Department of Environment and Science

Review of Water Plan (Border Rivers) 2003 and Resource Operations Plan

Environmental Assessment Report

January 2018

Queensland Government

Prepared by

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Executive summary

Background

The Queensland Government, through the Department of Natural Resources, Mines and Energy, is reviewing the Water Plan (Border Rivers) 2003 (herein referred to as the plan). The water planning process is prescribed in the *Water Act 2000*. This report presents the final stage of the environmental assessment process. Its objectives are to:

- assess the risk to the capacity to meet the environmental watering requirements of ecological assets within the plan area due to current water allocation and water management arrangements;
- review the effectiveness of the environmental strategies of the existing plan;
- assess the outcomes and effectiveness of the existing plan;
- provide recommendations on potential mitigation strategies to minimise the identified environmental risks for consideration in the new plan; and
- provide recommendations and priorities on areas requiring future research including identification of existing knowledge/data gaps.

The assessment has been conducted within the frame of ecological sustainable development as defined in the *Water Act 2000*, and draws on the outputs of an ecological risk assessment and environmental monitoring information, in a multiple levels and lines of evidence approach. The approach is also consistent with the Murray-Darling Basin Plan requirements.

Summary of results

Environmental risks

Five surface water assets and four groundwater assets were assessed in terms of the impact of water development scenarios on their viability and long term persistence. These assets were chosen based on their potential sensitivity to water management, and to represent the ecological outcomes of the plan.

Risks were identified across the low and high flow hydrological classes, but varied between indicators and across the plan area (Table i). Alterations to the low flow regime at the Dumaresq River at Roseneath and Macintyre River at Terrawah resulted in increased high risk years for a group of small bodied, stable flow spawning fish. The a concentration of medium risks occurred at the Macintyre River at Kanowna and The Weir River at Mascot where the return frequency for floodplain wetland inundation flows have been increased under the current water management arrangements as compared to pre-development.

Risk to groundwater dependent ecosystems (GDEs) were assessed at the Sustainable Diversion Limit (SDL) resource unit scale for consistency with the Basin Plan. The risk profile varied across the two SDL areas assessed. Medium risks to baseflow to streams were identified in the Border Rivers fractured rocks, and medium risk to baseflow to streams, terrestrial vegetation and non-riverine wetlands were identified in the Border River alluvium.

Table i Summary of ecological risks

Ecological asset indicator	Hydrological class	Plan ecological outcomes, and general outcomes with an ecological focus	Summary of risk status	
			Border Rivers	Stanthorpe
Surface water indicators				
Stable flow spawning fish	Low flows	9(e), 9(f) i, ii, iii, vi, 9(i)	**Medium**	n/a
			Collectively, these fish species showed a medium risk across the assessment area, however this varied by species and location. Three of the four species experience notable reductions in recruitment opportunities and increases in high risk years under both development scenarios.	
Macintyre River Billabongs	Medium and high flows	9(e), 9(f) iii, v, 9(i)	**Low**	n/a
			The number of filling days for the anabranch billabongs under both scenarios shows little change from pre-development to the full entitlement case.	
Fluvial geomorphology and river forming processes	High flows	9(e), 9(f) i, iv, 9(g), 9(i)	**Medium**	**Low**
			Risk to fluvial geomorphology and river forming processes varied across the plan area. The frequency and duration of bankfull flows associated with mobilisation of instream sediment has been reduced in the Border Rivers assessment area.	
Floodplain wetlands	High and overbank flows	9(e), 9(f) iii, v, 9(i)	**Low**	n/a
			Risk to floodplain wetlands was low across the assessment area. Although there is a reduction in the average return frequency of overbank flows that inundate wetlands, the frequency of events which provide breeding and recruitment habitat for fish, and the provision of energy subsidies to riverine food webs is largely unchanged.	
Eastern snake-necked turtle	No and overbank flows	9(e), 9(f) iii, v, 9(i)	**Medium**	n/a
			The risk to the eastern snake-necked turtle was medium throughout the Border Rivers assessment area. Five of the eight	

			assessment nodes experienced an increase in the average duration of stress periods under the full entitlement scenario.
Groundwater indicators*			
Springs	Groundwater–depth to water table	9(l)	No medium or high risks
Baseflow to streams			**Medium** risks in the Border Rivers fractured rock and alluvium
Terrestrial vegetation			**Medium** risks in the Border Rivers alluvium
Non-riverine wetlands			**Medium** risks in the Border Rivers alluvium

*medium and high risks only

Environmental management rules

Environmental management rules within the Border Rivers Resource Operations Plan (ROP) align with strategies of the Border Rivers Water Plan and are implemented to assist in achieving its ecological outcomes. Data from various sources were analysed to provide an assessment of the effectiveness of the existing environmental management rules in aligning with the intent of plan strategies.

Minimum operating levels of storages

The intent of this rule is to provide refuge for biota during extended dry periods. The ROP states minimum operating levels for four storages associated with the Macintyre Brook Water Supply Scheme (WSS). Records were only available for three of these storages (Coolmunda Dam, Whetstone and Ben Door Weirs) for the reporting period. During this period, minimum operating levels were maintained for all three storages.

Change in rate of release

The intent of this rule is to ensure release rates from infrastructure associated with WSSs do not adversely impact downstream aquatic ecosystems. There were no instances of scouring, bank erosion or bank slumping at any of the listed storages in the Macintyre Brook WSS area for the reporting period. While this suggests that rate of release procedures have not been causing adverse impacts on the geomorphology of the river channel, it is noted that there is no appropriate methodology associated with quantifying these impacts. The occurrence of fish kills downstream of Coolmunda Dam suggest that the operation of infrastructure may be potentially effecting downstream riverine environments.

Releases to provide for environmental flows

This rule is associated with the availability of water to support natural ecosystem processes and the maintenance of the natural variability of the flow regime downstream of Coolmunda Dam. It is difficult to assess this rule as the original intent was not focussed on providing environmental benefits. Therefore further monitoring is required to quantify ecological benefits including: water quality, waterhole habitat, connectivity providing for fish movement, riparian vegetation and macrophyte quality. A future review of the rule will be informed by this new information.

Waterhole management

The intent of this rule is to provide protection to waterholes within the WSS by only allowing pumping to occur to 0.5 metres below the cease-to-flow level. A threats analysis undertaken by DNRM indicated that there was a low threat to persistence of refuge waterholes within the watercourses utilised by the Macintyre Brook WSS. The current rule is likely to be sufficient for waterholes within the WSS, given that waterhole depths are adequate in terms of being able to persist past maximum no-flow spell periods and the fact that they can only be drawn down by supplemented water allocation holders to 0.5 metre below cease-to-flow. It is likely that waterholes are still providing sufficient habitat, of a high quality, to support biota under this rule.

Infrastructure operating rules

Water sharing arrangements for the Border Rivers are contained within the New South Wales – Queensland Border Rivers Intergovernmental Agreement (2008). The Dumaresq-Barwon Border Rivers Commission (BRC) directs the distribution of water made available to the two states under the terms of the *New South Wales–Queensland Border Rivers Act* (QLD 1946, NSW 1947) and the IGA. The Border Rivers ROP does not currently contain specific operating rules designed to minimise adverse environmental effects downstream of infrastructure associated with the Border Rivers WSS.

Impact of storages on aquatic ecosystems

Monitoring requirements currently exist which relate to reducing adverse environmental impacts downstream of infrastructure associated with Distribution operations licence (DOL) holders. There is no data available to assess whether water released as part of the Callandoon Water Supply Board or the Yambocully Water Board is having a detrimental effect on downstream aquatic ecosystems. Impacts of cold water releases from Glenlyon Dam on downstream aquatic ecosystems has been identified as a potential issue. There is currently no monitoring of releases downstream of the dam to determine the extent and scale of these impacts.

Ecological outcomes

Water has been allocated and managed in a way that recognises that the ecosystems have changed from their natural state. The plan seeks to achieve a balance between socio-economic and ecological outcomes. The current plan has 13 outcomes which specify the aspects of the environment the plan aims to support through sustainably managing water and the taking of water. Collectively, these outcomes represent the environmental values of the plan area and their dependencies across the full range of hydrological classes. Drawing on the combined outputs of the ecological risk assessment and environmental monitoring information, the plan was evaluated in terms of meeting these outcomes under the current settings; two outcomes were met, four partially met, two were not met; and there was insufficient information to assess four.

Recommendations

A range of recommendations are included in the report on potential mitigation strategies, monitoring requirements, and improved specification of outcomes for consideration in the new plan. These are summarised here and further discussed in Chapter 8:

- Event management strategies which preserve flow events at bankfull thresholds are required to mitigate the risks associated with sediment movement throughout the system. However, there is currently a lack of sufficient knowledge to set a target return frequency for such flows. Additional research is required to establish these targets to inform a future review of existing event management strategies.
- Implement event management to preserve over bank flow events to promote floodplain inundation. This may alleviate the risk to floodplain wetlands and dependent biota, particularly in high value areas. Additional knowledge is required on the water balance of key wetlands to inform setting flow return frequencies to support their dependent environmental values.
- New science has been collected over the life of the plan which can be used to refine the outcomes in the new plan. It is recommended that plan outcomes be revised to ensure that they are specific, measurable, and relate to the environmental values of the plan area which are likely to be influenced by the plan.

- Review existing storage operations procedures to minimise alteration of natural flow events. This may result in improved outcomes for fish communities which require stable flow conditions to breed and recruit, reduce bank slumping and reduce potential fish stranding events. Additional recommendations are provided on the current environmental management provisions in the ROP. This includes working with ROL holders to establish improved operating procedures for infrastructure, and revising and updating the departmental Water Monitoring standards.
- Impacts of cold water releases from Glenlyon Dam on downstream aquatic ecosystems has been identified as a potential issue. There is currently no monitoring of releases downstream of the dam to determine the extent and scale of these impacts. It is recommended that a monitoring regime be designed and implemented to assess this potential risk.
- It is recommended that the Border Rivers ROP makes provision for the operation of existing and future fish passage devices and existing rules that protect operation of the fishways during the irrigation season (also spawning and migration season for many species). The efficiency of existing fish passage devices in allowing the movement of fish under a range of flow conditions is unknown. It is recommended that research is conducted to determine the range of headwater and tailwater levels under which each specific fishway operates most effectively. Provision has been made for the operation of fishways in other Water Plan areas across the state. It is recommended that investigations be made into the feasibility of including similar rules in the Border Rivers ROP for fishways at Boggabilla Weir, Glenarbon Weir and Goondiwindi Weir, with provision for additional fishways that may be installed during the life of the plan.
- New science and improved knowledge has been developed throughout the life of the plan to inform this assessment and inform water management decisions; however knowledge of the flow- and groundwater dependent ecosystems of the plan area is still developing. A number of recommendations are made on key areas which should be prioritised to improve the evidence base on which future water management decisions will be made. Prioritisation of these knowledge gaps should be undertaken annually, based on the Water Planning Science Plan (2014–2019).

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1 Introduction

1.1 Background

The Queensland Government, through the Department of Natural Resources, Mines and Energy, is reviewing the Water Plan (Border Rivers) 2002 (herein referred to as the plan). The water planning process is prescribed in the *Water Act 2000.*

A water 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 the plan's 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 water necessary for sustaining the aquatic environment, including both surface water and groundwater dependent ecosystems.

1.2 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 plan;
- assess the outcomes and effectiveness of the existing plan; and
- provide recommendations for the new plan.

The assessment results presented in this summary report are a synthesis of the information in the Ecological Risk Assessment Report (DES 2018), and the Summary of Monitoring Report (DNRME 2018), and makes recommendations on mitigation strategies to minimise identified risks to inform the development of a new water plan.

1.3 Murray-Darling Basin Plan requirements

The Basin Plan is an adaptive management framework that has been drafted by the Murray-Darling Basin Authority (MDBA) to provide a coordinated approach to managing water resources across the four member states and territory in the Murray-Darling Basin (MDB).

The Basin Plan sets out the requirements for the Basin States to prepare a water resource plan for each of its plan areas. The water resource plan sets out the rules and arrangements relating to issues such as annual limits on water take, environmental water, managing water during extreme events and strategies to achieve water quality standards and manage risks. A risk assessment is the first step in the development of a water resource plan.

Chapter 10, Part 9 of the Basin Plan (Approaches to addressing risk to water resources) outlines how Basin States must undertake risk assessments as well as the MDBA's associated accreditation requirements. Risk assessments must:

- Be prepared having regard to current and future risks to the condition and continued availability of the water resources of the water plan area;

- Risks to the capacity to meet environmental watering requirements;
- Risks arising from potential interception activities; and
- Risks arising from elevated levels of salinity or other types of water quality degradation.

Further, section 10.41 requires that the risk assessment:

- Lists and assesses each identified risk;
- Defines the risk level of each risk (low, medium or high); and
- Describes any quantified uncertainties in the level of risk attributed to each risk.

When identifying risks, Queensland is obligated under section 10.41(3) of the Basin Plan to have regard to the risks to the condition, or continued availability, of Basin water resources listed in section 4.02 of the Basin Plan. These are:

- Insufficient water available for the environment;
- Water being of a quality that is unsuitable for use; and
- Poor health of water dependent ecosystems.

The Ecological Risk Assessment Report (DES 2018) considers all relevant environmental risks prescribed by the Basin Plan and used a methodology consistent with its requirements, including defining the level of risk and documenting uncertainties (section 10.41). This report provides a higher level summary of these environmental risks in the context of an evaluation of the current plans implementation and outcomes (DNRME 2018). The report also provides an amalgamation of some risk scores so they can be presented at the sub catchment scale. This is to be consistent with the spatial scale used in the assessment of other non-environmental risks in the plan area (identified as per section 10.41 of the Bain Plan)

Recommendations for potential mitigation strategies for any medium and high environmental risks are included in section 8 of this report. These recommendations meet both the requirements of the Queensland process to review its statutory water plan as well as meeting the section 10.42 and 10.43 requirements in the Basin Plan.

1.4 Methodology

The environmental assessment has been conducted by the Department of Natural Resources, Mines and Energy (DNRME) and Department of Environment and Science (DES). The assessment draws on the results of monitoring and research conducted by the Queensland Government in the plan area during the life of the plan, studies undertaken by other research institutions and input from relevant experts. The Queensland Government’s Environmental Flows Assessment Program (EFAP) (https://www.dnrm.qld.gov.au/water/catchments-planning/planning-process/supporting) is a key source of information on ecological assets and their critical flow requirements.

1.5 Environmental assessment report outline

This report is structured as follows:

Chapter 1–overview of environmental assessment purpose and scope

Chapter 2—outlines the hydrology and water resource development of the Border Rivers catchment.

Chapter 3—outlines the general water requirements for the surface water dependent ecosystem components of the Border Rivers catchment, and discusses the critical water requirements of selected ecological assets.

Chapter 4—outlines the general water requirements for the groundwater dependent ecosystem components of the Border Rivers catchment, and discusses the critical water requirements of selected ecological assets.

Chapters 5 and 6—assesses the effectiveness of the water resource plan based on selected ecological assets.

Chapter 7—assesses the current environmental provisions contained within the plan and ROP.

Chapter 8—outlines the conclusions and recommendations for environmental provisions in the new draft water plan.

2 Hydrology and water resource development of the plan area

2.1 Surface water

The Border Rivers catchment spans the Queensland and New South Wales state border (Figure 1). For management purposes, the catchment is divided along the state border with the northern portion managed by Queensland and the southern portion managed by New South Wales (see New South Wales–Queensland Border Rivers Agreement 2008). In Queensland, the Border Rivers headwaters rise in the Stanthorpe region near the Great Dividing Range. The Moonie and Condamine-Balonne catchments extend around the northern boundary of the catchment. The Gwydir River catchment of New South Wales abuts the southern extent of the Queensland portion of the Border Rivers catchment. The main river systems of the Border Rivers include the Macintyre River and Dumaresq River. Both rivers flow in a general east to south-west direction. The Border Rivers catchment (Queensland and New South Wales) is 45,675 km^2 which accounts for 4.4 per cent of the total area of the Murray-Darling Basin (DEE 2016).

The Dumaresq River runs along the state border in the eastern portion of the catchment until its junction with the Macintyre River, which flows in from New South Wales. The Macintyre River continues along the state border before joining the Barwon River north-east of Mungindi. The Weir River also joins the Macintyre River at this location and together they form the Barwon River. Ultimately, with the systems of the Border Rivers flowing into the Barwon River system, the Border Rivers forms part of the northern extent of the Murray-Darling Basin.

Elevation in the eastern range region reaches 1200 metres above sea level and quickly drops away towards the west along extensive flat, semi-arid plains which fall to 200 metres above sea level. Rainfall is seasonally variable with greater falls in summer months. Average annual rainfall varies between approximately 1000 mm at the Great Dividing Range to 500 mm at Mungindi in the west. Average summer rainfall across the catchment is 100 mm per month, with 40–50 mm per month from April to September. Annual evaporation varies from approximately 1200 mm in the east to over 2000 mm in the west (Green et al. 2012).

The Macintyre River is regulated and experiences regular flows throughout the year as a result of dam releases for downstream supplemented water users. The Weir River, in the west of the catchment, is unregulated and experiences natural drying and wetting periods in response to rainfall events. In dry periods flow, ceases and the system is reduced to a series of isolated waterholes. During periods of heavy rainfall, overbank flows in the west of the catchment create connectivity between river channels across floodplains. The low gradient western portion of the Border Rivers catchment is characterised by floodplain wetlands. DNRM currently has 25 gauging stations in the Border Rivers catchment to monitor flow (DNRM 2017b).

Surface water use in the Border Rivers is supplied from both supplemented and unsupplemented water sources. The Dumaresq-Barwon Border Rivers Commission (BRC) is the joint NSW-Queensland organisation responsible for sharing the water resource of the Border Rivers catchment between the states. In sharing the resource, the Commission is responsible for the operation and maintenance of Glenlyon Dam, Boggabilla Weir and a number of smaller weirs. However, the BRC uses the services of DNRME and SunWater to manage its infrastructure. Water is supplied from three storages, Glenlyon Dam (254,000 ML) on Pike Creek and Pindari Dam (312,000 ML) on the Severn River (NSW), and to a lesser extent, Coolmunda Dam (69,000 ML) on Macintyre Brook. Water is distributed from the storages through watercourses and reticulation networks and may take up to 21 days to travel from the release point to destination.

Two water supply schemes operate in the Border Rivers WRP area: the Macintyre Brook Water Supply Scheme (MBWSS) and the Border Rivers Water Supply Scheme (BRWSS). SunWater is the service provider for the MBWSS. The BRWSS is operated from infrastructure controlled by the Border Rivers Commission and managed by SunWater. Water is supplied along the Dumaresq, Macintyre and Barwon Rivers.

Unsupplemented surface water is diverted via water harvesting, area-based entitlements and through capture of overland flow. In the Border Rivers, unsupplemented water is managed in designated Water Management Areas (WMA) through rules in the ROP. The Border Rivers currently has seven WMAs – the Border Rivers, Lower Weir River, Upper Weir River, Northern Weir River, Callandoon Creek, Macintyre Brook and Stanthorpe.

On-farm water dams and weirs also regulate storage and use of water. Major structures along the Macintyre and Dumaresq Rivers include:

- Bonshaw Weir (Dumaresq River)
- Cunningham Weir (Dumaresq River)
- Glenarbon Weir (Dumaresq River)
- Boggabilla Weir (Macintyre River)
- Goondiwindi Weir (Macintyre River)
- Coomonga Weir (Coomonga Creek)
- Boomi Weir (Macintyre River)
- Boomi Regulator (Boomi River)
- Newinga Regulator (Flood channel from Barwon to Weir River)
- Mungundi Weir (Barwon River)

2.2 Groundwater

The majority of the managed groundwater within the plan area falls within the Border Rivers Alluvium. This area follows the Queensland/New South Wales border, along the Dumaresq and Macintyre Rivers. It begins downstream from Mingoola, slightly east of the confluence of Pike

Creek, Severn River and Mole River, extending southwest and then northwest under the towns of Texas and Goondiwindi, ending slightly west of the later. The alluvium also underlies the town of Inglewood and follows the Macintyre Brook River southwest, until in merges with the Dumaresq River, east of Keetah. The alluvial sediments cover an area of approximately 221,360 hectares and are generally confined to areas immediately underlying and adjacent to the Dumaresq and Macintyre Rivers, as well as Macintyre Brook.

A number of rock types provide variable yield and water quality, including porous sandstones, fractured granites and other sedimentary and volcanic rocks (CSIRO 2007). High yielding sources of groundwater are extracted from deposits associated with the Dumaresq and Macintyre Rivers, upstream of Keetah. The alluvium comprises of sediments ranging from large boulders, through cobbles, gravels, sands, silts and clay. The floodplain is up to 4.5 km wide and the sediments have a maximum thickness of 100 metres. The Upstream of Keetah Bridge alluvium is recharged by rainfall, side slope run-off and streamflow leakage from the regulated Dumaresq River.

The Border Rivers Alluvium Groundwater Management Area consists of two sub-areas. The sub-areas are managed separately and are assessed independently for the purpose of (i) determining announced allocation and (ii) determining rules for seasonal water assignments. The sub-area boundaries are based on local geology and existing hydro-geological conditions, such as transmissivity and storage capacity. The sub-areas can be described as follows:

- sub-area 1—extends from the confluence of Blackfellow Creek with the Dumaresq River, upstream to Mingoola
- sub-area 2—extends from the confluence of Blackfellow Creek with the Dumaresq River, downstream to where the Keetah Bridge crosses the Dumaresq River.

Water sharing rules and seasonal water assignment rules for the Border Rivers Alluvium Groundwater Management Area are prescribed in section 27 of the Water Regulation 2016, and the seasonal water assignment rules, as prescribed in Section 39 of the Water Regulation.

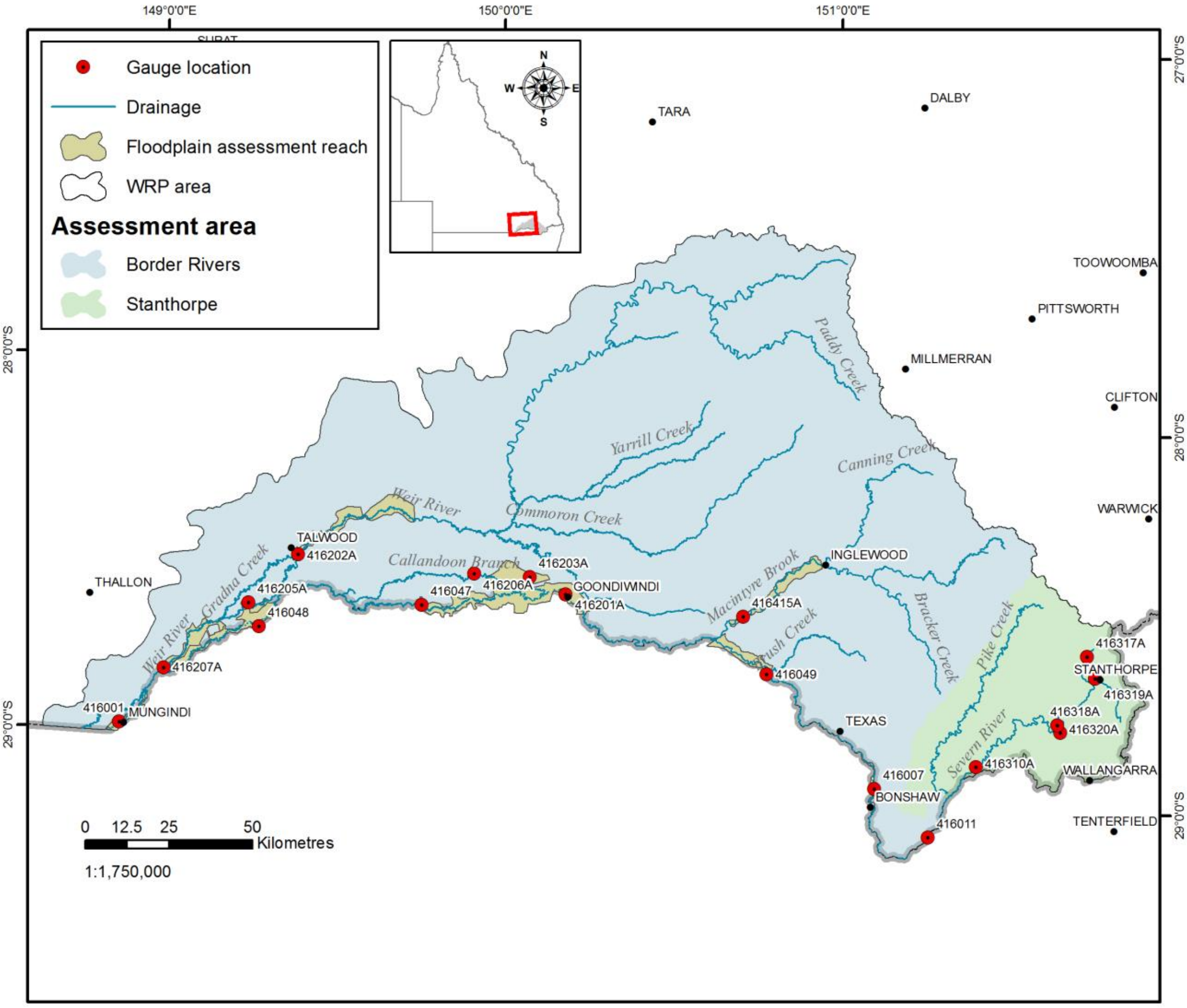

Figure 1 Border Rivers plan area showing the location of environmental assessment nodes (at stream gauge locations), floodplain assessment reaches and assessment areas

3 Surface water dependent ecosystems of the plan area

3.1 Ecosystem components

Floodplain wetlands

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 et al. 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 make inundated wetlands excellent breeding habitats for consumers such as waterbirds, fish and turtles.

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).

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.

Reptiles and amphibians

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.

3.2 Ecosystem processes

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). Many 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 metres 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):

- channels constricted on both banks by Aeolian dunes form short, wide and shallow waterholes;
- channels flanked on one bank by a single dune, valley margin or similar form longer and deeper waterholes;
- the confluence of multiple anastamosing channels draining inundated floodplains, which generate scour without channel constriction; and
- deeply penetrative bands of relatively high velocity can occur in waterholes during high-flow events, suggesting that localised values of bed shear could be quite large even when cross-sectional velocities 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 Condamine-Balonne, Border Rivers or Moonie 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 a single waterhole than there is variability between waterholes at a single time (Marshall et al. 2006a; 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, snails, yabbies and prawns, use waterholes as their primary habitat (DSITIA 2013). 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.

Fluvial geomorphology 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 shear stress, the force acting upon the substrate resulting from flow, is sufficient to entrain substrate sediments. The location of maximum shear stress moves up and down stream with changes in the magnitude of flow (Sear 1995; Wilkinson et al. 2003). High flows exert the greatest shear 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 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).

4 Groundwater dependent ecosystems of the plan area

Groundwater dependent ecosystems (GDEs) are ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011). In many cases groundwater dependence is either subtle or cryptic, and varies widely both temporally and spatially (Hatton & Evans 1998). There are three classes of groundwater dependent ecological assets (GDEs) commonly recognised in the literature (after Eamus et al. 2006):

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

Surface expression GDEs are formed by topographic or structural landscape features directing groundwater above the ground surface. Water can present either as a point source such as a spring vent or a seep/soak, diffusing as baseflow into rivers and streams or as a window into the water table, such as non-riverine wetlands. This also includes groundwater flowing through the hyporheic and parafluvial zones (the regions beneath, and lateral to, a stream bed respectively, where there is mixing of shallow groundwater and surface water).

Ephemeral or persistent palustrine and lacustrine wetland GDEs such as lakes, swamps, sedgelands and bogs can have a continuous or seasonal dependence on groundwater. They support dependent biota including fringing and aquatic plant communities, subsurface refuges as well as biota which depend on the surface expression of groundwater such as fish, macroinvertebrates, and algae.

Surface expression GDEs are vulnerable to drawdown of the water table below the ground surface. Drawdown beyond this threshold disconnects groundwater inputs from surface ecosystems, essentially removing their presence. Changing the groundwater dynamics can have significant impacts on receiving ecosystems changing persistent systems to ephemeral, and in extreme cases removing the ecosystem altogether (Boulton & Hancock 2006).

Ecosystems dependent on the sub-surface expression of groundwater include terrestrial vegetation that utilise groundwater in either an obligate or facultative way. Access to groundwater can maintain the health of vegetation communities during drought periods. This can provide landscape scale benefits such as maintaining vegetation refuges for terrestrial fauna during high stress drought periods, reduced erosion and geomorphological degradation, and enhancing ecosystem recovery after drought breaking rainfall.

GDE vegetation access groundwater through their root system extending into the capillary fringe or directly into the water table. The depth to which a root system can reach groundwater varies within and between species. Some vegetation communities have been shown to extend beyond perceived maximum rooting depths in response to falling groundwater levels. The capacity for physiological changes in rooting depth is possible if the rate of groundwater regime change is within adaptive limits of the species present (Canham et al. 2012). The limits of such physiological adaptions are as yet to be established.

Cave and aquifer systems with subterranean ecosystems are present throughout the plan area and have the potential to support groundwater fauna, (referred to as ‘stygofauna’) communities within them. They include ecosystems existing in aquifers or the zone of interaction between river water and the groundwater present in banks and beds of rivers. Aquifer sampling for stygofauna in the Condamine-Balonne and Border Rivers region (Schulz et al. 2013) has been undertaken confirming their presence, however at present the understanding of how these ecosystems function is insufficient to support the risk assessment process.

The western semi-arid areas receive lower rainfall and are characterised by large, low profile alluvial plains. The limited local recharge and the absence of topographic features directing groundwater towards the ground surface results in large alluvial systems and a lower number of surface expression GDEs. The groundwater present is often within the rooting depth of remnant vegetation communities supporting a mosaic of GDE terrestrial vegetation communities across the broader landscape and along ephemeral drainage lines.

5 Methods for assessing the effectiveness of the water plan

5.1 Ecological risk assessment process

The ecological risk assessment aims to identify and quantify risks from water resource development in the plan area. The assessment uses an ecohydrological modelling approach, based on the principles of ecological risk assessment. 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 (McGregor et al. 2017). A summary of the process is illustrated in Figure 2, and a detailed explanation of the risk assessment methodology provided in DES (2018).

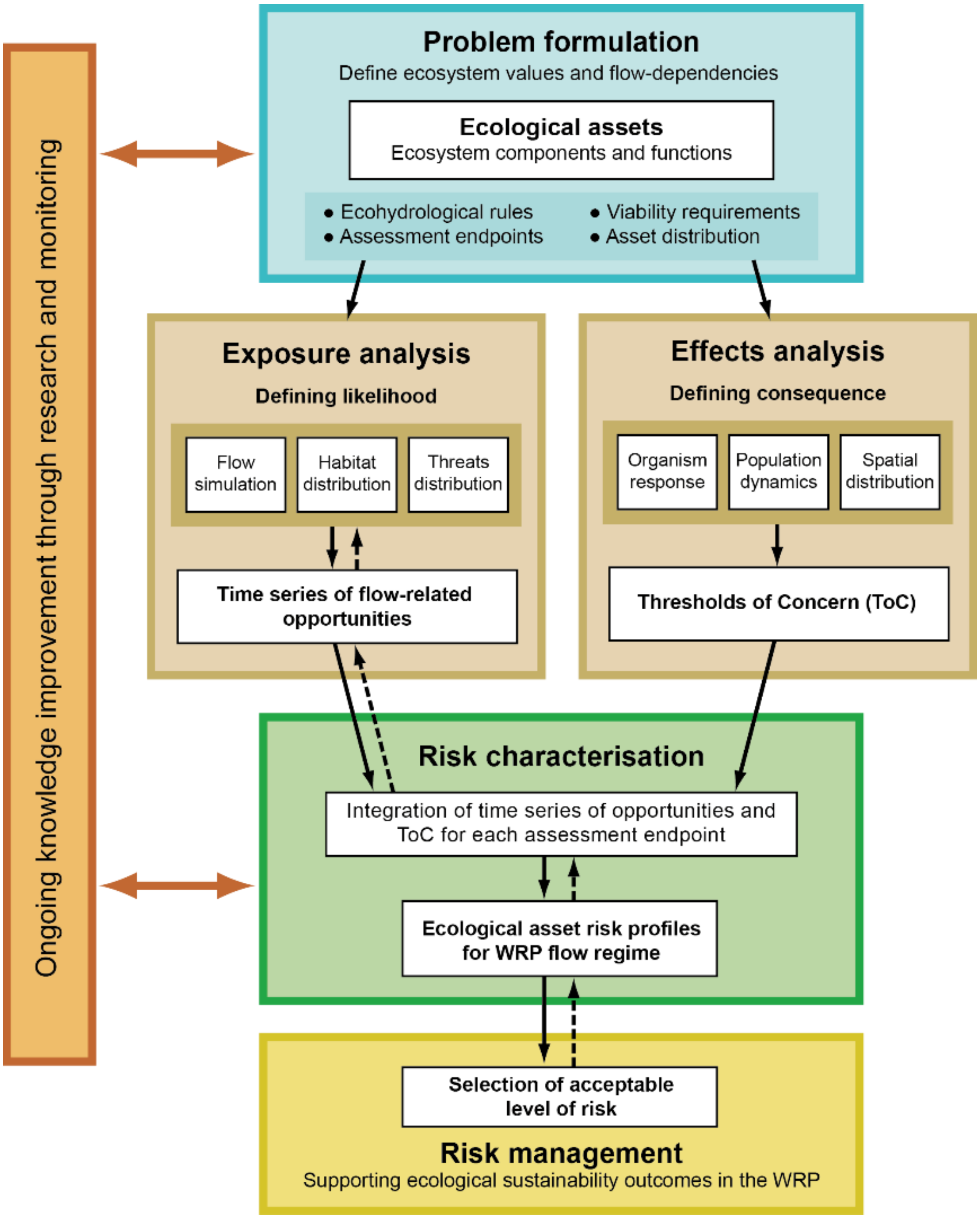

Figure 2 Summary of the risk-based ecohydrological modelling approach (after McGregor et al. 2017)

The approach partitions the critical flow/water requirements of ecosystem components, processes and services, and considers how these requirements have been altered over time under the water management scenarios representing the current plan settings. These ecosystem components, processes and services are used as indicators sensitive to flow or groundwater modification, and are therefore broadly representative of the ecosystem response under the current water management regime. Referred to as ecological assets, they may be a species, group of species, an ecological or process function, or a place of value.

5.1.1 Surface water risks

The risk to ecological assets within the plan area were assessed at all locations where hydrological simulations were available within its known distribution. Three surface water development scenarios were assessed:

1. pre-development: assumes no water resource development across the plan area, but with existing infrastructure in place.
2. full entitlement: full use of existing entitlements with current Resource Operation Plan (ROP) operating rules and existing infrastructure–this scenario does not reflect current utilisation of water entitlements
3. Inter Governmental Agreement: represents the level of development in the Border Rivers at the time of the moratorium including water licences, installed pumps, storages and planting practices/areas.

Risk was assessed at a range of spatial scales relevant to the asset (assessment node, floodplain assessment reach, and assessment area) (Figure 1). As such, the approach utilises the spatio-temporal sequence of risk generated by the hydrological scenario across multiple locations. Where possible, it incorporates aspects of population structure and dispersal characteristics of assets to define patterns of risk across the catchment (Hughes et al. 2012). This ensures that risk is evaluated at the spatial and temporal scale over which assets function (Arthington 2015).

Assessment nodes

Assessment nodes are hydrological model nodes which correspond to the location of stream gauge sites for which stream cross sectional, and flow ratings information was available.

Floodplain assessment reaches

The relatively sparse distribution of gauging stations along with the extensive areas of floodplain in the assessment area and the complex hydrology of floodplains means that it is unlikely that available gauge data is representative of the entire floodplain. The catchments were mapped by including the location of environmental assessment nodes and the areas identified as floodplains by the Queensland floodplain assessment overlay mapping (QRA 2010). Queensland government hydrologists and hydrographers used their local expert knowledge and an assessment of the location of tributaries and constrictions in the stream network to identify the relevant areas of floodplain associated with each environmental assessment node. Where the floodplains of multiple parallel channels merge, aerial and satellite images were used to identify intersecting ridges or other indications of predominant flow direction, and delineate areas of flood origin accordingly. These are termed floodplain assessment reaches (FARs). All floodplain asset assessments were confined to these reaches as they are parts of the floodplain that are represented by hydrology at the environmental assessment nodes.

Assessment areas

For the purposes of the assessment, the plan area was divided into two assessment areas reflecting river reaches with comparable hydrological and ecological attributes. Risk to ecological assets was assessed at both the individual node and assessment area scales.

5.1.2 Groundwater risks

Although the current plan manages all surface and groundwater in the Border Rivers catchment, there are currently no ecological outcomes in the plan that relate to GDEs, however the plan does aim to protect the productive base of groundwater (9(l)).

Groundwater models are not available across the entire assessment area to provide predictions of altered groundwater regimes in response to current management arrangements. Subsequently risk to GDEs was assessed using a semi-quantitative risk ranking process. To assess the consequence of an impact, an understanding of GDE functioning and the sensitivity of an ecosystem to changes in the groundwater regime was considered, based on conceptual models of system behaviour and benchmarking with published information on ecosystems that have experienced similar groundwater management impacts from comparable biophysical settings. GDEs were assessed at the Sustainable Diversion Limit (SDL) resource unit scale (MDBA 2012). SDL resource unit boundaries were determined according to the types of aquifers present and the management boundaries used by the Basin states.

5.2 Environmental monitoring

Environmental monitoring, research, and a number of science reviews has been undertaken across the plan area by several organisations over the life of the plan including:

- Department of Natural Resources, Mines and Energy
- Department of Environment and Science
- Department of Agriculture and Fisheries
- Resource Operations Licence Holders
- Murray-Darling Basin Authority
- Commonwealth Environmental Water Holder
- Several universities, research institutes and other science providers

A collation and synthesis of this information and new scientific knowledge has been undertaken to assist in evaluating the plan's performance in meeting its ecological outcomes (DNRME 2018).

6 Results

6.1 Ecological risk assessment

6.1.1 Ecological assets

A total of 2576 potential ecological assets including species of flora and fauna, vegetation communities, wetlands, instream and floodplain habitat and ecological processes were identified across the plan area (Ecological Asset Report, DNRM 2017). Using available information about each asset's requirements for surface water, the primary list was reduced to a subset of 101 ecological assets that were considered to be critically linked to flow or the groundwater regime.

These assets were considered as candidates for the ecological risk assessment. Of these candidate assets, sufficient knowledge of their flow or groundwater requirements was available for nine surface water assets and four groundwater dependent assets to enable analysis of the impact of water development scenarios on their viability and long term persistence to be quantitatively modelled (Table 1).

Table 1 Ecological asset indicators used in the ecological risk assessment, their link to hydrology and the plan outcomes

Ecological asset indicator	Indicator measurement endpoint	Hydrological class	Water plan ecological outcomes, and general outcomes with an ecological focus
Surface water indicators			
Stable flow spawning fish	Spawning and recruitment success of each species	Low flows	9(e), 9(f) i, ii, iii, vi, 9(i)
Macintyre River Billabongs	Frequency of billabong inundation events	Medium and high flows	9(e), 9(f) iii, v, 9(i)
Fluvial geomorphology and river forming processes	Frequency and duration of bankfull flow events	High flows	9(e), 9(f) i, iv, 9(g), 9(i)
Floodplain wetlands	Frequency and duration of wetland inundation events	High and overbank flows	9(e), 9(f) iii, v, 9(i)
Eastern snake-necked turtle	Frequency of high stress events	No and overbank flows	9(e), 9(f) iii, v, 9(i)
Groundwater indicators			
Springs	Potential interaction between GDEs and groundwater take (as altered depth to groundwater)	Groundwater–depth to water table	9(l)
Baseflow to streams			
Terrestrial vegetation			
Non-riverine wetlands			

6.1.2 Surface water indicators

Stable flow spawning fish

Four small-bodied fish species which have aspects of their reproductive development, migration, spawning and recruitment, linked to stable flow conditions at specific times of the year were assessed:

- Agassiz's glassfish (*Ambassis agassizii*)
- Purple-spotted gudgeon (*Mogurnda adspersa*)
- Murray River rainbowfish (*Melanoteania fluviatilis*)
- Carp gudgeons (*Hypseleotris* spp.)

Spawning and recruitment opportunities were assumed to have occurred for those species if daily flows were low (< median daily flow), and those flows coincided with suitable water temperatures (above the minimum known, species specific, spawning temperature) and occurred within the species specific spawning season and water levels remained stable for the duration of egg and larval development.

Opportunities for successful recruitment of stable flow spawning fish species are likely to be at greatest risk from rapid changes in water level due to flow management. Water levels that are too high or too low may result in a loss of spawning and nursery habitat, and water levels that fall too rapidly may result in the exposure and desiccation of eggs as well as greater rates of predation on eggs and larvae due to exposure (Pusey et al. 2004). In managed river networks rapid water level changes may result from either water extraction or flow supplementation. At the population scale, any reduction in the number of recruitment opportunities may influence the long term resilience and subsequent viability of the species. This represents high risk conditions for the population. Risk thresholds were established for each of these species based on the number of recruitment opportunities required to maintain long term population viability.

Risk to populations of stable low flow spawning fish species were modelled at seven assessment nodes in the Border Rivers plan area. Each of the four species being assessed has different distributions within the catchment area, therefore not all species were modelled at each of the assessment nodes. Collectively, these species showed a medium risk across the plan area, however this varied by species and location (Table 2); three of the four species experience notable reductions in recruitment opportunities and increases in high risk years under both development scenarios.

The glassfish experienced a decrease in the number of spawning opportunities under both development scenarios at all four nodes. The most significant impacts occurred at Dumaresq River at Roseneath and the Macintyre River at Terrawah, where the proportion of high risk years increased to 88.2 and 87.4 per cent for the full entitlement and IGA scenarios respectively. Recruitment opportunities for the rainbowfish were most impacted at the Macintyre River at Terrawah and Kanowna, where the proportion of high risk years has increased by 8.6 and 2.5 per cent respectively under full entitlement. Elsewhere, it was largely unaffected.

Five of the seven assessment nodes modelled for the carp gudgeon, and both the nodes modelled for the purple spotted gudgeon, experienced a decrease in the average annual number of spawning opportunities under the full entitlement scenario, compared to both development scenarios.

Table 2 Average annual recruitment opportunities and proportion of high risk years for stable flow spawning fish (pre-development=PD, full entitlement=FE, inter-governmental allocation=IGA; grey cells indicates species not present at this location)

	Ambassis agassizii			*Melanotaenia fluviatilis*			*Mogurnda adspersa*			*Hypseleotris* spp.		
Assessment nodes	PD	FE	IGA	PD	FE	IGA	PD	FE	IGA	PD	FE	IGA
Dumaresq River at Roseneath (416011)	7, 24.4	< 1, 73.1	< 1, 63.9	42, 0.0	22, 1.7	21, 0.9	14, 1.7	6, 6.0	4, 12.8	41, 0.0	26, 0.9	28, 0.0
Macintyre River at Terrewah (416047)	4, 41.2	1, 88.2	< 1, 87.4	19, 1.7	8, 10.3	8, 6.8				36, 0.0	17, 2.6	18, 1.7
Macintyre River at Kanowna (416048)				16, 2.6	8, 5.1	8, 8.5				32, 0.9	18, 0.0	18, 1.7
Macintyre River at Goondiwindi (416201A)	12, 14.3	2, 34.5	3, 43.7	50, 0.0	23, 0.9	23, 0.0	16, 2.6	3, 23.1	3, 30.8	52, 0.0	34, 0.0	34, 0.0
Weir River at Talwood (416202A)	38, 0.0	< 1, 89.9	40, 0.0							84, 0.0	14, 0.9	85, 0.0
Callandoon Creek at Carana Weir (416203A)										82, 0.0	89, 0.0	91, 0.0
Macintyre Brook at Booba Sands (416415A)				56, 0.0		40, 0.0				58, 0.0		53, 0.0

Macintyre River Billabongs

The system of waterbodies within the floodplain of the Macintyre River, downstream of Goondiwindi, is known as the Macintyre Billabongs. These include billabongs or ox-bow lakes, anabranches, and other wetland types. Much of the floodplain has been developed for irrigated agriculture and ~90 per cent of the water resources used for this purpose are supplied from surface water (CSIRO 2007). Between Boggabilla and Keetah, groundwater resources are also used for agriculture (Groundwater Management Units N22, N23 and N601) and may contribute to the water balance of some wetlands in this region (CSIRO 2007). Studies of flow thresholds required to fill billabongs on the Macintyre River floodplain (Reid 2006; Thoms et al. 2005) found that 90 per cent of the anabranches and billabongs are hydrologically connected with the river when flows at Goondiwindi exceed 20,000 ML/day, with commence-to-fill thresholds ranging from 200–54,000 ML/day (Southwell 2008).

Maintenance of an anabranch–river connection flow regime supports the associated environmental values including movement, spawning and recruitment of aquatic species, vegetation vigour, nutrient and carbon cycling, and lateral and longitudinal connectivity.

Flow thresholds representing commence to fill (CTF) thresholds for 65 anabranch billabongs were derived from Southwell (pers. com.). These CTF thresholds were applied to simulated flows at Macintyre River at Goondiwindi.

There is insufficient information to set a ToC relating to the frequency of anabranch billabong filling events, however an assessment of hazard was made by comparing hydrological deviation from the benchmark of the pre-development hydrological scenario.

The number of filling days for 65 anabranch billabongs under both scenarios shows little change from pre-development to the full entitlement case (Table 3). The filling days under full entitlement is slightly higher than pre-development flow thresholds from 100 to 3000 ML/day due to flow supplementation, whereas they are slightly lower under full entitlement for flow thresholds from 3000 to 10,000 ML/day. This data suggests a low risk for these billabongs under the current water management arrangements.

Table 3 Anabranch billabong filling frequency under pre-development and full entitlement

Commence to fill threshold category (ML/day)	Number of anabranch billabongs	Pre-development		Full entitlement	
		Number of inundation days	Percentage of total simulation	Number of inundation days	Percentage of total simulation
100–500	0	35,205	76	38,265	83
500–1000	4	21,017	45	24,515	53
1000–2000	10	14,681	32	16,431	36
2000–3000	17	9445	20	9062	20
3000–4000	12	6990	15	5926	13
4000–5000	5	5592	12	4440	10
5000–7500	8	4605	10	3568	8
7500–10,000	8	3139	7	2375	5

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 volume was chosen as the hydrological threshold at which the maximum shear 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, were assessed at 17 environmental assessment nodes in the plan area, across all four assessment areas. A ToC could not be established for this indicator as the relationship between the frequency of bankfull flows and their role in influencing river forming processes has not been adequately characterised.

Three of the five nodes within the Stanthorpe assessment area experienced reductions of bankfull flow event days of between 8 and 23.9 per cent from pre-development. Sites downstream of Dumaresq River at Roseneath to Macintyre River at Goondiwindi are all within the sediment transport valley functional process zones category (Alluvium 2010). Within this zone, two of three assessment nodes experienced reductions of bankfull flow days of between 7.7 and 12.5 per cent from pre-development. Bankfull flow events at Dumaresq River at Roseneath were unchanged.

The remainder of the assessment area downstream to the Queensland border fall within the sediment deposition valley functional process zones category (Alluvium 2010). Sediment, nutrients and organic matter is deposited in this zone and stored on benches, in anabranches and on the associated floodplain; there is generally a net loss of sediment movement downstream from this zone (Alluvium 2010). Contribution of authochonous organic material from periphyton production is much higher in these areas than further upstream. Across this process zone, bankfull flow days have been reduced by between 8.7 and 40.8 per cent from pre-development. This loss of high energy stream flows may lead to infilling of pool habitat and interstitial spaces with fine particles representing loss of habitat for aquatic biota.

Floodplain wetlands

Wetland habitat types within the Border Rivers include arid and semi-arid swamps, coastal and sub-coastal floodplain lakes, tree swamps, and grass-sedge wetlands and karst wetlands (State of Queensland 2017). Riparian vegetation along the lagoons and anabranches of the Macintyre and Weir Rivers has overstorey species that include river red gum, river cooba, coolabah, whitewood and black tea-tree, tangled lignum, Darling pea, black roly-poly and prickly Acacia. Emu bush and native bluebell may be found in a shrub layer (Capon et al. 2012). The endangered terrestrial herb, *Microcarpaea agonis,* is also found in the plan area, on the margins of ephemeral swamps between Goondiwindi and Millmerran (Bean 1997).

Flow thresholds representing filling of floodplain wetlands were derived from evaluation of a time-series of satellite imagery using the following three step process (DSITI 2017a): (i) selection of floodplain wetlands, (ii), time series analysis of satellite image scenes, and (iii) interpretation of wetting patterns in relation to gauged river flow data.

This process yielded either a single, or multiple, floodplain wetland inundation threshold(s) per FAR (DES 2018). Wetlands which had infrequent interaction with water from floodplain inundation (i.e. >

10 year average return interval), were deemed not to be strongly dependent on river flow to sustain their associated environmental values, and therefore not a sensitive indicator. These wetlands and associated inundation thresholds were subsequently excluded from the analyses.

There is insufficient information to set ToC relating to floodplain wetlands, however an assessment of hazard was made by comparing hydrological deviation from the benchmark of the pre-development hydrological scenario.

Floodplain wetlands were assessed across five FARs at seven flow thresholds. The persistence of floodplain wetlands across the plan area varies from 32 to 400 days. All sites showed a reduction in the number of wetland connection days under the full entitlement scenario of between 22.2 and 37.0 per cent.

Macintyre River at Kanowna showed a reduction in the average return frequency of floodplain wetland inundation flows of five months, with the maximum return frequency increasing by an additional two years. The Weir River at Mascot showed some of the largest impacts at the mid frequency range; average return frequency of floodplain wetland inundation flows reduced by three years; however the maximum return frequency was largely unchanged.

An important role for some of these wetlands is the provision of breeding and recruitment habitat for fish, and the provision of energy subsidies to riverine food webs. These values are supported by wetland rewetting events which occur within the same season, i.e. a return frequency of less than one year. In most cases the 25th percentile values for inundation return frequencies across the flow thresholds considered are unchanged. This suggests that this function is still supported across the five studied FARs under the full entitlement scenario.

Eastern snake-necked turtle

The eastern snake-necked turtle (*Chelodina longicolis*) is an iconic species which is found throughout the Queensland Murray-Darling Basin. It is an active species with great propensity for overland migration, capable of travelling up to 2.5 km when floodplain waterbodies 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 high stress periods and high risk events for populations of this species. The level of risk increases with an increase in the time between the availability of off-stream habitat (DES 2018).

A ToC was defined which represents the maximum length of high stress events the eastern snake-necked turtle population can tolerate. A population in the Jervis Bay area (NSW) took ten years to recover body condition sufficient for them to reproduce following a four year drought (A. Georges, pers. comm.). Based on this information a ToC of 4 years was used for the assessment. Spells between floodplain wetland inundation events at an environmental assessment node ≥ 4 years represent a threat to the long term persistence of the local population. For each assessment node, the flow threshold representing the floodplain wetland inundation event for the ToC was determined based on available remote sensed imagery for the region covering the assessment period (DES 2018).

Eight assessment nodes were used to model stress periods for the eastern snake-necked turtle in the Border Rivers assessment area (Table 4). Five of the eight assessment nodes experienced an increase in the average duration of stress periods under the full entitlement scenario compared to pre-development, as well as from the IGA scenario to both the full entitlement and pre-development scenarios. Results for two of the three remaining assessment nodes, Weir River at Jericho, and Macintyre Brook at Booba Sands, suggest that the entire 117 year simulation period from each of the three scenarios were high risk periods. Six of the eight assessment nodes also experienced an increase in the average duration of stress periods under the IGA scenario compared to pre-development, and four of those five nodes experienced an increase in the average duration of stress periods under the IGA scenario compared to the full entitlement scenario.

The ToC was exceeded at seven of the eight assessment nodes under all three scenarios. The exception was Macintyre River at Kanowna where the ToC was exceeded only under the IGA scenario with results showing that one per cent of years in the simulation period were high stress years. Three assessment nodes, Barwon River at Mungundi, Macintyre River at Goondiwindi, and Weir River at Mascot experienced increases in the percentage of high stress years in the simulation period from the pre-development scenario to the full entitlement scenario as well as from the full entitlement scenario to the IGA scenario.

Table 4 Stress periods for the eastern snake-necked turtle (pre-development=PD, full entitlement=FE, IGA flow scenarios)

Environmental assessment node	Number and average duration of stress periods (days)			Longest duration of high stress periods (years > 4 year ToC)		
	PD	FE	IGA	PD	FE	IGA
Barwon River at Mungundi	11; 3736	9; 4639	6; 7112	24.2	24.2	52.6
Macintyre River at Kanowna	20; 255	29; 484	27; 617	0	0.5	0.7
Dumaresq River at Mauro	11; 3809	9; 4712	9; 4709	24.2	24.2	24.2
Macintyre River at Goondiwindi	7; 5874	6; 6943	3; 14,427	29.1	29.1	77.2
Weir River at Talwood	30; 670	27; 946	27; 946	2.3	6.7	6.7
Weir River at Jericho	1; 44,366	1; 44,366	1; 44,366	117.5	117.5	117.5
Weir River at Mascot	12; 3393	10; 4158	9; 4658	24.2	24.2	24.2
Macintyre Brook at Booba Sands	1; 44,366	n/a	1; 44,366	117.5	n/a	117.5

6.1.3 Groundwater indicators

Queensland GDE mapping for the eastern Murray-Darling Basin catchments (V 1.5, March 2017) (wetlandinfo.ehp.qld.gov.au) was used as the basis for the risk assessment. The Queensland GDE mapping process employs a consultative process that integrates local, expert knowledge of landscapes (and the ecosystems within them) with detailed spatial data in order to map GDEs across catchments. The Queensland GDE Mapping Method capitalises on pre-existing ecosystem mapping data (e.g. regional ecosystem and wetlands mapping) available state wide for Queensland at minimum of 1:100,000 scale (DSITI 2015b). The Queensland GDE Mapping consists of five spatial data sets:

1. Surface expression GDEs (point features)
2. Surface expression GDEs (line features)
3. Surface expression GDEs (area features)
4. Terrestrial GDEs (area features)
5. Subterranean GDEs–caves (area features)

Each ecosystem identified as potentially groundwater dependent is assigned a confidence rating to indicate the level of confidence associated with the prediction that the ecosystem is groundwater dependent. Confidence is rated according to the level of confidence local experts had in the mapping rule-set that identified the specific ecosystem as potentially groundwater dependent (DSITI 2015).

Groundwater models are not available across the assessment area to provide predictions of altered groundwater regime in response to current management arrangements. Subsequently, risk to GDEs was assessed using a semi-quantitative risk ranking process (AS/NZS ISO 31000:2009; AS/NZS 4360:2004). Likelihood scores were based on probability of an impact occurring, and consequence scores were based on the potential impact using a simplified heuristic approach supported by existing ecological information and expert judgement (after Suter 2006). Rankings were derived for three risk categories as a product of the likelihood and consequence scores for each GDE asset.

Depth to groundwater is the principal attribute considered using this approach. It is recognised that aspects of groundwater quality and its interaction with surface water features is equally important; however knowledge limitations currently restrict our ability to define acceptable limits of change for these groundwater attributes.

GDEs were assessed at the Sustainable Diversion Limit (SDL) resource unit scale (MDBA 2012). SDL resource unit boundaries were determined according to the types of aquifers present and the management boundaries used by the Basin states. A number of the SDL resource units have also been vertically separated, to reflect that water is or can be extracted from different aquifers within the same resource unit. The QMDB includes 13 SDL areas, two fall within the Border Rivers plan area. SDL resource units were further divided into sub-units based on groundwater system attributes such as flow direction and connectivity (Table 5). The delineation of sub-area boundaries was conducted in consultation with Queensland Government scientists and groundwater resource managers/planners. The finer scale assessment allows for the separation of areas of low ecological risk from areas of higher concern within the context of management boundaries.

Table 5 SDL areas and subareas within the plan area

SDL area	Sub-areas
Border Rivers Fractured Rock	Granites, Trap Rock
Border Rivers Alluvium	Dumaresq, Goondiwindi

The groundwater resource that is considered as part of the Water (Great Artesian Bain) Plan 2006 is excluded by the *Water Act 2007* (Cth) from the Basin Plan process and thus was not part of this assessment. A summary of the medium and high risks identified by the assessment is provided in Table 6. Full details of risk ranking are provided in DES (2018).

Table 6 Summary of medium and high risks to GDEs

SDL area / sub-areas	GDE type	Risk ranking
Border Rivers fractured rock		
Granites	Baseflow to streams	Medium
Border Rivers alluvium		
Dumaresq	Baseflow to streams	Medium
	Terrestrial vegetation	Medium
	Non-riverine wetlands	Medium

6.2 Environmental monitoring

6.2.1 Water plan/resource operations plan monitoring

The Queensland Government's Environmental Flows Assessment Program (EFAP) undertakes ecological monitoring to assess the ecological performance of each water plan in meeting its stated outcomes. Ecological assets with critical links to flow that represent the plan outcomes and the various aspects of the flow regime were selected as indicators of the broader ecosystem for monitoring. Monitoring and information has been collated on a range of assets in the plan area over the past 10 years. Projects have been designed to identify critical flow requirements of assets and address identified knowledge gaps in the scientific literature. This work has concentrated on understanding flow-ecology relationships as a function of:

- environmental conditions and spawning of golden perch (*Macquaria ambigua*) (DERM 2010)
- the distribution and drown-out values of instream barriers and the extent to which individual barriers might influence fish movement (Kerr et al. 2015)
- habitat and flow requirements of stable flow spawning fish guild which support recruitment (DNRM 2015b)
- determining the inundation thresholds, and persistence of floodplain wetlands (DNRM 2017a)
- the response of populations of floodplain vegetation communities, fish and aquatic food-webs to floods (Woods et al. 2012)
- the distribution of groundwater dependent ecosystems (DERM 2011b).

6.2.2 Water quality monitoring

Surface water

The Department of Natural Resources, Mines and Energy manages, operates and maintains stream gauging stations across the plan area. The stream gauging station network is operated by trained hydrographic staff within a quality management environment under International Organisation for Standardisation ISO 9001:2008 accreditation. Streamflow measurements are an integral part of producing volumetric data at gauging stations. Stream gaugings are taken throughout low and high flow conditions to enable derivation of a full range of accurate streamflow volumes.

The frequency of water quality data collection is variable and occurs across a range of flow conditions. Continuous time series indicators include electrical conductivity, pH, and temperature. In-situ measurements may include any or all of these indicators (DEHP 2013).

Turbidity is generally high throughout the Queensland Murray-Darling sampling area, electrical conductivity is relatively high upstream in the Border Rivers catchment but declines downstream as the rock types become sandier. Water quality indicators are generally within guidelines in the upper Border Rivers section of the province, although there is some uncertainty, and nutrient data is deficient in many areas. The uncertainty increases downstream due to limited availability of data. Possible electrical conductivity rises accompanied by falling turbidity in the Border and Moonie Rivers sub catchments. Most of the electrical conductivity trends were probably influenced by climatic factors, although there is no apparent link between these and turbidity (DERM 2011b).

Groundwater

DNRME operates and maintains a network of groundwater monitoring bores across Queensland. There are 37 in the Border Rivers Alluvium, located with the Macintyre and Weir Rivers (4162), Dumaresq (4163) and Macintyre Brook (4164) sub-basins. Groundwater levels are measured an average of three to four times each year. Groundwater levels generally respond to surface water conditions (floods and droughts) combined with water resource use. Bores located closer to water courses may be influenced more heavily by fluctuations in stream flow.

The Groundwater Water Quality Network consists of a subset of bores from the Groundwater Water Level Network. Water samples are taken manually at each site, as required. Samples were analysed for major ions, total nutrients (TP, TN), filtered nutrients (FRP, NOx and NH4), electrical conductivity, pH, temperature and turbidity. A small number of sites have water quality monitored continuously. Water quality information is stored for individual bores by DNRME. Trends in water level or water quality on a basin scale are not geologically relevant as there is no significant interaction between the geological units and local events have a greater impact on bores than regional water management activity.

6.2.3 Riverine condition and trend

Sustainable Rivers Audit

The Queensland Government has undertaken assessments of the ecological condition of waterways in the plan area for the MDBA Sustainable Rivers Audit (SRA). The SRA commenced in 2004 and has progressed through two stages: SRA1 and SRA2. SRA1 focussed on three assessment themes: fish, hydrology, and macroinvertebrates, from 2004 to 2008. SRA2 assessed five themes: hydrology, fish, macroinvertebrates, vegetation, physical form, from 2009 to 2014. In 2015, the MDB Fish Survey commenced, using methodology and sampling sites of the SRA program, but with a focus solely on fish. The SRA is reported at valley scale and monitoring was conducted across sites within several zones in each valley; there were 23 valleys monitored across the Murray-Darling Basin (Davies et al. 2012). Condition assessments are scored on a five staged scale relative to reference condition (good to moderate, poor and very poor to extremely poor) (Davies et al. 2012).

Overall, the program reported the ecosystem health of the Border Rivers Valley as:

- <u>Moderate</u> (SRA1 data collected 2004–2007) (Davies et al. 2008).
- <u>Poor</u> (SRA2 data collected 2008–2010) (MDBA 2012).

The Murray-Darling Basin Fish Survey commenced in 2015 to monitor fish condition at the Basin scale. This data will be used to address fish targets set out in the Murray-Darling Basin Plan (Schedule 7) and the Basin-wide Environmental Watering Strategy. No results from this program are currently available and it is due to report in 2018.

Q-catchments Program

A threat prioritisation undertaken as part of the Queensland Government's Q-catchment Program identified priority threats of the eastern portion of the Queensland Murray-Darling Basin which incorporates the plan area (Negus et al. 2015). Of these threats, two were ranked as high risks and five as moderate to the condition of riverine ecosystems of the Border Rivers region:

High risk threats:

- Instream pest fauna

- Deposited sediment

Moderate risk threats:

- Hydrology (sub-threat in-channel flow variability)
- Climate change
- Hydrology (flow regime general)
- Riparian disturbance
- Instream connectivity (barriers)

6.2.4 Resource Operations Licence (ROL) holder monitoring

Monitoring is conducted by SunWater, the resource operations licence holder, under the requirements of the plan; this includes: Glenlyon Dam and Boggabilla Weir. The Border Rivers Resource Operations Plan requires ROL holders to monitor the impact of infrastructure operations on aquatic ecosystems (Chapter 14, Part 2). This has been undertaken with a focus on:

- Water quality (thermal and chemical stratification in each storage, contribution of the storage and its management to the quality of water released, and cumulative effect of successive storages on water quality), and cyanobacteria (blue-green algae) blooms;
- Bank condition (following rapid change in water level, large flows through storages and/or on other occasions when bank collapse is likely); and
- Fish stranding (reports of instances in watercourses or ponded areas associated with the infrastructure must be recorded and assessed).

Water quality

Water quality monitoring in water storages has been conducted by SunWater throughout the reporting period in: Glenlyon Dam and Boggabilla, Bonshaw and Mungindi Weirs (Border Rivers WSS); and Coolmunda Dam, Whetstone Weir, Ben Dor Weir, and Greenup Weir (Macintyre Brook WSS).

SunWater follows the Water Monitoring Data Collection Standard (DNRM 2007) which takes a risk management approach to water quality monitoring, based around storage stratification patterns. Sampling occurs in the area immediately downstream of the storage if safe to do so. Parameters sampled include temperature, dissolved oxygen, pH, electrical conductivity, total nitrogen, total phosphorus and total sulphide. Cyanobacteria (blue-green algae) are monitored by within the storage. Temperature and dissolved oxygen profiles within the storage may also be measured to better characterise the storage stratification pattern.

Water quality parameters such as nitrogen and phosphorus exceeded trigger values for all storages in most years. Electrical conductivity was within acceptable limits for all storages, except Whetstone and Ben Dor Weirs, for most years. Glenlyon Dam was the only storage that was thermally stratified. Chemical stratification was also strong for most years for Glenlyon Dam. Where reported, cyanobacteria levels were either ‘low to moderate’ or ‘moderate’ for Glenlyon Dam across the reporting period. Coolmunda Dam also had periods of ‘moderate’ levels of cyanobacteria.

For many of the impoundments the total nitrogen and total phosphorus levels have exceeded guidelines for the majority of the reporting period. SunWater suggests that these elevated levels of nitrogen and phosphorus arise from the predominantly agricultural land use in the areas surrounding many of the storages, or as point source pollution entering the water course upstream of each of the storages. They make this suggestion because their water quality monitoring data shows that nutrient values are generally lower in outflows compared to the values measured in the storage.

Bank condition

ROL holders relevant to the Border Rivers Operations Plan 2008 (Chapter 12, Part 1, Section 321) are required to inspect banks for evidence of erosion or slumping following rapid changes in water levels, large flows through storages and/or on other occasions when bank collapse is likely. The ROL holder must provide a summary of bank condition including:

- Results of investigations of banks for evidence of collapse and/or erosion downstream of diversion works defined in attachment 5(C) following instances of rapid water level changes or large flows through the works, or other occasions when collapse or erosion of banks may be likely, and
- Changes to operation of infrastructure to reduce instances of bank slumping and/or erosion.

According to the department and SunWater's annual reports, there were no reported instances of bank slumping downstream of Glenlyon and Coolmunda Dams, Boggabilla, Bonshaw, Mungindi, Whetstone, Ben Dor and Greenup Weirs.

Fish stranding

ROL holders are required to report and assess instances of fish stranding in watercourses or ponded areas associated with the infrastructure. The ROL holder must provide a summary of fish strandings including (i) results of any investigations of fish stranding downstream of storages; and (ii) changes to operation of infrastructure to reduce instances of fish stranding.

Where there have been instances of fish stranding, details of the event, mitigating actions taken and the result of these actions are provided to the department by the ROL holder through a special report as soon as possible after the event. Between 2008 and 2017, there was one incident of fish death that was observed in the tailwater of Coolmunda Dam and reported by SunWater in their annual reports.

An Operational Report was submitted to the department on 4 February 2011 regarding the fish kill. The report stated a fish kill incident was identified and reported to SunWater by Toowoomba Regional Council downstream of Coolmunda Dam in between Coolmunda Dam and Greenup Weir stretch on 28 January 2011. The event involved several hundred bony bream. Coolmunda Dam ceased to overflow on the 26 January 2011. Releases from Coolmunda Dam reduced from 280 ML/day (26 January 2011) to 20 ML/day (31 January 2011). The creek levels declined by approximately one metre. SunWater notified the department of the incident on 28 January 2011 in accordance with EPA Fish Kill Reporting Guidelines. SunWater notified the department of the incident on 31 January 2011 in accordance with Border Rivers ROP.

From the report it was determined that the rapid reduction in water flow being released may have contributed to the fish kill. This was the only fish kill reported in the SunWater Annual Reports for the Border Rivers between 2008 and 2017. However, there was another fish kill not reported in the SunWater Annual Report for 2012–2013. SunWater submitted a fish death notification on the 6 July 2012 to the EPA. In this event over 50 young bony bream were found dead in Coolmunda Dam. The report stated that it had been very cold with frost in the area over the previous week and easterly breezes blew the dead fish into the shore area. SunWater staff had noted similar occurrences in the past years during periods of cold weather.

6.2.5 Summary of other monitoring activities

A complete list of relevant environmental monitoring activities conducted within the plan area over the life of the plan is presented in the Summary of Monitoring Report (DNRME 2018).

7 Assessment of existing Resource Operations Plan management rules

Environmental management rules within the Border Rivers Resource Operations Plan (ROP) align with strategies of the Border Rivers Water Plan and are implemented to assist in achieving its outcomes. This chapter provides an assessment of the ROP environmental management rules, and other relevant rules, in terms of their ecological effectiveness.

The environmental management rules operating within the plan area, and contained within the ROP, relate to matters such as the release of water and stream flow requirements, the operation of infrastructure, the maintenance of water storage levels, and waterhole management within the Macintyre Brook Water Supply Scheme (MBWSS). There is also provision in the ROP for Distribution Operations Licence (DOL) Holders to provide monitoring information relating to the release of water and the effect on aquatic ecosystems.

There are no specific operating rules outlined in the ROP that are defined as environmental management rules for the Border Rivers Water Supply Scheme (BRWSS). However, the ROP points to operating infrastructure according to arrangements agreed to by Queensland and New South Wales, and procedures established by the Dumaresq-Barwon Border Rivers Commission (BRC).

The following sections include an assessment of compliance and ecological efficacy of rules relating to environmental management contained within the ROP. Recommendations have been made to refine particular management rules or to establish new rules where considered appropriate. As the ROP was implemented in March 2008, the period of assessment for this report is from this time, where data is available.

7.1 Minimum operating levels of storages s88 (Macintyre Brook Water Supply Scheme)

Except where provided for under section 90A, the resource operations licence holder must not release or supply water from a storage where the water level in that storage is at or below its minimum operating level.

Ecological effectiveness

The intent of this rule is to provide refuge for biota during extended dry periods. Whilst the storages monitored maintained levels above the minimum operating levels for the periods monitored, it is currently uncertain whether the quality of these storages are sufficient to act as refuge for biota.

For many of the impoundments the total nitrogen and total phosphorus levels have exceeded guidelines for the majority of the reporting period. Nutrient concentrations are generally lower in outflows compared to the concentrations measured in the storage. Poor water quality of impoundments may affect the suitability of these habitats as refuges for some biota. Moreover, large storages may not support aquatic populations capable of recolonising the larger catchment after sustained failures of other natural refuges due to instream barriers. Further research into the ecological carrying capacity of major storages and their ability to provide a habitat safeguard within a catchment is required.

Recommendations

Persistent refuge habitat may exist within a number of artificial impoundments within the MBWSS, notably Coolmunda Dam. Little information exists on the equivalence of this artificial habitat, in terms of its refuge habitat quality, as compared to natural waterholes. Further research is required to quantify the ecological role of storages in terms of providing quality refugial habitat.

As this rule relates to water releases once the minimum operating level is reached, release records are required to assess compliance. Whilst the ROP states minimum operating levels for three of the four storages associated with the MBWSS, it does not require ROL holders to record release data from Whetstone or Ben Dor Weirs.

7.2 Change in rate of release s89 (Macintyre Brook Water Supply Scheme)

The resource operations licence holder must minimise the occurrence of adverse environmental impacts by ensuring that any reduction or increase in the rate of release of water occurs incrementally.

Ecological effectiveness

The intent of this rule is to ensure release rates from infrastructure associated with the WSS do not adversely impact downstream aquatic ecosystems. This rule is supported by ROP reporting requirements in Chapter 11 which refer to monitoring and/or recording, and reporting on release rates and the reason for releases. Monitoring of storage water quality, downstream bank condition, and instances of fish stranding are also required to be reported on by the resource operations licence holder.

There were no instances of scouring, bank erosion or bank slumping at any of the listed storages in the MBWSS area for the reporting period. While this suggests that rate of release procedures have not been causing adverse impacts on the geomorphology of the river channel, it is noted that there is no appropriate methodology associated with quantifying these impacts. Fish kills downstream of Coolmunda Dam suggest that the operation of infrastructure may be potentially impacting downstream riverine environments.

Recommendations

It is recommended that the rate at which water is released better reflect natural flows. That is, the rate of release should be incrementally reduced over a number of days to mimic natural flows. It is recommended that the department work with SunWater to establish better practices relating to changing the rate of infrastructure releases.

The resource operations licence holder has frequently reported that there have been no impacts on the aquatic environment as a result of infrastructure operations. However, there is no supporting evidence, monitoring data or detailed discussion around how these conclusions were drawn. It is recommended that the department work with resource operations licence holders to:

- establish geomorphological baseline conditions in reaches downstream of listed storages, and
- develop a monitoring program suitable for reporting on bank slumping, scouring, channel erosion and fish kills.

Quarterly reports from resource operations licence holders include statements such as: “All releases complied with the operating rules as defined under the Border Rivers ROP.” While this may be accurate, it does not provide sufficient information to assess ecological effectiveness. It is recommended that resource operations licence holders report on compliance with each operating rule. Compliance around reporting by resource operations licence holders needs to be addressed so that the appropriate data is supplied in a timely manner. This is important for assessing ROP rules and risk to the environment.

It is further recommended that the department review and update its monitoring and reporting guidelines to better reflect data requirements.

7.3 Releases to provide for environmental flows s90 (Macintyre Brook Water Supply Scheme)

1. *The first 100 megalitres per day of inflow into Coolmunda Dam must be released through the outlet works where the water level in Coolmunda Dam is—*

   (a) less than full supply level; and

   (b) greater than 311.05 m AHD
2. *Notwithstanding subsection (1), where the capacity of the outlet works of Coolmunda Dam is insufficient to release both the volume required for water orders and the volume required under subsection (1), the amount to be released under subsection (1) may be reduced to the balance of the capacity of the outlet works after allowing for releases for water orders.*
3. *Where the resource operations licence holder acts under subsection (2), the balance of the volume required to be released under subsection (1) must be released as soon as practicable.*
4. *The total volume of releases made under subsection (1) for a water year must not exceed 6000 megalitres*

Ecological effectiveness

This rule is associated with the availability of water to support natural ecosystem processes and the maintenance of the natural variability of the flow regime downstream of Coolmunda Dam. An assessment of the effectiveness of the environmental flow strategy has shown a 100 ML/day flow travels to the Booba Sands gauging station on the Macintyre Brook, a distance of 62 km. A small proportion of the flow passes the Booba Sands gauging station and would likely travel the remaining 15 km to the Dumaresq River/Macintyre Brook junction under favourable conditions. The main environmental outcome from the release would be topping up waterholes along the Macintyre Brook and improved water quality and waterhole habitat.

Further monitoring is required to quantify ecological benefits including: water quality, waterhole habitat, connectivity providing for fish movement, riparian vegetation and macrophyte quality. Depending on the outcomes of the above research, the possibility to store and release the environmental flow may be considered. Larger flows may be more relevant, depending on the ecological outcome desired.

Recommendations

Further monitoring is required to quantify the ecological benefits this rule encompasses, including: water quality, waterhole habitat, connectivity providing for fish movement, riparian vegetation and macrophyte quality. It is further recommended that an assessment of the effectiveness of the current environmental releases (in terms of number of releases, the timing of the release/s and the rate of the release/s) be undertaken.

Improved annual reporting by the ROL holder could be considered to include: number of releases made, duration of releases, and length of stream in which environmental flow benefits. A compliance assessment of the ROP rule including correlating the number of inflows greater than 100 ML/day and the number of environmental releases of 100 ML/day, should be completed. The potential to store and release the environmental flow to the maximum capacity of the outlet pipe should be investigated.

7.4 Waterhole Management s91 (Macintyre Brook Water Supply Scheme)

The water level in any waterhole may be drawn down to 0.5 metres below the natural cease to flow level to allow water to be taken under a water allocation.

Ecological effectiveness

The intent of this rule is to provide protection to waterholes within the WSS by only allowing pumping to occur to 0.5 metres below the cease-to-flow level. A threats analysis undertaken by DNRM indicated that there was a low threat to persistence of refuge waterholes within the watercourses utilised by the Macintyre Brook WSS.

Recommendations

The current rule is likely to be sufficient for waterholes within the WSS, given that waterhole depths are adequate in terms of being able to persist past maximum no-flow spell periods and the fact that they can only be drawn down by supplemented water allocation holders to 0.5 metre below cease-to-flow. It is likely waterholes are still providing sufficient habitat, of a high quality, to support biota under this rule.

Resource operations licence holders are required to measure and record the level of water below cease-to-flow level for each day that supplemented water is taken from a waterhole. There has not been any reports of this occurring, and it is unlikely the ROL holder is aware of any instances. In terms of compliance, monitoring may assist.

Trade rules, such as those applied to waterholes in the Condamine and Balonne ROP area, should be implemented in the revised Border Rivers ROP. Upon trading and changing the location of the allocation, a condition including a visible pass flow requirement should be implemented to further protect waterholes. Stock and domestic pumping is also not covered by this rule, especially outside of the WSS reaches. Monitoring of pumping or a more encompassing rule is required.

While the Border Rivers Water Plan (Border WP, Part 4, Division 7, Section 44) currently has a provision that a resource operations plan may include a 0.5 metre pump down limitation through an application for a change in location of an ex-area based water allocation, there was no requirement to consider this provision in the current ROP as it did not convert any area based licences.
Infrastructure operating rules s140 (Border Rivers Water Supply Scheme)

(2) The resource operations licence holder must operate Glenlyon Dam, Boggabilla Weir, and Newinga regulator infrastructure in accordance with—

(a) water sharing arrangements agreed to by the State and New South Wales;

(b) operating procedures established by the Dumaresq–Barwon Border Rivers Commission.

Ecological effectiveness

Water sharing arrangements for the Border Rivers are contained within the New South Wales – Queensland Border Rivers Intergovernmental Agreement (2008). The Dumaresq-Barwon Border Rivers Commission (BRC) directs the distribution of water made available to the two states under the terms of the New South-Wales–Queensland Border Rivers Act (QLD 1946, NSW 1947) and the IGA. An assessment of these rules and/or agreements has not been undertaken here. The Border Rivers ROP does not currently contain specific operating rules designed to minimise adverse environmental effects downstream of infrastructure associated with the BRWSS.

Despite the lack of ROP operational rules pertaining to the environmental effects of infrastructure, as per the MBWSS, there are still requirements for the resource operations licence holder to report on the impact of storage operation on aquatic ecosystems (ROP Chapter 11 Division 2). These include reporting on: water quality (Section 300); bank condition (Section 301); and fish stranding (Section 302).

Recommendations

A rule protecting the stream ecology from sudden changes in water level (rate of release), water releases should be considered.

The rate at which water is released from infrastructure should reflect natural flows. That is, the rate of release should be incrementally reduced over a number of days to mimic natural flows. It is recommended that the department work with storage operators to establish better practices relating to changing the rate of infrastructure releases.

The resource operations licence holder has frequently reported that there have been nil impacts on the aquatic environment as a result of infrastructure operations. However, there is no supporting evidence, monitoring data or detailed discussion around how these conclusions were drawn. It is recommended that the department:

- establish geomorphological baseline conditions in reaches downstream of listed storages, and
- develop a monitoring program suitable for reporting on bank slumping, scouring, channel erosion and fish kills.

7.5 Border Rivers Water Supply Scheme

As outlined in the Border Rivers ROP (Chapter 6, Sections 137 and 138):

The BRWSS applies to water distribution and allocation, water storage, and operational infrastructure of the Border Rivers zones A and B (ROP Attachment 3A), extending from Glenlyon Dam downstream to Mungindi. The scheme includes the following in-stream water storages and associated infrastructure: Glenlyon Dam (Pike Creek); Bonshaw Weir, Cunningham Weir, Glenarbon Weir (Dumaresq River); Boggabilla Weir, Goondiwindi Weir, Boomi Weir (Macintyre River); Mungindi Weir (Barwon River), and the Newinga Regulator (flood channel between the Weir and Barwon Rivers). The State of Queensland represented by Department of Natural Resources, Mines and Energy is the Resource Operations Licence holder for the BRWSS.

Water access and sharing arrangements for the Border Rivers are contained within the New South Wales – Queensland Border Rivers Intergovernmental Agreement (IGA (2008). The Dumaresq-Barwon Border Rivers Commission (BRC) directs the distribution of water made available to the two states under the terms of the New South Wales – *Queensland Border Rivers Act* (QLD 1946, NSW 1947) and the IGA. As outlined in the Border Rivers ROP (Chapter 6, Part 1, Section 140):

1) This section applies to—

(a) Glenlyon Dam;

(b) Boggabilla Weir; and

(c) Newinga regulator.

(2) The resource operations licence holder must operate the infrastructure defined under subsection (1) in accordance with—

(a) water sharing arrangements agreed to by the State and New South Wales;

(b) operating procedures established by the Dumaresq–Barwon Border Rivers Commission.

Ecological effectiveness

<u>Water quality of infrastructure associated with water supply schemes</u>

Water quality monitoring has been conducted by SunWater throughout the reporting period for Glenlyon Dam and Boggabilla Dam but not for the Newinga regulator. Glenlyon Dam was the only storage that was considered to stratify thermally. Chemical stratification was strong for most years for Glenlyon Dam. Guidelines for pH were exceeded (or not reported) for both storages, for most years. Total nitrogen and total phosphorus levels exceeded guidelines for the majority of the reporting period. Where reported, cyanobacteria (blue-green algae) levels were either ‘Low to Moderate’ or ‘Moderate’ for Glenlyon Dam across the reporting period. Cyanobacteria was not measured at Boggabilla Weir. There are no current blue-green algae issues within the Border Rivers trunk stream. The algal suppression flow for the Interim North-West Flow Strategy has been triggered infrequently and is likely to be maintained at this stage.

The results discussed above suggest that reduced water quality in the storages in the plan area may not provide adequate habitat for biota. Also, water released from these storages may not be of sufficient quality for biota downstream. There is no requirement under the current ROP to report or give consideration to cold water releases from dams.

There are operating procedures for the monitoring of banks for collapse and or erosion at both Glenlyon Dam and Boggabilla Weir but there are no operating procedures for this monitoring at the Newinga regulator. According to DNRME and SunWater’s annual reports, there have been no instances of bank slumping downstream of Glenlyon Dam or Boggabilla Weir.

ROL holders relevant to the Border Rivers ROP are required to report and assess instances of fish stranding in watercourses or ponded areas associated with the infrastructure. There have been no reports of fish stranding’s or fish kills at either Glenlyon Dam or Boggabilla Weir, by either the DNRME or SunWater.

<u>Water sharing and access arrangements within the IGA</u>

As part of the IGA, the States agreed that all water in the Border Rivers Catchment would be managed to protect the riverine environment of the BRWSS. To achieve these objectives, the States agree to maintain or improve low to moderate flows in the Border Rivers through the following four methods:

1. Preservation of part of the tributary inflows to the Border Rivers through to Mungindi, during periods of regulated flow from 1 September of each year to 31 March of each following year.
2. Protection of natural low flows in the upper reaches of the Dumaresq River and the Severn/Macintyre Rivers from Pindari Dam downstream to the Dumaresq junction.

3. Protection of moderate flows in the Macintyre and Barwon Rivers from Goondiwindi to Mungindi.
4. End of System Flow

Recommendations

There is likely to be a good potential for recovery in both the fish and macroinvertebrates with improvements in low and moderate flows in the Border Rivers. The length and natural variability of the lower reaches should mean that most natural species are still present and an improvement in the flow regime would provide opportunities for recolonisation. To assist with this it is recommended that a rule pertaining to the rate of water release for the Border Rivers Water Supply Scheme be considered in the revised ROP. Rates of release should also be recorded and reported on, as per required for ROL holders of the Condamine and Balonne ROP.

Water quality of the storages in the plan area may not provide adequate habitat for biota and water released from these storages may not be of sufficient quality or of the correct temperature for biota downstream. Monitoring requirements within the BRC and IGA areas should mirror those that occur for ROL holders.

In relation to the IGA related environmental flow rules, there is insufficient specific monitoring to determine whether the rules are delivering the desired outcome as originally intended under the IGA and therefore, it is not possible to make any recommendations in this regard.

Any proposed changes to the current operating procedures or water sharing access rules for the Border Rivers Water Supply Scheme to provide for improved environmental outcomes, need to be discussed with New South Wales and moderated by the requirements under the IGA, for the States to develop an integrated environmental monitoring program. Therefore, any recommendations for changes to the Border Rivers ROP must not be in conflict with the IGA and must be agreed to by the New South Wales Government.

7.6 Impact of storages on aquatic ecosystems s321 (Callandoon Water Supply Board and Yambocully Water Board)

1. *The distribution operations licence holder must inspect banks for evidence of collapse and/or erosion downstream of diversion works defined in attachment 5(C) following instances of rapid water level changes or large flows through the works, or other occasions when collapse or erosion of banks may be likely.*
2. *Any instances of bank slumping or erosion observed must be investigated to determine if the instability was associated with the nature or operation of the infrastructure*.

Ecological effectiveness

This monitoring requirement is related to reducing adverse environmental impacts downstream of storage infrastructure. It is a ROP reporting requirement that is not associated with a ROP rule.

There is no data available to assess whether water released as part of the Callandoon Water Supply Board or the Yambocully Water Board is having a detrimental effect on aquatic ecosystems downstream of associated infrastructure.

Recommendations

For WSS covered by the Border Rivers ROP, provision is made to protect aquatic ecosystems downstream of infrastructure by implementing rules pertaining to rates of water release. The ROL holders are required to minimise the occurrence of adverse environmental impacts by ensuring changes in rates of release occur incrementally. Furthermore, ROL holders are required to report on water quality in relation to scheme infrastructure, bank condition downstream of infrastructure, and instances of fish stranding related to the operation of infrastructure.

8 Assessment of plan outcomes and recommendations for the new plan

The purpose of the environmental assessment is to evaluate the effectiveness of the plan, in terms of meeting its outcomes via the various water management strategies in the plan and associated ROP, and make recommendations for the new plan. The assessment has been conducted within the frame of ecological sustainable development defined in the *Water Act 2000.* It uses the outputs of the ecological risk assessment and environmental monitoring information, in a multiple levels and lines of evidence approach (after Norris et al. 2005).

The assessment process is consistent with an adaptive management framework that implements a regulatory process (the water plan and ROP), monitors critical receptors (environmental monitoring programs), regularly reviews performance (ecological risk assessment and plan review), incorporates new knowledge as it becomes available, and adjusts policy settings as required (new draft plan development). The results of the assessment is summarised in Table 7 and recommendations are provided for consideration in the new plan.

Table 7 Assessment of plan outcomes and recommendations for the new water plan

Plan outcome	Evidence base	Evaluation
9(e) to make water from the basin available to be stored and used while retaining water for the riverine and associated environment	Summary of monitoring in sections below.	This outcome has been achieved through the water plan framework that provides for the use of existing storage works whilst setting a cap on the amount of water that can be taken from the plan area. • The chief executive must not make a decision that would increase the average volume of water available to be taken in the plan area (Water Plan section 17). This ensures that water can continue to be taken whilst retaining some water for the environment. • The plan allows for existing overland flow works to continue to take water, and provides a process for licensing take of overland flow water • The Water Plan (s27) sets limits on storage of unsupplemented water–this ensures that entitlement holders can continue to store water on property but are limited by their current storage size. • As mentioned under outcome 9a, unallocated water was also made available in the Water Plan to provide for economic activity, but no entitlement has been issued from this reserve.
Recommendations	This outcome lacks adequate specificity and its inclusion in the new Water Plan is not recommended.	
9(f) i, maintaining pool habitats, and native plants and animals associated with the habitats, in watercourses	Sustainable Rivers Audit (SRA2), Q-catchments, modelling of fluvial geomorphology and river forming processes at 17 locations in the plan area.	See outcomes 9(f) iv
9(f) ii, maintaining natural riverine habitats that sustain native plants and animals	Sustainable Rivers Audit (SRA1, SRA2), Q-catchments threats assessment, risk modelling of stable flow spawning fish, operation of existing fishways.	Overall ecosystem health, based on an assessment of fish, hydrology, macroinvertebrates, terrestrial vegetation and physical form, has been assessed as poor (SRA2) with a high risk of increased sediment deposition (Q-catchments). Instream pest fauna pose a high risk to native riverine communities (Q-catchments). The risk to the four stable flow spawning fish species varied across the plan area, but was generally low throughout. There are no rules relating to the operation of fishways in the Border Rivers ROP (2011) although four fishways currently exist within the BRWSS area. The fishway at Boggabilla Weir operates according to

		summer and winter regimes. The fishway does not normally function under the winter regime. The Standard Operating Procedures of Boggabilla Weir (2004) state that the weir pool shall be maintained at a level that will operate the fishway "as often as possible" during irrigation season (September to March) and during the off-irrigation season (April–August), with exceptions for supplying water to downstream users. Collectively the information from these three indicators suggest that this ecological outcome has only partially been met.
Recommendations	Stable flow spawning fish are particularly vulnerable to abrupt changes in water depth, particularly during the breeding season. Therefore, water management actions such as storage operations and water harvesting are likely to have the greatest impacts. Flow supplementation, and water harvesting which reduce flow variability are also likely to reduce the risk profile for this indicator. It is recommended that provision be made for the operation of existing and future fish passage devices during the irrigation season (also spawning and migration season for many species). The efficiency of existing fish passage devices in allowing the movement of fish under a range of flow conditions is unknown. It is recommended that research is conducted to determine the range of headwater and tailwater levels under which each specific fishway operates most effectively. These investigations should consider: • adjustment of storage nominal operating levels (NOL) to provide for operation of fishways, • stipulations that flows are released preferentially through the fishway, • applying rules only to months when fish movement is critical for ecological reasons, and • applying rules when release rates are likely to provide a cue for movement. This ecological outcome lacks specificity and its inclusion in the new Water Plan is not supported. No clear measures or strategies can be associated with this outcome. It is recommended that this "riverine habitats" should be represented by the waterholes outcome as above.	
Key knowledge gaps relating to this outcome	Kerr et al. (2016) has summarised the key knowledge gaps relating to this indicator and its application in the Queensland Murray-Darling including: • upper and lower gauge height thresholds for each assessment node which define the flow band required for the inundation of edge habitat used as nesting sites • specific local population parameters such as the proportion of female that spawn with each spawning event and the proportion of eggs that survive to sexual maturity, to replace estimated values used to determine the ToC • for stream reaches with clear water supporting aquatic vegetation as the preferred spawning substratum, stable flow height and velocity based upon the requirements of these plants • stream cross-sections to improve the translation of local water height and flow velocity to gauge height and discharge as measured at upstream or downstream gauging stations	

9(f) iii, maintaining the natural abundance and species richness of native plants and animals associated with habitats within watercourses, riparian zones, floodplains and wetlands	Macintyre River Billabongs Eastern snake-necked turtle	The results suggest that the full entitlement scenario represents a low risk to the Macintyre Billabongs. This is consistent with analyses conducted by the MDBA (2012). The risk to the eastern snake-necked turtle is medium across the plan area. Five of the eight assessment nodes experienced an increase in the average duration of stress periods under the full entitlement scenario compared to pre-development. The ToC was exceeded at seven of the eight assessment nodes under all three scenarios. Three assessment nodes experienced increases in the percentage of high stress years in the simulation period. However the results also show that for much of the assessment area, habitat is marginal for the turtle, and that the risk is often high even under pre-development conditions. Based on the risk profile for this indicator, it is likely that the ecological outcome is being partially met across the plan area.
Recommendations	<u>Eastern snake-necked turtle</u> The results here suggest that for some locations in the plan area, the ephemeral nature of the wetland habitat is such that it provides only marginal habitat for the eastern snake-necked turtle. This is clear for those sites such as Weir River at Jericho and Macintyre Brook at Booba Sands, where stress periods spanned a significant proportion of the pre-development simulation period. Across the remaining site, the period exceeding the four year ToC was not significantly increased, suggesting that under the full entitlement scenario, this indicator is not at risk. Event management strategies which preserve events at flow thresholds identified here would mitigate any residual risks to the dependent floodplain wetlands. This ecological outcome lacks specificity and its inclusion in the new Water Plan is not supported. It is recommended that assets covered by the broad scope of this ecological outcome should be represented individually. This will enable a clear delineation of exactly which assets are to be assessed across the catchment and allows for the development of specific measures and strategies for future Water Plan assessment.	
Key knowledge gaps relating to this outcome	<u>Macintyre River Billabongs</u> The flow thresholds assessed here only relate to the frequency of anabranch billabong connection flows, and do not account for the return frequency of flows required to move fish recruits and nutrients and carbon from these anabranch features back to the main river channel. Future investigations should include establishing a minimum water residence time and return frequency for flows to support these processes. <u>Eastern snake-necked turtle</u> The time series analysis of wetland inundation and persistence behaviour using historical Landsat imagery has greatly improved the confidence in the thresholds used in the eastern snake-necked turtle model. However, the assumptions regarding which wetlands are the most critical in terms of providing optimal foraging habitat across the plan area need to be validated.	

	The current ToC for the eastern snake-necked turtle is based on observations from eastern New South Wales. The assumptions which underpin this ToC needs to be tested on populations from the plan area.	
9(f) iv, maintaining active river-forming processes, including sediment transport	Sustainable Rivers Audit (SRA2), Q-catchments, modelling of fluvial geomorphology and river forming processes at 17 locations in the plan area.	Physical form has been assessed as in moderate condition (SRA2). There is evidence of channel widening, bed degradation and increased sediment loads (SRA2) and sediment deposition (Q-catchments). Results from monitoring over the life of the plan, and from the quantitative risk assessment, indicate that river-forming processes are at a low risk in the Border Rivers plan area, with risk varying across the catchment. Contemporary land use practices have led to an oversupply of sediments in the systems, therefore the consequence of changes stream power is likely to be higher than it would have been historically. Additionally weirs and dams may trap sediment and alter downstream sediment movement. Lack of evidence of high level impacts suggests that the system is resistant to increase sediment deposition and reduced stream bed scouring. Despite the reduction in stream power due to water management, it is likely that this outcome has been partially met.
Recommendations	Event management strategies which preserve flow events at bankfull thresholds are required to mitigate the risks identified here. However, there is currently a lack of sufficient knowledge to set a target return frequency for such flows to maintain a sediment movement regime throughout the system which supports the dependent environmental values. Inclusion of this ecological outcome in the new plan is strongly supported. This ecological outcome has strong flow-ecology links with potential for clear measures and strategies to support implementation and assessment. Due to the relationship between waterhole persistence and scouring (i.e. river forming processes) it is recommended that these two outcomes be combined in the new plan.	
Key knowledge gaps relating to this outcome	• rates of net sediment export and accumulation–proximal land use activities may alter sediment transfer to streams and including the volume and distribution of sediment within the system. • accurate bankfull flow levels for gauges in the plan area–river channel cross-sectional data for stream reaches around gauging stations will improve current estimates of flow thresholds which represent maximum transport velocities. • sediment sourcing properties of different flow events–rates of sediment scouring and transport at a range of flow event sizes would improve estimates of sediment load and potential deposition.	
9(f) v, improving wetland inundation to provide for ecological processes;	Floodplain wetlands	The persistence of floodplain wetlands across the plan area varies from 32 to 400 days. All sites showed a reduction in the number of wetland connection days under the full entitlement scenario of between 22 and 37 per cent. Macintyre River at Kanowna showed a reduction in the average return frequency of floodplain wetland inundation flows of five

		months, with the maximum return frequency increasing by an additional two years. The Weir River at Mascot showed some of the largest impacts at the mid frequency range; average return frequency of floodplain wetland inundation flows reducing by three years; however the maximum return frequency was largely unchanged. Based on the risk profile for this indicator, it is unlikely that the ecological outcome is being met across the plan area.
Recommendations	Event management strategies which preserve events at flow thresholds identified here are required to mitigate risks to these dependent wetlands. Although many of the wetlands analysed here are ephemeral, with most persisting for less than one year, the importance of riverine inundation events in terms of contribution to their water budget, their role in promoting recruitment of wetland biota, and productivity subsidies to riverine food webs is widely acknowledged. There is a lack of sufficient knowledge to set a target return frequency for these wetlands to support the range of dependent environmental values discussed above. The data generated by the time series analysis of the hydrological and Landsat imagery provides a foundation for establishing these requirements over time. This ecological outcome lacks specificity and its inclusion in the new plan is not recommended. It is recommended that this be incorporated within a new outcome which includes “flows to support floodplain ecosystems”.	
Key knowledge gaps relating to this outcome	A number of ecological assets and associated environmental values have either a direct or indirect dependency on periodic floodplain inundation. Reliable digital elevation models linked to gauges; wetland persistence times based on bathymetry and rates and sources of water loss, are critical to progress future quantitative comparative analysis of water management scenarios which account for landscape changes and antecedent conditions. Water balance models which quantify the relative contribution of various water sources (i.e. rainwater, local overland flow, floodplain inundation from the river, groundwater flux, etc.) to the overall budget of a given wetland are required for key complexes which support high value assets, and are currently at threat from water management. Critical thresholds relating to the return frequency for floodplain inundation events is a knowledge gap for most dependent ecological assets, such as wetland vegetation, fish, birds, and turtles.	
9(f) vi, reducing the adverse impact of infrastructure on natural hydraulic bank erosion processes	ROL Holder Monitoring, Sustainable Rivers Audit (SRA1, SRA2), Q-catchments	The condition of hydrology in the Border Rivers has been assessed as good (SRA1). Physical form has been assessed as in moderate condition (SRA2). There is evidence of channel widening, bed degradation and increased sediment loads (SRA2) and sediment deposition (Q-catchments). ROP rules have been implemented to limit releases from storages and regulate rates of release. This aims to reduce fish stranding, excessive scouring and bank slumping downstream of Coolmunda Dam, Whetstone Weir and Ben Dor Weir. A single assessment of channel condition is not sufficient to assess the effectiveness of the ROP rules; however there have been no reports of bank slumping from ROL holders over the life of the plan.

		It is therefore likely that this outcome has been achieved.
Recommendations	This ecological outcome is considered to be important in highlighting the significance of continued monitoring and research to promote improved understanding of ecosystem health, and its inclusion in the new plan is supported. However, it is recommended that it be included as a general, social and/or economic outcome.	
Key knowledge gaps relating to this outcome	The resource operations licence holder has frequently reported that there have been no impacts on the aquatic environment as a result of infrastructure operations. However, there is a lack of supporting evidence, monitoring data or detailed discussion around how these conclusions were drawn. Establishing geomorphological baseline conditions in reaches downstream of listed storages, and implementing a monitoring program suitable for reporting on bank slumping, scouring, and channel erosion will provide the required information to inform a robust evaluation of current release strategies.	
9(g) to maintain water quality at levels acceptable for water use and to support natural ecological processes	Surface Water Ambient Network (SWAN); ROL Holder Monitoring	Nutrient concentrations in waterholes of the Weir River at Talwood and Giddi Giddi were above the ANZECC guideline values for aquatic ecosystems and eutrophic conditions with high algal productivity reported. However, catchment-wide monitoring data suggests that most water quality parameters are within acceptable limits, except for possible rising salinity accompanied by falling turbidity (SWAN) that may be associated with climatic factors (DEHP, 2012). Healthy waters management plans applying to the Queensland Border Rivers are being prepared by Department of Environment and Heritage Protection to meet the requirements of a Water Quality Management Plan (WQM Plan) under the Basin Plan 2012. Resource Operations Licence (ROL) holders collect water quality information from Glenlyon Dam. This does not include thermal data downstream of dams during spring / summer releases. There are also risks to this area from climate change (Q-catchments). Therefore, this outcome is likely to have only been partially met.
Recommendations	Impacts of cold water releases from Glenlyon Dam on downstream aquatic ecosystems has been identified as a potential issue. There is currently no monitoring of releases downstream of the dam to determine the extent and scale of these impacts. It is recommended that a monitoring regime be designed and implemented to assess this potential risk. It is recommended that ecological outcome 9(g) be amended in the new plan to reflect its intent to cover water quality impacts associated with the implementation of the plan, not from other non-water resource development stressors present in the catchment.	
Key knowledge gaps relating to this outcome	While flow creates the hydraulic conditions that support ecological assets and values; hydrological conditions also influences their physical and chemical environmental in terms of a range of water quality conditions and processes. The interacting effects of flow and water quality may be important for facilitating ecosystem processes and may mediate biogeochemical processes such as instream productivity, and nutrient and carbon cycling. There is currently insufficient information to	

	develop models which predict the interaction of key water quality parameters and the managed flow regime, particularly in unregulated systems. Some specific information needs to address this knowledge gap include: • What are the key water quality processes and/or indicators that are sensitive to a managed flow regime that may be used as an indicator? • What approaches could be used to model water quality processes and or indicators? • How can the effect of the flow regime on water quality processes be isolated from the range of other anthropogenic stressors present in the plan area?	
9(i) to promote improved understanding of the matters affecting the health of riverine and associated systems in the basin	Monitoring and research activities undertaken in the plan area. See Summary of Monitoring Report (DNRME 2018).	Environmental monitoring, research, and science reviews has been undertaken across the plan area by a number of organisations including: • Department of Natural Resources, Mines and Energy • Department of Environment and Science • Department of Agriculture and Fisheries • Resource Operations Licence Holders • Murray-Darling Basin Authority • Commonwealth Environmental Water Holder • Several universities, research institutes, and science providers A collation and synthesis of this information and new scientific knowledge has been undertaken to assist in evaluating the plan’s performance in meeting its ecological outcomes. Based on this improved knowledge, and science effort, this outcome has been achieved.
Recommendations	This ecological outcome is an important mechanism to highlight the need for ongoing monitoring and research to improve the knowledge base which underpins the plan. It is recommended that this be retained as a general plan outcome.	
Key knowledge gaps relating to this outcome	Key knowledge gaps relating to each water plan are collated and prioritised on an annual basis by DNRME based on the Water Planning Science Plan 2014–2019 (DSITIA/DNRM 2014).	
9(j) consistency with the Basin Plan 2012 (Cwlth)		This outcome is being primarily achieved through the new Plan which will provide a framework that is consistent with the requirements of the Basin Plan. • The current plan is taken to be a transitional water resource plan under the Water Act 2007 (Cth). • The new Plan will be developed to be consistent with the requirements of the Murray-Darling Basin Plan 2012.

Recommendations	This outcome is important in highlighting the significance of operating in a manner that is consistent with the Basin Plan, and its inclusion in the new plan is recommended.	
9(k) consistency with water sharing agreements and commitments between the State and New South Wales		This outcome has been achieved through the Plan providing a framework that is consistent with the NSW-Qld Border Rivers Intergovernmental Agreement. • A provision in the Plan requires that the Resource Operations Plan give effect to any agreement made between Queensland and New South Wales. The relevant agreement is the New South Wales – Queensland Border Rivers Intergovernmental Agreement 2008. • The New South Wales–Queensland Border Rivers Intergovernmental Agreement 2008 provides direction on water sharing and access, interstate trading, and managing the flows of streams shared by both states as well as water for the Murray-Darling Basin. • Water sharing rules in the ROP (Ch. 9) implement the Intergovernmental Agreement, including a mechanism to limit growth in long term average annual take, and the requirement for interstate trading agreements in relation to the administration of such trades. • The Border Rivers Commission directs the distribution of water which is made available to Queensland and New South Wales and undertakes operational and maintenance activities of jointly “owned” water infrastructure. The plan requires that data on water use and other information on the Border Rivers water supply scheme be provided to the Commission to support its operations.
Recommendations	This outcome is important in highlighting the significance of operating in a manner that is consistent with NSW water sharing agreements, and its inclusion in the new plan is supported as a general outcome.	
9(l) to protect the productive base of groundwater	Semi-quantitative risk ranking of GDEs across the plan area. The Groundwater Ambient Network (GWAN) which monitors groundwater levels and water quality in the Dumaresq, Macintyre and Weir Rivers and Macintyre Brook.	Risk to GDEs were identified in two of the SDL sub-areas. This outcome has been achieved through limitations on new take of groundwater. • Amendments to the Plan in 2014 brought groundwater into the water planning framework. • Take of groundwater without a water entitlement was permitted only for stock and domestic use and prescribed activities. No new licences that would increase take were to be granted.

		• Although outside of the plan itself, rules have been established for the Border Rivers Alluvium Groundwater Management Area that define water sharing and seasonal assignment arrangements and provide a stable water use accounting regime. • To further protect the resource, it may be beneficial to consider introducing limitations on stock and domestic take.
Recommendations	It is recommended that an ecological outcome relating to GDEs be included in the new Water Plan which reflects the need to maintain a groundwater regime which supports these dependent ecosystems.	

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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
authochonous	material found where they and their constituents were formed
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) types	Refers to the groundwater dependent ecosystem types as determined by 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 Plan	A plan approved under s50(2), (*Water Act 2000*, Schedule 4)