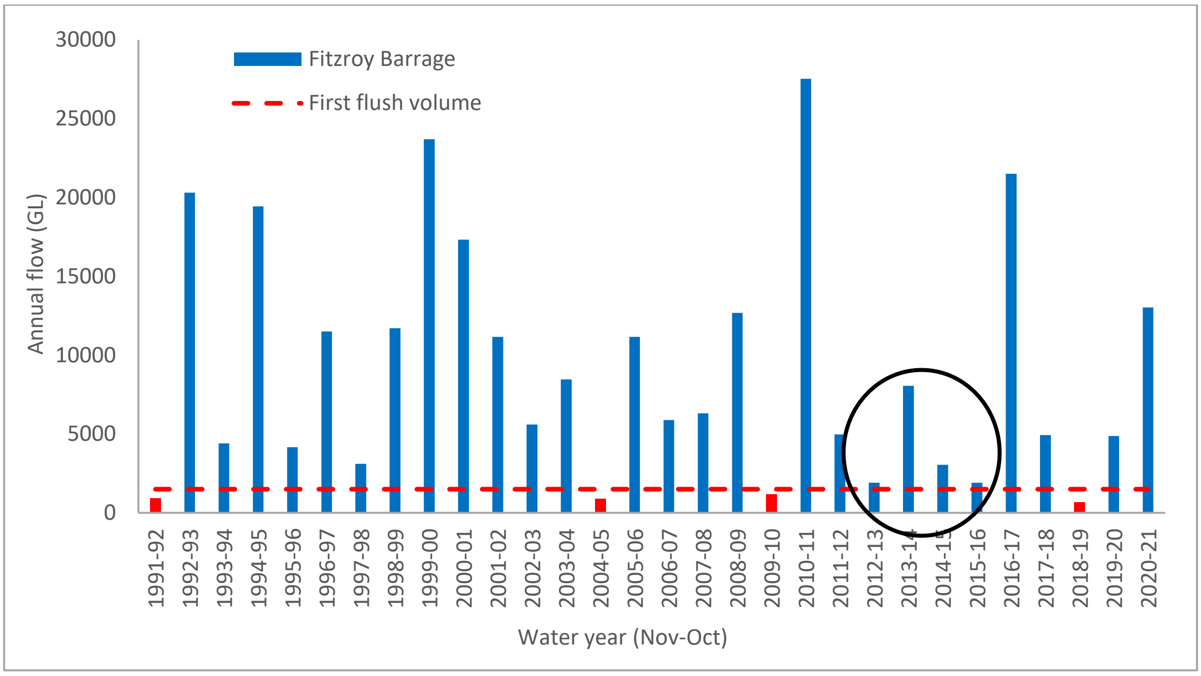

Figure 22 Years (1991–2021) when very low flow occurred (<1500 GL) and series of low-flow (dry) years from 2012–2013 to 2015–2016

Further work

Further regional scale assessment is required to determine the ecological water requirement for antecedent conditions. Although flow in any wet season is difficult to predict, there are strategies that can be put in place to ensure the impact of the take and use of water is minimised if successive low-flow years occur. For example, a minimum cumulative flow required during the upcoming wet season may be determined to ensure aquatic ecosystems persist through the next dry season.

Although a first flush or freshening flow greater than 1,500 GL is sufficient to reconnect river pools, further work is required to determine if this volume should be higher following consecutive years of very low flow and if not, what it should be.

6 Riparian and floodplain vegetation

Narrow zones of riparian vegetation fringe the Fitzroy River's main channel and larger tributaries. Healthy riparian vegetation is important to river health and provides a relatively productive ecosystem in an arid environment (Douglas et al. 2005; van Dam et al. 2005).

The values report (DWER 2023a) explains that riparian vegetation of the Fitzroy also provides habitat for terrestrial fauna including the conservation-listed Purple-crowned fairy wren (*Malurus coronatus coronatus),* Red goshawk (*Erythrotriorchis radiatus),* Gouldian finch (*Erythrura gouldiae)* and Northern quoll (*Dasyurus hallucatus).*

A vegetation distribution model developed by UWA/NESP (Canham et al. 2021) showed that species were grouped into distinct hydro-ecological habitats defined by distance from the river. These are riverbank, top-of-bank, floodplain and off-channel wetlands (Figure 23) and are described and characterised in Freestone et al. (2021).

Figure 23 Riverbank, top-of-bank, floodplain and off-channel wetland vegetation habitats

Riverbank and top-of-bank habitats form the riparian zone (Figure 23) (Freestone et al. 2021; Freestone et al. 2022). While riverbanks are steep, the top-of-bank habitats are relatively flat. Four tree species generally dominate these habitats, specifically *Melaleuca argentea* (Silver-leafed Melaleuca), *Barringtonia acutangula* (Freshwater mangrove), *Melaleuca leucadendra* (Green-leafed Melaleuca) and *Eucalyptus camaldulensis* (River red gum) (Figure 24).

Floodplain vegetation extends from the main channel and riparian zone outwards across much of the flat, open floodplain area and along off-channel wetlands (Figure 23) (Freestone et al. 2021; Freestone et al. 2022; Canham et al. 2021). Inundation during flooding and the frequency of high-flow events are strong drivers of species distribution (Pettit et al. 2001). Depth to groundwater is less a driver of distribution but has a role in areas over shallow aquifers.

Eucalyptus microtheca (Coolibah) is the most dominant species on the floodplain. It is also dominant on off-channel wetlands with *Eucalyptus camaldulensis* and some *Terminalia platyphylla* (Wild plum) (Freestone et al. 2021; Freestone et al. 2022; Canham et al. 2021) (Figure 24).

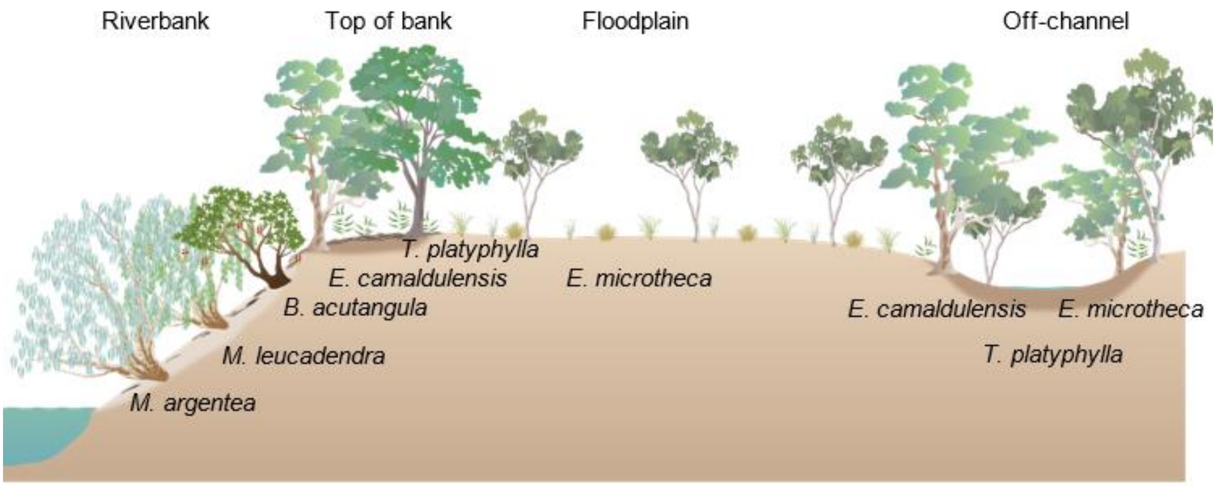

Figure 24 Distribution of key tree species across riparian, floodplain and off-channel wetland habitats (courtesy UWA/NESP)

6.1 Wet season

This section describes the ecological water requirements for riparian and floodplain vegetation across the within bank and overbank flow components of the wet season water regime (early November to end of April) (Figure 25).

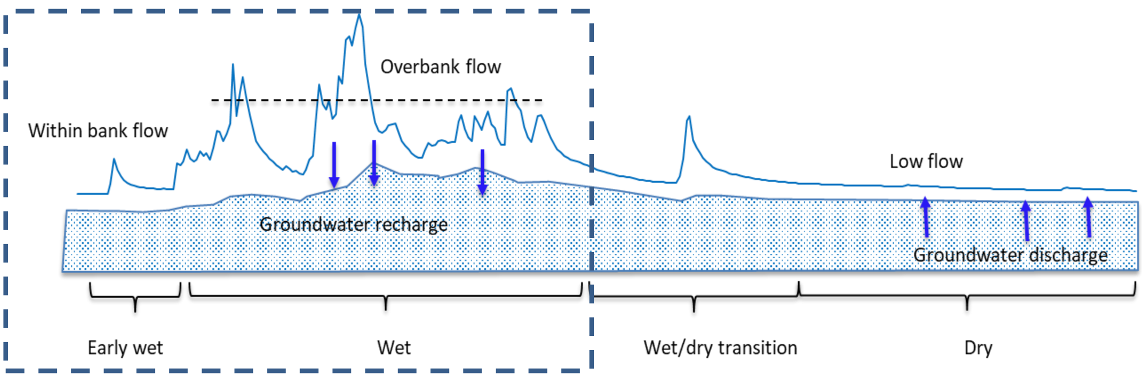

Figure 25 Wet season water regime components important to riparian and floodplain vegetation

L River flows to recharge the Alluvial aquifer and replenish soil moisture

The values report (DWER 2023a) explains that the Alluvial aquifer along the Fitzroy River mirrors the floodplain extent and is in hydraulic connection with the underlying regional aquifers and with the river and its tributaries. Wet season flood events recharge the Alluvial aquifer and, as the river levels decline in the dry season, the gradient is reversed, with water stored in the Alluvial aquifer flowing back into the river (Harrington & Harrington 2015).

Hydro-ecological outcome

In 2017 the State Groundwater Investigation Program (SGIP) installed groundwater monitoring bores (LF01, LF02, LF03B, LF04B, LF05) close to the river in the Camballin area (Figure 26) to measure levels in the Alluvial aquifer (DWER 2023b) (see Outcome O). We compared groundwater and surface water information gathered from three Alluvial aquifer bores and three streamflow gauging stations (Looma, Fitzroy Barrage & Fitzroy Crossing) (DWER 2023b).

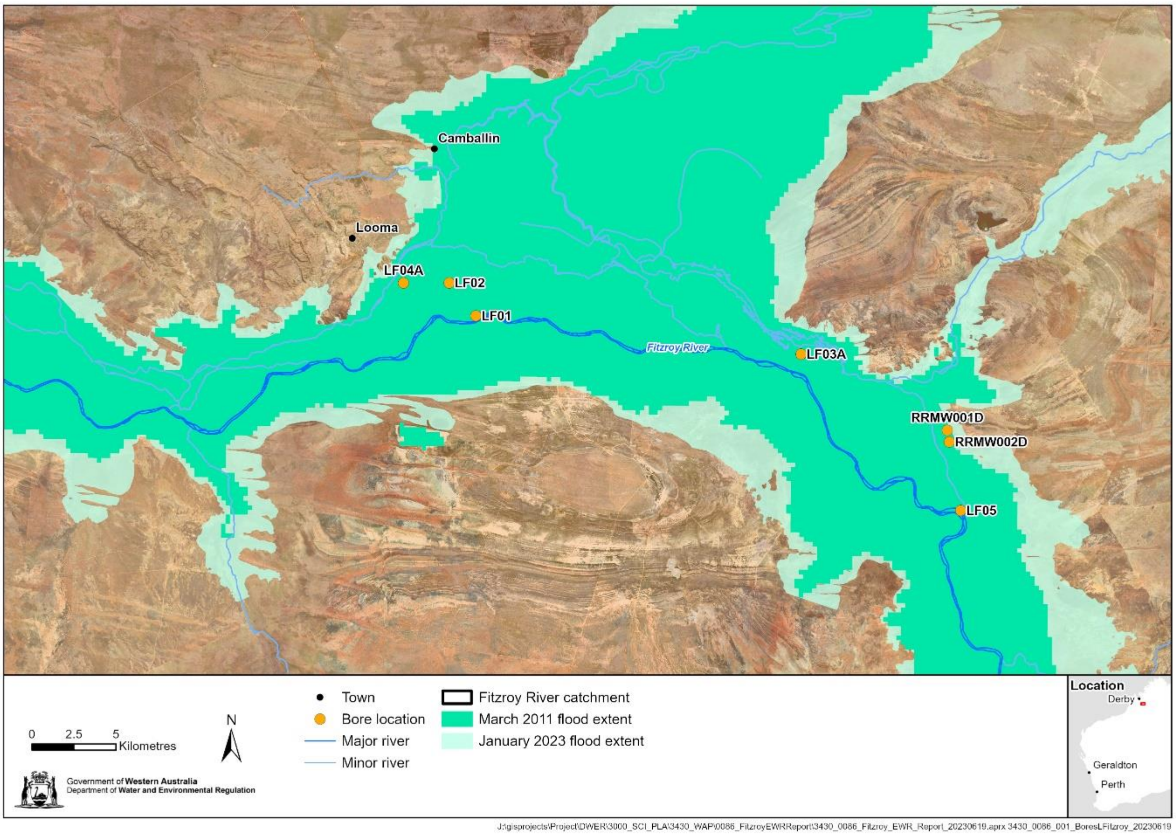

Figure 26 Location of LF (Lower Fitzroy) series bores and extent of floods in 2011 and 2023

Data indicates that the connection between the river and the Alluvial aquifer varies spatially, seasonally and interannually. Around Looma, the Alluvial aquifer discharges into the river during the dry season. This is reversed during the wet season and the river recharges the Alluvial aquifer. Around the Fitzroy Barrage and bore LF05, groundwater level monitoring between September 2017 and October 2019 shows there was only a brief interval at the end of the 2017–18 wet season where water from the Alluvial aquifer may have discharged to the river. Therefore, over this two-year period, the Alluvial aquifer was consistently recharged by streamflow. It also appears that surface water is consistently being lost to groundwater at some point or points further upstream along the reach of the river between the Fitzroy Barrage and Noonkanbah gauging stations (DWER 2023b).

Recharge of the Alluvial aquifer also increases plant-available soil moisture in the vadose zone. This is crucial for maintaining the health of riparian vegetation throughout the dry season.

As described earlier, researchers from UWA/NESP investigated vegetation distribution and composition in relation to potential groundwater sources (Canham et al. 2021b) and flood inundation (Freestone et al. 2021; Canham et al. 2021a; Freestone et al. 2022). A further study investigated key functional traits of trees that relate to drought and flood flows in nine common Fitzroy riparian and floodplain trees species (Canham et al. 2022).

This study found species that experience high water availability throughout the year are not physiologically adapted to drought conditions and are most vulnerable to periods of low water availability. The species that are most vulnerable are those on the riverbank in the alluvium:

- the silver-leafed paperbark (*Melaleuca argentea*)
- green paperbark (*Melaleuca leucadendra*)
- freshwater mangrove (*Barringtonia acutangula*), and
- Leichhardt pine (*Nauclea orientalis*) (Freestone et al. 2021; Canham et al. 2021a; Freestone et al. 2022).

The hydro-ecological outcome for river flows that recharge the Alluvial aquifer is:

L Within bank river flows during the wet season recharge the Alluvial aquifer and replenish localised soil moisture to maintain the health of riparian vegetation.

Ecological water requirement

The primary source of groundwater recharge to the Alluvial aquifer is surface water flows during wet season flooding (DWER 2023b). Direct rainfall and groundwater inputs from underlying aquifers also contribute, but to a lesser extent.

In the absence of information on the surface water regimes required to recharge the Alluvial aquifer, the current interannual flow regime with years of low, medium and high flows should maintain the Alluvial aquifer and associated soil moisture required by riparian vegetation.

The extent that the Alluvial aquifer is recharged by wet season flow in the Fitzroy River in a low, medium or high flow year is yet to be described. It is reasonable to expect that high and medium annual flows as well as flood events result in greater recharge of the Alluvial aquifer than would occur in a low-flow year. These recharge events are important to ensure there is sufficient water in the Alluvial aquifer to support riparian vegetation through low-flow years.

Further work

Further regional scale assessment is required to describe the relationship between the volume, frequency, duration and rates of river flow required to recharge the Alluvial aquifer and to support the high-water availability conditions that Fitzroy riparian species are physiologically adapted to. This relationship may be established in the future through ongoing monitoring of water levels in the Alluvial aquifer in groundwater monitoring bores located near to streamflow gauging stations.

M Frequent inundation of riparian vegetation

The values report (DWER 2023a) explains that reproduction, dispersal of propagules and age structure of riparian vegetation are dependent on the natural flow regime (Pettit et al. 2001). Seed fall needs to coincide with suitable flow conditions; for example, as floodwaters are receding and exposing fresh moist soils.

Hydro-ecological outcome

Researchers from UWA/NESP surveyed woody vegetation at 58 sites made up of 15 replicates of four different hydro-ecological habitats. Riverbank and top-of-bank habitats represented the extent of riparian vegetation (Canham et al. 2021a; Freestone et al. 2022) (Figure 27**Error! Reference source not found.**). The aim was to develop a species distribution model that identified the factors that best predicted the occurrence of riparian and floodplain species.

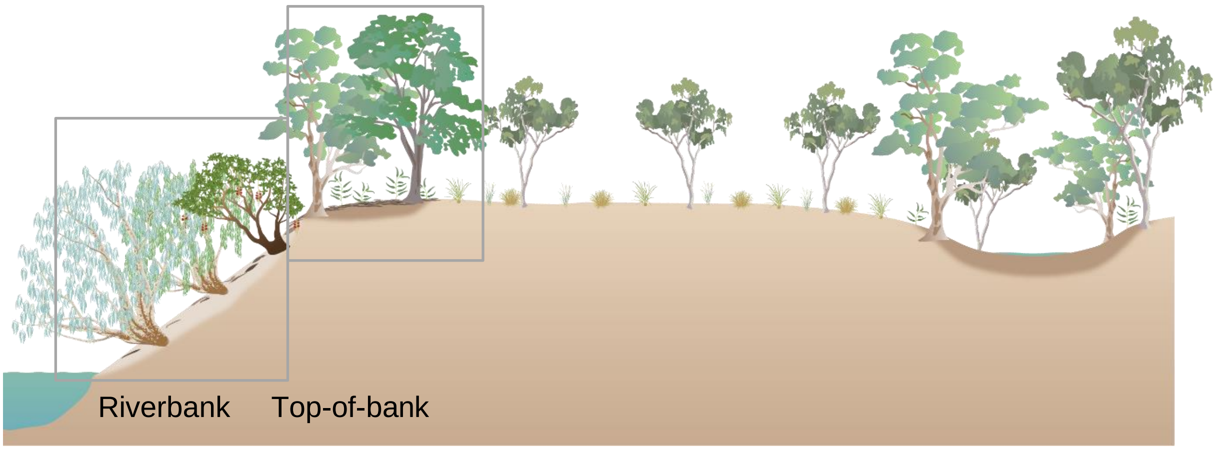

Figure 27 Riparian vegetation zones of the lower Fitzroy River (Freestone et al. 2021)

Barringtonia acutangula (freshwater mangrove), *Melaleuca argentea, M. leucadendra* and *Nauclea orientalis* were restricted to the wetter environments along the main channel and large distributary channels (Canham et al. 2021a) and are the most common species associated with the riverbank sites (Freestone et al. 2021; Freestone et al. 2022).

These species are physiologically adapted to long periods of inundation and high velocity flows. For example, very fine, but dense root mats (aerenchyma tissue) form on the trunks of *M. argentea* to allow the transfer of oxygen when the tree is inundated for a prolonged period of time. The three species are also more likely to be vulnerable to dry season water stress, as they demonstrate relatively lower water use efficiency and lower drought tolerance (as indicated by a high leaf osmotic potential at full hydration) (Canham et al. 2022).

The top-of-bank sites are dominated by *Eucalyptus camaldulensis* and *Atalaya hemiglauca* (Canham et al. 2021a; Freestone et al. 2022). These species are adapted to some inundation disturbance and probably rely on groundwater at the end of the dry season (Pettit & Froend 2018). Figure 28 shows the probability of occurrence of riparian species *Melaleuca argentea, B. acutangula* and *Eucalyptus camaldulensis* fringing the lower Fitzroy River under natural flow conditions.

Ecophysiological studies of the common riparian species identified patterns in tree water use on the lower Fitzroy (Canham et al. 2021b). It was found that trees preferentially used water that was 'easiest' to access. In the case of *Melaleuca argentea, M leucadendra and B. acutangula* this was predominantly surface water or shallow soil moisture, owing to their location on the edge of the riverbank (Canham et al. 2021b).

The hydro-ecological outcome for inundation of riparian vegetation is:

M River flow during the wet season inundates riverbank and top-of-bank habitats to maintain the health of riparian vegetation.

Ecological water requirement

We overlaid CSIRO's surface water model and persistent vegetation mapping (Sims et al. 2018) to illustrate the area of vegetation inundated in representative wet (1999–2000 – ~22, 000 GL), average (2005–2006 – ~8,000 GL) and dry (2012–2013 – <3,000 GL) years (Figure 29). Of note is that riparian vegetation on the main river is inundated to some extent even in the driest year.

The UWA/NESP distribution model identified that the number of days of inundation and the distance to the main river channel were the key drivers in species composition (Canham et al. 2021a). For each habitat type they determined the duration of inundation for a dry (2012–2013 – <3000 GL) and a wet year (1999–2000 — ~22,000 GL), using data from a hydrodynamic model by CSIRO (Karim et al. 2018 cited in Freestone et al. 2022).

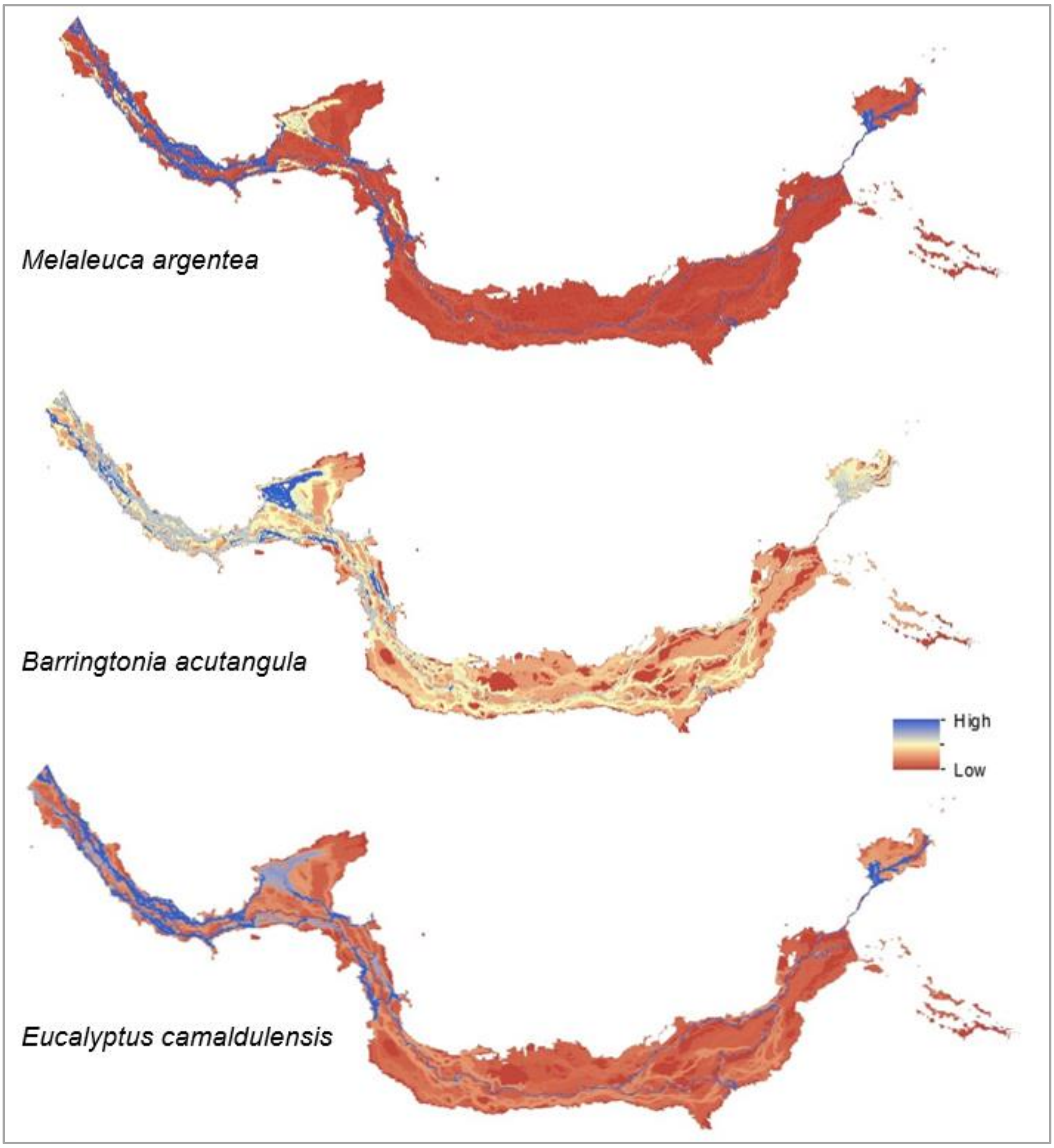

Figure 28 Probability of occurrence of Melaleuca argentea, Barringtonia acutangula and Eucalyptus camaldulensis under natural flow conditions

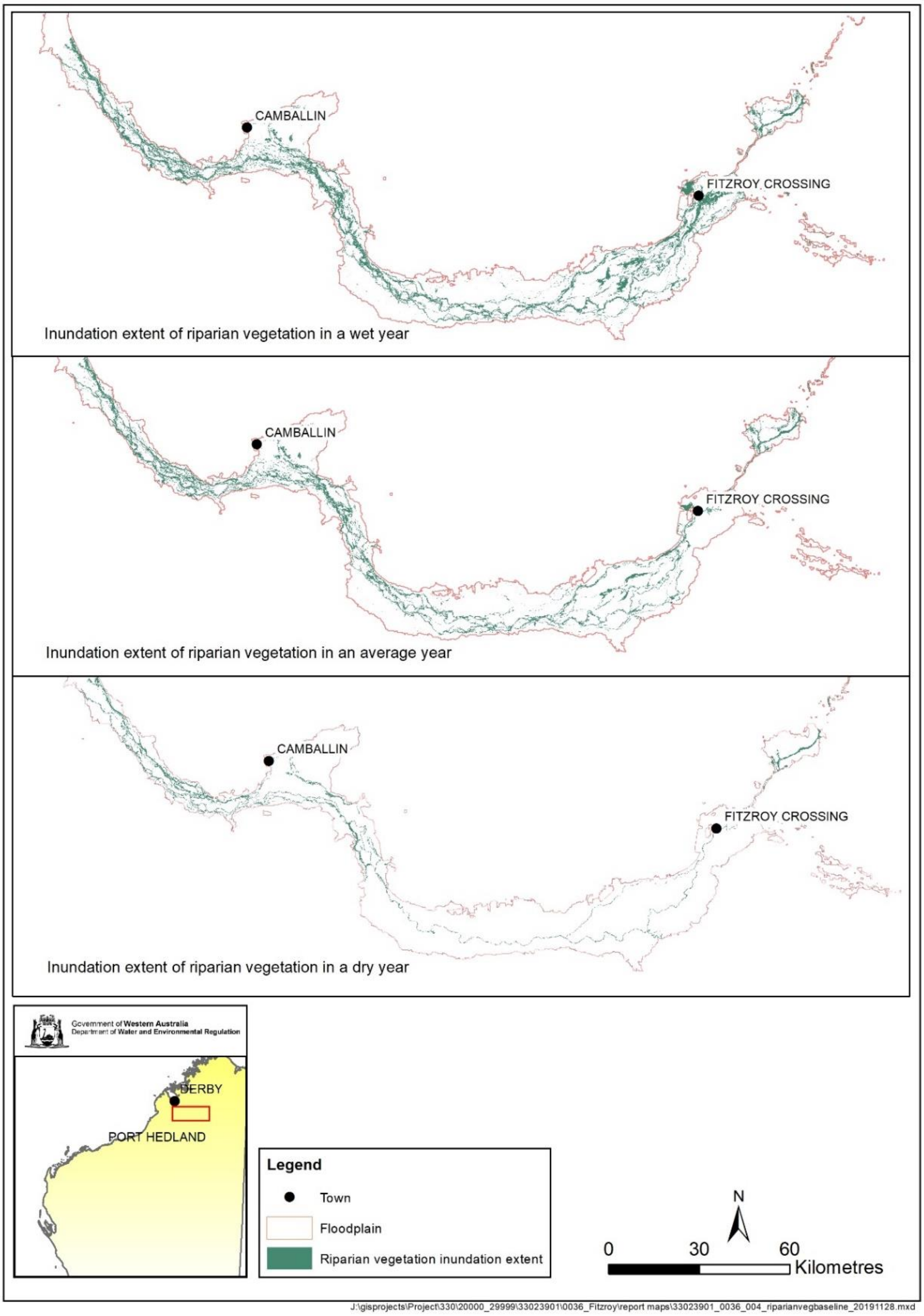

Figure 29 Modelled extent of riparian vegetation inundated in a) wet, b) average and c) dry years

The flow that occurred in a dry year was classified as a 1 in 1 year event – at least 3000 GL flow is likely to happen every year – and the flow that occurred in the wet year as 1 in 11-year event. Table 5 shows that on average even in dry years riverbank and top-of-bank vegetation sites were inundated for at least a month.

Table 5 Estimated duration of inundation of vegetation habitat types in a dry and wet year (from Freestone et al. 2022)

Habitat	Number of sites	Mean (and SE) duration of inundation in days	
		Dry year (2012/13)	Wet year (1999/2000)
Riverbank	16	53 (4)	110 (5)
Top-of-bank	16	37 (7)	100 (6)
Floodplain	17	7 (40)	52 (9)
Off-channel wetland	9	6 (6)	62 (13)

The extent and duration that riparian vegetation is required to be inundated in the wet season to maintain ecosystem health, which may be indicated through recruitment or crown vigour, is yet to be described. It is reasonable to expect that riparian vegetation is adapted to a high degree of inter-annual variation in inundation. However, development in the riparian zone has the potential to reduce the extent and duration of inundation of riparian vegetation, through a reduction in conditions suitable for recruitment of riparian species. This reduction is likely to have a greater impact in a dry and potentially an average year and less so in a wet year.

Further work

Any development that has the potential to reduce or interfere with the extent and duration of inundation of riparian vegetation should establish local ecological water requirements. This should consider the spatially variable relationship between vegetation and hydrology as demonstrated by Canham et al. (2021a) and the impact water use or water diversion may have on the health and condition of riparian vegetation.

N Inundation of floodplain and off-channel vegetation

The values report (DWER 2023a) explains that the distribution of floodplain and off-channel vegetation strongly reflects the area inundated during flooding and the frequency of high-flow events (Pettit et al. 2001).

Hydro-ecological outcome

On the lower Fitzroy River, vegetation extends outwards from the main channel and riparian zone across the floodplain and along off-channel wetlands (Figure 23; Figure 30). UWA/NESP characterised the floodplain habitat type as sparsely covered by *Eucalyptus microtheca* with a canopy cover of less than 30 per cent (Canham et al. 2021a; Freestone et al. 2022). Off-channel wetlands have higher canopy cover than floodplains, with greater species richness and recruitment (Freestone et al. 2022).

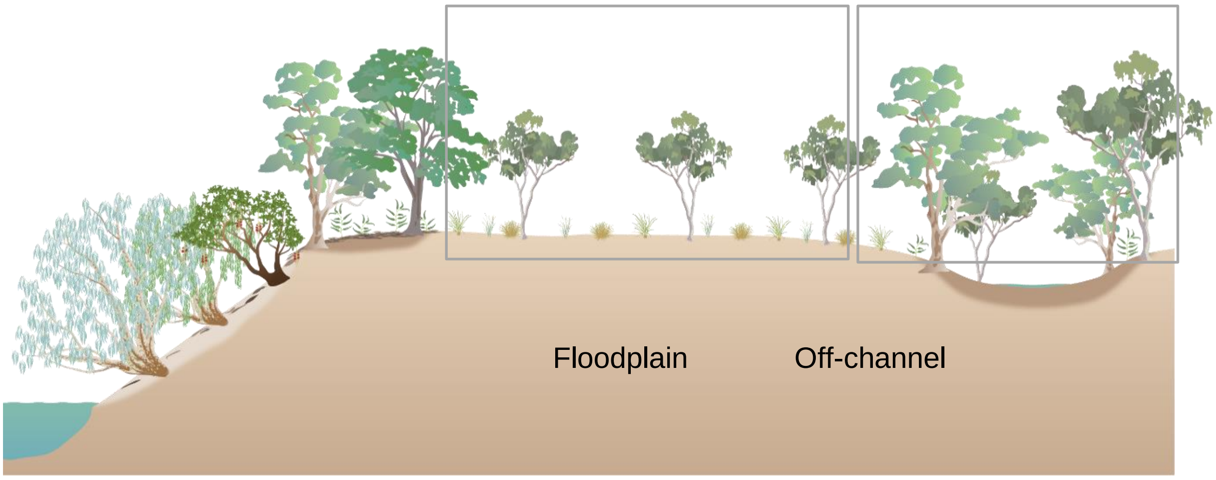

Figure 30 Floodplain vegetation zones of the lower Fitzroy River (Canham et al. 2021)

Although tree species of the floodplain and off-channel wetlands are less tolerant of prolonged inundation than riparian species, they do require periods of inundation for the distribution of seed and to replenish localised soil moisture across the floodplain (Hydrogeological outcome L describes flows to replenish soil moisture and the Alluvial aquifer for riverbank and top-of-bank species).

Floodplain wetlands also support a diverse mix of herbaceous ephemeral species which require flooding to germinate and establish (Brauhart 2021). A soil seedbank study by UWA/NESP investigated the relationship between water availability and the species composition of the soil seedbank across the Fitzroy (Brauhart 2021). Samples were collected from 15 floodplain wetlands and germinated in a glasshouse under different inundation treatments.

The study demonstrated that the composition of species is generally unique to each wetland and suggested that different watering treatments (regimes) stimulate the emergence of different species (Brauhart 2021).

The hydro-ecological outcome for inundation of floodplain vegetation is:

> **N Overbank river flows during the wet season inundate the floodplain to support recruitment and maintain the health of floodplain and off-channel wetland vegetation**

Ecological water requirement

UWA/NESP's species distribution model found Coolibah (*Eucalyptus microtheca)* covers more than 2,800 km^2 of the Fitzroy study area (Figure 31**Error! Reference source not found.**) compared to second most common species *E. camaldulensis* at 1,400 km^2 (Freestone et al. 2022). Although Coolibah was recorded across the four habitat types surveyed – riverbank, top of bank, floodplain and off-channel wetlands – it was the most abundant species in areas not inundated for long periods, occurring at 82 per cent of surveyed floodplain sites and 78 per cent of off-channel sites (Freestone et al. 2020).

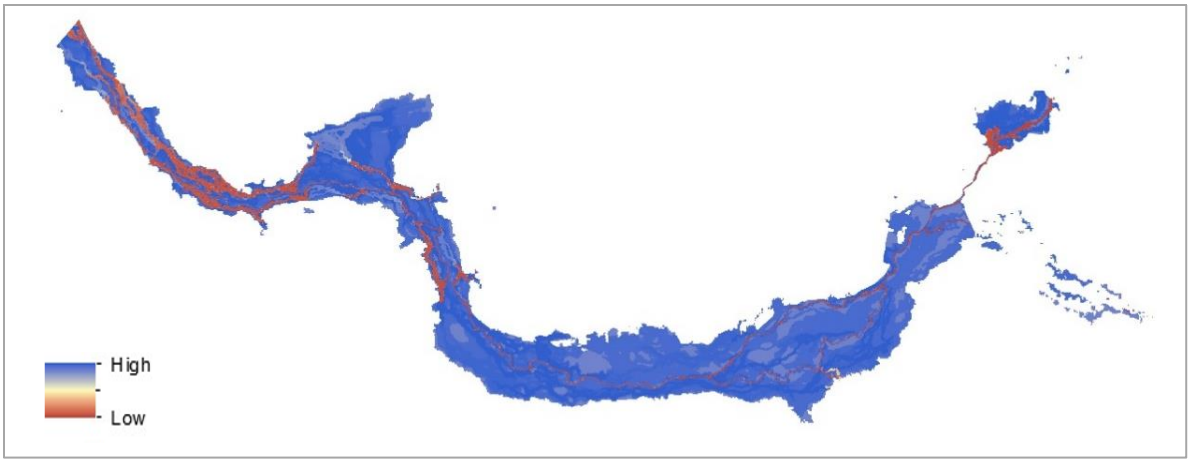

Figure 31 Probability of occurrence of Eucalyptus microtheca along the floodplain of the Fitzroy River under natural flow conditions

Coolibah may be adapted to regenerate after late summer flooding, as germination rates are high at high temperatures (Doran & Boland 1984). The species may also need a sequence of over-bank flow years for seedlings to establish (Roberts & Marston 2000). This would allow seed to be distributed across the floodplain and for soil moisture levels to be maintained over the extended period during the warmer months required to support germination and establishment of seedlings (Pettit & Froend 2001).

Coolibah does however, tolerate long dry periods. Although stable isotope studies showed it accesses shallow groundwater and deep soil water, stomatal conductance continues even when water availability is low (Canham et al. 2021b). This suggests this species is physiologically adapted to tolerate drier conditions (Canham et al. 2022). It is the long periods of limited water availability punctuated by periods of inundation that are likely to favour *E. microtheca's* domination of floodplain habitats (Freestone et al. 2022).

UWA/NESP modelled the duration of inundation for a dry (2012–2013; <3000 GL) and wet year (1999–2000; ~22,000 GL) across four different hydro-ecological habitats including 16 floodplain and 7 off-channel wetland sites (see hydro-ecological outcome M) (Freestone et al. 2022).

Table 5 shows that on average in a dry year, vegetation at these sites was inundated for a week. In a wet year floodplain sites were inundated for 52 days and off-channel wetland sites for 63 days. However, the duration or depth of inundation needed to enable seed distribution, germination and seedling establishment is currently unknown.The study of soil seedbanks provided evidence of a link between seedbank composition and water availability, and therefore a likely link to flood inundation period (Brauhart 2021).

Less frequent, less intense floods than those required by riparian vegetation are likely to be adequate to maintain the condition and persistence of vegetation on the floodplain. However, some larger flow events that inundate the full extent of the floodplain vegetation will recharge and freshen local groundwater, soil water and water in wetlands. Currently, inundation of the outer parts of the floodplain occurs during very large-flow events (e.g. 2023).

Our current understanding is that floodplain species are well adapted to the flooding regimes and groundwater dynamics that occur across the floodplain. However, further information is required to inform ecological water requirements in terms of the extent and duration of inundation required to support recruitment and maintain the health of floodplain vegetation. Development on the floodplain has the potential to impact the extent and duration of inundation and is likely to have a greater impact in a dry and potentially an average year and less so in a wet year.

Further work

Further regional-scale assessment is required to establish the relationship between the composition of soil seedbanks and the period of flood inundation required for successful germination, as there is currently little information available on up to half of the herbaceous species identified in the soil bank study (Brauhart 2021). In addition, the soil seedbank is not always representative of the existing vegetation (Capon & Brock 2005) and further studies are required to determine the current communities of the Fitzroy floodplain wetlands.

Any development that has the potential to reduce or interfere with the extent and duration of inundation of floodplain vegetation should consider the impact on the health and recruitment of floodplain tree species and herbaceous floodplain wetland species.

6.2 All seasons

This section describes the ecological water requirement for groundwater-supporting riparian and floodplain vegetation (Figure 32).

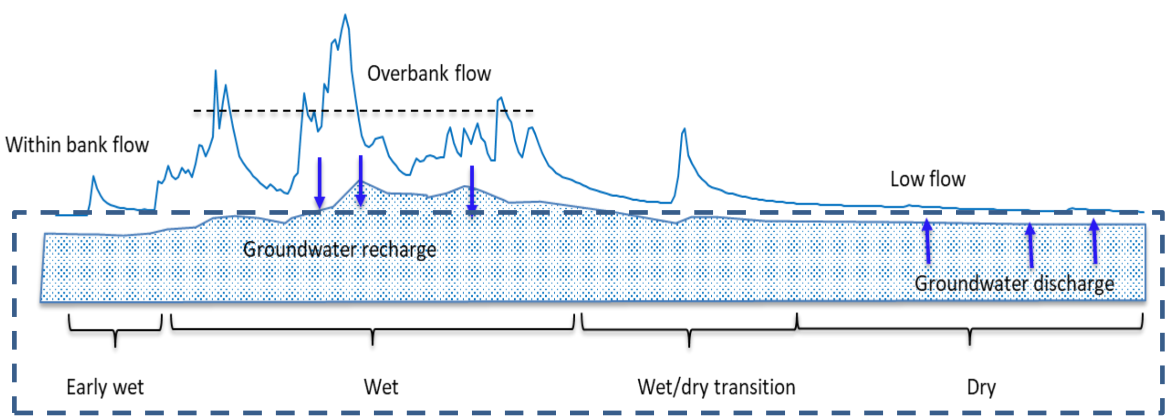

Figure 32 Annual groundwater regime to support riparian and floodplain vegetation

O Groundwater to support riparian and floodplain tree species

The values report (DWER 2023a) explained the importance of groundwater from the Alluvial and/or regional aquifers in supporting riparian and floodplain vegetation throughout the year, but particularly during the dry season and in dry years. The report also provided background on important riparian and floodplain tree species, including their potential water sources (DWER 2023a).

Hydro-ecological outcome

Dominant riparian tree species on the Fitzroy River – *Melaleuca argentea* (Silver-leafed Melaleuca), *Barringtonia acutangula* (Freshwater mangrove), *Melaleuca leucadendra* (Green-leafed Melaleuca) and *Eucalyptus camaldulensis* (River red gum) are restricted to areas where the depth to groundwater is shallow or trees have direct access to permanent surface or soil water derived from the river (Canham et al. 2021a). Here larger (relatively) deep-rooted riparian vegetation relies on groundwater to meet at least part of its water requirements (O'Grady et al. 2006; Zolfaghar et al. 2014).

The dominant floodplain tree species, *Eucalyptus microtheca* (Coolibah) tolerates long periods between flooding by accessing shallow groundwater and soil water and can maintain photosynthesis even when water availability is low (Canham et al. 2022).

To maintain the health and vigour of riparian and floodplain trees, groundwater needs to remain at a depth or range of depths accessible to tree roots (Zolfaghar et al. 2014). Seedling establishment and continued growth may also be dependent on floodwater or rainfall stored in the soils or shallow groundwater, whichever source is easiest for vegetation to access (Bunn et al. 2006; Canham et al. 2021b).

Currently, quantitative information suggests reduced importance of groundwater to riparian and floodplain tree species where depths exceed 10 m. However, it is assumed that at depths of 10–20 m trees can also use groundwater (Zencich et al. 2002; Eamus et al. 2006) especially in areas of low surface water or rainfall availability.

In 2017 the State Groundwater Investigation Program (SGIP) installed five groundwater monitoring bores to measure levels in the unconfined Alluvial Aquifer (DWER 2023b) (Figure 27). The 2017–18 average depths at these bores were less than 10 m.

Shallow depths to the alluvial aquifer suggest riparian and floodplain vegetation is highly likely to be accessing groundwater for at least part of the year. This evidence is supported by the correlation of riparian woodland distribution with areas of shallow groundwater.

The hydro-ecological outcome for groundwater availability for riparian and floodplain vegetation is:

> **O Groundwater depth is maintained within the range of tree roots to maintain the health of riparian and floodplain tree species throughout the year.**

Environmental water requirement

UWA/NESP undertook a groundwater sources study during the 2018–2019 dry season (August 2019), at two sites on the Lower Fitzroy (Canham et al. 2021b). One site at Myroodah Crossing sits over the alluvial aquifer where depth to groundwater was < 10 m. The study found that trees here used a mix of groundwater (alluvial), water from shallow and deep soils and river water (Canham et al. 2021b). In the dry season this is more likely to be restricted to deep soil moisture and groundwater, recharged by river flows from the previous wet season.

At the second UWA/NESP study site near Noonkanbah there is faulting in the Noonkanbah formation which underlies the Liveringa and Alluvial aquifers and river itself (Canham et al. 2021b). The faults facilitate groundwater discharge from the deeper confined Grant-Poole aquifer to the near surface (Canham et al. 2021b). This is illustrated in Figure 12.

The shallow depth to groundwater recorded at the SGIP and other bores supports the idea that *M. argentea, M. leucadendra, B. acutangula* and *E. camaldulensis* are most likely accessing the shallow groundwater of the alluvial or underlying regional aquifers for at least part of the year, especially at the end of the dry season. Therefore, the presence of these species in and around a river pool or wetland can be considered as indicator of shallow, accessible groundwater.

The depth to which riparian and floodplain vegetation of the Fitzroy can access groundwater to maintain ecosystem health and function is yet to be fully described. However, taking water from the alluvial and underlying regional aquifers lowers groundwater levels. This is likely to have a greater impact on vegetation in a dry and potentially an average year and less so in a wet year. Maintaining the current depth to groundwater in the Alluvial aquifer and underlying regional aquifers should maintain vegetation health and protect riparian habitat.

Further work

Riparian and floodplain tree species are adapted to the natural variation in groundwater depth throughout the year. Any development that proposes to take water from the Alluvial or connected regional aquifers should establish local ecological water requirements, if there is a risk that abstraction may impact the water levels supporting groundwater-dependent riparian and floodplain tree species.

7 Spring ecosystems

7.1 All seasons

P Groundwater to support springs

The values report (DWER 2023a) explained the importance of springs in arid and semi-arid environments, where they are critically important sources of water supporting terrestrial fauna, and aquatic and riparian habitat. Springs are often significant Aboriginal cultural places and sources of water for pastoralists.

Hydro-ecological outcome

Groundwater input into the 400+ springs mapped in the Fitzroy water planning area (Figure 33) is not well studied nor understood. However, sampling of C^{14} (Carbon 14) in surface water and biota from a spring approximately 5 km south of the Fitzroy showed evidence of ancient dissolved organic carbon from groundwater sustaining fauna living in springs (Tayer 2023). Additionally, invertebrate species known only in systems receiving groundwater inflow have been recorded in the North Kimberley Mound Springs Threatened Ecological Community complex (organic mound springs TEC) (Bennelongia 2017).

Springs can be present where faults form preferential pathways for groundwater to flow from deeper aquifers to the surface. These springs may occur in the Grant-Poole aquifer across anticlinal features where faults facilitate groundwater flow to the surface (i.e. around Noonkanbah).

The North Kimberley Mound springs, which may be fault springs in the fractured rock aquifer, occur in the north of the catchment where high pressures in interconnected fractures may force the upward movement of groundwater. There are also known faults at this location which could be facilitating groundwater movement to the surface, through any overlying alluvial sediments.

Springs may also form where a higher permeability layer is in contact with a lower permeability layer (DWER 2023b). Under these conditions groundwater flow across the boundary can be restricted, forcing water to the surface (DNRME 2016). These springs are often present along geological boundaries.

The Big Springs TEC Complex is located on and around the boundary of the coastal salt flats where the Grant-Poole aquifer is near the surface. It may be a contact spring where the Poole Formation (higher permeability) meets the Grant Group (lower permeability). It could also be where the landscape intersects the groundwater table.

Springs can also form where the landscape and the watertable intersect. This can happen through several mechanisms including erosion from surface water flows, wind erosion and in natural depressions such interdunal depressions. These springs are common in the Fitzroy water planning area. Lindsay and Commander (2005) described groundwater discharge from the Wallal aquifer to the Fitzroy River around

Willare. Another series of springs at the foot of the Devonian Reef complex may also have formed where the landscape and watertable intersect. Springs over the Alluvial aquifer on the Fitzroy River floodplain and in the riverbed itself may form where there has been erosion from surface water flows (Tayer 2023).

Hydro-ecological outcome for spring ecosystems is:

> **P Groundwater discharge from source aquifers is maintained to support spring ecosystems.**

Ecological water requirements

Spring ecosystems are adapted to the natural variation in groundwater discharge from source aquifers. However, the volumes, pressures and quality of groundwater discharge required to maintain them is yet to be described. The take of water from source aquifers has the potential to reduce the volume and duration of discharge to springs.

Further work

A local ecological water requirement study would be required to establish the water regime supporting any individual spring. This would be needed to inform the risk of water development impacting springs in the Fitzroy water planning area.

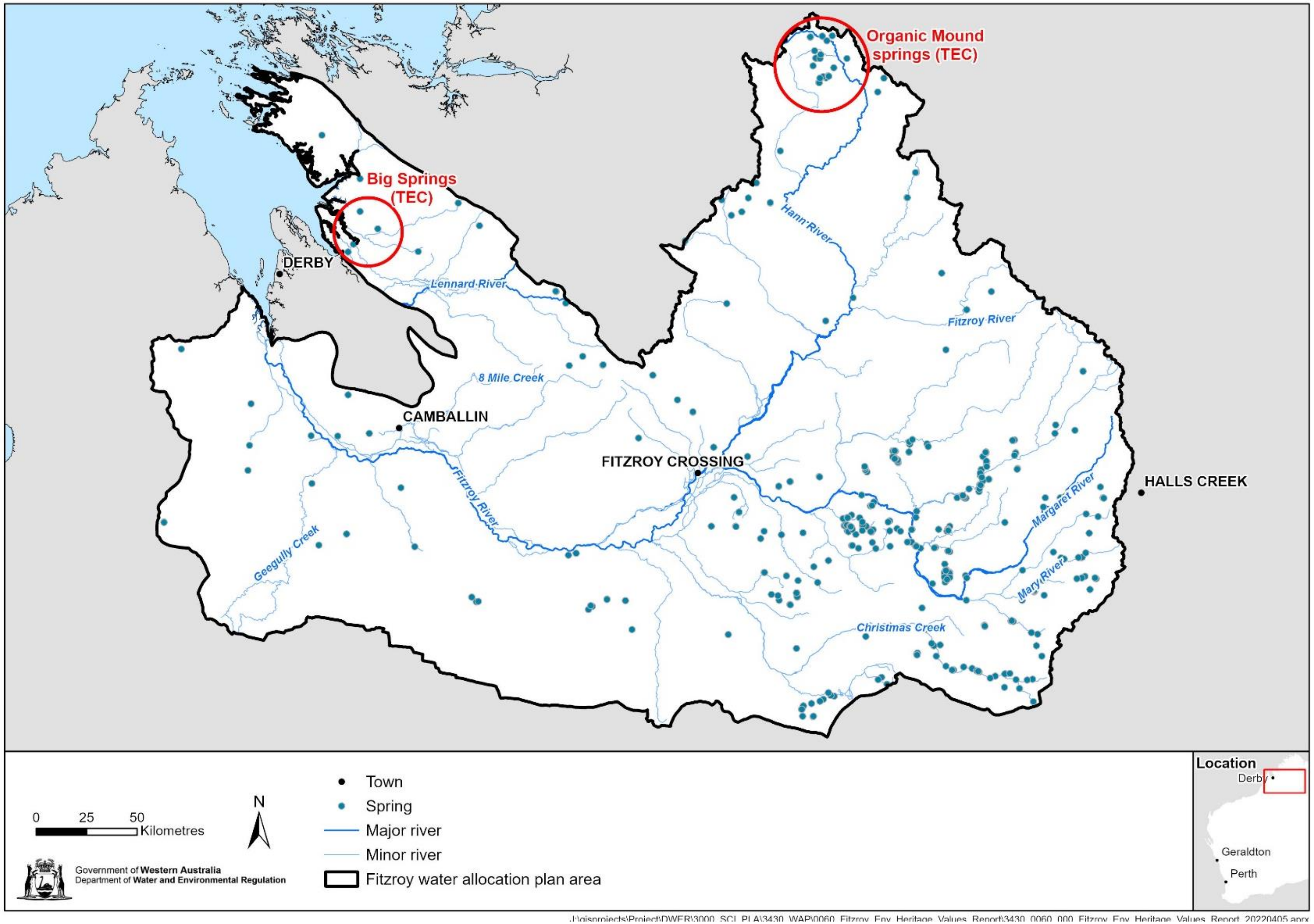

Figure 33 Location of TECs and other springs across the Fitzroy water planning area

8 Aquifer and subterranean ecosystems

8.1 All seasons

Q Groundwater to support aquifer and subterranean ecosystems

The values report (DWER 2023a) explained that aquifer and subterranean ecosystems, including alluvial aquifers, support a diversity of fauna and flora including stygofauna, obligate groundwater dwelling fauna, and benthic algae.

Hydro-ecological outcome

The presence of stygofauna is driven by depth to groundwater, groundwater salinity and suitability of habitat (EPA 2023). Depth to groundwater affects recharge and washing of nutrients and carbon into the aquifer after rainfall (Bennelongia 2021).

In groundwater, oxygen and nutrients generally decrease with depth. As a result, stygofauna, associated with aquifer ecosystems, are often most abundant and diverse at shallow depths, closer to the water-table. Richness and abundance of stygofauna generally decrease with distance below the top of the water-table (Korbel et al. 2019).

Stygofauna are generally most abundant and diverse in aquifers within 30 m of the surface and are not found beyond depths of 100 m, nor where oxygen concentration is less than 0.3 mg/L. Grain and pore size is also a good indication of where stygofauna may occur (Korbel et al. 2019), with most found where pore size is greater than 1 mm.

Burrows et al. (2020) investigated the importance of groundwater upwelling into the sediments at the bottom (hyporheic zone) of sandy river runs and pools of the lower Fitzroy during the dry season. These inputs support benthic algae which are an important part of riverine food webs (Beelsey et al. 2021). The investigations found that the biomass of benthic algae was greatest in areas of hyporheic upwelling, indicating the importance of groundwater inputs in sustaining food sources in river pools.

The hydro-ecological outcome for aquifer and subterranean ecosystems is:

> **Q Groundwater level or pressure head in an aquifer is maintained to provide groundwater to sustain dependent aquifer and subterranean ecosystems.**

Ecological water requirement

The department reviewed the known properties of aquifers in the Fitzroy water planning area. In addition to the Alluvial aquifer, which also supports hyporheic fauna and flora, the following formations shown in Figure 34 were identified as potentially hosting stygofauna where they are unconfined:

- Erskine Sandstone – high porosity
- Devonian Reef – a karstic system that has discrete cave systems that may contain endemic species
- Grant Group and Poole Sandstone.

The following were noted as not suitable for hosting stygofauna or needing further assessment (Figure 34):

- Noonkanbah Formation – local aquifers only
- Liveringa Group – need to understand which sandy units are outcropping – further assessment required
- Blina Shale – not suitable
- Millyit Sandstone – further assessment required
- Barbwire Sandstone – further assessment required
- Wallal Sandstone – might be prospective if not too deep
- Alexander Formation – might be suitable, silty
- Jarlemai Siltstone – not suitable
- Broome, Mowla and Meligo Sandstones – not suitable.

> Ecological water requirements to maintain groundwater to support aquifer and subterranean ecosystems (Hydro-ecological outcome Q):
>
> – maintain the depth and quality of groundwater where it is 100 m or less in unconfined aquifers that sustain aquifer and subterranean and ecosystems
>
> – maintain depth and quality of groundwater in the Alluvial aquifer

Further work

Where a watertable aquifer is less than 100 m and soils are suitable, a survey may be required to determine if that aquifer is hosting aquifer and subterranean ecosystems. A local ecological water requirement study could then determine the water levels and water quality required to sustain subterranean and aquifer ecosystems at a particular location.

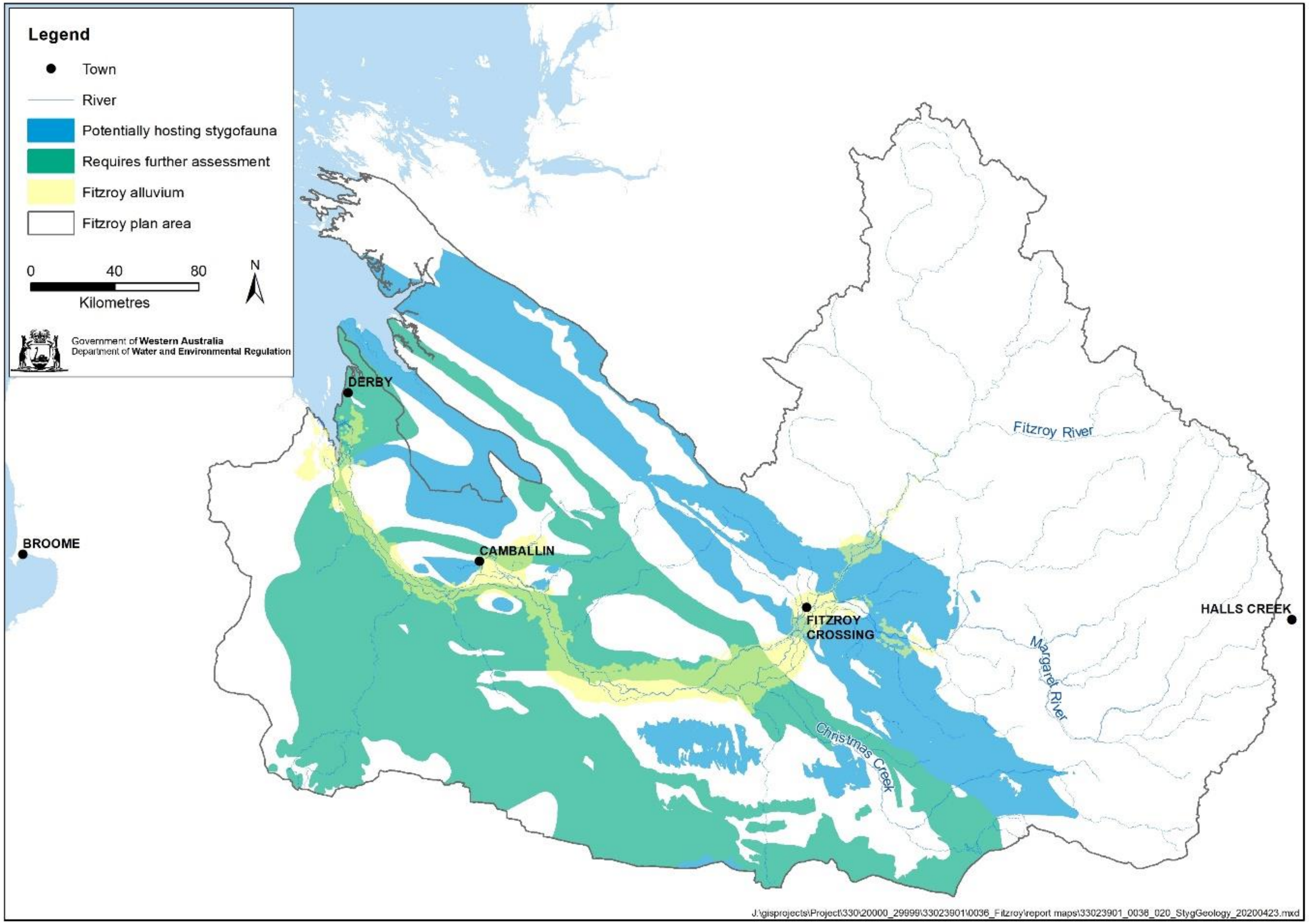

Figure 34 Potential stygofauna habitat in the Fitzroy water planning area

9 Estuarine and near-shore marine ecosystems of King Sound

Freshwater from the Fitzroy, May, Meda (Lennard) and Robinson rivers flows into King Sound, providing carbon and nutrients for numerous estuarine and near-shore marine ecosystems. Although groundwater discharge into King Sound is not well understood, inputs from aquifers that intersect or underlie the coast are likely.

9.1 Wet season

R River inflows to King Sound

The values report (DWER 2023a) explained that mangrove and salt flat communities border the Fitzroy River estuary and parts of King Sound. These habitats support 36 conservation-listed migratory bird species along with other listed flora and fauna species and threatened ecological communities.

Hydro-ecological outcome

Within-bank and over-bank flows of varying size connect the Fitzroy River to King Sound, flushing nutrients through the estuary and into the Sound itself and increasing productivity and reducing salinity (Baldwin et al. 2016). Connectivity also promotes the recruitment and movement of many diadromous species that move between fresh and saltwater habitats and use the estuary as a nursery (e.g. Barramundi and Cherabin).

Other species that use rivers as nurseries, including the Speartooth shark (*Glyphis glyphis*), Bull shark (*Carcharhinus leucas*) and Dwarf sawfish *(Pristis clavata*), also have their movement cued by flow/salinity, moving upstream during low-flow/high-salinity periods and downstream during high-flow/low-salinity periods. (Blaber et al. 1989; Lyon et al. 2017; Morgan et al. 2021; Thorburn et al. 2007).

The hydro-ecological outcome for inflows into King Sound is:

> **R Within and over-bank flows during the wet season connect the river to the estuary and King Sound.**

Ecological water requirements

Research on three Gulf of Carpentaria rivers – the Mitchell, Flinders and Gilbert – found that nutrients delivered by early wet season flows support fisheries species as well as other species including migratory shorebirds (Burford & Faggotter 2021). It was also found that primary productivity rates increased in the estuaries of all three rivers in response to nutrient inputs in both the dry and wet seasons (Burford & Faggotter 2021).

Nutrients delivered during the wet season were particularly critical in stimulating primary production in chronically nutrient deficient mudflats (Burford at al. 2021). Although the concentration of nutrients did not vary between wet seasons of different magnitude, the volume of nutrients (i.e. load) was higher in medium-to-large wet seasons due to larger discharges (Burford et al. 2021).

Inundation of salt flats along the estuary and King Sound during the wet season stimulates the algal crusts that cover them to photosynthesise and produce carbon. This plays an important role in the food web that supports fish, including Barramundi and other species that use the flooded areas as nursery and habitat (Pollino et al. 2018).

There is increasing evidence that freshwater inputs, such as river flow, rain and/or groundwater, are important for above-ground growth in mangroves and that they use this in preference to saline water (Hayes et al. 2018).

The frequency and magnitude of flows needed to inundate salt flats and mangroves are yet to be specifically described. However, the first flush/freshening flows in the early wet season as described in hydro-ecological outcome D (to reconnect the river through to the King Sound) will also mobilise nutrients that have built up in the soil during the dry season and contribute high nutrient concentrations to the estuary.

Maintaining an annual first flush of 1,500 GL in combination with higher in-stream and overbank flows during the wet season will meet the outcome to connect the river and estuary to King Sound.

Ecological water requirement to maintain within and over-bank flows during the wet season to connect the river to the estuary and King Sound (Hydro-ecological outcome R):

- a cumulative volume of 1,500 GL measured at the Fitzroy Barrage gauging station from November 1st

Further work

There is limited understanding of the ecology of the King Sound and how it is supported. Further regional scale assessment could provide a baseline understanding of:

- the water quality, including nutrient concentrations of the King Sound
- surveys of the seasonal distribution, abundance and biomass of seagrass in the King Sound
- survey for the presence and distribution of algal mat communities on the intertidal salt flats
- natural variation in the location of mangroves in the Fitzroy River estuary and King Sound
- phytoplankton productivity and nutrient limitation
- distribution, diversity and abundance of small forage fish and benthic invertebrates including mud crabs and Cherabin in the King Sound.

This information is needed to support future ecological water requirement studies that aim to understand the contribution of freshwater flows from the Fitzroy River on the ecology of the King Sound. It would also support a review of 1,500 GL as a suitable freshening flow.

S Occasional high-level river flows into King Sound

As described for hydro-ecological Outcome I (Section 6.2), short-duration, high-discharge events, usually associated with periods of heavy rainfall, maintain existing channel morphology, pool depth and water quality (McJannet et al. 2009). Importantly they also support large flushes of nutrients into King Sound (McJannet et al. 2009; Burford & Faggotter 2021).

Hydro-ecological outcome

Long-term observations after higher flow events suggest sediments and other materials from the Fitzroy River move along the western side of the sound to the mouth. Here they are caught in the southern current and carried down the western side of the Dampier Peninsula as far south as Willie Creek (Fowler pers comm., September 2019).

This finding was supported by a research program in which modelling of discharge into King Sound suggested the influence of Fitzroy during very high-flow years may extend as far as Roebuck Bay in the south and Collier Bay in the north (Hipsey et al. 2017).

S Occasional large flows during the wet season provide large flushes of nutrients and carbon into the King Sound to support marine food webs.

Ecological water requirement

The frequency and magnitude of high-level flows needed to flush large amounts of nutrients and carbon into the sound and further into the marine environment are yet to be specifically described. However, the occasional very high-level flows needed to allow sawfish migration (Outcome H) and to support scouring flows (Outcome I) should meet this requirement.

This was modelled as 175 GL/day for 14 days measured at Willare gauging station in any given wet season. However, it is physically improbable that abstraction or diversion from the river could have any impact on very high years.

> Ecological water requirement to support large flushes of nutrients into King Sound (Hydrogeological outcome S):
>
> – 175 GL/day (8.1 mAHD) for 14 days measured at Willare in any given wet season (not every wet season).

Further work

Further regional scale assessment may describe the frequency and magnitude of significant flushing events that provide nutrients and carbon to support marine food webs. However, it is physically improbable that abstraction or diversion from the river would impact this relationship in very high-flow years.

9.2 All seasons

T Groundwater to support estuarine and near shore marine ecosystems

The values report (DWER 2023a) explained there is increasing evidence that fresh groundwater inputs support above-ground growth in mangroves (Hayes et al. 2018), provide nutrients to seagrass (Green & Short 2003) and benefit mudflats communities.

Hydro-ecological outcome

Groundwater flow into Fitzroy estuary and King Sound is not well understood. However, inputs from aquifers that intersect or underlie the coast is likely. There is anecdotal evidence, provided by Traditional Owners, that groundwater interaction gives rise to freshwater seeps along the coastline of the King Sound.

The location of the inland interface between seawater and fresh groundwater is called the saltwater interface. The position of the seawater interface is usually kept stable by the natural pressure from the fresh groundwater pushing against it as the groundwater flows towards the sea (DoW & DRD 2017). If the pressure drops because the volume of water flowing out to sea changes through rainfall variations or because too much groundwater is pumped out of the aquifers, the seawater interface can move further inland (DoW & DRD 2017).

The hydro-ecological outcome for groundwater inputs to the Fitzroy estuary and King Sound is:

> **T Groundwater discharge to the estuary and the King Sound is maintained to provide freshwater inputs to mangroves, seagrass and salt-flat ecosystems.**

Ecological water requirements

The department is undertaking a groundwater investigation in the La Grange area to identify areas of groundwater input from the Broome sandstone aquifer into the near shore marine ecosystem. The outcomes of this investigation may provide insights into how groundwater is potentially supporting ecosystems of King Sound.

Maintaining the position of the seawater interface in groundwater resources that discharge to the King Sound should ensure that these ecosystems continue to receive the fresh groundwater inputs to which they are adapted. In the Fitzroy water planning area, the position of the seawater interface is uncertain.

Recent mapping of groundwater-dependent aquatic ecosystems suggests the Grant-Poole aquifer or other confined aquifers may provide groundwater inputs to estuarine ecosystems on Dambimangari (Dambeemangardee) Country in the northwest of the Fitzroy water planning area (DWER 2023d). There is potential that this is fault-induced discharge that may also provide freshwater inputs to the King Sound.

It is likely that the Wallal aquifer discharges into the sound on the northern side of the estuary south of Derby. This area is within the Derby groundwater plan area. It is also possible that the Liveringa or other aquifers are discharging to the coast in the north of the plan area. Where this discharge occurs, fresh groundwater inputs may sustain estuarine and near-shore marine ecosystems.

> Ecological water requirement to maintain groundwater discharge to the estuary and King Sound to provide freshwater inputs to near shore marine ecosystems (Hydro-ecological outcome T):
>
> – maintain the position of the seawater interface.

Further work

Any development near the coastline that proposes to take water from regional aquifers that discharge to estuaries or the King Sound should consider the impact of abstraction on the position of the seawater interface.

Local ecological water requirement studies would be required to identify the extent of mangroves, seagrass and salt-flat ecosystems and investigate how groundwater may be supporting these. In addition, studies to identify if and how groundwater abstraction may impact the discharge of fresh groundwater inputs to these ecosystems would be needed.

10 Summary of hydro-ecological outcomes and ecological water requirements

In this section we list the hydro-ecological outcomes and ecological water requirements presented in chapters 5 to 9 and the key evidence that supports them.

River pool and off-channel/floodplain wetland habitats

Dry season and dry years

<u>Hydro-ecological outcome A</u>

Water depth in deep-river pools and connected foraging habitat is maintained during the dry season and low-flow years to protect Freshwater sawfish.

- Ecological water requirement:
  - Maintain a water depth of 4 m in Camballin and Myroodah pools for as long as possible during the dry season
  - Protect all natural flows between 1 May and 31 October.
- Evidence:
  - Fitzroy – Gleiss et al. 2017; Whitty et al. 2017; Lear et al. 2021; DWER 2023a; Lear et al. 2023.

<u>Hydro-ecological outcome B</u>

Water depth and water quality in river pools and off-channel/floodplain wetland habitat is maintained during the dry season and dry years to support a diversity of fish species.

- Ecological water requirement:
  - Barramundi – 1.4 m water depth in river pools
  - Medium-bodied fish (i.e. Fork-tailed catfish, Bony bream and Western sooty grunter) – 0.9 m water depth in pools, 0.8 m water depth in floodplain wetlands
  - Water depth above 1.5 m in river pools and 1.1 m in wetlands to maintain a diversity of fish.
- Evidence:
  - Fitzroy – Beesley et al. 2018; Lear et al. 2020a; Gleiss et al. 2021; DWER 2023a; Gwinn et al. in prep.
  - Northern Australia – van Dam et al. 2005; Burrows & Butler 2012; DoW 2012.

<u>Hydro-ecological outcome C</u>

The natural pressure and water levels in aquifers maintains groundwater discharge to river pools and wetlands throughout the year.

- Ecological water requirement:

  - Further information is required to inform ecological water requirements to meet this hydro-ecological outcome.

- Evidence:
  - Fitzroy – Harrington & Harrington 2016; Pollino et al. 2018; Taylor et al. 2018; DWER 2023a; DWER 2023b.

Wet season

Hydro-ecological outcome D

A series of freshening flows reconnects the river through to the King Sound, cleaning out river pools and supporting movement and recruitment of aquatic fauna.

- Ecological water requirement:
  - a cumulative volume of 1,500 GL measured at the Fitzroy Barrage gauging station from 1 November
- Evidence:
  - Fitzroy – Toussaint et al. 2001; Baldwin et al. 2016; Douglas et al. 2019; Beasley et al. 2021b; Beesley et al. 2023; Lear et al. 2023; DWER 2023a; DWER 2023c.
  - Northern Australia – Novak et al. 2015; Novak et al. 2017; Burford et al. 2021.

Hydro-ecological outcome E

Flows of varying depths to allow fish passage over permanent obstacles on the Fitzroy River.

- Ecological water requirement:
  - Camballin Barrage:
    - all fish species – 1.60 m deep
    - Freshwater sawfish – 0.83 m deep
    - Barramundi and Bull sharks – 0.60 m deep.
  - Myroodah Crossing (depth measured at barrage):
    - Freshwater sawfish – 0.43 m deep
    - all fish species – 2.33 m deep.
- Evidence:
  - Fitzroy – Morgan et al. 2005; AECOM et al. 2009; Morgan et al. 2011c; Morgan et al. 2016; Morgan, 2019; DWER 2023a.

Hydro-ecological outcome F

River pools and flood-runner channels are connected along the river during the wet season supporting the movement of and providing habitat for aquatic fauna.

- Ecological water requirement:

  - Daily flow of 3 GL, measured at the Fitzroy Barrage gauging station during the early wet season
- Evidence:
  - Fitzroy – Beesley et al. 2020; Beesley et al. 2021b; DWER 2023a; Lear et al 2023; Pratt et al. in prep.

Hydro-ecological outcome G

Occasional high flows connect river pools to floodplain habitats during the wet season transferring nutrients and energy and connecting feeding, breeding and nursery habitat for fauna.

- Ecological water requirement:
  - Further information is required to inform ecological water requirements to meet this hydro-ecological outcome.
- Evidence:
  - Fitzroy – Jardine et al. 2012; Sims et al. 2018; Beesley et al. 2020; Lear et al. 2020a; Lear et al. 2021; Beesley et al. 2023; DWER 2023a; Pratt et al. in prep
  - Northern Australia – Finlayson et al. 2006; Burford & Faggotter 2021.

Hydro-ecological outcome H

Occasional very high flows that support Freshwater sawfish and Barramundi recruitment during the wet season.

- Ecological water requirement:
  - 175 GL/day (8.1 mAHD) for 14 days measured at Willare gauging station in any given wet season (not every wet season).
- Evidence:
  - Fitzroy – Whitty et al. 2017; Lear et al. 2019; Morrongeiollo et al. 2020; Roberts et al. 2021; DWER 2023a.

Hydro-ecological outcome I

Occasional, short duration, very high flows scour river pools, bars, and riffles to maintain channel morphology, providing a diversity of aquatic habitat.

- Ecological water requirement:
  - 175 GL/day (8.1 mAHD) for 14 days measured at Willare gauging station in any given wet season (not every wet season).
- Evidence:
  - Fitzroy – Storey et al. 2001; McJannet et al. 2009; Pollino et al. 2018; Lear et al. 2019; DWER 2023a
  - Northern Australia – Trayler et al. 2001; Erskine et al. 2003.

End of wet season

Hydro-ecological outcome J

Recessional flows at the end of the wet season support fish and Cherabin migration to refuge habitats.

- Ecological water requirement:
  - Cherabin – 0.05-0.55 depth of water flow over the Camballin Barrage
  - Large-bodied fish species: 0.60 m depth of water flow over the barrage
  - other fish species – maintain all flows during April and May
- Evidence:
  - Fitzroy – Morgan et al. 2011c; Lear et al. 2020b; Beesley et al. 2023; DWER 2023a
  - Northern Australia – Novak et al. 2015; Novak et al. 2017; Crook et al. 2019.

Hydro-ecological outcome K

Within bank and overbank flows from preceding wet season(s) considered to identify likelihood of cumulative impacts from successive poor wet seasons.

- Ecological water requirement:
  - Further regional scale assessment is required to determine the ecological water requirement to meet this hydro-ecological outcome.
- Evidence:
  - Fitzroy - Lear et al. 2020a; Beesley et al. 2021a; Beesley et al. 2021b; Lear et al. 2021; DWER 2023a; Lear et al. 2023
  - Northern Australia - Bayliss 1989; Doody et al 2003; Shine & Brown 2008; Leigh 2013; Fukuda & Saalfeld 2014; Leigh et al. 2015; Burford et al. 2021.

Riparian and floodplain vegetation

Wet season

Hydro-ecological outcome L

Within bank river flows during the wet season recharge the Alluvial aquifer and replenish localised soil moisture to maintain the health of riparian vegetation.

- Ecological water requirement:
  - Further regional scale assessment is required to determine the ecological water requirement to meet this hydro-ecological outcome.
- Evidence:
  - Fitzroy – Freestone et al. 2021; Canham et al. 2021a; Canham et al. 2021b; Canham et al. 2022; Freestone et al. 2022; DWER 2023a; DWER 2023b.
  - Northern Australia – Pettit et al. 2001; Pettit & Froend 2018.

Hydro-ecological outcome M

River flow during the wet season inundates riverbank and top-of-bank habitats to maintain the health of riparian vegetation.

- Ecological water requirement:
  - Further information is required to inform ecological water requirements to meet this hydro-ecological outcome.
- Evidence:
  - Fitzroy – Canham et al. 2021a; Canham et al. 2021b; Canham et. al 2022; Freestone et al. 2022; DWER 2023a.
  - Northern Australia - Pettit et al. 2001; Pettit & Froend 2018.

Hydro-ecological outcome N

Overbank river flows during the wet season inundate the floodplain to support recruitment and maintain the health of floodplain and off-channel wetland vegetation.

- Ecological water requirement:
  - Further information is required to inform ecological water requirements to meet this hydro-ecological outcome.
- Evidence:
  - Fitzroy – Freestone et al. 2021; Brauhart 2021; Canham et al. 2021a; Canham et al. 2021b; Canham et al. 2022; Freestone et al. 2022; DWER 2023a.
  - Northern Australia - Doran & Boland 1984; Roberts & Marston 2000; Pettit et al. 2001; Capon & Brock 2006.

All seasons

Hydro-ecological outcome O

Groundwater depth is maintained within the range of tree roots to maintain the health of riparian and floodplain tree species throughout the year.

- Ecological water requirement:
  - Further information is required to inform ecological water requirements to meet this hydro-ecological outcome.
- Evidence:
  - Fitzroy – Canham et al. 2021a; Canham et al 2021b; Canham et al. 2022; DWER 2023a; DWER 2023b.
  - Northern Australia – Zencich et al. 2002; Eamus et al. 2006; Bunn et al. 2006; O'Grady et al. 2006; Zolfaghar et al. 2014.

Spring ecosystems

All seasons

Hydro-ecological outcome P

Groundwater discharge from source aquifers is maintained to support spring ecosystems.

- Ecological water requirement:
  - A local study would be required to inform an ecological water requirement to meet this hydro-ecological outcome. This should occur to establish the risk of any water development impacting any spring.
- Evidence:
  - Fitzroy – Lindsay & Commander 2005; Bennelongia 2017; DWER 2023a; DWER 2023b; Tayer 2023.
  - Northern Australia - DNRME 2016.

Aquifer and subterranean and ecosystems

All seasons

Hydro-ecological outcome Q

Groundwater level or pressure head in an aquifer is maintained to provide groundwater to sustain dependent aquifer and subterranean ecosystems.

- Ecological water requirement:
  - maintain depth and quality of groundwater where it is 100 m or less in unconfined aquifers that sustain aquifer and subterranean ecosystems.
  - maintain depth and quality of groundwater in the Alluvial aquifer.
- Evidence:
  - Fitzroy – Burrows et a. 2020; Beesley et al. 2021; DWER 2023a.
  - Southern Australia – Korbel et al. 2019; Bennelongia 2021; EPA 2023.

Estuarine and near-shore marine ecosystems (King Sound)

Wet season

Hydro-ecological outcome R

Within and over-bank flows during the wet season connect the river to the estuary and King Sound.

- Ecological water requirement:
  - a cumulative volume of 1,500 GL measured at the Fitzroy Barrage gauging station from 1 November

  - further regional scale assessment is needed to provide a baseline understanding of the ecology of the King Sound.
- Evidence:
  - Fitzroy – Thorburn 2007; Baldwin et al. 2016; Pollino et al. 2018; Morgan et al. 2021; DWER 2023a.
  - Northern Australia – Blaber et al. 1989; Burford et al. 2021; Burford & Faggotter 2021; Hayes et al. 2018; Lyon et al. 2007.

Hydro-ecological outcome S

Occasional large flows during the wet season provide large flushes of nutrients and carbon into the King Sound to support marine food webs.

- Ecological water requirement:
  - 175 GL/day (8.1 mAHD) for 14 days measured at Willare gauging station in any given wet season (not every wet season)
- Evidence:
  - Fitzroy – Hipsey et al. 2017; DWER 2023a
  - Northern Australia – McJannet et al. 2009; Burford & Faggotter 2021.

All seasons

Hydro-ecological outcome T

Groundwater discharge to the estuary and the King Sound is maintained to provide freshwater inputs to mangroves, seagrass and saltflat ecosystems.

- Ecological water requirement:
  - Maintain the position of the seawater interface
- Evidence:
  - Fitzroy – DWER 2023a; DWER 2023d.
  - Northern Australia – DoW & DRD 2017; Hayes et al. 2018; DWER 2023d; DWER 2023e.
  - International – Green & Short – 2003.

10.1 Further work to establish ecological water requirements

Ecological water requirements can be based on targeted and specific research on a species or ecosystem or can be qualitative statements based on best available information (Richardson et al. 2011b). Researchers have been active in the lower Fitzroy in recent years, and we now have a better understanding of the water requirements of some species and habitats. However, the vast area of the catchment and the richness and abundance of water-dependent species and habitats mean data are still relatively limited.

In chapters 5 to 9 we have focused on the findings of recent ecological studies specific to the lower Fitzroy River to describe EWRs. Where local data are not available or of sufficient detail, we have widened our scope to include studies from northern Australia and to other regions if needed.

For 11 hydro-ecological outcomes, EWRs are presented as a flow volume or a river pool/ wetland depth. Other EWRs are qualitative and require that current flow regimes or water depths be maintained. For these outcomes we have presented the information available and identified the type of study that would provide more information to define an ecological water requirement.

This further work could occur in several ways:

- further work undertaken by the department as part of the State Groundwater Investigation Program
- further work undertaken by the department as part of water allocation planning in the Fitzroy water planning area
- investigations undertaken by an applicant to support an application for a water licence
- investigations undertaken by a proponent to support a proposal being assessed by another regulatory authority that may impact the water resource and its dependent ecosystems (i.e. an aquaculture project or renewable energy proposal).

In each case, this report provides a record of the current understanding of how the water regime supports water-dependent habitats and important species of the Fitzroy water planning area. It directs the reader to key sources of evidence (i.e. peer-reviewed journal articles and scientific reports) that can provide further information and guide the design of investigations that increase the understanding of the ecological water requirements to meet the range of hydro-ecological outcomes presented in this report.

Glossary

Term	Meaning
Abstraction	The taking of water from any source of supply.
Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock. Aquifer types include unconfined, confined, and artesian.
Aquitard	A geological formation that may contain groundwater but is not capable of transmitting significant quantities of it under normal hydraulic gradients.
Biodiversity	Biological diversity or the variety of organisms, including species themselves, genetic diversity and the assemblages they form (communities and ecosystems). Sometimes includes the variety of ecological processes within those communities and ecosystems.
Bore	A narrow, normally vertical hole drilled in soil or rock to monitor or withdraw groundwater from an aquifer.
Catchment	The area of land from which rainfall run-off contributes to a single watercourse, wetland or aquifer.
Climate change	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.
Confined aquifer	An aquifer lying between confining layers of low permeability strata (such as clay, coal or rock) so that the water in the aquifer cannot easily flow vertically.
Country (when used in connection to Aboriginal people)	Country means the lands, waterways, seas and skies to which Aboriginal peoples are intrinsically linked. The wellbeing, law, place, custom, language, spiritual belief, cultural practice, material sustenance, family and identity are all interwoven as one.
Discharge	The water that moves from the groundwater to the ground surface or above, such as a spring. This includes water that seeps onto the ground surface, evaporation from unsaturated soil, and water extracted from groundwater by plants (see Evapotranspiration) or engineering works.
Discharge rate	Volumetric outflow rate of water, typically measured in cubic metres per second.
Dissolved Oxygen	The concentration of oxygen dissolved in water normally measured in milligrams per litre (mg/L).
Dry season	The period from 1 May to 31October.
Ecological values	The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of these systems.
Ecological water requirement	The water regime needed to maintain the ecological values (including assets, functions and processes) of water-dependent ecosystems at a low level of risk.

Term	Meaning
Ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact, e.g. lake, to include all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.
Environment	Living things, their physical, biological and social surroundings, and interactions between all of these as defined under section 3, *Environmental Protection Act 1986* (WA).
Evaporation	Loss of water from the water surface or from the soil surface by vaporisation due to solar radiation.
Flow	Streamflow in terms of m3/a, m3/d or ML/a. May also be referred to as discharge.
Groundwater	Water which occupies the pores and crevices of rock or soil beneath the land surface.
Groundwater-dependent ecosystem	An ecosystem that is at least partially dependent on groundwater for its existence and health.
Hectare	A surface measure of area equal to 10,000 square metres or approximately 2.47 acres.
HEC-RAS	A computer program that models the hydraulics of water through natural rivers and other channels
Hydrogeology	The hydrological and geological science concerned with the occurrence, distribution, quality and movement of groundwater, especially relating to the distribution of aquifers, groundwater flow and groundwater quality.
Hydrograph	A graph showing the height of a water surface above an established datum plane for level, flow, velocity, or other property of water with respect to time.
Licence	A formal instrument granted under the *Rights in Water and Irrigation Act 1914* (WA) that entitles a licensee to take water (the licensed entitlement) from a water resource in accordance with the specified terms, conditions and restrictions on the licence.
Native title holder	A Native Title holder, in relation to Native Title, has the meaning given in section 224 of the *Native Title Act 1993* (Cth) and means: • a registered Native Title body corporate, also referred to as a prescribed body corporate; or • a person or persons who hold the Native Title.
Persistent river pool or wetland	A river pool or wetland that persists for 70% or more of the dry season over a period of time is indicative of persistence. Recognising the variable nature of flow in the Fitzroy River, this definition applies to persistent river pools that may ‘shift’ within a river reach in response to high wet season flow and erosion events.
Recharge	Water that infiltrates into the soil to replenish an aquifer.
Salinity	The measure of total soluble salt or mineral constituents in water. Water resources are classified based on salinity in terms of total

Term	Meaning
	dissolved salts (TDS) or total soluble salts (TSS). Measurements are usually in milligrams per litre (mg/L) or parts per thousand (ppt).
Spring	As defined in s 2(1) of the *Rights in Water and Irrigation Act 1914*, a spring means a spring of water naturally rising to and flowing over the surface of land but does not include the discharge of underground water directly into a **watercourse**, **wetland**, reservoir or other body of water.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Traditional Owner	An Aboriginal person/s is a Traditional Owner if they are: • a Native Title holder • a registered Native Title claimant or claim group • a member of a Regional Aboriginal Corporation established under a settlement agreement with the government, or • a person who is recognised as having the cultural authority to speak for a place.
Watercourse	As defined in section 3(1) of the *Rights in Water and Irrigation Act 1914,* a watercourse means: a) any river, creek, stream or brook in which water flows b) any collection of water (including a reservoir) into, through or out of which any thing coming within paragraph (a) flows c) any place where water flows that is prescribed by local by-laws to be a watercourse d) and includes the bed and banks of any thing referred to in paragraph a), b) or c).
Water-dependent ecosystems	Those parts of the environment, the species composition and natural ecological processes, of which are determined by the permanent or temporary presence of water resources, including flowing or standing water and water within groundwater aquifers.
Water regime	A description of the variation of flow rate or water level over time. It may also include a description of water quality.
Watertable	The saturated level of the unconfined groundwater. Wetlands in low-lying areas are often seasonal or permanent surface expressions of the watertable.
Waterways	All streams, creeks, stormwater drains, rivers, estuaries, coastal lagoons, inlets and harbours.
Wet season	The period from 1 November to 30– April.
Wetland	As defined in section 2 of the *Rights in Water and Irrigation Act 1914* (WA), a wetland is a natural collection of water, whether permanent or temporary, on the surface of any land and includes — a) any lake, lagoon, swamp or marsh; and b) a natural collection of water that has been artificially altered but does not include a watercourse.

Map information

Disclaimer

The maps in this report are a product of the Department of Water and Environmental Regulation. These maps were produced with the intent that they be used for information purposes within this document and at the scale shown when printing.

While the department has made all reasonable efforts to ensure the accuracy of this data, the department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Datum and projection information

Projection: GDA94 MGA zone 51 **Spheroid**: GRS 1980

Map Author: Hisayo Thornton **Compilation date**: June 2022

File path:
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Map sources

The department is custodian of the following datasets used in production of the maps in this report:

- Coastline – DWER 2006
- Fitzroy water allocation plan area – DWER 2019
- Groundwater connectivity – DWER 2022
- Potential Stygofauna Habitat – DWER 2019, derived from DMIRS 2019
- Rivers – DWER 2019
- Springs – DWER 2020, derived from Landgate 2020, DBCA 2022 and DWER 2022
- Surface geology – DWER 2019, derived from DMIRS 2019
- Stream gauging stations – DWER 2022
- The department acknowledges the following datasets and their custodians in the production of the maps in this report:
- Floodplain – Landgate 2011, 2023
- Imagery – Landgate 2022
- Persistent waterholes – CSIRO 2018, derived from Landsat archive
- Riparian vegetation inundation extent - CSIRO 2018, derived from Landsat archive
- Roads – Landgate 2022
- Towns – Landgate 2022

Units of measure

^{o}C	Degrees centigrade, a unit of measure for temperature
ha	Hectares
km^2	Kilometres squared
m	Metres
mbgl	Metres below ground level
mm	Millimetres
m^3s^{-1}	Cubic metres per second, a unit of discharge or flow
mS/cm	Millisiemens per centimetre, a unit of measure used for salinity

Shortened forms

BC Act	*Biodiversity Conservation Act 2016 (WA)*
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBCA	Department of Biodiversity, Conservation and Attractions
DWER	Department of Water and Environmental Regulation
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999 (Cth)*
NAWRA	Northern Australian Water Resource Assessment
NESP	National Environmental Science Program (NESP) researchers, based at the University of Western Australia (UWA) and Griffith University, and the Centre for Sustainable Aquatic Ecosystems at Murdoch University.
PEC	Priority Ecological Community
TEC	Threatened Ecological Community

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