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

Hydrology of the Fitzroy River

Information to support water management in the Fitzroy River, Kimberley, Western Australia

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Acknowledgement of Country

The Department of Water and Environmental Regulation acknowledges the Traditional Owners and Custodians in 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 area and their cultures. We acknowledge the Traditional Owners have been Custodians of Country for countless generations and that water is integral to life.

We recognise that Aboriginal people and their culture across the Fitzroy water planning area are diverse and that continued custodianship of the land and water is fundamental to their health, spirit, culture and community.

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.

Contents

Figures

Tables

Summary

This technical report describes the hydrology of the Fitzroy River using streamflow monitoring and modelling. We present information on the volume, variability and seasonality of flow in the Fitzroy River and tributaries to support water management in this region. This report is a first for the department for this catchment and provides a summary of existing knowledge on the hydrology of the river and its tributaries.

The Fitzroy River catchment is one of the largest catchments in Western Australia, covering an area of around 94,000 km^2. Located in the Kimberley region, the catchment has a semi-arid to arid monsoonal climate with large seasonal and annual variations in rainfall. The climate is characterised by a distinct wet season between November to April and a dry season with little to no rainfall.

The Fitzroy River flows west from its headwaters in the Wunaamin-Miliwundi Ranges in the Central Kimberley into King Sound near Derby. The Fitzroy River has the largest average annual streamflow of any river in Western Australia. The river and tributaries range from well-defined incised channels to poorly channelised floodplains with braided streams. The river and tributaries are steeper in the northern and eastern parts of the catchment than the southern and western parts, which are characterised by relatively flat lowland floodplains.

During the wet season, large rainfall events related to monsoonal and cyclonic weather can generate large flows in the Fitzroy River. During these events, water can overtop the riverbanks and inundate the floodplain. As rainfall decreases from around April onwards, water levels in the river recede. Groundwater discharge to the river can maintain water in permanent and semi-permanent pools until groundwater levels fall below the riverbeds. At this point, parts of the river dry to form a series of disconnected pools.

Flow in the Fitzroy River varies significantly between years. Up to 2020, the highest annual flow at Fitzroy Crossing was almost 60 times greater than the lowest annual flow recorded. In January 2023, a flood on the Fitzroy River exceeded all events previously recorded by up to 4 m. The annual flow for the 2022–23 wet season is therefore likely to exceed the largest annual flow ever recorded. The large variability in rainfall and streamflow is a challenge for water management in the region. These variations are also a strong influence on the ecological values of the area.

The Fitzroy River, its floodplain and tributaries provide important habitats for a diverse range of vegetation communities, flora and fauna. The river, its tributaries and wetlands support 40 native fish species, 25 of which are freshwater species. The natural inundation of the river and floodplains help sustain these native populations and provide opportunities for these species to access habitats that are generally restricted.

Traditional Owners of the land within the Fitzroy River catchment have called it their home for at least 40,000 years. They are the region's first water managers and the

Traditional Owners of their Country, as recognised in the Native Title determinations across the region.

The Fitzroy River, its floodplain and tributaries contain a vast array of highly valued ecological, cultural and social places and interconnected landscapes. Many of these values are the subject of legislation, policy and guidance – see *Environmental and heritage values and the importance of water in the Fitzroy* (DWER 2023a) for details. This report describes the streamflow volume, variability and seasonality that supports these important values in the river.

For information about the groundwater monitoring and conceptualisation within the region, see the *Fitzroy Valley groundwater investigations 2015–2018, Kimberley, Western Australia* (DWER 2023b). These reports provide a technical foundation for water management decision-making.

1 Introduction

The Department of Water and Environmental Regulation acknowledges that Traditional Owners have an enduring connection to and comprehensive knowledge of water in this region. In this report, we describe how the river flows through analysis of monitoring, modelling, climate data and other supporting measurements. This approach should complement, not take the place of the science and knowledge that Traditional Owners can provide on the flow of the Fitzroy River.

1.1 Background

The Fitzroy River catchment has been the subject of many planning processes for water management and development – instigated both by government and the community. The State Government is working collaboratively to deliver a suite of election commitments to:

- create the Fitzroy River National Park, which will extend the Danggu Geikie Gorge National Park along the Fitzroy River to the north and along the Margaret River to the east
- develop a management plan for the Fitzroy River to ensure the health of the river and provide a basis for sustainable economic development
- not allow the Fitzroy River or its tributaries to be dammed.

This report provides an overview of Fitzroy River's hydrology and other information relevant to managing water in this region. Its builds on previous studies, including streamflow and flood modelling from the Northern Australia Water Resource Assessment (NAWRA) (Hughes et al. 2017; Karim et al. 2018), and published research from a variety of sources including the National Environmental Science Program and other departmental reports (DWER 2023a; DWER 2023b).

1.2 Location

The Fitzroy River catchment in the Kimberley region of Western Australia covers an area of almost 94,000 km^2. Parts of the catchment are in the shires of Wyndham–East Kimberley, Halls Creek and Derby–West Kimberley.

About 8,200 people reside in the catchment (DPIRD 2020), mostly in the major towns of Fitzroy Crossing and Derby, or otherwise in small remote communities. The Fitzroy River catchment has sustained Aboriginal people for more than 40,000 years and is the lifeblood of the community. Water in the catchment underpins cultural practices and social structures, including kinship relationships with fish and other beings (Douglas, Jackson et al. 2019).

Aboriginal people have significant custodial responsibilities for land and waters in the region. Traditional Owners hold determined Native Title rights under the *Native Title Act 1993* (Cth.) over most of the catchment (Figure 1).

In 2011, the Australian Government acknowledged the Fitzroy River's importance under the West Kimberley National Heritage Listing.[1] The listing includes the river's floodplain and most of its north-eastern catchment (Figure 2).

The river, its floodplain, wetlands and tributaries provide important habitat for a diverse array of vegetation communities, flora and fauna, including 40 native fish species. Of these species, 25 are freshwater and 15 are estuarine or marine but may spend part of their lives in freshwater environments (Shelley, Morgan et al. 2018). Mammals, native and introduced, rely directly on the river for water and the riparian habitat it supports (DWER 2023a). Also within the catchment are internationally significant geological sites such as the Devonian reef system, Danggu Geike Gorge and Mimbi Caves.

The Fitzroy River and its tributaries are a proclaimed surface water area under the *Rights in Water and Irrigation Act 1914* (WA). The department manages water resources through water permits and licences in proclaimed areas.

The proclamation boundary differs from the hydrological catchment boundary (Figure 1) but covers most watercourses in the Fitzroy River catchment. This difference has arisen because the information and mapping available at the time of proclamation were not as accurate as what we have now – derived from remote sensing. We expect surface water abstraction would be unlikely to occur outside the proclamation area based on the limited reliability of water, topography and distance from watercourses.

[1] see Australia Heritage Council 2011 and Department of Sustainability, Environment, Water, Population and Communities 2011

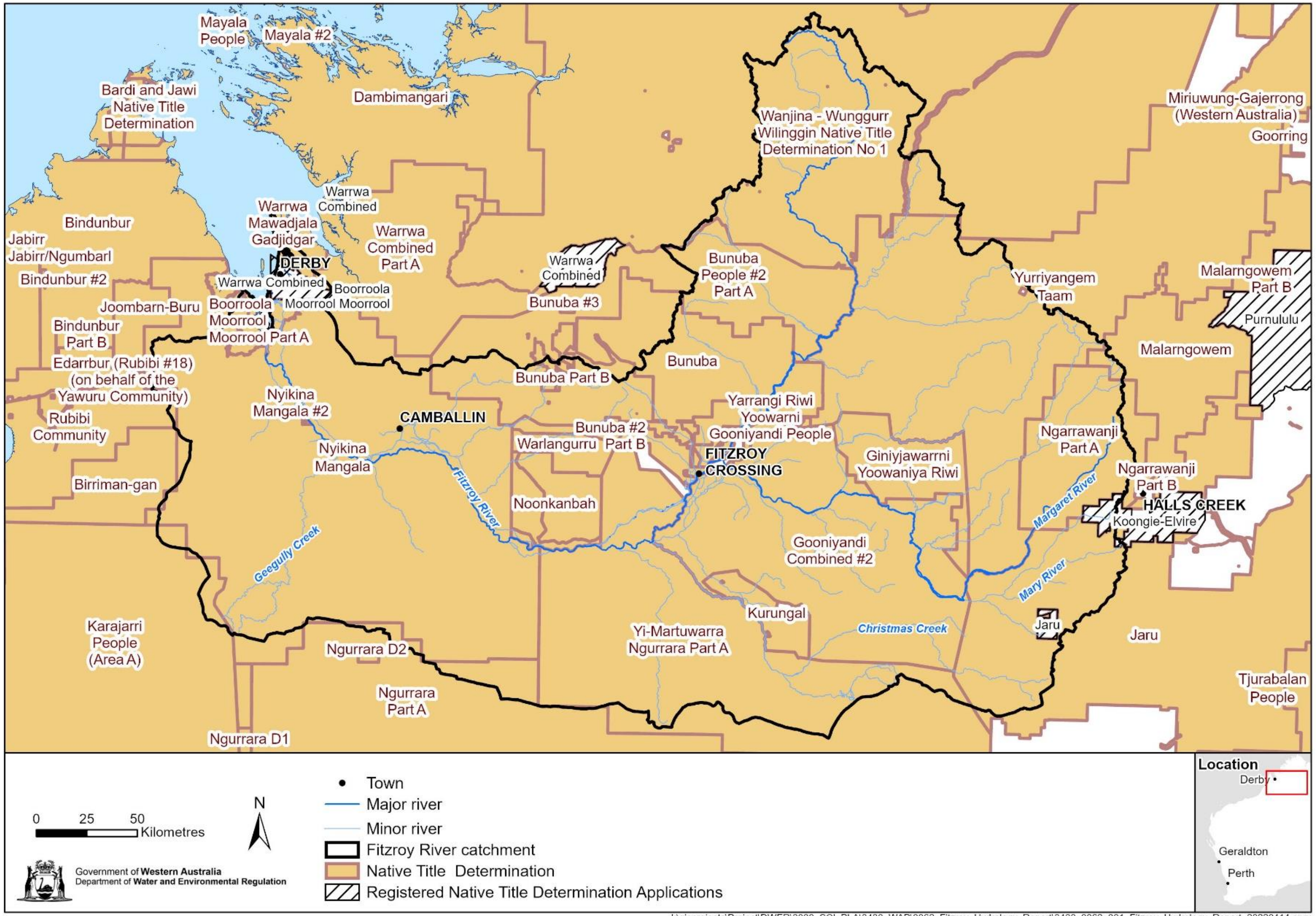

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Figure 1 Native title determinations and registered claims

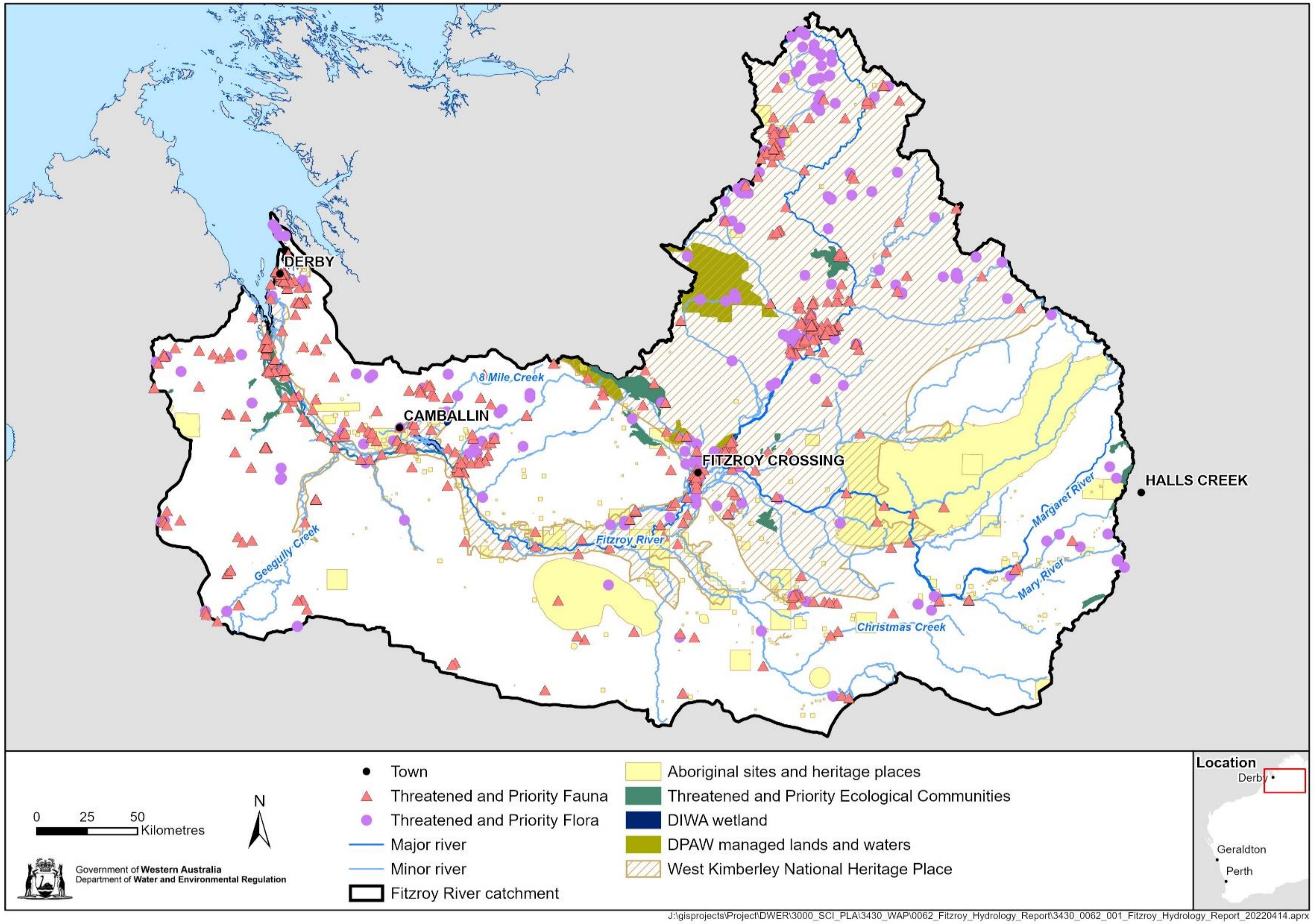


Figure 2 Environment and heritage values

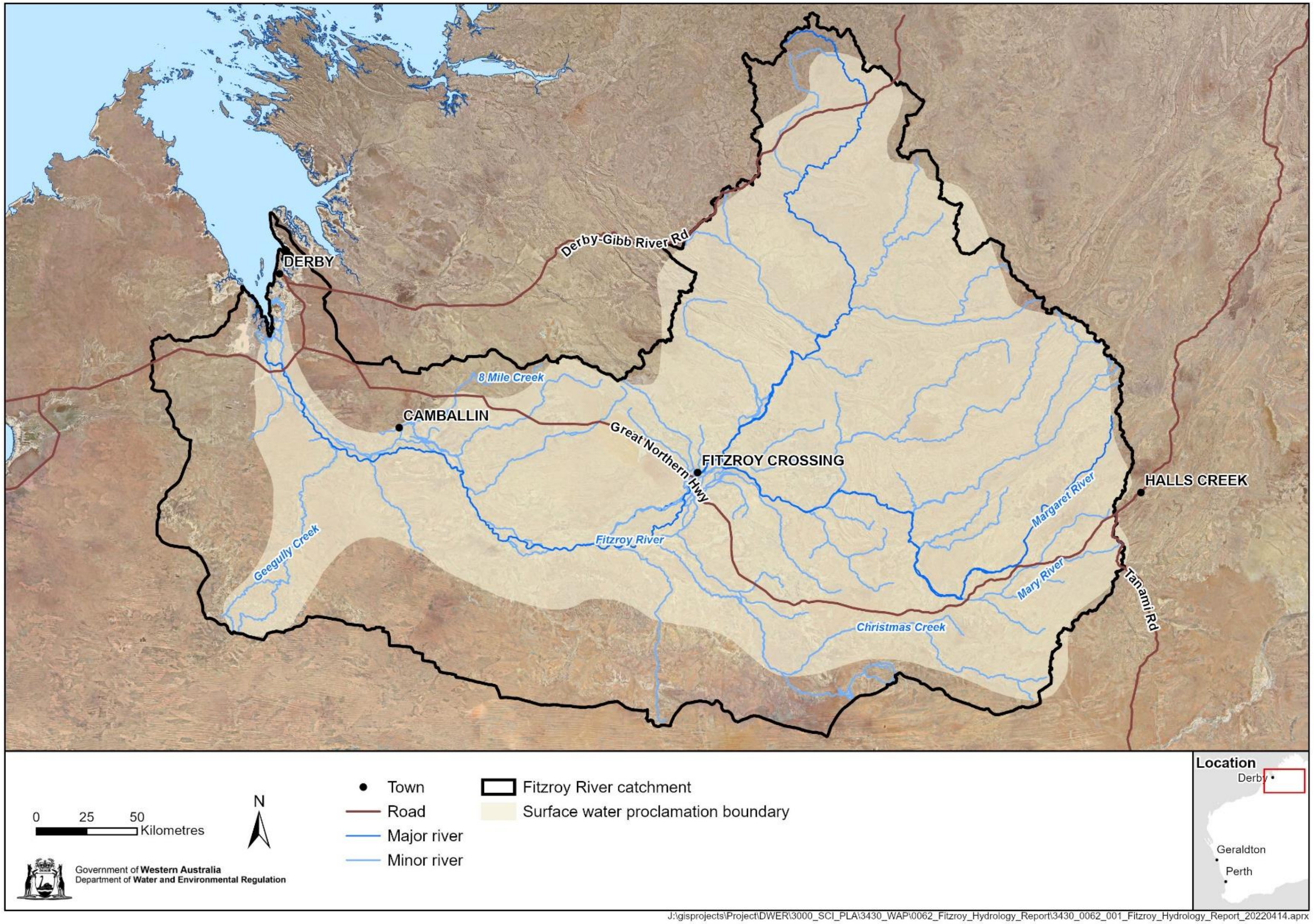


Figure 3 Proclaimed surface water area

1.3 Topography

The Fitzroy River catchment rises from the coast to elevations of about 400 to 600 m above sea level in the north-east (Figure 4). The elevated areas in the north-east feature exposed rock with tributaries flowing through many rocky gorges (Figure 5a).

The river and tributaries in the catchment's north-east respond quickly to heavy rainfall, generating runoff that moves rapidly over the land due to the steep rocky terrain. In contrast, the river's lower reaches are relatively flat lowland floodplains and sandy alluvial sediments (Figure 5b). The downstream areas of the catchment have a low gradient, resulting in slower runoff (Islam et al. 2013).

Figure 6 shows the topographic elevation and slope changes along the Fitzroy River from the headwaters to the coast. It also shows some of the department's streamflow gauges to indicate the slope changes between the sites.

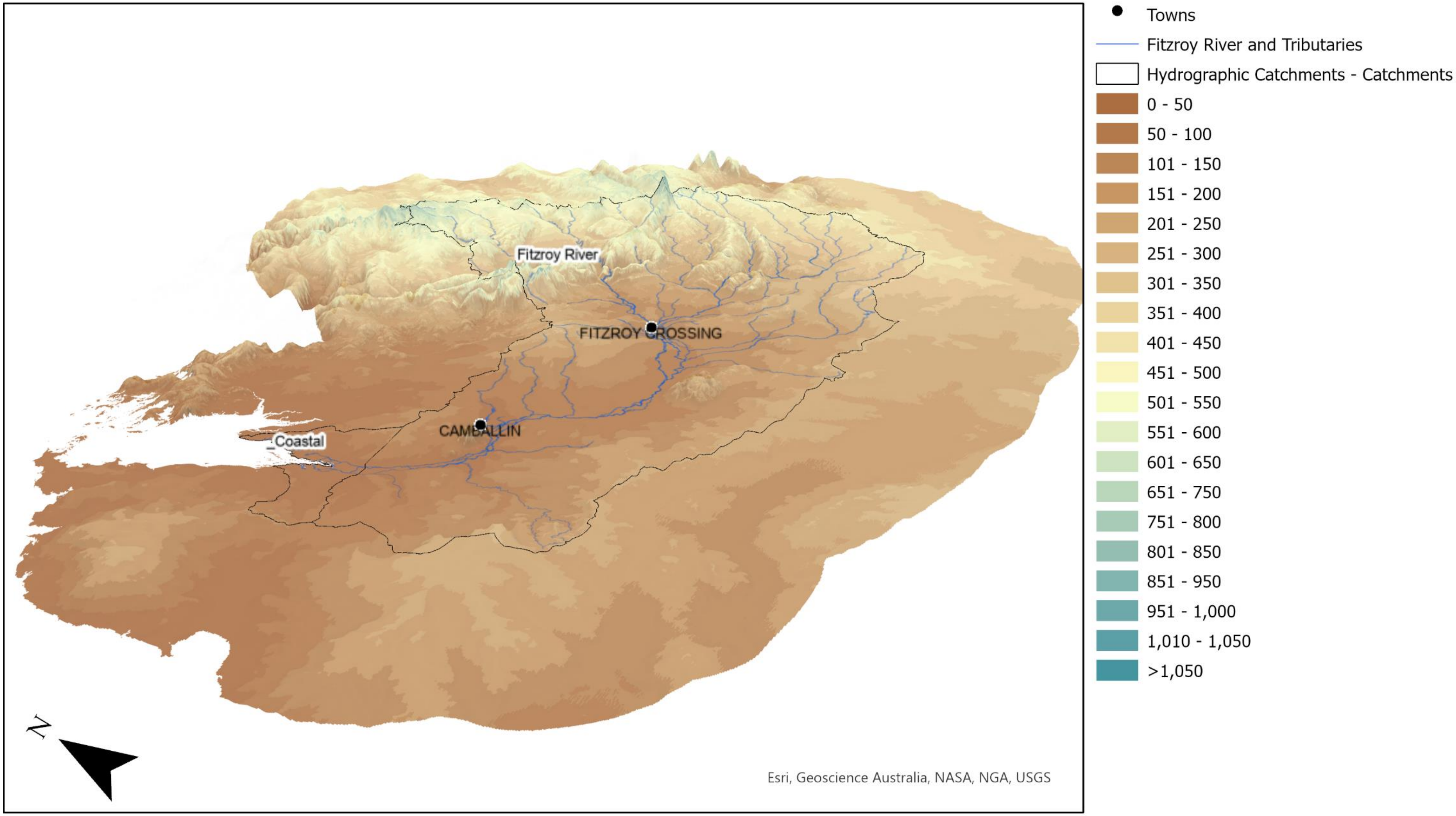


Figure 4 3D visualisation of the Fitzroy River digital elevation model (DEM)

(a)

(b)

Figure 5 *Representative images of the Fitzroy River (a) Dimond Gorge in the upper headwaters of the Fitzroy River on Wanjina-Wunggurr Wilinggin Country and (b) near Looma gauging station along the lower Fitzroy River on Nyikina Mangala Country*

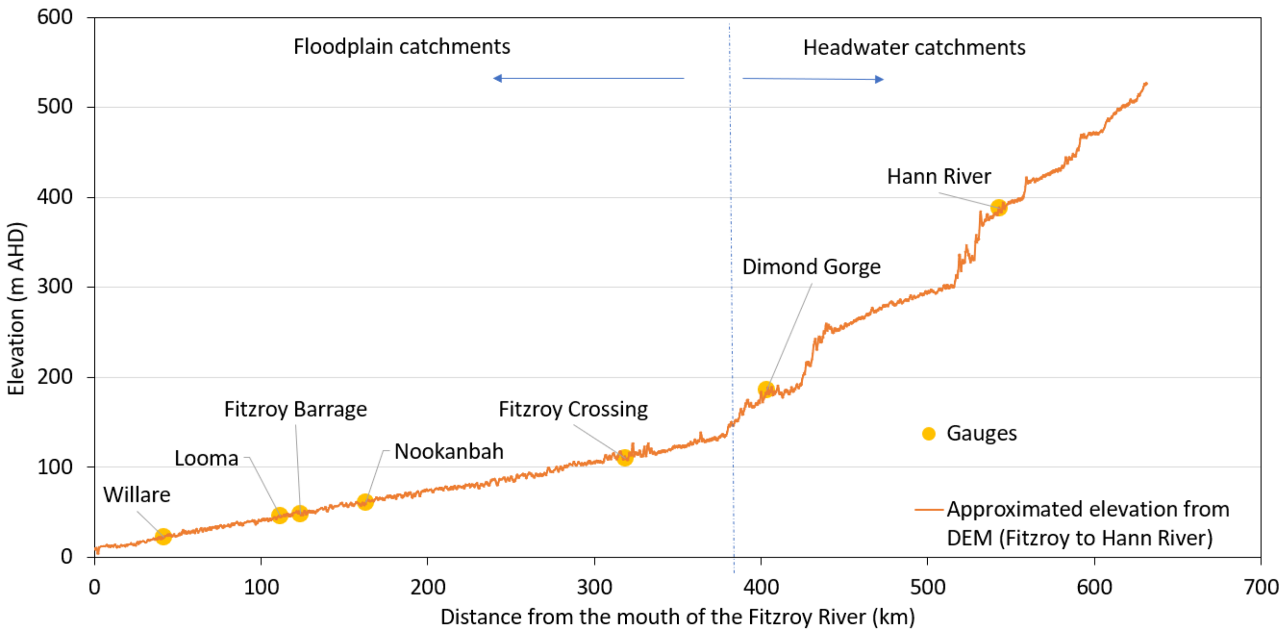


Figure 6 *Elevation changes along the Fitzroy River and location of streamflow gauging stations*

1.4 Soils

Soil types vary across the Fitzroy River catchment and influence the amount of runoff generated and flows into the river and tributaries. The soils of the river's upper, north and eastern parts are rockier than those of the lower part of the catchment, where alluvial sands and cracking clays characterise the floodplain soils (Figure 7). These differences in soil type affect how much and the rate at which rainfall seeps into the ground.

Extensive soil mapping undertaken by CSIRO for the NAWRA (Thomas et al. 2018*)* indicates soil types with high, moderate, slow or very slow permeability.[2] Most of the Fitzroy River catchment has soils with moderate permeability (Figure 8). Areas of low permeability soils fringe the river and tributaries and are associated with alluvial deposits (clays and silts) (Thomas et al. 2018).

a) b)

Figure 7 a) Shallow/rocky soils at Phillips Range streamflow station on Wanjina-Wunggurr Wilinggin Country compared with b) the alluvial sands and cracking clay soils at Noonkanbah streamflow station on Noonkanbah Country

[2] Permeability refers to how easily water moves through the soil. Low permeable soils (i.e. clays) have a low infiltration capacity and highly permeable soils (i.e. sands) have a high infiltration capacity.

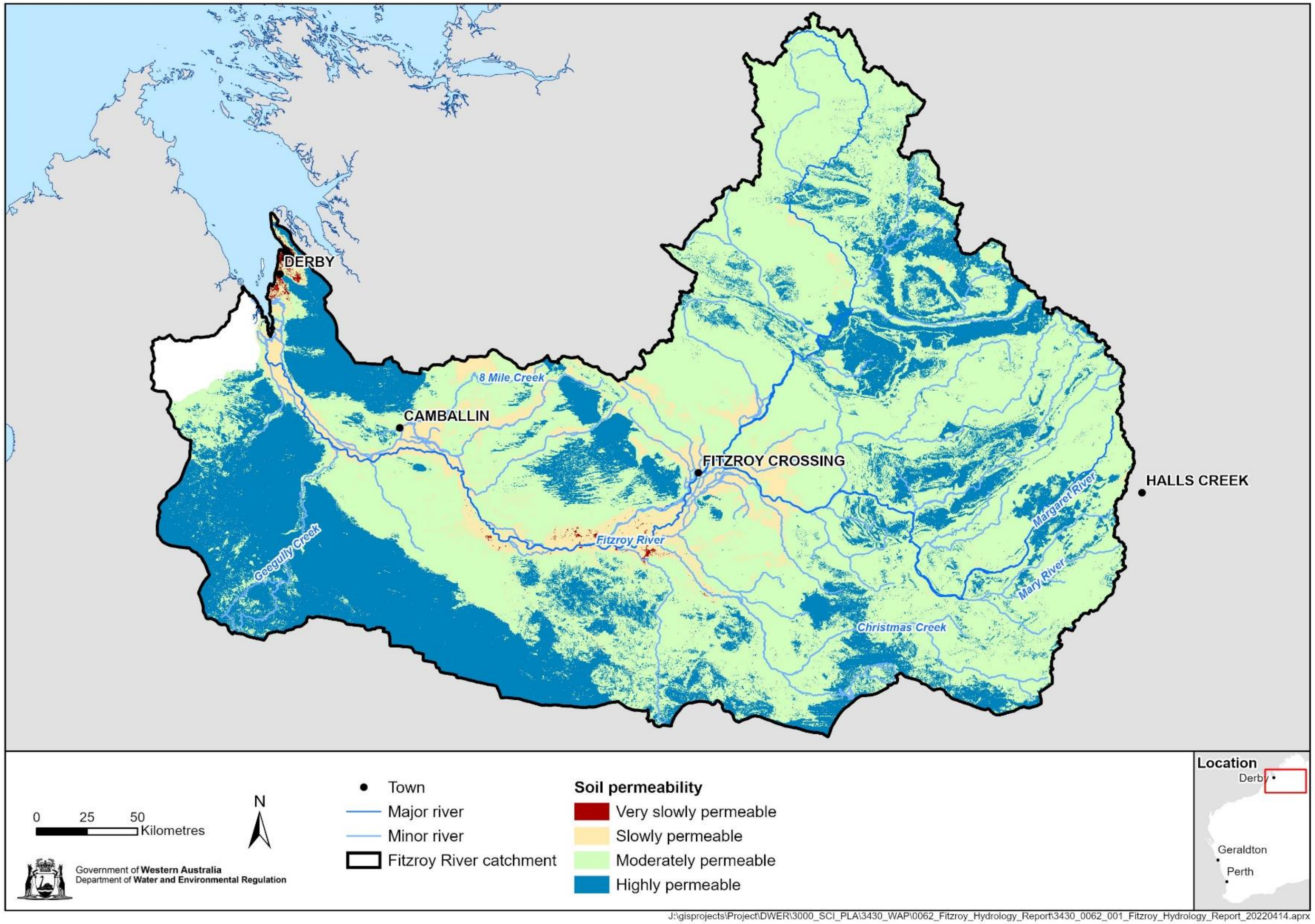


Figure 8 Permeability mapping produced by CSIRO (Thomas et al. 2018)

1.5 Riparian and floodplain vegetation

Vegetation type and density affect the amount of rain intercepted by plants and the amount that infiltrates the soil. Vegetation can increase transpiration and impede overland flow, giving water more time to infiltrate into the soil and reducing the volume of runoff generated.

Fox et al. (2001) mapped vegetation units associated with riparian and floodplain areas at a scale of 1:1,000,000 (Figure 9). Detailed vegetation types cannot be shown at this scale of mapping; however, the displayed vegetation units are likely to need permanent access to either surface or groundwater and occasional inundation. They include:

- C7: *Eucalyptus camaldulensis* (river red gum) and/or *Eucalyptus microtheca* (coolibah) or *Eucalyptus coolabah* (coolibah) or *Eucalyptus gymnoteles (*coolibah) woodland on channels and levees.
- C10: *E. microtheca* (coolibah) or *Eucalyptus gymnoteles* (coolibah) and/or *Eucalyptus* spp. +/- *Excoecaria parvifolia* (gutta percha) grassy low woodland.
- C18: *Dichanthium fecundum* (curly bluegrass) and *Chrysopogon fallax* (golden beard grass) tussock grassland sparsely wooded with low trees.
- C20: Swamps, lakes and lagoons, frequently ephemeral, +/- fringing woodlands, shrublands, herblands and sedgelands.

DWER (2023a) provides more in-depth commentary on the vegetation of the Fitzroy River catchment.

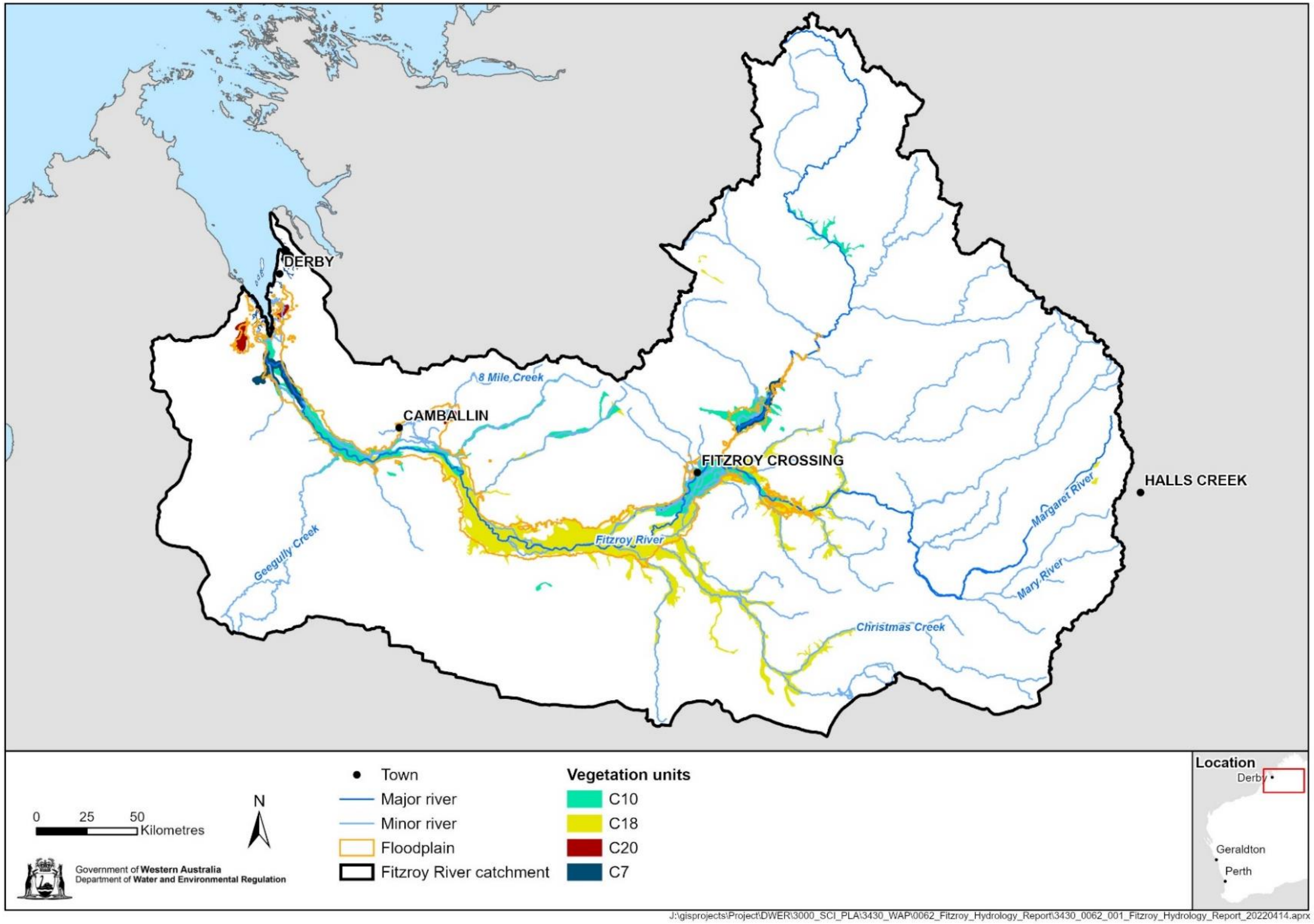


Figure 9 Vegetation units of the Fitzroy River and floodplain Fox et al. (2001). See the preceding text for a description of the vegetation units C10, C18, C20 and C7

1.6 Land use

Pastoral development

By the 1890s, pastoral leases covered most of the Fitzroy River catchment. High sheep and cattle numbers led to a decrease in vegetation density, soil compaction and large areas of erosion, especially around the riverbanks (Lindsay & Commander 2005). Fewer livestock numbers since 1978, watering points being established away from the riverbanks and improved fencing are factors helping to reduce these impacts. Pastoral leases for 49 stations cover 95 per cent of the catchment (Figure 10).

Current and historical surface water developments and learnings

The Camballin Barrage (also known as the Fitzroy Barrage) was built in the 1950s to support large-scale irrigation of rice and other crops. The barrage impounds and raises the river's water height to allow water to flow under gravity down a diversion channel, referred to as Uralla/Snake Creek.

The original intent was to divert water to fill the Seventeen Mile Dam and create large-acreage lots for rice farming. Yet both the agricultural trials and full-scale agriculture mostly failed due to periodic flooding (which caused considerable damage to crops and infrastructure), pest damage, weed infestation, animal grazing, wind damage and bacterial blight (GHD 2009). These days water diversions down Uralla/Snake Creek support the irrigation of fodder.

Mining

Current and pending mining leases are scattered across the Fitzroy catchment. Past, present and proposed mining activities include coal, lead and zinc, tight gas and diamonds (Harrington & Harrington 2015). Most mining leases are located away from the Fitzroy River.

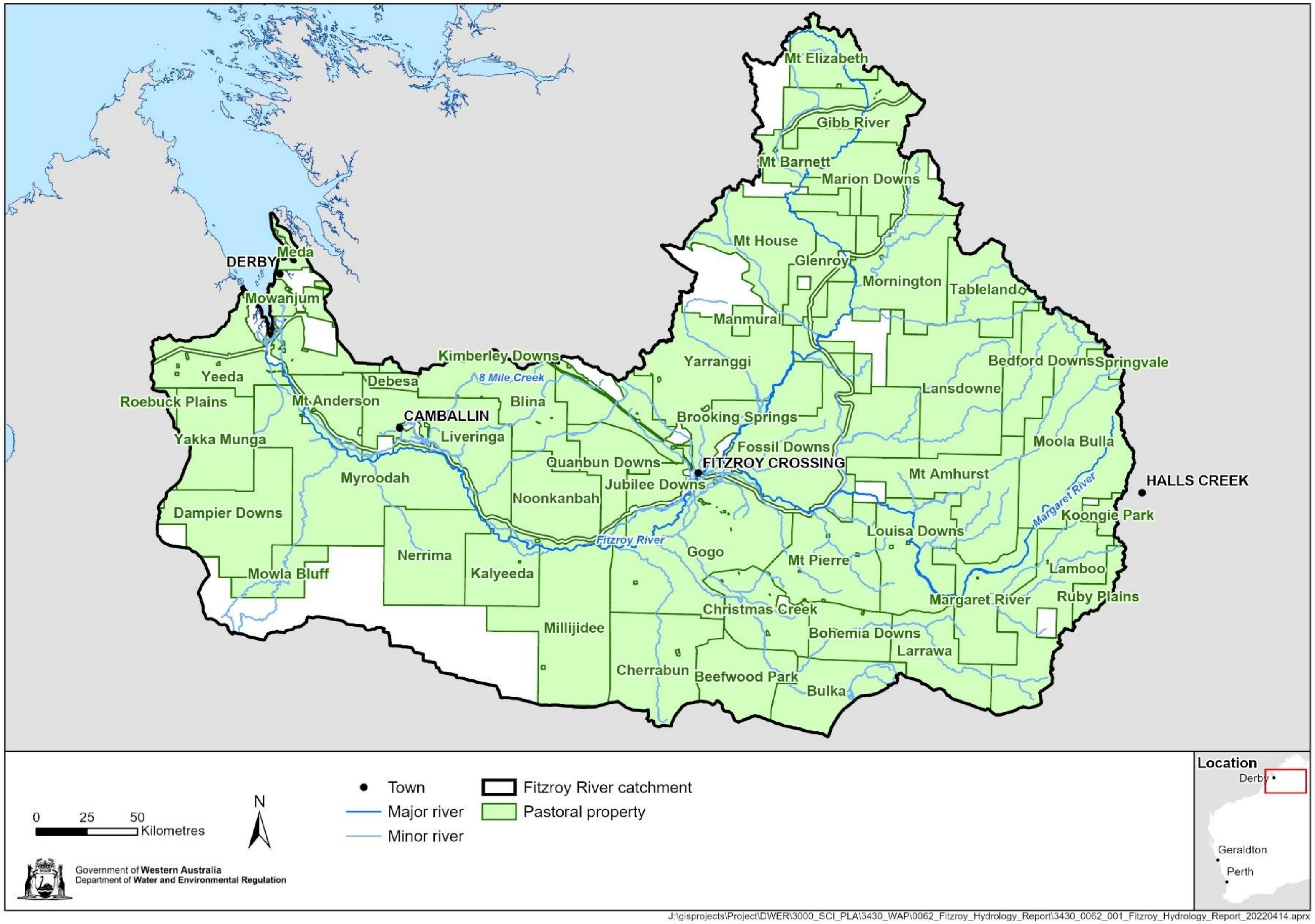


Figure 10 Pastoral leases within the Fitzroy River catchment

2 Climate

2.1 Rainfall

The strongest influences on rainfall and streamflow generation in the Fitzroy River catchment are intensity and tropical cyclone intensity and frequency (Moise et al. 2015).

The monsoon usually starts in late December and persists until April (Brown 2018). Monsoonal rainfall is more sustained than the short bursts of high-intensity rainfall associated with tropical cyclones.

There is a reasonably high risk of cyclones between November and April over the Fitzroy River catchment (Charles et al. 2016). From 1969–70 to 2017–18, the average occurrence of cyclones ranged from four in five years near the coast (0.8 genesis count in) to one in five years inland (0.2 genesis count) (Figure 11). Strong winds related to cyclones pose a risk to above-ground infrastructure (sheds, irrigation pivots etc.) and crops.

The Fitzroy River catchment has several rainfall monitoring stations (Figure 12). We analysed data from five of these stations to understand how rainfall observations vary with time and location (Bureau 2021b).

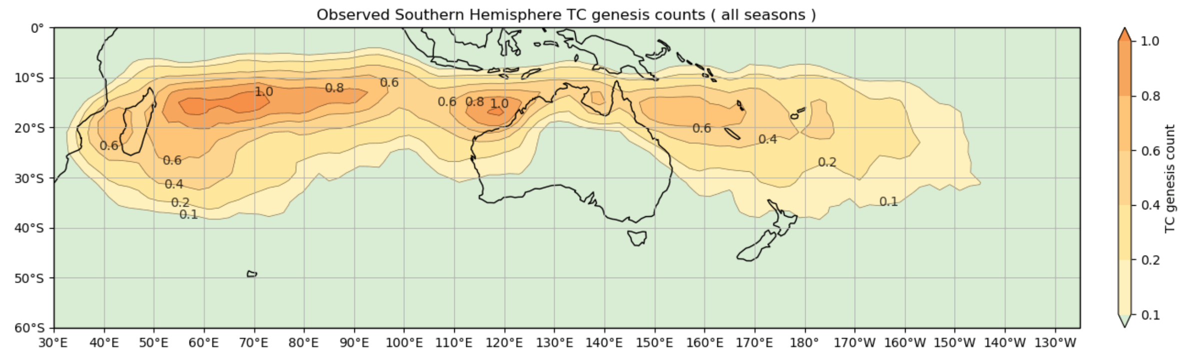


Figure 11 Average annual number of tropical cyclones based on 48 years of data from 1970 to 2018 (Bureau 2021a)

Annual rainfall

The highest average annual rainfall in the Fitzroy River catchment is recorded in the north-east, with average rainfall decreasing towards the south-west. The lowest average annual rainfall is recorded along the catchment's southern boundary, which borders the Great Sandy Desert.

Figure 13 illustrates the variation in average annual rainfall over the catchment with a change from dark blue shading in the higher-rainfall north-eastern area, to light blue shading in the lower-rainfall area, along the catchment's southern boundary.

Annual rainfall across the catchment has shown an increasing trend since the 1960s (black line in Figure 13). However, low rainfall years still occur – the 2018–19 wet season being an example.

Large variations in annual rainfall are typical. For example, at Myroodah rainfall station (Bureau of Meteorology ref. 3018 – see Figure 13), the annual rainfall recorded in the 2018–19 season was 324 mm, four times lower than the annual rainfall recorded two years prior in the 2016–17 season (1,263 mm).

Numerous studies (Petheram et al. 2008; Pusey & Kath 2015; Douglas, Jackson et al. 2019) highlight that the variability in rainfall and streamflow in the Fitzroy is a key consideration for any water management decisions. In tropical monsoonal climates, the amount of water that can be reliably allocated for consumptive purposes is constrained by the drier years in the historical record (Petheram et al. 2018).

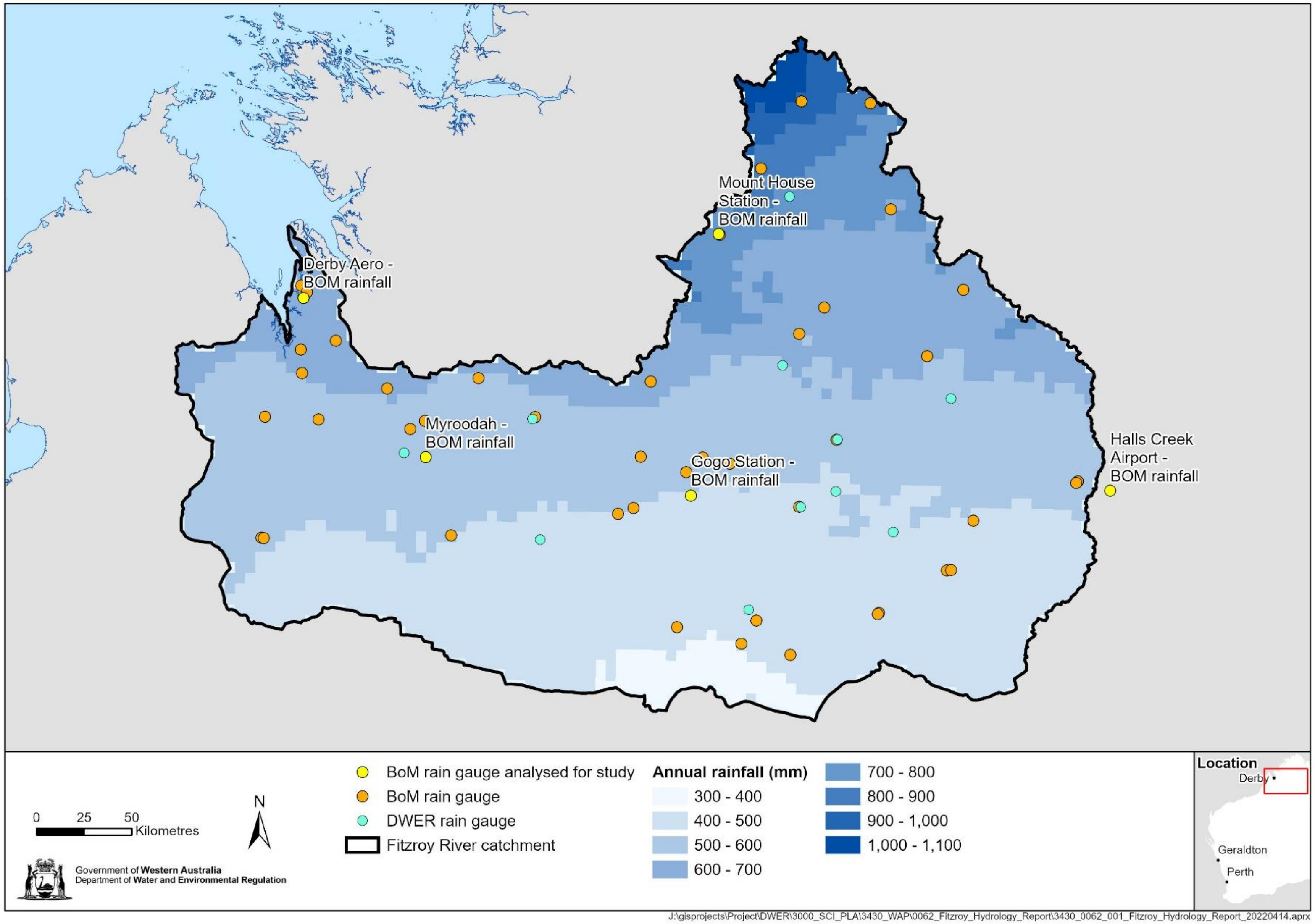
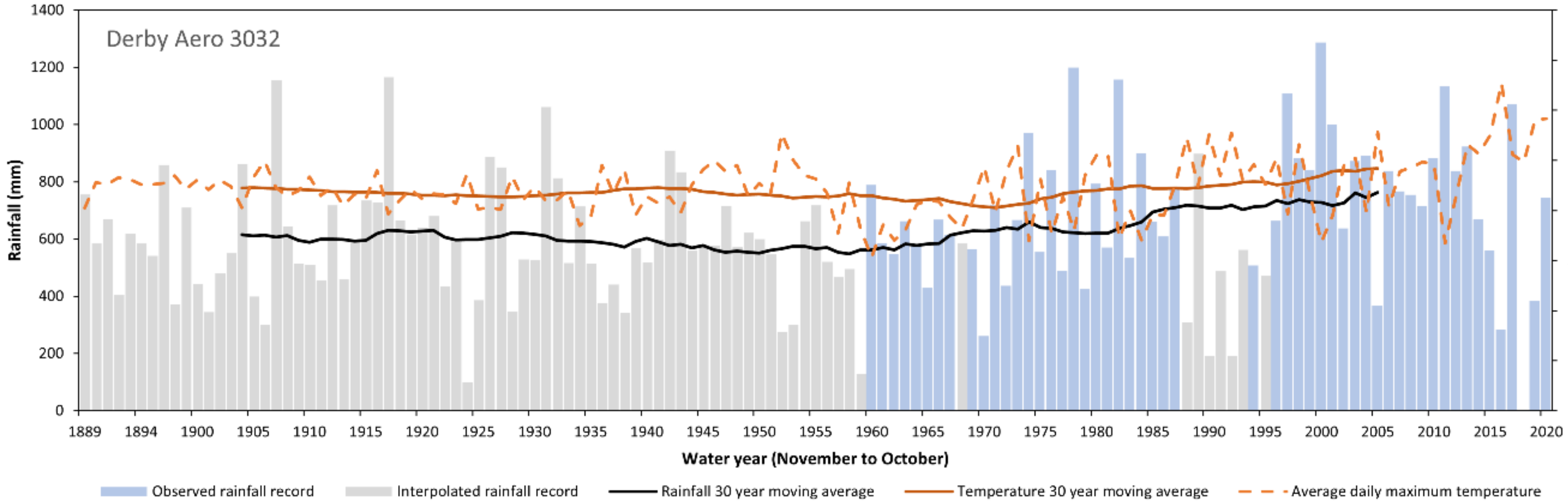
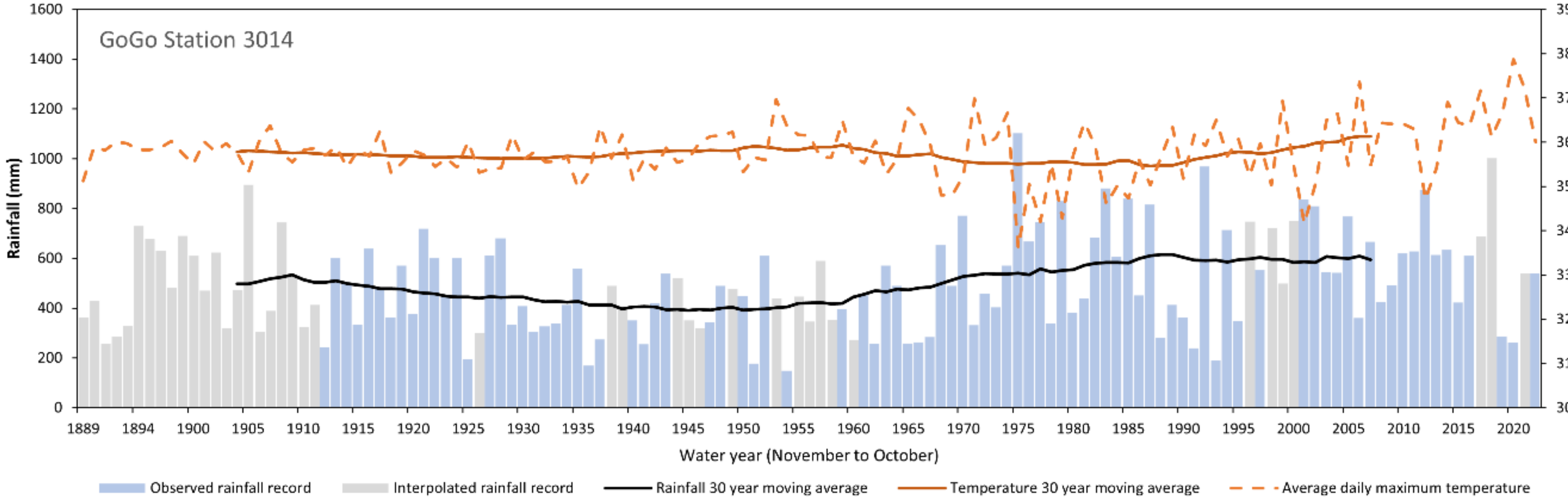
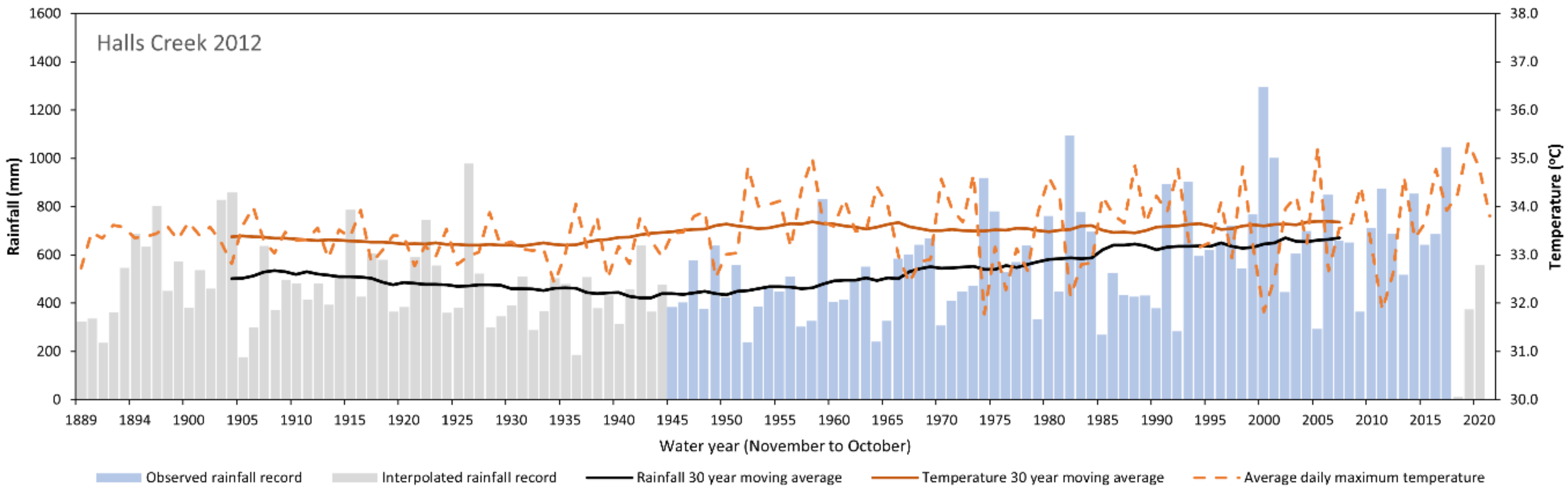
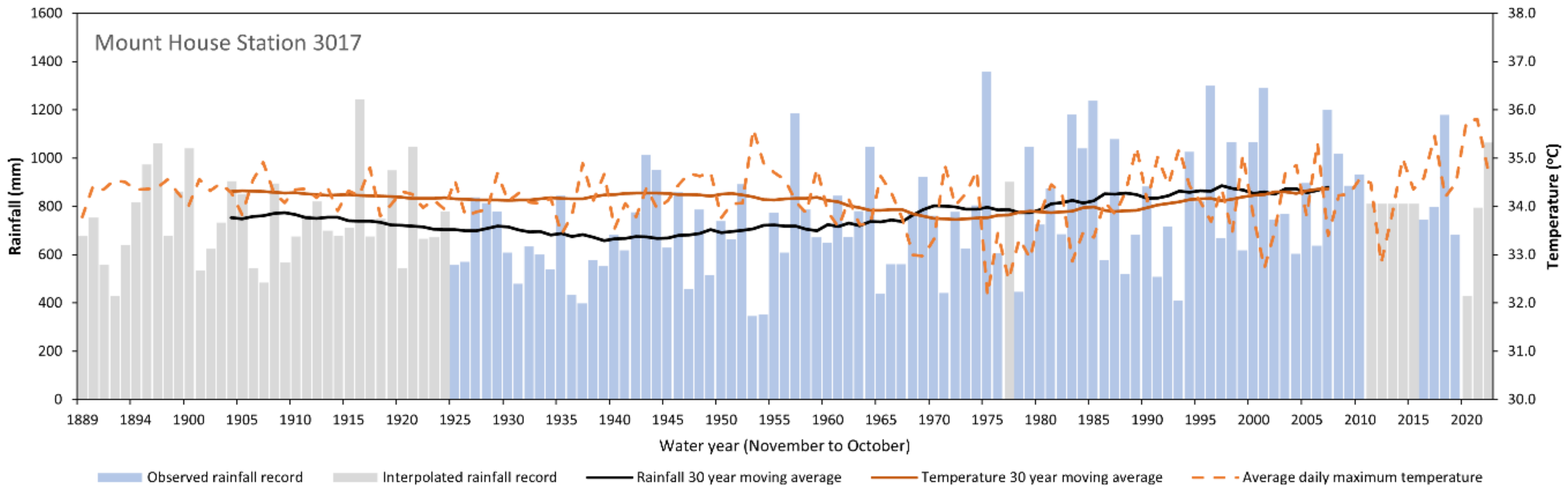


Figure 12 Average annual rainfall across the Fitzroy catchment based on SILO rainfall data from 1890 to 2020


Derby Aero 3032
Rainfall (mm)
Temperature (°C)
Water year (November to October)
Observed rainfall record
Interpolated rainfall record
Rainfall 30 year moving average
Temperature 30 year moving average
Average daily maximum temperature


GoGo Station 3014
Rainfall (mm)
Temperature (°C)
Water year (November to October)
Observed rainfall record
Interpolated rainfall record
Rainfall 30 year moving average
Temperature 30 year moving average
Average daily maximum temperature


Halls Creek 2012
Rainfall (mm)
Temperature (°C)
Water year (November to October)
Observed rainfall record
Interpolated rainfall record
Rainfall 30 year moving average
Temperature 30 year moving average
Average daily maximum temperature


Mount House Station 3017
Rainfall (mm)
Temperature (°C)
Water year (November to October)
Observed rainfall record
Interpolated rainfall record
Rainfall 30 year moving average
Temperature 30 year moving average
Average daily maximum temperature

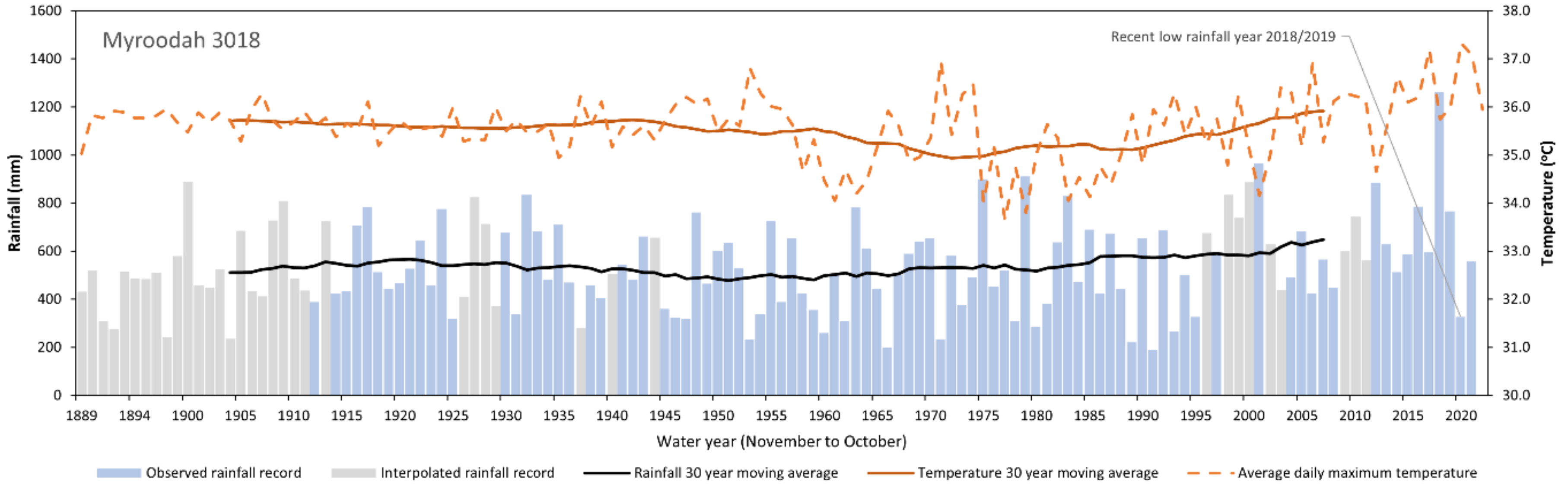


Figure 13 Annual rainfall and maximum temperature at selected rainfall sites with a long-term record (interpolated rainfall record taken from SILO dataset (Queensland Government, data accessed: 16 June 2021)

Monthly rainfall

Rainfall over the Fitzroy River catchment is highly seasonal. Most rain falls between November and April, with low average monthly rainfall during the dry season from May to October (Figure 14). We assessed rainfall data at five representative sites, all of which indicated the same seasonal rainfall pattern.

On average, the highest monthly rainfall was recorded in January and February, and the lowest – generally less than 20 mm/month – during the dry season. However, large rainfall events can occur during the dry season, such as in May 2016 when 115 mm of rainfall was recorded at Myroodah over four days.

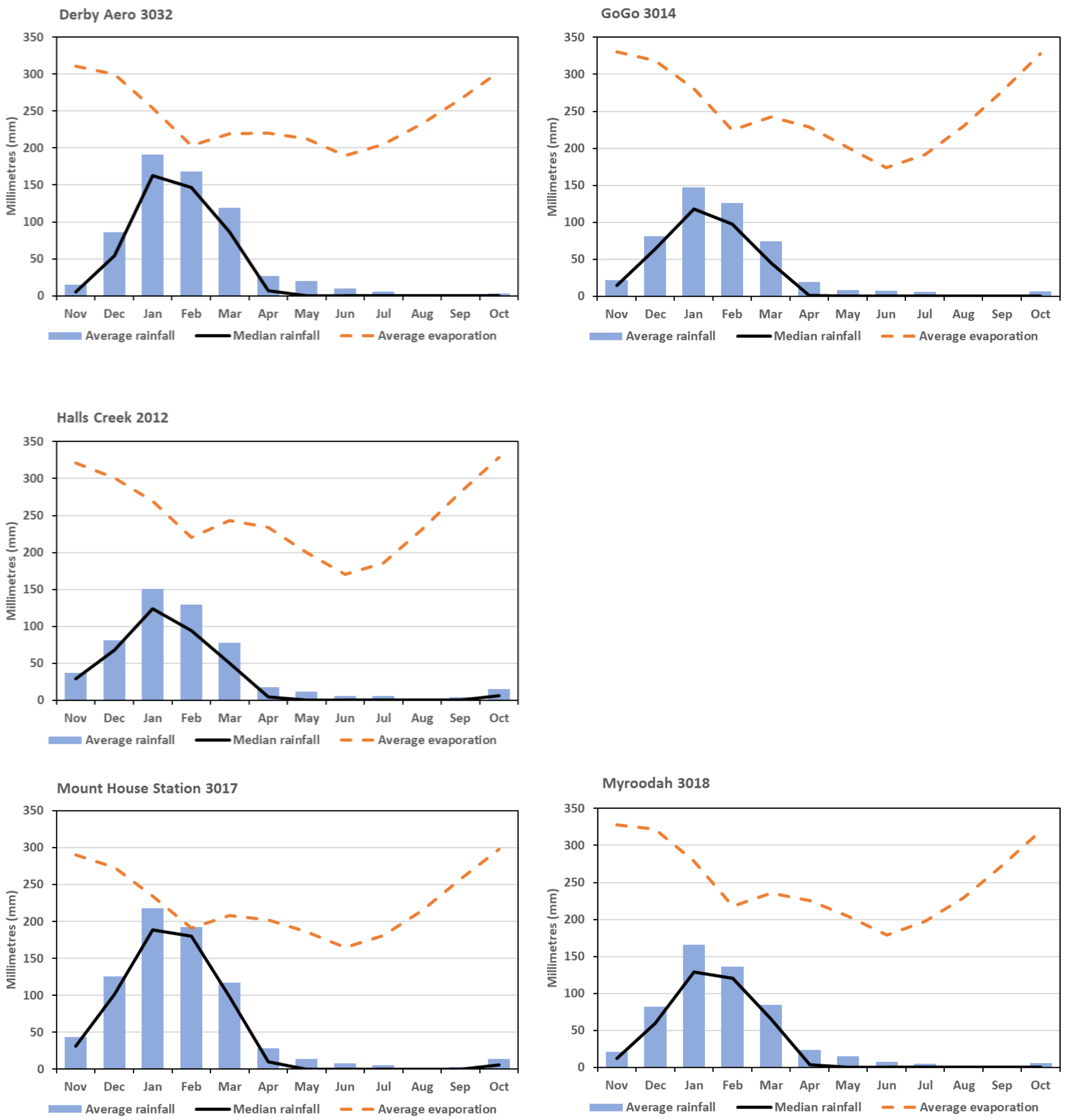


Figure 14 Mean and median monthly rainfall totals and average evaporation rates at selected representative rainfall sites using data from 1890 to 2020

2.2 Temperature and evaporation

Average daily maximum temperatures during the wet season can exceed 35°C, while during the dry season they are around 30°C (Figure 15 and Figure 16).

Despite the higher rainfall totals between November and April, average potential evapotranspiration exceeds rainfall every month (Figure 14). This can result in a large rainfall deficit (~1,200 to 1,500 mm) – influencing runoff generation and adversely affecting potential surface water storage opportunities (Petheram et al. 2018).

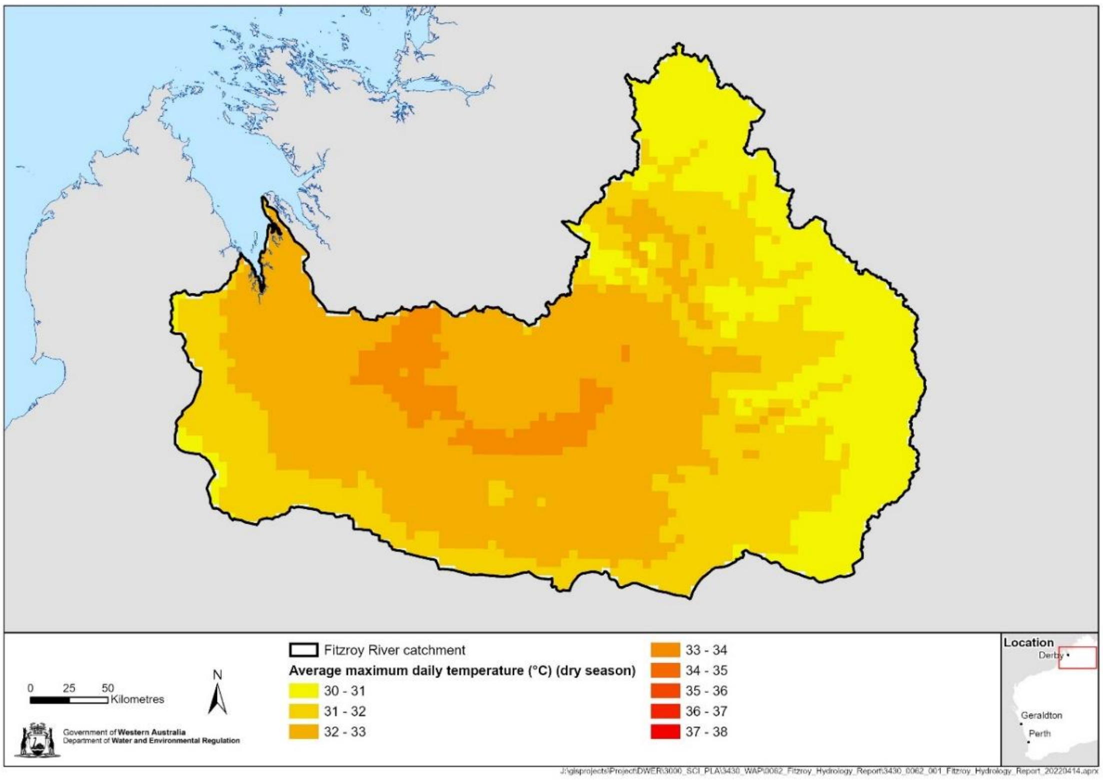


Figure 15 Variation in average maximum daily temperature during the dry season using data from 1890 to 2020

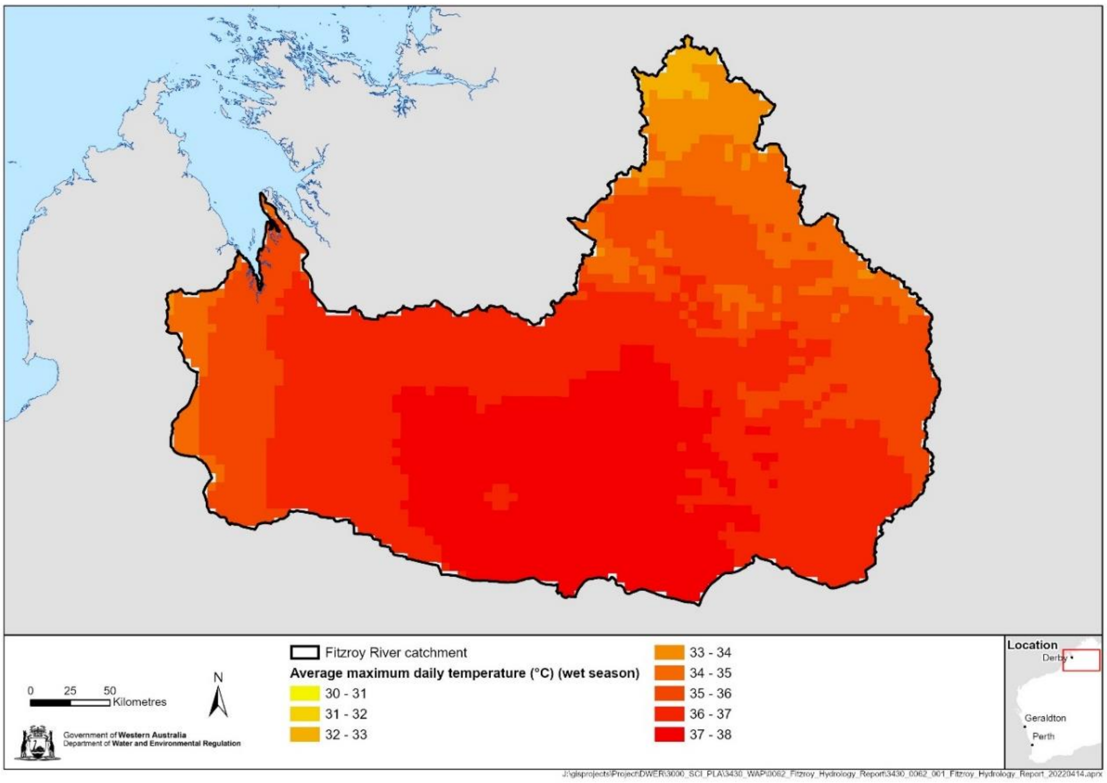


Figure 16 Variation in average maximum daily temperature during the wet season using data from 1890 to 2020

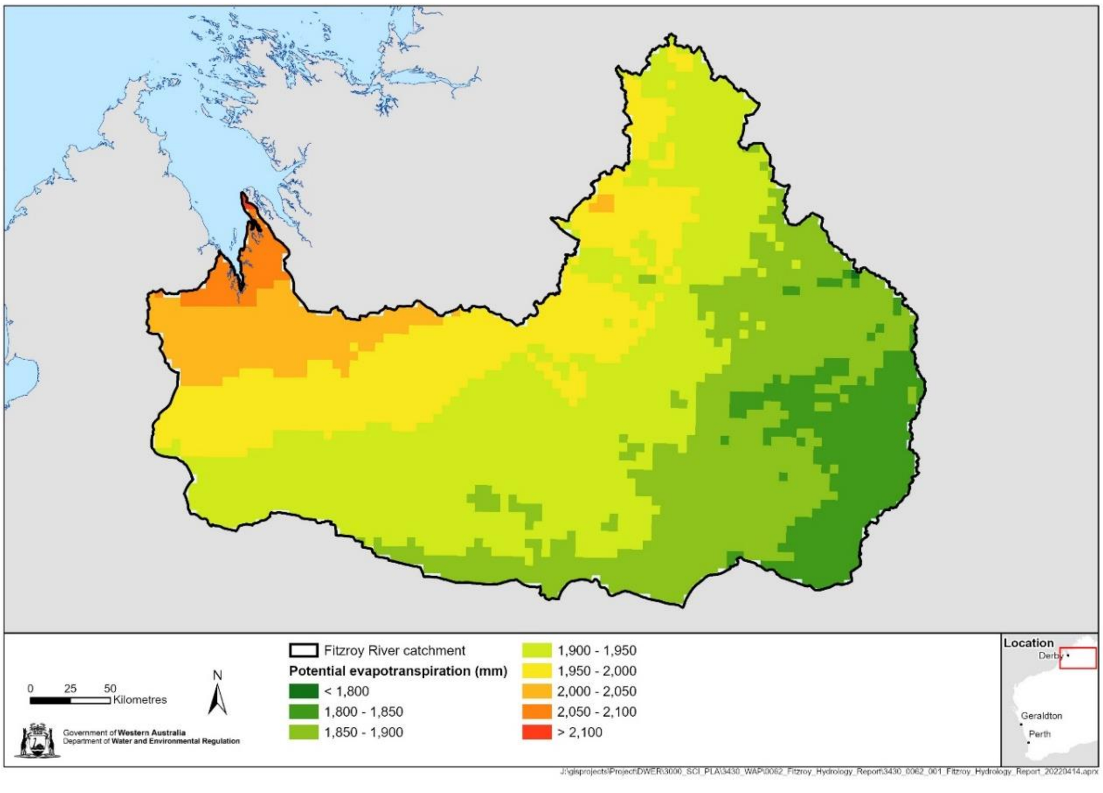


Figure 17 Variation in potential evapotranspiration across the Fitzroy catchment using data from 1890 to 2020

2.3 Climate change

Using global climate models (GCMs), the Bureau of Meteorology (Bureau) has provided projections of future climate change to the end of the century for the monsoonal north of Australia, including the Kimberley region (Bureau 2022). See awo.bom.gov.au for more information on the projections.

The climate change projections are provided at a 5-km-grid scale. These were produced using medium and high greenhouse-gas-emission scenarios (two representative concentration pathways[3]) to drive four GCMs from the Coupled Model Intercomparison Project Phase 5 (CMIP5). These were then downscaled, re-gridded, and corrected for discrepancies between climate input and observation using three bias correction methods (Bureau 2022).

Climate change projections for northern Australian rainfall provide no clear indication of the direction of change in annual (and seasonal) rainfall volumes in a future warmer world (Brown 2018; CSIRO & Bureau 2015). Two of the four GCMs project a wetting trend for wet seasonal rainfall, while two project a decrease in wet season rainfall over northern Australia (Bureau 2022).

While the GCMs cannot represent key climate drivers associated with monsoonal rain, both increases and decreases in wet season rainfall are plausible. The models agree that rainfall variability (from daily to seasonal timescales) will increase, and more intense rainfall extremes are possible. Multi-year dry periods are also projected to increase. Changes in average rainfall are less certain (Narsey et al. 2020), with little change to dry season rainfall projected.

With no clear trend in average rainfall from global climate modelling and the inability of global climate models to adequately model northern Australia's climate processes, the department's current position is to use long-term historical climate data for our water modelling and planning in the state's north-west (DoW 2015). This approach means we can consider the full range of potential climate variability.

The Australian summer monsoon, which is the southern-most part of the Asian-Australian monsoon system, brings most of the rainfall to northern Australia (Wheeler & McBride 2011). Narsey et al. (2020) explored the latest global climate model results (CMIP6[4]), finding that the range in climate change projections of Australian monsoon rainfall had reduced compared with the previous global climate modelling results (CMIP5[5]). However, the new generation of global climate models continue to disagree on the magnitude and direction of rainfall projections in northern Western Australia.

[3] The two concentration pathways reported are 4.5 and 8.5 from IPCC Fifth Assessment Report.

[4] Coupled Model Intercomparison Project Phase 6: an ensemble of climate change models based on the Intergovernmental Panel on Climate Change Sixth Assessment Report.

[5] Coupled Model Intercomparison Project Phase 5: an ensemble of climate change models based on the Intergovernmental Panel on Climate Change Fifth Assessment Report.

Higher temperatures lead to more moisture in the atmosphere, which supports heavier rainfall. However, the warming climate also tends to slow the circulation of the atmosphere in the tropics, weakening the upward motion that produces rainfall in the monsoon regions (Brown 2018).

Although uncertainty surrounds the plausible wetter and drier rainfall projections, the Bureau projections show that temperature and potential evapotranspiration are projected to increase (Bureau 2022). Projected changes for potential evapotranspiration are correlated to temperature. Global climate modelling suggests temperature increases in all seasons across the Fitzroy River catchment with high confidence (Moise et al. 2015).

Higher temperatures and higher evaporation may reduce the permanence of river pools and off-channel wetlands and their ability to sustain water over the dry season without any groundwater interaction. Such increases would also affect crop water demands and evaporation from open waterbodies. Dry season soil moisture – important for maintaining vegetation and shallow groundwater inputs to the river – would also decrease.

Higher evaporation would also affect the ability of any off-stream surface water storages to sustain water for use over the dry season. It is estimated that large farm-scale off-stream storages (ring tanks) could lose about half their water storage to evaporation and seepage between May and November. Using stored water early in the dry season is the most effective way to reduce losses (Petheram et al. 2018).

At present the department uses *Selection of future climate projections for Western Australia* (DoW 2015) to guide how we consider climate change in our water planning, both in the Fitzroy catchment and across the state. Together with the Bureau we are working on an update to this guidance. We anticipate this will take the form of a scalable, practical, risk-based framework to guide how hydrologists, hydrogeologists, water planners and other decision-makers in the water sector might choose climate projection datasets for water modelling and planning. We will revise this guidance periodically as new information from future global climate models becomes available.

3 Fitzroy River hydrology

The Fitzroy River is 730 km long and flows west from its headwaters in the Wunaamin-Miliwundi Ranges in the Central Kimberley to King Sound near Derby. The Fitzroy is one of Australia's largest unregulated rivers (Lindsay & Commander 2005) and has the largest average annual discharge volume of any river in Western Australia (Petheram et al. 2014). Its main tributaries are the Hann, Margaret and Leopold rivers, and Christmas and Mt Wynne creeks (Figure 18).

River channels in the upper reaches of the Fitzroy River catchment are steeper, deeper and narrower in shape than those in the lower reaches. The channel depths in the river's lower reaches meander through a broad, unconfined alluvial floodplain. The riverbeds in the lower reaches are sandier than those in the upper reaches, and cracking clay soils exist within the vast floodplain (>10 km wide).

During high-flow events, water can scour sediment along the bed and banks of the river channel. These scouring flows create river pools along the outer edges of the river bends (DoW 2018). Scouring and channel erosion can expose the roots of riparian vegetation and make riverbanks unstable (Figure 19).

Scouring flows also function to remove the build-up of sediments within the river channel. Without them, flow will often become constrained by sediment and vegetation build-up. If flow is constrained and exceeds the carrying capacity of the main channel, water spills onto the floodplain, resulting in braided channels and anabranching[6] (Taylor 2009).

The Fitzroy's anabranches include the Cunningham anabranch downstream of Fitzroy Crossing and Uralla Creek, which leaves the main channel just upstream of Camballin Barrage and re-joins the main channel, as Snake Creek, downstream of the Looma streamflow gauging station. We do not measure flows in the anabranches directly but can estimate them using modelling.

These auxiliary channels and flow paths can alter between years, making it difficult to define the river channel network. Figure 18 shows two different mapped river networks. The first network is the Hydrography, Linear (Hierarchy)[7] dataset, which we use for broadscale streamline presentation of major and minor watercourses. The second network is Geoscience Australia's Surface Water Hydrology Lines[8] dataset (Crossman 2015), which defines the flow paths for the Fitzroy River catchment.

Major and minor tributaries are shown in blue of Figure 18, with all other potential drainage lines in orange. The major and minor tributaries are defined based on the Hydrography, Linear (Hierarchy) dataset. All other drainage lines are based on the

[6] An anabranch is a section of a river or stream that diverts from the main channel or stem of the watercourse and re-joins the main stem downstream.

[7] Hydrography, Linear (Hierarchy) (DWER-031) - Datasets - data.wa.gov.au

[8] National Surface Water Information | Geoscience Australia (ga.gov.au)

Surface Water Hydrology Lines dataset and may not convey water in every year or may only flow occasionally and for short periods.

The combination of these datasets can provide a fine-scale coverage of possible watercourses within the catchment. On-ground observation should be used to validate and ground-truth this information.

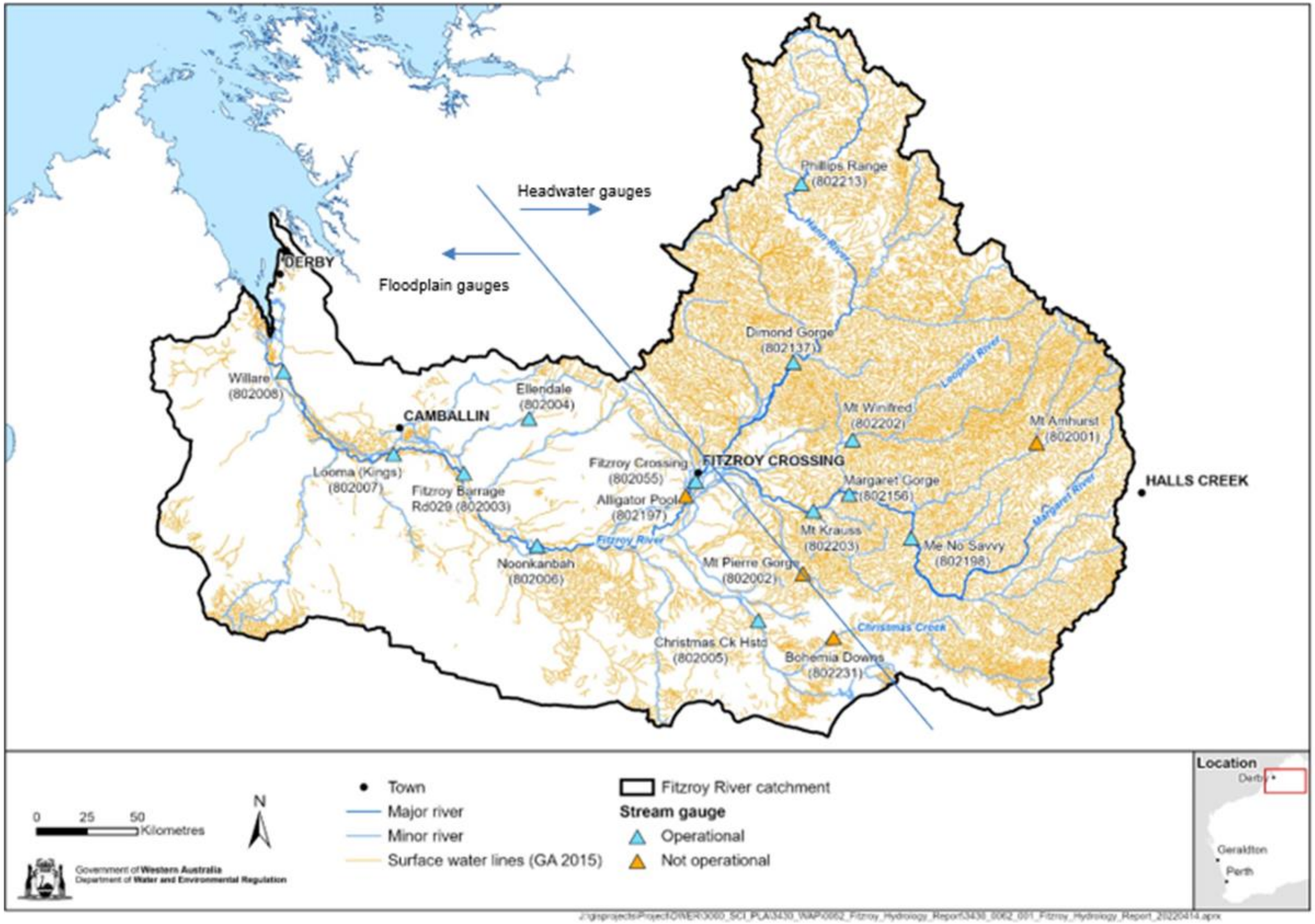


Figure 18 Stream network and streamflow gauging stations in the Fitzroy River catchment

Figure 19 Erosion of riverbanks and effect on the stability of riparian vegetation

3.1 Streamflow data

Gauged data

At present the department operates 13 gauging stations, which together provide good spatial coverage of streamflow across the Fitzroy River catchment (Figure 20). Streamflow monitoring began in the 1950s (Figure 18 and Figure 19), and since then we have operated 17 streamflow gauging stations for varying lengths of time.

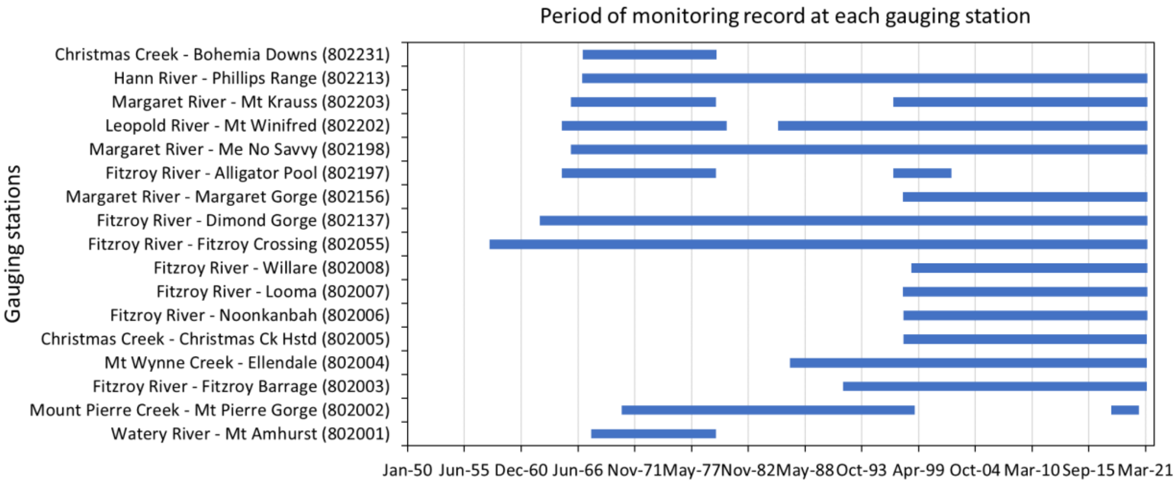


Figure 20 Duration of flow data at streamflow gauging stations

Stream gauges measure the water's height relative to the level of the stream bed. They use a gas-bubble pressure-sensed water-level recorder that sits inside an installation with a pressure line to an orifice within the river (Figure 21). An electronic pressure transducer senses the back pressure and converts it to a water level reading in metres.

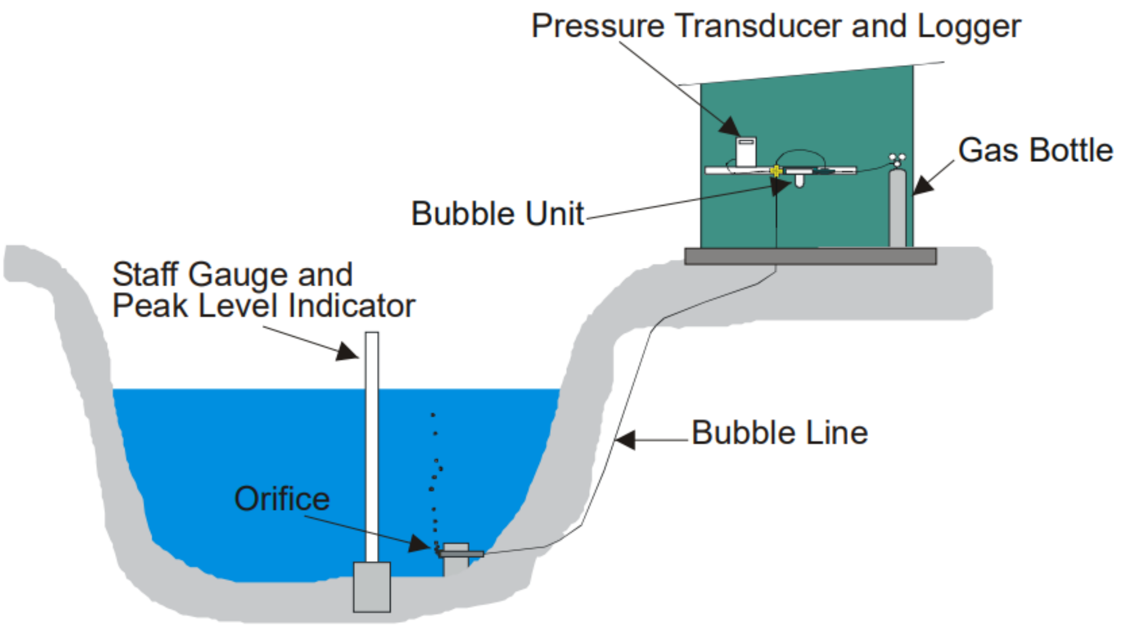


Figure 21 Schematic of a streamflow gauge installation for measuring river depths on the Fitzroy River

Many methodologies in hydrology rely on information about streamflow discharge rates rather than water level. Streamflow discharge is calculated from the continuously recorded stage levels, using a relationship developed from direct measurements of the flow undertaken at the site and theoretical methods using information on the hydraulic behaviour of the gauge reach. This relationship is known as a rating curve.

Direct measurements during floods are difficult due to the sheer size of the active floodplain, which can cover up to 20 km on the lower Fitzroy River, and safety concerns such as debris load in the flow or partially submerged vegetation and infrastructure (bridges, fences etc.). We use information on the channel geometry, observations of peak water levels and hydraulic modelling techniques to provide greater confidence in the high-flow rating curves and resulting hydrologic analyses using the stream gauge data.

Other significant ecologic and hydrologic analyses rely on accurate information for very low flows. Such data can help us understand the interaction between groundwater and surface water, or indicate when flow stops and the system recedes into disconnected pools. Ideally, a stream gauge is located on a reach where the channel geometry remains relatively constant over time.

Road crossings, weirs and natural rock bars can provide stable low-flow controls, which define the river level at which flow downstream ceases. The stream gauges at Dimond Gorge, Noonkanbah and Fitzroy Barrage (Camballin Barrage) have stable low-flow controls. Sometimes this is not possible due to the nature of the river system.

The streamflow gauges at Fitzroy Crossing, Looma and Willare are on reaches without stable low-flow controls. At these sites, the sandy riverbed can change during each flow event. The location of the end of the gauge pool, and the river level at which downstream flow ceases, can change from year to year or more frequently during each flow season. During site visits we survey these riverbed movements and adjust rating curves to account for these changes. However, some uncertainty remains about when these riverbed levels change and how they change between site visit surveys.

Modelled data

In 2017 the CSIRO published a series of modelled streamflow datasets for the Fitzroy River basin from 1890 to 2015 (Hughes et al. 2017) using the Australian Water Resource Assessment Landscape and River models (AWRA-L and AWRA-R), including the 60 years before monitoring began in the 1950s.

The model uses climate input data from the Australian Water Availability Project (AWAP) dataset (Jones et al. 2009). The CSIRO calibrated the model to observed streamflow data collected at selected gauging stations across the Fitzroy River catchment. It varied the calibration period based on the availability of streamflow data at each site.

Gauges along the floodplain, below Fitzroy Crossing, have a relatively short record, beginning in the 1990s. Generally, the model performed better in the catchment’s northern part than its southern and eastern parts (Hughes et al. 2017). The large catchment area, sporadic rainfall gauges and varying length of streamflow records increase the uncertainty in the model performance.

In recent decades, rainfall has been higher than longer-term records. Assessing only the recent streamflow data discounts potentially drier years or drier sequences of years experienced over a longer timeframe. These periods are important for managing water to protect vulnerable systems and values. Therefore, we report on observed and modelled data to analyse flow in the catchment over a longer time horizon.

3.2 Streamflow characteristics

The climate of the Fitzroy River catchment follows a highly seasonal pattern: a hot wet season from November to March and a warm dry season from April to October (see section 3.1 above). As this season extends across two calendar years, we have adopted a November to October water year for reporting streamflow.

We present streamflow data from gauging stations and modelled data from Hughes et al. (2017) to show how streamflow varies between the headwater catchments and the floodplain areas of the lower Fitzroy River. We also use this data to show how streamflow varies across water years, seasons and days.

Our streamflow gauging records vary in length at different locations in the catchment (Figure 20). This can affect the comparison of streamflow characteristics between sites.

To overcome this issue, we compare gauged streamflow records over a common recorded period from 1999 and 2020 (Table 1). This period is wetter than the longer-term records. Therefore, we also include longer-term modelled data from 1890 to 2015 from Hughes et al. (2017) to show the longer-term variability in annual streamflow. Metrics may slightly differ from Hughes et al. (2017) as data is reported over a different water year from 1 September to 31 August.

The modelling by Hughes et al. (2017) suggests the median for the long-term modelled record is significantly lower (20 to 50 per cent) than for the recent gauge period. However, minimum and maximum annual totals over the recent observed flow period are equal or similar to the long-term modelled maximum and minimum annual flows. Therefore, we consider the recent gauged period (1999 to 2020) to cover the full range of flows experienced in the Fitzroy catchment. The use of median or average values based on the observed streamflow gauge records during this shorter period (1999 to 2020) may be skewed towards wetter conditions compared with the longer-term data.

We report on four stream gauging stations in the headwater catchments of the Fitzroy River and four along the lower Fitzroy River (Figure 18).

Headwater catchments:

- Hann River at Phillips Range (gauging station number 802213) on Wanjina-Wunggurr Wilinggin Country
- Margaret River at Me No Savvy (gauging station number 802198) on Gooniyandi Country
- Leopold River at Mount Winifred (gauging station number 802202) on Giniyjawarrni Yoowaniya Riwi Country
- Christmas Creek at Christmas Creek Hardstand (gauging station number 802005) on Gooniyandi Country.

Floodplain catchments:

- Fitzroy River at Fitzroy Crossing (gauging station number 802055) on the boundary of Bunuba and Gooniyandi Country
- Fitzroy River at Noonkanbah (gauging station number 802006) on the boundary of Noonkanbah and Nyikina Mangala Country
- Fitzroy River at Fitzroy Barrage (gauging station number 802003) on Nyikina Mangala Country
- Fitzroy River at Looma (gauging station number 802007) on Nyikina Mangala Country.

The headwater catchments north of Fitzroy Crossing (e.g. Hann River) consist of intrusive granites, quartzites and sedimentary rocks. The soils of the headwater catchments to the south, such as Christmas Creek, are characterised by permeable sands. Figure 22 illustrates the changes in riverbed composition at the four representative headwater catchments. The floodplain sites are all located in the main Fitzroy River channel and consist of a similar riverbed composition (Figure 23).

a) Hann River

b) Leopold River

c) Margaret River

d) Christmas Creek

Figure 22 Example channel forms for headwater catchments on a) Wanjina-Wunggurr Wilinggin Country, b) Giniyjawarrni Yoowaniya Riwi Country, c) Gooniyandi Country and d) Gooniyandi Country.

a) Fitzroy Crossing

b) Noonkanbah

c) Fitzroy Barrage

d) Looma

Figure 23 Example channel forms for floodplain catchments on a) boundary of Noonkanbah and Nyikina Mangala Country, b) boundary of Noonkanbah and Nyikina Mangala Country, c) Nyikina Mangala Country and d) Nyikina Mangala Country

Annual flow and runoff

Significant differences in annual streamflow occur between wet and dry years across the Fitzroy River catchment. These differences are highlighted in Table 1 comparing the maximum, median and minimum annual streamflow for each representative streamflow gauge.

The Hann River streamflow gauge (shown in Table 1) is a good example that highlights the large difference in annual streamflow between wet and dry years. The largest annual flow recorded at the Hann River streamflow gauge is four times the median annual flow, and over 200 times greater than the lowest annual flow (Table 1).

Volumetrically, this is a difference of more than 4,000 gigalitres (GL) between a dry year and a wet year. This variability is also replicated in the long-term modelled flows. In the lowest 10 per cent of modelled years, annual flows at this site are less than 350 GL (the 10th percentile). In the highest 10 per cent of modelled years, annual flows exceed 4,760 GL (the 90th percentile).

The floodplain streamflow gauges show a similar variability between wet and dry years. As an example, the largest annual flow at the Fitzroy Barrage streamflow gauge is four times the median annual flow, and around 50 times greater than the lowest annual flow.

Over the long-term modelled flow record at Fitzroy Barrage, annual flows are less than 1,460 GL in the lowest 10 per cent of modelled years, (the 10th percentile). In the highest 10 per cent of years, annual flows exceed 13,800 GL (the 90th percentile) – further demonstrating the high variability in streamflow totals between wet and dry years.

The difference between the maximum and minimum annual flow at the floodplain streamflow gauges is not as large as the headwater streamflow gauges (notably the Hann River streamflow gauge). This is because the individual headwater catchments do not record their wettest conditions in the same year. For example, maximum annual flow was recorded at Phillips Range on the Hann River in 2011, whereas for Margaret River at Me No Savvy it was recorded in 1993 (Figure 24).

As all the individual headwater catchments contribute to the flows in the lower floodplain, the effect of maximum annual flows within the headwater catchments in different years results in a reduced relative variability between the minimum and maximum flow at the floodplain sites. To elaborate further, the lowest recorded annual flow at Fitzroy Barrage in 2018–19 coincides with the minimum at Hann River, but not the minimum annual flow recorded at Margaret River or Christmas Creek.

Across the representative headwater catchments, each gauge monitors roughly a similar catchment size ranging from 5,070 km^2 to almost 7,670 km^2 (Table 1). However, the minimum, median and maximum streamflow vary across each site. The median annual streamflow (1999 to 2020) ranges from less than 160 GL/year for Christmas Creek in the catchment's south-east to more than 700 GL/year for the Hann River in its north. This corresponds to median runoff rates of 30 mm/year (6 per cent of annual rainfall) for Christmas Creek to 180 mm/year (19 per cent of annual rainfall) for the Hann River.

In dry years, runoff rates can be less than 1 per cent of rainfall; in wet years, runoff rates of more than 45 per cent have been observed. However, the maximum observed runoff in Christmas Creek is only about 20 per cent of catchment rainfall. The lower average rainfall and greater infiltration capacity of the soils in the Christmas Creek catchment result in less runoff generation and the lowest recorded average annual flow of the four headwater gauges analysed (Table 1).

The representative sites for the floodplain all monitor flow within the main Fitzroy River channel and capture flows generated within all of the headwater catchments. Consequently, there is less variation in the runoff response across the floodplain sites with median runoff rates ranging from around 90 to 110 mm/year (about 12 per cent of annual rainfall). Runoff rates are low in dry years at about 2 per cent of rainfall, like the headwater catchments.

Table 1 Statistical summary of streamflow information at department gauging stations for a common record from 1999 to 2020

River	Location	Streamflow gauging station	Catchment area (km2)	Annual flow 1999 to 2020 (GL/year)			
				Minimum	Median	Mean	Maximum
Hann River	Headwater north	Phillips Range (802213)	5070	18	1092	1057	4248
Leopold River	Headwater east	Mt Winfred (802202)	5115	68	760	869	2960
Christmas Creek	Headwater south	Christmas Creek (802005)	5989	65	230	274	1144
Margaret River	Headwater east	Me No Savvy (802198)	7646	203	621	754	1887
Fitzroy River	Transitional central	Fitzroy Crossing (802055)	46133	509	5062	6229	19972
Fitzroy River	Floodplain	Noonkanbah (802006)	61540	547	5780	7278	23039
Fitzroy River	Floodplain	Fitzroy Barrage (802003)	73293	676	6954	9120	27646
Fitzroy River	Floodplain	Looma (802007)	78372	570	6583	8811	27919

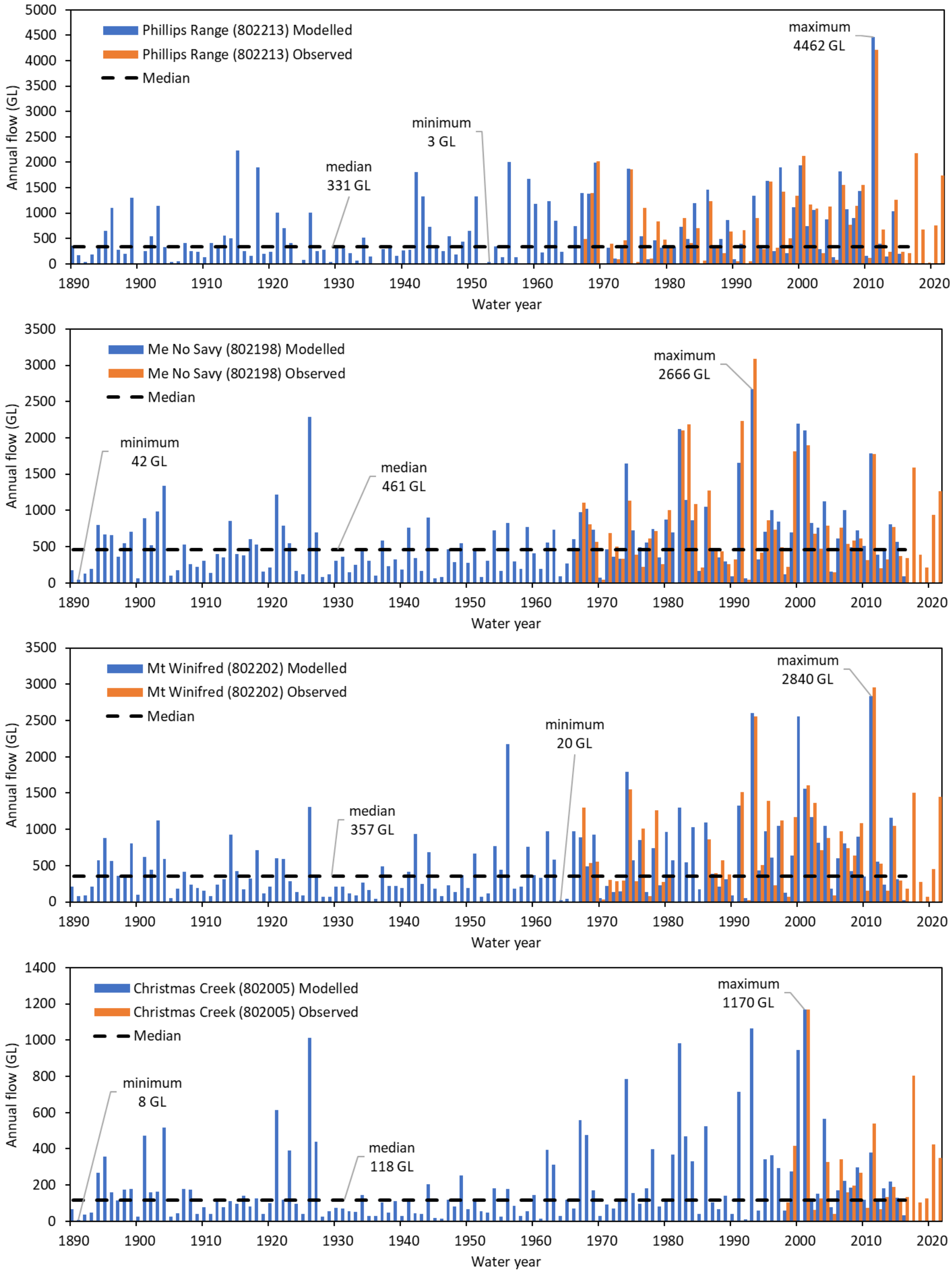


Figure 24 Modelled and observed flow at gauging stations in the headwaters of the Fitzroy River– maximum, minimum and median values correspond with the modelled record

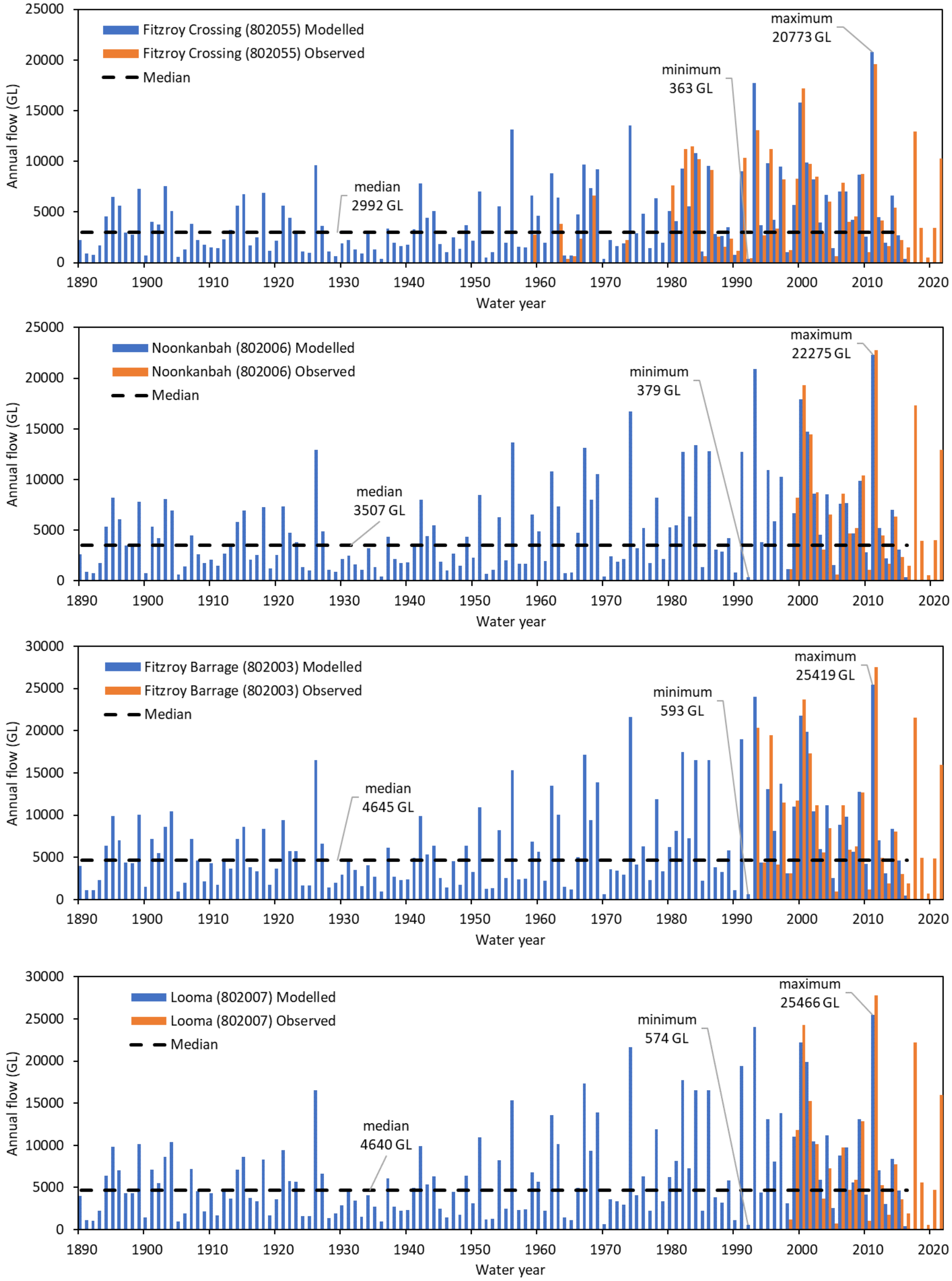


Figure 25 Modelled and observed flow at gauging stations in the lower floodplain of the Fitzroy River – maximum, minimum and median values correspond with the modelled record

Monthly flow

Streamflow is highly seasonal in the Fitzroy River and tributaries. On average, more than 90 per cent of water flows over three months from January to March (Figure 26). The highest median monthly flow for Christmas Creek was recorded in January and for Hann River/Phillips Range, Mt Winifred and Me No Savvy in February.

The median monthly flow is zero during the dry season months of June, July, August, September and October for the headwater catchments (Mt Winifred, Christmas Creek and Me No Savvy). These rivers and tributaries have a consistent cease-to-flow period.

The lower floodplain sites (Noonkanbah, Fitzroy Barrage and Looma) record a median monthly flow greater than 5 GL through June and July. Lower median monthly totals are recorded for August, September and October, and flow ceases during these latter dry season months, particularly after a dry wet season.

All sites recorded the widest range between the minimum and maximum monthly flow in March. However, the largest range between the 25th and 75th percentiles occurred in February. This indicates that despite the rare large rainfall events in March, the flows in February are typically the most variable between years.

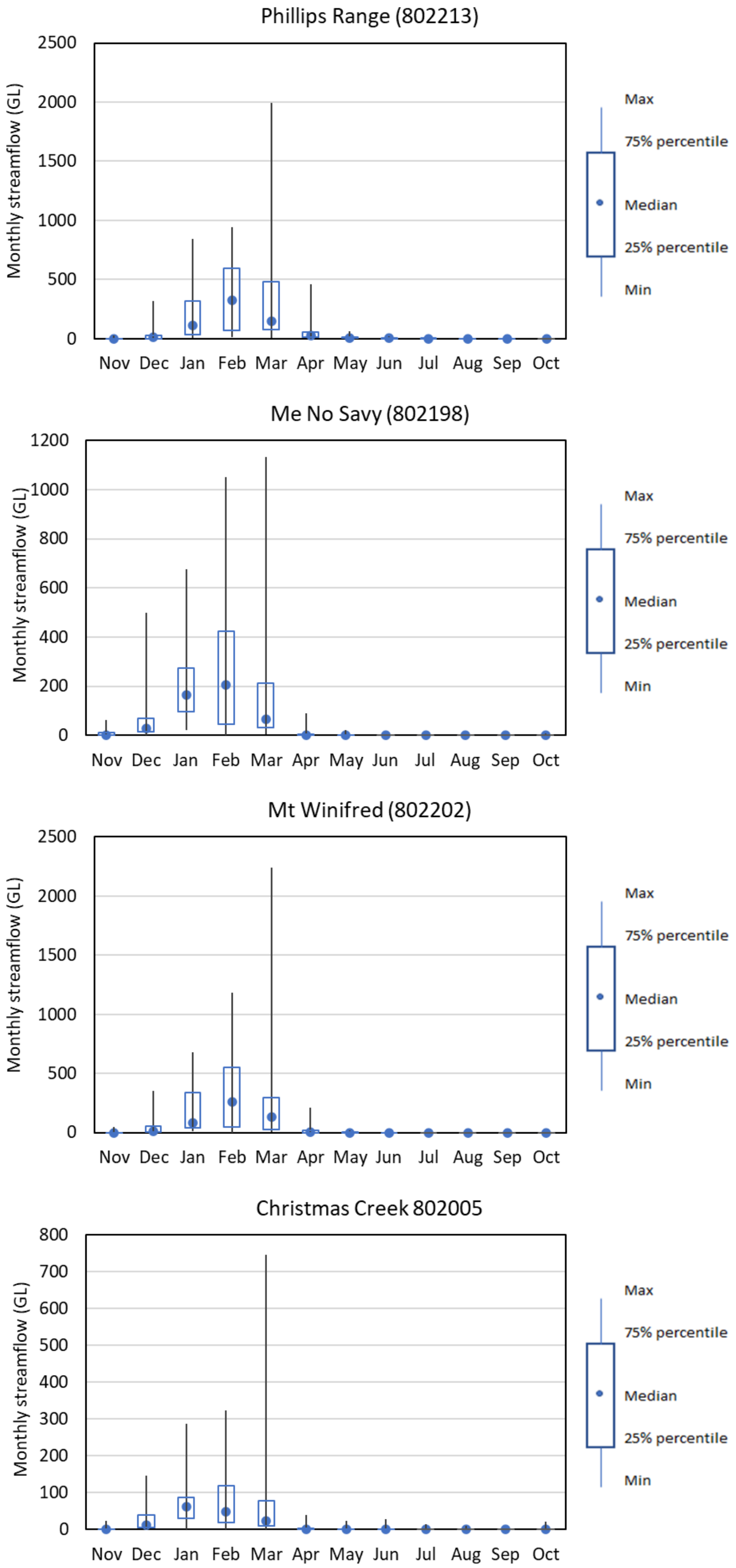


Figure 26 Monthly observed streamflow totals for headwater catchments at Hann River/Phillips Range, Mt Winifred, Me No Savvy and Christmas Creek gauging stations using data from 1999 to 2020

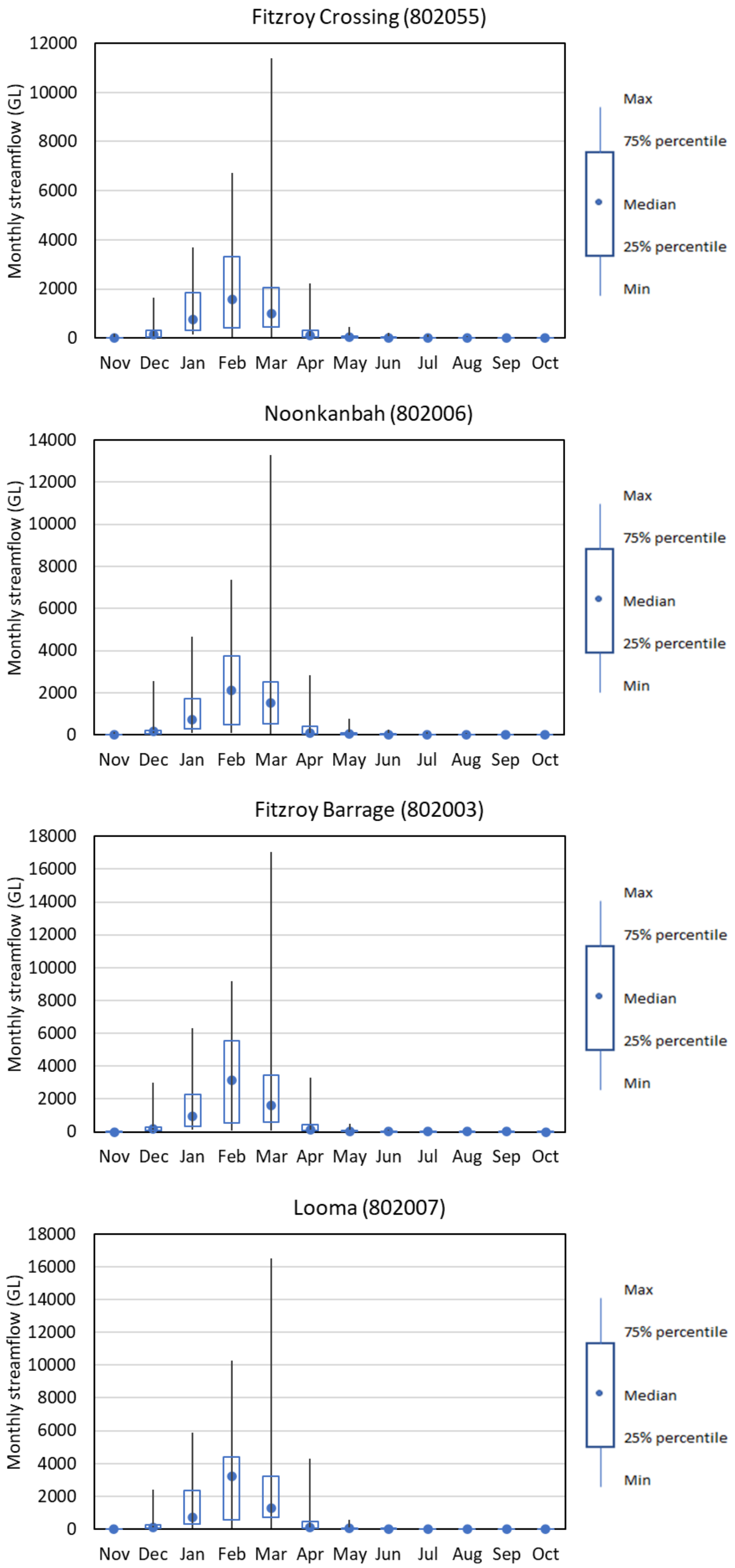


Figure 27 Monthly observed streamflow totals for floodplain catchments at Fitzroy Crossing, Noonkanbah, Fitzroy Barrage and Looma gauging stations using data from 1999 to 2020

Daily flows

Flow duration curves show how often (over the 1999 to 2020 data record) a certain flow rate was exceeded. Flow duration curves are a useful tool to explore the variability in daily flow and the frequency of daily flows between sites.

The flow duration curve for Phillips Range (yellow line in Figure 28) shows flows exceeded 0.1 megalitres (ML) per day more than 70 per cent of the time between 1999 and 2021. This flow rate was only exceeded less than 50 per cent of the time at Me No Savvy (orange line in Figure 28) and Mt Winifred (grey line in Figure 28) and less than 40 per cent of the time at Christmas Creek (blue line in Figure 28). Thus the flow duration curves show us that flow at the Christmas Creek gauge has the shortest flow period.

As discussed previously, Christmas Creek is situated over permeable sandy soils and receives the lowest annual rainfall across the catchment (Figure 12) Therefore we expect that on a daily scale, it would have the shortest flow period out of the gauges analysed.

Of the headwater catchments, the gauge on the Hann River at Phillips Range recorded the longest presence of flow (greater than 0.1 ML per day) on 70 per cent of days between 1999 and 2020.

The flow at Noonkanbah was greater than 0.1 ML per day for more than 95 per cent of the time between 1999 and 2020. This is the longest flow period of all the streamflow gauges on the Fitzroy River and its tributaries. The other streamflow gauges on the floodplain reach recorded flow greater than 0.1 ML per day for around 85 per cent of the record (Figure 29).

The longer duration of flow along the floodplain sites compared with the headwater catchments is a result of the floodplain sites recording flow from all upstream areas and connectivity with underlying groundwater aquifers (see Section 3.4 Groundwater/surface water interaction).

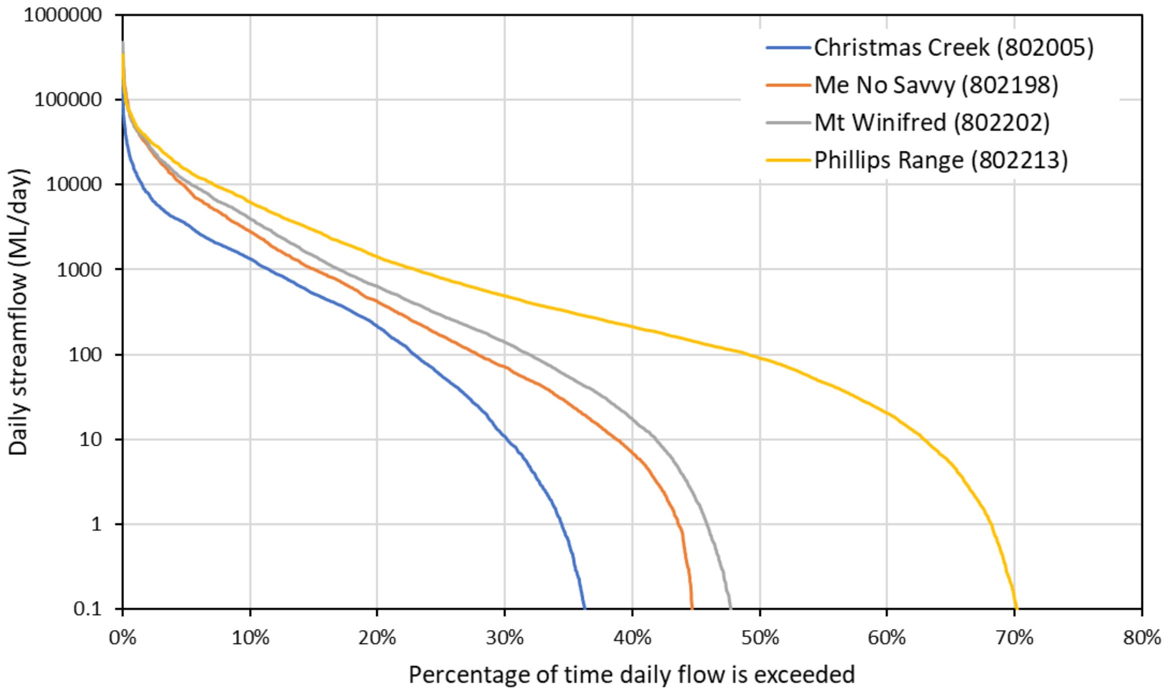


Figure 28 Flow duration curves at the Christmas Creek, Me No Savvy, Mt Winifred and Phillips Range gauging stations in the headwater catchment of the Fitzroy River using data from 1999 to 2020

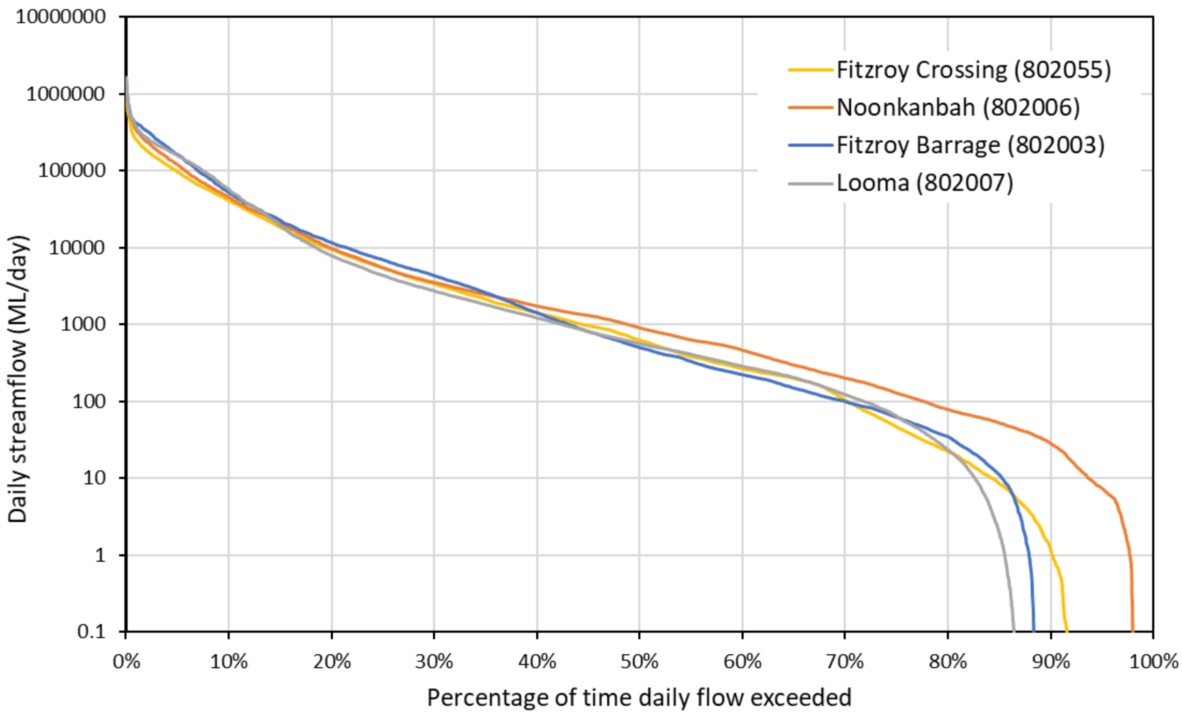


Figure 29 Flow duration curves at the Fitzroy Crossing, Noonkanbah, Fitzroy Barrage and Looma gauging stations on the lower Fitzroy River using data from 1999 to 2020

Dry year run length and magnitude

The Fitzroy catchment's natural environment has adapted to climate and streamflow patterns that include lengthy periods of dry years. Petheram (2008) outlines metrics to consider:

- length of consecutive dry years (number of consecutive years below the median annual flow)
- magnitude of dry year length (average volume of all years below the median).

We reproduced the two metrics above using the CSIRO's modelled long-term flow records (Hughes et al. 2017) for two headwater catchments (Hann River at Phillips Range and Christmas Creek) and two floodplain sites (Fitzroy Crossing and Looma). These metrics provide useful indicators of the severity and frequency of dry years, which can be a period of stress for the river's ecology. Dry years are also likely to be a time when water availability is constrained compared with the more abundant high-flow years.

Based on modelled data, the most frequent length of consecutive dry years for the headwater gauges was one to two years (Figure 30 and Figure 31). This is the same for the floodplain sites at Fitzroy Crossing and Looma (Figure 32 and Figure 33) The maximum length of consecutive dry years for the headwater catchments is six years, and for the floodplain sites up to nine years (1928 to 1936). The latter extended dry period is reported as a 'notable dry period' in the *Climatic survey of the Kimberley region* (Bureau 1996).

The magnitude of dry year length at the headwater sites is 630 GL at Phillips Range and 58 GL at Christmas Creek. This equates to a 54 and 52 per cent of the long-term modelled median annual flow at these sites respectively. The magnitude of dry year length at the floodplain sites is 1,640 GL at Fitzroy Crossing and 2,050 GL at Looma. This equates to 55 and 56 per cent of the long-term modelled median annual flow at these sites respectively. This means that in dry years, the average flow is around half the median annual total across the entire catchment.

The blue columns in the top graph for Figures 30 to 33 indicate wet years in blue and dry years in orange. As discussed in section 2 above, the recent record has been generally wetter than the longer period. This is shown in the larger number of blue columns in the more recent years (see post 1990) in Figures 30 to 33. However, during this wetter period, some dry periods with low annual flows still occur (see 1991–92). The modelling data finishes in 2015 and does not include recent dry years such as the 2018–19 season.

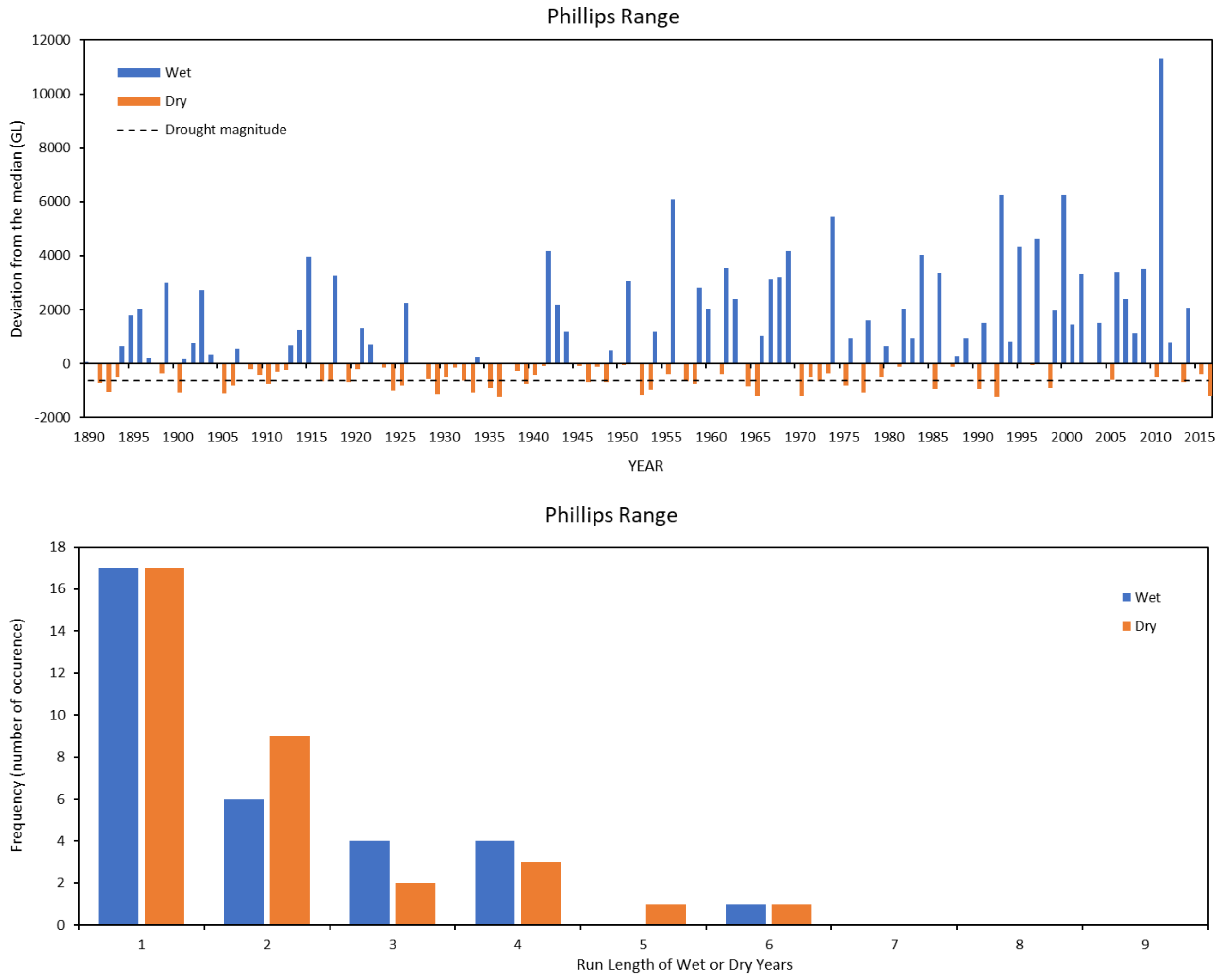


Figure 30 Frequency of wet and dry years at the Hann River at Phillips Range (802213) gauging station

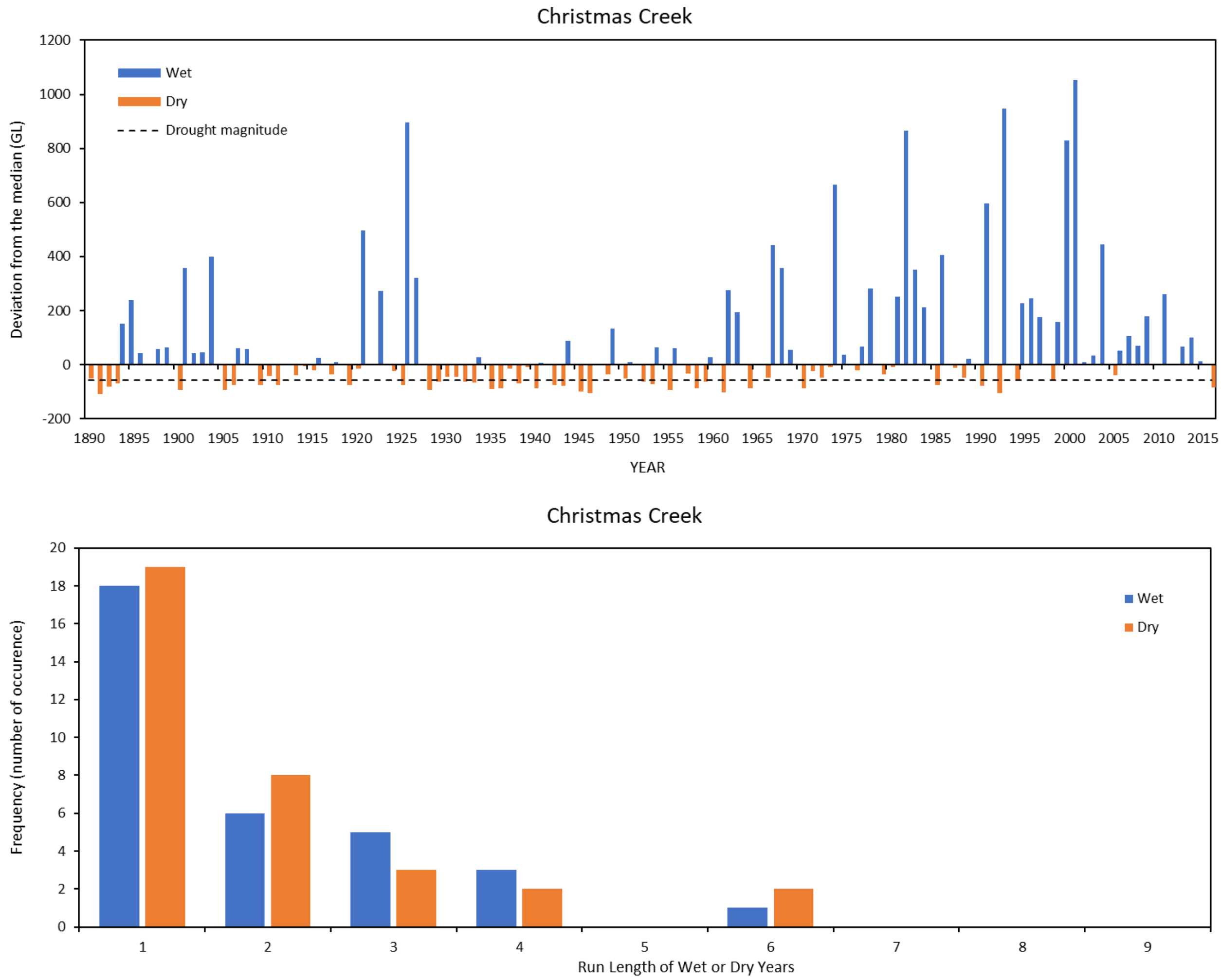
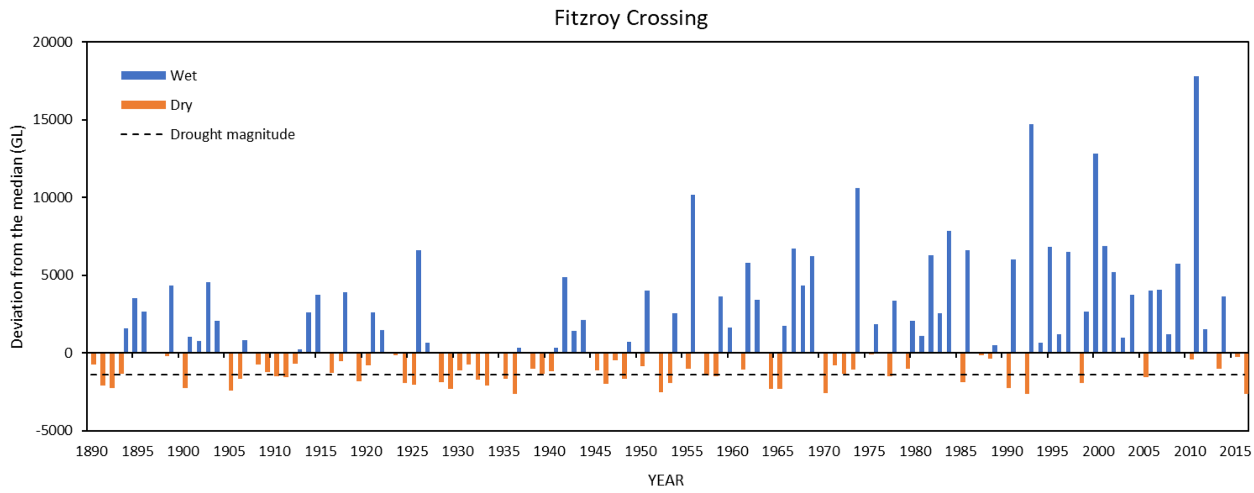


Figure 31 Frequency of wet and dry years at the Christmas Creek (802005) gauging station



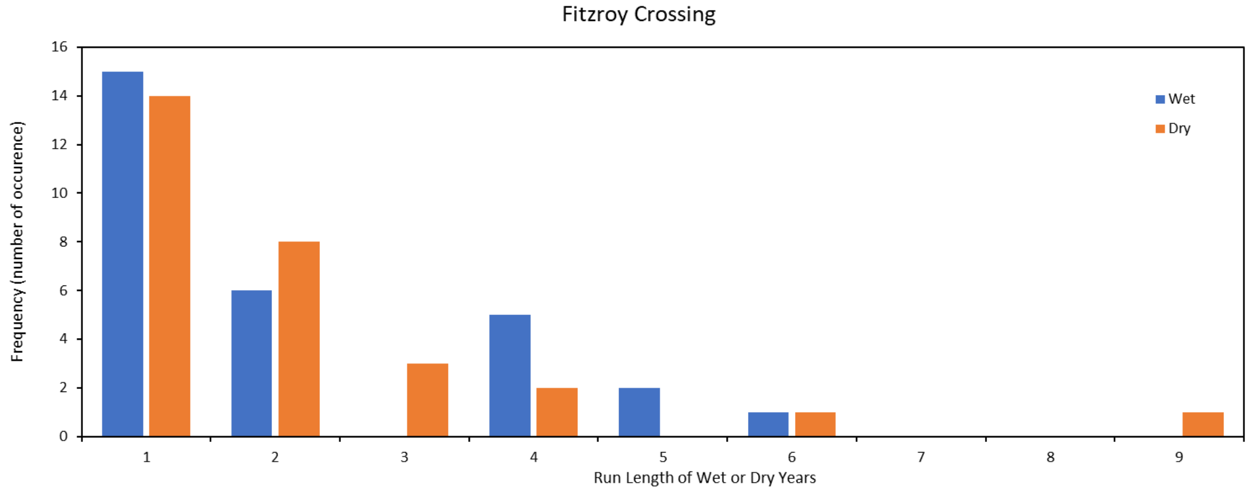
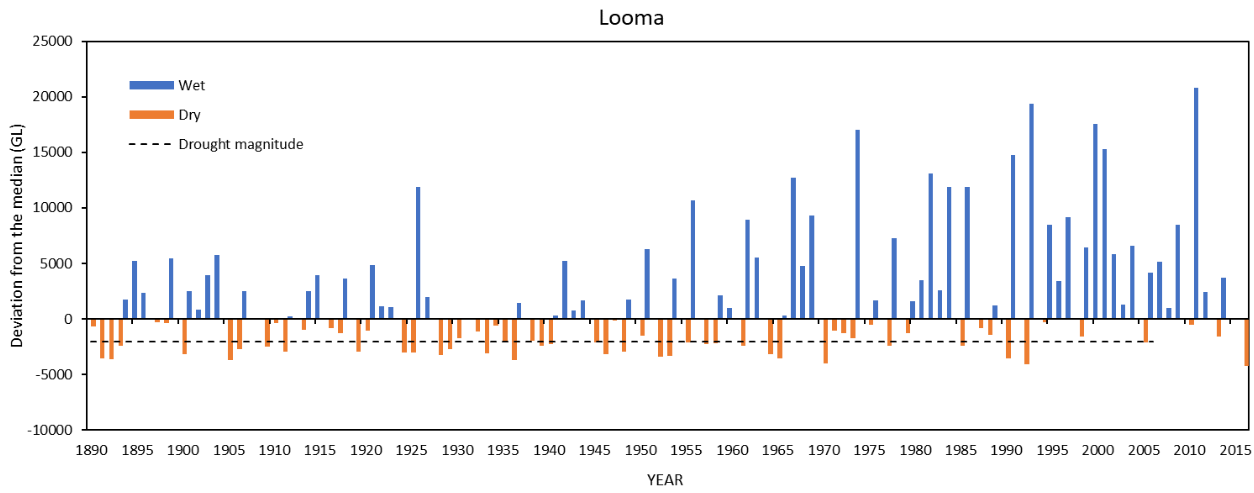


Figure 32 Frequency of wet and dry years at the Fitzroy Crossing (802055) gauging station



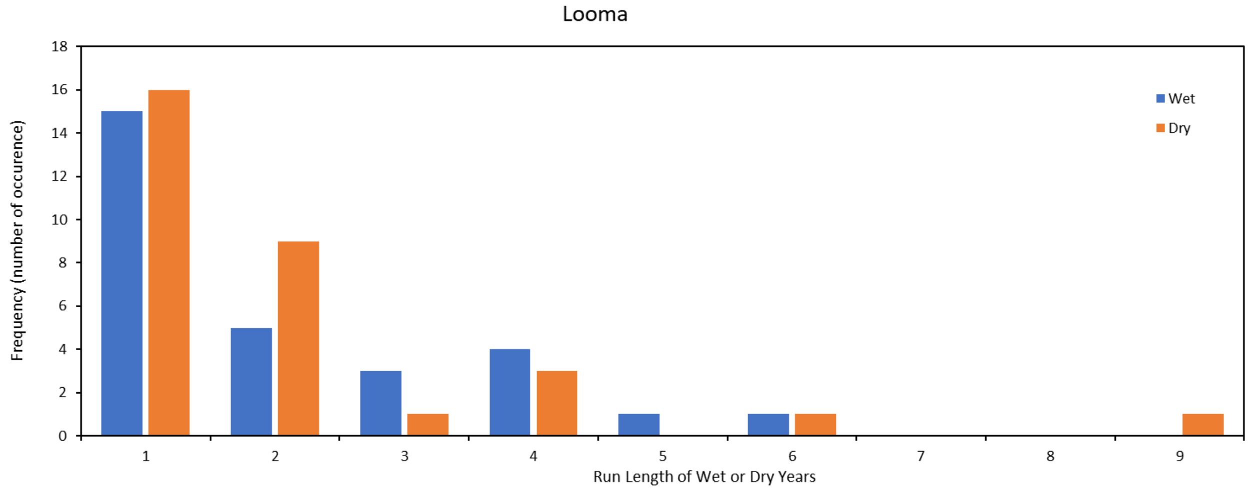


Figure 33 Frequency of wet and dry years at the Looma (802007) gauging station

3.3 Flooding and inundation

Rivers flood when water overtops the riverbanks and flows out onto the floodplain. The recurrence interval of flow overtopping the riverbank (bankfull flow) is generally within the range of one to two years (Leopold et al. 1964), although for tropical regions this figure is closer to one year (McDermott & Pilgrim 1983; Pilgrim 2001).

In response to the 2002 flooding at Fitzroy Crossing, the then Department of Environment prepared floodplain mapping for the townsite area and recommended a floodplain development strategy to support planning and development at Fitzroy Crossing (DoE 2003). The strategy is based on two guiding principles:

- proposed development has adequate flood protection
- proposed development does not detrimentally affect the existing flooding regime.

Fitzroy Crossing is likely to experience regular flood events – every two to three years on average – with the impacts being magnified when the Margaret and Fitzroy rivers rise concurrently. The same floodplain development principles could be applied along the greater Fitzroy River floodplain.

Figure 34 Floodwaters surrounding Fitzroy airport in January 2023

We have supported Department of Planning flood studies, including local-scale floodplain mapping and flood risk assessments, and recommended development strategies for some Aboriginal communities (Wangkatjungka, Looma, New Looma, Kupungarri, Ngallagunda and Dodnun). We also have some historic flood information for several other communities, including Yungngora, Muludga, Bayulu, Gillaroong, Camballin, Pandanus Park and Kupartiya.

In January 2023, a flood on the Fitzroy River 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 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 (Figure 35).

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 went under about 2 m of water.

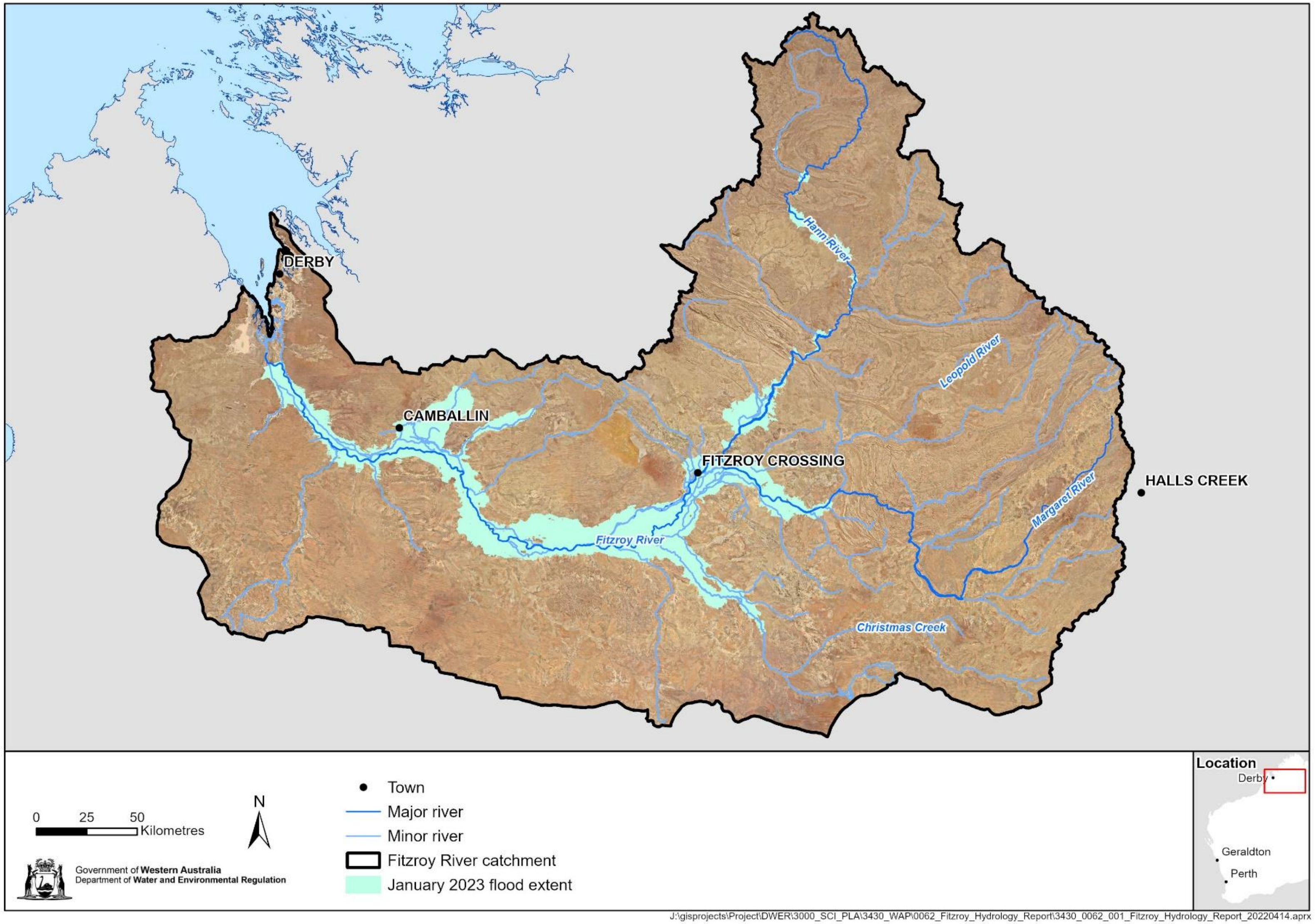


Figure 35 January 2023 flood extent mapped using radar satellite technology

Fitzroy River flood model

As part of the NAWRA project, the CSIRO developed a two-dimensional hydrodynamic model for the Fitzroy River floodplain (Karim et al. 2018). The model covers an area of 35,000 km^2, equivalent to 37 per cent of the Fitzroy River catchment. The model extends from near the Dimond Gorge gauging station on the Fitzroy River, Mount Krauss streamflow gauge on the Margaret River and Christmas Creek streamflow gauge to the Great Northern Highway crossing at Willare (Figure 36). Flow information from these gauging stations provided inputs to the model.

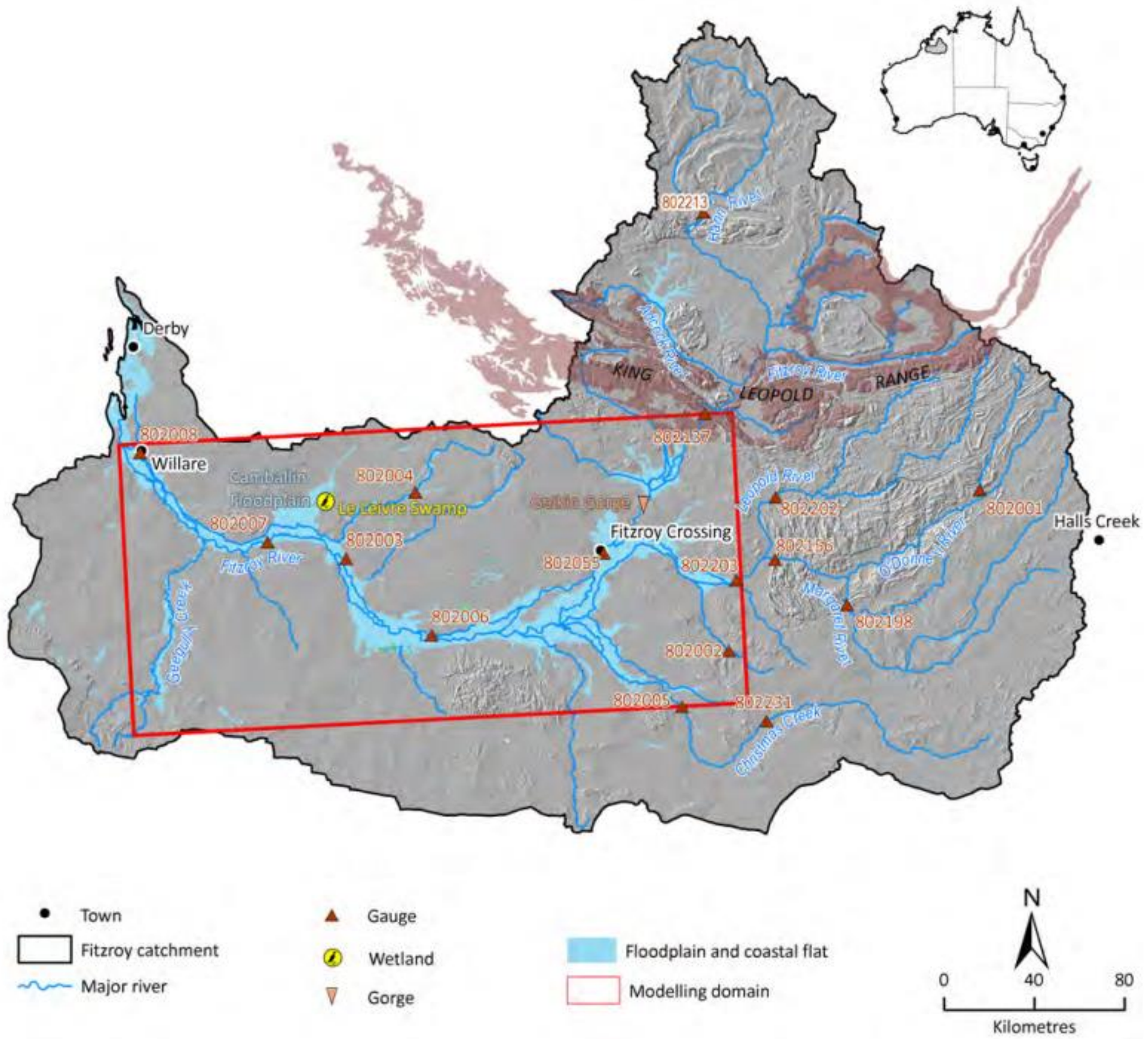


Figure 36 Modelling domain of the Fitzroy River floodplain

The CSIRO modelled the flood inundation for individual flood events from 1999 to 2015, which it calibrated using high-quality MODIS and Landsat imagery and recorded data at the streamflow gauges within the model domain.

The model simulates the movement and depth of water within the river and across the floodplain. Karim et al. (2018) provides estimates of the AEP of the events;

however, these are not supported by rigorous flood frequency analyses. As such, the estimates should be considered indicative only.

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). Figure 37 shows the representative hydrographs for these three representative years. The resulting inundation maps are presented below. These can be used to assess the frequency and duration of water inundating important environmental, social or cultural sites along the lower floodplain.

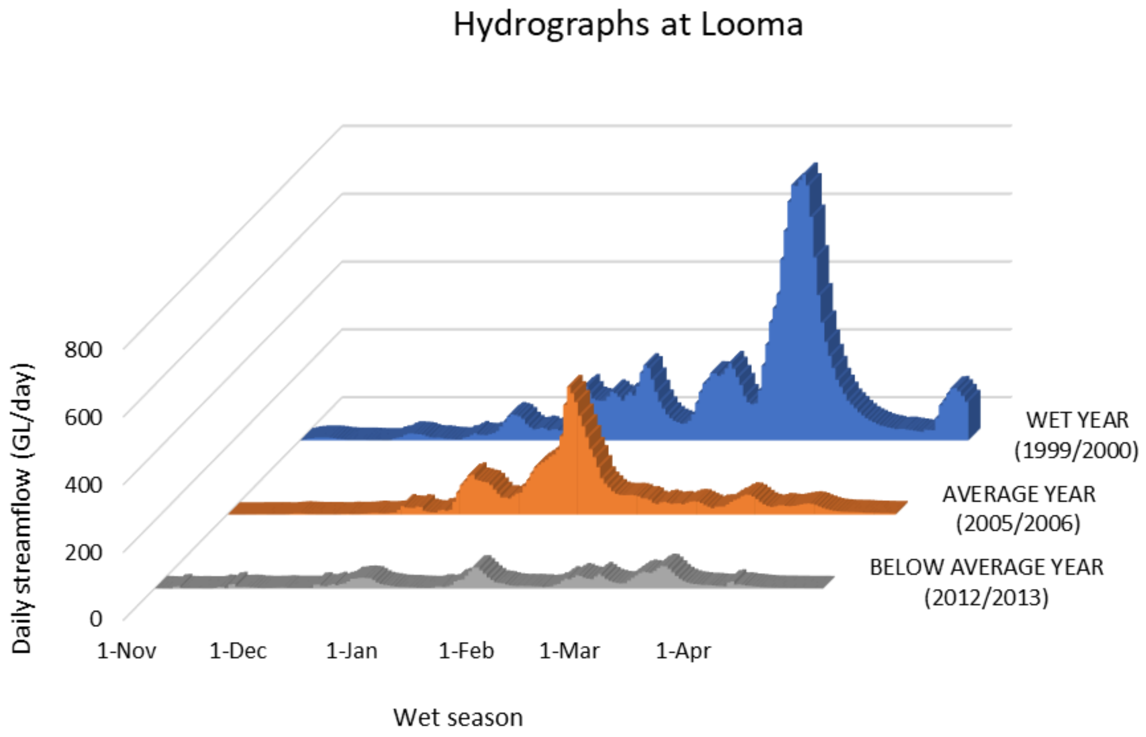


Figure 37 Representative low-, medium- and high-flow years modelled at Looma to understand floodplain inundation depth and extent

Variation in the extent of inundation

The CSIRO's modelling of flood inundation found the width of the floodplain is greater than 10 km in both the average and above-average scenarios (Figure 38). However, a greater proportion of the floodplain between the flood relief channels is inundated during the above-average event. The modelled flood extent covered 4,170 km^2 during the high-flow year (1999–2000), 2,470 km^2 during the average-flow year (2005–06) and 620 km^2 during the below-average-flow year (2012–13).

Water levels can reach greater than 7 m deep in the Fitzroy River during large flood events. The modelling showed that flood depths across the floodplain were generally less than 1 m.

Variation in the duration of inundation

The duration of floodplain inundation varies with the magnitude of flow (Figure 39). Model results indicate that in a below-average-flow year, the floodplain is inundated for less than 10 days. This suggests little connectivity between the river and floodplain.

During a high-flow year, the connection with the floodplain exceeds 30 days in wet years, with some wetland areas on the floodplain being inundated for more than 60 days (two months – areas shown as dark green in the top image of Figure 39). In an average-flow year, the duration of floodplain inundation and connectivity with the river is between 10 and 30 days.

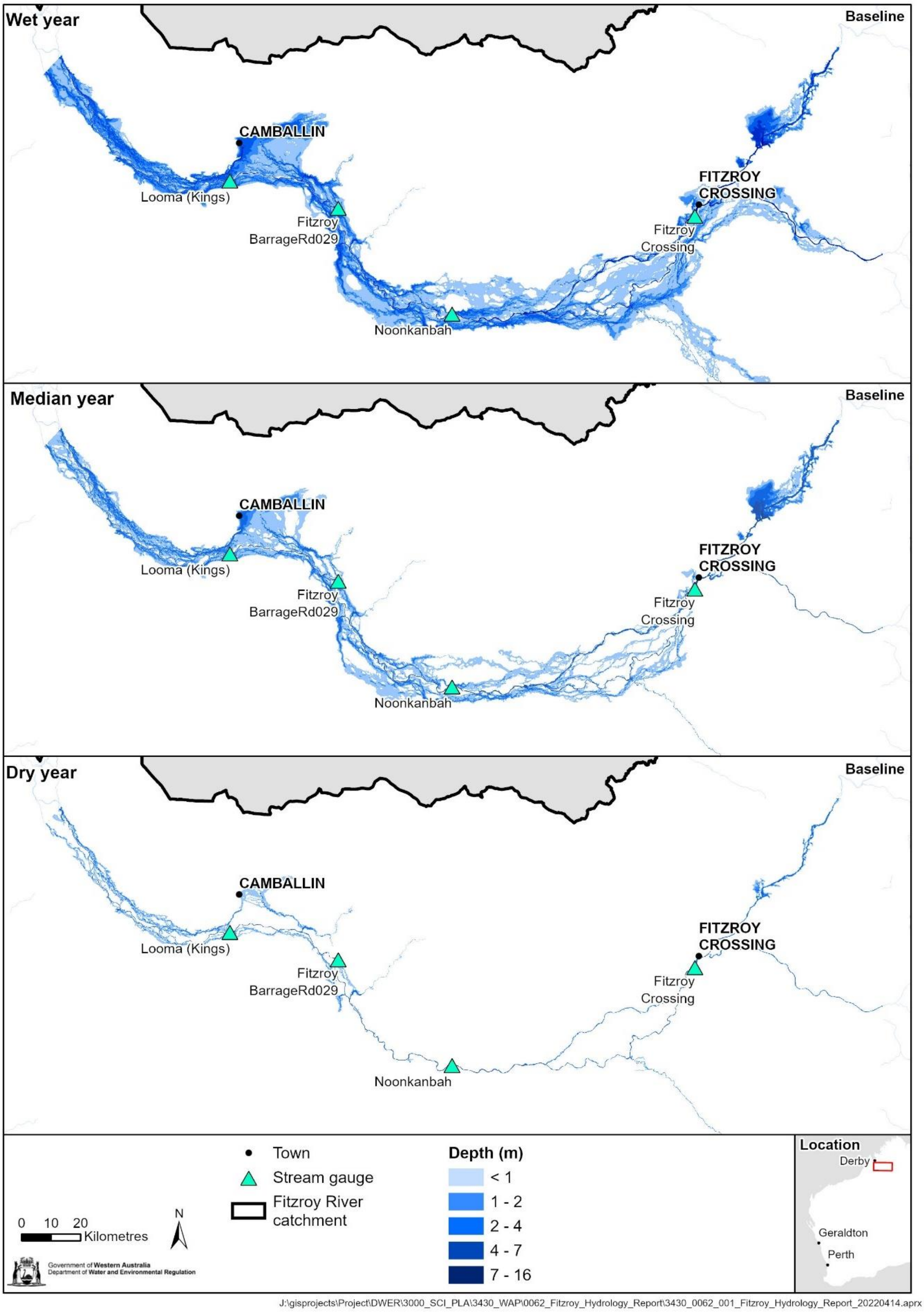


Figure 38 Modelled flood depths on the Fitzroy River floodplain for an above-average-flow, average-flow, and below-average-flow year

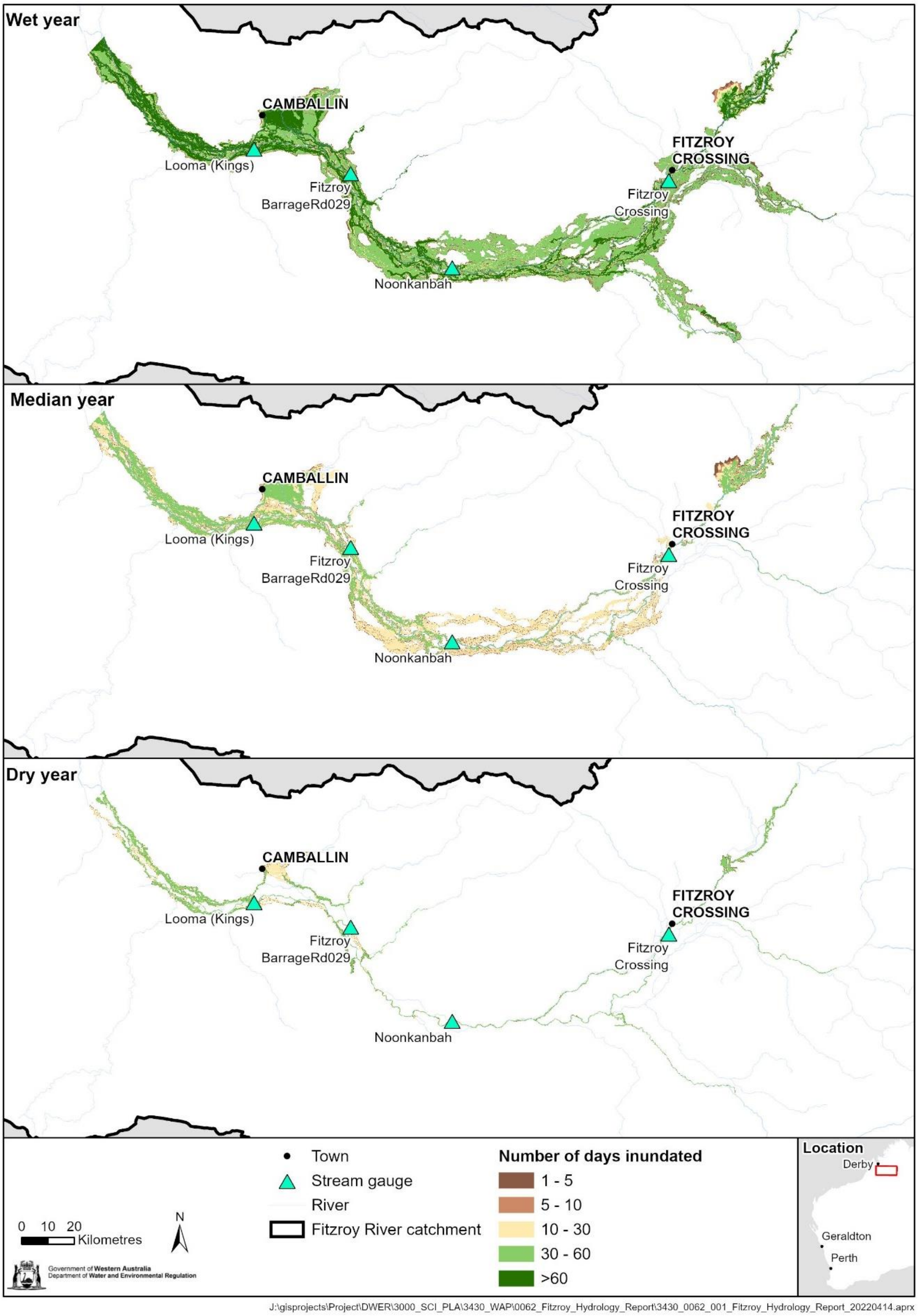


Figure 39 Modelled duration (number of days) of floodplain inundation during an above-average-flow, average-flow and below-average-flow year

3.4 Groundwater/surface water interaction

In DWER (2023b) we interpret possible interactions between the catchment's regional aquifers and alluvial aquifer along the Fitzroy River with surface water in the river. This interpretation is presented in Figure 41 and determined from:

- distribution of geological formations
- hydrogeological properties of different geological units
- groundwater and surface water hydrographs
- streamflow gauging data
- the location and persistence of baseflow and river pools
- water chemistry and isotopic tracers, most notably ^{4}He and ^{222}Rn.

During the wet season, we have assumed recharge of the alluvial aquifer and the underlying regional aquifers will occur. During the dry season, the interaction between the regional aquifers and the river system is less certain and may vary between recharging and discharging along the river reach. The magnitude of the interaction is also likely to vary.

For further information on regional aquifer connectivity, see *Fitzroy Valley groundwater investigations 2015–2018, Kimberley, Western Australia* (DWER 2023b).

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.

Harrington and Harrington (2015) propose a general conceptual model of the Fitzroy River recharging the alluvial aquifer system during wet season flooding. In the dry season, as the river levels decline, the gradient is reversed, and water stored in the alluvial aquifer flows back into the river. This conceptualisation is supported by comparison of paired surface water/groundwater-level information gathered from groundwater bores near streamflow gauging stations at Noonkanbah, Looma, Fitzroy Barrage and Fitzroy Crossing (DWER 2023b).

Conceptualisation of the interaction is illustrated at the Looma gauge (Figure 40), located about 6 km west of bore LF01, which is screened in the alluvial aquifer. The hydrograph shows river levels increasing from around November, corresponding with the start of the wet season and significant river flow at the gauging station.

Figure 40 suggests that groundwater levels in the alluvial aquifer are generally higher than river levels through the dry season, and lower than river levels through the wet season. This indicates that while the river is generally gaining flow from the alluvial aquifer, there is periodic recharge of the alluvial aquifer associated with higher flows during the wet season. The increase in groundwater levels was more subdued during the 2018–19 wet season when the river peaked about 2 m lower than in 2017–18.

This indicates that higher volumes of recharge are related to higher river levels, and that higher rainfall totals also contribute to larger recharge.

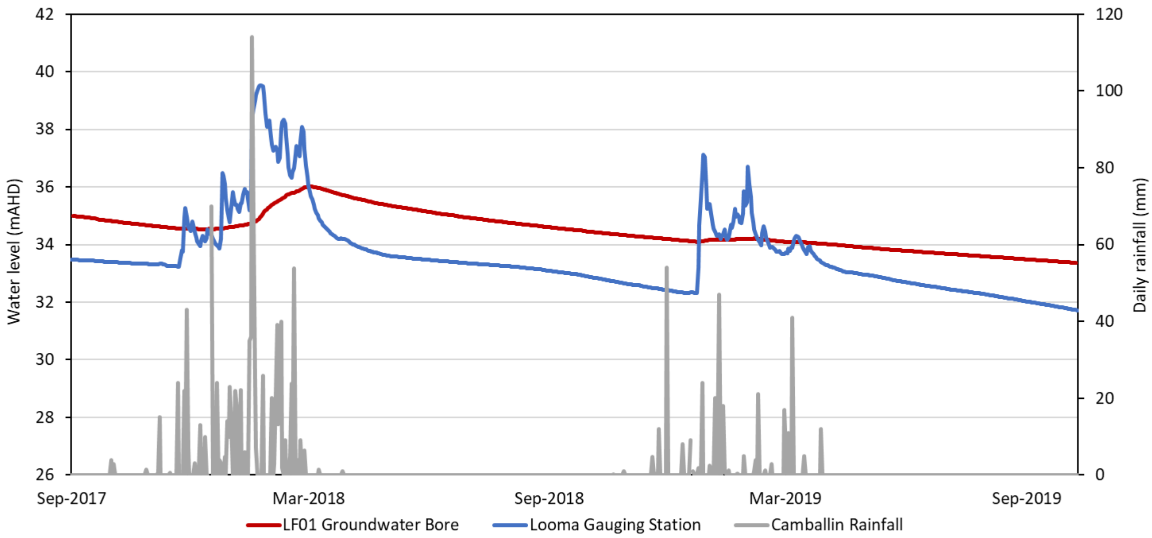


Figure 40 River level data at Looma, groundwater level data at LF01 groundwater bore and rainfall data at Camballin rainfall site (Bureau ref. 3040)

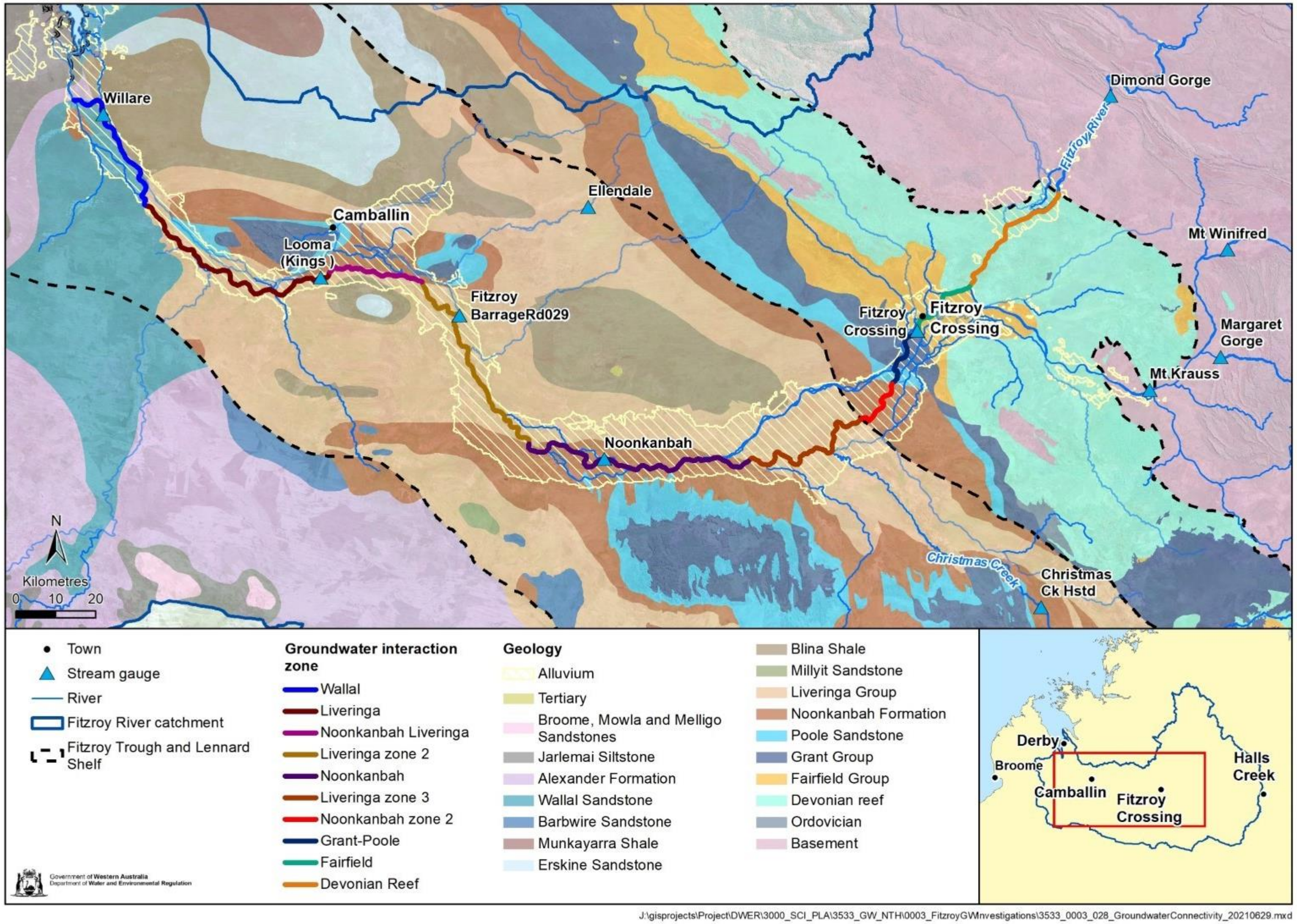


Figure 41 Aquifer/surface water interactions along the Fitzroy River and underlying surface geology (DWER 2023b)

3.5 Water quality

Water quality in the Fitzroy is influenced by storms that deliver large amounts of water to the river. This can cause erosion and transport soil and debris downstream.

First-flush events after the dry season result in very rapid changes to water quality as flows replenish the river and scour debris and nutrients that have built up during the dry season (Commonwealth of Australia 2013).

These initial high-flow events can cause nutrient and sediment concentrations to fluctuate rapidly (Butler & Burrows 2007) (Figure 42). The timing and magnitude of the first high-flow event varies each year depending on the season and can be related to monsoon onset or tropical cyclones.

Figure 42 Visual difference in water quality at confluence near Hann River

To date the water quality information available for the lower Fitzroy River has been limited. However, recent studies by the Centre for Sustainable Aquatic Ecosystems at Murdoch University (Gleiss et al. 2021) and NESP (Beesley et al. 2018) provide information on the physicochemical conditions specific to river pools of the Fitzroy. See DWER (2023a) for a good overview and summation of these studies and the water quality of river pools.

Figure 43 Riverbank erosion near Fitzroy Crossing following flow in 2002

As flow declines or ceases during the dry season, evaporation losses can lead to the concentration of particulate matter and dissolved and suspended nutrients and salts that affect water quality. Historical conductivity measurements at the Fitzroy Barrage from 2007 to 2010 reflect the increasing trend of conductivity over the dry season before wet season flows cause a reset (Figure 44). See DWER (2023b) for more detailed river chemistry and isotopic information.

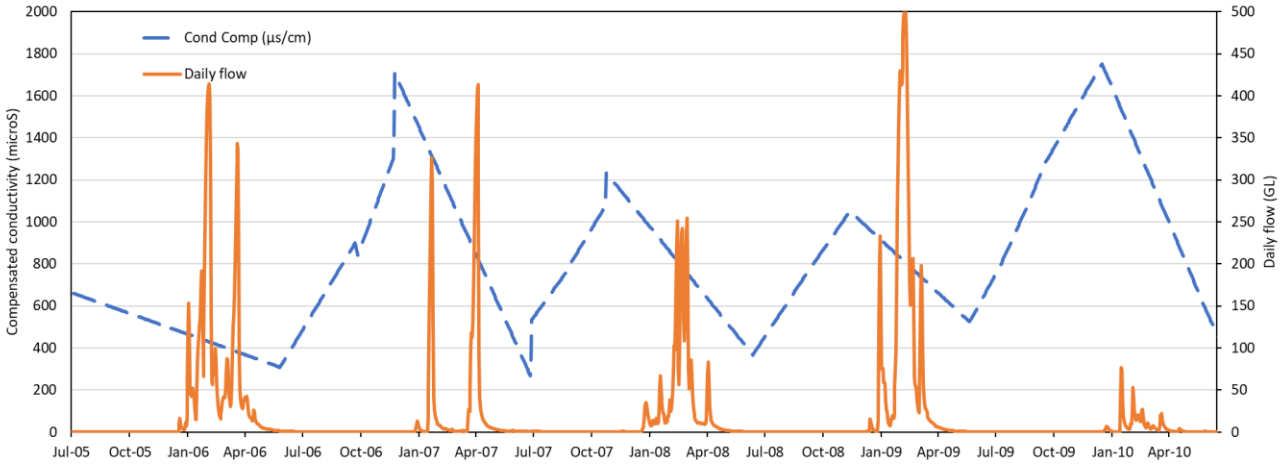


Figure 44 Compensated conductivity and daily flow at Fitzroy Barrage from 2007 to 2010

4 Climate change implications for streamflow

Section 3 presents observed and modelled historical information. Looking forward, climate change may cause variations in the occurrence and magnitude of streamflow in the Fitzroy River. As discussed in Section 2.3, global climate models indicate the potential both for increases and decreases in average rainfall into the future. As a result, the influence of climate change on average river flow is also wide ranging.

Climate change could affect the extreme flow scenarios by increasing the magnitude of flooding, the severity and duration of droughts, or a combination of both. DWER (2021) highlights the possible effect of climate change on streamflow in the Fitzroy River:

> *Tropical cyclones are projected to decrease in frequency, but it is expected that a greater proportion will be higher intensity.*

Under this scenario, it is expected that higher-intensity tropical cyclones may generate a higher amount of rainfall over a short duration. But less frequent tropical cyclones could lead to a reduction in flows and more below-average annual flows.

The observed peak daily (and weekly) rainfall observed in January 2023 has been compared with the historical data and projections from four global climate models using the quantile mapping bias correction method for extremes and for two representative concentration pathways (RCPs – see Section 2.3). This work suggests that events like the January floods will still be very rare occurrences in the future.

The observed January 2023 rainfall exceeds at least 90 per cent of the future projections of daily (Figure 45a) and weekly (Figure 45b) rainfall. While this analysis was only undertaken for a small number of locations, the data suggests that the annual maximum weekly rainfall could increase under future climate. This increase is thought to reflect an overall shift in monsoonal precipitation patterns. Yet the magnitude and timing of the increase in extremes from natural climate variability cannot be projected with certainty as it depends on the RCP, the projections assessed, and the period chosen (Srikanthan et al. 2022). This could potentially lead to an increase in the magnitude and extent of river flooding. Larger floods could lead to an increase in scouring and erosion of the river channels and banks.

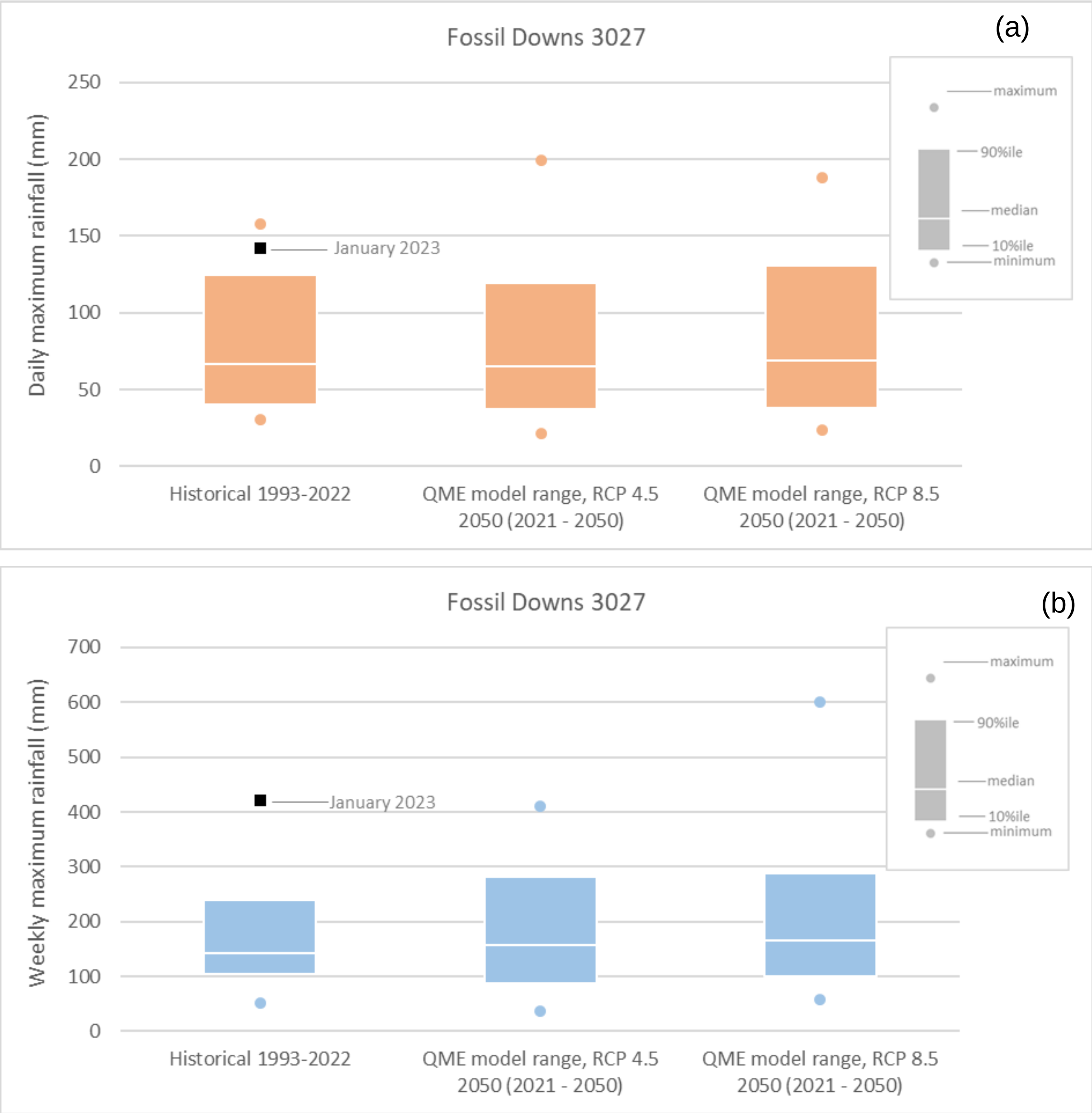


Figure 45 Comparison of January 2023 observed rainfall at the Bureau of Meteorology rainfall gauge at Fossil Downs with historic and future climate projections of a) annual peak daily rainfall and b) annual peak weekly rainfall volumes

DWER (2021) highlights the possible effect of climate change on temperature in the region:

> *Mean, maximum and minimum temperatures will continue to increase in all seasons.*

Future increases in temperature will increase the rate of evaporation loss from river pools and waterbodies over the dry season. In areas without groundwater discharge, this may affect the ability of some waterbodies to persist throughout the year. Higher temperatures may also affect the water quality in pools, through temperature stratification or increased concentrations of nutrients.

As discussed in Section 2.3, at present we consider how streamflow may change into the future by assessing the full range of flows in the long-term records (DoW 2015). We will continue to collaborate with research agencies and the Bureau of Meteorology to improve our confidence in global climate model projections for north-west Western Australia and their implications for streamflow.

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Shortened forms

Bureau	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cth.	Commonwealth
DoW	former Department of Water
DWER	Department of Water and Environmental Regulation
GCMs	Global Climate Models
IPCC	Intergovernmental Panel on Climate Change
km	kilometres
RCP	Representative Concentration Pathway
WA	Western Australia

Volumes of water

One litre	1 litre	1 litre	(L)
One thousand litres	1000 litres	1 kilolitre	(kL)
One million litres	1 000 000 litres	1 Megalitre	(ML)
One thousand million litres	1 000 000 000 litres	1 Gigalitre	(GL)

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