Hughenden Irrigation Project

High-level Assessment of the Implications for Flinders River Environmental Flows

Report for Engeny Pty Ltd

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Executive Summary

This report provides a high-level desktop assessment of the proposed Hughenden Irrigation Project ('the Project') in relation to the environmental flow requirements of the Gulf Water Plan. The main report (Chapters 1 to 8) focuses on the 'Reference Project', which is based on gravity diversions at the proposed Flinders River Weir into the proposed Saego Dam (190 GL capacity) and provides an average annual supply volume of 68 GL. Engeny subsequently modelled an alternative scenario to test sensitivity and compliance, which is discussed in an Addendum to this report (Chapter 9).

Hydrological Impacts on the Flinders River

Hydrological modelling provided by Engeny shows that the Project will lead to reductions in river flows downstream of the Project area. Medium and high flows (particularly smaller floods) will be reduced but smaller flows will be passed through the weir. The hydrological effects of the Project will be mitigated by inflows from tributaries downstream of the Project area, particularly below the Stawell River confluence. The Saego Dam model case, which reflects the cumulative impacts of the Project and other existing water resource development, complies with for 4 out of 7 Gulf Water Plan environmental flow objectives (EFOs).

Environmental, Social and Economic Values

The environmental, economic, social and cultural values associated with the Gulf Water Plan environmental flow requirements for the Flinders River system were identified based on reviews of existing reports and papers.

The Flinders River has an anabranching pattern and is bordered by extensive floodplains. The flow regime is ephemeral, and waterholes provide critical refugia for aquatic biota. Previous studies indicate that permanent or persistent waterholes occur mainly in the vicinity of the Stawell River and further downstream. The riverine, floodplain and wetland ecosystems associated with the Flinders River are generally considered to be in a good condition.

The riparian zone and floodplain vegetation associated with the Flinders River includes 'of concern' regional ecosystems. Twenty-two obligate riparian plant species have been identified, all with a conservation status of 'least concern' under the *Nature Conservation Act 1992 (Qld)* (NC Act).

More than 50 freshwater fish species have been recorded in the Flinders River catchment, including the freshwater sawfish, *Pristis pristis,* which listed as 'vulnerable' and migratory under the *Environmental Protection and Biodiversity Conservation Act 1999 (Cth)* (EPBC Act), as well as fishery species.

Other flow-reliant fauna associated with the Flinders River include aquatic macroinvertebrates, frogs and toads, freshwater turtles, crocodiles, lizards, snakes, birds and mammals. Species of conservation significance associated with the Flinders River include:

- Estuarine crocodile *Crocodylus porosus* (listed as 'vulnerable' under the *Nature Conservation Act 1992 (Qld)* (NC Act) and migratory under the EPBC Act)
- Worrell's turtle or diamond head turtle *Emydura subglobosa worrellii* (listed as 'near threatened' under the NC Act)
- Waterbird and wader species listed under the EPBC Act and international migratory bird agreements
- Other bird species associated with the riparian zone or floodplain, including species listed under the NC Act and/or EPBC Act

The Gulf Water Plan requires the cumulative impacts of water resource development to be assessed in relation to EFOs for the Flinders River at Walkers Bend and specifies outcomes relating to estuarine and marine ecosystems and biota. Floodplain and salt flat habitats and a number of estuarine species including mud crabs, white banana prawns, some species of fish, sea snakes and migratory shorebirds) are susceptible to reductions in river flow. The Southern Gulf Aggregation is listed in the Directory of Important Wetlands in Australia and supports colonial waterbird breeding.

Fish have high economic and social importance in the Southern Gulf of Carpentaria (SGoC) region and are targeted by commercial, recreational and indigenous fisheries. The Flinders River contributes approximately 16% of the river inflows to the SGoC and influences the Gulf of Carpentaria (GoC) fisheries. Recreational fishing has been identified as the primary reason for tourists visiting North-west Queensland. The Flinders River also has indigenous cultural values.

Environmental Flow Risk Assessment

A high-level risk assessment was undertaken of the cumulative impacts of flow regime changes resulting from the Project and other existing water resource development. A three-point rating scale (low [L], medium [M], high [H]) was used to show indicative levels of risk to flow-related values based on the likelihood and consequences of impacts in each reach.

The Project area is situated approximately 700 km upstream of the mouth of the Flinders River and the catchment area upstream of the Project area is 7% of the total Flinders River catchment. The Project will substantially reduce flows in the Flinders River immediately downstream of the Project area and at Richmond, resulting in a high risk of geomorphological and ecological changes in Reaches 1 to 3. Downstream of the Stawell River, the hydrological effects of the Project are significantly mitigated by tributary inflows but the effects of other water resource development increase. The risk of geomorphological and ecological changes associated with the cumulative impacts of flow regime change decreases to medium/high in Reach 4 and low/medium in Reach 5. The risk to estuarine and marine ecosystems and values from the cumulative impacts of water resource development is rated as medium for the Flinders River estuary (Reach 6) and low/medium for the SGoC (Reach 7), reflecting partial compliance with the Gulf Water Plan EFOs. Further investigations are to clarify key uncertainties in the environmental flow risk assessment are outlined.

Alternative Scenario

Engeny modelled an alternative scenario with a 25% reduction in the storage capacity of Saego Dam (a nominal number) to test sensitivity and compliance. The alternative scenario is compliant with 6 of the 7 Gulf Water Plan EFOs and is marginally non-compliant with the 7th EFO. Engeny advised that it would be feasible to resolve this in the design phase to achieve full compliance.

If the Project fully complies with all of the EFOs for the Flinders River at Walkers Bend, the requirements of the Gulf Water Plan in regard to EFOs will be met. The environmental flow studies in the next stages of the process (including the DBC and EIS processes) could then move forward to address questions relating to environmental management rules, water storage design and environmental impact mitigation. It is expected that environmental flow-related risks would be lower for the alternative scenario than the Reference Project and easier to resolve or mitigate, and that the required studies would be confined to the non-tidal reaches of the Flinders River.

1 Introduction

1.1 Background and Scope

This report provides a high-level desktop assessment of the proposed Hughenden Irrigation Project ('the Project') in relation to the environmental flow requirements of the Gulf Water Plan.

The Project is based on water harvesting by gravity diversion from the Flinders River at the Flinders River Weir into an 'offstream' storage at Saego Dam (Figure 1). It will provide an average annual supply volume of 68 GL/year, which is intended to be used in the proposed irrigation area shown on Figure 1.

Engeny (2019) provided the following information about the infrastructure associated with the Project:

- Flinders River Weir – diversion weir 7 m high, backwater from the weir will impound sections of the Flinders River and Betts Gorge Creek
- Saego Dam – 190 GL capacity water storage dam on Stewart Creek
- A gravity diversion channel from the Flinders River Weir to Saego Dam (250 cumecs capacity prior to overtopping of the weir [equivalent to 21,600 ML/d diversion capacity])
- An open channel delivery system to irrigation areas mainly to the south of Flinders River.

The main report (Chapters 1 to 8) focuses on the 'Reference Project' outlined above. Engeny subsequently modelled a scheme with a 25% reduction in the storage capacity of Saego Dam (a nominal number) to test sensitivity and compliance. The implications of this alternative scenario are discussed in an Addendum to the report (Chapter 9).

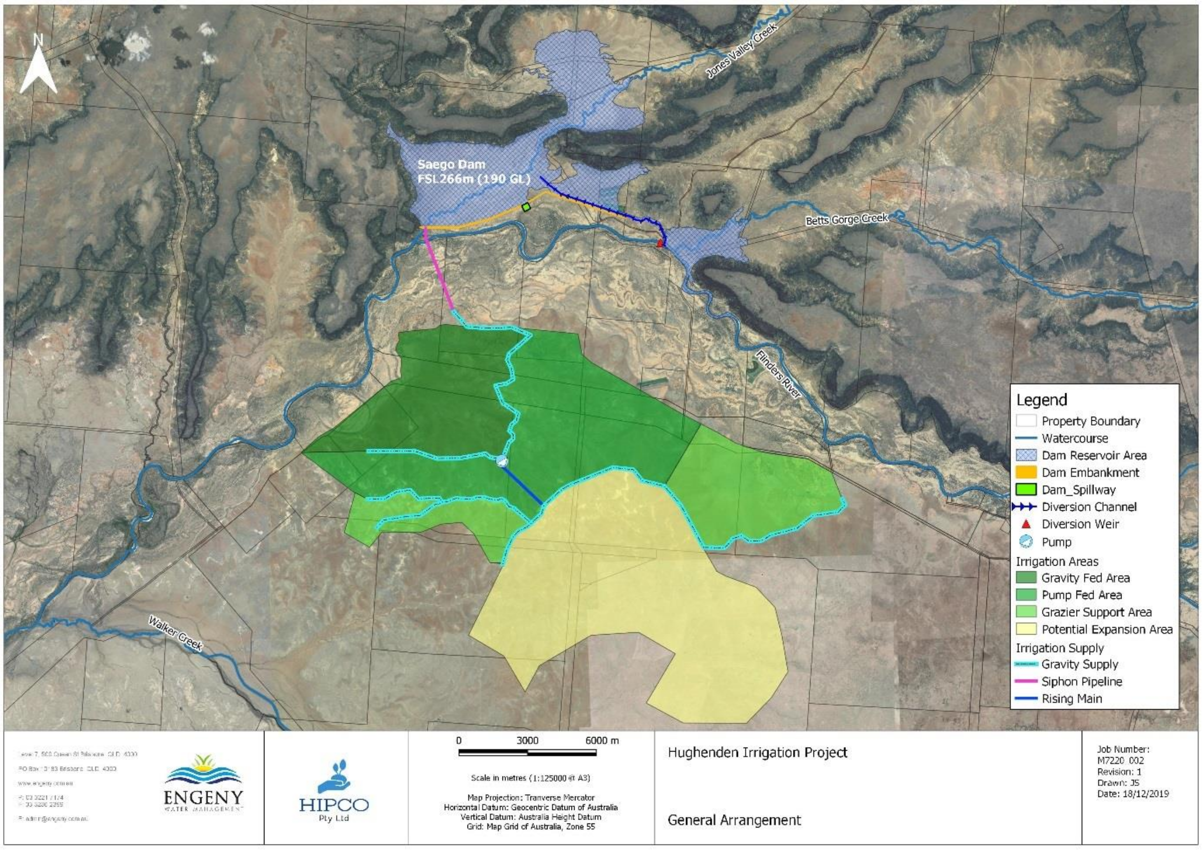

Figure 1 Hughenden Irrigation Project – general arrangement

1.1.1 Study Area

This report focuses on the implications of the Project for the Flinders River downstream of the Project area, including outflows from the Flinders River to the Southern Gulf of Carpentaria (SGoC).

The 'study area' for this report is the area potentially affected by changes in the flow regime of the Flinders River resulting from the Project, namely the Flinders River downstream of the Flinders River Weir and outflows from the Flinders River to the SGoC. The 'study area' is different to the 'Project area', which is the area directly affected by the Project, including the Flinders River Weir, Saego Dam offstream storage, water diversion and supply channels and the new irrigation area, as shown on Figure 1.

1.2 Objectives

This report addresses the following objectives:

a) Description of the hydrological impacts of the Project in relation to the Flinders River flow regime, with particular reference to flow indicators relevant to environmental flows.
b) Description of environmental and other values (social, economic and cultural) associated with environmental flow requirements for the Flinders River system downstream of the Project[1], including values of the receiving waters in SGoC that are associated with Flinders River flows.
c) Assessment of the implications of hydrological impacts of the Project for the environmental and other values identified.

1.2.1 Exclusions

This report does not provide an assessment of the effects of the Project within the Project area or on the river system further upstream. Issues that are excluded from the assessment on this basis include:

- Implications arising from impoundments, including the Flinders River Weir pondage or Saego Dam pondage
- Implications of the Flinders River Weir for the fish fauna and ecology of the Flinders River upstream of the weir
- Implications of irrigation development, including fertilizer, herbicide and pesticide application, and impacts on groundwater

This report does not include any assessment of the implications of climate change or sea level rise.

1.3 Methodology

1.3.1 General Approach

The Flinders River was divided into reaches to provide a spatial reference framework for the study (Chapter 2). A framework for defining the environmental and other values associated with the Gulf Water Plan environmental flow requirements was developed based on the outcomes specified in the Gulf Water Plan (Section 1.3.2).

The general approach taken in relation to the objectives set out above is as follows:

a) Description of the hydrological impacts of the Project on the Flinders River flow regime
    - Hydrological impacts were described based on hydrological information provided by Engeny (from modelling and post-processing by HARC)

[1] As specified in the *Water Plan (Gulf) 2007*

- This assessment was undertaken at a high level based on the following flow statistics:
  - Annual flow statistics, including mean and median annual flow, and median annual summer flow
  - Flow duration curves
  - Assessment of compliance with Gulf Water Plan EFOs for the Flinders River at Walkers Bend
- The description of hydrological impacts is presented in Chapter 3.

b) Description of environmental and other values
   - The environmental and other values (social, economic and cultural) associated with environmental flow requirements for the Flinders River system were identified based on reviews of existing reports and papers. Key information sources are outlined in Section 1.3.3
   - The results of the assessment of environmental and other values are presented in Chapters 4 to 7

c) Implications of the Project for environmental and other values
   - The implications of hydrological impacts of the Project for the environmental and other values associated with environmental flow requirements for the Flinders River were identified were assessed on a reach by reach basis, based on the hydrological impacts described in Task (a) and the values described in Task (b)
   - The implications of the Project were ranked using a 3-point rating scale – high, medium, low – to indicate levels of risk
   - A high-level risk-based approach was used in developing the ratings, based on:
     - The likelihood of an impact occurring based on the assessment of flow regime change
     - The consequences of the impact for the environmental and other values identified in this study
   - The results of the assessment of environmental and other values are presented in Chapter 8

d) The implications of an alternative scenario (25% Smaller Dam) are examined in an addendum to the report (Chapter 9)

1.3.2 Environmental and Other Values

The environmental and other values (social, economic and cultural) associated with environmental flow requirements for the Flinders River were defined for the purposes of this report with reference to outcomes for sustainable management of water specified in the Gulf Water Plan.[2]

The following 'environmental outcomes' in the Gulf Water Plan are relevant to the ecosystems associated with the Flinders River downstream of the Project:[3]

> *(a) maintenance of the natural variability of flows that support the habitats of native plants and animals and migratory birds in watercourses, floodplains, wetlands, lakes and springs;*

[2] *Water Plan (Gulf) 2007* Chapter 3
[3] *Water Plan (Gulf) 2007* s 15(1)

(b) provision for the continued capability of a part of a river system to be connected to another part, including by maintaining flood flows that—

(i) allow for the movement of native aquatic animals between riverine, floodplain, wetland, estuarine and marine environments; and

(ii) deliver nutrients and organic matter throughout the plan area to support natural processes such as breeding, growth and migration in riverine, floodplain, wetland, estuarine and marine environments; and

(iii) deliver water and sediment throughout the plan area to support river-forming processes;

(c) minimisation of changes to natural variability in water levels to support natural ecological processes, including the maintenance of refugia associated with waterholes and lakes;

(d) maintenance of the permanence of water in … river bed sands that provide water to support native plants and animals, particularly during dry seasons;

(e) the promotion of improved understanding of the matters affecting flow-related health of ecosystems in the plan area;

… [environmental outcomes (f) and (g) are not relevant to the Project] …

(h) maintenance of flood flows to the estuarine and marine environments of the Gulf of Carpentaria to stimulate breeding, growth and migration of native aquatic animals;

(i) maintenance of the natural variability of flood flows that inundate, and deliver nutrients, organic matter and sediment to, the wetlands of the areas known as the Southern Gulf Aggregation and the Southeast Karumba Plain Aggregation;

The Gulf Water Plan also specifies the following economic outcome that are relevant to the ecosystems associated with the Flinders River (s 13):

(h) support of tourism in the plan area, including, for example, by protecting flows that support the natural aesthetics of watercourses and their surroundings;

(i) support of commercial fishing in the Gulf of Carpentaria, including, for example, by protecting flood flows that may deliver nutrients and water to estuarine and marine environments to stimulate growth and movement of native aquatic animals, including fish, prawns and crabs.

The Gulf Water Plan also species the following social outcomes that are relevant to the ecosystems associated with the Flinders River:

(b) support of water-related cultural values of Aboriginal and Torres Strait Islander communities in the plan area;

… [social outcome [c] is not relevant to the Project] …

(d) maintenance of flows that support water-related aesthetic, cultural and recreational values in the plan area.[4]

For the purposes of developing the monitoring program for the Gulf Water Plan, 'ecological assets' were identified that relate to the environmental and ecosystem-related outcomes (DNRME 2018). Ecological assets were defined as:

… natural components of an ecosystem for which flow is critical. [5]

This report takes a broader view of the environmental and other values (social, economic and cultural) associated with environmental flow requirements for the Flinders River system than the suite of ecological assets defined by DNRME (2018) (Table 1). These values are grouped into four broad categories: riverine habitats, flora and fauna, estuarine and marine, and economic and social values. The flow-related ecological assets identified by DNRME (2019) are included in the review of information in relation to each class of values.

In addition to values, the Gulf Water Plan outcomes also refer to geomorphological and ecological processes. These topics are not separately addressed in this high-level assessment report, but key principles are embedded in discussions of values and the assessment of implications of the Project as relevant. There has been extensive research on ecological processes including food webs and primary productivity in the Flinders River (e.g. Jardine *et al.* 2013, Leigh *et al.* 2012, Fagotter *et al.* 2013).

Table 1 Framework for reviewing the environmental and other values (social, economic and cultural) associated with the Gulf Water Plan environmental flow requirements

Category	Riverine Habitat	Waterholes	Conservation Values
		Riffles / Glides	
		Hyporheos	
		Riparian Zone	
		Anabranching Systems	
		Floodplains and Wetlands	
		Connectivity	
	Flora and Fauna	Riparian vegetation	
		Aquatic vegetation	
		Macroinvertebrates	
		Fish	
		Amphibians	
		Reptiles	
		Birds, including migratory birds	
		Mammals	
	Estuarine and Marine Habitats and Biota	Flow-reliant Estuarine Habitats	
		Flow-reliant Estuarine Biota	
		Commercial Fisheries	Social and Economic Values
		Recreational Fishery	
		Indigenous Fishery	
		Tourism	
		Indigenous Cultural Values	

[4] *Water Plan (Gulf) 2007* s 14

[5] DNRME (2018) p 9

1.3.3 Key Information Sources

Information sources for the present study included reports produced through major programs concerned with water resource management and northern Australia, as well as other reports, papers and theses. Several online databases were also used, including Biomaps[6] and SPRAT[7].

Extensive investigations of environmental, social and economic matters relating to water resource management were undertaken as part of the Queensland Government's water planning program. The following key reports were identified for the Gulf Water Plan:

- Geomorphological and ecological assessment (Smith *et al.* 2006) and economic and social assessment (Economic Associates 2006)) for the development of the Gulf Water Resource Plan
- Environmental assessments by the Queensland government for reviews of the Gulf Water Plan (DSITIA 2014, DNRME 2018)
- An assessment by CSIRO of the water needs of fisheries and ecological values in the GoC (Bayliss *et al.* 2014)

The 'Tropical Rivers Inventory and Assessment Project' (TRIAP) was an initiative of Land & Water Australia and the National Heritage Trust as part of the (Australian) National Rivers Consortium (Finlayson and Lukacs 2008). It was a multiple-stakeholder and multi-disciplinary initiative in northern Australia that sought to study the wetlands and waterways within Australia's two northern drainage divisions as one region. The Flinders River catchment was one of three focus catchments. The aim of TRIAP was to collate existing information to establish an integrated information base and framework for assessing the status and change in Australia's tropical rivers, and to support ongoing research and natural resource management.

The Flinders and Gilbert Agricultural Resource Assessment (FGARA) was undertaken by CSIRO under the auspices of the North Queensland Irrigated Agriculture Strategy (Petheram *et al.* 2013). The FGARA aimed to provide a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of expanding irrigated agriculture in the Flinders and Gilbert catchments. It included a range of detailed scientific and technical studies, including the following reports that are particularly relevant to this study:

- Instream waterholes (McJannet *et al.* 2013)
- Waterhole ecology (Waltham *et al.* 2013)
- Floodplain inundation (Dutta *et al.* 2013)
- Surface-groundwater interactions (Jolly *et al.* 2013)
- Indigenous water values, rights and interests (Barber 2013)

The Northern Australia Water Futures Assessment (NAWFA) was a multidisciplinary Program that aimed to create a knowledge base on the water resources in northern Australia and the watering needs of key ecosystem, community and cultural assets, jointly delivered by the National Water Commission (NWC) and the Department of Sustainability, Environment, Water, Populations and Communities (DSEWPaC). The NAFWA report on *Assessment of the likely impacts of development and climate change on aquatic ecological assets in Northern Australia* was used as a reference for this report (Close *et al.* 2012).

The Queensland Department of Environment and Science (DES) has undertaken Biodiversity Planning Assessments (BPAs) for the bioregions relevant to the study area as well as aquatic

[6] http://qldspatial.information.qld.gov.au/biomaps/
[7] 'Species Profiles and Threats Database', https://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl

ecosystems in the Eastern Gulf of Carpentaria (EGoC) region.[8] The BPAs identified ecological values and their conservation significance and were intended to help governments and others to make planning decisions about appropriate land use.

[8] *Aquatic Conservation Assessments (ACA) and AquaBAMM, WetlandInfo* 2013, Department of Environment and Science, Queensland, viewed 13 January 2020, <https://wetlandinfo.des.qld.gov.au/wetlands/assessment/assessment-methods/aca/>; *Biodiversity planning assessments,* Department of Environment and Science, Queensland, viewed 13 January 2020, <https://www.qld.gov.au/environment/plants-animals/biodiversity/planning>.

2 Study Area

The Flinders River study area extends across three bioregions:

- Mitchell Grass Downs
- Gulf Plains Bioregions
- Einasleigh Uplands.

Rainfall and streamflows are strongly seasonal, with a monsoonal climate characterised by a pronounced summer wet season and long winter dry season. The Flinders River system is drier with a greater number of no flow days than the other EGoC catchments because of lower rainfall and limited connectivity to underlying groundwater (DES 2018).

The rivers and streams in the study area were subdivided into reaches to provide a consistent spatial reference framework for this report (Table 2). The reach subdivision took into account the following considerations:

- The configuration of the Project
- The location of the Source hydrology model reporting nodes
- River channel and floodplain geomorphology
- Bioregions
- Major tributary confluences
- Reach subdivisions used in previous studies (Smith *et al.* 2006, Saynor *et al.* 2008, Erskine *et al.* 2017)

Table 2 Flinders River reaches downstream of the Project area

Reach	**Smith *et al.* (2006) reaches**	**Saynor *et al.* (2008) classification**	**Relevant Source Model Node(s)**	**Key Attributes**
Reach 1 – Flinders River Weir to Walkers Creek	Flinders 4 - Hughenden to Stawell River	Wandering river	Node 009	• Immediately downstream of the Flinders River Weir and adjacent to the Project area • Einasleigh Uplands and Mitchell Grass Downs Bioregions
Reach 2 – Walkers Creek to Dutton River (Richmond)	Flinders 4 (continued)	Anabranching river	Node 009 Richmond	• Downstream of the first major tributary below the Project area • Einasleigh Uplands and Mitchell Grass Downs Bioregions
Reach 3 – Dutton River to Stawell River	Flinders 4 (continued)	Anabranching river	Richmond	• River reach directly associated with the 'Richmond' hydrology node • Mitchell Grass Downs and Gulf Plains Bioregions
Reach 4 – Stawell River to Euroka Springs	Flinders 5 - Stawell River to Euroka Springs	Anabranching river	Richmond Etta Plains	• Gulf Plains Bioregion • Anabranching system more extensive than further upstream

Reach	Smith *et al.* (2006) reaches	Saynor *et al.* (2008) classification	Relevant Source Model Node(s)	Key Attributes
Reach 5 – Euroka Springs to Tidal Limit	Flinders 6 - Euroka Springs to Canobie Flinders 7 - Canobie to Cloncurry Confluence Flinders 8 - Cloncurry Confluence to Walkers Bend	Anabranching river	Etta Plains Walkers Bend	• Gulf Plains Bioregion • Extensive anabranching system • Complex interactions between the Flinders River and other rivers including the Cloncurry and Saxby Rivers
Reach 6 – Estuary (Tidal Limit to River Mouth)	Flinders 9 - Walkers Bend to end of system.	Estuarine river	Walkers Bend	• Gulf Plains Bioregion • Estuary – transition from river-dominated tidal channel to a meandering tide-dominated channel system bordered by extensive mangrove forest
Reach 7 – Southern Gulf of Carpentaria	Flinders 9 (continued)	NA	Walkers Bend	• Affected by flood outflows from the Flinders River

Smith *et al.* (2006) subdivided the Flinders River into reaches as a basis for the geomorphological and ecological assessment for the Gulf Water Plan.

Saynor *et al.* (2008) undertook a catchment-scale geomorphic classification of major rivers and streams in the Flinders River catchment as part of the TRIAP, which is also discussed in Erskine *et al.* (2017). In the TRIAP focus catchments (including the Flinders), they worked at a scale of at 1:250,000 using remote sensed imagery. They subdivided the rivers and streams into homogeneous reaches based on 12 river types. Saynor *et al.* (2008) mapped the Flinders River in the study area as follows:

- The Flinders River upstream of Walkers Creek (including the Project area) was mapped as a ‘wandering river’
- The Flinders River between Walkers Creek and Walkers Bend was mapped as an ‘anabranching river’
- The Flinders River downstream of Walkers Bend was mapped as an ‘estuarine river’

3 Hydrological Implications of the Project

The implications of the Project for the flow regime of the Flinders River downstream of the Flinders River Weir are examined in this chapter. This chapter is based on information provided by Engeny including hydrological modelling outputs and post-processing results.

3.1 Hydrologic Model Nodes and Cases

The hydrological modelling was undertaken using a Source model for the Flinders River catchment covering a simulation period of 122 years (July 1889 to June 2011). Model outputs were provided by Engeny for four reporting nodes (Figure 2, Table 3):

- Flinders River downstream of the Project area (Source model node 009)
- Flinders River at Richmond
- Flinders River at Etta Plains
- Flinders River at Walkers Bend

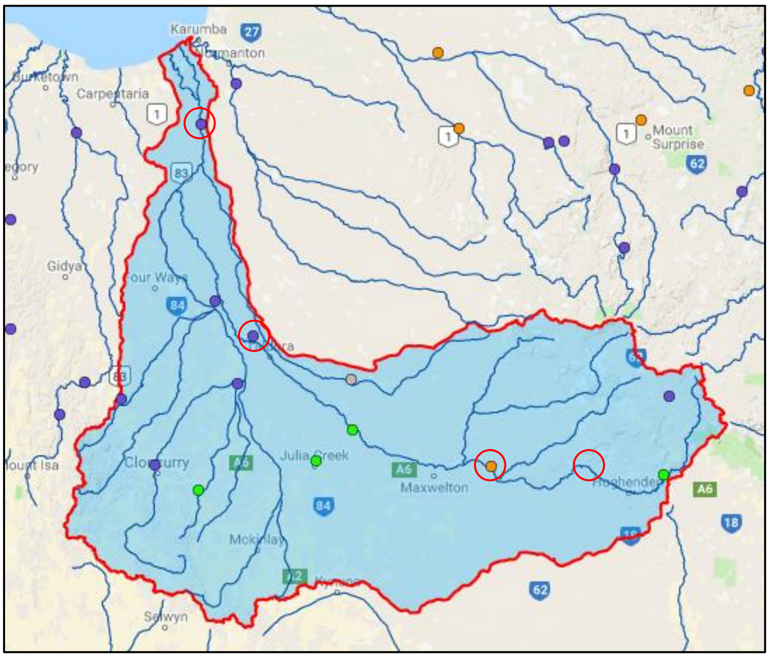

Figure 2 Source model reporting nodes (Source: Engeny)

Table 3 Source model reporting nodes and gauging stations (distances and catchment areas from the Queensland Government Water Monitoring Information Portal https://water-monitoring.information.qld.gov.au/)

Model Node/ Gauging Station No.	Model Node/Gauging Station Name	Distance from River Mouth (km)	Catchment Area (km^2)
GS 915004A	Hughenden	774	2,519
Node 009	Downstream of the Project area		
GS 915008A	Richmond	620	17,380
GS 915012A	Etta Plains	350	46,130
GS 915003A	Walkers Bend	103	106,300

Three water resource management cases were simulated in the model:

- Pre-development
- WRP-ROP case – full use of entitlements specified in the Gulf Water Plan and Gulf Resource Operations Plan
- Saego Dam

The Saego Dam case simulates the cumulative impact of water resource development including the Project and full use of other entitlements specified in the Gulf Water Plan and Gulf Water Resource Plan. This case builds on the WRP-ROP case and makes the following assumptions:

- Assumed buy-back of existing surface water entitlements upstream of the Project area
- Removal of remaining unallocated water reserves (general and strategic reserves) along the Flinders River in lieu of the Project's water take
- Diversion of water from the Flinders River Weir to Saego Dam:
    - 8 m^3/s flow threshold on diversion weir (all river flows up to 8 m^3/s are passed through weir)
    - Diversion channel capacity: 250 m^3/s
    - Flows in excess of diversion channel capacity overflow the weir
- No environmental release from Saego Dam
- 84 GL/year target irrigation supply out of Saego Dam

3.2 Flow Indicators

The hydrologic model outputs for the three cases were compared on the basis of annual and daily flows to provide a high-level assessment of the effects of the Project on the flow regime of the Flinders River. Compliance with Gulf Water Plan EFOs was also assessed.

3.2.1 Annual Flows

The following statistical indicators were used to quantify the effects of the Project on annual flows at all four reporting nodes:

- Mean annual flow
- Median annual flow

Mean and median annual flows are both important measures of the effects of water resource management. In the Flinders River, like other rivers in northern and western Queensland, more than half of all years have flows that are much smaller than the mean annual flow, and therefore median annual flow provides a better indicator of the flow in any given year (Smith *et al.* 2006).

Time series plots of annual flows were used to examine effects on wet and dry years, including runs of wet or dry years.

3.2.2 Daily Flows

Flow duration analysis was used to assess the effects of the Project on daily flows at all four reporting nodes. Flow duration curves were used to examine low and medium flows. Flow duration tables for flows that occur on up to 5% of days were used to examine medium and high flows. Bankfull flows for Richmond, Etta Plains and Walkers Bend were identified based on estimates derived by DSITIA (2014) from 1.5-year ARI daily flows. Bankfull discharge is not known for Node 009.

3.2.3 Gulf Water Plan EFOs

The Gulf Water Plan specifies EFOs for one reporting node in the Flinders River catchment, Flinders River at Walkers Bend. A compliance assessment was undertaken for this node.

3.3 Results and Discussion

3.3.1 Annual Flows

Table 4 presents the results for mean and median annual flow. In the Saego Dam case, there are substantial reductions in annual flow immediately downstream of the Project area (Node 009) and at Richmond, but further downstream at Etta Plains and Walkers Bend, the effects of the Project are ameliorated by inflows from other parts of the catchment.

Table 4 Annual flow statistics (Source: Engeny)

	Pre-development	WRP-ROP		Saego Dam	
	ML/year	ML/year	% of Pre-dev	ML/year	% of Pre-dev
Mean annual streamflow					
Node 009	306,504	285,196	93.0%	244,365	79.7%
Gauge- 014 - GS915008A Richmond	421,919	399,423	94.7%	328,795	77.9%
Gauge- 028 - GS915012A Etta Plains	1,259,770	1,195,107	94.9%	1,122,880	89.1%
Gauge- 060 - GS 915003A Walkers Bend	2,769,732	2,550,544	92.1%	2,558,605	92.4%
Median annual streamflow					
Node 009	138,797	107,564	77.5%	26,907	19.4%
Gauge- 014 - GS915008A Richmond	167,987	133,097	79.2%	42,601	25.4%
Gauge- 028 - GS915012A Etta Plains	599,147	535,180	89.3%	489,603	81.7%
Gauge- 060 - GS 915003A Walkers Bend	1,431,038	1,163,315	81.3%	1,156,063	80.8%

The Saego Dam case will reduce mean annual flow to around 80% of pre-development immediately downstream of the Project but flows remain around 90% of pre-development at Etta Plains and 92% of pre-development at Walkers Bend.

The reductions in median annual flow are greater than the reductions in mean annual flow, particularly at Node 009 and at Richmond (Table 4). This is due to the diversion of mid-flows into Saego Dam, resulting in a greater effect on dry years and average years than very wet years (Figure 3).

3.3.2 Daily Flows

The flow duration analysis shows the following effects of the Saego Dam case on daily flows (Figure 4, Table 4):

- Limited change in low flows due to the 8 m^3/s flow threshold on the diversion weir
- A substantial reduction in medium flows due to the effects of the diversions
- Reductions in high flows, particularly at Node 009 and at Richmond

Large reductions in medium and high flows immediately downstream of the Project area are mitigated further downstream by tributary inflows (Figure 4, Table 5). At Richmond, the duration of flows equal to and exceeding bankfull discharge will be reduced from > 1%/<2% to less than <1% of days and the magnitude of the 1% daily flow will be reduced to two-thirds of the pre-development flow. Further downstream at Etta Plains and Walkers Bend, flood durations are longer, as indicated by the duration of flows exceeding bankfull discharge (>2%/<3% of days at Etta Plains and >3%/<4% of days at Richmond, and the percentage reductions in medium and high flows are smaller than further upstream (Table 5).

3.3.3 Gulf Water Plan EFOs

Table 6 provides an assessment of the modelled flow regime changes for Walkers Bend in relation to the Gulf Water Plan EFOs. It shows that the Saego Dam case complies with four (4) of the seven (7) EFOs. It does not comply with the high flow objectives based on the 1.5, 5- and 20-year ARI daily flow volumes.

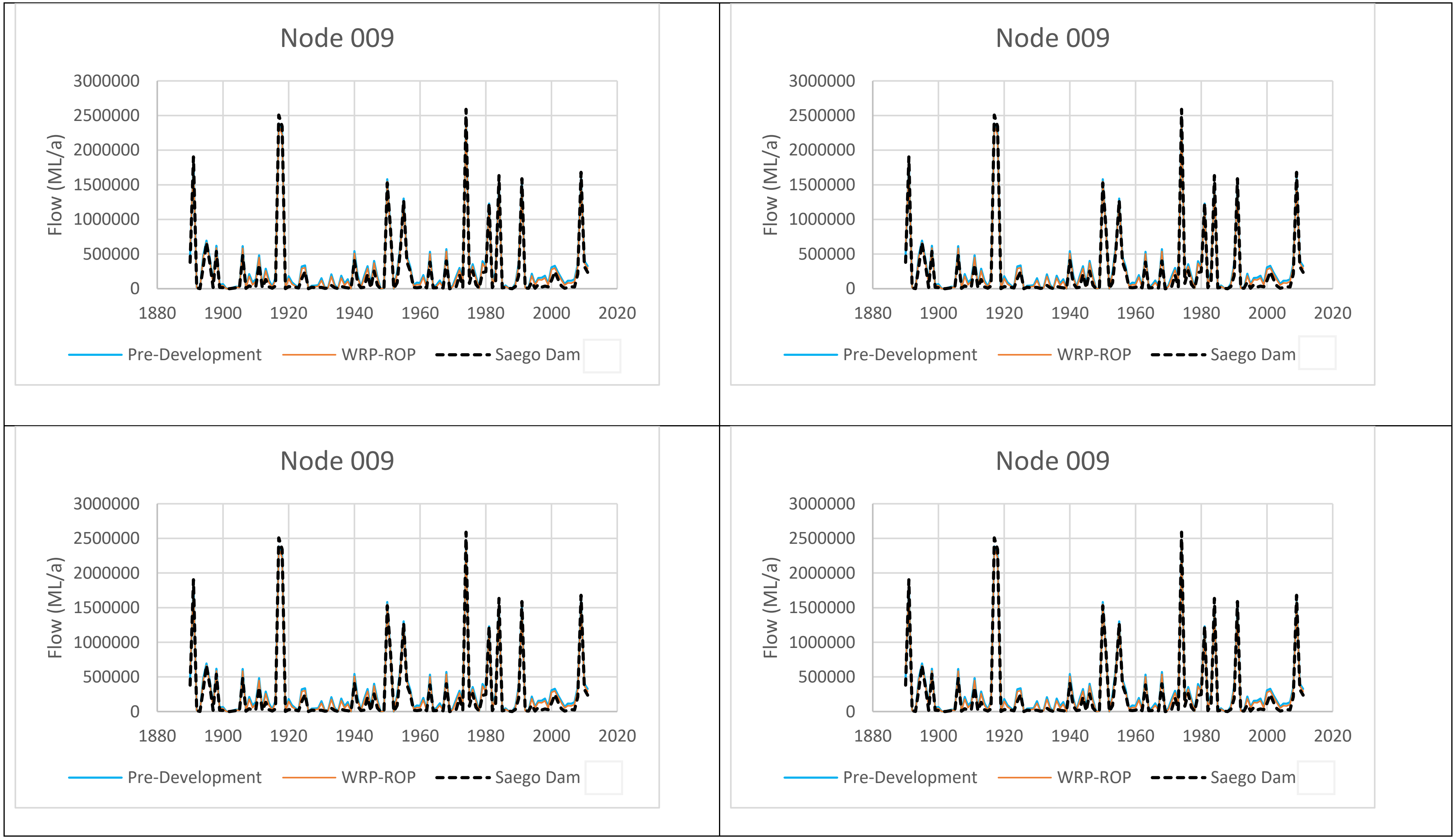

Figure 3 Annual flows over the full simulation period (based on flow data provided by Engeny)

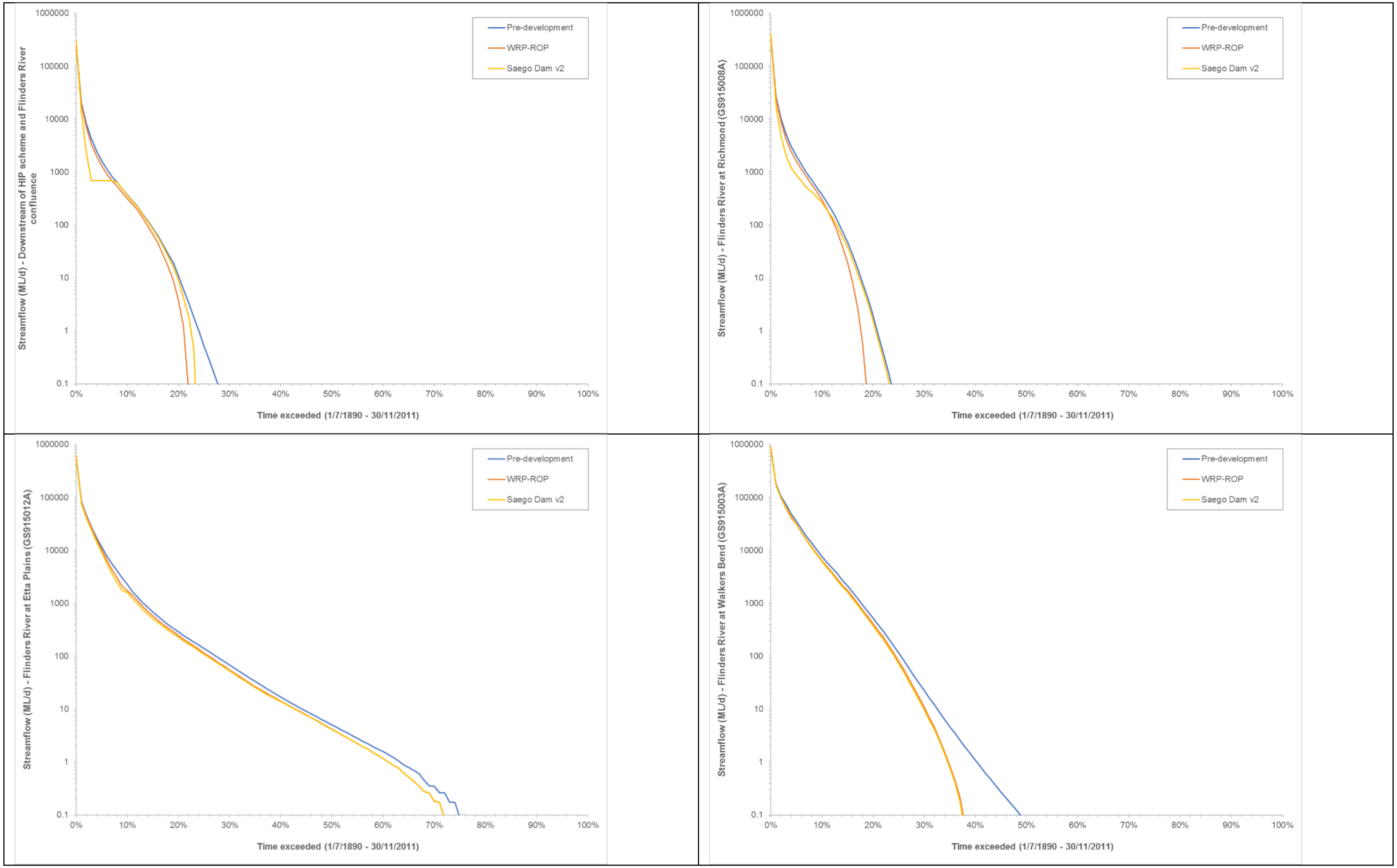

Figure 4 Flow duration curves (Source: Engeny)

Table 5 Flow duration table for medium and high flows that are exceeded on 5% of days or less. The grey shading indicates flows exceeding bankfull discharge. Bankfull discharge for the Node 009 is not known. (Based on flow duration analysis provided by Engeny and thresholds defined by DSITIA 2014)

	Time Exceeded (% of days)											
	0%		1%		2%		3%		4%		5%	
	ML/d	% of Pre-dev	ML/d	% of Pre-dev	ML/d	% of Pre-dev	ML/d	% of Pre-dev	ML/d	% of Pre-dev	ML/d	% of Pre-dev
Node 009												
Pre-development	265,965		20,274		8,123		4,246		2,551		1,629	
WRP-ROP	265,811	100%	18,724	92%	6,877	85%	3,316	78%	2,032	80%	1,296	80%
Saego Dam	312,130	117%	13,138	65%	2,231	27%	691	16%	691	27%	691	42%
GS915008A Richmond												
Pre-development	**416,394**		**26,871**		10,289		5,269		3,109		2,000	
WRP-ROP	**415,851**	100%	**24,630**	92%	8,827	86%	4,233	80%	2,456	79%	1,631	82%
Saego Dam	**410,422**	99%	17,967	67%	4,753	46%	2,076	39%	1,202	39%	879	44%
GS915012A Etta Plains												
Pre-development	**631,035**		**83,695**		**46,091**		28,027		17,639		11,421	
WRP-ROP	**630,056**	100%	**81,484**	97%	**43,663**	95%	26,662	95%	16,202	92%	10,019	88%
Saego Dam	**608,168**	96%	**75,445**	90%	**40,718**	88%	24,599	88%	14,681	83%	8,973	79%
GS915003A Walkers Bend												
Pre-development	**919,270**		**178,781**		**104,750**		**73,340**		49,908		35,353	
WRP-ROP	**917,356**	100%	**170,628**	95%	**96,596**	92%	**62,367**	85%	42,376	85%	30,859	87%
Saego Dam	**918,284**	100%	**169,854**	95%	**97,144**	93%	**66,536**	91%	45,376	91%	30,895	87%

Table 6 Assessment of the Saego Dam case in relation to Gulf Water Plan EFOs for the Flinders River at Walkers Bend (Source: Engeny)

EFO summary

Results	Results as a % of Pre-Dev			Requirement	Flow Requirement Satisfied?		
EFO ID	WRP-ROP (Nigel Kelly)	WRP-ROP	Saego Dam (v2)		WRP-ROP (Nigel Kelly)	WRP-ROP	Saego Dam (v2)
1		68.3%	68.5%	**<70%**		Y	Y
2	91.8%	92.1%	92.4%	**>90%**	Y	Y	Y
3	80.9%	81.3%	80.8%	**>78%**	Y	Y	Y
4	81.6%	81.2%	82.6%	**>75%**	Y	Y	Y
5	92.0%	91.9%	85.5%	**>90%**	Y	Y	N
6	98.3%	98.3%	94.7%	**>96.5%**	Y	Y	N
7	99.1%	99.0%	97.5%	**>98%**	Y	Y	N

Water Resource Gulf Plan 2007 Requirements (Page 50/51)

EFO ID	
1	*The proportion of no flow days in the simulation period should be no more than 70%*
2	*The mean annual flow as a percentage of pre- development flow should be at least 90%*
3	*The median annual flow as a percentage of pre-development flow should be at least 78%*
4	*The median Jan-March flow as a percentage of pre-development flow should be at least 75%*
5	*The 1.5 year daily flow volume as a percentage of pre-development flow volume should be at least 90%*
6	*The 5 year daily flow volume as a percentage of pre-development flow volume should be at least 96.5%*
7	*The 20 year daily flow volume as a percentage of pre-development flow volume should be at least 98%*

4 Key Riverine Habitats

The riverine and aquatic habitats associated with the Flinders River catchment are defined by the interaction of river flows/surface water with geomorphological features and vegetation. Six major types of riverine habitat are discussed is this chapter (Sections 4.1 to 4.6):

- Waterholes
- Riffles / Glides
- Hyporheos
- Riparian zone
- Anabranching System
- Floodplain and Wetlands

This chapter also discusses connectivity (Section 4.8).

DNRME (2018) identified three types of riverine habitat as 'flow-related ecological assets':

- Riffles
- Waterholes
- Floodplain wetlands.

River flows in the Flinders River are highly seasonal and dominated by flow that occurs during the wet season. The river is subject to prolonged dry periods – there is no flow for more than half the year at the Richmond and Walkers Bend gauging stations (Chapter 3). The ephemeral and highly variable flow regime plays a key role in defining riverine habitats. Dry riverbeds are an emerging area of ecological research (Steward 2012, Steward *et al.* 2011, 2012, 2018).

There is limited information about surface-groundwater interactions in the Flinders River catchment apart from work by Jolly *et al.* (2013) for the FGARA. Groundwater appears to play a minimal role in relation to maintaining aquatic habitats along the Flinders River, except possibly in association with the Sturgeon basalt province, which is upstream of Richmond, immediately to the north of Reaches 1 and 2 (Jolly *et al.* 2013). Groundwater recharge rates for the alluvium/bedsands associated with the river appear to be low due to the highly ephemeral flows in the Flinders River, the heavy textured soils on the floodplain that limit rainfall infiltration and high evaporation rates in the dry season (Jolly *et al.* 2013).

4.1 Waterholes

Waterholes have been identified across Queensland as priority ecological assets because of their importance as dry season refugia for many species and they have been identified as a flow-related ecological asset for the Gulf Water Plan (DNRME 2018).

In ephemeral dryland rivers, waterholes that persist through the dry season may provide the only permanent water habitat in an arid landscape and therefore provide critical habitat for the survival of aquatic biota (Magoulick & Kobza 2003; Humphries & Baldwin 2003). They provide a source from which broader reaches are recolonised when aquatic habitat is expanded by river flows and floods (Balcombe *et al.* 2007).

DES (2018) reported that perennial waterholes provide critical refugial habitat in the seasonally dry rivers of the EGoC region, for aquatic fauna including migratory fish and freshwater turtles. Iconic species such as barramundi and freshwater sawfish rely on perennial waterholes as refugia.

DES (2018) identified the following waterholes as having particularly high ecological significance:

- Flinders River near Marathon (Reach 1) – 'braided systems', with waterholes likely to be important for fish breeding and spawning
- Washpool Lagoon Complex (Reach 4) – the best development of deep pools and 'braiding' on the Flinders River, a feature of regional significance
- Intersection of Flinders and Saxby Rivers (Reach 5) – diversity and concentration of deep waterholes that are connected to the estuarine systems making them important for fish migration and spawning
- Deep waterholes just above the estuarine extent (Reaches 5 and 6) – important nursery habitat for fish

4.1.1 Presence of Waterholes

Several attempts have been made to map the permanent or more persistent waterholes in the Flinders River. These assessments are outlined below, and the results of these assessments are summarised on a reach basis in Table 7.

The information from previous studies summarised in Table 7 indicates that permanent or persistent waterholes occur mainly in the vicinity of the Stawell River confluence and further downstream. The following conclusions regarding the presence of permanent or persistent waterholes in the Flinders River were drawn on a reach basis:

- Reach 1: There is no evidence of any permanent waterholes in the Flinders River in Reach 1, although DNRME (2018) reported a waterhole with >50% persistence. Waltham *et al.* (2013) reported on a waterhole on Betts Gorge Creek (Fairlight Creek) close to the confluence with the Flinders River, a short distance upstream of Reach 1; however, local landholders have advised that they have not observed a permanent waterhole at this location.
- Reach 2: No permanent or persistent waterholes have been identified in Reach 2. Waltham *et al.* (2013) studied three seasonal waterholes in this reach, one on the Flinders River and two off-channel waterholes.
- Reach 3: Several studies identified persistent waterhole habitat near the Stawell River confluence
- Reach 4: Persistent or permanent waterhole habitat was identified in all previous studies
- Reach 5: Persistent or permanent waterhole habitat was identified in three previous studies. Waltham *et al.* (2013) did not systematically search for waterhole habitat in this reach

DSITIA (2014) conducted the most spatially extensive survey of waterholes in the Flinders River catchment and observed that:

> *Headwaters and some tributaries had no permanent waterholes, indicating that local extinctions of water dependent biota occur in these parts during dry years, and that recolonisation via catchment connectivity is vital to the aquatic ecology of the Flinders River. In wetter years many of the non-permanent waterholes in the system may persist and provide refuges for biota, but over long time-scales it is the permanent waterholes and broad connectivity that will sustain viable populations of biota.*

Table 7 Summary of information regarding the presence of persistent waterholes in the non-tidal reaches of the Flinders River

Reach	**'Persistent pools' – pools with > 90% persistence (McJannet *et al.* (2013)**	**'Assessment Waterholes' (Waltham *et al.* 2013) (Numbers refer to Figure 8)**	**'Permanent waterholes' - DSITIA (2014)**	**DNRME 'Waterholes as refugia' - waterholes with > 50% persistence (DNRME 2018)**
Reach 1 – Flinders River Weir to Walkers Creek	None identified	Waterhole on Betts Gorge Creek just upstream of the study area (F01)[9] ; none identified within Reach 1	No permanent waterholes	One waterhole identified
Reach 2 – Walkers Creek to Dutton River (Richmond)	None identified	Seasonal waterholes on the Flinders River (F02 – channel; F03, F04 – off-channel)	No permanent waterholes	No waterholes identified
Reach 3 – Dutton River to Stawell River	One persistent pool identified	Permanent waterhole on the Flinders River (F05)	No permanent waterholes	One waterhole identified
Reach 4 – Stawell River to Euroka Springs	Three persistent pools identified	Permanent waterhole on the Flinders River (F07); Seasonal waterhole (off-channel - F06)	One permanent waterhole	Several waterholes identified
Reach 5 – Euroka Springs to Tidal Limit	Only the upstream end of the reach was assessed. One persistent pool identified (on the Cloncurry River, within the zone of interaction with the Flinders River)	None identified in this reach	Several permanent waterholes	Several waterholes identified

4.1.1.1 McJannet et al. (2013) – Persistent Pools

McJannet *et al.* (2013) identified persistent pools within defined river reaches in the Flinders River catchment by applying a water index algorithm to Landsat imagery for the period 2003 to 2010. Approximately 90 scenes were analysed for their 'mid-Flinders' reach. Pools that existed for more than 90% of the time were classified as 'key aquatic refugia'. Figure 5 shows the reaches included in McJannet et al.'s assessment (blue lines) and the location of pools defined as 'key aquatic refugia'.

[9] Local landholders have advised that they have not observed a permanent waterhole at this location

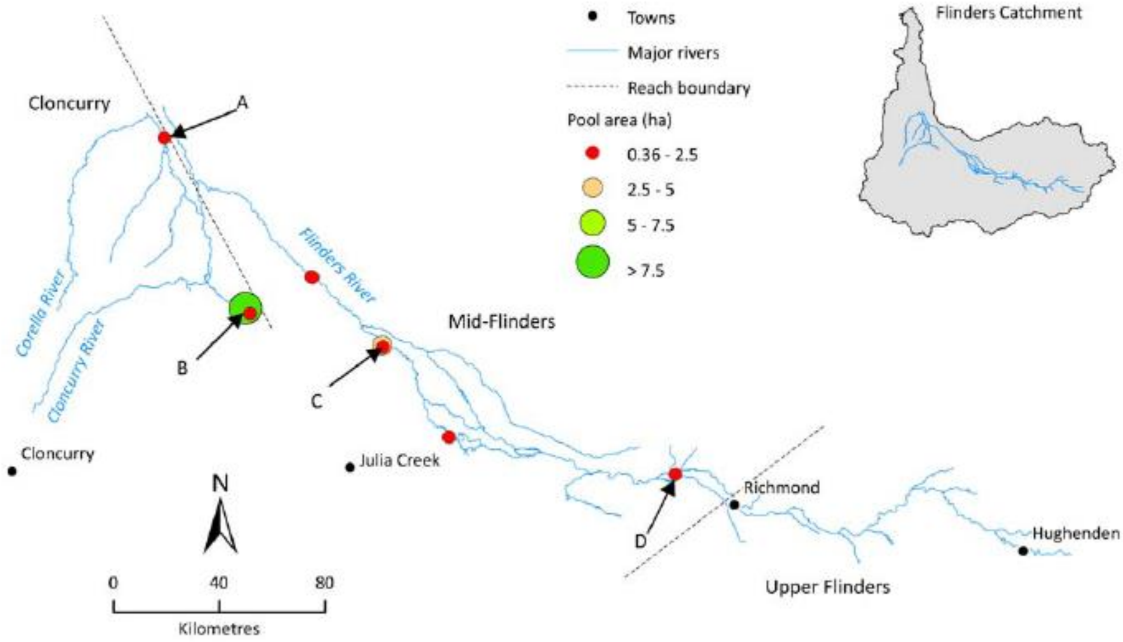

Figure 5 Instream pools mapped as 'key aquatic refugia' by McJannet et al. (2013)

The pools mapped as ‘key aquatic refugia’ contract significantly in drier years (Figure 6). McJannet *et al.* (2013) developed statistical relationships between total pool and time since flow ceased for Mid-Flinders and Cloncurry reaches shown on Figure 5 as well as the Gilbert River. They noted that similar rates of percentage reduction in total pool area on all three reaches and on this basis developed a generalised relationship between the duration of zero flow and reduction in pool area for use in comparisons of alternative water management scenarios (Figure 7).

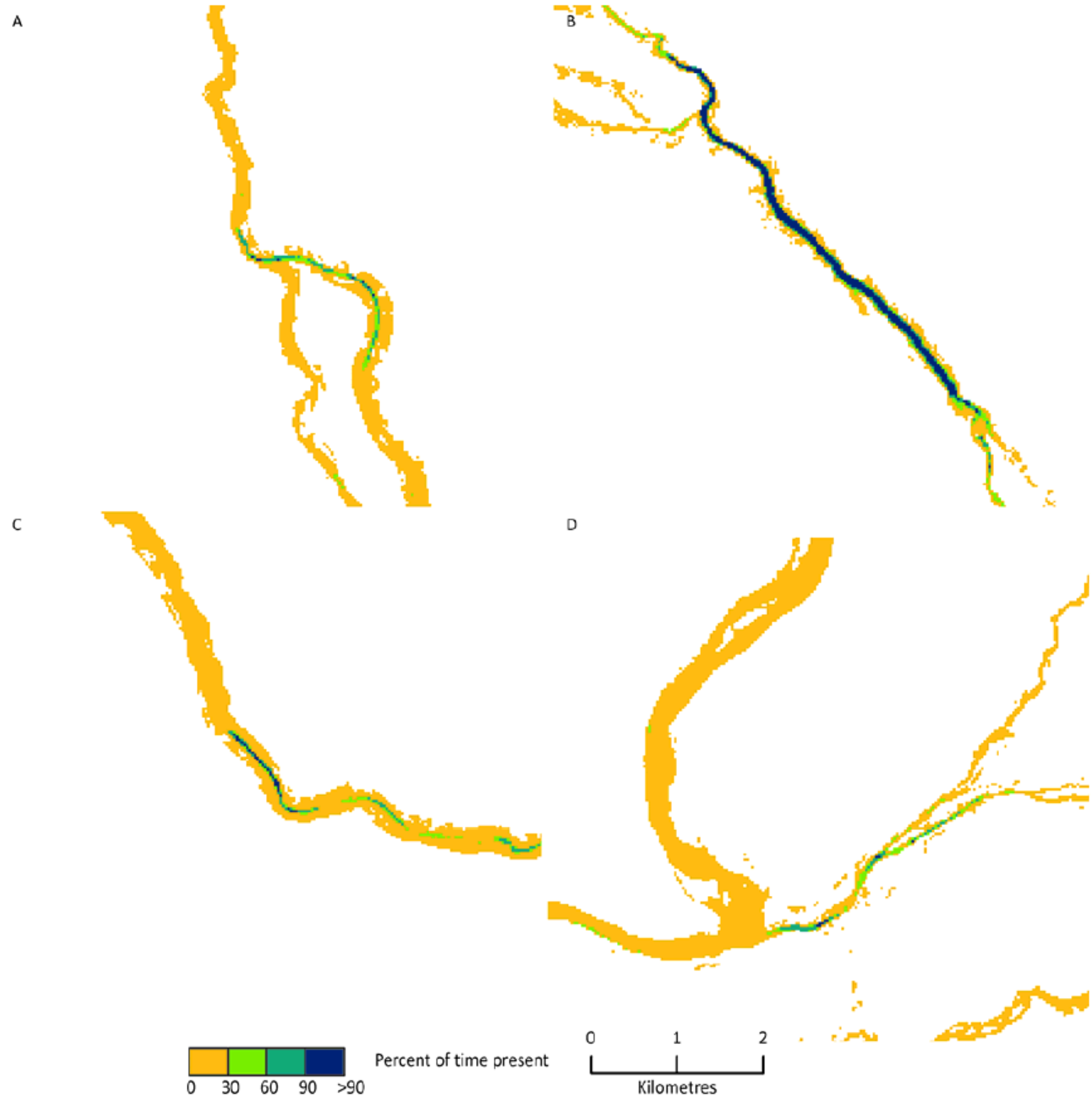

Figure 6 Persistence maps for the pools shown in Figure 5. Pools C and D are on the Flinders River, A is on the Cloncurry River, in the zone of interaction with the Flinders. From McJannet et al. (2013)

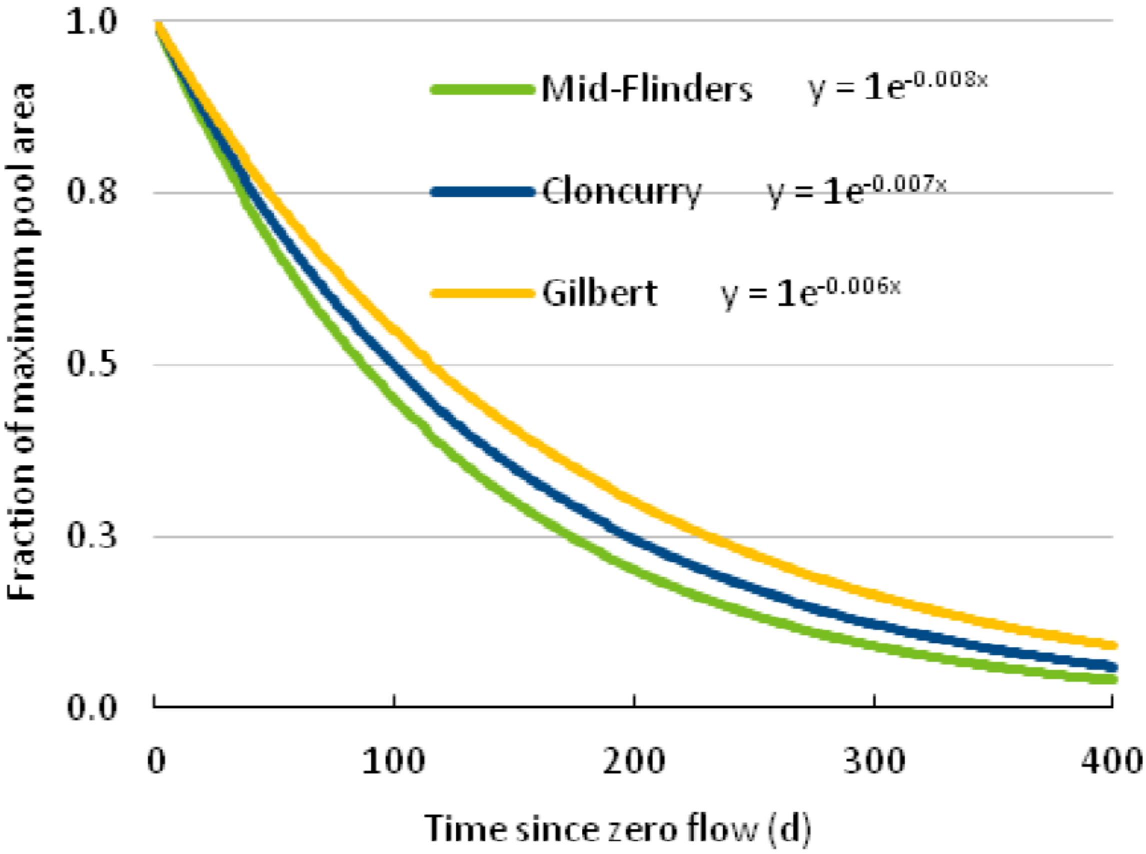

Figure 7 Fractional decrease in total pool area with time since zero flow (from McJannet et al. 2013)

4.1.1.2 Waltham et al. (2013) – Waterholes for Ecological Assessment

Waltham *et al.* (2013) undertook an assessment of waterhole ecology concurrently with McJannet *et al.'s* (2013) persistent pool mapping study. They selected ten waterholes in the Flinders River catchment for detailed ecological assessment. Some of their assessment waterholes coincided with the permanent pools identified by McJannet *et al.* (2013) but others are different (Figure 8). Waltham *et al.* indicated that the reasons for this discrepancy included the unavailability of the results of McJannet et *al.'s* (2013) assessment at the time Waltham *et al.* (2013) commenced their study, as well as access considerations. The following 'assessment waterholes' are located within the study area (Table 7):

- F02 – Flinders River channel; F03, F04 – Flinders River – off-channel
- F05 – permanent waterhole, Flnders River channel
- F06 – seasonal waterhole, Flinders River, off-channel
- F07 – permanent waterhole, Flinders River channel

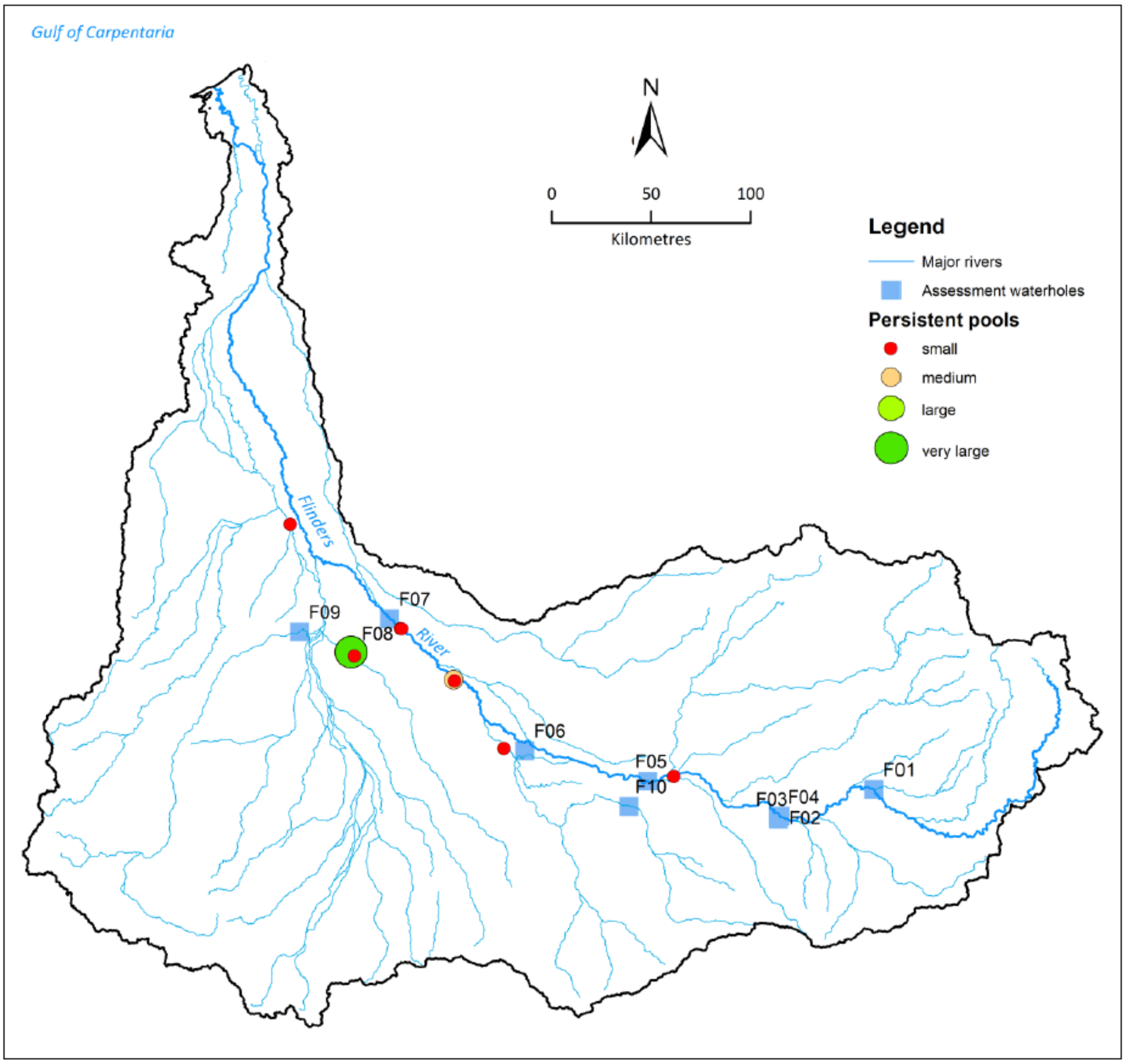

Figure 8 Comparison of 'assessment waterholes' chosen by Waltham et al. (2013) with 'permanent pools' identified by McJannet et al. (2013)

Waltham et al.'s (2013) report indicates that Waterhole F01 ('permanent waterhole, Fairlight Creek') is situated in Betts Gorge Creek just above its confluence with the Flinders River. It is located within the Project area (not the study area) and will be inundated by backwater from the Flinders River Weir. Local landholders have advised that they have not observed a permanent waterhole at this location. Further investigations will be required in the next stage of the Project to resolve the status of waterhole F01.

4.1.1.3 DSITIA (2014) – 'Permanent waterholes'

Department of Science, Information Technology, Innovation and the Arts (2014) undertook a mapping exercise to identify and locate all permanent in-channel waterholes in the Flinders and Gilbert catchments using Landsat imagery over the 25-year period from 1988 to 2013. They noted that that the 'persistent pools' identified by McJannet *et al.* (2013) were not necessarily 'permanent waterholes'.

The locations of permanent waterholes identified by DSITIA (2014) are shown on Figure 9. The 'permanent waterholes' downstream of GS915003A (Flinders River at Walkers Bridge) are situated in the estuary and differ from the waterholes in the non-tidal reaches of the Flinders River because the presence of water in these estuarine waterholes is maintained by tidal inundation. In addition to the permanent waterholes, DSITIA (2014) found many other waterholes that retained water through some but not all dry seasons.

They proposed that comparisons of waterhole persistence (in days) and maximum dry spell duration should be used the assessment of implications of water resource management scenarios for waterholes.

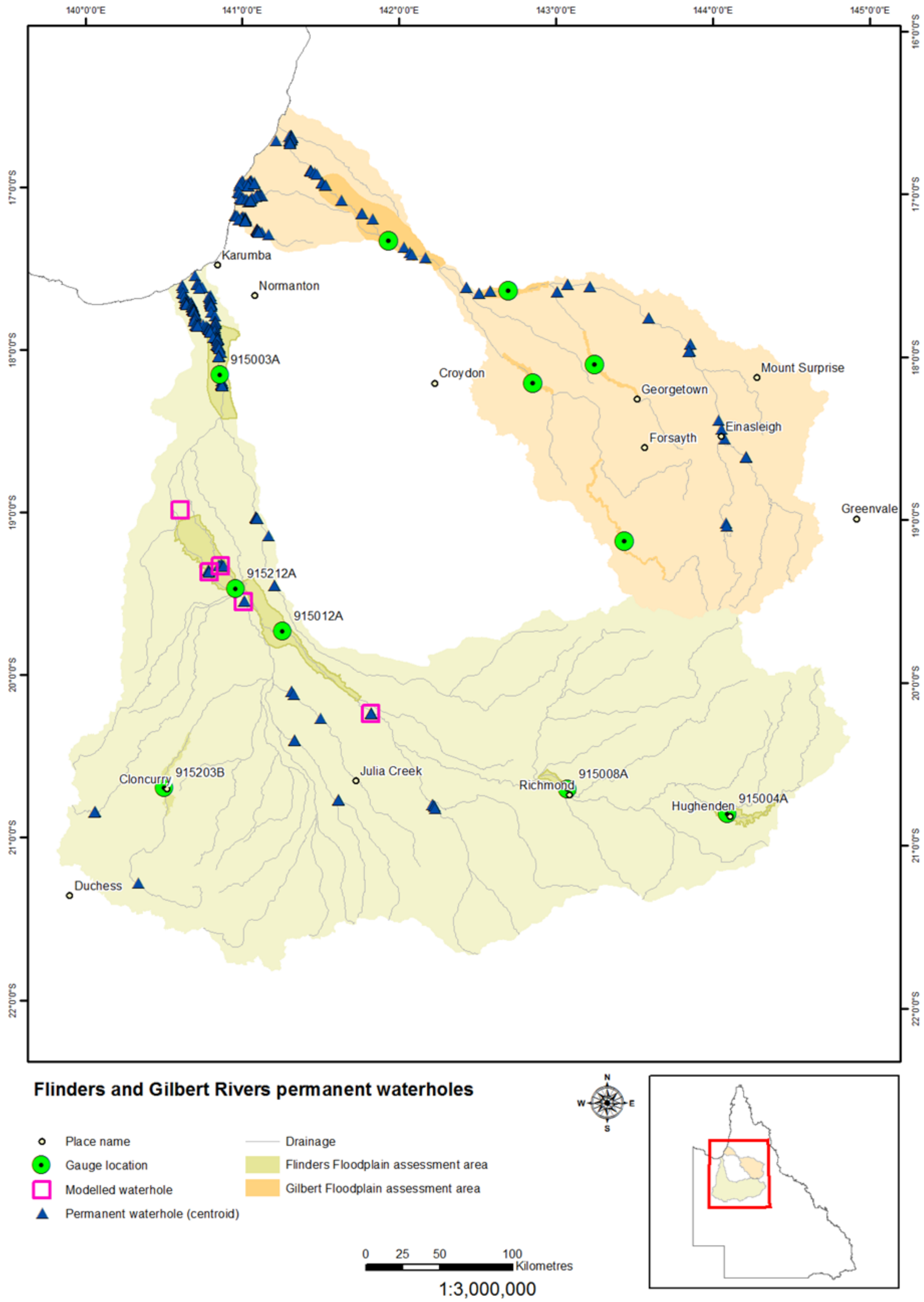

Figure 9 Location of permanent waterholes in the Flinders and Gilbert catchments identified by DSITIA (2014)

4.1.1.4 DNRME 'Waterholes as Refugia Project' (DNRME 2015, cited in DNRME 2018)

DNRME (2015 cited in DNRME 2018) undertook a remoted sensed waterhole selection process targeting persistent pools in Flinders and Gilbert Rivers. They used Landsat imagery from the period 1987–2014. They identified 27 waterholes across the two catchments with persistence values exceeding 50% (Figure 10) and 20 waterholes with persistence values exceeding 70%. A subset of sites was selected for water level monitoring and modelling, which DNRME (2018) indicated was expected to be completed in 2018. The furthest upstream waterhole identified by DNRME (2015 cited in DNRME 2018) is very close to the Project area but appears to be in Reach 1 rather than the Project area (

Figure 10); DNRME (2018) did not provide any further information that would allow its precise location to be determined.

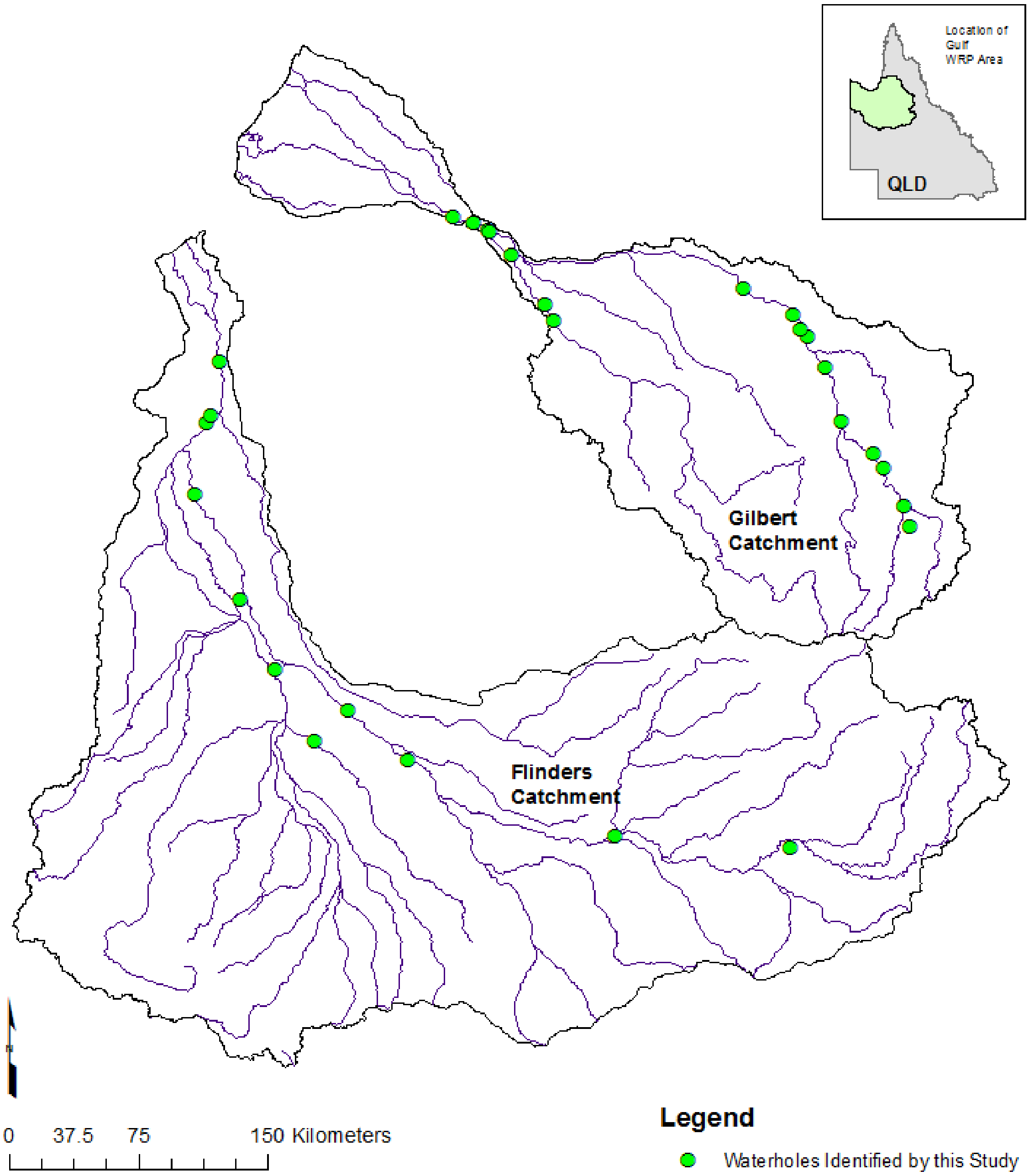

Figure 10 Flinders and Gilbert waterholes identified by the DNRME 'Waterholes as Refugia Project' remote sensing project with persistence greater than 50% of the time (From DNRME 2018)

4.1.2 Role of Groundwater

Jolly *et al.* (2013) used major ion chemistry, and naturally occurring radioactive and stable isotopes of water were used to assess the likelihood of groundwater presence at 17 waterhole sites in the Flinders River catchment (including eight sites on the Flinders River) and concluded that most were assessed to have a nil to low likelihood of groundwater inflow based on the indicators used. However, they noted that the indicators are more suited to detecting the inflow of groundwater that has reasonably long flow paths (months to years) rather than subsurface flows with short flow paths of days to months as may occur in parafluvial groundwater.

DNRME (2018) reported that persistence modelling for waterholes indicated some of the Flinders River waterholes (i.e. Rocky Waterhole) appeared to be gaining from groundwater inputs, whilst others (i.e. Ten Mile Waterhole) appear to be seeping and losing water faster than the calculated evaporation potential.

The conclusion from these studies is that while groundwater may possibly be contributing to the hydrology of some waterholes, groundwater cannot be relied upon to sustain waterhole habitat.

4.1.3 Waterhole Characteristics

The Flinders River waterholes are characterised by high turbidity.

Lymeburner and Burrows (2009) examined the turbidity of waterholes in the southern Gulf catchment using remote sensing and reported that the waterholes of the Flinders River are generally 'always turbid' or 'usually turbid', with the exception of a small number of waterholes in the upper Flinders.

Waltham *et al.* (2013) undertook detailed studies of the waterholes of the Flinders and Gilbert River catchments and classified the waterholes of the Flinders River as 'Persistently turbid with highly ephemeral flow'. They reported that the waterholes in the Flinders River were generally more turbid than waterholes in the Gilbert catchment.

DNRME (2018) reported that waterholes in the Flinders River have higher turbidity and shallower euphotic depths than waterholes in the Mitchell River.

4.2 Riffles / Glides

No specific information is available regarding riffle habitat in the Flinders River. Photographs of the Flinders River show a sandy substrate and many written descriptions refer to a sandy bed. Glides rather than riffles are likely to form in a sandy bed when flow occurs. Some rock outcrops also occur (e.g. Rocky Waterhole). Riffle and/or glide habitat is present in all of the non-tidal reaches in the study area.

The Flinders River is subject to prolonged dry periods; therefore, riffle or glide habitat is temporary habitat. Riffle or glide habitat is important for providing connectivity along the river when flows occur. In general terms, riffles and glides provide habitat for lotic (flowing-water) species.

4.3 Hyporheos

The hyporheos is the region of subsurface water beneath the stream bed (Smith *et al.* 2006). It has been assumed that substantial hyporheic zones exist in the larger sand bed rivers of the Gulf Water Plan area, including the Flinders (Smith *et al.* 2006, Close *et al.* 2012 p. 60, 63). Smith *et al.* (2006) reported that 'Even in sand bed river stretches that do not have persistent hyporheic aquifers, temporary aquifers will persist for some time after the cessation of flow and persistence of surface waters' (Smith *et al.* 2006 p. 75).

The hyporheos may provide refuge for a range of aquatic organisms and support obligate hyporheic fauna (Smith *et al.* 2006, Ecowise Environmental 2007 cited in DES 2008). The literature review for this report identified a paper by Waltham (2016) on freshwater crabs in the Flinders River system that burrow into the channel margins to estivate during dry periods.

DNMRE (2018) reported that no local studies of hyporheic zone are known for any of the rivers in the Gulf Water Plan area and in general terms the hyporheic zone is poorly studied (DNRME 2018, p 58). There is insufficient information to establish the ecological and conservation significance of the hyporheos in the Flinders River or its sensitivity to flow alterations (Smith *et al.* 2006, p 75).

4.4 Riparian Zone

EHP (2015a) identified the Flinders River and its riparian zone as a ‘riparian corridor’ of ‘State significance’. EHP (2015a) noted that riparian corridors are significant for biodiversity, both as a climatic refuge and as a major element of habitat continuity.

Riparian zone habitat is highly dependent on riparian vegetation, which is discussed in Section 5.1.1, and is not separately discussed in this chapter.

4.5 Anabranching Channel System

An anabranching planform is an important characteristic of the geomorphology of the Flinders River and an important component of its riverine and floodplain habitat. Anabranching is apparent at multiple scales. Table 8 provides a reach-based summary of the anabranching characteristics of the Flinders River.

Twidale (1966) observed that the anabranching[10] occurs at two scales: 1) interwoven channels distributing floodways, and 2) anabranching channels formed by the subdivision of a single channel through the development of depositional islands, which are commonly steep-sided and well vegetated and rise high above the river bed. He noted that the second type is very common and occurs within the channels of the first type.

Examination of GoogleMaps imagery indicates at least three scales of anabranching, although in reality there is a continuum of scales:

1) subdivision of the main channel by instream islands (all reaches except the estuary)
2) multiple channels within the ‘meander belt’ of the Flinders River (all reaches except the estuary)
3) multiple interconnected meander belts (Reaches 4 and 5), which are interwoven with major tributaries including the Cloncurry River and Saxby River in Reach 5. In the estuary, the Flinders River divides into two major distributaries, the Flinders and the Bynoe.

As discussed in Chapter 2, a catchment-scale geomorphic classification of major rivers and streams in the Flinders River catchment was undertaken by Saynor *et al.* (2008) as part of the TRIAP. They reported that anabranching rivers are predominant, comprising 78% of the total channel length of the major streams in the Flinders River catchment. Saynor *et al.* (2008) reported that Reach 1 of the Flinders River is wandering, and the other reaches in the study area (except the estuary) are anabranching. They defined a ‘wandering river’ as an ‘intermediate form between meandering and braided rivers with islands and bars’. Anabranches are evident on the floodplain in this reach on GoogleMaps imagery.

Table 8 Summary of anabranching characteristics of the Flinders River

Reach	**Type of Anabranching**		
	Instream Islands	**Anabranching channels within ‘meander belt’**	**Anabranching meander belts**
Reach 1 – Flinders River Weir to Walkers Creek	X	X	
Reach 2 – Walkers Creek to Dutton River (Richmond)	X	X	

[10] Twidale (1966) used the term ‘braided’ to describe the anabranching channels, as the term ‘anabranching’ was not commonly used in geomorphology at the time he was writing

Reach	Type of Anabranching		
	Instream Islands	**Anabranching channels within 'meander belt'**	**Anabranching meander belts**
Reach 3 – Dutton River to Stawell River	X	X	
Reach 4 – Stawell River to Euroka Springs	X	X	X
Reach 5 – Euroka Springs to Tidal Limit	X	X	X The Flinders River meander belt is interwoven with meander belts of major tributaries including Cloncurry River and Saxby River
Reach 6 – Estuary (Tidal Limit to River Mouth)	NA	NA	The Flinders River bifurcates into two major distributaries, the Flinders and the Bynoe
Reach 7 – Southern Gulf of Carpentaria	NA	NA	NA

Channel-forming processes have not been specifically studied in the Flinders River, although there is literature on the geomorphology of other rivers on the Gulf Plains including the Gilbert and Mitchell (e.g. Nanson *et al.* 2005, Lane *et al.* 2016, Lane *et al.* 2017). Nanson *et al.* (2005) drew attention to the role of inherited landforms and induration of alluvium in relation to current fluvial geomorphological processes including the ongoing dynamics and development of the anabranching system of the Gilbert River.

DSITIA (2014) identified the 1.5-year daily flow volume as an indicator for assessing impacts of various scenarios on channel forming processes, with this flow approximating 'bankfull' discharge. This would apply to the main channel of the Flinders River and is broadly consistent with the frequency of overbank flooding indicated by flood analysis by Dutta *et al.* (2013). Larger flows would generally be associated with channel forming processes in secondary channels and very large floods with avulsions. Lane *et al.* (2016, 2017) reported that megafan avulsions on the Mitchell fan/delta have a frequency of >3/1000 years.

4.6 Floodplain and Wetlands

The Flinders River is bordered by floodplains in all reaches of the study area, with anabranching channels extending across the floodplain (as discussed in Section 4.5 above). The Queensland Government's Wetland Info database shows numerous floodplain wetlands on the Flinders River floodplain. The floodplains and wetlands provide habitat for many flora and fauna species. Wetlands of national significance are outlined in Section 4.6.1. DES (2018) also identified regionally significant wetland areas, including the Flinders River and floodplain near Richmond, Washpool Lagoon Complex (Reach 4) and Lower Flinders River Floodplain (Reaches 5 and 6).

An extensive study of flood inundation patterns and floodplain hydraulics was undertaken as part of the FGARA (Dutta *et al.* 2013). Due to the size of the study area, conventional high-accuracy flood modelling was not considered to be practical or feasible, and an alternative approach based on coarse-resolution two-dimensional modelling and remote sensing was adopted (Ticehurst *et al.* 2015).

Flood mapping by Dutta *et al.* (2013) shows the extent of areas subject to inundation in the Flinders River (Figure 11). The floodplain is relatively narrow in Reaches 1 to 3 (e.g. in the order of 2 to 5 km at Richmond) and situated within a defined valley.

Downstream of the Stawell River confluence, the Flinders River emerges onto a 'megafan' that extends across the Gulf Plains (Reaches 4 to 6). Floodwater spread out across a very broad area (tens of kilometres) and the anabranching channels of the Flinders River become intermingled with tributary channels in Reach 5, as discussed above in Section 4.5. During major floods, there is interconnection between catchments that are otherwise hydrologically isolated (Close *et al.* 2012, Zhao *et al.* 2017). This is illustrated by Figure 12, which shows the connection between the Flinders and Norman Rivers in the 1991 flood.

Biomaps wetland coverage identifies numerous riverine and palustrine wetlands on the Flinders River floodplain, transitioning to extensive estuarine wetlands near the GoC. There are three wetlands listed in the Directory of Important Wetlands in Australia, which are discussed separately in 4.6.1.

The Flinders River floodplain is subject to frequent inundation in the wet season. This is illustrated by time series plots of water levels in relation to thresholds for minor, moderate and major flooding (Figure 13). Flood extents and the duration of inundation are variable, e.g. as shown in Figure 14. Floodplain wetlands require high overbank flows for connectivity (DNRME 2018).

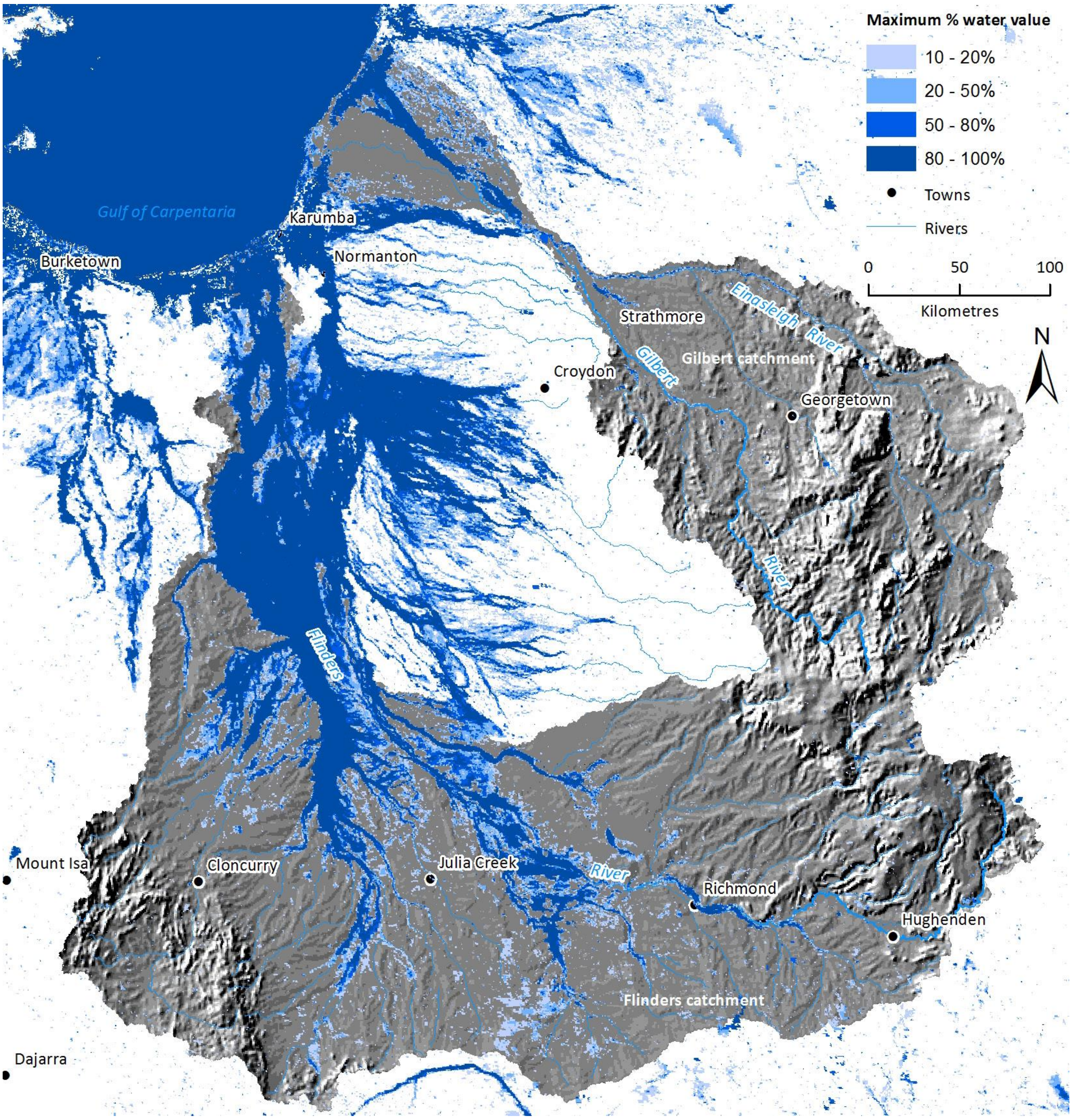

Figure 11 Flood map based on remote-sensed flood extents from 2000, 2001, 2004, 2008, 2009, 2010 and 2011 (From Dutta et al. 2013)

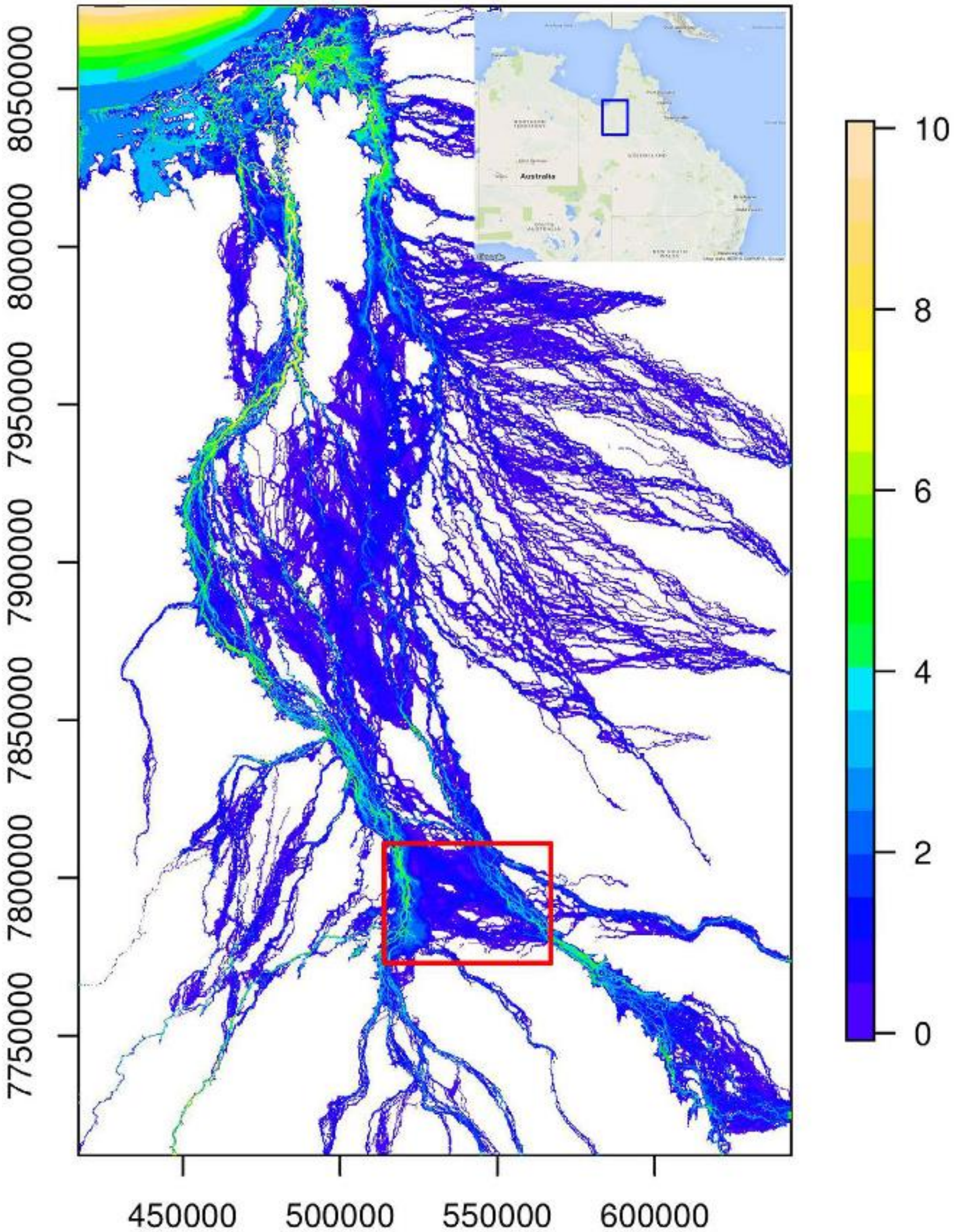

Figure 12 Modelled flood extent map for the 1991 flood for the Flinders and Norman Rivers (Source: Zhao et al. 2017)

Figure 13 Daily water levels at Richmond (915008A) (top) and Walker's Bend (915003A) (bottom) in the Flinders catchment highlighting the period of the minor (green line), moderate (yellow line) and major (red line) flooding as classified by the Bureau of Meteorology (From Dutta et al. 2013)

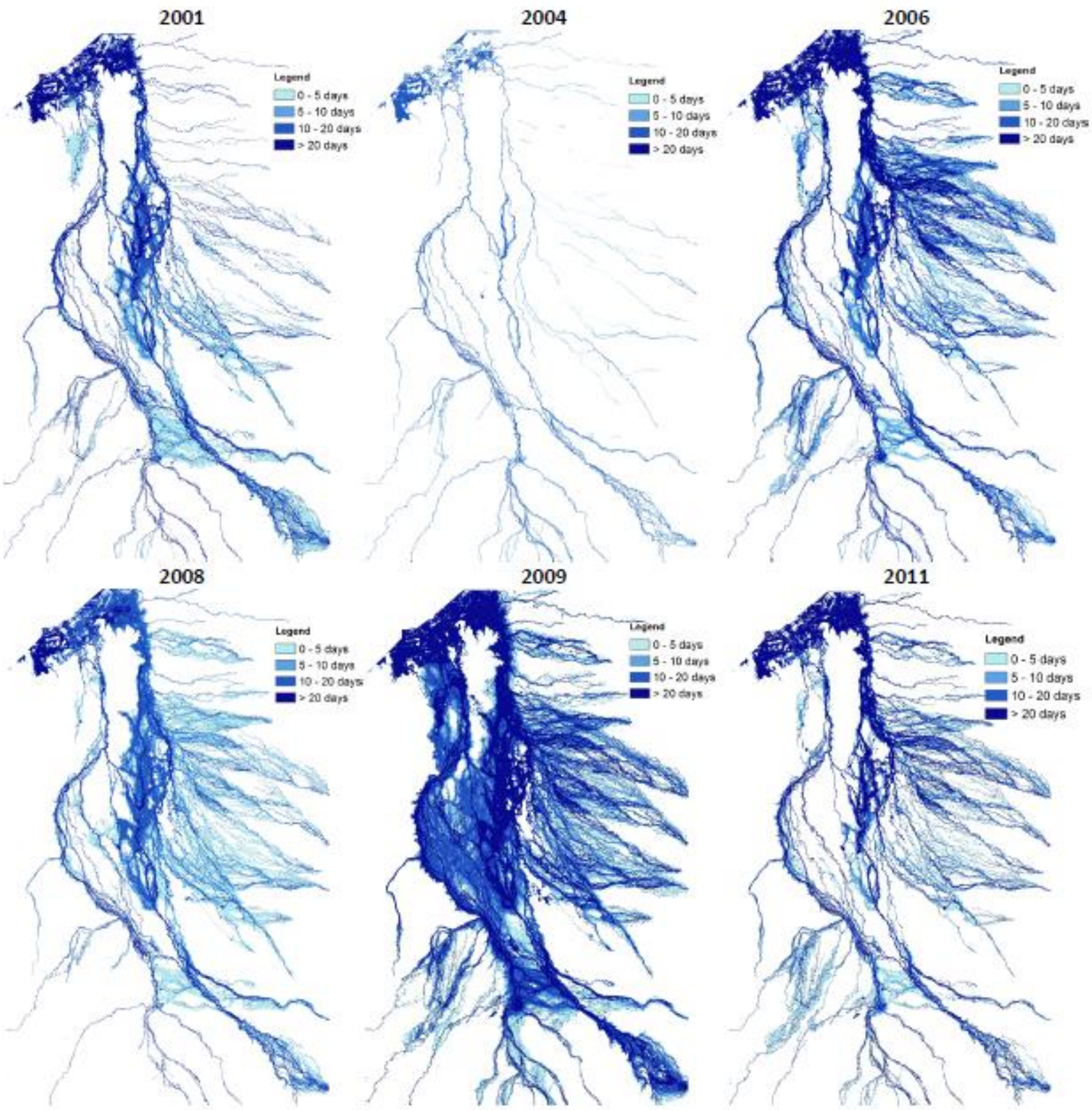

Figure 14 Extent and duration of inundation as shown in flood simulations (from Dutta et al. 2013)

4.6.1 Wetlands of National Significance

There are three wetlands listed in the Directory of Important Wetlands in the Flinders River catchment, and all have been identified as 'flow-related ecological assets' by DNRME (2018) (Table 9). The Southern Gulf Aggregation is considered to be particularly important because it meets all six criteria for inclusion in the Directory of Important Wetlands (DNRME 2018).

The Southern Gulf Aggregation and Stranded Fish Lake are associated with Reach 6 of the Flinders River. Lignum Swamp is situated in the Cloncurry River catchment, upstream of the first junction of the Cloncurry River with the Flinders River (via Caroline Creek) in Reach 5.

Table 9 Wetlands listed in the Directory of Important Wetlands in Australia

Wetland Name	Wetland Type[11]	Hydrology[12]	Connectivity to Flinders River
Southern Gulf Aggregation	Marine and coastal zone wetlands (A1, A2, A5, A10, A7, A8, A9, A6)	A large wetland subject to regular inundation by marine and estuarine tidal waters, and wet season flooding from rivers and streams from the inland catchment, combined with local runoff.	Dutta *et al.* (2013) reported that the Southern Gulf Aggregation is an onstream wetland complex situated directly adjacent to the Flinders River
Stranded Fish Lake	Marine and coastal zone wetlands (A10)	'The catchment of the lake is purely local. Tidal waters may enter the depression during the highest astronomical tides'.	Dutta *et al.* (2013) reported that Stranded Fish Lake is 5.7 km from the Flinders River. They estimated of connectivity (number of days) to streams in the Flinders floodplain for the flood events of 2001 (20 days), 2009 (27.5 days) and 2011 (25.3 days)
Lignum Swamp	Inland Wetlands (B2, B13, B10, B9)	'The swamp is formed in an impeded drainage depression below the junction of Lake and Rosie creeks. … Water supply: principally stream flow from Lake and Rosie creeks, as well as local seasonal runoff and seepage.'	Dutta *et al.* (2013) reported that Lignum Swamp is associated with the Cloncurry River. They estimated of connectivity (number of days) to streams in the Flinders floodplain for the flood events of 2001 (2 days), 2009 (13 days) and 2011 (4.3 days). Aerial imagery indicates that Lignum Swamp is situated near the Cloncurry River approximately 25 km (in a straight- line distance) from its first 'confluence' with the Flinders River (via Caroline Creek)

4.7 Connectivity

The Gulf Water Plan environmental outcomes put significant emphasis on connectivity. Currently the Flinders River in the study retains a high of natural connectivity. There are no major dams or weirs to significantly impede sediment transport or movement of biota, including fish passage. The flow regime has undergone relatively minor change from pre-development and floodplains remain extensively engaged.

Several local ecological studies have drawn attention to the importance of connectivity for specific biota. Leigh and Sheldon (2009) investigated patterns of macroinvertebrate biodiversity in the Gregory and Flinders Rivers and found that hydrological connectivity was the most important factor affecting macroinvertebrate community composition and diversity in these rivers. Many of the fish

[11] Details of subcategories in 'Directory of Important Wetlands in Australia', http://www.environment.gov.au/node/25064#diwa-classification, viewed 30 November 2019.
[12] From Directory of Important Wetlands Information Sheets

species present in the Flinders River are migratory species. Waltham *et al.* (2013) attributed the distribution of the freshwater sawfish *Pristis pristis* along the Flinders River to considerable distances inland to the existing connectivity along the river and absence of significant fish passage barriers.

5 Vegetation and Fauna

This chapter describes the vegetation and fauna of the study area based on a review of previous reports and regional ecosystem (RE) mapping. The conservation significance of flora and fauna species is identified based on statutory listings under the *Environmental Protection and Biodiversity Conservation Act 1999 (Cth)* (EPBC Act) and *Nature Conservation Act 1992 (Qld)* (NC Act). The biodiversity status of regional ecosystems (REs) is based on the *Vegetation Management Regulation 2012* (*Qld)*.

5.1 Vegetation

5.1.1 Riparian Zone and Floodplain Vegetation

DNRME (2018) identified four 'flow-related ecological assets' for the Flinders River relating to riparian zone and floodplain vegetation:

- Riparian vegetation (in general)
- Floodplain wetlands (in general), and
- Two tree species, River redgum (*Eucalyptus camaldulensis)* and Coolabah *(Eucalyptus coolabah)*

5.1.1.1 Regional Ecosystems (REs)

The vegetation across the entire study area, including riparian zones and wetlands, has been mapped as part of the Queensland Herbarium's statewide regional ecosystem (RE) mapping at a scale of 1:100,000 (Neldner *et al.* 2019).

Table 10 provides a summary of key vegetation values associated with REs in each reach. It is based on two main sources:

- Smith et al.'s (2006) summary of the flow-dependent REs in various reaches of the Flinders River
- Current RE mapping available in Biomaps[13].

Biomaps was used to confirm the presence and distribution of 'endangered' and 'of concern' flow-related REs associated with each of the river reaches defined for this study. This was necessary for several reasons, including updates to the RE mapping since the completion of Smith et al.'s (2006) report and differences between the reach subdivision used in this study and Smith et al.'s (2006) reach subdivision. Two coverage layers were used:

- Broad vegetation groups (BVGs) remnant REs[14] – to identify flow-related REs (Appendix A)
- Biodiversity status of remnant REs[15] – to determine the conservation status of flow-related REs (Appendix B).

The BVGs remnant REs mapping (Appendix A) shows that:

- 'Eucalypt open forests to woodland on floodplains' (BVG 16-16d) occurs extensively along the Flinders River and floodplain between the Project area and Stawell River

[13] http://qldspatial.information.qld.gov.au/biomaps/
[14] Queensland Herbarium (2015) Remnant 2013 Broad Vegetation Groups of Queensland, Version 2.0 (April 2015) (Department of Science, Information Technology and Innovation: Brisbane)
[15] Queensland Herbarium (2015) Biodiversity Status of 2013 Remnant Regional Ecosystems of Queensland, Version 9.0 (April 2015) (Department of Science, Information Technology and Innovation: Brisbane)

- The floodplain vegetation downstream of the Stawell River includes ‘Eucalypt open forests to woodland on floodplains’ (BVG 16-16d) and ‘Tussock grasslands and forblands’ (BVG 30-32b). This general vegetation pattern continues downstream to the estuary
- At the lower end of the estuary, there is ‘Mangrove and saltmarsh’ (BVG 35-35b) with ‘Other coastal communities or heaths’ (BVG 28-29b) on ridges parallel to the coast

Table 10 and Appendix B show that:

- Flow-dependent REs are present along all of the reaches of the study area
- There are no ‘endangered’ flow-dependent REs in the study area
- RE 9.8.6 ‘*Acacia cambagei* low open forest on scree slopes and footslopes of basalt tablelands’ (‘of concern’) abuts the river channel in parts of Reaches 1 and 2. This RE is associated with basalt tablelands rather than rivers and does not appear to be flow-dependent
- ‘Of concern’ flow-dependent REs occur extensively in the lower part of Reach 3, throughout Reaches 4 and 5, and the upper and middle sections of Reach 6

In addition to values indicated by conservation status, riparian vegetation also has broader values in relation to the function of riverine ecosystems (e.g. food, shelter and physical structure).

Table 10 Flow-related REs associated with the Flinders River and floodplain (based on Smith et al. 2006 and Biomaps 'Remnant REs' mapping

Reach	Smith *et al.* (2006) Regional Ecosystems					'Endangered' and 'Of Concern' REs mapped from Biomaps
	Instream and fringing ecosystems including pools, waterholes, and riparian woodlands and forests	Fringing woodlands on alluvial levees, terraces and floodplains	Fringing woodlands incorporating seasonal and permanent wetland features.	Grasslands on alluvial plains and drainage lines.	Coastal ecosystems including seasonally inundated grassy plains, estuaries, and intertidal flats	
Reach 1 – Flinders River Weir to Walkers Creek	• Fringing woodland of River Red Gum, Coolibah on larger watercourses (RE 4.3.1; 4.3.2; 4.3.3) ('least concern')	• Coolibah woodland and open woodland ecosystems on terraces and alluvial plains (RE 4.3.4) 'least concern' • Acacia woodlands (Gidgee, Boree) on braided channels or alluvial plains (RE 4.3.8; 4.3.20a) 'least concern'	• NA	• Grasslands on alluvium and drainage lines (RE 4.3.14; 4.3.19) 'least concern'	• NA	• No 'endangered' REs • RE 9.8.6 'Acacia cambagei low open forest on scree slopes and footslopes of basalt tablelands' ('of concern') abuts the river channel in parts of the reach
Reach 2 – Walkers Creek to Dutton River (Richmond)	• As above	• As above	• NA	• As above	• NA	• No 'endangered' REs • RE 9.8.6 'Acacia cambagei low open forest on scree slopes and footslopes of basalt tablelands' ('of concern') abuts the river channel in parts of the reach
Reach 3 – Dutton River to Stawell River	• As above	• As above	• NA	• As above	• NA	• No 'endangered' REs • 'Of concern' RE 2.3.26b 'Eucalyptus camaldulensis +/- Melaleuca spp. woodland fringing sandy, seasonal channels' occurs in the lower part of reach
Reach 4 – Stawell River to Euroka Springs	• Fringing forest including River Red Gum, Coolibah, Leichhardt Tree, Melaleuca on major channels (RE	• Frontage woodlands on alluvial plains, levees and in-filled prior stream channels (RE 2.3.25), 'least	• Coolibah and Gutta-percha woodland on alluvium and tertiary surfaces including depressions and	• Grasslands on alluvium and drainage lines (RE 2.3.3; 2.3.4, 'least concern')	• NA	• No 'endangered' REs evident from reach-scale mapping • 'Of concern' REs are dominant and

Reach	Smith *et al.* (2006) Regional Ecosystems					'Endangered' and 'Of Concern' REs mapped from Biomaps
	Instream and fringing ecosystems including pools, waterholes, and riparian woodlands and forests	Fringing woodlands on alluvial levees, terraces and floodplains	Fringing woodlands incorporating seasonal and permanent wetland features.	Grasslands on alluvial plains and drainage lines.	Coastal ecosystems including seasonally inundated grassy plains, estuaries, and intertidal flats	
	2.3.17) 'least concern'	concern' • Acacia woodlands (Gidgee) on braided channels or alluvial plains (RE 2.3.7) 'least concern'	lagoons that are seasonally inundated (RE 2.3.11, 'least concern'; 2.3.13, 'of concern')			subdominant in parts of the riparian zone and floodplain
Reach 5 – Euroka Springs to Tidal Limit	• Fringing forest including River Red Gum, Coolibah, Leichhardt Tree, Melaleuca on major channels (RE 2.3.17, 'least; 2.3.26, 'of concern')	• Frontage woodlands on alluvial plains, levees and in-filled prior stream channels (RE 2.3.9; 2.3.25; 2.3.20, 'least concern') • Acacia woodlands (Gidgee) on braided channels or alluvial plains (RE 2.3.7, 'least concern').	• Coolibah and Gutta-percha woodland on alluvium and tertiary surfaces including depressions and lagoons that are seasonally inundated (RE 2.3.11, 'least concern'; 2.3.12, 'of concern'; 2.3.13, 'of concern')	• As above	• NA	• No 'endangered' REs evident from reach-scale mapping • 'Of concern' REs are dominant and subdominant in parts of the riparian zone and floodplain
Reach 6 – Estuary (Tidal Limit to River Mouth)	• NA	• NA	• NA	• NA	• Seasonally inundated (predominantly freshwater) low-lying grassland plains that become wetlands (RE 2.3.1 *'least concern'*). • Remnants of prior river channels within low-lying plains subject to seasonal inundation by fresh and saline waters (RE 2.3.2 *'of concern'*) • Low coastal rises subject to tidal inundation (RE 2.1.2 *'least concern'*) • Predominantly unvegetated saline clay plains that are periodically inundated (RE 2.1.4, *'least*	• No 'endangered' REs evident from reach-scale mapping • 'Of concern' REs are dominant and subdominant in parts of the riparian zone and floodplain

Reach	Smith *et al.* (2006) Regional Ecosystems					'Endangered' and 'Of Concern' REs mapped from Biomaps
	Instream and fringing ecosystems including pools, waterholes, and riparian woodlands and forests	Fringing woodlands on alluvial levees, terraces and floodplains	Fringing woodlands incorporating seasonal and permanent wetland features.	Grasslands on alluvial plains and drainage lines.	Coastal ecosystems including seasonally inundated grassy plains, estuaries, and intertidal flats	
					concern'). • Margins and levees of estuary channels (RE 2.1.3 *'least concern'*) • Offshore tidal flats (RE 2.1.least *concern'*)	

5.1.1.2 Species

River redgums and Coolabahs occur extensively in all of the reaches of the study area (Smith *et al.* 2006, DES 2018).

A catchment-scale species level assessment of riparian vegetation was undertaken by Dowe (2008). He undertook an assessment of the distribution and ecological preferences of riparian vegetation across the TRIAP project area in northern Australia, including a detailed assessment of the Flinders River catchment as one of three focus catchments. He reported a total of 264 plant species occurring in the riparian zone in the three focus catchments of the TRIAP study area (Flinders, Daly and Fitzroy River catchments), categorised as follows:

- 23 obligate riparian species (i.e. occurring in no other habitats except the riparian zone)
- 126 facultative riparian species (occurring in the riparian zone and also in non-riparian habitats)
- 84 freshwater aquatic species
- 28 mangrove species

A total of 22 of the 23 obligate riparian plant species identified by Dowe (2008) are reported to have been recorded in the Flinders River catchment (21/23 by Dowe (2008) plus *Sesbania erubescens* reported by Smith *et al.* 2006). Table 11 lists the 22 obligate-riparian species for the Flinders River catchment. None of these species is listed under the EPBC Act and all have a conservation status of 'least concern' under the NC Act. A conservation status of 'least concern' under the NC Act applies to Australian indigenous plant species that are not extinct in the wild, endangered or near threatened.[16] Dowe (2008) focused on widespread species to examine spatial distributions across the TRIAP catchments and did not investigate the distribution of rare or restricted riparian species.

Dowe (2008) highlighted the relatively small number of obligate riparian species. He concluded that rivers in seasonally dry tropical Australia are characterised by a low level of species diversity, but a high level of individual species coverage.

Table 11 Obligate riparian plant species identified as occurring in the Flinders River system by Dowe (2008) and Smith et al. (2006).

Family	Species	Common Name	Status – NC Act	Status – EPBC Act
Arecac.	*Livistona rigida*	Mataranka palm	LC	
Casuarin.	*Casuarina cunninghamiana*	River oak	LC	
Cyper.	*Cyperus difformis*	Rice Sedge, Dirty Dora	LC	
Euphorb.	*Flueggea virosa*		LC	
Fab.	*Aeschynomene indica*	Budda Pea	LC	
Fab.	*Sesbania cannabina*	Sesbania Pea, Yellow Pea-bush	LC	
Fab.	*Sesbania erubescens*		LC[17]	
Gooden.	*Goodenia strangfordii*		LC	
Myrt.	*Asteromyrtus symphyocarpa*	Liniment tree	LC	
Myrt.	*Corymbia bella*	Ghost gum	LC	
Myrt.	*Eucalyptus camaldulensis*	River redgum	LC	
Myrt.	*Lophostemon grandiflorus*		LC	
Myrt.	*Melaleuca argentea*	Silver-leafed paperbark	LC	
Myrt.	*Melaleuca bracteata*	River tea-tree	LC	

[16] Nature Conservation (Wildlife) Regulation 2006 (Qld) Schedule 6

[17] Smith *et al.* (2006) reported that *S. erubescens* was 'rare' under the NC Act, but its present status under the NC Act is 'LC'

Family	Species	Common Name	Status – NC Act	Status – EPBC Act
Myrt.	*Melaleuca fluviatilis*		LC	
Myrt.	*Melaleuca stenostachya*		LC	
Myrt.	*Melaleuca trichostachya*		LC	
Myrt.	*Melaleuca leucadendra*	Weeping paperbark	LC	
Poa.	*Chrysopogon oblongatus*		LC	
Polygon.	*Persicaria attenuata*	Velvet knotweed	LC	
Euphorb.	*Calycopeplus casuarinoides*		LC	
Mimos.	*Cathormion umbellatum*		LC	

NC Act Status: E = endangered, V = vulnerable, NT = near threatened, LC = least concern.

EPBC Act Status: Ex = extinct, CE = critically endangered, E = endangered, V = vulnerable.

DES (2018) identified 465 wetland indicator species relevant to the riverine and non-riverine wetlands of the EGoC catchments. They used a broad definition of 'wetland indicator species' which included submerged and floating aquatic plants as well as riparian species found in littoral zone or the toe of the bank. The list included riparian species such as Eucalypts (River redgums and Coolabahs) and Melaleucas. They identified 10 species of conservation significance relevant to the riverine and non-riverine wetlands of EGoC region (Table 12). Further investigations would be necessary to determine if any of the species listed in Table 12 occur within the present study area.

Table 12 Aquatic dependent near threatened and threatened flora taxa for the EGoC region (Based on DES 2018)

Scientific Name	Common Name	Status – NC Act	Status – EPBC Act
Riverine Species			
Caesalpinia hymenocarpa		NT	
Dichanthium setosum	Bluegrass	LC	V
Elaphoglossum callifolium		NT	
Non-Riverine Species			
Eriocaulon carsonii	Salt Pipewort, Button Grass	E	E
Eriocaulon carsonii subsp. *orientale*	Salt Pipewort, Button Grass	E	E
Fimbristylis carolinii		NT	
Fimbristylis micans		V	
Myrmecodia beccarii	Ant Plant	V	V
Stylidium elachophyllum	trigger plant	E	
Stylidium trichopodum		NT	

NC Act Status: E = endangered, V = vulnerable, NT = near threatened, LC = least concern.

EPBC Act Status: Ex = extinct, CE = critically endangered, E = endangered, V = vulnerable.

5.1.2 Aquatic Vegetation

As discussed above in Chapter 4, the instream habitats of the Flinders River consist of waterholes and dry riverbed/temporary river. There is limited information available on the aquatic vegetation of the EGoC region apart from the regional overview by DES (2018), who noted significant differences in aquatic vegetation between catchments within the EGoC region.

All the available information indicates that there is little aquatic vegetation in the Flinders River due to high turbidity and hydrologic constraints (ephemeral flow regime coupled with high rates of evapotranspiration) (Close *et al.* 2012). The high turbidity makes conditions unfavourable for submerged macrophytes (Waltham *et al.* 2013). DNRME (2018) did not identify any 'flow-related ecological assets' based on aquatic vegetation for the Flinders River catchment.

The dry riverbeds are potentially susceptible to aquatic weed invasion if flows were to become more permanent (Waltham *et al.* 2013).

5.2 Macroinvertebrates

Knowledge of the macroinvertebrate fauna of the EGoC region is limited compared to the vertebrate fauna (DES 2018). The macroinvertebrate fauna associated with the Flinders River has been studied from three perspectives:

- Aquatic macroinvertebrate communities
- Terrestrial invertebrate communities
- Freshwater crabs

Data on aquatic macroinvertebrate communities has been collected by the Queensland government through the AUSRIVAS program, which included sites in the Flinders River catchment (Humphrey *et al.* 2008). No published analysis of this data in relation to the macroinvertebrate fauna of the Flinders River was found. Humphrey *et al.* (2008) set out to analyse existing species-level macroinvertebrate data for northern Australia (including the Flinders River catchment) but found that it would be impractical to extract and compile these data because of the enormity of the task (involving thousands of species) and issues associated with data custodianship and ownership.

Waltham *et al.* (2013) aimed to generate a comprehensive list of aquatic species known from the Flinders and Gilbert River catchments. With regard to aquatic macroinvertebrates, they undertook surveys at investigation pools, for three different habitat types – bank edges, pool bottom and macrophytes (where available). They recorded 50 macroinvertebrate taxa in the Flinders catchment, dominated by the families Cladocera (water fleas - 22%), Ostracoda (seed shrimp - 17%) and Corixidae (water boatmen- 13%). The assemblage composition reflected the high turbidity of the Flinders catchment waterholes.

The dry riverbeds of ephemeral streams provide habitat for terrestrial invertebrates. Surveys have been undertaken in the Flinders River, which show a diverse terrestrial invertebrate assemblage dominated by ants (Formicidae) and beetles (Coleoptera) (Steward *et al.* 2011).

Freshwater crabs occur in the Flinders River catchment. DES (2018) identified 5 species of freshwater crab that are 'priority' species for the EGoC region, which includes Flinders River. Waltham (2016) undertook a detailed study of the Inland Freshwater Crab, *Austrothelphusa transversa*, which has adapted to the ephemeral flow regime of the Flinders River system by burrowing into the channel sides during dry periods (Waltham 2016).

DNRME (2018) identified one macroinvertebrate species as a 'flow-related ecological asset' for the Flinders River, *Macrobrachium rosenbergii, the* Mitchell prawn or cherabin. No information about the distribution of this species within the Flinders River system could be found.

5.3 Fish

There have been a number of previous studies and reports relating to freshwater fish in the Flinders River (including Hogan and Vallance 2005 and Waltham *et al.* 2013).

DES (2018) identified 102 native fish species relevant to the riverine and non-riverine wetlands of EGOC region. Waltham *et al.* (2013) assembled a list of the fish species that have been recorded in the Flinders River catchment, based on data collected during their study as well as published literature, museum records and expert local knowledge. They reported a total of 50 freshwater fish species recorded from the Flinders River catchment. DNRME (2018) identified 27 fish species as 'flow-related ecological assets' for the Flinders River (or 26 fish species if a suspected duplication is removed from their list). Several of the fish species identified by DNRME (2018) as 'flow-related ecological assets' are not in the fish species list reported by Waltham *et al.* (2013), including *Ambassis agrammus* and *Melanotaenia splendida splendida.* This is likely to reflect the results of additional fish surveys undertaken since 2013.

Table 13 presents a list of freshwater fish species for the Flinders River based on Waltham *et al.* (2013) and DNRME (2018). The distributions of the various fish species within the Flinders River catchment are not sufficiently well known to assign species to particular reaches of the Flinders River.

Waltham *et al.* (2013) noted that the assemblage of fish communities in the Flinders River reflected the high turbidity of the river and was different to the nearby Gilbert River where the waterholes were relatively clear. For example, Sooty grunter was rare in the Flinders catchment but common in the Gilbert. Many more fish were recorded in surveys in the Gilbert than the Flinders (Waltham *et al.* 2013).

None of the fish species in Table 13 is listed under the NC Act (Nature Conservation (Wildlife) Regulation 2006 (Qld)). One of the freshwater fish species recorded in the Flinders River, the freshwater sawfish, *Pristis pristis,* is listed as 'vulnerable' and migratory under the EPBC Act. It is also protected under Queensland law under the *Fisheries Act 1994* (*Fisheries Regulation 2008*) (EHP 2015b).

Waltham *et al.* (2013) also draw attention to the giant freshwater whipray, *Himantura dalyensis* as a species of conservation significance. They noted that *H. dalyensis* was formerly known as *H. chaophraya,* which is listed as 'endangered' on the IUCN Red List (Waltham *et al.* 2013) but has recently been recognised as a separate species. DES (2018) reported that *H. dalyensis* is one of only three or four obligate freshwater elasmobranchii (a class of cartilaginous fishes) and the only freshwater stingray in Australia. The GoC region is its stronghold. It is listed as 'least concern' on the IUCN Red List (Kyne 2016) but has no special conservation status under the EPBC Act or NC Act.

Waltham *et al.* (2013) mapped captures or sightings of *P. pristis* and *H. dayleynsis* (Figure 15). They stressed that this map was based on limited information and that dedicated studies targeting these species would be required to confirm their distribution. Despite this limitation, it is evident that *P. pristis* occurs throughout the entire study area. *H. dayleynsis* appears to be associated with the lower reaches of the Flinders River system, on the Gulf Plains.

DES (2018) reported that several fish species are endemic to the EGoC region, including the Gulf Grunter and Gilbert's Grunter. They also drew attention to the Flinders River catfish, which is potentially an undescribed endemic taxon.

Longitudinal connectivity along the Flinders River is important for its fish fauna, because migratory species represent a significant proportion of the freshwater fish fauna of the Flinders River catchments (DERME 2018). Tagged Barramundi *Lates calcarifer* have been recorded traversing 360 km of Flinders River in less than a year (Hogan and Vallance 2005). *P. pristis* is a migratory species.

DES (2018) reported that the EGoC region is largely free of exotic fish. *Gambusia holbrooki* (mosquitofish) occur in the Flinders River system (Table 13) but are not common (Waltham *et al.* 2013).

Table 13 Freshwater fish species recorded in the Flinders River (based on Waltham et al. 2013 and DNRME 2018)

Scientific Name	Common Name	Waltham *et al.* 2013	Ecological asset - DNRME 2018	Asset Guild (DNRME 2018)	Status – NC Act	Status – EPBC Act
Ambassis agrammus	Sailfin glassfish	(Gilbert only)	x	Stable flow spawning fish		
Ambassis macleayi	Macleay's glassfish, reticulated perchlet	x	x	Stable flow spawning fish		
Amniataba percoides	Barred grunter	x	x	Migratory fish		
Anodontiglanis dahli	Toothless catfish	x				
Arrhamphus sclerolepis	Snub-nosed garfish	x				
Brachirus salinarum	Saltpan sole	x				
Brachirus selheimi	Freshwater sole	x				
Butis butis	Crimson-tipped flathead gudgeon	x				
Cinetodus froggatti	Small-mouthed catfish	x				
Clupeoides cf. papuensis	Papuan river sprat	x				
Chlamydogobius ranunculus	Tadpole goby	x				
Gambusia holbrooki	Mosquitofish	x		Exotic species		
Glossamia aprion	Mouth almighty	x	x	Stable flow spawning fish		
Glossogobius aureus	Golden goby	x				
Glossogobius giuris	Flathead goby	x				
Glossogobius sp. C	Square-blotched goby	x				
Hephaestus fuliginosus	Ssooty grunter, black bream	x	x	Perennial flow and wet season spawner guild		
Himantura daylensis[18]	Freshwater whipray	x	x	Migratory fish		
Kurtus gulliveri	Nursery fish	x				
Lates calcarifer	Barramundi	x	x	Migratory fish		
Leiopotherapon unicolor	Spangled perch	x	x	Migratory fish		
Liza ordensis	Diamond mullet	x				
Megalops cyprinoides	Oxeye herring / Tarpon	x	x	Migratory fish		
Melanotaenia splendida inornata	Chequered rainbowfish	x	x	Stable flow spawning fish		
Melanotaenia splendida	Eastern rainbowfish	(not in list)	x	Stable flow spawning fish		
Mogurnda mogurnda	Northern trout gudgeon	x	x	Stable flow spawning fish		
Nematalosa erebi	Bony bream	x	x	Migratory fish		
Neoarius berneyi	Berney's catfish	x	y	Migratory fish		
Neoarius graeffei	Fork-tailed Catfish, blue catfish	x	y	Migratory fish		

[18] Formerly known as *Himantura chaophyra* (Kyne 2016)

Scientific Name	Common Name	Waltham *et al.* 2013	Ecological asset - DNRME 2018	Asset Guild (DNRME 2018)	Status – NC Act	Status – EPBC Act
Neoarius paucus	Carpentaria catfish	x				
Neoarius midgleyi	Silver cobbler	x				
Neosilurus ater	Black tandan, butter jew, narrow-fronted tandan, black catfish	x	x	Migratory fish		
Neosilurus graeffei[19]	Blue or salmon catfish		x	Migratory fish		
Neosilurus hyrtlii	Hyrtl's tandan	x	x	Migratory fish		
Oxyeleotris lineolatus	Sleepy cod	x	x	High flow spawning fish		
Oxyeleotris selheimi	Striped sleepy cod, giant or blackbanded gudgeon	x	x	High flow spawning fish		
Parambassis gulliveri	Giant glassfish	x	x	Stable flow spawning fish		
Pingalla gilberti	Gilbert's grunter	x	x	Wetland dependent fish		
Porochilus argenteus	Silver tandan	x				
Porochilus sp.	Catfish Un Id.	x				
Porochilus rendahli	Rendahl's catfish	x	x	Migratory fish		
Prionobutis microps	Small-eyed sleeper	x				
Pristis pristis	Freshwater sawfish	x	x	Migratory fish		V, Migratory
Pseudogobius sp.	Goby	x				
Redigobius bikolanus	Speckled goby					
Sciades leptaspis	Lesser salmon	x				
Scortum ogilbyi	Gulf grunter	x	x	Fish		
Strongylura kreffti	Freshwater longtom	x	x	Migratory fish		
Thryssa scratchleyi	Freshwater anchovy	x				
Toxotes chatareus	Seven-spot archerfish	x	x	Migratory fish		
Zenarchopterus spp.	River garfish	x				

NC Act Status: E = endangered, V = vulnerable, NT = near threatened, LC = least concern.

EPBC Act Status: Ex = extinct, CE = critically endangered, E = endangered, V = vulnerable.

[19] This is likely to be a duplication of *Neoarius graeffei*. Both are listed by DNRME (2018) as 'blue or salmon catfish'.

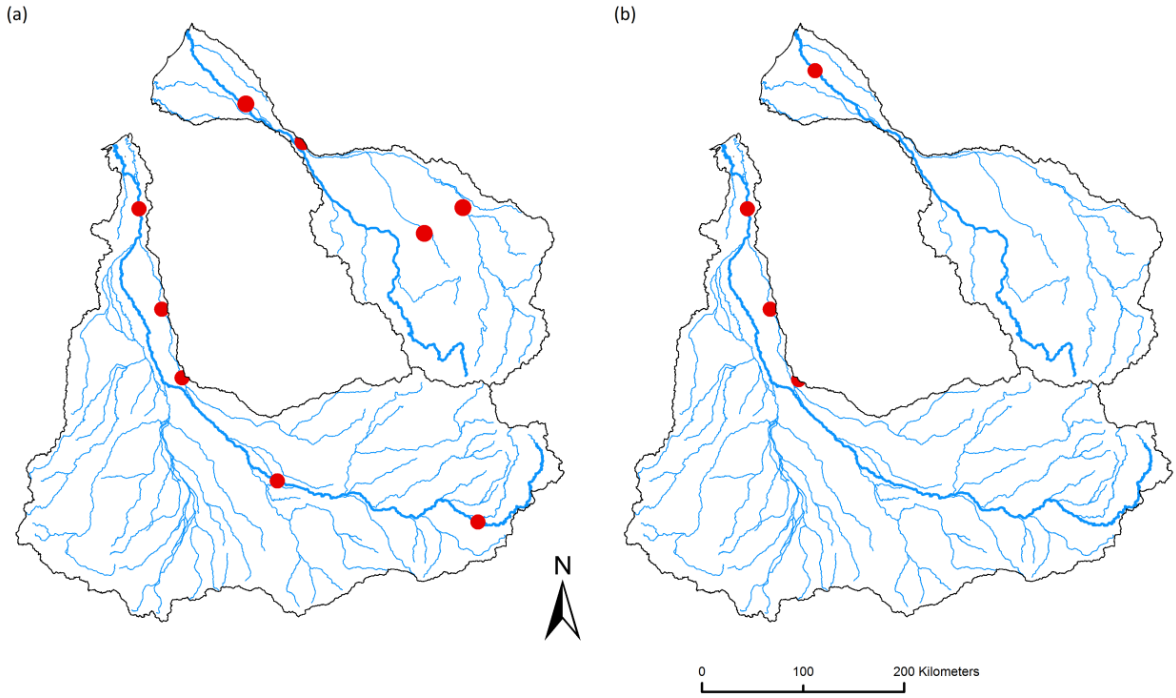

Figure 15 Captures or sightings of (a) freshwater sawfish (Pristis pristis); b) freshwater whipray (Himantura dalyensis) (Source: Waltham et al. 2013)

5.4 Other Vertebrates

The other vertebrate fauna of the Flinders River includes amphibians, reptiles, birds and mammals. Previous studies provide information at a regional or catchment scale. Key studies have included:

- TRIAP – provided lists of reptiles and waterbirds across the TRIAP study area, which extended across northern Queensland, northern Territory and northern WA, and included the Flinders River catchment as a focus catchment
- Waltham *et al.* (2013) – provided a list of amphibian species associated with the Flinders Rivers
- DES (2018) – provided lists of aquatic-dependent fauna across the EGoC region but did not provide details of the distribution of these species in particular river systems or reaches.

The patchiness of fauna records in the Flinders River catchment was noted in previous studies (Fox 2008, Franklin 2008, EHP 2015b). Further investigations would be required to determine the other vertebrate fauna species relevant to each reach. Such investigations would include compilation and analysis of fauna records, extrapolations based on habitat suitability, and potentially surveys and monitoring of key species or groups.

5.4.1 Amphibians

The amphibian species associated with the Flinders River include frogs and toads. Smith *et al.* (2016) noted that frogs associated with the river systems in the Gulf Water Plan area are reliant on temporary waterholes and floodplain wetlands for habitat. They drew attention to important frog breeding habitat associated with the Flinders River downstream of the Stawell River. However, they did not provide any specific information about the amphibian species associated with the Flinders River.

Waltham *et al.* (2013) identified thirty species of native frogs and toads that have been recorded in the Flinders River catchment (Table 14 Instream frog species recorded from the Flinders catchment (From Waltham et al. 2013) and noted that several other species may also be present because the Flinders River catchment falls within their range (Waltham *et al.* 2013). Many are common along watercourses but can also breed and survive in other types of waterbodies (Waltham *et al.* 2013). Burrowing frogs are generally restricted to areas with sandy substrates (Waltham *et al.* 2013). The exotic cane toad (*Rhinella marina*) is widespread in the Flinders River catchment (Waltham *et al.* 2013). The native frog and toad species identified by Waltham *et al.* (2013) are not listed under the EPBC Act and all have a conservation status of 'least concern' under the NC Act (*Nature Conservation (Wildlife) Regulation 2006 (Qld*)).

DES (2018) identified 57 aquatic-dependent native amphibian species relevant to riverine and non-riverine wetlands in the EGoC catchments. A number of these species have high conservation significance, including 8 species listed under both the NC Act and EPBC Act, one species listed under the NC Act, and two other species that are not listed as rare/threatened but are largely restricted to the EGoC catchments. The regional list reported by DES (2018) includes some species that appear unlikely to occur in the Flinders River study area reaches, such as the waterfall frog.

DNRME (2018) did not identify any amphibian species as 'flow-related ecological assets' for the Flinders River.

Table 14 Instream frog species recorded from the Flinders catchment (From Waltham et al. 2013)

Family	**Common Name**	**Species**	**Status – NC Act**	**Status – EPBC Act**
Hylidae	Greenstripe Frog	*Litoria alboguttata*	LC	
	Northern sedgefrog	*Litoria australis*	LC	
	Superb collared frog	*Litoria bicolor*	LC	
	Northern sedgefrog	*Litoria brevipes*	LC	
	Common green treefrog	*Litoria caerulea*	LC	
	Sandstone frog	*Litoria coplandi*	LC	
	Earless frog	*Litoria cryptotis*	LC	
	Grassland collared frog	*Litoria cultripes*	LC	
	Northern waterfrog	*Litoria dahlii*	LC	
	Buzzing treefrog	*Litoria electrica*	LC	
	Graceful treefrog	*Litoria gracilenta*	LC	
	Bumpy rocketfrog	*Litoria inermis*	LC	
	Broad-palmed rocketfrog	*Litoria latopalmata*	LC	
	Eastern snapping frog	*Litoria novaehollandiae*	LC	
	Pallid rocketfrog	*Litoria pallida*	LC	
	Northern laughing treefrog	*Litoria rothii*	LC	
	Ruddy treefrog	*Litoria rubella*	LC	
Limnodynastidae	Marbled frog	*Limnodynastes convexiusculus*	LC	
	Spotted grassfrog	*Limnodynastes tasmaniensis*	LC	
	Scarlet sided pobblebonk	*Limnodynastes terraereginae*	LC	
	Brown shovelfoot	*Notaden melanoscaphus*	LC	
	Desert shovelfoot	*Notaden nichollsi*	LC	
	Ornate burrowing frog	*Platyplectrum ornatum*	LC	

Family	Common Name	Species	Status – NC Act	Status – EPBC Act
Myobatrachidae	Chirping froglet	*Crinia deserticola*	LC	
	Northern froglet	*Crinia remota*	LC	
		Crinia sp	LC	
	Great brown broodfrog	*Pseudophryne major*	LC	
	Stonemason gungan	*Uperoleia lithomoda*	LC	
	Einasleigh gungan	*Uperoleia littlejohni*	LC	
	Mimicking gungan	*Uperoleia mimula*	LC	
	Orange shouldered gungan	*Uperoleia trachyderma*	LC	

NC Act Status: E = endangered, V = vulnerable, NT = near threatened, LC = least concern.
EPBC Act Status: Ex = extinct, CE = critically endangered, E = endangered, V = vulnerable.

5.4.2 Reptiles

The riverine and aquatic reptile species associated with the Flinders River include crocodiles, freshwater turtles, lizards and snakes. Marine turtles are associated with the estuary and SGoC.

Smith *et al.* (2006) did not provide a species list for reptiles for the Flinders River but noted two reptile species of conservation significance associated with the Flinders River:

- Estuarine crocodile *Crocodylus porosus* (NC Act -V, EPBC migratory)
- Worrell's turtle or diamond head turtle *Emydura subglobosa worrellii* (NC Act – NT)

They also identified four marine turtle species listed as migratory under the EPBC Act that are associated with the Flinders River:

- Loggerhead turtle *Caretta caretta* (NC Act – E, EPBC – E)
- Green turtle *Chelonia mydas* (NC Act – V, EPBC – V)
- Hawksbill turtle *Eretmochelys imbricata* (NC Act – E, EPBC – V)
- Flatback turtle *Natator depressus* (NC Act – V, EPBC – V)

More extensive lists of reptile species associated with the Flinders River have been compiled in subsequent studies. All have noted a paucity of data and records. Table 15 summarises the reptile species that have been identified as relevant to the Flinders River system or its broader region (e.g. EGoC region or TRIAP region). The regional lists include species that appear unlikely to occur in the Flinders River. Further work would be required to develop more targeted species lists for the Flinders River and study area reaches.

Fox (2008) undertook a review of information on the aquatic and semi-aquatic reptiles of the TRIAP study area, which included the Flinders River catchment as a focus catchment. Fox (2008) identified 30 species of aquatic or semi-aquatic reptiles relevant to the TRIAP study area. It is likely that some of these species do not occur in the Flinders River, for example, the Atlas of Living Australia shows no records of the sandstone snake-necked turtle *Chelodina burrungandji* in Queensland.[20] Fox (2008) noted that the data for the Flinders River were very limited, consisting of 13 records of aquatic and semi-aquatic reptiles, covering 7 species:

- 2 species of crocodiles - Freshwater crocodile, Estuarine crocodile
- 3 species of turtles - *Chelodina rugosa*, *Elseya latisternum*, *Emydura subglobosa*
- 1 species of lizard - *Varanus mertensi*
- 1 species of snake - *Tropidonophis mairii* (Freshwater keelback snake)

Fox (2008) considered the existing records to be inadequate to properly characterise the reptile fauna. He considered it likely that the water python, *Liasis fuscus*, three colubrid snakes, *Fordonia*

[20] '*Chelodina (Macrochelodina) burrungandjii* Thomson, Kennett & Georges, 2000', https://bie.ala.org.au/species/urn:lsid:biodiversity.org.au:afd.taxon:081e9772-1f59-4567-ab4b-40670f5c0302, viewed 19/12/2019

leucobalia, *Myron richardsonii* and *Tropidonophis mairii*, and *V. panoptes* were likely to occur across all of the catchments of TRIAP study area.

Waltham *et al.* (2013) reported that the distribution and extent of freshwater turtles in the Flinders catchment is not known. They suggested that 5 turtle species are likely to occur in the Flinders and/or Gilbert catchments (Table 15). They did not assess the distribution and extent of snakes and lizards.

DES (2018) identified 20 wetland-dependent native reptile species relevant to the riverine and non-riverine wetlands of the EGoC region (Table 15). They noted that the knowledge of freshwater turtles for the EGoC region is very poor and noted the possibility there may be an endemic *Elseya* taxon or that the range or *Elseya lavarackorum (NCA – V, EPBC – E)* extends into the EGoC.

DNRME (2018) identified two reptile species as 'flow-related ecological assets' for the Flinders River (Table 15):

- *Chelodina canni* - Cann's long-necked turtle (NCA – LC)
- *Chelodina oblonga* – northern snake-necked turtle (NCA – LC)

Table 15 Riverine and aquatic reptile species associated with the Flinders River

Family	Genus	Species	**Common Name**	**Status – NC Act**	**Status – EPBC Act**	**Fox 2008 – species relevant to TRIAP region**	**Fox 2008 – species recorded or likely for Flinders River**	**Waltham *et al.* (2013) – species relevant to the Flinders River**	**DES 2018 – Species relevant to EGoC Region**	**DNRME (2018) – Flow-related ecological assets**
Crocodylidae	*Crocodylus*	*johnstoni*	Australian freshwater crocodile	LC		x	x	x	x	
	Crocodylus	*porosus*	Estuarine Crocodile,	V	EPBC - migratory	x	x	x	x	
Carettochelydidae	*Carettochelys*	*insculpta*	Pig-nosed turtle	LC		x				
Chelidae	*Chelodina*	*canni*	Cann's long-necked turtle	LC		x		x	x	* asset
	Chelodina/ Macrochelodina	*oblonga/rugosa*	Northern snake-necked turtle	LC		x	x	x	x	* asset
	Chelodina	*novaeguineae*	New Guinea snake-necked *turtle*	LC		x				
	Chelodina	*Kuchlingi / colliei*	Kuchling's long-necked turtle	LC		x				
	Chelodina	*burrungandjii*	Ssandstone snake-necked turtle	LC		x				
	Chelodina sp.		turtle sp.	LC					x	
	Elseya	*dentata*	Northern snapping turtle	LC		x				
	Elseya	*lavarackorum*	Gulf Snapping Turtle	V	E	x				
	Elseya	*latisternum*	Saw-shelled turtle	LC		x	x	x	x	
	Elseya sp.		turtle sp.	LC					x	
	Emydura	*australis*	Northern red-faced turtle	LC		x				
	Emydura	*macquarii krefftii*	Krefft's river turtle	LC					x	
	Emydura	*subglobosa*	Red-bellied short-necked turtle	NT		x	x		x	
	Emydura	*victoriae*	Red-faced turtle (NT/WA)	LC		x				
	Emydura	*tanybaraga*	Northern yellow-faced turtle	LC		x		x	x	
	Emydura	*worrelli*	Diamond head turtle	NT		x		x	x	

Family	Genus	Species	**Common Name**	**Status – NC Act**	**Status – EPBC Act**	**Fox 2008 – species relevant to TRIAP region**	**Fox 2008 – species recorded or likely for Flinders River**	**Waltham *et al.* (2013) – species relevant to the Flinders River**	**DES 2018 – Species relevant to EGoC Region**	**DNRME (2018) – Flow-related ecological assets**
	Emydyura sp.		turtle sp.	LC					x	
Agamidae	*Intellagama*	*lesuerii*	Eastern water dragon	LC					x	
Varanidae	*Varanus*	*indicus*	Mangrove monitor	LC		x				
	Varanus	*mertensi*	Mertens' water monitor	LC		x	x		x	
	Varanus	*mitchelli*	Mitchell's water monitor	LC		x			x	
	Varanus	*panoptes*	Argus monitor	LC		x	l			
	Varanus	*semiremex*	Rusty Monitor	LC		x				
Achrochordidae	*Acrochordus*	*arafurae*	Arafura file snake	LC		x			x	
	Acrochordus	*granulatus*	Little file snake	LC		x			x	
	Liasis	*fuscus*	Water python	LC		x	l			
	Liasis	*mackloti*	Water python	LC					x	
Boidae	*Cerberus*	*rynchops*	Australian bockadam (snake)	LC		x				
Colubridae	*Enhydris*	*polylepis*	Macleay's Water Snake	LC		x			x	
	Fordonia	*leucobalia*	White-bellied mangrove snake	LC		x	l			
	Myron	richardsonii	Richardson's mangrove snake	LC		x	l			
	Stegonotus	*cucullatus*	Slaty-grey snake	LC		x				
	Tropidonophis	*mairii*	Freshwater snake, common keelback	LC		x	x		x	

Fox (2008) X – recorded in Flinders Catchment; l – likely to occur in all TRIAP catchments including Flinders

NC Act Status: E = endangered, V = vulnerable, NT = near threatened, LC = least concern.
EPBC Act Status: Ex = extinct, CE = critically endangered, E = endangered, V = vulnerable.

5.4.3 Birds

The bird species associated riverine and aquatic environments associated with the Flinders River include the following groups:

- Waterbirds that use flooded areas and waterholes for feeding and/or breeding
- Waders associated with the estuary including tidal flats along the GoC shoreline
- Bird species associated with the riparian zone.

No list of bird species associated with riverine and aquatic environments was found that was limited to the Flinders River system. Franklin (2008) reviewed datasets compiled by Birds Australia for the Flinders River catchment and identified a total of 2844 records for the catchment. However, this was part of a study extending across the TRIAP region and they only presented a species list across the entire TRIAP region, not a separate species list for the Flinders River.

DES (2018) identified 109 native bird species in the EGoC region that use freshwater wetland environments including riverine environments for all or part of their life history (Table 16). They drew attention to five rare/threatened species:

- *Calidris ferruginea* curlew sandpiper (NCA - E; EPBC - CE)
- *Epthianura crocea* yellow chat (NCA - V) (two subspecies are listed under the EPBC Act, *Epthianura crocea macgregori* – CE (Dawson/Capricorn), and *Epthianura crocea tunneyi* – E (Alligator Rivers) - SPRAT).
- *Erythrotriorchis radiatus* red goshawk (NCA - E; EPBC -V)
- *Neochmia phaeton evangelinae* Crimson finch (white-bellied subsp.) (NCA - E; EPBC - E)
- *Rostratula australis* Australian painted snipe (NCA - E; EPBC - E)

Franklin (2008) mapped the location of records of Australian painted snipe from the Flinders River system. They noted that the painted snipe has been recorded as breeding in flooded grasslands within the TRIAP area.

DES (2018) reported that 23 of the bird species associated with the riverine and non-riverine wetlands in the EGoC region are migratory bird species listed under Japan Australia Migratory Bird Agreement (JAMBA), the China Australia Migratory Bird Agreement (CAMBA), Republic of Korea Australia Migratory Bird Agreement (ROKAMBA) and/or the Convention on Migratory Species (Bonn).

Colonial waterbird breeding has been reported from the floodplain and estuarine reaches of the Flinders and Bynoe Rivers in Reach 6 (Jaensch and Richardson 2013). Apart from the work of Jaensch and Richardson (2013), no other surveys of colonial waterbird breeding in the Flinders River system has been identified, and it is possible that much more extensive areas of floodplains are used for colonial waterbird breeding when these areas are inundated during major floods.

Although reach by reach information is not available for all Reaches, Reach 6 has been highlighted as particularly important for birds:

- The Flinders River estuary and floodplain are part of the Gulf Plains Important Bird Area (IBA) (Dutson *et al.* 2009). It provides migratory wader and waterbird roosting, feeding and breeding sites (DES 2018)
- The GoC provides a 'gateway to Australia' for migratory waders on the East Asian-Australasian Flyway (Bamford *et al.* 2008, DES 2018). The south-east GoC has been identified the third most significant site in Australia for migratory shorebirds using the East Asian-Australasian Flyway (Bamford *et al.* 2008)
- The Southern Gulf Wetland Aggregation provides significant habitat for birds (Smith *et al.* 2006)

EHP (2015b) stated that 'the Gulf Plains bioregion is critical for wetland taxa', drawing attention to its importance for migratory shorebirds as well as the presence of wetlands that provide refugia for waterbirds including waterfowl, herons and ibis.

DNRME (2018) identified five bird species as 'flow-related ecological assets' for the Flinders River:

- *Ephippiorhynchus asiaticus* black-necked stork/ jabiru (NCA – LC)
- *Epthianura crocea* yellow chat (NCA - V)
- *Malurus coronatus* purple-crowned fairy-wren (NCA-V)
- *Rostratula australis* painted snipe (EPBC - E, NCA – E)
- *Stictonetta naevosa* freckled duck (NCA – LC)

The purple-crowned fairy-wren *Malurus coronatus* is a riparian zone species and was not included in list of aquatic species identified by DES (2018). However, the eastern subspecies *Malurus coronatus macgillivrayi* was identified by EHP (2015) as 'One of the few iconic animals' of the Gulf Plains. The western subspecies, *Malurus coronatus coronatus*, is listed as Endangered under the EPBC Act.

Table 16 Native riverine and wetland-dependent bird species relevant to the EGoC region (from DES 2018)

Scientific name	**Common name**
Acrocephalus australis	Australian reed-warbler
Actitis hypoleucos	common sandpiper
Amaurornis cinerea	white-browed crake
Amaurornis moluccana	pale-vented bush-hen
Anas castanea	chestnut teal
Anas gracilis	grey teal
Anas querquedula	garganey
Anas rhynchotis	Australasian shoveler
Anas superciliosa	Pacific black duck
Anhinga novaehollandiae	Australasian darter
Anseranas semipalmata	magpie goose
Ardea ibis	cattle egret
Ardea intermedia	intermediate egret
Ardea modesta	eastern great egret
Ardea pacifica	white-necked heron
Ardea sumatrana	great-billed heron
Aythya australis	hardhead
Biziura lobata	Musk Duck
Butorides striata	striated heron
Calidris acuminata	sharp-tailed sandpiper
Calidris ferruginea	curlew sandpiper
Calidris melanotos	pectoral sandpiper
Calidris ruficollis	red-necked stint
Ceyx azureus	azure kingfisher
Ceyx pusillus	little kingfisher
Charadrius dubius	little ringed plover
Charadrius ruficapillus	red-capped plover
Charadrius veredus	Oriental plover
Chenonetta jubata	Australian wood duck
Chlidonias hybrida	whiskered tern
Chlidonias leucopterus	white-winged black tern
Chroicocephalus novaehollandiae	silver gull
Circus approximans	swamp harrier
Cisticola exilis	golden-headed cisticola
Cisticola juncidis normani	Zitting cisticola (Normanton subsp.)
Cygnus auratus	black swan
Dendrocygna arcuata	wandering whistling-duck
Dendrocygna eytoni	plumed whistling-duck

Scientific name	Common name
Dendrocygna guttata	spotted whistling-duck
Egretta garzetta	little egret
Egretta novaehollandiae	white-faced heron
Egretta picata	pied heron
Elanus scriptus	letter-winged kite
Elseyornis melanops	black-fronted dotterel
Ephippiorhynchus asiaticus	black-necked stork
Epthianura crocea	yellow chat
Erythrogonys cinctus	red-kneed dotterel
Erythrotriorchis radiatus	red goshawk
Eulabeornis castaneoventris	chestnut rail
Fulica atra	Eurasian coot
Gallinago hardwickii	Latham's snipe
Gallinago megala	Swinhoe's snipe
Gallinula tenebrosa	dusky moorhen
Gallirallus philippensis	buff-banded rail
Gelochelidon nilotica	gull-billed tern
Glareola maldivarum	Oriental pratincole
Grus antigone	sarus crane
Grus rubicunda	brolga
Haliaeetus leucogaster	white-bellied sea-eagle
Haliastur indus	brahminy kite
Himantopus himantopus	black-winged stilt
Hydroprogne caspia	Caspian tern
Irediparra gallinacea	comb-crested jacana
Ixobrychus dubius	Australian little bittern
Ixobrychus flavicollis	black bittern
Lewinia pectoralis	Lewin's rail
Limosa limosa	black-tailed godwit
Malacorhynchus membranaceus	pink-eared duck
Megalurus gramineus	little grassbird
Megalurus timoriensis	tawny grassbird
Microcarbo melanoleucos	little pied cormorant
Myiagra alecto	shining flycatcher
Myiagra nana	paperbark flycatcher
Neochmia phaeton evangelinae	Crimson finch (white- bellied subsp.)
Neochmia phaeton phaeton	crimson finch
Nettapus coromandelianus	cotton pygmy-goose
Nettapus pulchellus	green pygmy-goose
Numenius minutus	little curlew
Nycticorax caledonicus	nankeen night-heron
Pandion cristatus	eastern osprey
Pelecanus conspicillatus	Australian pelican
Phalacrocorax carbo	great cormorant
Phalacrocorax sulcirostris	little black cormorant
Phalacrocorax varius	pied cormorant
Phalaropus fulicarius	grey phalarope
Platalea flavipes	yellow-billed spoonbill
Platalea regia	royal spoonbill
Plegadis falcinellus	glossy ibis
Pluvialis fulva	Pacific golden plover
Podiceps cristatus	great crested grebe
Poliocephalus poliocephalus	hoary-headed grebe
Porphyrio porphyrio	purple swamphen
Porzana fluminea	Australian spotted crake
Porzana pusilla	Baillon's crake
Porzana tabuensis	spotless crake
Rallina tricolor	red-necked crake
Recurvirostra novaehollandiae	red-necked avocet

Scientific name	Common name
Rhipidura dryas	Arafura fantail
Rostratula australis	Australian painted snipe
Stictonetta naevosa	freckled duck
Tachybaptus novaehollandiae	Australasian grebe
Tadorna radjah	radjah shelduck
Threskiornis molucca	Australian white ibis
Threskiornis spinicollis	straw-necked ibis
Tribonyx ventralis	black-tailed native-hen
Tringa glareola	wood sandpiper
Tringa nebularia	common greenshank
Tringa stagnatilis	marsh sandpiper
Vanellus miles	masked lapwing

5.4.4 Mammals

Smith *et al.* (2016) assessed the likely occurrence of rare or threatened fauna in the Flinders River and did not identify any rare of threatened mammals associated with the non-tidal reaches. They noted that that riparian vegetation provides favourable habitat for arboreal mammals and refuge for macropods.

DES (2018) identified four aquatic-dependent mammals that occur in the EGoC catchments and are potentially relevant to the riverine and non-riverine wetlands of the study areas:

- water rat *Hydromys chrysogaster* (NC Act – LC)
- large-footed myotis (a vesper bat) *Myotis macropus* (NC Act – LC)
- northern/mangrove pipistrelle (a small vesper bat) *Pipistrellus westralis* (NC Act – LC)
- swamp rat *Rattus lutreolus* (NC Act – LC)

DNRME (2018) did not identify any mammal species as 'flow-related ecological assets' for the Flinders River.

The estuarine zone provides habitat for dugong (Smith *et al.* 2006, Bayliss *et al.* 2014). The dugong is a listed migratory species under the EPBC Act and listed as Vulnerable under the NC Act.

6 Estuarine and Marine

The Gulf Water Plan requires the cumulative effects of all water resource development in the Flinders River catchment to be assessed in relation to EFOs for the Flinders River at Walkers Bend. It specifies outcomes relating to estuarine and marine ecosystems and biota that are influenced by river flows. Therefore, it is relevant to consider estuarine and marine ecosystems and biota in this report.

The Project area is situated near Hughenden, approximately 700 km upstream of the Flinders River mouth and approximately 600 km upstream of the head of the Flinders River estuary, which is located a short distance downstream of Walkers Bend (Table 3). Mean and median annual flows in the Flinders River at the Project area are an order of magnitude smaller than flows at Walkers Bend (Table 4).

The Flinders River catchment is one of 29 Australian Water Resources Council (AWRC) catchments in the GoC Drainage Division. A regional hydrological analysis by CSIRO (2009) showed that the Flinders Leichardt Region comprises 23% of the GoC Drainage Division but contributes 7% of the freshwater inflows. The Flinders River catchment area is 17% of the GoC Drainage Division. The Flinders River contributes approximately 16% of the river inflows to the Southern GoC, with other significant inflows to the Southern GoC coming from the Gilbert, Leichardt, Norman and Staaten Rivers (Bayliss *et al.* 2014).

This chapter outlines the flow-reliant estuarine habitats (Section 6.1) and flow-reliant estuarine biota (Section 6.2) associated with the Flinders River, including habitats and biota in the SGoC that are influenced by Flinders River flows. Section 6.3 provides a brief review of quantitative relationships between Flinders River flows and estuarine biota.

6.1 Flow-Reliant Estuarine Habitats

The Flinders River estuary is classified as a delta, a progradational landform that the Flinders River has built up over time at its entrance to the GoC. Export of sediment derived from the river system is a fundamental process in the development and maintenance of deltas.

Bayliss *et al.* (2014) identified four habitat types associated with the Flinders River estuary as being susceptible to reductions in flow in the Flinders River:

- Floodplains
- Salt flats
- Mangroves
- Seagrasses

Bayliss *et al.* considered floodplains and salt flats to have moderate susceptibility to reductions in flow, and mangroves and seagrasses to have low susceptibility. Floodplains and salt flats are connected to the Flinders River by flooding; overbank flooding and inundation extents associated with Flinders River flows were examined in Section 4.6.

The Flinders River estuary is associated with the Southern Gulf Aggregation, a wetland listed in the Directory of Important Wetlands in Australia (Section 4.6.1).

6.2 Flow-Reliant Estuarine Biota

Bayliss *et al.* (2014) identified 46 taxa (species or species groups) for assessment in terms of susceptibility to reductions in flow in the Flinders and Gilbert rivers. Assessment taxa were chosen based on their ecological importance (including endangered, endemic and keystone species) and/or because they are fishery species (including commercial and non-commercial species). Bayliss *et al.*

noted that many more species could potentially be affected by reductions in flow, but they did not have the time or resources to formally assess all species.

Table 17 provides a list of these taxa, shows Bayliss et al.'s (2014) risk ranking (based on likelihood and consequence of impacts resulting from flow regime change, which indicates susceptibility), and identifies key values associated with each taxon.

Table 17 Priority estuarine species identified for the Flinders River estuary by Bayliss et al. 2014, showing their susceptibility to reductions in flow and key values (based on Bayliss et al. 2014)

Category	Species /Group	Risk ranking	Commercial Fisheries	Recreational	Indigenous	Conservation Listed[21]	Ecosystem Keystone
Plankton	Plankton	LOW					
Invertebrates	Mud Crab	HIGH	x	x	x		x
	White Banana Prawn	HIGH	x	x	x		x
	Blue Swimmer Crab	LOW	x	x	x		
	Brown Tiger Prawn	LOW	x				x
	Cephalopods	LOW	x				
	Grooved Tiger Prawn	LOW	x				x
	Slipper Lobsters	NEGLIGIBLE	x				
Fish	Barramundi	HIGH	x	x	x		x
	Blue Threadfin	HIGH	x	x	x		
	Bull Shark	HIGH					
	Freshwater Sawfish	HIGH				x	
	Freshwater Whipray	HIGH				x	
	King Threadfin	HIGH	x	x	x		
	Mullet	HIGH		x	x		x
	Northern River Shark	HIGH				x	
	Pikey Bream	HIGH		x	x		
	Sooty Grunter	HIGH		x			
	Speartooth Shark	HIGH				x	
	Black Jewfish	MODERATE	x	x	x		
	Blue Catfish	MODERATE	x	x	x		
	Green Sawfish	MODERATE				x	
	Grunter	MODERATE	x	x	x		
	Mangrove Jack	MODERATE	x	x	x		
	Narrow Sawfish	MODERATE				x	
	Talang Queenfish	MODERATE	x	x	x		x

[21] Includes the NC Act, EPBC Act and IUCN Red List

Category	Species /Group	Risk ranking	Commercial Fisheries	Recreational	Indigenous	Conservation Listed[21]	Ecosystem Keystone
	Winghead Shark	MODERATE					
	Blue spot Trevally	LOW		x	x		x
	Golden Snapper	LOW	x	x			
	Grey Mackerel	LOW	x	x	x		
	Hammerhead Sharks	LOW					
	Red Emperor	LOW	x	x			
	Black-tip Shark	NEGLIGIBLE	x		x		
	Bony Bream	NEGLIGIBLE		x	x		x
	Crimson Snapper	NEGLIGIBLE	x	x			
	Goldband Snapper	NEGLIGIBLE	x	x			
	Hamilton's Thryssa	NEGLIGIBLE					
	Largescaled terapon	NEGLIGIBLE					
	Saddletail Snapper	NEGLIGIBLE	x	x			
	Sawtooth Barracuda	NEGLIGIBLE					
	Spanish Mackerel	NEGLIGIBLE	x	x	x		
Reptiles	Sea snakes	HIGH				x	
	Marine Turtles	LOW					
	Saltwater crocodile	LOW					
Birds	Migratory Shorebirds	HIGH					
Mammal	Dugong	LOW					

Bayliss *et al.* (2014) indicated that traits contributing to the high susceptibility of some taxa to reductions in flow included:

- Euryhaline fish species that use coastal waters to reproduce as adults, with juveniles moving into estuarine and freshwater habitats
- Species with highly subdivided populations for which individual rivers in the southeastern GoC support self-sustaining populations (e.g. Blue and King Threadfin, Pikey Bream, Barramundi)

Bayliss *et al.* (2014) reported that the species with lowest susceptibility completed most of their life cycles in offshore waters and had wide geographic distributions of single populations that extended beyond the GoC.

The following species/groups are listed under the EPBC Act (Bayliss *et al.* 2014):

- Sawfish
- Marine turtles
- Speartooth shark
- Dugong
- Saltwater crocodile

- Migratory shorebirds
- Sea snakes

The following species/ groups are listed by IUCN (non-statutory listing) (Bayliss *et al.* 2014):

- Freshwater whipray
- Dugong
- Saltwater crocodile
- Migratory shorebirds

Species/groups with conservation significance under the NC Act include marine turtles, dugong, estuarine crocodile and migratory shorebirds (Nature Conservation (Wildlife) Regulation 2006 (Qld)).

Other species/groups that are not necessarily listed as having conservation significance may have an important ecological role as predator species, forage species and keystone species (Table 17).

Freshwater sawfish and freshwater whipray require access to freshwater habitats (as discussed in Section 5.3). Green and dwarf sawfish as less reliant on freshwater flows (Bayliss *et al.* 2014). The Flinders River provides suitable habitat for Riversharks, including Speartooth Shark (*Glyphis glyphis*) (an EPBC-listed species).

6.3 Quantitative Relationships between Flow and Estuarine Biota

Bayliss *et al.* (2014) established quantitative models to make predictions about the effects of change in flow regime for White Banana Prawns and Barramundi. These models are reviewed in Sections 6.3.1 and 6.3.2.

Further research to refine these models is currently underway in a research project led by Professor Michele Buford (Griffith University) titled 'Ecological modelling of the impacts of water development in the GoC with particular reference to impacts on the Northern Prawn Fishery (NPF)'. Further research on Barramundi is also being undertaken by Julie Robins (Qld Fisheries). A discussion with Professor Burford indicated that statistical relationships are being refined, with the aim of estimating the effects of flow regime change on fisheries productivity as an input to benefit-cost analysis, so that the value of estuarine fishery production can be compared to other uses of water. The cumulative effect of the Flinders, Mitchell and Gilbert Rivers is being investigated. The Griffith University project is scheduled to be completed in 2021 and new/revised models are not yet available.

6.3.1 White Banana Prawns

There has been a substantial body of research over several decades that indicates a strong relationship between river flows and commercial catches of prawns in the GoC including:

- Life history studies (e.g. Staples 1984; Staples and Vance 1986, 1987; Vance 1991; Vance *et al.* 2003)
- predictive statistical model of catch on regional rainfall (Venables *et al.* 2011; Buckworth *et al.* 2014)

Freshwater inflows from the river systems contribute to the productivity of the estuaries, supporting the recruitment of juvenile prawns. Higher flow (and the consequent drop in the salinity of the estuary) results in emigration of prawns from the estuaries into the GoC, where they become available to the fishery.

Bayliss *et al.* (2014) established multiple regression models that predict annual prawn catches (in tonnes/year) for NPF Zones 7, 8 and 9. The models are based on fishing effort and combined flows in the Flinders and Gilbert Rivers (NPF Zones 7 and 8) or Gilbert River only (NPF Zone 9).

Bayliss *et al.* (2014) noted a number of limitations with these models, including:

- The Flinders and Gilbert Rivers together contribute 41% of the total 'end of system' riverine flow to NPF zones 7, 8 and 9, with the contributions from other major rivers being Leichhardt 11% Norman 22% and Staaten 26%.
- The regression models may be an oversimplification as they consider only two factors affecting White Banana Prawn fishery productivity, fishing effort and river flows

6.3.2 Barramundi

6.3.2.1 Catch-Flow Analysis

There has been extensive previous research indicating that freshwater flows affect Barramundi populations and fisheries productivity (e.g. Robins *et al.* 2006, Halliday *et al.* 2010). In particular, floodplain inundation is important for Barramundi, and a reduction in the number of years with floods large enough to inundate the floodplain would adversely impact this fishery (M. Burford, pers. comm.).

Bayliss *et al.* (2014) developed a multiple regression model to predict commercial Barramundi catch in the Flinders River from fishing effort and wet season flow. This model showed that observed Barramundi catches associated with the Flinders River are explained by fishing effort rather than flow, but Bayliss *et al.* (2014) warned that this should be 'treated with caution' because the fishery was recovering from decadal-scale droughts during the 1980s combined with heavy fishing.

6.3.2.2 Year Class Strength (YCS)

Year Class Strength (YCS) analysis provides another approach to assessing the effects of flow regime change resulting from water resource development on Barramundi (Staunton-Smith *et al.* 2004). This approach was used by Bayliss *et al.* (2014) to quantify the relative risk of alternative water resource management scenarios for the Barramundi population associated with the Flinders River.

The predictive equation relating Flinders River flow to YCS was based on age-structure data for commercially caught Barramundi from Halliday *et al.* (2012). Bayliss *et al.* (2014) indicated that the YCS analysis could be improved through dedicated analysis of age-structure data held by Fisheries Queensland including recent flood years.

7 Social and Economic

The social and economic values associated with the Flinders River environmental flow requirements are outlined in this chapter. Fisheries are a major non-consumptive water user in the Flinders River catchment (Economic Associates 2006) and are discussed in Section 7.1. Tourism is discussed in Section 7.2 and indigenous cultural values are discussed in Section 7.3.

7.1 Fisheries

Fish have high economic and social importance in the Flinders River catchment, and are targeted by commercial, recreational and indigenous fisheries (Figure 16). The commercial fisheries associated with the Flinders River are part of the GoC fisheries.

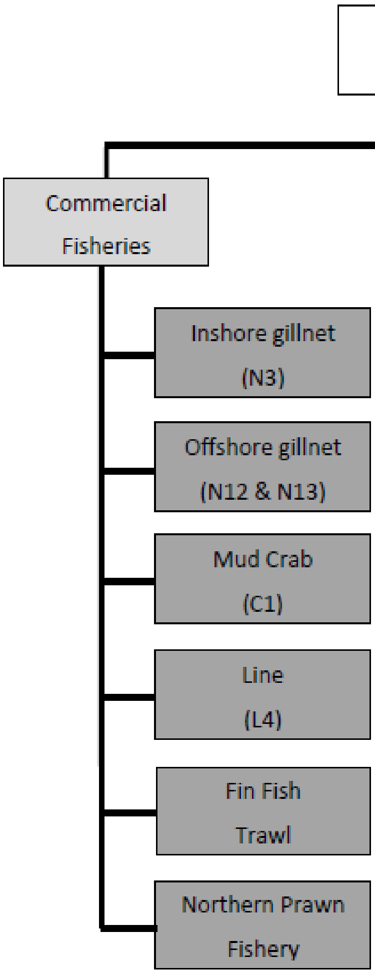

Figure 16 Fisheries associated with the Flinders River (from Bayliss et al. 2014)

7.1.1 Commercial Fisheries

There are six commercial fisheries in the GoC that target species that influenced by river flows (Figure 16). The GoC fisheries are a major part of Queensland's fisheries. The total Gross Value of Production (GVP) of these fisheries in 2018 was equivalent to approximately/almost three quarters of the total value of Queensland's commercial fishing in 2016-17 of $189 M (Qld Ag Trends 2018). The Northern Prawn Fishery is considered to be one of Australia's most valuable fisheries (Bayliss *et al.* 2014).

As discussed in Chapter 6, the Flinders River contributes approximately 16% of the river inflows to the SGoC and is one of 25 river systems draining into the GoC. Information is not readily available on the proportional contribution of the Flinders River to the catch and value of the GoC fisheries.

7.1.2 Recreational Fishery

Recreational fishing is undertaken in the freshwater and estuarine reaches of the Flinders River as well as the GoC. Recreational fishing is popular in the Flinders River catchment (Waltham *et al.* 2013).

Recreational fishing is an important component of Queensland's fisheries. The Queensland Government (2018) forecast that the 2019 value of recreational fishing would be $94M but indicated that this was a conservative estimate.

The Queensland Statewide Recreational Fishing Survey 2019-20 showed that almost 943,000 Queenslanders went recreational fishing in 2019 (DAF 2019). The most recent information at a regional level is from the 2013/14 Queensland Statewide Fishing survey. This showed that the fishing effort by Queenslanders in regions encompassing the Flinders River study area was approximately 70,000 fisher days (Karumba coastal waters - 10,000 fisher days; Gulf catchment - 60,000 fisher days; Mornington Island – unknown). These figures exclude recreational fishing by visitors from interstate, which is not captured in the Queensland fishing surveys (Bayliss *et al.* 2014).

The most important species in the recreational fishery, in terms of numbers of fish caught, are Barramundi (125,000 fish/year Pikey Bream (49,000 fish/year) and Barred javelin ('Grunter') (38,000 fish/year (Bayliss *et al.* 2014). Other key recreational fishery species include Forktail catfish, Blue and King Threadfin, Mangrove Jack, Mullet and Mud Crab (Bayliss *et al.* 2014).

Bayliss *et al.* (2014) reported that the key recreational fishery species caught in freshwater were Sooty Grunter, Eeltail catfish, Archerfish and Spangled perch (Bayliss *et al.* 2014). Waltham *et al.* (2013) reported that other freshwater fish species targeted by anglers include Sleepy Cod and Giant Gudgeon.

7.1.3 Indigenous fishery

Fishing is an important food source for indigenous people but there has been little scientific documentation of Indigenous fishing practices and the composition of the catch for the Flinders River (Bayliss *et al.* 2014). Economic Associates (2006) reported that traditional fisheries included line fishing, crabbing, hunting dugong and collecting molluscs and crustaceans.

Bayliss *et al.* (2014) reported that the following species/groups are common targets for the indigenous fisheries associated with the Flinders and Gilbert Rivers: prawns, mullet, pikey bream, blue catfish, mud crab and barramundi. In addition, marine turtles (including their eggs) and dugong are also part of the indigenous fishery (Bayliss *et al.* 2014). Sawfish (e.g. *Pristis pristis*) have cultural significance for food and ceremonial purposes (Approved Conservation Advice for *Pristis pristis* (Largetooth Sawfish), 2014).

EHP (2015b) reported that the Northern Snake-necked Turtle *Chelodina rugosa* (a freshwater turtle) is an important traditional food resource for indigenous people, who dig them out of aestivating sites.

7.2 Tourism

Economic Associates (2006) identified tourism (especially recreational fishing and camping) as an important non-consumptive use of water within the plan area and estimated that there are about 100,000 visitors per year to the Gulf Water Plan area. Total annual tourism-related expenditure in the region in 2004 was estimated to be in of the order of $11 million (in 2004 dollars) plus additional indirect economic benefits, and direct and indirect employment (Pascoe 2014).

Recreational fishing has been identified as the primary reason for tourists visiting North-west Queensland (Economic Associates 2006, Pascoe 2014, Stoeckl *et al.* 2006; Greiner and Patterson 2007). Many of the tourists are retired couples who fish for food (Pascoe 2014).

7.3 Indigenous Cultural Values

This section briefly examines indigenous cultural values associated with the environmental flow requirements for the Flinders River. It does not attempt to cover all of the indigenous values associated with the water resources of the Flinders River or to address cultural flows. It is important to note that indigenous people have much wider interests in water resources and water management than values associated with environmental flows, including aspirations for social and economic development (Barber 2013). Barber (2013) reported that:

> *Indigenous people have a diverse array of water values, rights and interests in the Flinders and Gilbert catchments and a strong desire to be involved in the ongoing protection, development and management of the catchments.*

The Flinders River catchments has a dispersed Indigenous population with significant variations in terms of residential patterns and governance arrangements (Barber 2013). Barber (2013, 2014) outlined indigenous perspectives in relation to water resource management for the Flinders and Gilbert River catchments (Barber 2013) and associated estuarine and marine areas (Barber 2014). The following key themes relating to indigenous cultural values associated with the Flinders River environmental flow requirements have been identified:

- Water in the landscape –
    - Often a crucial focus for dreaming, including rivers and waterholes
    - Enough water to maintain healthy landscapes (environmental flows)
    - Access to water sites
    - Pre-contact Aboriginal occupation of the area focussed on sources of permanent and semi-permanent water, resulting in a concentration of archaeological sites in these areas (McIntyre-Tamwoy *et al.* 2013)
- The natural large seasonal variations in flow, especially the larger flows of the wet season, as an important part of the natural cycle
- Water quality – the importance of clean water for human populations and ecosystems
- Animals, including –
    - fish migrations
    - iconic species such as sawfish
    - Food resources for fishing and hunting
    - Strong social and religious connections between people and other creatures
- Vegetation – including foraging for bush plants
- Culturally significant places, such as habitation sites, birthing sites and story places.

Barber (2013) noted that other key water resource management issues for indigenous people include:

- maintaining adequate supplies for human consumption
- securing sufficient water reserves for current and future economic activity
- deriving benefits from water resource development and water use

8 Environmental Flow Risk Assessment

This chapter provides a high-level assessment of the implications of the cumulative impacts of flow regime changes resulting from water resource development including the Project (as represented by the Saego Dam case) for the Flinders River downstream of the Project area and associated environmental, social and economic values.

The assessment in this chapter does not investigate the effects of the Project within the dam and weir pondage areas, or the implications of the Project for the river system upstream. However, it is noted that the increased extent and duration of water in the landscape resulting associated with the dam and weir impoundments is likely to locally create more favourable conditions for some indigenous and exotic biota.

8.1 Assessment Process

A three-point rating scale (low [L], medium [M], high [H]) is used to show indicative levels of risk to flow-related ecosystems and values in each reach. The risk ratings reflect the likelihood and consequences of potential cumulative impacts of water resource development including the Project.

The risk assessment is based on expert appraisal of information about the Flinders River outlined in the review of values (Chapters 4 to 7) in relation to the results of the hydrological modelling of the Saego Dam case (Chapter 3) and information provided by Engeny regarding proposed infrastructure and irrigation areas.

The following hydrological criteria were considered in the development of the risk ratings:

- The Gulf Water Plan EFOs
- Environmental flow 'benchmarking' studies undertaken as part of the development of Queensland's water plans
- Hydrological 'rules of thumb' including the 'two thirds rule' (Cullen 2001).

Cullen (2001) proposed two-thirds of the median flow as a restoration target for over-allocated rivers. This is broadly consistent with 'moderate' levels of ecosystem impact defined in the environmental flow 'benchmarking' that was used in the development of Queensland's water plans. The 'two thirds rule' has been cited in relation to 'working rivers' in the Murray Darling basin (Wentworth Group of Concerned Scientists *et al.* 2010). The use of hydrological rules of thumb as the primary basis for setting environmental flow requirements has been criticised for lack of scientific rigour, and the use of specialised flow indicators that relate more directly to specific ecosystems or components is recommended (e.g. Arthington *et al.* 2006). However, rules of thumb are useful as a preliminary guide for identifying key issues and scoping subsequent more detailed assessments.

8.2 Results and Discussion

Section 8.2.1 presents and discusses the risk ratings on a reach by reach basis. Section 8.2.2 provides more detailed discussion of implications for key habitats. Section 8.2.4 outlines key implications of major water infrastructure.

The assessment of risks for specific flora and fauna (or groups) would require lists of flow-reliant species recorded or likely to occur in each reach. Catchment-wide lists are available for some groups (e.g. fish, amphibians) while only wider regional lists are available for other groups (e.g. reptiles, birds, mammals). Further work would be required to compile reach-scale species lists.

8.2.1 Overview

The risk ratings are presented in Table 18. The Project will substantially reduce flows in the Flinders River at Node 009 and Richmond, resulting in a high risk of geomorphological and ecological changes in Reaches 1 to 3 including changes in channel form, habitat structure, riparian zone communities and connectivity with anabranch and floodplain habitat.

Downstream of the Stawell River, the hydrological effects of the Project are significantly mitigated by tributary inflows but the effects of other water resource development increase. The net effect at Walkers Bend is a reduction in mean annual flow to 92.4% of pre-development and a reduction in median annual flow to 80.8% of pre-development. The risk of geomorphological and ecological impacts associated with the cumulative impacts of flow regime change decreases to medium/high in Reach 4 and low/medium in Reach 5, reflecting the lesser extent of flow regime change and partial compliance with the Gulf Water Plan EFOs.

The risk rating of medium/high for Reach 4 is based on flows at Richmond and Etta Plains, and may be conservative. More detailed modelling of the Flinders River between Richmond and Etta Plains quantify the effects of major tributary inflows would enable clearer definition of the sections of the river subject to various levels of risk.

Passing flows are expected to maintain low flow habitat and longitudinal connectivity immediately downstream of the Project area but there are uncertainties regarding transmission losses further downstream. It is recommended that transmission losses be examined in more detail during the design phase to confirm the adequacy of passing flow provisions for maintaining waterholes, pools and low flow connectivity.

The risk to estuarine and marine ecosystems and values from the cumulative impacts of water resource development in the Saego Dam case is rated as medium for the Flinders River estuary (Reach 6) and low/medium for the SGoC (Reach 7), reflecting partial compliance with the Gulf Water Plan EFOs. Key values that are associated with high flows in the estuarine and marine zone include floodplain wetlands, including Southern Gulf Aggregation (nationally significant), and commercial, recreational and indigenous fisheries. Further investigations could be undertaken to clarify the significance of variations from the 1.5-, 5- and 20-year daily flow volume EFOs for these values. In particular, the following investigations would be relevant:

- Analysis of the Source model outputs in relation to floodplain inundation regimes to specifically assess implications of partial compliance with the Gulf Water Plan EFOs for floodplain habitats and biota, including differences between the Saego Dam case and WRP-ROP case. The Gulf Water Plan EFOs for the 5-year and 20-year daily flow volume appear to be conservative and it is unclear whether minor departures from these EFOs would have a discernible effect on floodplain ecosystems or biota
- Application of flow-productivity models for White Banana Prawns and Barramundi to compare the effects of the Saego Dam case with the WRP-ROP case in relation to these fisheries. Suitable models have been established by Bayliss *et al.* (2014) and are currently being reviewed and refined in research projects led by Prof. M. Burford and J. Robins

Table 18 High- level risk assessment of the cumulative impacts of water resource development including the Project on flow-related ecosystems and values downstream of the Project area

Reach	Risk Rating	Key Issues
Reach 1 – Flinders River Weir to Walkers Creek	H	• Change in channel forming processes and channel morphology due to reductions in medium and high flows, with implications for habitat structure and dynamics • Passing flows are expected to maintain wetted instream habitat and longitudinal connectivity • Effects of infrastructure, including barrier effects of Flinders River Weir on sediment transport and fish passage. It is assumed that the weir will incorporate a fishway but this is unlikely to fully mitigate all impacts on fish passage. The freshwater sawfish's access to the catchment upstream of the weir requires specific consideration. • Effects associated with adjacent irrigation areas – including potential groundwater rise and potential riparian zone disturbance (e.g. weeds)
Reach 2 – Walkers Creek to Dutton River (Richmond)	H	• Change in channel forming processes and channel morphology due to reductions in medium and high flows, with implications for habitat structure and dynamics • Passing flows are likely to maintain wetted instream habitat, including seasonal waterholes and riffles/glides, and longitudinal connectivity • Reductions in medium and high flows have implications for channel maintenance processes, riparian zone communities and connectivity with anabranch and floodplain habitat
Reach 3 – Dutton River to Stawell River	H	• Change in channel forming processes and channel morphology due to reductions in medium and high flows, with implications for habitat structure and dynamics • The effectiveness of passing flows in maintaining wetted instream habitat and longitudinal connectivity may be reduced by transmission losses, with implications for persistent and seasonal waterholes. Further investigations would be required to clarify and confirm this. • Reductions in waterhole habitat persistence and/or quality would have implications for fish and other vertebrates that rely on these refugia, including species of conservation significance such as the freshwater sawfish • Reductions in medium and high flows have implications for channel maintenance processes, riparian zone communities and connectivity with anabranch and floodplain habitat • Reductions in flow have potential implications for 'of concern' REs in this reach (Appendix B)

Reach	Risk Rating	Key Issues
Reach 4 – Stawell River to Euroka Springs	M/H	• This is a long reach, and the hydrological effects of the Project are significantly mitigated by tributary inflows. Median annual flow increases from 25.4% at Richmond (upstream of the Stawell River confluence, which marks the start of this reach) to 81.7% of pre-development at Etta Plains near the downstream end of reach, and mean annual flow increases from 77.9% to 89.1%. More detailed hydrological modelling of this reach would enable more accurate identification of the extent of zones of differing levels of risk • Reductions in medium and high flows have implications for channel maintenance processes, riparian zone communities and connectivity with anabranch and floodplain habitat; the magnitude of these hydrological impacts decreases substantially between Richmond and Etta Plains • Reductions in medium and high flow have potential implications for 'of concern' REs in this reach (Appendix B) • This reach has persistent waterholes that are dependent on surface flows. The Source modelling indicates that passing flows from the Flinders River Weir minimise impacts on the incidence of no flow but the modelling does not appear to account for transmission losses. Further investigations would be required to clarify this. • Reductions in waterhole habitat persistence and/or quality would have implications for fish and other vertebrates that rely on these refugia, including species of conservation significance such as the freshwater sawfish • The effectiveness of passing flows in maintaining wetted habitat on riffles/glides and longitudinal connectivity may be reduced by transmission losses
Reach 5 – Euroka Springs to Tidal Limit	L/M	• The Saego Dam case complies with four out of seven EFOs for the Flinders River at Walkers Bend. High flows (1.5-, 5- and 20-year daily flow volumes) vary from the EFOs • Reductions in small to medium floods have potential implications for floodplain connectivity and inundation, but this is complicated by complex interactions between the Flinders River and major tributaries as well as spatio-temporal variability between flood events • Reductions in flow have potential implications for 'of concern' REs in this reach (Appendix B) • This reach has persistent waterholes that are dependent on surface flows. The Source modelling indicates that passing flows from the Flinders River Weir minimise impacts on the incidence of no flow but the modelling does not appear to account transmission losses. Further investigations would be required to clarify this. • Reductions in waterhole habitat persistence and/or quality would have implications for fish and other vertebrates that rely on these refugia, including species of conservation significance such as the freshwater sawfish • The effectiveness of passing flows in maintaining wetted habitat on riffles/glides and longitudinal connectivity may be reduced by transmission losses
Reach 6 – Estuary (Tidal Limit to River Mouth)	M	• The Saego Dam case complies with four out of seven EFOs for the Flinders River at Walkers Bend. High flows (1.5-, 5- and 20-year daily flow volumes) vary from the EFOs • Key values in this reach that are associated with high flows include commercial, recreational and indigenous fisheries, and the Southern Gulf Aggregation (listed in the Directory of Important Wetlands in Australia) • Further investigations would allow enable the significance of variations from the 1.5-, 5- and 20-year daily flow volume EFOs for these values to be clarified, as discussed in the text
Reach 7 – Southern Gulf of Carpentaria	L/M	• The Saego Dam case complies with four out of seven EFOs for the Flinders River at Walkers Bend. High flows (1.5-, 5- and 20-year daily flow volumes) vary from the EFOs. However, the Flinders River contributes only 16% of total river inflows to the SGoC. • Further investigations using models for White Banana Prawns and Barramundi would enable the implications for the GoC fisheries to be clarified

8.2.2 Implications for Key Habitats

8.2.2.1 Waterholes

Waterholes have high ecological importance in the Flinders River because they provide critical dry season refugia for many fauna species, including fishery species and species of conservation significance such as the freshwater sawfish.

Passing flows are provided by the Project; however, transmission losses are potentially high, particularly at the ends of dry spells, with significant losses expected due to filling of empty pools and soakage into the dry sandy bed. Further investigations should be undertaken to ensure that passing flows are adequate to maintain waterhole refugia despite transmission losses.

The substantial reductions in medium and high flows indicated by the nodes closest to the Project area (Node 009 and Richmond) have potential implications for the physical structure of pool and waterhole habitats, particularly in Reaches 1 to 3. Reductions in pool/waterhole depth, which may occur if scouring flows are reduced, would reduce the availability and quality of refugial habitat.

Table 19 Implications of the Saego Dam case for waterhole habitat

Reach	**Implications for Waterhole Habitat**
Reach 1 – Flinders River Weir to Walkers Creek	• No permanent waterholes are known. One persistent waterhole has been identified, close to the Project area • Passing flows are expected to maintain persistent seasonal waterhole habitat • High risk of change in habitat structure due to reductions in medium and high flows, with implications for habitat quality
Reach 2 – Walkers Creek to Dutton River (Richmond)	• No permanent or persistent waterholes are known. • Passing flows are expected to maintain seasonal waterhole habitat • High risk of change in the habitat structure of seasonal waterholes due to reductions in medium and high flows, with implications for habitat quality
Reach 3 – Dutton River to Stawell River	• At least one permanent or persistent waterhole has been identified in this reach, in the vicinity of the Stawell River confluence • Uncertain whether passing flows will maintain waterhole habitat quality persistence due to the risk of transmission losses, particularly at the end of dry spells when pools and waterholes further upstream are empty • High risk of change in habitat structure of waterholes due to reductions in medium and high flows, with implications for habitat quality
Reach 4 – Stawell River to Euroka Springs	• Several waterholes have been identified, including at least one permanent waterhole • Uncertain whether passing flows will maintain waterhole habitat quality and persistence due to the risk of transmission losses, particularly at the end of dry spells when pools and waterholes further upstream are empty • Medium risk of flow-related change in habitat structure of waterholes
Reach 5 – Euroka Springs to Tidal Limit	• Several permanent waterholes have been identified • Uncertain whether passing flows will maintain waterhole habitat quality and persistence due to the risk of transmission losses, particularly at the end of dry spells when pools and waterholes further upstream are empty • Low/medium risk of flow-related change in habitat structure of waterholes

8.2.3 Riffles and Glides

The Flinders River is highly ephemeral, with no riffle/glide habitat or longitudinal connectivity for extended periods. The passing flows proposed appear to be sufficient to hydraulically maintain the existing riffle/glide habitats and connectivity along the river, provided that they are efficiently transmitted downstream as indicated by the Source model. Further investigations should be undertaken to ensure that passing flows are adequate to provide connectivity down the river, taking into consideration transmission losses.

The structure of riffle/glide habitat may potentially change due to reductions in high flows that provide channel maintenance functions, particularly in Reaches 1 to 3. The reaches closest to the Project area (particularly Reaches 1 and 2) may also be affected by other impacts of the Project not measured in the hydrology model, including alterations in sediment delivery caused by the Flinders River Weir, a possible increase in flow persistence due to irrigation return flows, and possible rise in groundwater levels resulting from irrigation. More persistent flows in the river (or bedsands) may enable the growth of aquatic macrophytes, which would alter the substrate as observed in other rivers in Queensland with supplemented flows.

Reductions in medium and high flows have potential implications for the physical structure of riffle and glide habitats, particularly in the reaches closes to the Project area (Reaches 1 to 3) where the hydrologic impact are the largest.

8.2.3.1 Riparian Zone, Anabranches and Floodplains

Reductions in medium and high flows have implications for riparian zone vegetation, anabranches (connectivity and channel maintenance processes) and floodplains. Substantial reductions in medium and high flows in the reaches closest to the Project area (particularly Reaches 1 to 3) could potentially lead to changes in riparian and floodplain vegetation communities (including high conservation significance REs in Reach 3) and reduce the availability of inundated anabranch and floodplain habitat. This may affect colonial waterbirds if they use habitat within Reaches 1 to 3 for breeding, as suggested by DES (2018).

8.2.4 Implications of Infrastructure

The infrastructure arrangements associated with the Project have been taken into account in the risk assessment. The following key issues were identified:

- Effects of the Flinders River Weir on fish passage
- Effects of the Flinders River Weir on sediment transport
- Effects associated with the ponding and inundation caused by the Flinders River Weir and the Saego Dam offstream storage, including changes in water quality resulting from impoundment effects and changes in flora and fauna that have the potential to affect the ecology of downstream (and upstream) reaches (e.g. source of plant propagules, habitat for predators, refuge for fauna dispersal)

The Project area is situated approximately 700 km upstream of the mouth of the Flinders River (Table 3). Information provided by Engeny indicates that the catchment area upstream of the Project area is 7% of the total Flinders River catchment. On this basis, effects of the Flinders River on fish passage and sediment transport are expected to have local rather than regional significance.

It is assumed that the Flinders River Weir will incorporate a fishway to mitigate impacts on fish passage along the Flinders River. Waltham *et al.* (2013) expressed concern regarding the ability of the freshwater sawfish to negotiate instream passage barriers given the fish's length and saw-shaped rostrum, and this will need to be addressed in the fishway design. In general terms, scientific reviews have shown that the effectiveness of fishways is variable and many constrain the passage of fish communities (e.g. Harris *et al.* 2016).

9 Addendum – Alternative Scenario

Following the completion of the assessment of the Reference Project, Engeny examined options to improve compliance with the Gulf Water Plan EFOs. They modelled an alternative scenario with a 25% reduction in the storage capacity of Saego Dam (a nominal number) to test sensitivity and compliance.

Table 20 presents an assessment of this alternative scenario in relation to the Gulf Water Plan EFOs. The alternative scenario fully complies with 6 of the 7 Gulf Water Plan EFOs and varies from the 1.5-year daily flow volume EFO by 1% (
Table 20). Engeny advised that the alternative scenario indicates that with minor refinements to the design of the Project it would be possible to comply with all of the Gulf Water Plan EFOs without materially changing the economic outcomes identified in the preliminary business case.

Table 20 Assessment of the alternative scenario (25% reduction in Saego Dam storage capacity) in relation to Gulf Water Plan EFOs for the Flinders River at Walkers Bend (Source: Engeny)

Results	Results as a % of Pre-Dev			Requirement	Flow Requirement Satisfied?		
EFO ID	WRP-ROP	HIP Scheme	HIP Scheme (25% smaller Saego Dam)		WRP-ROP	HIP Scheme	HIP Scheme (25% smaller Saego Dam)
1	68.3%	68.5%	68.5%	<70%	Y	Y	Y
2	92.1%	92.6%	93.1%	>90%	Y	Y	Y
3	81.3%	81.5%	83.2%	>78%	Y	Y	Y
4	81.2%	83.7%	83.8%	>75%	Y	Y	Y
5	91.9%	87.4%	89.0%	>90%	Y	N	N
6	98.3%	95.2%	97.4%	>96.5%	Y	N	Y
7	99.0%	97.8%	98.7%	>98%	Y	N	Y

Water Resource Gulf Plan 2007 Requirements (Page 50/51)	
EFO ID	
1	*The proportion of no flow days in the simulation period should be no more than 70%*
2	*The mean annual flow as a percentage of pre- development flow should be at least 90%*
3	*The median annual flow as a percentage of pre-development flow should be at least 78%*
4	*The median Jan-March flow as a percentage of pre-development flow should be at least 75%*
5	*The 1.5 year daily flow volume as a percentage of pre-development flow volume should be at least 90%*
6	*The 5 year daily flow volume as a percentage of pre-development flow volume should be at least 96.5%*
7	*The 20 year daily flow volume as a percentage of pre-development flow volume should be at least 98%*

If the Project fully complies with all of the EFOs for the Flinders River at Walkers Bend, the requirements of the Gulf Water Plan in regard to EFOs will be met. The environmental flow studies in the next stages of the process (including the DBC and EIS processes) could then move forward to address questions relating to environmental management rules, water storage design and environmental impact mitigation.

The Project area is situated approximately 600 km upstream of the estuary and only a small percentage of the total Flinders River catchment area is situated upstream of the Flinders River Weir. Therefore, it is expected that compliance with the Gulf Water Plan EFOs will mean that environmental flow requirements relating to the Flinders River estuary and Gulf of Carpentaria are met, and further environmental flow studies for Project would be confined to the non-tidal reaches of the Flinders River.

Relevant matters outlined in the Gulf Water Plan, Chapter 5 'Strategies for achieving outcomes' include (but are not limited to):

- streamflows required to maintain:
    - the longitudinal connectivity of low flow habitats
    - the wetted habitats at riffles and other streambed features
    - the natural seasonality of flows and zero flows
    - the replenishment of refuge pools

    - the lateral connectivity between the Flinders River and adjacent riverine environments, including floodplains
- effects of the Flinders River Weir and Saego Dam, including implications for instream water levels, sediment transport, the river bed, banks and riparian vegetation, flora and fauna habitat, movement of fish and other species, and ecological values

The high-level risk assessment in Chapter 8 provides an overview of key issues and risks for the Reference Project. Hydrological modelling of the alternative scenario in the Source model (as presented in Chapter 3 for the Reference Project") would be necessary to enable comparative risk ratings for the alternative scenario. However, in general terms, environmental flow-related risks would be expected to be lower for the alternative scenario than the Reference Project, and easier to resolve or mitigate.

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