# Review of Water Resource (Warrego, Paroo, Bulloo, and Nebine) Plan 2003 and Resource Operations Plan

## Environmental Assessment Report–Stage 2

October 2013

**Science Delivery | Water Planning Sciences**
Department of Science, Information Technology, Innovation and the Arts

Queensland Government

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**Citation**

DSITIA 2013. Review of Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003. Review of Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 and Resource Operations Plan: Environmental Assessment Report–Stage 2. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

October 2013

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# Executive summary

The Queensland Government, through the Department of Natural Resources and Mines is reviewing the Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 (herein referred to as the plan). The water resource planning process is prescribed in the Water Act 2000. This report presents the second stage of the environmental assessment of the plan which (i) reviews the effectiveness of the environmental strategies of the existing Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 and Basin Resource Operations Plan; (ii) assesses the outcomes and effectiveness of the existing WRP; and (iii) provides recommendations for the new WRP. The assessment uses an eco-hydraulic modelling approach, based on the principles of ecological risk assessment to assess the risk to aquatic ecosystem components, processes, and services from the plan area. The approach draws on existing information and knowledge of the ecological values of the plan area as well as relevant flow-ecology information in the broader scientific domain.

Overall, the environmental assessment identified low risk to surface water ecological assets from water resource management activities in the plan area which was consistent with a broad threat prioritisation undertaken for the region as part of the Queensland Government's Stream and Estuary Assessment Program. The risk to all surface water ecological asset indicators identified for the plan area could not be assessed due to insufficient information about the consequence of changed hydrological conditions. However for those which were assessable there were some cases where there was an increased risk profile due to the alteration of hydrologic conditions that support them.

Potential groundwater dependent ecosystems were identified across the plan area, but risk to these from the current plan could not be assessed because there was insufficient information available on both their dependency on groundwater hydrological attributes and how current management has modified natural groundwater hydrology.

In order to mitigate identified increases in risk, or enable future investigation of currently unassessed risks, the following actions are recommended. Updates to the current WRP and ROP should consider these recommended strategies for environmental risk management alongside the social and economic strategies and outcomes being managed by the plan.

**Warrego**

1. For new and traded entitlements develop and apply cease to pump waterhole depth thresholds. Such thresholds are intended to protect the persistence of waterholes and thus the availability of habitat for fish and other biota, during protracted periods without flow.

2. Monitor the occurrence of flow events that provide fish migration opportunities at gauging stations, and if the time since the previous suitable event is > 3 years, protect the next event to enable fish dispersal. Additional hydrological analysis would be required to derive a rule that achieves this protection and maximises the likelihood of a migration event occurring. Such a rule could form an additional criterion under the Announced Period water sharing rules in s. 97(2) of the ROP.

3. Ensure that stock and domestic water releases from Allan Tannock Weir are not only of equivalent volume to inflows, but are also of at least equivalent duration and with equivalent rates of rise and fall to the pre-development scenario, to prevent fish responding to flow cues and being stranded by artificially shortened events.

4. Knowledge improvement activities could be conducted over the life of the plan to improve the understanding of interactions between riverine flooding, local rainfall and groundwater in supporting the watering requirements of floodplain vegetation, and the wetting regime required to support the ecological values and processes of wetlands.
5. Knowledge improvement activities, including waterhole mapping and persistence modelling, around the Cunnamulla node over the life of the plan could be undertaken to establish Thresholds of Concern and thus enable an assessment of the risk posed by the full entitlement scenario to waterholes as refugia.
6. Knowledge improvement activities, such as waterhole sediment depth profiling and core analysis, may be implemented over the life of the plan to establish accumulation and scouring rates and determine the frequency with which river-forming flows are required to enable an assessment of risk.

**Paroo**

No increase in risk was identified between the pre-development and full entitlement IQQM scenarios for the two assets modelled in the Paroo catchment.

**Bulloo**

No increase in risk was identified between the pre-development and full entitlement IQQM scenarios for the two assets modelled in the Bulloo catchment.

**Nebine**

The risk assessment for the Nebine catchment identified changes in the provision of flow requirements that may pose a threat to one of the six assets assessed—flow spawning fish. The recommendations to mitigate the identified risk are the same as those for the Warrego catchment for this asset (see above).

# 1. Introduction

## Background

The Queensland Government, through the Department of Natural Resources and Mines is reviewing the Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 (herein referred to as the plan). The water resource planning process is prescribed in the Water Act 2000.

A water resource plan is a framework for sustainable management of water. It defines water availability, priorities of water use, management strategies, performance indicators and monitoring and reporting requirements that apply over its 10–year life.

The key objective of the planning process is to find an acceptable balance between existing water users, the environment and potential future water users by providing for ecologically sustainable water extraction. The plan's strategies for managing and allocating water are designed to maintain ecosystem health and to help provide the necessary water requirements to sustain the aquatic environment, including both surface water and groundwater dependent ecosystems.

## Purpose of the environmental assessment

This report presents the second stage of the environmental assessment of the plan. The objectives of the environmental assessment are to:

- review the effectiveness of the environmental strategies of the existing Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 and Basin Resource Operations Plan;
- assess the outcomes and effectiveness of the existing WRP; and
- provide recommendations for the new WRP.

The assessment results are presented in this summary report, and are supported by a series of technical reports. This summary report synthesises the information in the Stage 1 assessment and results from the Stage 2 technical report and makes recommendations on mitigation strategies to minimise identified risks, in order to inform the development of a new WRP.

## Methodology

The Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 environmental assessment has been conducted by the Department of Natural Resources and Mines (DNRM) and Department of Science, Information Technology, Innovation and the Arts (DSITIA). The assessment draws upon the results of monitoring and research conducted by the Queensland Government in the plan area during the life of the current plan, studies undertaken by other research institutions, and relevant expert knowledge. The Queensland Government’s Environmental Flows Assessment Program (EFAP) is a key source of information on ecological assets and their critical flow requirements.

## Environmental assessment report outline

This report presents a summary of information contained in Review of Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 and Resource Operation Plan: Environmental risk assessment for selected ecological assets (DSITIA 2013a). To provide context, this report is intended to be read in conjunction with the Environmental Assessment Report–Stage 1.

This report is structured as follows:

Chapter 2—outlines the hydrology and water resource development of the Warrego, Paroo, Bulloo and Nebine River Basins.

Chapter 3—outlines the flow requirements for the general ecosystem components for the Warrego, Paroo, Bulloo and Nebine River Basins and discusses the critical water requirements for selected ecological assets.

Chapters 4 and 5—an assessment of the effectiveness of the water resource plan based on selected ecological assets.

Chapter 6—an assessment of the current environmental provisions contained with the existing WRP and ROP.

Chapter 7—conclusions and recommendations for environmental provisions for the new draft WRP and ROP.

# 2. Hydrology and water resource development of the plan area

The WPBN Plan area is comprised of the Queensland portions of the Warrego, Paroo, Bulloo and Nebine catchments, which lie to the west of the Condamine-Balonne catchment, and east of the Cooper Creek catchment in south-western Queensland (Figure 1). The plan area comprises more than 50% of the total drainage area in the Queensland portion of the Murray-Darling system (QDPI 1993), covering approximately 190 956 km$^2$ (DERM 2010a). Rainfall is highly variable and summer-dominant, with 60% to 70% falling between October and March. The drainage systems usually consist of a string of waterholes, some of which are permanent, with the main stem dividing into channels downstream. The main rivers include: the Warrego River, the Paroo River, the Bulloo River, Nebine Creek, Wallam Creek and Cuttaburra Creek. The Warrego and Paroo Rivers feed various wetlands, including floodplain wetlands, freshwater wetlands and saline lakes (Kingsford et al. 2002). During large floods, the Warrego and Paroo Rivers also drain into the Darling and Culgoa Rivers of the Murray-Darling Basin in north-west New South Wales. The Bulloo River does not flow into the Murray-Darling Basin, but terminates at Bulloo Lakes in Queensland.

The Nebine, Warrego, Paroo and Bulloo catchments experience variable and ephemeral flow conditions. Streams and rivers in the Warrego and Paroo catchments have flow regimes that correspond to class 11 (unpredictable summer highly intermittent) and 12 (variable summer extremely intermittent) respectively after Kennard et al. (2009). Class 11 streams and rivers are less predictable than other intermittent stream types and exhibit weak seasonality, with high flows occurring at any time during the summer (Kennard et al. 2009). Class 12 streams and rivers are extremely intermittent. They are dominated by infrequent large floods that can occur at any time of the year–they are also characterised by very high daily flow variability (Kennard et al. 2009).

There has been little hydrological modification within the plan area, and grazing is the dominant land use (Porter et al. 2007). There are two publically owned storages: Allan Tannock Weir (4350 ML) on the Warrego and Bollon Weir on Wallum Creek (Cottingham 1999). SunWater operates the only Water Supply Scheme (WSS) in the plan area (Cunnamulla WSS), while DNRM operates the five (unsupplemented) Water Management Areas:  Upper Warrego WMA, Lower Warrego WMA, Paroo WMA, Bulloo WMA and Nebine WMA (DERM 2010a).

## Warrego catchment

The primary waterway of the Warrego basin is the Warrego River. The tributary rivers of the Nive, Ward and Langlo flow from the upper part of the catchment and drain into the main river below Augathella (Nive River) and below Charleville (Ward and Langlo Rivers). The main towns situated in the Warrego catchment are: Augathella, Charleville and Cunnamulla. The average annual rainfall varies between 374.5 mm at Cunnamulla to 498.7 mm at Charleville. Stream flow records for the Warrego River are available for gauging stations at Allan Tannock Weir (1992–present), Cunnamulla (1961–1976), Wallen (2006–present), Wyandra (1967–present), Charleville (1926–1978), Augathella (1967–present) and Binnowee (1999–present) in Queensland, and for Barringun (1993–present) and Ford's Bridge (1921–present) in New South Wales. Stream flows in the Warrego River catchment are variable and seasonal. The variability is illustrated by the stream flow records from the Wyandra stream gauging station for the period 1967 to 2005 which show that annual discharge for the Warrego River varied from 579 ML in 2003 to more than 84 000 ML in

1990. Most stream flow events occur in summer although significant flows can occasionally occur in the winter months.

There is minimal cropping in the catchment, with some water extraction for cotton. There are 70 privately owned water storages in the Warrego, and State-owned Allan Tannock Weir at Cunnamulla. The catchment has several Nationally Important Wetlands listed: Warrego River Distributary System (QLD169), Lake Dartmouth (QLD168), Wyandra-Cunnamulla Claypans Aggregation (QLD166) and "Murrawondah" Lakes (QLD174). The waterholes of the Warrego Distributary System are also considered to be Aboriginal cultural sites.

## Paroo catchment

The Paroo River flows from the north part of the catchment, above Cheepie, and meets Beechal Creek just below the property of "Humeburn". It then passes through Eulo before crossing the Queensland-New South Wales border at Hungerford. The average annual rainfall at Eulo is 332.1 mm. Stream flow records for the Paroo River are available for gauging stations at Caiwarro (1967–present) and Yarronvale (1967–1988) in Queensland, and for Willara Crossing (1975–present) in New South Wales. Stream flow in the Paroo River catchment is variable and seasonal. The variability is illustrated by the stream flow records of the Caiwarro stream gauging station for the period 1967–2005 which show that annual discharge for the Paroo River varied from approximately 1200 ML in 1979 to more than 67 000 ML in 1990. Most stream flow events occur in summer although significant flows can occasionally occur in the winter months.

The primary land use in the Paroo catchment is sheep and cattle grazing. Irrigation is minimal and includes a date and fig farm at Eulo, and some cattle fodder crops. The Paroo River is essentially an unregulated stream with no significant in-stream storage, and is considered to be the last unregulated river in the Murray-Darling basin. Based on license information, there are two private water storages in the Paroo. The catchment has several Nationally Important Wetlands listed: Paroo River Waterholes ("Caiwarro" section of Currawinya National Park) (QLD176), Lake Numalla Aggregation (QLD123), Lake Wyara (QLD124), Lake Wombah-Kungi Lake Group (QLD175), Lakes Bindegolly and Toomaroo (QLD125). Aboriginal cultural sites include: Corni Paroo Waterhole, sites around Lakes Numalla and Wyara. There are also Ramsar listed areas in the catchment: Currawinya National Park (which includes Lakes Numalla and Wyara, and Paroo River Waterholes).

## Bulloo catchment

The Bulloo River rises in the Gowan Range, and is joined by Blackwater Creek just below Adavale. It flows south before terminating at Lake Bulloo, approximately 170 km south-west of Thargomindah. Thargomindah and Quilpie are the major towns in the catchment. Average annual rainfall within the catchment varies from 391.4 mm at Adavale to 286.9 mm at Thargomindah. Stream flow records for the Bulloo River are available for gauging stations at Autumnvale (1967–present), Quilpie (1967–present) and Thargomindah (1959–1960) in Queensland. Flow in the Bulloo River catchment is seasonal and variable, demonstrated by records from the Autumnvale stream gauging station for the period 1967 to 2005 which show that annual discharge for the Bulloo River varied from approximately 1721 ML in 1980 to more than 95 000 ML in 1974. Most stream flow events occur in summer although significant flows can occasionally occur in the winter months.

The primary land use in the Bulloo catchment is cattle grazing. There is little to no irrigation. The Bulloo River is essentially an unregulated stream with no significant in-stream storage. There are four privately owned water storages in the Bulloo. The catchment has several Nationally Important Wetlands listed: Bulloo Lake (QLD024), Lake Bullawarra (QLD031), Nooyeah Downs Swamps Aggregation (QLD041), Quilpie (Bulloo River Floodplain) waterholes (QLD167), Mitchell Swamp (QLD170). Waterholes at Quilpie are considered to be Aboriginal cultural sites.

## Nebine catchment

The Nebine basin is comprised of three main creek systems–the Nebine, Mungallala and Wallam Creeks. Mungallala Creek rises in the Chesterton Ranges, whilst the Nebine and Wallam Creeks commence further south. All three creeks flow south, parallel to each other, before crossing the Queensland-New South Wales border west of Hebel. The system then flows into the Culgoa River before joining the Darling River. Bollon is the major town in the catchment and experiences average annual rainfall of 461.9 mm. Stream flow records for the Nebine Basin are available for a gauging station on Wallum Creek at Cardiff (1999-present), above Bollon, and one on Nebine Creek (2007–present) above the Culgoa National Park.

The primary land use in the Nebine catchments is sheep grazing. From existing license information, there are 13 privately owned water storages in the catchment, and a publicly owned weir at Bollon. The Nebine catchment has two nationally Important Wetlands listed: Wyandra-Cunnamulla Claypan Aggregation (QLD166), and “Myola”–“Mulga Downs” Salt Lake and Claypans (QLD173).

# 3. Flow-dependent ecosystems of the plan area

## Ecosystem components

### Floodplain wetlands and vegetation

Floodplains are complex landscapes that are highly spatially and temporally variable. The combination of topography, soil type and land use leads to variability in both the frequency with which different parts of the floodplain receive water and the duration that surface water persists. Because of this, floodplains are a mosaic of ecosystems that utilise the hydrologic regime at relatively small scales. Flow regime changes resulting from water resource development, particularly alterations in medium and high flows, have potentially significant implications for riparian and floodplain plant communities (Mackay & Thompson 2000). Flood harvesting may reduce the magnitude of individual floods and thus increase the duration of spells between flooding for some habitats and, over longer periods, influence the distribution of floodplain species (Bren 1992; Kingsford & Thomas 1995; Bowen et al. 2003; Thoms 2003).

Large river floodplains support vegetation communities that are amongst the most productive and diverse in the world (Capon 2004). The structure and floristic composition of floodplain plant communities are influenced by environmental gradients related to fluvial dynamics, floods and soil moisture availability (Naiman & Décamps 1997). Flood flows provide moisture, disperse seed, deposit sediments that provide a growth medium for colonising vegetation and stimulate the recruitment of riparian and floodplain species (Petitt et al. 2001; Woods 2012). Soil moisture conditions are influenced by stream flow, along with rainfall and shallow groundwater. The interactions between these sources of water are complex, often making it difficult to determine the effect of stream flow changes on the availability of water to riparian zone and floodplain plants (Eamus et al. 2006).

Floodplain wetlands sustain diverse ecological communities that are adapted to take advantage of the resources that are periodically available (Westlake & Pratt 2012). In dryland river landscapes, floodplain wetlands play an important role in the exchange of carbon and nutrients, provide ecosystem services such as water quality buffering, act as refuges during dry spells and provide habitat to a diverse community of plants and animals (Thoms 2003; DSEWPC 2012). Patterns of hydrological connectivity and subsequent wetland wetting and drying cycles are important drivers regulating species diversity and richness (Boulton & Brock 1999). The sequence of drying and rewetting in temporary floodplain wetlands makes them highly productive. As the wetlands dry, decaying aquatic organisms create a rich substrate for the growth of dryland grasses and herbs and upon rewetting, breakdown of these provide substantial resources for aquatic invertebrates, algae and plants (Scott 1997). The rapid development of these food sources makes inundated wetlands excellent breeding habitats for consumers such as waterbirds, fish and turtles.

The plan area is home to several iconic floodplain plant species including river red gum, black box, coolabah, tangled lignum, river cooba and yapunyah gum, which require riverine flooding for both successful reproduction and recruitment, and to maintain the vigour of adult plants (Roberts & Marston 2000, Rogers 2011, Woods et al. 2012). Floodplain wetlands are present in all four plan area catchments and support ecological values including waterbird breeding opportunities and provision of preferred habitat for the eastern snake-necked turtle (*Chelodina longicollis*).

## Vertebrates

### *Fish*

Flows play a key role in providing habitat for fish, via hydraulic habitat and connectivity, maintenance of channel morphology and substrate and influences on water quality and aquatic vegetation.

Flows provide cues for the life history processes of a number of fish species, including migration, spawning, recruitment and dispersal (e.g. Humphries & Lake 2000). Many Australian species require seasonal flooding, with changes in water temperature and day length contributing to the spawning cue. In contrast, other species require elevated spring temperatures and low, stable flows for spawning, and successful larval development and upstream dispersal movements of juveniles of many species often occur during low flow periods (Pusey et al. 2004). Low flows provide the opportunity for larvae to encounter high prey densities. Still or slow flowing water also ensure that eggs and larvae are not flushed downstream which will in turn increase stock for juvenile recruitment (Pusey et al. 2004).

Eighteen species of native fish have been recorded in the plan area, including the popular angling fish Yellowbelly, Murray Cod, listed as vulnerable under the EPBC Act, and eel-tailed catfish which has suffered population declines in southern parts of the Murray-Darling Basin (Rourke & Gilligan 2010). Fish of the region tend to be generalists, tolerant of the harsh conditions during dry spells, and possessing life history strategies to take advantage of the intermittent periods of flow (Balcombe et al. 2006). Three exotic fish species, European Carp, Goldfish and *Gambusia* are also present in the plan area.

### *Birds*

Many species of birds are associated to some degree with riverine and non-riverine wetlands during their life cycle, including waterbirds and species that inhabit riparian zones. Overbank flooding may trigger mass breeding events for some waterbird species. Maintenance of water levels within these wetlands is critical during the fledgling period to support nesting habitat and reduce predator access.

In the plan area, 57 species of waterbirds have been recorded including species of ducks, herons, spoonbills, and grebes, along with shorebirds and waders such as snipes, sandpipers and avocets. The Bulloo Floodplain, Paroo Floodplain and Currawinya, Lake Numalla and Lake Bindegolly have been identified as nationally or internationally important bird habitats, supporting significant proportions of the populations of Grey Teal, Australasian Shoveler, Hardhead, Sharp-tailed Sandpiper, Black Swan, Pink-eared Duck, Red-necked Avocet, Caspian Tern, Freckled Duck and Marsh Sandpiper (Watkins 1993; Kingsford & Porter 1994; Birdlife International 2012).

Many species breed in response to flooding, and utilise the inundated wetlands and lakes of the region for foraging, nesting and rearing young. In wet years, sites such as the Ramsar-listed Currawinya Lakes in the Paroo catchment can provide breeding habitat for thousands of colonial-nesting waterbirds such as ibis, egrets and pelicans (R. Kingsford pers comm.). Migratory species listed under international conventions, including many of the shore birds, do not breed in Australia but utilise the wetlands and lakes of the plan area as an overwintering habitat where they feed and build body condition prior to migrating north for the breeding season.

### *Amphibians and reptiles*

Many amphibians and reptiles are associated with aquatic habitats and have specific instream habitat requirements to support critical life history stages. For example, freshwater turtles access areas of exposed sand bars, gravel benches or structures such as large fallen trees to bask. Hence, the flow requirements of these species include flows for the maintenance of hydraulic habitat, water quality and the physical structure of instream habitats. Other amphibians and reptiles are associated with habitat provided by riparian zones, and hence their requirements include a flow regime that maintains the integrity of these areas.

There are 21 species of amphibians recorded in the plan area including tree frogs, burrowing frogs and toadlets. While these species do require water for parts of their life-cycle, they tend to utilise small, off-channel habitats where they are protected from large aquatic predators, and as such are more responsive to local rainfall than river flow. Five aquatic reptile species, turtles from the genera *Chelodina* and *Emydura*, have also been recorded in the plan area. Only one species, *Chelodina longicollis*, is known to have specific flow requirements.

### Invertebrates

Aquatic macroinvertebrates encompass a diverse range of biota including obligate aquatic organisms such as shrimp, crayfish, bivalves and snails, and insects with aquatic larval and juvenile stages such as dragonflies, mayflies, caddis flies, beetles, and true bugs. Collectively they play a critical role in the processing of nutrients and organic energy in aquatic ecosystems, and are a major constituent of the food for higher trophic levels (Arthington & Pearson 2007).

Most macroinvertebrates have specific habitat preferences related to flow and substrate, and are strongly influenced by the nature and extent of instream microhabitats. The interaction of water depth and velocity with the substrate profile determines the range of potential microhabitats available to benthic macroinvertebrates (Statzner et al. 1988; James et al. 2008).

Macroinvertebrate dispersal is facilitated by flow (Bilton et al. 2001). Species with flying adult stages often follow river channels along riparian flight paths. The larval and juvenile stages of many macroinvertebrates use drift as a dispersal strategy. Although this is a globally recognised phenomenon, several studies have shown that it is not a significant strategy in Australian macroinvertebrate populations (Kerby et al. 1995; Hughes et al. 1998).

The macroinvertebrate fauna of the plan area is typical of western Queensland arid and semi-arid rivers and as such is numerically dominated by tolerant insect taxa of the orders diptera, coleoptera, odonata, ephemeroptera and hemiptera, bivalve molluscs and crustacean taxa (Marshall et al. 2006a, 2006b). The shrimp *Macrobrachium australiense* is a conspicuous component of the fauna and important as a source of food for predatory fish (Sternberg et al. 2008; Woods et al. 2012). The snail *Notopala* sp. occurs in the Bulloo River and upper Warrego River where invasive carp are absent, but has been driven to extinction or near extinction throughout much of its natural range within the Murray Darling Basin (Sheldon & Walker 1997), including the remainder of the plan area, probably as a result of predation by carp in combination with other impacts.

### Instream vegetation

Instream vegetation includes both microphytic and macrophytic communities. Microphytic vegetation comprises benthic, epiphytic and metaphytic communities of single-celled, colonial and filamentous microalgae, macroalgae, and cyanobacteria. Carbon produced by these communities is a major contributor to food webs in sub-tropical river systems (Bunn et al. 1999; Hadwen et al. 2010). Their composition, distribution and productivity are influenced by environmental factors regulating biomass accrual and loss (Francoeur et al. 1999; Segura et al. 2010).

Otherwise known as macrophytes, aquatic plants are the most conspicuous instream vegetation and include both submerged (i.e. foliage below or at the water surface) and emergent (foliage above the water surface) forms. Flow regime changes have been associated with changes in the species diversity and abundance of riverine macrophyte assemblages. Flow regime changes are often conducive to macrophyte growth, especially where flow variations or flood magnitudes are reduced. Reductions in flow variability due to water resource development (flow supplementation) often lead to an increase in macrophyte biomass (e.g. Mackay 2006; Mackay & Thompson 2000).

In the rivers of the plan area, macrophytes are relatively rare. Those that are present, such as *Ludwigia peploides*, *Azolla pinnata* and *Persicaria* spp. are either floating or emergent, allowing them to survive the often high turbidity and fluctuating water levels. A range of planktonic microphytes inhabit the rivers and again the most common taxa, cryptophytes, chloropytes and euglenophytes, are those that are able to maintain their position near the water surface using buoyancy or motility in order to stay within the shallow photic zone (McGregor et al. 2006).

## Ecosystem processes

**Fluvial geomorphology (river landforms) and river-forming processes**

The primary drivers of channel morphology are hydrology, the underlying geology of the river channel and sediment availability (Clifford & Richards 1992). Geology determines the extent to which flows can alter channel characteristics such as stream bed, bed slope and meander, whereas sediment availability and entrainment processes can determine the development and maintenance of pools and bars. Biota can also influence geomorphological processes–burrowing animals can mobilise sediments, riparian vegetation protects surfaces from erosion and instream vegetation affects stream power by altering hydraulic roughness.

Stream channels are generally comprised of an alternating series of shallow bars and deeper pools (Newbury & Gaboury 1994). During no-flow periods, pools become a series of isolated waterholes separated by bars and those waterholes become important refugial habitats for biota. The creation and maintenance of channel bars and deeper pools is known to be dependent on flow driven sediment entrainment and deposition processes (Wilkinson et al. 2003; Haschenburger & Wilcock 2003). Sediment transport occurs when sheer stress, the force acting upon the substrate resulting from flow, is sufficient to entrain substrate sediments. The location of maximum sheer stress moves up and down stream with changes in the magnitude of flow (Sear 1995; Wilkinson et al. 2003). High flows exert the greatest sheer stress, scouring fine sediments from pools and depositing them on bars, while low flows tend to shift bar substrates and deposit them in pools (Wilkinson et al. 2003). In this way, changes in flow regime can influence the arrangement and persistence of waterholes.

The Queensland portions of the Murray-Darling Basin and the Bulloo have generally shallow relief and low stream segment slopes resulting in low disturbance intensity from flow events (DEHP 2012). Much of the area is depositional valley bottom flat, with silt/clay streambed substrates and development of extensive floodplains (DEHP 2012). Some waterholes in the region have experienced fine sediment accumulation (DSITIA, unpublished data).

### Waterholes as refugia

Waterholes are sparse but characteristic geomorphic features of low-gradient, muddy, anastomosing, dryland rivers. They have been defined as self-scouring features of channels and floodplains that maintain water during periods without flow in otherwise temporary rivers (Nanson et al. 2002). Much of the published accounts of their morphology, formation and ecology are from studies conducted in Cooper Creek in Lake Eyre Basin.

Waterholes commonly exhibit contemporary splays of mud and sand deposited at their downstream ends as a result of scour from the waterhole and channels may consequently bifurcate at their downstream ends (Knighton & Nanson 2000). They occur in a variety of settings including in rocky gorges, in flood outs and as isolated features on floodplains away from main river channels, but those best known are relatively deep and wide sections of river channels. Waterholes are too irregularly distributed to be considered deepened pools in an orderly bed sequence (Knighton & Nanson 2000). They tend to remain in fixed channel positions at locations of flow convergence and these attributes indicate a recent origin with their dimensions in equilibrium with the contemporary flow regime of the river. Thus they are not a legacy of earlier Quaternary flow regimes, at least in Cooper Creek.

The abundance of waterholes in Cooper Creek may be related to the presence of a more easily eroded sand sheet at depths of only 2-9 m below cohesive surface sediments (Knighton & Nanson 1994). Four mechanisms of waterhole formation and maintenance have been proposed, all based on settings that provide sufficient shear stress associated with flood events to provide scour (Nanson et al. 2002, Knighton & Nanson 2000):

i. channels constricted on both banks by Aeolian dunes form short, wide and shallow waterholes;
ii. channels flanked on one bank by a single dune, valley margin or similar form longer and deeper waterholes
iii. the confluence of multiple anastamosing channels draining inundated floodplains, which generate scour without channel constriction;
iv. deeply penetrative bands of relatively high velocity can occur in waterholes during high-flow events, suggesting that localized values of bed shear could be quite large even when cross-sectional averages are usually less than 1 m/sec

By focusing erosional energy when the floodplain is broad, waterholes play a significant role in maintaining existing river channel morphology (Knighton & Nanson 1994).

It is generally expected that flow velocity at a site increases with discharge, with a major discontinuity in this trend occurring at bankfull discharge because of water spilling onto the floodplain at this stage, after which discharge maximum velocity remains constant and mean velocity decreases (Knighton & Nanson 2000, 2002). However, this was not the case at two of three waterholes investigated in Cooper Creek, where velocity continued to increase with discharge before levelling off at discharges greater than bankfull. These anomalies were probably associated with local variability in the discharge stages at which flood width increased, possibly due to errors in establishing bankfull discharge at waterholes where channels were relatively confined, or possibly because of unstable velocity discharge relationships (Knighton & Nanson 2000). Such relationships have not been published for Warrego, Paroo Bulloo or Nebine waterholes, and so we assume the general expectation of maximum velocity and thus scour at bankfull.

Waterholes, where water persists during often prolonged spells without river flow, provide the primary drought refuges for the biota of dryland rivers and are therefore critical to their aquatic ecosystems. The types of aquatic biota utilising refuges varies spatially between waterholes and temporally at individual waterholes. Typically there is more variability in assemblage composition through time in single waterhole than there is variability between waterholes at a single time (Marshall et al. 2006, Mcgregor et al. 2006, Arthington et al. 2005). This indicates that a mosaic of waterholes through space and time is needed to maintain viable populations of all dependent aquatic species (Sheldon et al. 2010). This variability is driven by occasional, but critical connectivity between refuges, with population viability also depending upon rates of dispersal and recolonisation during occasional flow events which punctuate periods of waterhole isolation. There are three general dispersal modes evident in the life histories of dryland river biota (Sheldon et al 2010): 'movers', which are not truly aquatic and can disperse by air or overland and not fully beholden to hydrology to provide connectivity; 'networkers' which are aquatic species restricted to refugia during isolation phases and which disperse and recolonise rapidly via hydrological connections when they occur; and 'refugals' which remain in refuge waterholes even when there is connectivity between them. Examples of each class are common in Queensland dryland rivers.

The quality of waterhole refuges is also critical to their function. In general the longer isolation continues, the harsher conditions in refuges become, yet aquatic populations must remain viable throughout these periods for species to persist (Sheldon et al. 2010). Quality is supported by energy subsidies from floodplain production during flood events, but in situ benthic algal production is vital during isolation phases. In turbid systems, light limitation acting in concert with the morphology of individual waterholes determines production potential, but at any given time the influence of hydrology on water depth controls this interaction (DERM 2010). Thus changes to connectivity between waterholes, their persistence during dry phases, or their connections to adjacent floodplains will impact their functioning as refuges and impact upon the diversity and resilience of entire dryland river ecosystems (Sheldon et al. 2010).

Many aquatic species found in the plan area, including fish and invertebrates such as freshwater mussels, *Notopala* snails, yabbies and prawns, use waterholes as their primary habitat (DSITIA 2013b). Other fauna such as freshwater turtles and waterbirds move to waterholes when their preferred wetland habitats dry, relying on them to survive extended dry spells.

## Groundwater dependent ecosystems

Groundwater dependent ecosystems (GDEs) by definition require access to groundwater to meet all or some of their water requirements, however in many systems groundwater dependence is either subtle or cryptic, extending beyond ephemeral or permanent expressions of groundwater at the surface (Hatton & Evans 1998). Following current understanding, GDEs can be categorised into three types after Eamus et al. (2006):

i. cave and aquifer systems (karstic, fractured rock, alluvial aquifers, hyporheic zone);
ii. ecosystems dependent on the surface expression of groundwater (baseflow, non-riverine wetlands, and mound springs); and
iii. ecosystems dependent on the sub-surface expression of groundwater, often accessible via the capillary fringe when roots penetrate this zone (terrestrial vegetation).

Cave systems are not present within the plan area. Subterranean aquifers and hyporheic zones (the zone of interaction between river water and the groundwater present in the banks and beds of rivers) are present throughout the plan area and have the potential to support groundwater fauna, or stygofauna, communities within them. The results of extensive aquifer sampling for stygofauna conducted in the Condamine-Balonne and Border Rivers region (DERM, unpublished data), located to the immediate east of the water resource plan area, were evaluated to identify aquifer chemical or morphological attributes associated with the presence/absence and composition of stygofauna assemblages. No meaningful associations were found between aquifer characteristics and stygofauna occurrences.

Ecosystems dependent on the surface expression of groundwater are not well documented within the catchments of the plan area. Non-riverine wetlands in the region have been mapped and these were assessed for possible dependence on groundwater (DSITIA 2013b). As most of these wetlands are shallow–generally less than 2 m (Andrew Biggs, pers comm.), and therefore do not intersect with aquifers in the region which were recorded to have depth to water table deeper than these wetland bases, it is unlikely that they are groundwater dependent. Mound springs associated with the great artesian basin are also present but are not influenced by shallower aquifers present in the water resource plan area and as such are not within the scope of this assessment.

In the plan area, ecosystems dependent on the sub-surface expression of groundwater are represented by terrestrial vegetation communities that depend on groundwater. This includes deep and/or shallow rooting terrestrial vegetation communities that utilise groundwater in either an obligate or facultative way. It does not include aquatic macrophytes that have an obligate requirement for either partial or complete submergence in water.

As part of the environmental assessment of the plan, groundwater dependent vegetation has been mapped for the Warrego, Paroo, Bulloo and Nebine catchments. In the Warrego, 26% of the area of the Queensland section of the Warrego catchment was occupied by potential groundwater dependent terrestrial vegetation communities dominated by *Acacia aneura*, *A. cambagei*, *A. victoriae*, *Eucalyptus populnea*, *E. ochrophloia*, *E. coolabah* and other low woodland species growing on residuals, alluvial plains and sand plains.

Similarly in the Paroo catchment 38% of the area of the Queensland section of the Paroo catchment was occupied by potential groundwater dependent terrestrial vegetation communities dominated by similar species. For the Bulloo catchment, where groundwater depth data is lacking, assessments could not be made using the methods applied to the other three catchments. Alternatively, distributions of RE (Regional Ecosystem) types that had been identified as potential

GDEs in the other catchments were used as an indicator GDE distribution (DSITIA 2013b). Using this modified method, 17% of the area of the Queensland section of the Bulloo catchment was determined to be occupied by potential groundwater dependent REs. For the Nebine catchment, 31% the area of the Queensland section of the Nebine catchment was occupied by potential groundwater dependent REs.

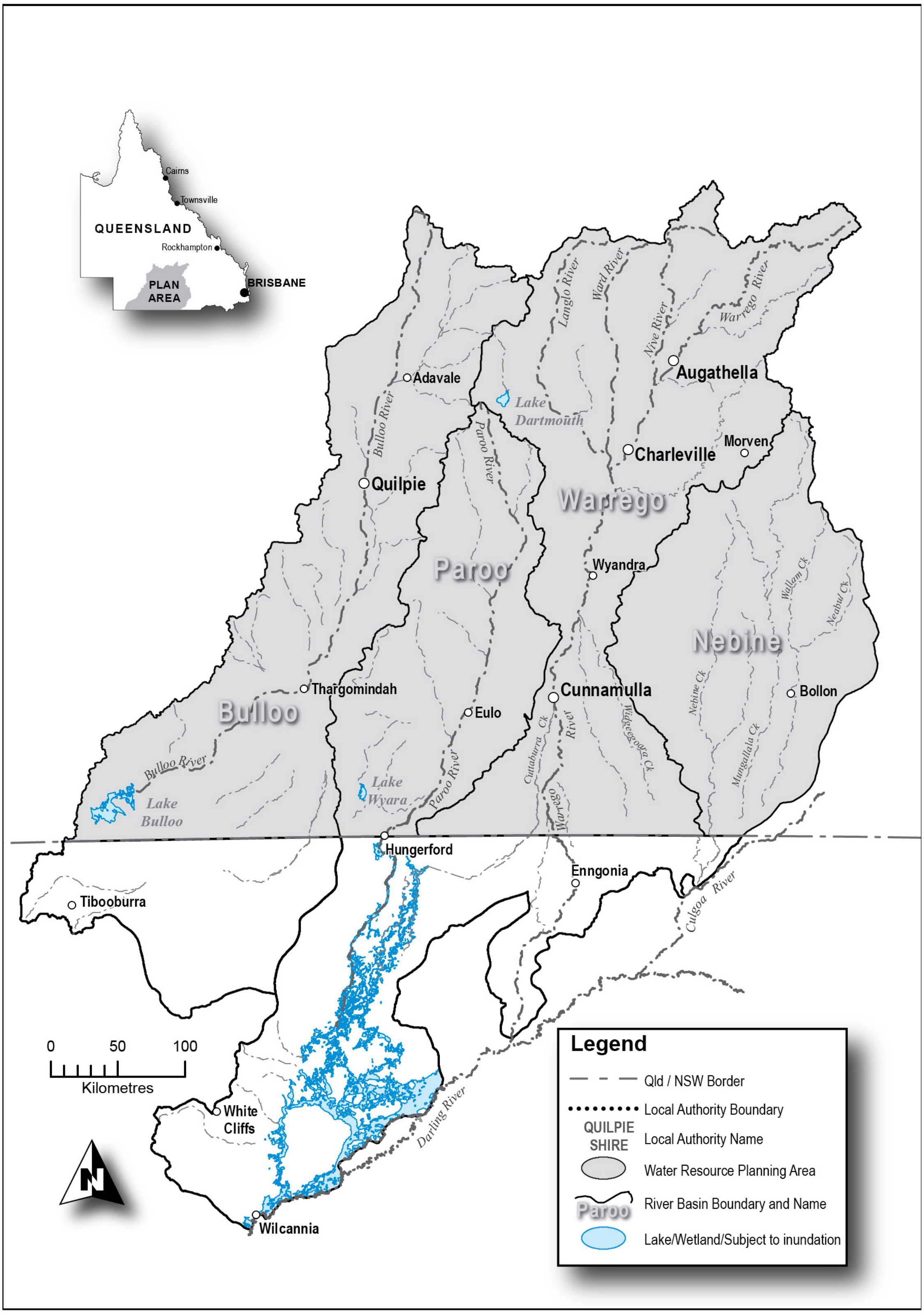


**Figure 1: Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 area**

# 4. Methods for assessing the effectiveness of the water resource plan

## Environmental risk assessment process

The environmental risk assessment aims to quantify the risks from water resource development specified in the plan. This risk assessment will inform the development of water management options for the new plan. The ecological risk assessment uses an eco-hydraulic modelling approach, based on the principles of ecological risk assessment (ERA) to assess the risk to aquatic ecosystem components, processes, and services from the plan area. The approach draws on existing information and knowledge of the ecological values of the plan area as well as relevant flow-ecology information in the broader scientific domain. The approach is consistent with the Framework for assessing the Environmental Water Requirements of Groundwater Dependent Ecosystems Report 1 Assessment Toolbox (Clifton et al. 2007) and the principals outlined in Ecological Risk Assessment of Water Resource Plans (Marshall & McGregor 2006). A summary of the process is illustrated in Figure 2.

The approach partitions the critical flow dependencies of ecosystem components, processes and services and considers how these water requirements are provided over time under the water management scenarios represented by the WRP. These components, processes and services are indicators sensitive to flow modification and are therefore broadly representative of the ecosystem response to a modified flow regime. Referred to as ecological assets, they are broadly defined as ecosystem components, processes or services that are dependent on the conditions provided by the flow regime to support their long term viability. An ecological asset may be a species, a group of species, a biological/ecological function, an ecosystem, or a place of value.

## Methods

**Selecting surface water ecological assets for the environmental assessment**

***Identification of surface water dependent ecological assets***

Surface water dependent ecological assets that are relevant to the plan area were identified from a comprehensive review of the scientific literature, information in technical reports, guidelines, action plans, regional ecosystem mapping, government databases, and through extensive consultation with relevant local experts and stakeholders (see Ecological Asset Selection Report, DSITIA 2013b).

For the purposes of the assessment, ecological assets were considered as a sub-set of the water dependent ecosystem components, processes and services that are:

i. critically-linked to one or more aspects of the flow regime (i.e. magnitude, duration, timing, rate of change, etc.) in order to maintain its long term viability; and
ii. potentially sensitive to water allocation and management (i.e. its distribution coincides with the areas affected by the plan).

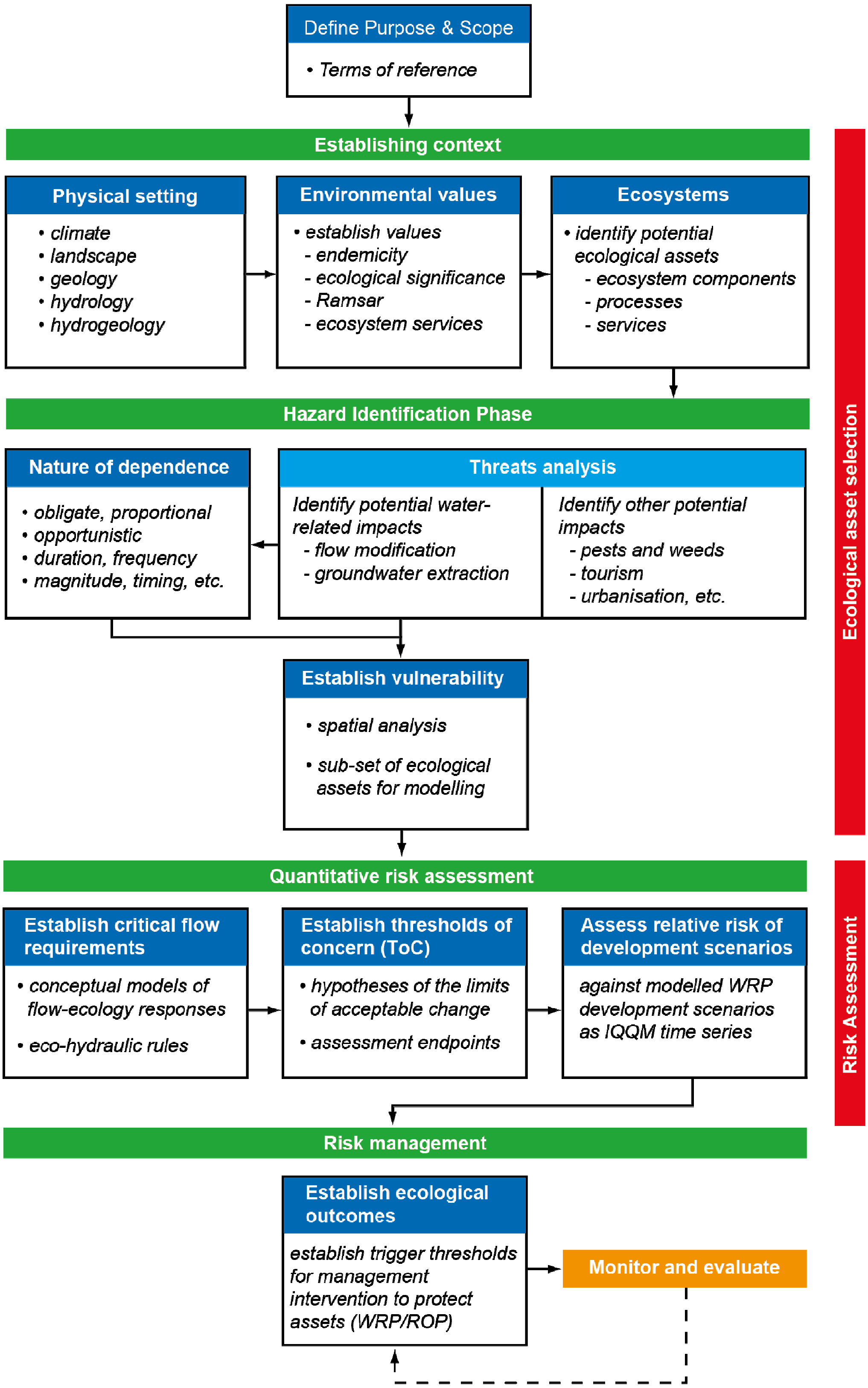


**Figure 2: Summary of the environmental assessment process (adapted from Clifton et al. 2007)[1]**

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[1] Red boxes refer to the relevant technical reports where the results of the process are detailed

A total of 2937 ecological assets including species of flora and fauna, vegetation communities, wetlands, instream and floodplain habitats and processes, and estuaries were identified from across the plan area (see Ecological Asset Selection Report, DSITIA 2013b). Based on best current information from the scientific literature and expert knowledge, 94 ecological assets were determined to be critically linked to aspects of the flow regime and therefore potentially vulnerable to water resource development. These assets are broadly representative of the ecosystem responses to a managed flow regime and were considered candidates for the environmental assessment.

### *Selecting ecological assets for the environmental assessment*

Of these 94 candidate assets, there were nine for which sufficient knowledge of their flow requirements was available to enable detailed analysis of the impact of water resource development on their persistence (Table 2).

From this sub-set of ecological assets, data on their life history or process requirements were distilled into discrete aspects of the flow regime with respect to location, timing, magnitude, duration frequency, habitat features and associated water quality attributes where relevant. This allows the risk to the asset's long term viability to be assessed.

Surface water dependent assets were categorised into three hydrological classes based on their critical flow requirements (Table 1). Each hydrological class represents a particular aspect of the flow regime. By categorising assets into these classes, the risks to assets can be understood in relation to specific changes to the flow regime that occur as a result of water resource development.

**Table 1: Hydrologic classes**

| Hydrologic class | Summary description |
|---|---|
| No-flow | No-flow assets have a critical flow requirement that is linked to periods without river flow. |
| Low flows | Low flow assets have critical flow requirements that are linked to low flow events, which are typically associated with flows persisting outside of flood events and events associated with high, seasonal rainfall. For example, these links may be associated with baseflow contributions from groundwater or contributions from small rainfall events in the dry season. |
| Medium flows | Medium flow assets have critical flow requirements that are linked to medium flow conditions. These links are typically associated with intermediate flow conditions that occur between low and high flows. For example, these links may be associated with flow periods following flood events as flow subsides, or with rainfall events of sufficient size to increase flow volumes but not large enough to produce flooding. |
| High flows | High flow assets have critical flow requirements that are linked to high flow conditions that are typically associated with high, seasonal rainfall during wet periods. For example, these links may be associated with flood plain inundation or spawning/migration cues. |

### Defining assessment endpoints

Assessment endpoints are the focus of the risk assessment. In this context, they represent the flow-dependent ecological components and processes of the plan area. For most ecological assets, the assessment endpoints relate to the maintenance of their long-term viability in the plan area.

Typically assessment endpoints cannot be directly measured. Therefore measurement endpoints are used to represent them. For most species-based assets, the measurement endpoints relate to the provision of connectivity, or spawning and recruitment opportunities provided by aspects of the flow regime. Measurement endpoints for ecological processes vary, however they generally relate to the provision of critical habitat, or conditions that support ecosystem structure and/or function.

Assessment endpoints were defined for each of the eight assets selected as suitable for the environmental assessment. The assessment endpoints for each of these assets and their link to hydrology (hydrologic class) are summarised in Table 2. The process of defining assessment endpoints provides the necessary detail to progress with the sub-phase "Establish critical flow requirements", under the "Quantitative risk assessment phase" shown in Figure 2.

**Establishing critical flow requirements (eco-hydraulic rules)**

The exposure analysis phase of the ERA uses information on the flow requirements of the prioritised ecological assets to develop a time series of opportunities for each water resource development scenario as it relates to a specific ecological response defined as the measurement endpoint. The flow requirements of ecological assets in terms of aspects of the flow regime (e.g. magnitude, duration, timing, rate of change) are defined and expressed as eco-hydraulic rules. For each ecological asset, best current scientific understanding is used to describe the nature of the flow dependency by defining the flow related conditions needed to trigger an ecological response. This understanding is then used to formulate eco-hydraulic rules that define an opportunity for the ecological response in terms of facets of the flow regime. Eco-hydraulic rules are then applied to a daily flow time series representing a water resource development scenario to generate a time series of opportunities for the ecological response. This likelihood or exposure data represents the probability of an ecological asset/indicator experiencing the critical conditions required when and where they are needed over the assessment period.

**Defining thresholds of concern (ToC)**

The effects analysis phase of the ERA uses information on the consequence of altering the provision of the critically-linked response to the long term viability of the ecological asset. In this ERA flow context, consequence or effects data is the characterisation of an adverse ecological effect or response. Consequence is the impact of the valued attributes of an ecological asset/indicator of not providing the conditions it critically requires.

In this ERA application, Thresholds of Concern (ToC) (after Rogers & Biggs 1999) are defined to represent the frequency of opportunities required to protect asset viability. ToCs represent failure points for the ecological asset and as such can be considered minimum water requirements. The probability of achieving a desired ecological outcome is directly related to meeting a ToC over time. Where possible, ToCs are based on the biology or process knowledge of the asset. In most cases, ToCs represent the known time species-based ecological assets will survive without experiencing a flow-based opportunity or the reproductive life time of the asset. For those ecological assets without a clear life history basis for setting a ToC, thresholds can be related to the frequency of opportunity provision modelled to occur under the pre-development flow regime. Because even natural flow regimes are not without risk to ecological assets, the risk from management scenarios is considered relative to the risk from the pre-development flow regime.

The process outlined above requires both a sound conceptual understanding of the flow dependent ecological assets and detailed biological and/or process knowledge relating to their critical flow dependencies. The synthesis of this knowledge is presented in the Risk Assessment for Selected Ecological Assets Report (DSITIA 2013a) for each ecological asset and forms the basis for the ecological model development and setting of ToCs. The risk characterisation phase of the ERA is also presented and summarised in the subsequent sections of this report.

### Eco-hydraulic modelling

#### *Modelled daily flow time series*

Daily flow time series (as ML/day) were modelled for the pre-development and development scenarios at a series of nodes in the water resources management model called the Integrated Quantity and Quality Model (IQQM). The IQQM model is a hydrological system simulation model that operates on a daily time step. For the Warrego, Paroo, Bulloo and Nebine river basins, a 122 year simulation period was modelled for the period 1889–2011 inclusive.

#### *Time series of flow-related opportunities*

For each ecological asset, eco-hydraulic rules were defined that express their critical flow requirements (see Risk Assessment for Selected Ecological Assets Report, DSITIA 2013a). These rules were applied to the modelled daily flow, river height, salinity and temperature time series to generate a time series of flow-related opportunities for the ecological responses, over the simulation period. Opportunities were represented by days for which all daily flow, height, and temperature requirements were met.

### Assessing the risk to surface water dependent ecological assets

Using the approach outlined above, risks to assets were modelled under the two water resource development scenarios:

1. pre-development–assumes no water resource development in each catchment
2. full entitlement–reflects the full use of existing entitlements with current ROP operating rules

Risk to ecological assets was modelled at assessment nodes reflecting their present distribution. Because even unmodified flow regimes are not without risk to assets, the risk to ecological assets is expressed in terms of the frequency of ToC exceedance over the simulation period, contrasting the development scenarios with the pre-development scenario.

### Assessing the hazard to groundwater dependent ecosystems from water resource development

Three classes of groundwater dependent ecosystems (GDEs) were considered in this assessment (after Eamus et al. 2006): (i) cave and aquifer systems (karstic, fractured rock, alluvial aquifers, hyporheic zone); (ii) ecosystems dependent on the surface expression of groundwater (baseflow, non-riverine wetlands, and mound springs); and (iii) ecosystems dependent on the sub-surface expression of groundwater, often accessible via the capillary fringe when roots penetrate this zone (terrestrial vegetation).

In terms of this assessment, a critical link to the groundwater regime is considered as a dependency on groundwater to provide for the ecological asset's long term viability or persistence, in the absence of which, the ecosystem would undergo major structural and/or functional change. For a dependent community or species, the long-term persistence would need to depend critically on attributes of groundwater (level, flux, pressure and quality).

### *Cave and aquifer systems*

Cave systems are not present within the water resource plan area, so cave and aquifer systems were represented by aquifer-dwelling stygofauna for this assessment. Subterranean aquifers and hyporheic zones (the zone of interaction between river water and the groundwater present in the banks and beds of rivers) are present throughout the water resource plan area and have the potential to support groundwater fauna, or stygofauna, communities within them.

The results of extensive aquifer sampling for stygofauna conducted in the Condamine-Balonne and Border Rivers region (DERM, unpublished data), located to the immediate east of the water resource plan area, were evaluated to identify aquifer chemical or morphological attributes associated with the presence/absence and composition of stygofauna assemblages. No meaningful associations were found between aquifer characteristics and stygofauna occurrences, consequently this group was not included in the asset selection process.

### *Ecosystems dependent on the surface expression of groundwater*

Ecosystems dependent on the surface expression of groundwater within the plan area may include wetlands and springs. Non-riverine wetlands in the region have been mapped and these were assessed for possible dependence on groundwater. Mound springs associated with the great artesian basin are also present but are not influenced by shallower aquifers present in the water resource plan area and as such are not within the scope of this assessment. A GIS-based approach was applied to identify non-riverine groundwater dependent wetlands across the water resource plan area using the Queensland Wetland Mapping Database (DSITIA 2013a).

### *Ecosystems dependent on the sub-surface expression of groundwater*

In the area, ecosystems dependent on the sub-surface expression of groundwater are represented by terrestrial vegetation communities that depend on groundwater. This includes deep and/or shallow rooting terrestrial vegetation communities that utilise groundwater in either an obligate or facultative way. It does not include aquatic macrophytes that have an obligate requirement for either partial or complete submergence in water.

A rules-based GIS and remote sensing approach was used to identify potential groundwater dependent terrestrial vegetation communities within the plan area using the Queensland Regional Ecosystem (RE) mapping (DSITIA 2013a). As a dynamic groundwater model was not available across the plan area, the assessment was conducted as a vulnerability analysis which considered the spatial intersection of GDEs with the location of registered groundwater bores, including estimates of their volumetric entitlements.

# 5. Results

## Surface water dependent ecological assets

A total of 2937 ecological assets including species of flora and fauna, vegetation communities, floodplain wetlands, instream and floodplain habitats and processes were identified across the plan area. Based on the best current information from the scientific literature and expert knowledge, 95 ecological assets were determined to be critically linked to aspects of the flow regime and therefore potentially vulnerable to water resource development (see Risk Assessment for Selected Ecological Assets Report, DSITIA 2013a).

These assets were considered to be candidates for the environmental assessment. Of these candidate assets, sufficient knowledge of their flow requirements was available for nine, enabling detailed analysis of the impact of development scenarios on their viability and long term persistence (Table 2).

**Table 2: Surface water ecological assets used in the environmental assessment, their link to hydrology, assessment endpoints, and their distribution in the plan area. Ticks indicate assets used in the ecological risk assessment, while circles indicate assets present in a catchment but unassessed because there was no difference in the relevant aspect of hydrology between flow scenarios.**

| Ecological asset | Assessment endpoint | Link to hydrology | | | | Catchment | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No-flow | Low flows | Medium flows | High flows | Warrego | Paroo | Bulloo | Nebine |
| **Ecosystem components** | | | | | | | | | |
| Flow spawning fish | Population viability of Yellowbelly (*Macquaria ambigua*) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Migratory fish species | Maintenance of movement opportunities for migratory fish species | ✓ | ✓ | ✓ | | ✓ | ○ | ○ | ✓ |
| Eastern snake-necked turtle (*Chelodina longicollis*) | Population viability of Eastern snake-necked turtle (*Chelodina longicollis*) | ✓ | | | ✓ | ✓ | ○ | ○ | ✓ |
| Absence of exotic fish species | Minimised abundance and distribution of European carp (*Cyprinus carpio*) | | | ✓ | ✓ | ✓ | ○ | ○ | ✓ |
| Floodplain vegetation | Viability of floodplain vegetation communities | | | | ✓ | ✓ | ○ | ○ | ✓ |
| Floodplain wetlands | Maintenance of wetting regime to support floodplain wetlands | | | | ✓ | ✓ | ○ | ○ | ✓ |
| Unique genetic diversity of aquatic biota within the Bulloo basin | Absence of translocated genotypes of Yellowbelly in the Bulloo | | | | | | | ✓ | |

| Ecological asset | Assessment endpoint | Link to hydrology | | | | Catchment | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No-flow | Low flows | Medium flows | High flows | Warrego | Paroo | Bulloo | Nebine |
| | | | | | | | | | |
| **Ecosystem processes** | | | | | | | | | |
| Waterholes as refugia | Spells of no-flow isolation<br>Distance between waterholes | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| Fluvial geomorphology and river forming processes | Events at or above bankfull flows | | | ✓ | ✓ | ✓ | ○ | ○ | ○ |

## Warrego catchment

Detailed analyses were conducted at seven assessment nodes on eight ecological assets in the Warrego catchment (Figure 3). The results of the assessment are provided in the subsequent sections and summarised in Table 5.

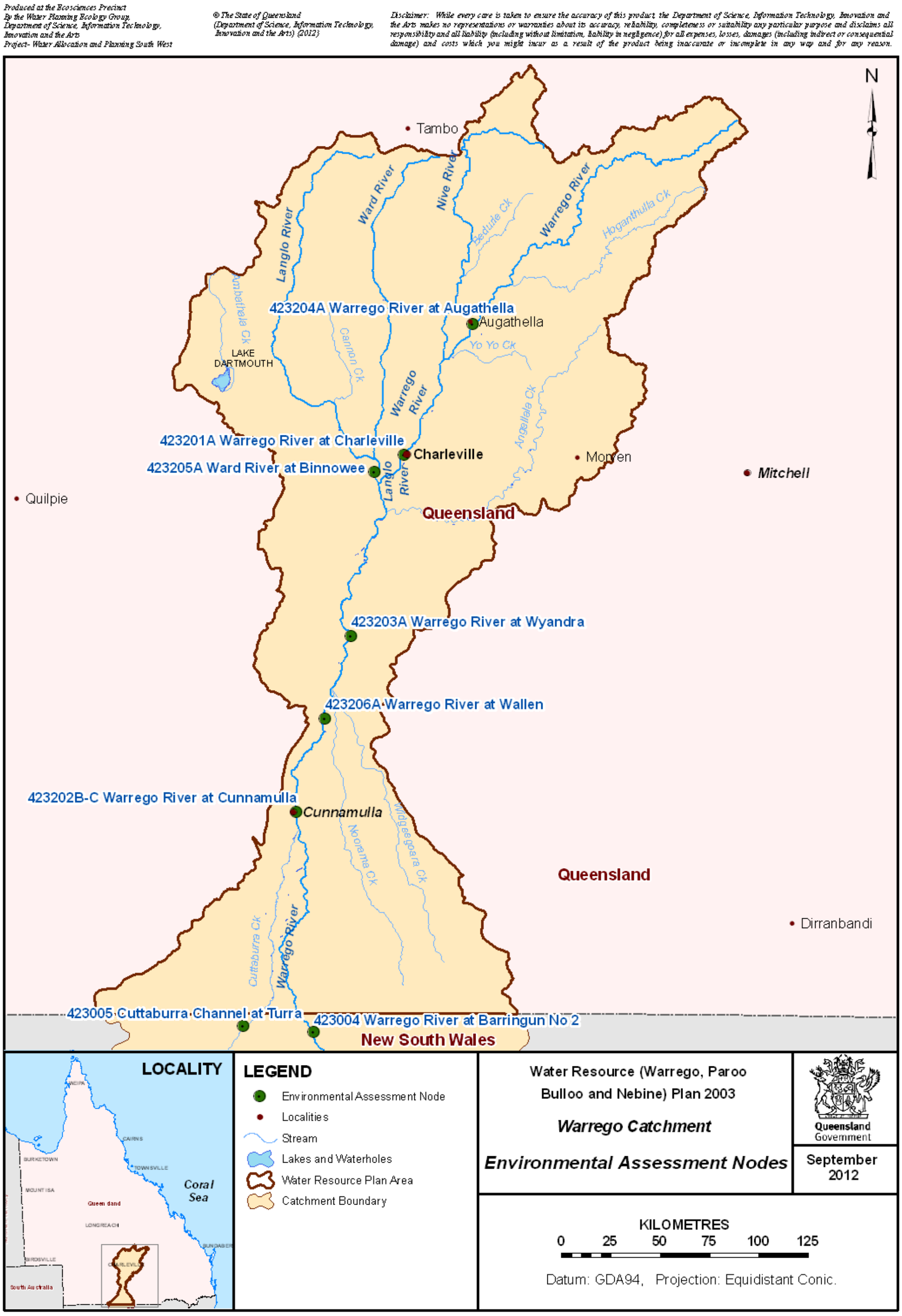


**Figure 3: Location of environmental assessment nodes in the Warrego catchment. IQQM pre-development flow simulation data were unavailable for 423205A.**

## Ecosystem components

### *Flow spawning fish*

Eight flow spawning fish have been identified as ecological assets in the plan area. These species have flexible spawning strategies cued by elevated river flows, with recruitment that is responsive to inundation of the floodplain. For the purposes of the assessment, they are collectively represented by the yellowbelly (*Macquaria ambigua*). Their flow requirements are outlined in the Risk Assessment for Selected Ecological Assets Report (DSITIA 2013a). In summary, the first post-winter flow is closely associated with annual spawning activity. Waterholes represent critical in-channel habitat for the juveniles and adults. The pattern of waterhole persistence within the catchment over time is an important attribute relating to yellowbelly population viability. Waterhole persistence and opportunities for connectivity between adjacent waterholes are potentially affected by an altered flow regime and licensed waterhole pumping (i.e. entitlements with a nil passing flow condition).

Yellowbelly abundance was modelled at seven environmental assessment nodes in the Warrego catchment. A catchment-scale ToC of 5000 adult individuals was established based on a minimum population density threshold to support the long term viability of the yellow belly (DSITIA 2013a).

At the catchment-scale, the full entitlement scenario reduced yellow belly abundance by 31% in comparison to the pre-development scenario. Changes varied across the environmental assessment nodes, with the largest reductions observed at Warrego River at Charleville (423201A) and Warrego River at Wyandra (423203A) represented by reductions of 51% and 45% respectively. There were no periods in the simulation where the catchment-scale population abundance fell below the ToC of 5000 adult individuals.

### *Migratory fish species*

Eight migratory fish have been identified as ecological assets in the plan area. These species undertake spawning migrations that are thought to be triggered by rising water levels. In some species, movement is territorial and related to searching for suitable mates. In such cases, movement behaviours may be highly individualistic. Migratory fish species represent a significant component of the freshwater biodiversity of rivers and streams of the four catchments that comprise the plan area. Their critical water requirements are outlined in the Risk Assessment for Selected Ecological Assets Report (DSITIA 2013a).

The opportunities for movement by migratory fish species was measured by the frequency and duration of flow events that provide longitudinal connectivity. The minimum event duration that represents an opportunity for migration between suitable habitats was determined to be eight days (DSITIA 2013a). Risk to these species in terms of altered durations between longitudinal connectivity opportunities were modelled against three ToC risk categories (Table 3) at seven nodes in the Warrego catchment.

**Table 3: Risk categories for changes in the frequency of connectivity opportunities***

| Low risk | Moderate risk | High risk |
|---|---|---|
| < 4 years | 4–10 years | > 10 years |

* number of consecutive years without longitudinal connectivity opportunities

The number and duration of connection events were altered at six of the seven assessment nodes as a consequence of the full entitlement scenario. The least affected sites were in the upper part of the catchment–Warrego River at Augathella (423204A) and Warrego River at Charleville (423201A) which showed a 0% and 1.35% reduction respectively in the duration of connection events. The effect was more pronounced for assessment nodes in the mid and lower reaches of the catchment with reductions in the duration of connection events varying between 6.4% and 11.7%.

At four assessment nodes there was an increase in the number of years that exceeded the moderate risk ToC (Table 4). In all cases these increases represented a change of less than 5% in the proportion of the simulation period where longitudinal connectivity was not provided for within a four year return interval due to the full entitlement scenario. There was no increase in the number of high risk spells at any of the assessment nodes as a consequence of the full entitlement scenario.

**Table 4: Percentage of years in the simulation period in the moderate risk category (4–10 years without an eight day connection) for longitudinal connectivity opportunities**

| Assessment node | Pre development | Full entitlement |
|---|---|---|
| Warrego River at Augathella (423204A) | 19.5 | 19.5 |
| Warrego River at Charleville (423201A) | 19.5 | 19.5 |
| Warrego River at Wyandra (423203A) | 0 | 2.5 |
| Warrego River at Wallen (423206A) | 0 | 0.8 |
| Warrego River at Cunnamulla Weir (423202C) | 0 | 2.5 |
| Warrego River at Barringun (423004) | 0 | 0 |
| Warrego River at Turra (423005) | 0.8 | 5.1 |

***Eastern snake-necked turtle (Chelodina longicollis)***

The eastern snake-necked turtle is an iconic species, and is found in the Warrego, Paroo and Bulloo catchments. It is an active species with great propensity for overland migration, capable of travelling up to 2.5 km when floodplain water bodies start to fill (Kennett & Georges 1990). It has direct links to three aspects of the flow regime: (i) overbank flows, (ii) the duration of no-flow spells and (iii) the persistence of refuge waterholes. It aestivates on inundated floodplains for up to seven months after which time, if off-stream conditions remain unfavourable, individuals must return to the refuge of permanent in-channel waterholes. Individuals are known to lose body condition when restricted to these waterholes. Subsequently these represent stress periods and high risk events for populations of the eastern snake-necked turtle. The level of risk increases with an increase in the time between the availability of off-stream habitat (Risk Assessment for Selected Ecological Assets Report, DSITIA 2013a).

A ToC was defined that represents the maximum length of high stress events the eastern snake-necked turtle population can tolerate. This ToC was based on observations of populations from eastern Australia following prolonged drought. This data showed that it took ten years for individuals to become reproductively active following a four year drought (A. Georges pers comm.). Based on this information a ToC of 4 years was used in the assessment. Periods between floodplain inundation at an environmental assessment node ≥ 4 years represents a threat to the long term persistence of the local population. Risk to the eastern snake-necked turtle in relation to increased frequency of high stress periods was modelled against a four year flood inundation return frequency ToC at five assessment nodes in the Warrego catchment (DSITIA 2013a).

There was no change in the number and duration of high stress periods due to the full entitlement scenario at any of the five assessment nodes. Although there were substantial periods of the simulation where the four year flood inundation return frequency ToC was exceeded at all assessment nodes, there was no increase in risk due to the full entitlement scenario compared with pre-development. These results suggests that some floodplain areas associated with these assessment nodes (notably Warrego River at Augathella (423204A), Warrego River at Barringun (423004), and Warrego River at Turra (423005)), are marginal habitat for this species with high stress periods exceeding 30 years in duration.

### *Absence of exotic fish species*

Introduced fish represents a significant environmental stressor and threat to aquatic ecosystems. Invasive fish species impact on native species through predation, competing for food or habitat, uprooting aquatic vegetation and disturbing sediments, and by spreading diseases or parasites. The European carp (*Cyprinus carpio*) is considered to be the most abundant freshwater fish species in Australia (Koehn 2004) and is the most abundant large freshwater fish in the Murray-Darling Basin (Lapidge 2003). Consequently the absence of exotic species represents a key ecological value. For the purposes of this assessment, the threat posed by exotic fish species in the plan area has been represented by the European carp. Its current distribution includes the Warrego, Paroo, and Nebine catchments of the plan area. There are currently no known European carp populations in the Bulloo catchment.

Access to inundated floodplain wetlands has been shown to positively influence European carp spawning rates and the habitat provided by inundated floodplains is also known to increase recruitment success. There were two flow-related components to the requirements for strong recruitment opportunities for the European carp: (i) spawning and recruitment associated with overbank flows, and (ii) opportunities for dispersal of recruits associated with flows within 12 months of an overbank flow (DSITIA 2013a).

A ToC could not be derived for the European carp as the relationship between the frequency of strong recruitment opportunities and their viability across the plan area has not been adequately characterised. The potential for water resource development to affect European carp recruitment opportunities was modelled at five environmental assessment nodes in the Warrego catchment based on a comparison of the proportional change between the pre-development and full entitlement scenarios.

There was no change in the percentage of years in the simulation period where strong recruitment was modelled to occur due to the full entitlement scenario at three of the five assessment nodes. However there were small reductions in the duration of these events at Warrego River at Cunnamulla Weir (423202C) and Warrego River at Turra (423005) of 9.9% and 5.5% respectively.

There were however, small reductions in both the percentage of years in the simulation period where strong recruitment was modelled to occur and the duration of these events due to the full entitlement scenario at two nodes. At Warrego River at Wyandra (423203A) there was a 1.6% reduction of strong recruitment years with the duration of these events reduced by 9.9%. At the Warrego River at Barringun (423004) there was a 2.5% reduction of strong recruitment years with the duration of these events reduced by 12.4%.

### ***Floodplain vegetation and wetlands***

*Floodplain vegetation*

Flow regimes are relevant to the maintenance and persistence of floodplain vegetation communities in terms of the length of spells without inundation, the duration of inundation events and in some cases the timing of these events (Roberts & Marston 2011). Flow magnitude interacts with the landscape morphology to determine the size of events necessary to meet species-specific inundation requirements in a particular floodplain setting (Overton et al. 2009). Many species have flexible growth strategies that allow them to grow in arid and semi-arid areas.

*Floodplain wetlands*

The length of time between inundation events and the persistence of water in a wetland are governed by a number of factors including position in the landscape, water source, climate and substrate (Jaensch & Young 2010). The sequence of drying and rewetting in temporary floodplain wetlands makes them highly productive. In the plan area, floodplain wetlands support several ecological values including waterbird breeding opportunities and provision of preferred habitat for the eastern snake-necked turtle*,* and in some cases, are recognised by state, national and international conservation agreements such as Ramsar or protected in National Parks.

The pattern of inundation of floodplain vegetation and wetlands following over bank flows was modelled to assess the risk posed by modification of the flow regime on these ecological assets. Flow thresholds representing wetting frequencies for floodplain vegetation communities (represented by Queensland Regional Ecosystem mapping) and floodplain wetlands (Queensland wetland mapping) were derived using a combination of floodplain extent mapping and Landsat satellite image analysis (see Risk Assessment for Selected Ecological Assets Report, DSITIA 2013a).

ToCs could not be derived for a water regime that maintains the viability of floodplain vegetation communities (including recruitment processes and maintenance of mature plants) and floodplain wetlands (including timing of events and the spatial extent of wetlands) in the plan area due the complexity of the landscape and the multiple species that contribute to each vegetation community. The potential for water resource development to affect the floodplain vegetation and wetland inundation regime was assessed at floodplain areas associated with seven environmental assessment nodes (Figure 4) based on a comparison of the proportional change between the pre-development and full entitlement scenarios.

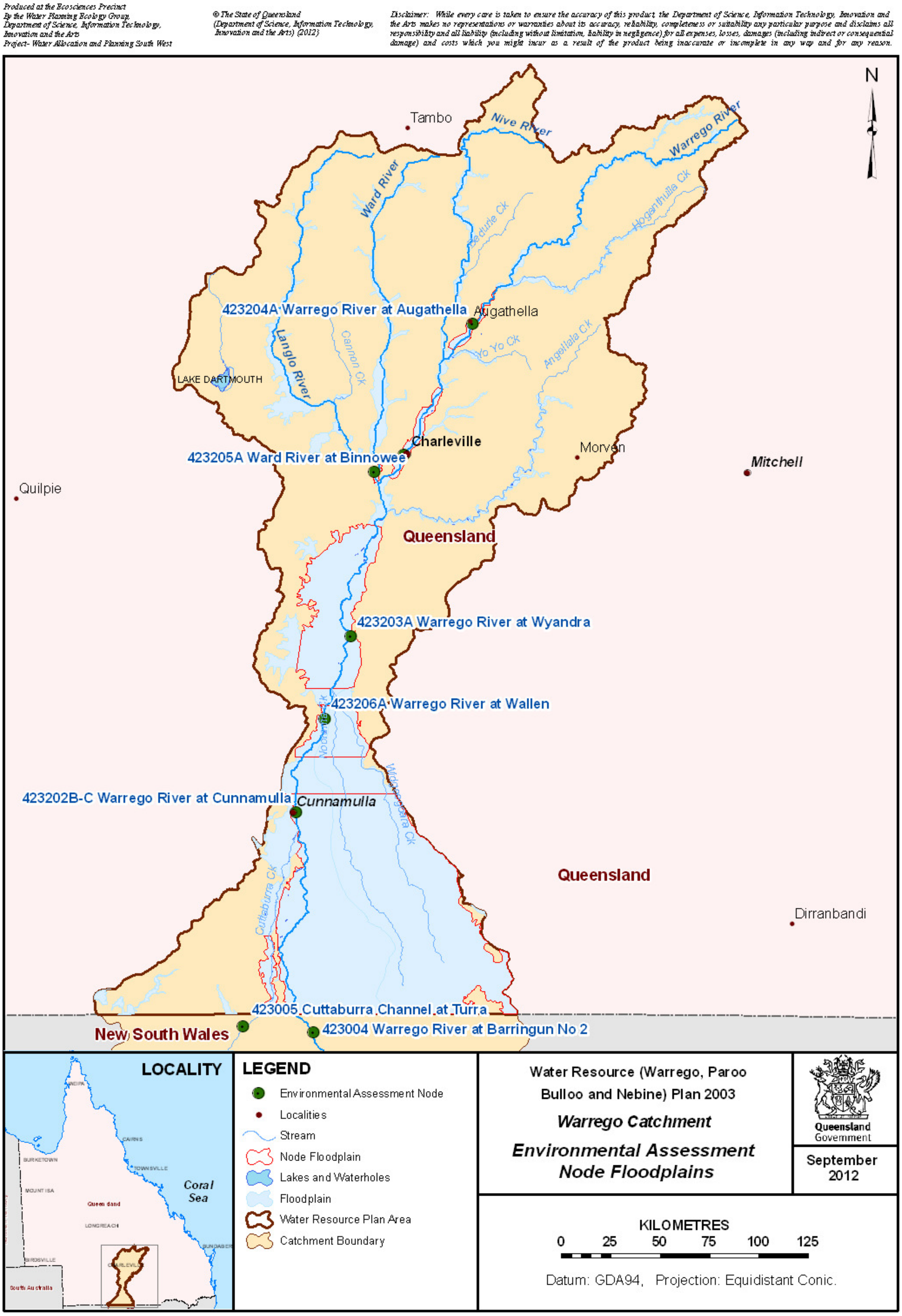


**Figure 4: Location of floodplain areas associated with each environmental assessment node in the Warrego catchment**

Floodplain vegetation communities and wetland inundation frequencies under the full entitlement scenario were unchanged from pre-development for floodplain areas associated with Warrego River at Augathella (423204A), Warrego River at Wyandra (423203A), Warrego River at Wallen (423206A), Warrego River at Cunnamulla (423202C), and Warrego River at Turra (423005).

At Warrego River at Barringun (423004), spells between inundation events of floodplain vegetation community patches and wetlands at the small flood threshold (5000 ML/day) have been shortened under the full entitlement scenario. Under pre-development 74% of spells between floods lasted one year or less, whereas under full entitlement 82% of spells were shorter than a year. Spells between inundation events of floodplain vegetation patches and wetlands at medium-flood thresholds (5431, 7970 and 8470 ML/day) have been lengthened under full entitlement. This indicates that these floodplain features are inundated less often under full entitlement than under pre-development. These results may reflect the influence of flood event harvesting upstream of this node; some flood events that would inundate these features under pre-development may not do so under full entitlement due to reduced river levels. Consequently, the affected floodplain wetlands and vegetation patches may be under water stress more often under full entitlement than pre-development, however the duration of spells between floods under full entitlement is still within the range experienced under pre-development. There is no difference between pre-development and full entitlement in the frequency of flooding at the large-flood threshold (19140 ML/day).

## Ecosystem processes

### *Waterholes as refugia*

Refugial waterholes are defined as main channel water bodies that retain water which supports stream biota between no-flow spells. Typically, these channel waterholes are maintained by in-channel surface water flows. In some cases waterholes may also be supplemented by groundwater. Waterholes provide a vital ecosystem function and are one of the few sources of habitat for aquatic biota during dry spells. As such waterholes support the resistance and resilience of aquatic populations, and processes essential for vigour and long term viability, by providing habitat to 'ride out' dry spells (Davis & Thoms 2002; Humphries & Baldwin 2003; Magoulick & Kobza 2003) and allow dispersal during subsequent flow events (Puckridge et al. 1998; Balcome et al. 2007). Permanent waterholes occur across the plan area catchments (Silcock 2009).

The permanence of waterholes is directly linked to the frequency and duration of no-flow spells and the rates of extraction where licensed extraction occurs. Two aspects of flow management were assessed that relate to the spatial distribution and pattern of connectivity of permanent waterholes (including those with and without pumping entitlements): (i) frequency of waterhole isolation spells, and (ii) change in the distance between permanent waterholes due to licensed waterhole pumping activities.

#### *Waterhole isolation*

Waterhole isolation spells correspond to those periods when flow ceases and waterholes are disconnected from each other. A ToC could not be derived for assessing the impact of altering the frequency of waterhole isolation spells as their role in providing the required refugial opportunities for aquatic biota across the plan area has not been adequately characterised. The potential for water resource development to affect the pattern of waterhole persistence, as measured by isolation spells, was assessed at seven nodes in the Warrego catchment based on a comparison of the proportional change between the pre-development and full entitlement scenarios (DSITIA 2013a).

Of the seven nodes assessed, only Warrego River at Augathella (423204A) showed no change from pre-development with respect to the number and duration of waterhole isolation spells. Of the remaining six nodes, Warrego River at Charleville (423201A) showed the least influence, with a 1.35% increase in isolation spell duration. The five nodes downstream of Charleville all showed increases in isolation spell duration of between 6.4% and 11.5%.

#### *Waterhole pumping*

Extraction from waterholes reduces their persistence time, potentially increasing the number of reaches between permanent habitats that are longer than the dispersal capacity of fish. This reduces potential source populations and may inhibit effective recolonisation of parts of the catchment following flow events.

A spatial analysis was conducted to assess potential changes in the distance between permanent waterholes and their influence on fish dispersal opportunities due to licensed waterhole pumping activities (DSITIA 2013a). For the purposes of the analysis, the distance travelled by yellowbelly (*Macquaria ambigua*) was used to establish the relevant spatial context. In the absence of physical barriers to dispersal, yellowbelly tend to traverse distances up to 20 km along rivers during connection events (DSITIA 2013a).

Distances from waterholes with water entitlements to the nearest upstream and downstream waterhole without an entitlement are summarised in DSITIA (2013a–Appendix 5) for the Warrego, Bulloo, Paroo and Nebine catchments respectively, representing the distribution of permanent waterholes under pre-development. The total distance between neighbouring waterholes is also presented, to simulate the effect of waterhole pumping on the distribution of permanent waterholes.

Of the 133 refugial waterholes identified in the Warrego catchment (Silcock 2009), there are 16 subject to licensed extraction. Under pre-development, three of these are located > 20 km to the nearest permanent waterhole, while under the full entitlement extraction scenario there were eight segments longer than the 20 km threshold. These results show that the hazard due to licensed waterhole extraction was increased in five of the 17 assessment reaches.

***Fluvial geomorphology and river forming processes***

River forming flows provide for processes such as sediment movement through erosion, transport and deposition. Disruption to the frequency and duration of river forming flows by water resource development can affect these processes and lead to long-term changes in the physical attributes of the stream network and concurrent influences on the function of riverine ecosystems. For the purposes of this assessment, bankfull discharge was chosen as the hydrological threshold at which the maximum sheer stress and peak scouring of the stream bed occurs. Bankfull discharge is typically the discharge at which the product of average cross-sectional flow velocity and water surface slope is at a maximum (Newbury & Gaboury 1994).

The influence of the full entitlement scenario on bankfull discharge, incorporating measures of their frequency, magnitude and duration, was assessed at seven environmental assessment nodes in the Warrego catchment (DSITIA 2013a). A ToC could not be derived for the measurement endpoint as the relationships between the frequency of bankfull flows and their role in driving river forming processes has not been adequately characterised.

There was no change in the number of bankfull events for three nodes–Warrego River at Augathella (423204A), Warrego River at Charleville (423201A), Warrego River at Charleville (423201A), and Warrego River at Wyandra (423203A), and a 0.6% decrease at Warrego River at Wallen (423206A). The three nodes south of Charleville experienced a decrease of between 2.9% and 7.9% compared to pre-development.

**Table 5: Summary of risks to ecological assets of the Warrego catchment, their link to hydrology and modelled risk in comparison to pre-development**

| Ecological asset | Measurement endpoint | Link to hydrology | Risk in comparison to pre development* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 423204A Augathella | 423201A Charleville | 423203A Wyandra | 423206A Wallen | 423202C Cunnamulla | 423004 Barringun | 423005 Turra | Whole catchment |
| **Ecosystem component** | | | | | | | | | | |
| Flow spawning fish | Abundance of yellowbelly | no-flow, medium flow, high flow | low | low | low | low | low | low | low | low |
| Migratory fish species | Frequency of longitudinal connectivity opportunities | no-flow, medium flow | low | low | low | low | low | low | low | n/a |
| Eastern snake-necked turtle | Frequency of high stress events | no-flow, high flow | low | low | low | low | low | low | low | low |
| Absence of exotic fish species | Frequency of strong recruitment opportunities for European carp | medium flow, high flow | 0% | n/a | –1.6% | n/a | 0% | –2.5% | 0% | n/a |
| Floodplain vegetation and wetlands | Length of spells between inundation events | high flow | 0% | n/a | 0% | 0% | 0% | +4%** | 0% | n/a |
| **Ecosystem processes** | | | | | | | | | | |
| Waterholes as refugia | Spells of no-flow isolation (maximum no-flow spell duration) | no-flow, low flow | 0% | 0% | +2% | +2% | +25% | –6% | 0% | n/a |
| | Change in the distance between permanent waterholes due to licenced waterhole pumping | no-flow, low flow | n/a | n/a | n/a | n/a | n/a | n/a | n/a | +2% |
| Fluvial geomorphology and river forming processes | Duration of events at or above bankfull flows | medium flow, high flow | 0% | 0% | 0% | –0.6% | –3% | –8% | –5.2% | n/a |

* risk expressed as exceedance of ToC or proportional deviation from pre-development where no ToC could be determined; n/a = not assessed

** At the moderate flood threshold, spells between flood inundations of greater than 12 months increased from 37% under predevelopment to 41% under full entitlement. There was no increase in spell length at other flood threshold levels.

## Paroo catchment

The risk to two ecological asset indicators including ecosystem components and processes (Table 6) was modelled at two environmental assessment nodes in the Paroo catchment (Figure 5). Six ecological indicators were not modelled as there was no difference between the flow regimes under the pre-development and full entitlement IQQM scenarios in the Paroo catchment.

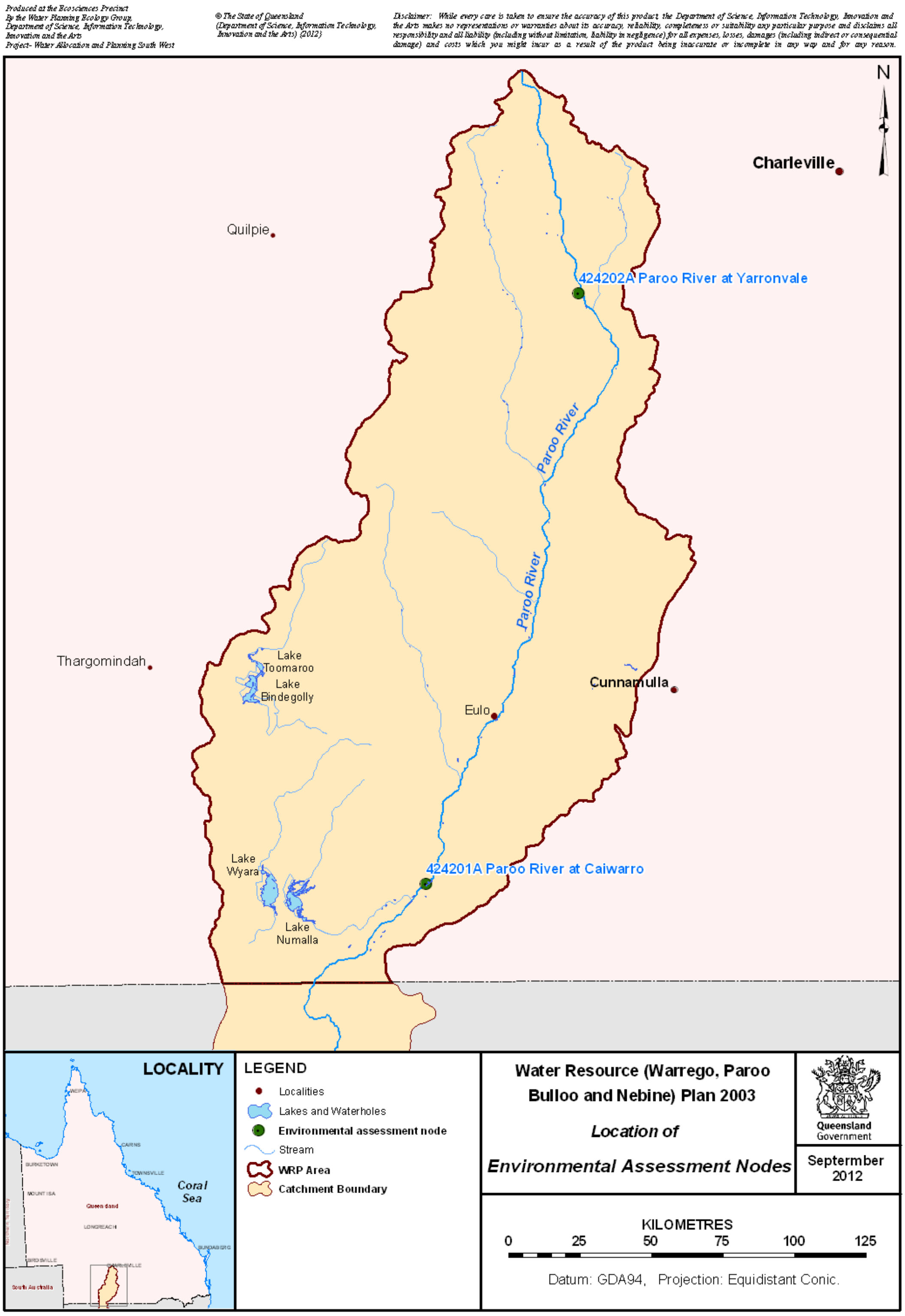


**Figure 5: Location of environmental assessment nodes in the Paroo catchment**

## Ecosystem component

### *Flow spawning fish*

Yellow belly abundance was modelled at two environmental assessment nodes in the Paroo catchment. A catchment-scale ToC of 5000 adult individuals was established based on a minimum population density threshold to support the long term viability of the yellow belly (DSITIA 2013a).

At the catchment-scale, the full entitlement scenario reduced yellow belly abundance by 3% in comparison to the pre-development scenario. Changes varied between the two environmental assessment nodes, with the largest reduction of 3% observed at Paroo River at Caiwaroo (424201A). There were no periods in the simulation where the catchment-scale population abundance fell below the ToC of 5000 adult individuals.

## Ecosystem processes

### *Waterholes as refugia–waterhole pumping*

A spatial analysis was conducted to assess potential changes in the distance between permanent waterholes and their influence on fish dispersal opportunities due to licensed waterhole pumping activities. For the purposes of the analysis, the distance travelled by yellow belly was used to establish the relevant spatial context. In the absence of physical barriers to dispersal, yellowbelly tend to traverse distances up to 20 km along rivers during connection events.

Distances from waterholes with water entitlements to the nearest upstream and downstream waterhole without an entitlement are summarised in DSITIA (2013a–Appendix 2) for the Warrego, Bulloo, Paroo and Nebine catchments respectively, representing the distribution of permanent waterholes under pre-development. The total distance between neighbouring waterholes is also presented, to simulate the effect of waterhole pumping on the distribution of permanent waterholes.

There were two waterholes with water entitlements in the Paroo catchment. Under both the pre-development and extraction scenarios, distances between permanent waterholes were less than the fish dispersal threshold. Consequently, effective dispersal of migratory fish is not threatened by permanent waterhole distribution in this catchment.

**Table 6: Ecological assets modelled in the Paroo catchment, their link to hydrology and modelled risk in comparison to pre-development**

| Ecological asset | Measurement endpoint | Link to hydrology | Risk in comparison to pre development* | | |
|---|---|---|---|---|---|
| | | | 424202A Yarronvale | 424201A Caiwarro | Whole catchment |
| **Ecosystem component** | | | | | |
| Flow spawning fish | Abundance of yellowbelly | no-flow, medium flow, high flow | low | low | low |
| **Ecosystem processes** | | | | | |
| Waterholes as refugia | Change in the distance between permanent waterholes due to licenced waterhole pumping | no-flow, low flow | n/a | n/a | 0% |

* risk expressed as exceedance of ToC or proportional deviation from pre-development where no ToC could be determined; n/a = not assessed

## Bulloo catchment

The risk to three ecological asset indicators including ecosystem components and processes (Table 7) was modelled at two environmental assessment nodes in the Bulloo catchment (Figure 6). Six ecological indicators were not modelled as there was no difference between the flow regimes under the pre-development and full entitlement IQQM scenarios in the Bulloo catchment.

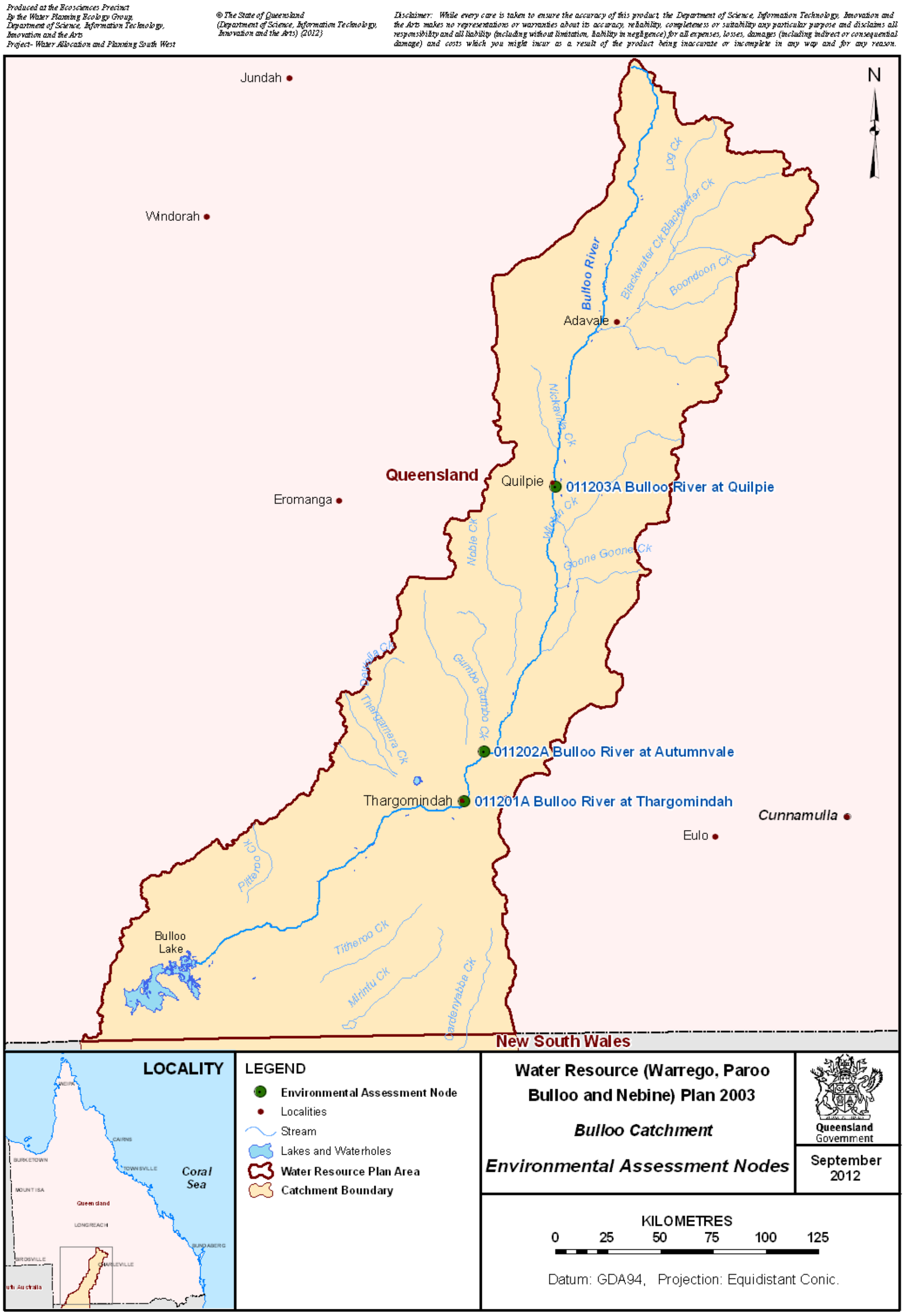


**Figure 6: Location of environmental assessment nodes in the Bulloo catchment. IQQM flow simulation data were unavailable for 011201A.**

### Ecosystem components

#### *Flow spawning fish*

Yellowbelly abundance was modelled at three environmental assessment nodes in the Bulloo catchment. A catchment-scale ToC of 5000 adult individuals was established based on a minimum population density threshold to support the long term viability of the yellow belly (DSITIA 2013a).

At the catchment-scale, the full entitlement scenario reduced yellow belly abundance by 3% in comparison to the pre-development scenario. Changes varied between the two environmental assessment nodes, with the largest reduction of 9.5% observed at Bulloo River at Quilpie (011203A). There were no periods in the simulation where the catchment-scale population abundance fell below the ToC.

#### *Genetic diversity of aquatic biota in the Bulloo catchment*

Ecological outcome 9f (vi) of the plan states that: water is to be allocated and managed in a way that seeks to achieve a balance— to achieve ecological outcomes consistent with maintaining a healthy riverine environment, floodplains and wetlands, including, for example, maintaining the unique genetic diversity of aquatic plants and animals within the Bulloo basin.

Genetic diversity can be threatened by the introduction of individuals of the same species from populations that have been isolated for long evolutionary times and consequently have large genetic differences (Page et al. 2010). Translocation of new species may also pose a hazard to biodiversity in the catchment by altering species interactions such as predation pressure and food webs (Strayer 2010; Reynolds 2011). Such an event in the Bulloo could lead to the loss of local endemic genotypes and thus the unique genetic diversity of aquatic biota.

Movement of water between river catchments is one mechanism for introducing alien aquatic species and genotypes, both of which can readily be delivered as live biota within transferred water (Page et al. 2010). In some Queensland catchments, inter-basin transfer schemes are used to meet urban, industrial and agricultural water needs (e.g. the Water Grid in south-east Queensland, the Mareeba-Dimbulah Irrigation Area). Movement of water in this way may unintentionally transport aquatic biota, which can affect ecosystems in the receiving rivers (Page et. al 2010; Lynch et al. 2011).

No such schemes exist in the WPBN plan area; consequently the only potential mode of water and aquatic biota transfer between catchments is via water storages near catchment boundaries that could receive water from one catchment and release or use it in another. The location and conditions of water entitlements in the Bulloo and Paroo catchments were assessed to determine the hazard they pose to the genetic diversity of the Bulloo. The likelihood of naturally occurring cross-catchment water transfer events between the Paroo and the Bulloo via the Bindegolly-Wyara (Dynevor) valley was also investigated.

There are two water entitlements in the Bulloo, both of which are nil-flow (i.e. not water harvesting). The entitlements have a fixed location, well away from the catchment boundary and there are no provisions under the WRP for pumping across the catchment boundary. In the neighbouring Paroo catchment, there are two water entitlements, and one unconverted water entitlement for urban use, all of which are located more than 30 km from the catchment boundary with the Bulloo. There are three properties authorised to take overland flow on the western side of the Paroo River, far from the catchment boundary and again, the WRP and ROP do not contain any provisions that would allow pumping of water between catchments. Based on this information, the distribution and operation of entitlements does not increase risk to the genetic diversity of the Bulloo catchment.

Lakes Bindegolly and Wyara are large, shallow salt lakes that lie within the Dynevor Valley, nominally at the western edge of the Paroo catchment (Andrew Biggs pers comm.). Geological evidence suggests that the Dynevor Valley once formed part of the flow path of the Bulloo River (Power et al. 2007). Today, the lakes are isolated from the Bulloo and are filled from relatively small, internally-draining catchments (Directory of Important Wetlands). While the lakes are known to have received waters from and contributed to floodwaters on the Paroo floodplain, hydrological connections to the Paroo River are rare (Timms 1998, Andrew Biggs and Mark Handley pers comm.). The Dynevor valley is considered an unlikely route for the transfer of aquatic biota between the Paroo and Bulloo because of the infrequent flow events, barriers formed by sand dunes and the inhospitable nature of the lakes due to their salinity (Andrew Biggs and Mark Handley pers comm.). Further, because connections are only possible during very large floods, the frequency is not affected by current water resource management strategies.

**Ecosystem processes**

***Waterholes as refugia–waterhole pumping***

A spatial analysis was conducted to assess potential changes in the distance between permanent waterholes and their influence on fish dispersal opportunities due to licensed waterhole pumping activities. For the purposes of the analysis, the distance travelled by yellow belly was used to establish the relevant spatial context. In the absence of physical barriers to dispersal, yellowbelly tend to traverse distances up to 20 km along rivers during connection events.

Distances from waterholes with water entitlements to the nearest upstream and downstream waterhole without an entitlement are summarised in DSITIA (2013a–Appendix 2) for the Warrego, Bulloo, Paroo and Nebine catchments respectively, representing the distribution of permanent waterholes under pre-development. The total distance between neighbouring waterholes is also presented to simulate the effect of waterhole pumping on the distribution of permanent waterholes.

There were two waterholes subject to licensed extraction in the Bulloo catchment. The distance between permanent waterholes was greater than 20 km in one reach, even under pre-development, while in the other reach, waterholes were within the dispersal threshold under both scenarios. These results suggest there is no increase in hazard to fish dispersal due to the spatial pattern of licensed waterhole pumping activities.

**Table 7: Ecological assets modelled in the Bulloo catchment, their link to hydrology and modelled risk in comparison to pre-development**

| Ecological asset | Measurement endpoint | Link to hydrology | Risk in comparison to pre development* | | |
|---|---|---|---|---|---|
| | | | 011203A Quilpie | 011202A Autumnvale | Whole catchment |
| **Ecosystem component** | | | | | |
| Flow spawning fish | Abundance of yellowbelly | no-flow, medium flow, high flow | low | low | low |
| Genetic diversity of aquatic biota in the Bulloo | Movement of water between catchments | | n/a | n/a | low |
| **Ecosystem processes** | | | | | |
| Waterholes as refugia | Change in the distance between permanent waterholes due to licenced waterhole pumping | no-flow, low flow | n/a | n/a | 0% |

* risk expressed as exceedance of ToC or proportional deviation from pre-development where no ToC could be determined; n/a = not assessed

## Nebine catchment

Detailed analyses were conducted at two assessment nodes on eight ecological assets in the Nebine catchment (Table 9, Figure 7).

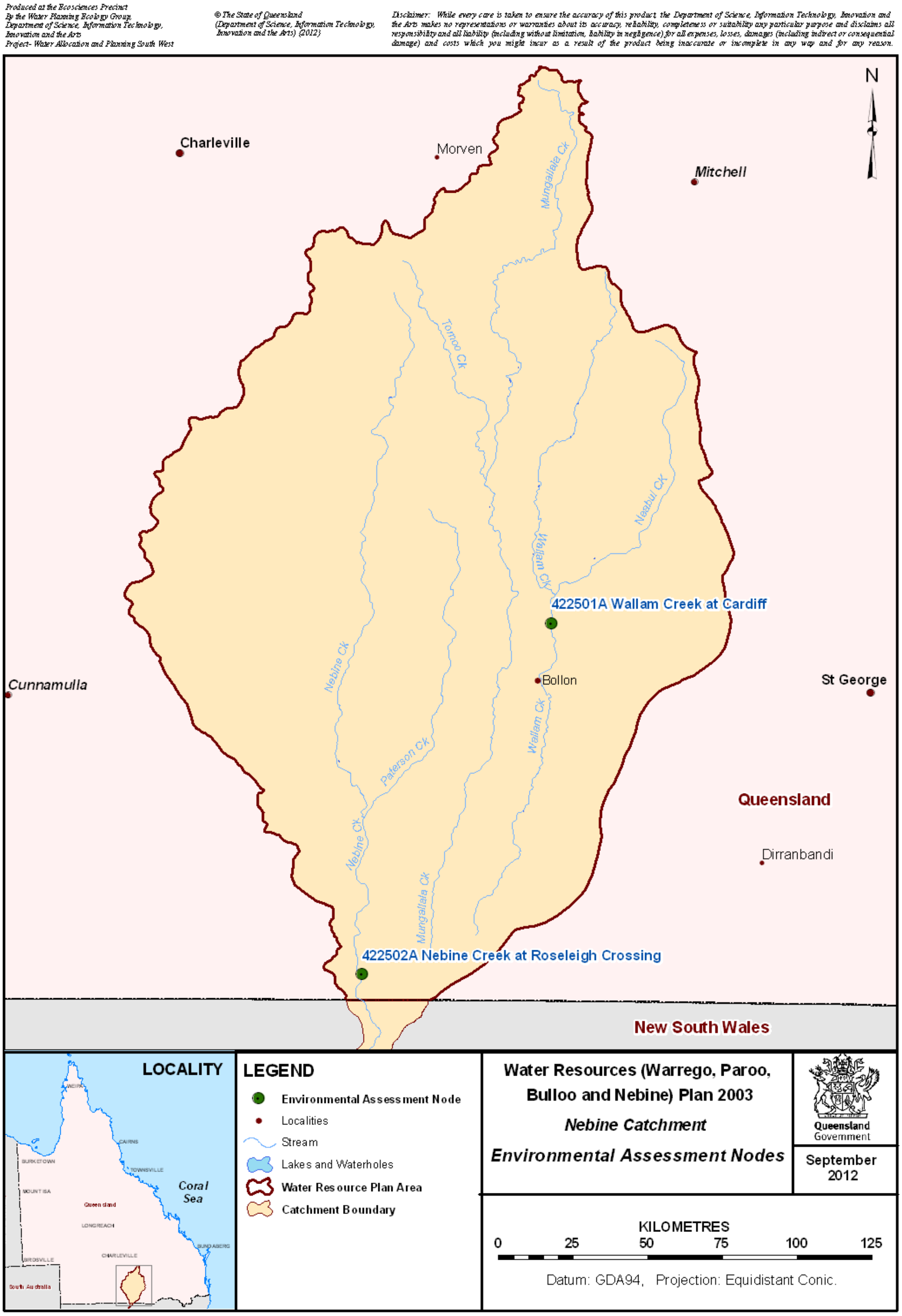


**Figure 7: Location of environmental assessment nodes in the Nebine catchment**

## Ecosystem components

### *Flow spawning fish*

Yellowbelly abundance was modelled at two environmental assessment nodes in the Nebine catchment. A catchment-scale ToC of 5000 adult individuals was established based on a minimum population density threshold to support the long term viability of the yellow belly (DSITIA 2013a).

At the catchment-scale, the full entitlement scenario reduced yellowbelly abundance by 22% in comparison to the pre-development scenario. Changes varied between the two environmental assessment nodes, with the largest reduction of 43% observed at Wallam Creek at Cardiff (422501A). There were no periods in the simulation where the catchment-scale population abundance fell below the ToC of 5000 adult individuals.

### *Migratory fish species*

Eight migratory fish have been identified as ecological assets in the plan area. These species undertake spawning migrations that are thought to be triggered by rising water levels. In some species, movement is territorial and related to searching for suitable mates. In such cases, movement behaviours may be highly individualistic. Migratory fish species represent a significant component of the freshwater biodiversity of rivers and streams of the four catchments that comprise the plan area. Their critical water requirements are outlined in the Risk Assessment for Selected Ecological Assets Report (DSITIA 2013a).

The opportunities for movement by migratory fish species was measured by the frequency and duration of flow events that provide longitudinal connectivity. The minimum event duration that represents an opportunity for migration between suitable habitats was determined to be eight days (DSITIA 2013a). Risk to these species in terms of altered durations between longitudinal connectivity opportunities were modelled against three ToC risk categories (Table 8) at Nebine Creek at Roseleigh Crossing (422502A) in the Nebine catchment.

**Table 8: Risk categories for changes in the frequency of connectivity opportunities***

| Low risk | Moderate risk | High risk |
|---|---|---|
| < 4 years | 4–10 years | > 10 years |

* number of consecutive years without longitudinal connectivity opportunities

There was no change in the number and duration of connection events for migratory fish under the full entitlement scenario compared to pre-development. Consequently there was no increase in the frequency of moderate or high risk events under the full entitlement scenario.

### *Absence of exotic fish species*

Access to inundated floodplain wetlands has been shown to positively influence European carp spawning rates and the habitat provided by inundated floodplains is also known to increase recruitment success. There were two flow-related components to the requirements for strong recruitment opportunities for the European carp: (i) spawning and recruitment associated with overbank flows, and (ii) opportunities for dispersal of recruits associated with flows within 12 months of an overbank flow (see Risk Assessment for Selected Ecological Assets Report, DSITIA 2013a).

A ToC could not be derived for the European carp as the relationship between the frequency of strong recruitment opportunities and their viability across the plan area has not been adequately characterised. The potential for water resource development to affect European carp recruitment opportunities for was modelled at Nebine Creek at Roseleigh Crossing (422502A) in the Nebine catchment based on a comparison of the proportional change between the pre-development and full entitlement scenarios (Figure 8).

There was no change in the percentage of years in the simulation period where strong recruitment was modelled to occur due to the full entitlement scenario. These results suggest that the full entitlement scenario does not increase the frequency of strong recruitment opportunities as compared to the pre-development scenario.

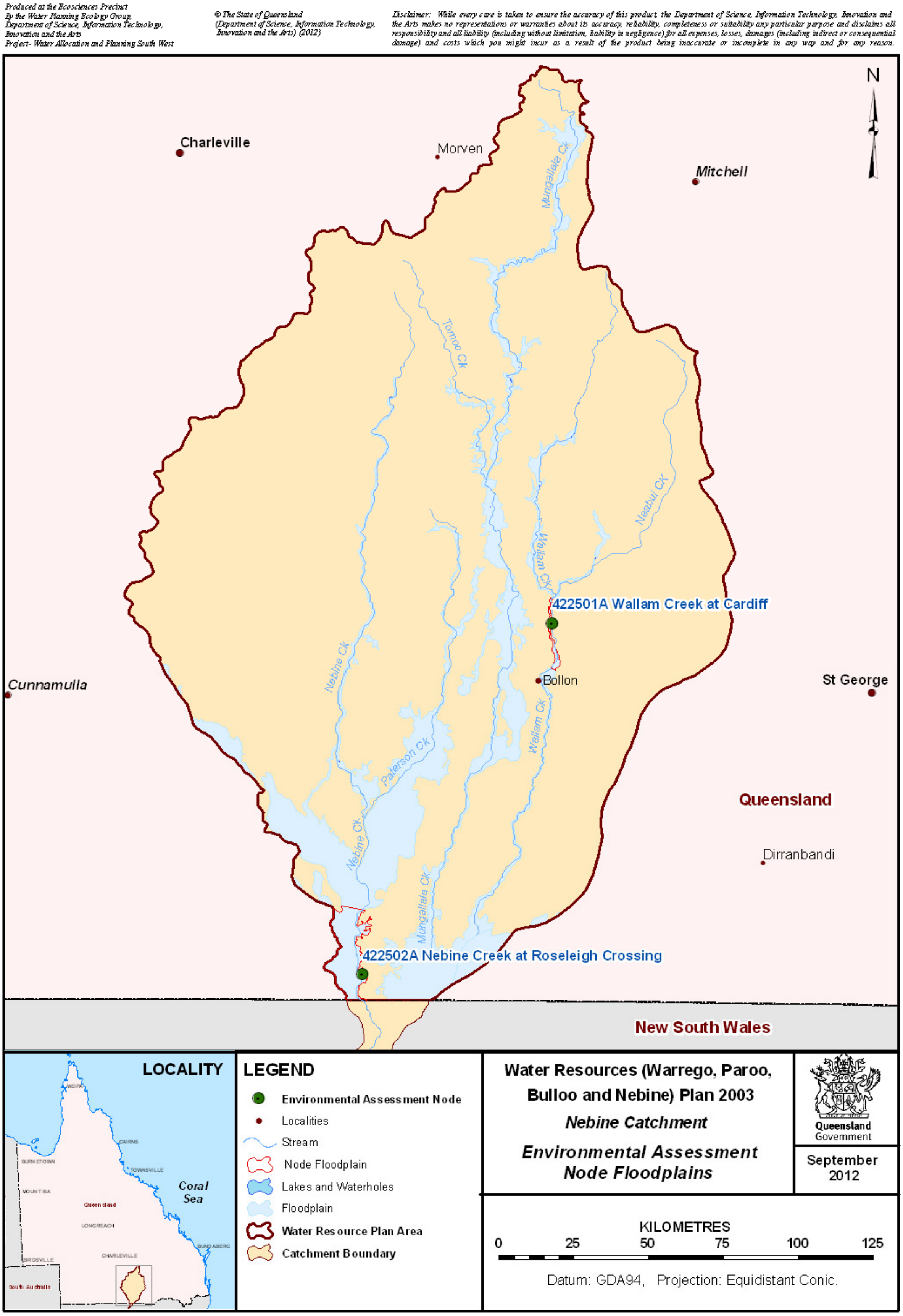


**Figure 8: Location of floodplain areas associated with each environmental assessment node in the Nebine catchment**

### *Floodplain vegetation and wetlands*

The pattern of inundation of floodplain vegetation and wetlands following over bank flows was modelled to assess the risk posed by modification of the flow regime on these ecological assets. Flow thresholds representing wetting frequencies for floodplain vegetation communities (represented by REs) and floodplain wetlands (Queensland wetland mapping) were derived using a combination of floodplain extent mapping and Landsat satellite image analysis (see Risk Assessment for Selected Ecological Assets Report, DSITIA 2013a).

ToCs could not be derived for a water regime that maintains the viability of floodplain vegetation communities (including recruitment processes and maintenance of mature plants) and floodplain wetland (including timing of events and the spatial extent of wetlands) in the plan area due the complexity of the landscape and the multiple species that contribute to each vegetation community. The potential for water resource development to affect the floodplain vegetation and wetland inundation regime was assessed at floodplain areas associated with one environmental assessment node–Nebine Creek at Roseleigh Crossing (422502A) (Figure 8) based on a comparison of the proportional change between the pre-development and full entitlement scenarios.

The results of floodplain vegetation and wetland inundation event analyses show that the vegetation and wetland inundation frequencies under the full entitlement scenario were unchanged from pre-development for floodplain areas associated with Nebine Creek at Roseleigh Crossing (422502A).

## Ecosystem processes

### *Waterholes as refugia*

*Waterhole isolation spells*

Waterhole isolation spells correspond to those periods when flow ceases and waterholes are disconnected from each other. A ToC could not be derived for assessing the impact of altering the frequency of waterhole isolation spells as their role in providing the required refugial opportunities for aquatic biota across the plan area has not been adequately characterised. The potential for water resource development to affect the pattern of waterhole persistence, as measured by isolation spells, was assessed at one environmental assessment node–Nebine Creek at Roseleigh Crossing (422502A) in the Nebine catchment based on a comparison of the proportional change between the pre-development and full entitlement scenarios.

Under the full entitlement scenario, Nebine Creek at Roseleigh Crossing (422305A) showed no change from pre-development with respect to the number and duration of isolation spells.

*Waterhole pumping*

A spatial analysis was conducted to assess potential changes in the distance between permanent waterholes and their influence on fish dispersal opportunities due to licensed waterhole pumping activities. For the purposes of the analysis, the distance travelled by yellowbelly was used to establish the relevant spatial context. In the absence of physical barriers to dispersal, yellowbelly tend to traverse distances up to 20 km along rivers during connection events.

Distances from waterholes with water entitlements to the nearest upstream and downstream waterhole without an entitlement are summarised in DSITIA (2013a–Appendix 5) for the Warrego, Bulloo, Paroo and Nebine catchments respectively, representing the distribution of permanent waterholes under pre-development. The total distance between neighbouring waterholes is also presented, to simulate the effect of waterhole pumping on the distribution of permanent waterholes.

In the Nebine catchment, there was only one waterhole subject to licensed extraction. In this reach, permanent waterholes were greater than 20 km apart, even under the pre-development scenario, so extraction from waterholes posed no additional hazard. Fish in this catchment may require longer or more frequent hydrological connectivity events in order to disperse effectively and maintain their distribution.

**Table 9: Ecological assets modelled in the Nebine catchment, their link to hydrology and modelled risk in comparison to pre-development**

| Ecological asset | Measurement endpoint | Link to hydrology | Risk in comparison to pre development* | | |
|---|---|---|---|---|---|
| | | | 422501A Cardiff | 422502A Roseleigh | Whole catchment |
| **Ecosystem component** | | | | | |
| Flow spawning fish | Abundance of yellowbelly | no-flow, medium flow, high flow | low | low | low |
| Migratory fish species | Frequency of longitudinal connectivity opportunities | no-flow, medium flow | n/a | low | n/a |
| Eastern snake-necked turtle | Frequency of high stress events | no-flow, high flow | n/a | low | n/a |
| Floodplain vegetation and wetlands | Length of spells between inundation events | high flow | 0% | 0% | n/a |
| **Ecosystem processes** | | | | | |
| Waterholes as refugia | Spells of no-flow isolation | no-flow, low flow | n/a | 0% | n/a |
| | Change in the distance between permanent waterholes due to licenced waterhole pumping | no-flow, low flow | n/a | n/a | 0% |

* risk expressed as exceedance of ToC or proportional deviation from pre-development where no ToC could be determined; n/a = not assessed

## Groundwater dependent ecological assets

### Non-riverine wetlands

The assessment concluded that none of the non-riverine wetlands across the water resource plan area are potentially dependent on groundwater because they are shallow–generally less than 2 m (Andrew Biggs, pers comm.), and therefore do not intersect with aquifers in the region which were recorded to have depth to water table deeper than these wetland bases (DSITIA 2013b).

### Springs

Springs were mapped in all catchments within the water resource plan area (refer to Attachment E), however all were identified as GAB springs dependent on the surface expression of groundwater from that aquifer. As such, these springs are only applicable to the Water Resource (Great Artesian Basin) Plan 2006 and are not considered further in this assessment (DSITIA 2013b).

### Stygofauna

Stygofauna in the Condamine-Balonne and Border Rivers region located to the immediate east of the water resource plan area, were found to occur in aquifers with widely varying chemical and morphological attributes (DNRM, unpublished data). Therefore it was not practicable to identify particular characteristics of aquifers associated with the presence or absence and composition of stygofauna assemblages. From this it is possible that all aquifers in the water resource plan area may possibly harbour stygofauna, and that investigations are needed to identify and document stygofauna occurrence in the water resource plan area.

### Terrestrial vegetation communities

#### *Warrego catchment*

Twenty-six percent of the area of the Queensland section of the Warrego catchment was occupied by potential groundwater dependent terrestrial vegetation communities (DSITIA 2013b). Of this total, 18% of the area (represented by 7962 individual RE vegetation patches) was defined as likely GDEs and 8% possible GDEs (represented by 5404 individual RE vegetation patches). In terms of area occupied, the dominant REs identified as likely GDEs were dominated by mulga (*Acacia aneura)*, gidgee (*A. cambagei)*, gundabluie (*A. victoriae)*, poplar box (*E. populnea)*, yapunyah (*E. ochrophloia)*, coolibah (*E. coolabah)* and other low woodland species growing on residuals, alluvial plains and sandplains.

***Paroo catchment***

Thirty-eight percent of the area of the Queensland section of the Paroo catchment was occupied by potential groundwater dependent terrestrial vegetation communities (DSITIA 2013b). Of this total, 22% of the area (represented by 3703 individual vegetation patches) was defined as likely GDEs and 16% possible GDEs (represented by 2303 individual vegetation patches). In terms of area occupied, the dominant REs identified as likely GDEs were dominated by mulga (*Acacia aneura)*, gidgee (*A. cambagei)*, yapunyah (*Eucalyptus ochrophloia)*, poplar Box (*E. populnea)*, coolibah (*E. coolabah)*, river red gum (*E. camaldulensis)* and other low woodland, wetland and tall shrubland species growing on sand plains, alluvium and residuals. The possible GDEs were also dominated by REs containing *A. aneura* and *E. populnea*.

***Bulloo catchment***

The Bulloo was not represented in the available groundwater depth data, so assessments could not be made using the methods applied to the other three catchments. Alternatively, distributions of RE types that had been identified as potential GDEs in the other catchments were used as an indicator GDE distribution (DSITIA 2013b). As this is a less robust method to that used for the other catchments there is less confidence in the Bulloo GDE assessment. Therefore, all REs identified here should be interpreted as potential GDEs rather than any being likely GDEs.

Using this modified method, 17% of the area of the Queensland section of the Bulloo catchment was occupied by potential groundwater dependent REs (represented by 2248 individual vegetation patches). In terms of area occupied, the dominant REs identified were dominated by gidgee (*Acacia cambagei)*, mulga (*A. aneura)* and yapunyah (*Eucalyptus ochrophloia)* with poplar box (*E. populnea)*, coolibah (*E. coolabah)*, river red rum (*E. camaldulensis)*, desert bloodwood (*Corymbia terminalis)* and other woodland and shrubland species growing on alluvium, residuals and sand plains.

***Nebine catchment***

Thirty-one percent of the area of the Queensland section of the Nebine catchment was occupied by potential groundwater dependent REs. Of this total, 31% of the area (represented by 14 665 individual vegetation patches) was defined as likely GDEs and less than 1% possible GDEs (represented by only 21 individual vegetation patches). In terms of area occupied, the dominant REs identified as likely GDEs were dominated by mulga (*Acacia aneura)*, poplar box (*Eucalyptus populnea)*, silver-leafed ironbark (*E. melanophloia)*, gum coolibah (*E. intertexta)* white cypress (*Callitris glaucophylla)* and other wetland, woodland, shrubland and forest species growing on alluvium, residuals and sand plains.

# 6. Assessment of existing Resource Operations Plan management rules

Management rules in the current Resource Operations Plan (ROP) are not explicitly linked to the WRP ecological outcomes (Table 10), however some of the rules–the Cunnammulla Water Supply Scheme operating rules and the water sharing rules for unsupplemented water–are relevant to the flow requirements of ecological assets.

Where the environmental risk assessment process identified potential threats to assets, recommendations for mitigation have been proposed (see Recommendations section, below). Adoption of these strategies as additional ROP management rules will enhance its effectiveness in achieving the WRP ecological outcomes by providing flow conditions required by the ecological assets.

## Cunnamulla Water Supply Scheme operating rules

The current ROP specifies that in operating Allan Tannock Weir, water release rates must be managed such that environmental impacts including fish stranding, blue-green algae blooms and bank slumping are minimised (section 62(1)). The plan also allows stock and domestic water to be temporarily stored in the weir, but requires an equivalent volume to be released or spilled within one month of inflow (section 63).

ROL holder monitoring identified no adverse environmental impacts of these types resulting from the operation of Allan Tannock Weir over the life of the plan (DSITIA 2013c) suggesting that the rate of water releases have been managed appropriately. ROL holder monitoring of fish stranding and bank slumping downstream of the weir should continue and could be enhanced by reporting of rates of water releases from the weir.

The environmental risk assessment (DSITIA 2013a) identified that at both the Barringun (423004) and Turra (423005) nodes downstream of the weir, under the full entitlement scenario there was an increased number of flow events that provide opportunities for fish migration over the simulation period but at a slightly shorter total duration. This resulted in a slight increase in risk to migratory fish at Turra under the full entitlement scenario (i.e. a 4.3% increase in the number of moderate risk years). The Allan Tannock Weir stock and domestic water release rule, may be contributing to this by interrupting flows and then passing them following a delay of up to one month, potentially creating a greater number of events without increasing the total duration of those events.

In order to minimise this risk to migratory fish communities downstream of the weir, releases of held stock and domestic water should be of equivalent volume as currently specified by the rule, but should also be of equivalent duration and with equivalent rates of rise and fall, to the inflow events (see recommendations below). This modified rule would reduce the likelihood of fish responding to movement cues and getting stranded by migration events that are artificially shortened.

## Water sharing rules for unsupplemented water

The current ROP requires that water entitlements are used in accordance with specified conditions such as passing flow thresholds, take rates, volumetric limits, spatial location and other special conditions. The plan also identifies the criteria that determine the start and finish of announced periods for the taking of water under those entitlements. In order to allow flows to pass through the system, in addition to the specified conditions that apply to each entitlement, there are requirements to delay the announced period for events greater than 1000 ML/day either until the flow peak has passed the location of the entitlement or until 36 hours after the peak has passed, depending on the length of time since the preceding flow event (section 97(2)).

In terms of the ecological assets used in the environmental risk assessment (DSITIA 2013a), migratory fish are mostly likely to be affected by the implementation of this rule. The rule should help to protect the hydrologic connectivity these fish require. However, because the rule is intended to service several different objectives including stock and domestic water supply, it was not designed specifically to provide opportunities for fish connectivity and at some nodes there was a slight increase (0–4.3%) in the occurrence of moderate risk events under the full entitlement scenario.

In order to mitigate increased risk to migratory fish, an additional announced period delay criterion, more closely reflecting the asset's requirements for migration opportunities, could be added to the current rule (see recommendations for migratory fish below).

# 7. Recommendations

Overall, the environmental risk assessment (DSITIA 2013a) identified low risk to surface water ecological assets from water resource management activities in the plan area. A broad threat prioritisation undertaken for the region as part of the Queensland Government's Stream and Estuary Assessment Program (SEAP) also indicated that the risk to aquatic ecological condition from water resource management is low (Negus et al. 2012).

In some instances, however, assets have increased risk profiles because the provision of hydrologic conditions that support them has been impacted under the full entitlement flow scenario. Also, the risk to some assets could not be comprehensively assessed because insufficient information about the consequence of changed conditions was available (see also DSITIA 2013a, Knowledge Gaps).

Potential groundwater dependent ecosystems (GDEs) were identified across the plan area (DSITIA 2013a), but risk to these from the current plan could not be assessed because there was insufficient information available on both their dependency on groundwater hydrological attributes and how current management has modified natural groundwater hydrology. Improved knowledge on both aspects is required before assessments of risk to GDEs could be undertaken in future.

In order to mitigate identified increases in risk, or enable future investigation of currently unassessed risks, the following actions are recommended. Updates to the current WRP and ROP should consider these recommended strategies for environmental risk management alongside the social and economic strategies and outcomes being managed by the plan.

## Warrego

The assessment for the Warrego catchment, under the full use of all entitlements in line with the current WRP and ROP, identified changes in the provision of flow requirements that may pose a risk to six of the eight assets assessed.

**Flow spawning fish**

Flow spawning fish populations (represented by yellowbelly) in the Warrego are at low risk from flow management practices under the plan. However, local population abundance in some parts of the catchment is significantly reduced under the full entitlement flow scenario, when the maximum permitted licensed extraction from waterholes during no-flow spells is considered. While the current reality is that entitlement holders value and conserve the water in waterholes and thus do not use entitlements to their full permitted extent, pumping limits could be set to codify this management practice and provide some certainty to the further protection of the persistence of key waterholes and the yellowbelly populations they support.

Recommendations

For new and traded entitlements:

1. Develop and apply cease to pump (CTP) waterhole depth thresholds. Such thresholds are intended to protect the persistence of waterholes and thus the availability of habitat for fish and other biota, during protracted periods without flow

2. Appropriate CTP threshold levels for individual waterholes are currently unknown so knowledge improvement is recommended over the life of the plan focusing on information including waterhole bathymetric profiling and water level monitoring.
3. In the interim, a generic cease to pump threshold of 0.5 m below the cease to flow depth of the waterhole, as used in other QMDB plan areas, could be adopted.
4. Section 105(2)(b) of the current ROP stipulates a CTP threshold of 0.5 m below the cease to flow depth of the waterhole, which is brought into effect when the location of a nil passing threshold entitlement (i.e. a waterhole pumping license) is changed or during any periods when they are subject to seasonal assignments (akin to a short-term lease of the entitlement to another location).

For existing entitlements:

1. Consider application of CTP thresholds on priority waterholes, identified as being of high ecological importance to maintaining flow spawning fish populations during periods without flow. Such thresholds are intended to protect the persistence of waterholes and thus the availability of habitat for fish and other biota, during protracted periods without flow.
2. A modelling optimisation should be conducted to prioritise which waterholes have the highest ecological value and hence require this enhanced level of protection.
3. Knowledge improvement to enable appropriate threshold setting as above.

**Migratory fish**

In the Warrego, opportunities for fish migration (in terms of the total duration of appropriate connectivity) are slightly reduced under the full entitlement flow scenario and the length of spells between connectivity events has increased. While at some nodes, populations are at moderate or even high risk under both scenarios (because there were instances where spells between migration opportunities were greater than the ToC of 4 or 10 years), in three locations, the increase in spell length resulted in migratory fish communities that would have experienced a low risk at all times, now experiencing a moderate risk during periods within the simulation period. In order to mitigate this increase in risk, strategies to preserve flow events that occur following extended dry periods could be implemented.

Recommendations

1. Monitor the occurrence of flow events that provide fish migration opportunities at gauging stations (i.e. events that meet criteria identified in the eco-hydraulic rule, DSITIA 2013a), and if the time since the previous suitable event is > 3 years (i.e. approaching the 4 year ToC for moderate risk to the viability of migratory fish populations), protect the next event to enable fish dispersal. Additional hydrological analysis would be required to derive a rule that achieves this protection and maximises the likelihood of a migration event occurring. Such a rule could form an additional criterion under the Announced Period water sharing rules in s. 97(2) of the ROP.
2. Ensure that stock and domestic water releases from Allan Tannock Weir are not only of equivalent volume to inflows, but are also of at least equivalent duration and with equivalent rates of rise and fall to the pre-development scenario, to prevent fish responding to flow cues and being stranded by artificially shortened events.

### Floodplain vegetation and wetlands

The assessment identified changes in the frequency of small and medium sized flood events at one node in the Warrego (Warrego River at Barringun 423004). However, the consequence of these changes cannot be interpreted because of insufficient information to set a threshold of concern for these assets.

Recommendation

1. Knowledge improvement activities could be conducted over the life of the plan to improve the understanding of interactions between riverine flooding, local rainfall and groundwater in supporting the watering requirements of floodplain vegetation, and the wetting regime required to support the ecological values and processes of wetlands.

### Waterholes as refugia

At one node, Warrego River at Cunnamulla Weir (423202C), the maximum no-flow spell duration increased by 25% under the full entitlement scenario. This may increase the probability of some permanent waterholes in the reach going dry when they would have retained water under the pre-development scenario. However, no information on waterhole persistence times is currently available to assess the consequence of this change. Throughout the catchment as a whole, waterhole pumping under full entitlement allowances also slightly increases (2%) the number of reaches where the distance between permanent waterholes threatens fish dispersal.

Recommendations

1. Knowledge improvement activities, including waterhole mapping and persistence modelling, around the Cunnamulla node over the life of the plan could be undertaken to establish ToCs and thus enable an assessment of the risk posed by the full entitlement scenario to waterholes as refugia.
2. Development and application of waterhole CTP thresholds as outlined for flow-spawning fish may be implemented (see flow spawning fish recommendations above).

### River forming processes

There is a slight reduction in both the number and total duration of flow events with the maximum capacity to mobilise sediments in the lower reaches of the Warrego under the full entitlement scenario. However, the consequence of these changes cannot be interpreted because of insufficient information on sediment dynamics in relation to these events to set a threshold of concern for this asset.

Recommendations

1. Knowledge improvement activities, such as waterhole sediment depth profiling and core analysis, may be implemented over the life of the plan to establish accumulation and scouring rates and determine the frequency with which river-forming flows are required to enable an assessment of risk.

## Paroo

No increase in risk was identified between the pre-development and full entitlement IQQM scenarios for the two assets modelled in the Paroo catchment.

## Bulloo

No increase in risk was identified between the pre-development and full entitlement IQQM scenarios for the two assets modelled in the Bulloo catchment.

## Nebine

The risk assessment for the Nebine catchment identified changes in the provision of flow requirements that may pose a threat to one of the six assets assessed—flow spawning fish. The recommendations to mitigate the identified risk are the same as those for the Warrego catchment for this asset (see above).

## Modifications to plan outcomes

The current WRP identifies twelve outcomes for the sustainable management of water as a consequence of implementing the plan. Four of these are directly related to the ecological condition of the plan area and are thus relevant to this environmental assessment of the plan (Table 10).

**Table 10: Current water resource plan ecological outcomes**

| Ecological outcome | Description |
|---|---|
| 9f | to achieve ecological outcomes consistent with maintaining a healthy riverine environment, floodplains and wetlands, including, for example, maintaining—<br>(i) pool habitats, and native plants and animals associated with the habitats, in watercourses; and<br>(ii) natural riverine habitats that sustain native plants and animals; and<br>(iii) the natural abundance and species richness of native plants and animals associated with habitats within watercourses, riparian zones, floodplains and wetlands; and<br>(iv) active river-forming processes, including sediment transport; and<br>(v) the success of bird breeding in the Currawinya lakes system, the Paroo overflow lakes, the Bulloo lakes and other significant wetland systems in the Paroo and Bulloo basin; and<br>(vi) the unique genetic diversity of aquatic plants and animals within the Bulloo basin; and<br>(vii) the near pristine condition of riverine habitats and associated native plants and animals within the Paroo and Bulloo basins; |
| 9g | to maintain water quality at levels acceptable for water use and to support natural ecological processes; |
| 9j | to maintain beneficial flooding in the water resource plan area |

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# Glossary of terms

| Term | Definition |
|---|---|
| aestivate | a state of animal dormancy, similar to hibernation, characterized by inactivity and a lowered metabolic rate, that is entered in response to high temperatures and arid conditions |
| baseflow | stream flow sustained by shallow groundwater sources between rainfall events (sometimes called low flow or groundwater recession flow) |
| ecological outcome | As defined in the *Water Act 2000*, i.e. "means a consequence for an ecosystem in its component parts specified for aquifers, drainage basins, catchments, sub catchments and watercourses." Comparable to "management goal" in the WQM process. |
| ecological values | Taken in its broadest sense, it includes not only the aquatic biota (fish, invertebrates, macrophytes) but also the biota of the riparian or foreshore zone, the river habitats and geomorphology. It is also taken to include the river processes, both physical and biological, and the roles a river may play in sustaining other systems such as, karst, estuary, floodplains and wetlands. The concept of an 'ecological value' relates particularly to the 'aquatic ecosystems' environmental value. |
| ecosystem attributes | Selected biological, chemical and physical components comprising an aquatic ecosystem e.g. fish community, geomorphology, water chemistry etc. |
| ecosystem component | Abiotic and biotic components of ecosystems, e.g. hydrology, geomorphology, riparian vegetation, aquatic vegetation, aquatic macroinvertebrates, fish, other vertebrates. |
| endemic species | Species found only within the specified range |
| environmental values | Formerly referred to as "beneficial uses". Particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health, and which require protection from the effects of threatening processes including pollution, waste discharges and deposits. They reflect the ecological, social and economic values and uses of the waterway. |
| ephemeral | transitory or brief |
| floodplain | flat or nearly flat land adjacent a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge |
| GIS | Geographic Information Systems |
| geomorphology | landforms and the processes that shape them |
| guideline | Numerical concentration limit or narrative statement (water quality) recommended to support and maintain a particular objective (NWQMS 1994; Bennett 2008). |
| indicators | A property that is able to be measured or decided in a quantitative way (*Environmental Protection Policy for Water 1997*, section 8) |
| macroinvertebrate | invertebrate that is large enough to be seen without the use of a microscope; invertebrate is an animal without a backbone |
| macrophyte | aquatic plant, large enough to be seen by the naked eye |
| obligate aquatic species | aquatic biota that cannot live in the absence of water, i.e. fish, shrimp, etc. |
| periphyton | complex mixture of algae, cyanobacteria, heterotrophic microbes, and detritus that are attached to submerged surfaces in aquatic ecosystems |
| Regional Ecosystem (RE) | Refers to the groundwater dependent ecosystem types as determined by |

| Term | Definition |
|---|---|
| types | Queensland Regional Ecosystem (RE) mapping (see Appendix A – Sections 4.2.4 and 5.3) |
| Resource Operation Plan (ROP) | A plan approved under s103(2), (*Water Act 2000*, Schedule 4) |
| refugial | acting as a refuge |
| riparian | habitat situated on the bank of a water body |
| stygofauna | fauna that live within groundwater systems, such as caves and aquifers |
| values /assets | The perceived value of the environmental, economic, social attributes of an ecosystem. |
| water quality | The status of an aquatic ecosystem (including surface, soil and groundwater), including physical, chemical, biological and aesthetic characteristics. (after NWQMS 1994; Bennett 2008) |
| water quality parameter | A measurable or quantifiable characteristic or feature of water quality e.g. pH, conductivity, nutrient concentration, etc. |
| Water Resource Plan (WRP) | A plan approved under s50(2), (*Water Act 2000*, Schedule 4) |