Department of Environment and Science

Review of Water Plan (Moonie) 2003 and Resource Operations Plan

Environmental Assessment Report

January 2018

Queensland Government

Prepared by

Glenn McGregor, Jon Marshall, Jaye Lobegeiger, Dean Holloway, Norbert Menke, Brad Mayger, Myriam Raymond, Marianna Joo, John Bowlen, Cameron Schulz, Alisha Steward
Water Planning Ecology, Science Division
Department of Environment and Science
PO Box 5078
Brisbane QLD 4001

ISBN 978-1-925075-41-0

Disclaimer

Citation

DES 2018 Review of Water Plan (Moonie) 2003 and Resource Operations Plan. Environmental Assessment Report. Department of Environment and Science, Queensland Government.

Acknowledgements

This report has been prepared by the Department of Environment and Science. Acknowledgement is made of Department of Natural Resources, Mines and Energy (DNRME) South-West Region ecology team including Andrea Prior, Janice Kerr, James Fawcett, Doug Harding, and Tess Mullins who undertook research and monitoring to underpin this assessment, and other staff from DNRME who provided valuable advice throughout the review process including Peter Brownhalls, Suzi Johnson, Julie Coysh, Jason Chavasse, Andrew Biggs, and Adrian McKay.

January 2018

Executive summary

The Queensland Government, through the Department of Natural Resources, Mines and Energy, is reviewing the Water Plan (Moonie) 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 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 low across all hydrological classes for all ecological assets (Table i). Changes to the high flow regime has resulted in reductions to the frequency and duration of bankfull and over bank flows; however the scale of this change is not likely to manifest in significant ecological risks.

The largest groundwater Sustainable Diversion Limit (SDL) unit has a current Baseline Diversion Limit of 0.1 GL. Current mapping indicates there are many potential GDEs in the Moonie catchment, however as current groundwater extraction occurs outside of management units contained within the plan, and there is the relative small scale of the extraction pressure, GDEs were not considered in this risk assessment.

Environmental management rules

The Moonie River Resource Operation Plan (ROP) covers the Moonie River from headwaters to the Queensland-New South Wales border. The ROP applies to water distribution and allocation within the Moonie River management area, and includes no major in-stream water storages or associated infrastructure. Data from various sources was analysed to provide an assessment of the effectiveness of the existing environmental management rules in aligning with the intent of plan strategies.

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
Refuge waterholes	No and low flow	9(d), 9(e) i, ii, iii, 9(f), 9(h)	**Low** The risk, based on the eight modelled waterholes, was low across the plan area.
Stable flow spawning fish	Low flows	9(d), 9(e) ii, iii, 9(h)	**Low** Collectively, these three species showed a low risk across the plan area with no increase in the number high risk years under the full entitlement scenario.
Fluvial geomorphology and river forming processes	High flows	9(d), 9(e) i, iv, 9(f), 9(h)	**Low** The risk to fluvial geomorphology and river forming process is low, however, bankfull flow days have been reduced by between 10 and 22 per cent from pre-development.
Floodplain wetlands	High and overbank flows	9(d), 9(e) iii, 9(h)	**Low** The risk to floodplain wetlands is low, despite a small reduction in the frequency and duration of overbank flows.
Eastern snake-necked turtle	No and overbank flows	9(d), 9(e) ii, iii, 9(h)	**Low** The risk to eastern snake-necked turtle is low, with only a small increase in the duration of stress periods at all three assessment nodes.

Change of location for allocations with nil passing flow condition

This rule is associated with the maintenance of natural riverine habitats and supporting ecological processes. The intent of this rule is to provide some protection to waterholes by allowing pumping to occur only to 0.5 metres below the cease-to-flow level. This condition is placed on traded allocations where a change in location has taken place.

There is no monitoring of this ROP rule and as such there is no reporting on any instances where the take of supplemented water from a waterhole results in the waterhole being drawn down to more than 0.5 metres below its natural cease-to-flow level. Therefore compliance cannot be assessed for waterholes in the Moonie River WP areas, as the individual waterholes are not gauged and/or monitored. Stock and domestic pumping is not covered by this rule, therefore there is no restriction on pumping waterholes below 0.5 metres from cease-to-flow to water stock.

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 10 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; four outcomes were met, three partially met, and there was insufficient information to assess three.

Recommendations

The risk to ecological assets was low throughout the plan area. A range of recommendations are included in the report concerning potential monitoring and mitigation strategies should this change in the future. Recommendations are also provided on improved specification of outcomes for consideration in the new plan. These are summarised here and further discussed in Chapter 8.

- Strategies to mitigate potential risk to refuge waterholes may involve implementation of event management following extended periods of no-flow for a particular area, where this period exceeds the persistence time of the modelled waterholes.
- Implement event management to preserve flows at bankfull thresholds to promote sediment movement throughout the system. This may also alleviate sedimentation of riverine habitats, including refuge waterholes.
- Implement event management to preserve flows at over bank thresholds 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 and knowledge has been developed 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.
- 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 on which future water management decisions will be based.

Prioritisation of these knowledge gaps should be undertaken on an annual basis, based on the Water Planning Science Plan (2014–2019).

Contents

List of tables

List of figures

1 Introduction

1.1 Background

The Queensland Government, through the Department of Natural Resources, Mines and Energy is reviewing the Water Plan (Moonie) 2003 (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 it life.

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

Chapter 3—outlines the general water requirements for the surface water dependent ecosystem components of the Moonie 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 Moonie 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—provides conclusions and recommendations for environmental provisions in the new draft water plan.

2 Hydrology and water resource development of the plan area

The Moonie plan area is situated in south-west Queensland, east of St George. No major urban centres exist in the catchment. The catchment is bordered to the north and west by the Condamine-Balonne catchment and to the east by the Border Rivers catchment (Figure 1). The Moonie River is a dryland system 525 km in length and drains an area of 14,870 km^2 (DNRM 1999). The majority of the catchment lies in Queensland where the river flows generally south-west, crossing into northern New South Wales where it joins the Barwon River. The Moonie River forms part of the northern Murray-Darling Basin with the Barwon River contributing to the Darling River in New South Wales. The catchment has a low gradient with the river passing from an altitude of ~350 metres in the upper catchment to ~150 metres in the lower catchment at the junction with the Barwon. The Moonie catchment represents 1.4 per cent of the total area of the Murray-Darling Basin (MDBA 2016).

Several minor tributaries feed the Moonie River and include Teelba Creek, Stephens Creek, Parrie Moolan Creek, Wongle Wongle Creek, and Toombilla Creek. The climate of the Moonie catchment is classed semi-arid and is typified by 500–600 mm average rainfall per year with a mean annual evaporation rate of 1800–2200 mm per year. Temporal variation in annual temperature and rainfall is high (Bureau of Meteorology 2007). River flow is dominated by rainfall run-off as opposed to being a groundwater fed system. The sporadic nature of rainfall events characterises the hydrology of the system which typically shows high variability in flow. Frequent periods when the system is absent of flow are interspersed with unpredictable and intermittent large-scale flow events that reflect the rainfall trends in the region. The Nindigully gauge station reportedly shows flow in the Moonie River occurs just 35 per cent of the year. This trend produces river morphology dominated by a series of disconnected waterholes (DNRM 2007).

Three gauge stations currently monitor flow in the Moonie River: Fenton gauge (most downstream gauge), Nindigully gauge (middle catchment) and Flinton (most upstream gauge) (DNRM 2016). In the downstream reach of the Moonie River, large flow events can result in flooding of low lying areas and create overland flow which connects the Moonie, Weir and Macintyre Rivers (DNR 1999).

Land use in the catchment is dominated by grazing and dryland cropping with a small amount of irrigated agriculture for cotton and pasture (DSITI 2015). The Moonie River is subject to moderate water regulation, with several weirs and off-channel storages (Sternberg et al. 2008). Small to medium weirs interspersed along the river provide water storage for irrigation purposes (predominantly cotton) and the Thallon weir supplies town water. The majority of stored water is harvested from overland flow and stored in ring tanks. The Moonie River has no major water storages (MDBA 2016). No water supply schemes exist in the Plan area, however there is one Water Management Area (WMA), the Moonie WMA covering the entire catchment, which is managed by DNRME.

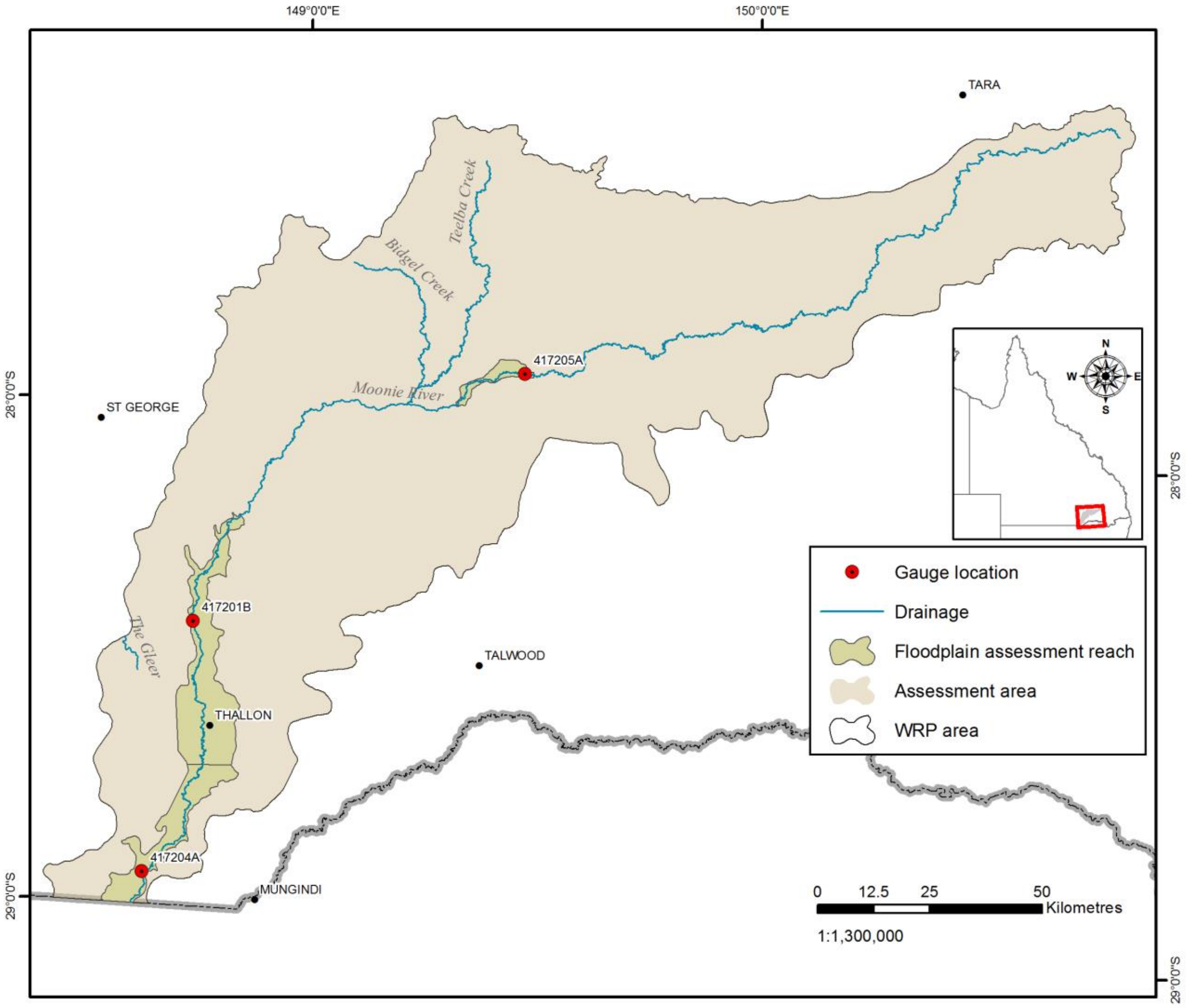

Figure 1 Moonie plan area showing the location of environmental assessment nodes (as stream gauge locations), floodplain assessment reaches and assessment areas

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, may 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 streamflow, 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; additionally, 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 anastomosing channels draining inundated floodplains, which generate scour without channel constriction;
- 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 averages are usually less than 1 m/sec.

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

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

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

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

Many aquatic species found in the plan area, including fish and invertebrates such as freshwater mussels, 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.

Groundwater dependent vegetation access groundwater through their root systems extending into the capillary fringe or directly into the water table. The depth to which a root systems 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.

Aquifer systems with subterranean ecosystems are thought to be 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).

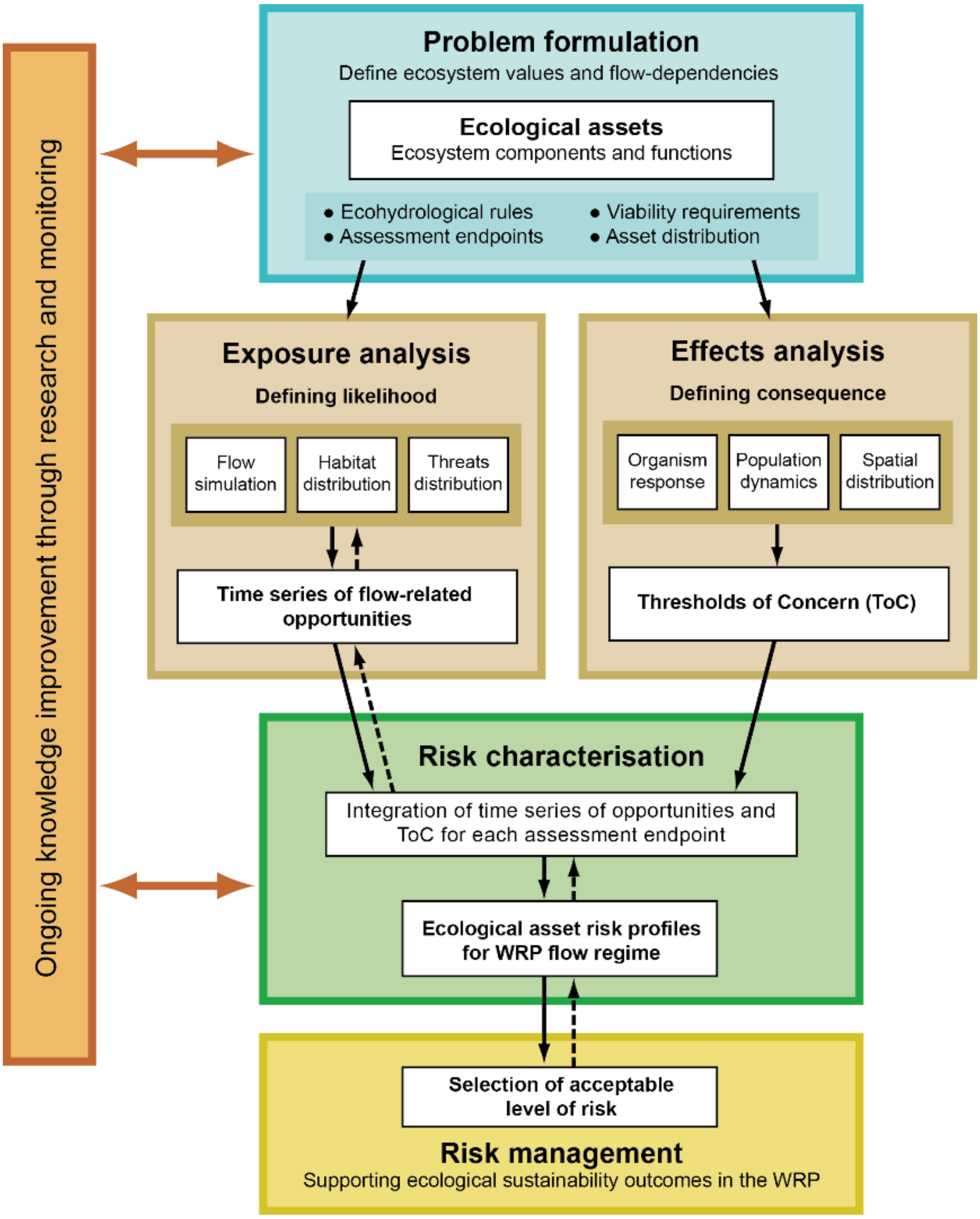

Figure 2 Summary of the risk-based ecohydrological modelling approach (after McGregor et al. 2017)

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. Two 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

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 were available.

Floodplain assessment reaches

The relatively sparse distribution of gauging stations coupled 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.

5.1.2 Groundwater risks

There are no ecological outcomes in the current plan that specifically relate to GDEs, however the plan aims to protect the productive base of groundwater (general outcome 9(k)). Groundwater development in the Moonie catchment is currently low. The largest groundwater SDL unit has a current Baseline Diversion Limit of 0.1 GL; this is significantly lower than the SDL set at 32.5 GL (MDBA 2012). This limit refers to the sediment above the Great Artesian Basin and is therefore considered in the Water Plan (Great Artesian Basin) 2006. There is a small overlap of the St George Alluvium SDL into the Moonie catchment, with a current take Baseline Diversion Limit of 0.01 GL compared to the SDL of 0.69 GL. Current mapping indicates many potential GDEs in the Moonie catchment (DSITI 2017), however as current groundwater extraction occurs outside of management units contained within the plan, and there is the relative small scale of the extraction pressure, GDEs were not considered in this risk assessment.

5.2 Environmental monitoring

Environmental monitoring, research, and a number of science reviews have 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 outcomes (DNRME 2018).

6 Results

6.1 Ecological risk assessment

6.1.1 Ecological assets

A total of 1054 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 (DNRME 2018). Using available information about each asset's requirements for surface water, the primary list was reduced to a subset of 78 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 were available for five surface water 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 outcomes of the plan

Ecological asset indicator	Indicator measurement endpoint	Hydrological class	Plan ecological outcomes, and general outcomes with an ecological focus
Refuge waterholes	Frequency of waterhole failures	No and low flow	9(d), 9(e) i, ii, iii, 9(f), 9(h)
Stable flow spawning fish	Spawning and recruitment success of each species	Low flows	9(d), 9(e) ii, iii, 9(h)
Fluvial geomorphology and river forming processes	Frequency and duration of bankfull flow events	High flows	9(d), 9(e) i, iv, 9(f), 9(h)
Floodplain wetlands	Frequency and duration of wetland inundation events	High and overbank flows	9(d), 9(e) iii, 9(h)
Eastern snake-necked turtle	Frequency of high stress events	No and overbank flows	9(d), 9(e) ii, iii, 9(h)

6.1.2 Surface water indicators

Waterholes as refugia

Australia's dryland rivers exist in an environment which is characterised by long periods without significant inflows of water, during which time they dry into a series of waterholes. These waterholes provide an important source of water for agriculture, towns, industry and other human consumptive uses, as well as serving an important ecological function by providing refuge habitat for aquatic organisms during dry times.

There are three key attributes of a waterhole that contribute to its ability to function as a drought refuge:

- persistence time: the length of time that waterholes are able to hold water without inflows;
- connectivity: the spatial distribution of waterholes is important; they must be numerous enough and distributed such that, when they are connected during flow, resident biota are able to move throughout the system and recolonise the river (Sheldon et al. 2010); and
- refuge quality: attributes such as water quality, habitat availability and availability and quality of food deteriorate as waterholes become shallower (Waltham et al. 2013; Wallace et al. 2016).

To maintain populations of aquatic organisms, a network of waterholes is required to persist through extended dry periods (DERM 2010; DSITI 2015). Persistent waterholes occur across the plan area and were identified using two methods:

- individual waterhole scale: a selection of eight representative waterholes were mapped to create a depth profile and water loss was measured through a drying phase to create a quantitative water loss model for the site; and
- plan area scale: remote sensing time series analysis was used along with hydrological information to determine where persistent surface water is located after various no flow spells across a large section of river channel.

A threshold of concern (ToC) of 0.5 metres minimum waterhole depth was used for individual waterholes to identify periods of limited habitat availability and poor habitat quality, termed here *waterhole failure.* While refuge waterholes often experience changes in water depth, and waterhole biota are adapted to cope with these conditions, periods of very shallow water depths represent a high risk.

The Moonie River is highly ephemeral, with the proportion of no-flow days in the pre-development simulation across the three assessment nodes ranging between 66 and 73 per cent. These spells were almost unchanged between the pre-development and full entitlement scenarios at the three assessment nodes. While the average no flow spell duration increased at all three nodes by between five and twelve days, the maximum spell length remained unchanged. The risk based on the eight modelled waterholes was low across the plan area. There were no instances of ToC failure, and consequently no occurrences of simultaneous failures.

The spatial analysis identified 270 waterhole habitat patches covering a total area of 7.6 km^2 across the Moonie catchment. Spatially these areas containing waterholes were aggregated in three main groups: (i) three upstream of Flinton, (ii) downstream of the confluence of the Moonie River and Teelba and Bidgel Creeks, and (iii) within the Nindigully FAR. Of this waterhole habitat, an area of 1.3 km^2 remained persistent throughout the period 1988–2015.

Stable flow spawning fish

Three 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*)
- 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 over 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 three assessment nodes in the plan area. Each of the three 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 low risk across the plan area (Table 2); all three species showed no increase in the number high risk years under the full entitlement scenario.

Table 2 Average annual recruitment opportunities and proportion of high risk years for stable flow spawning fish (pre-development=PD, full entitlement=FE)

Environmental assessment nodes	*Ambassis agassizii*		*Melanotaenia fluviatilis*		*Hypseleotris* spp.	
	PD	FE	PD	FE	PD	FE
Moonie River at Nindigully	27, 2.5	35, 0.8	80, 0.0	89, 0.0	75, 0.0	83, 0.9
Moonie River at Fenton	53, 0.0	57, 0.0	117, 0.0	125, 0.0	107, 0.0	115, 0.0
Moonie River at Flinton	8, 17.6	21, 0.0	69, 0.0	90, 0.0	61, 0.0	87, 0.0

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 three environmental assessment nodes in the plan area. 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.

The risk to fluvial geomorphology and river forming processes across the plan area was low as modelled at three environmental assessment nodes in the Moonie catchment. Across the plan area, bankfull flow days have been reduced by between 10.3 and 22.1 per cent from pre-development, with the largest changes at Moonie River at Fenton. There is some published information on the quantity, source, and movement of soft sediment in Moonie River waterholes (DSITI 2016), however the effect of changed spell lengths between scouring events still remains a key knowledge gap. Contemporary land use practices have led to an increased supply of sediments in the system, therefore the consequence of changed stream power may be higher than it would have historically been.

Floodplain wetlands

The Moonie River floodplain contains more than 100 floodplain wetlands larger than one hectare in size (CSIRO 2008), with all wetlands in the catchment covering a total of 9611 hectares (State of Queensland 2017). Most of these are found in the southern (lowland) section of the catchment, downstream of Nindigully (CSIRO 2008). Throughout the catchment there are 158 palustrine wetlands and 87 riverine wetlands (State of Queensland 2017). The Moonie catchment contains significant shallow and deep groundwater resources, including the St George alluvium and the sedimentary aquifers of the Great Artesian Basin (MDBA 2017). Shallow aquifers may contribute inflows to some wetlands.

Wetland habitat types within the Moonie plan area include coastal and sub-coastal floodplain lakes, tree swamps and grass-sedge wetlands (State of Queensland 2017). The swamps are dominated by eucalyptus and melaleuca species. The Moonie catchment also supports the endangered “southern brigalow belt” (MDBA 2017) and a variety of endangered and vulnerable species associated with this bioregion (*Brigalow Belt South (BBS) IBRA bioregion, WetlandInfo*). The Thallon Waterholes, located on the Bullamon Plains station, and Thallon Swamp, 10 km south of Thallon, are wetlands of ecological significance. Thallon waterholes consists of two relatively permanent lakes of 12 and 21 hectares (DNR 1999) and are capable of supporting abundant and diverse waterbird populations (Kingsford et al. 1997). Black swans, grey teal and little black cormorant have been observed breeding at this site (DNR 1999) and banded lapwing and wandering whistling-duck have occurred in high abundance (Bino et al. 2015). There is little additional information available about Thallon Swamp.

Flow thresholds representing filling of floodplain wetlands were derived from evaluation of a time-series of satellite imagery using the following three step process (DES 2018): (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. Floodplain wetlands were not assessed in the Maranoa as the high/overbank flow regime is largely unchanged under the full entitlement scenario.

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 three FARs at seven flow thresholds. Floodplain wetlands in this area are highly ephemeral with persistence values between 96 and 208 days. All sites showed a reduction in the number of wetland connection days under the full entitlement scenario of between 6 and 18 per cent.

Moonie River at Fenton shows the largest reduction in both the number and duration of floodplain wetland inundation days under full entitlement within this assessment area. The average return frequency for the 12,000 ML/day flood threshold have been increased by six months, and the maximum return frequency by five and a half years. The spatial analysis showed one main cluster of floodplain wetlands in this assessment area associated with the Moonie River at Nindigully FAR. Wetland inundation flow days at this site have been reduced by six per cent under full entitlement, with the largest change in the average return frequency relating to the 29,500 ML/day flood threshold, which has increased by two years.

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).

Risk was modelled at three assessment nodes in the plan area representing those areas which correspond to the distribution of the turtle (Table 3). All three assessment nodes experienced a small increase in the average duration of stress periods under the full entitlement scenario compared to the pre-development scenario. The longest duration of high stress remained the same between the pre-development and the full entitlement scenario at two of the three assessment nodes, whereas at Moonie River at Fenton there was an increase in the longest duration of high stress from one year under the pre-development scenario to 1.8 years under full entitlement.

Risk increased under the full entitlement scenario compared to pre-development at two of the three assessment nodes, Moonie River at Nindigully and Moonie River at Fenton, and remained unchanged between the full entitlement and pre-development scenarios at the remaining assessment node. At Moonie River at Nindigully there were 26 per cent of years in the high risk category under pre-development and 27 per cent of years in the high risk category under the full entitlement scenario. At Moonie River at Fenton there were one per cent of years in the high risk category under pre-development and three per cent of years in the high risk category under the full entitlement scenario.

Table 3 Stress periods for the eastern snake-necked turtle under pre-development and full entitlement scenarios

Environmental assessment nodes	Number and average duration of stress periods (days)		Longest duration of high stress periods (years > 4 year ToC)	
	Pre-development	Full entitlement	Pre-development	Full entitlement
Moonie River at Nindigully	31, 1091	30, 1144	11.1	11.1
Moonie River at Fenton	56, 381	47, 537	1.0	1.8
Moonie River at Flinton	35, 367	35, 435	0.0	0.0

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 ecological outcomes. Ecological assets with critical links to flow that represent the plan outcomes and the various aspects of the flow regime are 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 relating to:

- 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 (DNRM 2017)
- 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)
- waterholes as refugia (DERM 2010).

6.2.2 Water quality monitoring

Surface water

DNRME operates and maintains three stream gauging stations across the Moonie River catchment. 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 undertaken throughout low and high flow conditions to enable derivation of a full range of streamflow volumes.

The frequency of water quality data collection is variable and occurs across a range of flow conditions to build long term datasets on various flows. 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 geology 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 increased downstream due to limited availability of data. Possible electrical conductivity rises accompanied by falling turbidity in the Border and Moonie Rivers sub catchment and in the western section of the sampling area appeared to be reversed in the Balonne and Condamine 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 2011).

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 2014, the program changed to the MDB Fish Survey which focuses only on fish. The SRA is reported at valley scale and monitoring is 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 were scored on a five staged scale relative to reference condition (good to moderate, poor and very poor to extremely poor) (Davies et al. 2012). The Moonie River catchment was not assessed individually under the SRA, but was included within the Border Rivers assessment. Thus overall rankings for the Border Rivers catchments are inclusive of the Moonie catchment and are reported here. Overall, the ecosystem health of the Border Rivers Valley, as reported by the SRA1 and SRA2 are:

- Moderate (SRA1-data collected 2004 to 2007) (Davies et al. 2008).
- Poor (SRA2-data collected 2008 to 2010) (MDBA 2012).

The Murray-Darling Basin Fish Survey commenced in 2014 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, three were identified as either moderate or high for the Moonie catchment:

High risk threats:

- Instream pest fauna
- Deposited sediment

Moderate risk threats:

- Climate change

6.2.4 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

The Moonie River ROP covers the Moonie River from headwaters to the Queensland-New South Wales border. The ROP applies to water distribution and allocation within the Moonie River management area, and includes no major in-stream water storages or associated infrastructure. As such, the environmental management rules operating within the Moonie River Basin relate only to allocation and water take limitations. The following section includes an assessment of compliance and ecological efficacy of rules relating to environmental management in Chapter 3 of the Moonie River ROP.

7.1 Change of location for allocations with nil passing flow condition

1. *This section applies to a water allocation that has a flow condition that allows water to be taken when there is no passing flow ('a nil passing flow condition').*
2. *A change to the location on the allocation is permitted provided –*
   a. *there is no change to the zone from which water may be taken;*
   b. *after the change is made, the allocation includes the following special condition:*
      'Taking water under this water allocation is prohibited whenever the water level in the waterhole is less than 0.5 metres below the level at which it naturally overflows';
   c. *after the change is made, the 'place' component of the location of the water allocation must be limited to an area no larger than the ponded area of the waterhole from which the water will be taken*

Ecological effectiveness

This rule relates to plan outcomes (d), (e) (i, ii, iii), (f) listed in Section 9, and strategies outlined in Section 30 of the plan. The rule is associated with the maintenance of natural riverine habitats and supporting ecological processes. The intent of this rule is to provide some protection to waterholes by allowing pumping to occur only to 0.5 metres below the cease-to-flow level. This condition is placed on traded allocations where a change in location has taken place.

There is no monitoring of this ROP rule and as such there is no reporting on any instances where the take of supplemented water from a waterhole results in the waterhole being drawn down to more than 0.5 metres below its natural cease-to-flow. Therefore compliance cannot be assessed for waterholes in the Moonie River WP areas, as the individual waterholes are not gauged and/or monitored.

Recommendations

Risk to waterhole persistence is low across the plan area. Strategies to mitigate risk should the situation change in the future may involve implementation of event management following extended periods of no-flow for a particular area, where this period exceeds the persistence time of the modelled waterholes.

There is currently no monitoring of existing waterhole extraction in the Moonie River and no way to determine if there are any instances where the licenced take of water from a waterhole results in the waterhole being drawn down to more than 0.5 metres below its natural cease-to-flow. Measurement may assist with this.

Because of the low persistence rates of the waterholes in the Moonie River, combined with the infilling from increased sedimentation rates, the restriction of pumping below 0.5 metres from cease-to flow is very important, especially in the more shallow waterholes in the Moonie.

Stock and domestic pumping is not covered by this rule, therefore there is no restriction on pumping a waterholes below 0.5 metres from cease-to-flow to water stock. Development of monitoring program for this rule may be considered.

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). This is summarised in Table 4 and recommendations are provided for consideration in the new plan.

Table 4 Assessment of plan outcomes and recommendations for the new water plan

Plan outcome	Evidence base	Evaluation
9(d) to make water from the basin available to be stored and used while retaining water for the riverine and associated environment		See results 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 (WP section 18). 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. • 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 due to lack of demand.
Recommendations	This outcomes lacks specificity and is not recommended for inclusion in the new plan.	
9(e) i, maintaining pool habitats, and native plants and animals associated with the habitats, in watercourses	Modelling of eight refuge waterholes, remote sensing analysis of persistent waterholes across the plan area	Results from monitoring over the life of the plan, and from the quantitative risk assessment, indicate that there is a low risk of waterholes changing from persistent to intermittent. Remote sensing analysis identified 270 waterhole habitat patches covering a total area of 7.6 km^2 across the Moonie catchment, 1.3 km^2 of this area remained persistent throughout the period 1988–2015. It is therefore likely that this outcome has been achieved.
Recommendations	Risks to refuge waterholes is low in the plan area. Potential strategies to mitigate risks if this situation changes may involve implementation of event management following extended periods of no-flow for a particular area, where this period exceeds the persistence time of the modelled waterholes. Releases for stock and domestic use may also alleviate risk under these circumstances, however there is no explicit recognition of this potential environmental benefit in the current plan. Inclusion of this ecological outcome in the new plan is strongly supported. Clear measures and strategies can be associated with the waterholes outcome, and it will provide a sound base from which to assess the success of the Water Plan in future review processes.	
Key knowledge gaps relating to this outcome	Alteration to the high flow regime across the plan area has resulted in a net reduction in bankfull flow days, a threshold associated with mobilisation and transport of instream sediments. Over time, this may result in reduced waterhole depth due	

	to sediment deposition, and subsequent reduction in persistence. Improved knowledge on the sedimentation of refuge waterholes across the plan area is required to further assess this risk.	
9(e) 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	Overall ecosystem health, based on an assessment of fish, hydrology, macro-invertebrates, terrestrial vegetation and physical form, has been assessed as poor (SRA2). Risks from instream pest fauna are high (Q-catchments). The risk to the three stable flow spawning fish species varied across the plan area, but was generally low throughout. Collectively the information from these three indicators suggest that this ecological outcome has been 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 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. 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 'riverine habitats" should be represented by the waterholes outcome 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 should be based upon the requirements of these plants • stream cross-sections are required 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(e) iii, maintaining the natural abundance and species richness of native plants and animals associated with habitats within watercourses, riparian zones, floodplains and wetlands	Sustainable Rivers Audit (SRA1, SRA2), Q-catchments threats assessment, risk modelling of floodplain wetlands, eastern snake-necked turtle	Overall ecosystem health, based on fish, hydrology, macroinvertebrates, terrestrial vegetation, and physical form, has been assessed as poor (SRA2). Risks from instream pest fauna are high (Q-catchments). Collectively the results of floodplain wetland inundation modelling suggest that these wetlands, supported by the overbank flow regime across the plan area, are at low risk. This is consistent with the modelling results from the eastern snake-necked turtle, a wetland specialist (see below). The risk to the eastern snake-necked turtle was low at all three

		environmental assessment nodes evaluated under the full entitlement scenario. This reflects a full entitlement river-wetland flooding regime which has not substantially changed from pre-development. Therefore this outcome has been partially met.
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 supported. It is recommended that assets covered by the broad scope of this ecological outcome should be represented individually. This will enable clear delineation of exactly which assets are to be assessed across the catchment and allow the development of specific measures and strategies for future plan assessments.	
Key knowledge gaps relating to this outcome	Floodplain wetlands 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 are a knowledge gap for most dependent ecological assets, such as wetland vegetation, fish, birds, and turtles. Eastern snake-necked turtle 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 three locations in the plan area.	The condition of the hydrology in the Moonie catchment has been assessed as good (SRA1) and 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 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 in 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 increased 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 any future risks. 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. Continued inclusion of this outcome in the new plan is strongly supported. It has strong flow-ecology links with a potential for measures and strategies to support implementation and assessment.	
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 effective transport velocities. • sediment scouring 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) to maintain water quality at levels acceptable for water use and to support natural ecological processes	Surface Water Ambient Network (SWAN)	The data suggests that most water quality parameters are within acceptable limits, except that turbidity is elevated throughout the catchment (SWAN) and salinity may be high in lowland reaches. These results suggest that this outcome has been met.
Recommendations	It is recommended that outcome 9(f) 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; hydrology also influences their physical and chemical environment 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: • the key water quality processes and/or indicators that are sensitive to a managed flow regime • approaches to model water quality processes and or indicators • approaches to isolate the effect of the flow regime on water quality processes from the range of other anthropogenic stressors present in the plan area	
9(h) 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 have 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
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 (DSITI/DNRM 2014).	
9(i) consistency with the Basin Plan 2012 (Cwlth)		This outcome is being primarily achieved through the new Moonie Water 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 (Cwlth). • The new Plan will 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(j) consistency with		This outcome is being achieved through the ROP being consistent with

water sharing agreements and commitments between the State and New South Wales		existing interstate water management arrangements. • The Water Plan requires that the ROP be developed to give effect to any agreement between Queensland and New South Wales about water in the Plan area. • The ROP was developed to meet the requirements of the NSW–QLD Intergovernmental Agreement.
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(k) to protect the productive base of groundwater	Semi-quantitative risk ranking of GDEs across the plan area.	No risk to GDEs were identified within the plan area. This outcome has been achieved through limitations on take of groundwater, and no issuing of new licences. • 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.
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.	

9 References

Arthington AH, Balcombe SR, Wilson GG, Thoms MC & Marshall JC 2005, ‘Spatial and temporal variations in fish assemblage structure in isolated waterholes during the 2001 dry season of an arid-zone floodplain river, Cooper Creek, Australia’, *Marine and Freshwater Research*, vol. 56, pp 25–35.

Arthington, AH, 2015, ‘Environmental flows: a scientific resource and policy framework for river conservation and restoration’, *Aquatic Conserv Mar Freshwater Ecosyst*, vol. 25, pp. 155–161.

Bino, G, Kingsford, RT & Porter, J 2015, ‘Prioritizing wetlands for waterbirds in a boom and bust system: Waterbird refugia and breeding in the Murray-Darling Basin’, *PLoS One*, vol. 10, no. 7, pp. e0132682.

Boulton, AJ & Brock, MA 1999, Australian Freshwater Ecology: Processes and Management, Cooperative Research Centre for Freshwater Ecology, Canberra.

Boulton, AJ, & Hancock, PJ 2006, ‘Rivers as groundwater-dependent ecosystems: a review of degrees of dependency, riverine processes and management implications’. *Australian Journal of Botany*, vol. 54, no. 2, pp.133–144.

Bowen, ZH, Bovee, KD & Waddle, TJ 2003, 'Effects of flow regulation on shallow-water habitat dynamics and floodplain connectivity', *Transactions of the American Fisheries Society*, vol. 132, pp. 809–823.

Bren, LJ 1992, 'Tree invasion of an intermittent wetland in relation to changes in the flooding frequency of the River Murray, Australia', *Australian Journal of Ecology*, vol. 17, pp. 395–408.

Bureau of Meteorology, 2007, Queensland Flood History. (Bureau of Meterology, Commonwealth of Australia: Canberra.) http://www.bom.gov.au/hydro/flood/qld [Verified 4 June 2007].

Canham, C.A., Froend, R.H., Stock, W.D. & Davies, M., 2012. Dynamics of phreatophyte root growth relative to a seasonally fluctuating water table in a Mediterranean-type environment. *Oecologia*, vol.170, no. 4, pp. 909–916.

Capon, SJ 2004, ‘Flow variability and vegetation dynamics in a large arid floodplain: Cooper Creek, Australia’, PhD thesis, Griffith University.

Clifford, NJ & Richards, KS 1992, ‘The reversal hypothesis and the maintenance of riffle-pool sequences: a review and field appraisal’, pp. 43–70. In PA Carling & GE Petts (eds), Lowland Floodplain Rivers: Geomorphological Perspectives, John Wiley, Hoboken, U.S.A.

CSIRO 2008, Water availability in the Moonie: Summary of a report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia.

Davies, P, Stewardson, M, Hillman, T, Roberts, J & Thoms, M 2012, Sustainable rivers audit 2: The ecological health of rivers in the Murray-Darling Basin at the end of the Millennium Drought (2008–2010), Technical Report vols. 2–3, Murray-Darling Basin Authority, Canberra.

Davies, PE, Harris, JH, Hillman, TJ and Walker, KF, 2008, SRA Report 1: A Report on the Ecological Health of Rivers in the Murray-Darling Basin, 2004–2007. Prepared by the Independent Sustainable Rivers Audit Group for the Murray-Darling Basin Ministerial Council. Murray-Darling Basin Commission, Canberra ACT, Australia.

Department of Environment and Heritage Protection 2012, Wetlandinfo: Freshwater biogeographic provinces, Department of Environment and Heritage Protection, Queensland Government. Available at http://wetlandinfo.derm.qld.gov.au/wetlands/ScienceAndResearch/ConceptualModels/Riverine/FBP/Murray-Darling/Geology-Topography.html [Accessed 18 October 2012]

Department of Environment and Heritage Protection, (DEHP), 2013, Surface Water Ambient Network (SWAN) – Water quality, WetlandInfo. Department of Environment and Heritage Protection, Queensland. Last updated: 22 March 2013. Accessed 7 September 2016. https://wetlandinfo.ehp.qld.gov.au/wetlands/assessment/monitoring/current-and-future-monitoring/surface-water-ambient-network.html [Verified 20/09/2017].

Department of Environment and Resource Management (DERM) 2010, Refugial Waterholes Project: Research Highlights, Queensland Government, Brisbane.

Department of Environment and Resource Management, (DERM), 2011, Ambient Surface Water Quality in Queensland 2004–8 Summary Report. State Government of Queensland, Department of Environment and Resource Management, Brisbane, Queensland.

Department of Natural Resources and Mines (DNRM), 2017, Waterholes as Refugia, Upper and Middle Condamine–Drawdown Monitoring Report, Toowoomba, QLD, Australia.

Department of Natural Resources and Mines, (DNRM), 2007, Water Monitoring Data Collection Standards (Version 2.1). Available at https://www.dnrm.qld.gov.au/water/catchments-planning/planning-process/supporting [Verified 17/08/2017].

Department of Natural Resources and Mines, (DNRM), 2016, Water Management - Catchments and Resource Planning–Moonie River Catchment; Moonie water planning area map. Site accessed 31/08/2016. https://www.dnrm.qld.gov.au/_data/assets/pdf_file/0005/108752/moonie-map.pdf

Department of Natural Resources, Mines and Energy (DNRME), 2018, Review of Water (Moonie) Plan 2003: Summary of Monitoring. Toowoomba, Queensland.

Department of Science, Information Technology and Innovation (DSITI) 2016, Waterhole refuge mapping and persistence analysis in the Lower Balonne and Barwon-Darling rivers, Queensland Government, Brisbane.

Department of Environment and Science (DES) 2018, Review of Water (Moonie) Plan 2003. Ecological Risk Assessment Report. Queensland Government, Brisbane.

Department of Science, Information Technology and Innovation (DSITI) 2017, Groundwater Dependent Ecosystems Atlas, Queensland Government, Brisbane. Available from http://www.bom.gov.au/water/groundwater/gde/index.shtml

Department of Science, Information Technology, Innovation and the Arts (DSITIA) 2014, Targeted review of the Water Resource (Gulf) Plan 2007: Environmental assessment, Queensland Government, Brisbane.

Department of Science, Information Technology, Innovation and the Arts (DSITIA) 2013, Review of the Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003: Environmental Risk Assessment for selected ecological assets. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Department of Sustainability, Environment, Water, Population and Communities (DSEWPC) 2012, Issues paper: The role of wetlands in the carbon cycle, Australian Government, Canberra.

DNR 1999, Overview of Water Resources and Related Issues: The Moonie River Catchment, Department of Natural Resources, Queensland Government. ISBN 0 7345 16134.

Eamus, D, Hatton, T, Cook, P & Colvin, C 2006, Ecohydrology. Vegetation function, water and resource management, CSIRO Publishing, Collingwood, Australia.

Haschenburger, JK & Wilcock, PR 2003, ‘Partial transport in a natural gravel bed channel’, *Water Resource Research*, p. 39, doi:10.1029/2002WR001532.

Hatton, T & Evans, R 1998, Dependence of ecosystems on groundwater and its significance to Australia, Land and Water Resources Research and Development Corporation (Australia), Occassional Paper no. 12/98

Hughes, JM, Real, KM, Marshall, JC & Schmidt, DJ 2012, ‘Extreme genetic structure in a small-bodied freshwater fish, the purple spotted gudgeon, *Mogurnda adspersa* (Eleotridae)’, *PloS One*, vol. 7.

Humphries, P & Lake, PS 2000, 'Fish larvae and the management of regulated rivers'. *Regulated Rivers: Research and Management*, vol. 16, pp. 421–432.

Kennett, RM & Georges, A. 1990, ‘Habitat utilization and its relationship to growth and reproduction of the eastern long-necked turtle, *Chelodina longicollis* (Testudinata: Chelidae), from Australia’, *Herpetologica*, vol. 46, pp. 22–33.

Kerr, J, Fawcett, J, & Prior, A 2016, *Stable low-flow spawning fish. Assessment of generic model parameters for use in Condamine-Balonne, Border Rivers and Moonie Water Resource Plans*. Queensland Department of Natural Resources and Mines, Toowoomba.

Kingsford, RT & Thomas, RF 1995, 'The Macquarie Marshes in arid Australia and their waterbirds: a 50-year history of decline', *Environmental Management*, vol. 19, pp. 867–878.

Kingsford, RT, Thomas, RF & Wong, PS 1997, Significant wetlands for waterbirds in the Murray-Darling Basin, NSW National Parks and Wildlife Service, Hurstville.

Knighton, AD & Nanson, GC 2000, ‘Waterhole form and process in the anastomosing channel system of Cooper Creek, Australia’, *Geomorphology*, vol. 35, no. 1, pp. 101–117.

Knighton, AD, & Nanson, GC 1994, ‘Waterholes and their significance in the anastomosing channel system of Cooper Creek, Australia’, *Geomorphology*, vol. 9, pp. 311–324.

Mackay, SJ & Thompson, CT 2000, ‘Flow requirements of submerged aquatic macrophytes’ pp. 169–217. In AH Arthington & JM Zalucki (eds), Environmental flow requirements of the Brisbane River Downstream from Wivenhoe Dam, Southeast Queensland Water Board and Centre for Catchment and In-Stream Research, Griffith University, Brisbane,

Marshall, JC, Steward, AL & Harch, BD 2006a, ‘Taxonomic resolution and quantification of freshwater macroinvertebrate samples from an Australian dryland river: The benefits and costs of using species abundance data’, *Hydrobiologia*, vol. 572, pp. 171–194.

Marshall, J, Sheldon, F, Thoms, M and Choy, S 2006b, ‘The macroinvertebrate fauna of an Australian dryland river: spatial and temporal patterns and environmental relationships’, *Marine and Freshwater Research*, vol. 57, pp. 61–74.

Marshall, JC & McGregor, G 2006, Ecological Risk Assessment of Water Resource Plans, Department of Natural Resources and Water, Queensland Government, Brisbane.

Marshall, J, Sheldon, F, Thoms, M and Choy, S 2006b, ‘The macroinvertebrate fauna of an Australian dryland river: spatial and temporal patterns and environmental relationships’, *Marine and Freshwater Research*, vol. 57, pp. 61–74.

McGregor, GB, Marshall, JC & Thoms, MC 2006, ‘Spatial and temporal variation in algal assemblage structure in isolated dryland river waterholes, Cooper Creek and Warrego River, Australia’, *Marine and Freshwater Research*, vol. 57, pp. 453–466.

McGregor, GB, Marshall, JC, Lobegeiger, JS, Holloway, D, Menke, N & Coysh, J 2017, ‘A Risk-based Ecohydrological Approach to Assessing Environmental Flow Regimes.’, *Environmental Management* (DOI 10.1007/s00267-017-0850-3).

Murray Darling Basin Authority (MDBA), Moonie: Snapshot, viewed June 2017. Murray-Darling Basin Authority, Canberra. https://www.mdba.gov.au/discover-basin/catchments/moonie

Murray–Darling Basin Authority, (MDBA), 2012, Sustainable Rivers Audit 2 The ecological health of rivers in the Murray–Darling Basin at the end of the Millennium Drought (2008–2010) Interpreting the results. Murray–Darling Basin Authority, Canberra ACT, Australia.

Murray–Darling Basin Authority, (MDBA), 2016, Discover the basin – catchments; Moonie. Commonwealth of Australia (Murray–Darling Basin Authority). http://www.mdba.gov.au/discover-basin/catchments/moonie. Accessed 31/08/2016.

Naiman, RJ & Décamps, H 1997, 'The ecology of interfaces: riparian zones', *Annual Review of Ecology and Systematics*, vol. 28, pp. 621–658.

Nanson, GC, Tooth, S, & Knighton, AD 2002, ‘A global perspective on dryland rivers: perceptions, misconceptions and distinctions’. In Bull, L. L. J., & Kirkby, M. J. (Eds.). Dryland rivers: hydrology and geomorphology of semi-arid channels. Wiley. com.

Negus, P, Blessing, J, Steward, A, Clifford, S, Hansen, D and Hammill, B, 2015, Ecological risk assessment and threat prioritisation in Queensland’s eastern Murray Darling Rivers: Condamine, Balonne and Maranoa; Lower Balonne; Moonie; and Border Rivers, 2012. Q–catchments program: Water Planning Ecology, Department of Science Information Technology and Innovation, Queensland Government. Brisbane.

Newbury, RW & Gaboury, MN, 1994, Stream analysis and fish habitat design–A field manual, Newbury Hydraulics Ltd. and The Manitoba Habitat Heritage Corporation, Canada.

Norris, R, Liston, P, Mugodo, J, & Nichols, S, 2005, Multiple lines and levels of evidence for detecting ecological responses to management intervention, American Geophysical Union, Spring Meeting 2005.

Pettit, NE, Froend, RH & Davies, PM 2001, 'Identifying the natural flow regime and the relationship with riparian vegetation for two contrasting Western Australian rivers', *Regulated Rivers: Research and Management*, vol. 17, pp. 201–215.

Pusey, B, Kennard, M, & Arthington, A 2004, Freshwater Fishes North-Eastern Australia, CSIRO Publishing: Australia.

Queensland Department of Natural Resources and Mines 2013 ‘Queensland Floodplain Assessment Overlay - Queensland Reconstruction Authority (QRA). Bioregional Assessment

Source Dataset'. Viewed 20 September 2017, http://data.bioregionalassessments.gov.au/dataset/ea785644-eff9-4ee2-9f1a-8dca1dde7ee5

Richardson S, Irvine E, Froend R, Boon P, Barber S, Bonneville B, 2011, Australian groundwater-dependent ecosystems toolbox part 1: assessment framework, National Water Commission, Canberra. Available from http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf

Schultz, C, Steward, A, & Prior, A 2013, 'Stygofauna presence within fresh and highly saline aquifers of the Border Rivers region in southern Queensland', *Proceedings of the Royal Society of Queensland*, vol. 118, pp. 27–35.

Scott, A 1997, Relationships between waterbird ecology and river flows in the Murray-Darling Basin: Technical Report 5/97, CSIRO Land and Water, Canberra.

Sear, DA 1995, 'Sediment transport processes in pool-riffle sequences', *Earth Surface Processes and Landforms*, vol. 21, pp. 241–262.

Sheldon, F, Bunn, SE, Hughes, JM, Arthington, AH Balcombe SR & Fellows, CS 2010, 'Ecological roles and threats to aquatic refugia in arid landscapes: dryland river waterholes', *Marine and Freshwater Research*, vol. 61, pp. 885–895.

Sternberg, D, Balcombe, SR, Marshall, JC & Lobegeiger, J, 2008, 'Food resource variability in an Australian dryland river: evidence from the diet of two generalist native fish species', *Marine and Freshwater Research*, vol. 59, pp.137–144.

Thoms, MC 2003, 'Floodplain–river ecosystems: lateral connections and the implications of human interference', *Geomorphology*, vol. 56, no. 3, pp. 335–349.

Wallace, J, Waltham, N & Burrows, D 2016, 'A comparison of temperature regimes in dry-season waterholes in the Flinders and Gilbert catchments in northern Australia', *Marine and Freshwater Research*, vol. 68, pp. 650–667.

Waltham, N, Burrows, D, Butler, B, Wallace, J, Thomas, C, James, C, & Brodie, J 2013, Waterhole ecology in the Flinders and Gilbert catchments, CSIRO Water for a Healthy Country and Sustainable Agriculture flagships, Australia.

Westlake, M & Pratt, K 2012, What, why and how wetlands work, Wetlandcare Australia, Ballina.

Wilkinson, SN, Keller, JR & Rutherford, ID, 2003, 'Phase-shifts in shear stress as an explanation for the maintenance of pool-riffle sequences', *Earth Surface Processes and Landforms*, vol. 29, pp. 737–753.

Woods, RJ, Lobegeiger, JS, Fawcett, JH & Marshall, JC. (eds) 2012, Riverine and floodplain ecosystem responses to flooding in the lower Balonne and Border Rivers, Department of Environment and Resource Management, Queensland Government, Brisbane.

Glossary of terms

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

Term	Definition
	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)