Improving our understanding of the ecosystem effects of varying water levels in weir pools of lowland floodplain rivers: What role can weir pool manipulations play in restoring the health of the River Murray channel?

Prepared by: Paul Brown and Susan Gehrig

April 2018

Final Report

MDFRC Publication 180/2018

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Final Report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre.

Murray–Darling Basin Authority
Level 6, 33 Allara Street | GPO Box 1801
Canberra City ACT 2601

Ph: (02) 6279 0100; Fax: (02) 6248 8053

This report was prepared by The Murray–Darling Freshwater Research Centre (MDFRC). The aim of the MDFRC is to provide the scientific knowledge necessary for the management and sustained utilisation of the Murray–Darling Basin water resources. The MDFRC is a joint venture between La Trobe University and CSIRO.

For further information contact:

Paul Brown

The Murray–Darling Freshwater Research Centre
PO Box 4095
Mildura VIC 3502
Ph: (03) 5051 4050

Web: www.mdfrc.org.au
Enquiries: mdfrc@latrobe.edu.au

Report Citation: Brown P, Gehrig S (2018) Improving our understanding of the ecosystem effects of varying water levels in weir pools of lowland floodplain rivers: What role can weir pool manipulations play in restoring the health of the River Murray channel? Final Report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre, MDFRC Publication 180/2018, April, 19pp.

Cover Image: Wetland in Lock 9 weir pool

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Document history and status

Version	Date Issued	Reviewed by	Approved by	Revision type
Draft v1	6/4/2018	Daryl Nielsen		
Draft v2	8/5/2018	Daryl Nielsen		

Draft v3	9/5/2018	Helen Missen		Format
Draft v3	1/6/2018	Sarah Commens & Gill Whiting, MDBA.	D. Nielsen	Content
Draft v3	4/6/2018	Susan Watson, DELWP	D. Nielsen	Content
Draft V5	15/6/2018	Sarah Commens	D. Nielsen	Content

Distribution of copies

Version	Quantity	Issued to
Draft v3	1	Carla Tadich (MDBA)
Draft v5	1	Carla Tadich (MDBA)
Final	1	Carla Tadich (MDBA)

Filename and path: MDFRC\Projects\MDBA\637 MDBA MDFRC Collaboration Agreement\BOC questions\2017-2018\Weir pool manipulation

Author(s): Paul Brown, Susan Gehrig

Author affiliation(s): La Trobe University

Project Manager: Daryl Nielsen

Client: MDBA

Project Title: BOC 2017-18 Weir pool manipulation

Document Version: Final

Project Number: M/BUS/637, 17/00796

Contract Number: MD3291

Final June 2018

Acknowledgements: Thanks to Daniel Hanisch (DEWNR, SA) and Scott Jaensch (NSW DPI Crown Lands and Water Division.), for their help with information about weir pool manipulations in their respective states. Thanks to Sarah Commens and Gill Whiting, MDBA and Susan Watson, DELWP for constructive comments on an earlier draft. The Murray–Darling Freshwater Research Centre offices are located on the land of the Latje Latje and Wiradjuri peoples. We undertake work throughout the Murray–Darling Basin and acknowledge the traditional owners of this land and water. We pay respect to Elders past, present and future.

Contents

Abstract

The practice of manipulating (or varying) weir pool levels over greater operational ranges than historically (but within limits specific to each weir), is showing promising early signs of being an important management tool to support the achievement of ecological objectives in the Basin Plan. Sites in the River Murray where weir pool manipulation has been trialled to date include weir pools upstream of Locks 1, 2, 4, 5 & 6 in South Australia (in 2000, 2005, 2014, 2015, 2016 & 2017) and Locks 7, 8, 9 & 15 in New South Wales (in 2013, 2014, 2015, 2016 and 2017).

The practice of varying weir pool levels is expected to restore some of the natural seasonal variability that would have occurred prior to river-regulation, in river levels, water velocities and the associated wetting-and-drying of littoral areas along the main river channel and within wetlands connected to weir pools. It is hypothesised that this could help protect and rehabilitate biodiversity and ecosystem functions in the littoral and riparian zone of waterways and adjacent wetlands throughout a reach. If proven, weir pool manipulations (WPM) are expected to improve the productivity of these areas, increase the extent and/or health of water-dependent vegetation and promote increased populations of fish, increased waterbird foraging, and connectivity to other significant sites.

Firstly, we describe the range of WPM events that have been completed. We broadly examine the range of ecological objectives for river reaches potentially affected by WPM. Information is collated about WPM-hypotheses which have been tested and we summarise the existing knowledge and knowledge-gaps around the effects of WPM with respect to the ecological objectives. Ecological objectives will ultimately be set out in the Long term Watering Plan's, however, they are not yet all in place/approved. In some cases WPM is shown to provide the expected ecological responses. In many cases, the role of WPM in supporting the achievement of environmental objectives remains untested, unclear or is unproven and requires further investigation.

In many areas where a positive effect of WPM can be demonstrated, the effect cannot easily be separated from that of the flow-pulse provided along with the WPM. While it seems likely that WPM can play a role in restoring the health of the Murray-River channel, it is equally likely that restoration will be limited unless both flows and WPM are provided and managed together.

1 Background

It has long been recognised that the biology and productivity of many plants and animals in freshwater ecosystems are linked to hydrological cycles at a range of scales; either as regular seasonal effects (Finlayson et al. 1990; Merendino et al. 1990; Thomson 1950) or as irregular hydrological events (Blanch et al. 1999; Frith 1967; Mitchell 1969; Puckridge et al. 2000).

The Murray River is the longest river in southern Australia and together with its tributary, the Darling, drains about a fifth of the Australian continent (MacKay & Eastburn 1990). Development and operation of a series of large reservoirs, irrigation agricultural systems and weirs for commercial navigation has resulted in the present day, highly modified state of the Murray–Darling River system. These modifications have altered the ecology of the Murray–Darling River system by disturbing the timing of seasonal peak flows, reducing the frequency of occurrence of moderate flows and small-freshes, fragmenting physical river habitat, barring fish-passage and altering water-temperature distributions (Poff et al. 1997; Rolls et al. 2012; Walker & Thoms 1993). Many research studies have suggested causal links between these alterations and the decline in distribution, abundance and health of native flora and fauna of the Murray – Darling Basin.

The current water reforms, put in place by the Murray – Darling Basin Authority (MDBA), provide a potential opportunity to mitigate some of these impacts by managing weir pools levels with a focus on achieving environmental outcomes. The manipulation of weir pool levels over a greater range than has historically been carried out may provide another effective management tool for helping to achieve a healthy working River Murray.

This review broadly examines the range of ecological management objectives for river reaches potentially affected by weir pool manipulation; then collates information about which relevant hypotheses have been tested and summarises the existing knowledge and knowledge-gaps around the effects of WPM with respect to the ecological objectives.

2 Existing weir pool manipulation practice

Along the River Murray, the practice occurs of varying weir pool levels to achieve ecological outcomes by surcharging and/or drawing-down water levels beyond full-supply level. Active sites have included weir pools upstream of Locks 1, 2, 4, 5 & 6 in South Australia (in 2000, 2005, 2014, 2015, 2016 & 2017)(Barnett et al. 2003; DEWNR 2012a; Hanisch et al. 2017a; Souter et al. 2012) and Locks 7, 8, 9 & 15 in New South Wales (in 2013, 2014, 2015, 2016 and 2017)(NSW Government 2017).

Varying weir pool levels to mimic patterns of modelled-natural hydrology should restore some of the natural seasonal variability in river levels, water velocities and the associated wetting-and-drying of littoral areas along the main river channel and within wetlands connected to weir pools that would have occurred prior to river-regulation (DEWNR 2012a). This could contribute to the protection and rehabilitation of biodiversity and ecosystem functions in a small but important component of the ecosystem – the littoral and riparian zone of watercourses and fringing wetlands throughout the reach. Weir pool manipulations (WPM) are expected to improve the productivity of these areas, increase the extent and health of vegetation, promote increased populations of fish, increased waterbird foraging and connectivity to other significant sites. If so, it is likely that progress towards ecological objectives can be achieved with minimal investment in new infrastructure or water use.

In South Australia, WPM to date has largely been restricted to surcharges (of relatively small magnitude) and has not included drawdowns. While the operations of the SA WPM trials have so far been relatively restricted, there has been considerable investment in the development of conceptual models/frameworks, hypotheses and understanding of the potential ecological outcomes (benefits and/or trade-offs) that may occur if a wide range of surcharge or drawdown scenarios are implemented (see DEWNR 2012a, 2012b, 2015). Hence, the WPM trials undertaken in SA between 2014-16 were extensively monitored and evaluated for their ecological effects (multiple sources synthesised in Hanisch et al. 2017b).

For locks and weirs upstream of South Australia, both drawdowns and surcharges have been trialled at a number of locks/weirs (eg. Locks 7, 8, 9 & 15), with an initial focus on developing an incremental understanding of the operational limitations through learning-by-doing; with less focus to-date on ecological monitoring and evaluation (Unpublished WaterNSW 2016).

Given the differences in approaches to WPM implementation and evaluation between these regions, there is potential to facilitate greater interstate exchange of knowledge. For example, the outcomes and learnings from drawdowns in areas upstream of South Australia may determine whether these practices could be implemented within South Australia in the future. Respectively, the results from intensive monitoring and evaluation investigations of surcharges within South Australia, could be used to guide further WPM upstream of South Australia

2.1 South Australia

Since the year 2000, South Australia has recognised the potential for using locks and weirs to manipulate river levels to mimic some of the natural variability that riverine flora and fauna would have experienced pre-development (Blanch et al. 2000). This is summarised in an educational video on the practice of WPM in South Australia, using Lock 5 as an example (https://www.youtube.com/watch?v=PKcZ2SjzepM). The scale and schedule of these WPM achieved to-date in South Australia are shown in Table 2.1. Lock 3 weir pool was used as a reference site during evaluation of WPM at other weir pools. Due to the unique lotic characteristics of its upper pool, in an otherwise broadly-lentic lower River Murray, it is deemed an inappropriate target for weir pool level raising (Hanisch et al. 2017a).

Table 2.1. Maximum operating ranges of River Murray weir pool manipulations trailed in SA relative to normal operating level (0.00 m) (data Courtesy of D. Hanisch, S.A. Govt. and Bice and Zampatti 2015, Bice Zampatti and Tonkin 2016, Souter et al 2012, Souter and Walter 2014).

Year	Lock 1	Lock 2	Lock 4	Lock 5	Lock 6
2000	+0.20 m	+0.25 m	+0.45 m	+0.50 m	
2005	+0.15 m	+0.10 m	+0.30 m	+0.50 m	+0.15 m
2014	+0.50 m	+0.50 m			+0.40 m
2015		+0.50 m		+0.45 m	
2016		+0.75 m		+0.50 m	+0.60 m
2017		+0.55 m		+0.50 m	

2.2 Upstream of South Australia

Trial WPM at Locks 8 and 9 has been implemented since 2013-14 (Unpublished WaterNSW 2016), based initially on recommendations in (Ecological Associates 2013). The program was extended to include Locks 7 and 15 from 2014-15 (Table 2.2).

Table 2.2. Maximum operating ranges of River Murray weir pool manipulations trialled in NSW relative to normal operating level (0.00 m)

Year	Lock 7	Lock 8	Lock 9	Lock 15
2013–14		+0.40m to -0.50m	+0.20m to -0.10m	
2014–15	+0.50m to -0.80m	+0.85m to -0.80m	+0.25m to -0.10m	
2015–16	+0.50m to -0.80m	+0.85m to -0.80m	+0.25m to -0.10m	+0.60m to -0.30m
2016-17	+0.55m to -0.9m	+0.85m to -1.0m	+0.24m to -0.1m	+0.6m to -0.45m

In New South Wales reaches of the River Murray, a project is presently using WPM as a way to support environmental outcomes similar to those proposed in the Basin Plan, but with less water; effectively considering WPM as a 'complementary measure'. The proposed project, *Locks 8 and 9 Weir Pool Manipulation, Carrs, Capitts and Bunberoo Creeks connectivity and Frenchman's Creek fish passage (Murray Weirs)* (NSW Government 2017), includes provision of regulators and fishways to provide connectivity with the named creeks. Restoring fish passage around the inlet regulator of Lake Victoria will be achieved through in-channel habitat enhancement and fish passage measures and will be supported using increasing weir pool variability through WPM. Anticipated ecological outcomes of the project include improvements to Murray cod and Golden perch populations.

The WPM trials for Locks 7-15 not only change water levels in the River Murray main channel and connected wetlands, but also through hydrological -connections to waterways on Lindsay, Mulcra and Wallpolla Islands. Hence, WPM will influence flows through several anabranch creeks. Floodplain inundation objectives for Mulcra Island depend upon weir pool raising (Lock 8) along with operation of the Lower Potterwalkagee regulator (Mallee CMA 2009). There are currently discussions between the jurisdictions around how lowering components of WPM trials may hydrologically disconnect the upper Lindsay and upper Potterwalkagee Creeks and whether lower weir pool levels may affect how Victoria manage these sites and meet their management and ecological objectives.

3 Relevant ecological objectives

This section seeks to summarise the ecological objectives defined by research and management plans within each state and the potential role of WPM in achieving these objectives.

3.1 South Australia

The Murray Futures/Riverine Recovery Program (DEWNR 2012a), aims to improve the health of the wetlands, floodplains and the South Australian River Murray upstream of the Lower Lakes. Its three objectives can be summarised as:

- Improve the health of wetlands, floodplains and the river
- Save water for the environment (i.e. establish an efficient water-use system for the environment)
- Give security to regional communities

The maintenance of stable weir pools associated with river regulation has resulted in permanent inundation of 75% of the wetland area in this reach; while the remaining areas suffers from extended periods of complete dryness (Pressey 1986). An expert workshop approach generated a series of principles for designing wetting and drying cycles for ecological outcomes (DEWNR 2012a), to achieve the above objectives. These principles are summarised in Appendix 1.

The ecological objectives for the SA Riverine Recovery project relate to the whole River Murray floodplain from the SA Border downstream to Wellington. In Appendix 1, the likelihood that WPM-alone, without additional flow-management, will contribute to achieving these objectives is expressed as 'likely', 'probable', 'possible' and 'unachievable'. This assessment relates to a scale that is locally appropriate to an individual WPM and does not necessarily imply that achieving the objective is probably throughout the whole Murray-River floodplain reach. For example, an assessment of 'likely' means that there is evidence that an objective can be achieved primarily using WPM without significant additional flow-management. This semi-subjective assessment was based on the presence/absence or amount and strength of evidence reviewed in published papers and government reports. These assessments are accompanied by supporting evidence of hypothesis testing during research and monitoring activities, where available.

Twenty-seven principles or driving objectives were identified as important in the design of wetting and drying cycles to manage ecological assets (i.e., vegetation, frogs, fish, waterbirds and water quality) on the River Murray floodplain (DEWNR 2012a). Of these, 26% were assessed as 'likely' to be achievable using WPM alone; 30% as 'probably' achievable using WPM alone; and 37% as 'possible' to achieve using WPM alone. Whereas 7% were assessed as 'unachievable' using WPM alone due to mismatched spatial scope or independence from WPM (Appendix 1).

The South Australian River Murray Channel Priority Environmental Asset is the 560 km of River Murray upstream of Wellington, South Australia to the border; along with lateral extent of the floodplain area inundated at flows up to 40,000 ML/day (measured at the SA border under normal River operations). The fifteen 'biotic' ecological objectives identified for this 'Channel PEA' are relevant for consideration of the role and value of WPM (Kilsby & Steggles 2015), and have been developed as required by the Basin Plan. As such, they are broadly compatible with ecological objectives for the River Murray Channel (Wallace et al. 2014), and floodplain sites within the reach (Kilsby & Steggles 2015). On review of the targets specified for these ecological objectives, none of them is likely to achieve target-level using WPM alone; all are also likely to require delivery of targeted flows to achieve targets. This is mainly because the targets are specified at the scale of the whole managed floodplain and WPM-effects are limited to spatial scope of the channel and a proportion of this managed floodplain.

3.2 New South Wales

The present development of the Murray Lower Darling Long Term Watering Plan (MLD LTWP) includes a range of ecological objectives and targets for fish, native vegetation, waterbirds and ecological functioning and connectivity (NSW, Office of Environment and Heritage, draft in development). These draft objectives are summarised below (Appendix 2) along with an assessment of the role of WPM in contributing to the achievement of these objectives and the rationale for this assessment. This assessment was undertaken using the same method described in the previous section for appendix 1.

The planning units considered by the MLD LTWP include reaches of the River Murray channel that could potentially be influenced by WPM (downstream of the Murrumbidgee River junction); as well as planning units beyond the influence of WPM trials undertaken to date (e.g., River Murray upstream of Murrumbidgee junction; Edward and Wakool rivers, Darling River valley, etc.) Weir pool manipulation is understood to be an integral contributor to the objectives of the MLD LTWP in planning units influenced by WPM.

In the development of the MLD LTWP, twenty-three draft ecological objectives were identified (to date) around the ecological assets and processes of native fish, native vegetation, waterbirds and functions/connectivity. Our assessment of the likelihood that WPM will contribute to the achievement of these objectives indicates that of these; WPM alone will contribute to 'partially' achieving 81% of the objectives. These objectives are more likely to be achievable if targeted flows are also delivered, but without specific flows, WPM could only partially achieve the objective. The 19% that are 'unachievable or not-applicable', using WPM (Appendix 2) are specific to areas not affected by WPM or dependent on non-flow and non-WPM interventions. Much of the evidence supporting the rationale for how WPM can assist with achieving objectives is from previous studies in South Australia (see above, section 3.1) although much of this research is likely to be transferable to reaches upstream.

4 Weir pool manipulation: Hypotheses tested to date

Collecting data that tests hypotheses about the role of WPM in achieving a range of desirable objectives for riverine ecology has often proven difficult in a context of background environmental variability including the often-confounding influence of other management actions (Hanisch et al. 2017b). Even when flow-related effects are shown to be beneficial; separating the effects of water level variability (WPM) from those of managed or natural flow-pulses has proved challenging (Ye et al. 2008; Ye et al. 2017). As a management tool to assist in achieving ecological objectives, flow-delivery and WPM should be considered a combined package. Although it may be beneficial to investigate the mixed effects of a combination of management actions (i.e., flow releases in conjunction with WPM), this makes it difficult to test specific hypothesis around WPM alone.

Much of the hypothesis testing work to-date has occurred as part of WPM with relatively minor variable operating ranges (0.10 m–0.50 m), often following single WPM 'events' rather than a regime of multiple events across years (Gehrig et al. 2016). In a recent synthesis of 15 separate research studies evaluating South Australian WPM events Hanisch et al (2017b), prescribed a pragmatic "balance of probabilities" approach, which together with appropriate risk-monitoring was considered sufficient to support proceeding with development of a WPM regime as an adaptive-management program. Stronger evidence to support the use of WPM in achieving ecological objectives may now be more attainable following a regime of WPM trials that have occurred since 2013 at Lock 8 and 9 (in NSW) with larger operating ranges, or at Locks 2 and 5 (in SA) which have occurred for 3-4 consecutive years.). The ongoing development and refinement of WPM in regards to trialling various magnitudes, durations and frequencies of particular surcharge/drawdown events further highlights the need for collaboration and knowledge exchange knowledge between interstate agencies in regards to the monitoring and evaluating the outcomes of such management actions.

A range of research studies have focussed on hypotheses that underlie the assumptions behind the development of the principles and driving objectives for the management of ecological assets. Key studies are tabulated with referenced cited where appropriate in Appendix 1 and 2.

Long term intervention monitoring showed enhanced primary production associated with inundation from WPM in Lock 5 weir pool; however, the WPM-effect was confounded by the presence of return flows from inundation of Chowilla (Ye et al. 2017). This flow pulse also delivered faster flowing water in addition to the elevated river levels of the WPM.

During WPM, soil water availability and quality increased adjacent to the river and in marginal wetlands, which led to increased tree vigour. Also, floodplain and amphibious plant species diversity increased at sites influenced by WPM (Gehrig et al. 2016).

The response of lignum (*Duma florentula*) shrublands to WPM in 2005 was minor and not consistently positive (Souter & Walter 2014), despite lignum being known as a flood-responsive species (Freestone et al. 2017). The authors concluding that the lack of response to WPM may be due to the monitored plants not being water-stressed before the WPM. Given that the improved condition and maintenance of viable populations of lignum shrublands on lower elevations of the floodplain are an ecological objective of the NSW MLD LTWP, the potential for WPM to partially-address this objective, needs further investigation.

Small-bodied native fish populations, as secondary consumers, are hypothesised to benefit from WPM through improved primary productivity. However, Bice et al (2016), showed that for Australian smelt in three weir pools there was no difference in growth rates among populations with or without WPM. Although there was possibly a weak benefit in a slightly extended spawning season. They concluded that either the primary production enhancement measured was not large enough to translate into a detectable increase in fish growth-rate; or the organic matter produced by primary production did not enter a trophic pathway that directly benefited this small-bodied fish species. An alternative hypothesis that may be useful to test, is that small-bodied fish species benefit from habitat changes caused by WPM. Increased cover from complex habitats in enhanced littoral vegetation has been shown to reduce natural mortality and enhance recruitment (vegetated habitats forming enhanced nursery habitat) for many species (Alexander et al. 2015; Cheminée et al. 2016).

In combination, increased flow and WPM at Lock 5 in 2005 resulted in successful spawning and recruitment of Golden perch, a flood-recruitment specialist species (Ye et al. 2008). However, Long Term Intervention Monitoring in 2015 did not detect any significant effect on spawning or recruitment for large bodied native fish species in the Lock 1, 2 and 5 weir pools consistent with ecological objectives of improving population structure (Ye et al. 2017). Without triggers for spawning (e.g. Golden and Silver perch) and enhanced connectivity (all species) developed through flow pulses; WPM is unlikely to contribute effectively to these environmental objectives for large bodied species.

Local, evidence that supports the benefits of WPM for achieving waterbird objectives is scant. Variation in wetland water levels throughout the duration of an inundation coincide with changes in abundance of waterbirds and species diversity (MDBA 2009). Overseas studies have shown that flow management for variability in depth and vegetation has been successful for enhancing waterbird diversity and abundance when average depth was 10–20 cm (Taft et al. 2002). Therefore, riparian wetlands and weir pool margins, which are sporadically inundated by WPM, may be expected to contribute to some of the waterbird ecological objectives.

There has been limited monitoring of the response of ecological assets to the larger WPM trialled in NSW at Locks 7, 8, 9 and 15 to date. An unpublished progress report (Locks 7, 8, 9 and 15 Weir Pool manipulation trial, June 2016, NSW Govt.), collates information on inundation, hydraulic-diversity, River red-gum recruitment and the response of other vegetation, salinity and fish-passage through fishways on the locks during WPM events. More recent, semi-quantitative analysis of photo-point monitoring data suggests that WPM at locks 7, 8, 9 and 15 (between 2013 and 2017) were consistent with minor changes over time in vegetation communities (Gehrig 2018).

Small effects measured during small WPM events (in SA) suggested that such bigger 'events' repeated as a multi-year regime may provide bigger benefits, but this hypothesis requires further research attention. Gehrig (2018), demonstrated that incremental increases in some vegetation responses were detectable for the lock 8 weir pool manipulation trials, where the magnitude and frequency of successive WPM was relatively high.

Hypotheses tested to-date, about the benefits of WPM to fish and gross primary production suggest that WPM may be able to play a role in restoring the health of the River Murray channel. However, these benefits are likely to be greatest when WPM occurs in conjunction with flow management, with appropriate regard given to the combined effect of weir pool level and flow on hydraulics. To restore essential riverine processes in the main channel lotic conditions may need to be restored by almost annual delivery of flow pulses of 15-25 GL/day at the SA border (Bice et al. 2017). However, without the benefits of WPM, achievement of the required environmental objectives may require even larger quantities of environmental water.

5 Summary and conclusion

This review broadly examines the practice of weir pool manipulation in the lower River Murray.

We present the ecological objectives for river reaches in South Australia and upstream of South Australia that are potentially affected by WPM.

We collate information about hypotheses that have driven the development of these objectives and about which of these have been tested. The existing knowledge and knowledge-gaps around the effects of WPM are summarised with respect to the ecological objectives.

It is clear that to achieve targets set for ecological objectives in the Basin Plan and Long term Watering Plans, WPM are likely to add value to the impact of delivered flows. However, without specific flows WPM-alone can only be expected to partially-deliver some of the objectives.

6 Recommendations

As a management tool to assist in achieving ecological objectives, flow-delivery and WPM should be considered a combined package.

6.1 Monitoring & evaluation

Most of the research evaluation of the effects of WPM on river ecology have been implemented along with relatively small , sporadic WPM of short duration (Hanisch et al. 2017b). In some cases, this science has produced results that 'hint' at the validation of the conceptual models supporting the development of the WPM programs—perhaps enough to provide the "balance of probability assessment" required for adaptive management decisions.

Potentially greater cumulative ecological effects of a continuous regimes of WPM and of larger WPM's, including drawdowns and surcharges achievable in NSW, should be further evaluated through testing hypotheses based on the required ecological objectives (Appendix 2) and learnings from SA research and monitoring (Appendix 1).

While most of the learnings to-date about the effects of WPM are probably reasonably transferable within the lower Murray region; specific differences among fluvial geomorphology, and floodplain topography among reaches will need to be taken into account. To achieve this efficiently, there is a need for ongoing and multi-jurisdictional cooperation, collaboration and investment in the science evaluating WPM as a strategy for contributing to achieving Basin Plan and State long-term watering objectives.

There is a need for consideration of the wider impacts of WPM on hydrological connections and hydraulics, anabranch flows, etc., as well as the directly intended impacts on the River Murray and adjacent wetlands and riparian areas.

There may be added value in re-analysis of existing data-sets, collected for other purposes, to glean what can be learned about the effects of WPM. An evaluation strategy, particularly one addressing medium to long-term effects of a WPM regime, should include initially an examination of existing data sources including, but not limited to:

- The Living Murray Condition and Intervention monitoring around LMW and Chowilla Icon sites
- Environmental Water Knowledge and Research (EWKR)
- Long term intervention monitoring (LTIM)
- Hydro-dynamic modelling of the Lock 7 & 8 reaches of the River Murray including anabranches (Lindsay River-Mullaroo Creek and Potterwalkagee Creek)

7 References

Alexander M, Kaiser H, Weyl O, Dick J (2015) Habitat simplification increases the impact of a freshwater invasive fish. *Environmental biology of fishes* **98**, 477-486.

Baldwin DS, Rees GN, Wilson JS, Colloff MJ, Whitworth KL, Pitman TL, Wallace TA (2013) Provisioning of bioavailable carbon between the wet and dry phases in a semi-arid floodplain. *Oecologia* **172**, 539-550.

Barnett S, Cresswell D, Walter M, Yan W (2003) Salinity impacts of River Murray weir pool lowering in SA – Phase 1. DWLBC 2003/26,

Bice C, Gehrig S, Zampatti B, Nicol J, Wilson P, Leigh S, Marsland K (2014) Flow-induced alterations to fish assemblages, habitat and fish–habitat associations in a regulated lowland river. *Hydrobiologia* **722**, 205-222.

Bice CM, Gibbs MS, Kilsby NN, Mallen-Cooper M, Zampatti BP (2017) Putting the "river" back into the lower River Murray: quantifying the hydraulic impact of river regulation to guide ecological restoration. *Transactions of the Royal Society of South Australia* **141**, 108-131.

Bice CM, Zampatti BP, Tonkin Z (2016) The influence of weir pool raising in the South Australian lower River Murray on condition and growth of the Australian Smelt (*Retropinna semoni*). South Australian Research and Development Institute. SARDI Research Report Series No, 907, 37 p.

Blanch SJ, Ganf GG, Walker KF (1999) Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers: Research & Management: An International Journal Devoted to River Research and Management* **15**, 43-62.

Blanch SJ, Walker KF, Ganf GG (2000) Water regimes and littoral plants in four weir pools of the River Murray, Australia. *Regulated Rivers: Research & Management* **16**, 445-456.

Cheminée A, Merigot B, Vanderklift M, Francour P (2016) Does habitat complexity influence fish recruitment? *Mediterranean Marine Science* **17**, p. 39-46.

DEWNR (2012a) Riverine Recovery Monitoring and Evaluation Program: Conceptual understanding of the ecological response to water level manipulation Department for Environment, Water and Natural Resources (DEWNR). Adelaide, South Australia. 77 p.

DEWNR (2012b) Riverine Recovery weir pool manipulation – vegetation and wetland inundation. 135 p.

DEWNR (2014) Riverine Recovery overview of monitoring to assess the ecological response to the Locks 1 and 2 weir pool raising, spring 2014. Department of Environment, Water and Natural Resources. Adelaide. 33 p.

Ecological Associates (2013) Locks 8 and 9 Weir Pool manipulation Optimisation Plan - Analysis Report. Ecological Associates report ES001-2-C prepared for NSW Office of Water, Buronga. 87 p.

Finlayson CM, Cowie ID, Bailey BJ (1990) Characteristics of a seasonally flooded freshwater system in monsoonal Australia. *Wetland ecology and management: Case studies*, 141-162.

Freestone FL, Brown P, Campbell CJ, Wood DB, Nielsen DL, Henderson MW (2017) Return of the lignum dead: Resilience of an arid floodplain shrub to drought. *Journal of Arid Environments* **138**, 9–17.

Frith HJ (1967) *Waterfowl in Australia.* Angus and Robertson.

Gehrig S (2018) Assessment the responses of littoral and riparian vegetation to weir pool manipulations in Weir Pools: 7, 8, 9 and 15 of the River Murray. Draft Report prepared for the Murray Darling Basin Authority by the School of Life Sciences Albury-Wodonga and Mildura. XX p.

Gehrig S, Frahn K, Nicol J (2015) Monitoring the response of littoral and floodplain vegetation to weir pool raising - 2014. South Australian Research and Development Institute (Aquatic Sciences). SARDI Research report Series No. 844, Adelaide. 74 p.

Gehrig S, Frahn K, Nicol J (2016) Monitoring the response of littoral and floodplain vegetation and soil moisture flux to weir pool raising - 2015. South Australian Research and Development Institute (Aquatic Sciences). SARDI Research report Series No. 899, Adelaide. 93 p.

Hanisch DR, Hillyard KA, Smith J (2017a) Riverine Recovery - Synthesis of the ecological response to weir pool raising at Locks 1, 2 and 5 of the River Murray, 2014-16. Adelaide.

Hanisch DR, Hillyard KA, Smith J (2017b) Riverine Recovery - Synthesis of the ecological response to weir pool raising at Locks 1, 2 and 5 of the River Murray, 2014-16 Adelaide.

Kilsby N, Steggles T (2015) Ecological objectives, targets and environmental water requirements for the South Australian River Murray floodplain priority environmental asset. DEWNR Technical Report 2015/15.

MacKay N, Eastburn D (1990) *The Murray* Murray Darling Basin Commission, Canberra, Australia.

McCarthy B, Ellis I, Gawne B (2004) Drawdown of the Mildura Weir Pool 2001, 2002 & 2003: Water Quality Responses. Murray Darling Freshwater Research Centre. Report to the Murray Darling Basin Commission Strategic Investigations and Education Unit No 58 p.

MDBA (2009) Environmental Watering for Waterbirds in The Living Murray Icon Sites.

Merendino MT, Smith LM, Murkin HR, Pederson RL (1990) The response of prairie wetland vegetation to seasonality of drawdown. *Wildlife Society Bulletin (1973-2006)* **18**, 245-251.

Mitchell D (1969) The ecology of vascular hydrophytes on Lake Kariba. *Hydrobiologia* **34**, 448-464.

NSW Government (2017) NSW SDL Adjustment Projects. Supply Measure. Locks 8 and 9 Weir Pool Manipulation, Carrs, Capitts and Bunberoo Creeks connectivity and Frenchman's Creek fish passage, p. 4.

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC (1997) The natural flow regime. *BioScience*, 769-784.

Pressey R (1986) Wetlands of the River Murray below Lake Hume. A report for the River Murray Commission No Canberra, Australia.

Puckridge JT, Walker KF, Costelloe JF (2000) Hydrological persistence and the ecology of dryland rivers. *Regulated Rivers-Research & Management* **16**, 385-402.

Rolls RJ, Leigh C, Sheldon F (2012) Mechanistic effects of low-flow hydrology on riverine ecosystems: ecological principles and consequences of alteration. *Freshwater Science* **31**, 1163-1186.

Souter N, Walter M, Wen L (2012) Weir pool surcharge and a corresponding increase in algal biofilm community diversity in the Lower River Murray, South Australia. *River Research and Applications* **28**, 1853-1857.

Souter NJ, Walter M (2014) An unexpected lack of response in lignum (Muehlenbeckia florulenta Meissn.) to a managed rise in the level of the Lower River Murray, South Australia. *Transactions of the Royal Society of South Australia* **138**, 124-134.

Taft OW, Colwell MA, Isola CR, Safran RJ (2002) Waterbird responses to experimental drawdown: implications for the multispecies management of wetland mosaics. *Journal of Applied Ecology* **39**, 987-1001.

Thomson AL (1950) Factors determining the breeding seasons of birds: an introductory review. *Ibis* **92**, 173-184.

Unpublished WaterNSW (2016) Locks 7, 8, 9 and 15 Weir Pool Manipulation Trial 2015/16 Progress report.

Walker KF, Thoms MC (1993) Environmental effects of flow regulation on the lower River Murray, Australia. *Regulated Rivers: Research & Management* **8**, 103-119.

Wallace T, Daly R, Aldridge K, Cox J, Gibbs M, Nicol J, Oliver R, Walker K, Ye Q, Zampatti B (2014) River Murray Channel: Environmental Water Requirements: Ecological Objectives and Targets No. 14/4, , Adelaide, South Australia.

Ye Q, Cheshire K, Fleer D (2008) Recruitment of Golden perch and selected large-bodied fish species following the weir pool manipulation in the River Murrat, South Australia. SARDI Aquatic Sciences. Adelaide. 33 p.

Ye Q, Giatas G, Aldridge K, Busch B, Gibbs M, Hipesey M, Lorenz Z, Mass R, Oliver R, Shiel R, Woodhead J, Zampatti BP (2017) Long-term Intervention Monitoring of the Ecological Responses to Commonwealth Environmental Water Delivered to the Lower Murray River Selected Area in 2015/16. A report prepapred for the Commonwealth Environmental Water Office. South Australian Research and Development Institute, Aquatic Sciences. 204 p.

Appendix 1: A list of ecological principles driving the design of wetting and drying cycles for ecological outcomes from (DEWNR 2012a), their likelihood of being achieved with weir pool manipulation and whether the underlying hypotheses have been tested in a research context.

Ecological Asset	**Principles or Driving objective** **(DEWNR 2012a)**	**Likelihood of WPM being able to achieve objective without additional flow-management (0=unachievable or not-applicable, 1=possible, 2=probable, 3=likely)**	**Hypothesis tested in a research context? If so, key learnings**
Vegetation	Summer/Autumn drawdown	2	Draw down in summer achieved (Gehrig et al. 2016)
	expose emergent plants (by 0.1 m) at least 1 in 2 years,	3	Achieved (Gehrig et al. 2016)
	to at least 0.5 m below River Red gum elevation every 1.25 years,	3	Not in SA to-date. Not Achieved by weir pool raising only.
	refill in late winter early spring at a rate of between 0.02 m/day (preferred) to 0.1 m/day after duration of up to 0.5 years and before terrestrial weeds set-seed	3	Yes. Refill rate achieved in Winter/Spring 2014, Lock 1 & 2 for 5 months. (Gehrig et al. 2016)
	Inundate whole floodplain to terrestrial edge 1 in 10 years	0	Obvious limited spatial scope for WPM
	Vary max. and min. depths in successive years to encourage diversity and fuzzy boundaries	2	Possibly achieved for Lock 5 (Gehrig et al. 2016)

Ecological Asset	Principles or Driving objective (DEWNR 2012a)	Likelihood of WPM being able to achieve objective without additional flow-management (0=unachievable or not-applicable, 1=possible, 2=probable, 3=likely)	Hypothesis tested in a research context? If so, key learnings
	Complementary invasive/exotic species management (e.g. Willows, *Juncus acutus,* Noogoora Burr, Common carp, etc.)	0	Limited dependence upon WPM. Untested.
	Increased establishment of floodplain and amphibious functional groups	2	Not on river banks with infrequent WPM of short duration (Gehrig et al. 2015), but was detected in off-channel areas where area inundated was greater (Gehrig et al. 2015; 2016).
	Increased abundance of riverbank, emergent vegetation	2	Minimal change detected on main river channels, but some increased abundance detected in wetlands with WPM of short duration.(Gehrig et al. 2015, 2016)
	Improve the crown condition of River red gums adjacent to the river bank and wetlands	2	Some improvement, but most not attributable to WPM of short duration. (Gehrig et al. 2015).
Frogs	inundated marginal habitat from late winter through until early autumn	1	Yes, marginal habitat inundated, particularly in upper weir pool zones (Gehrig et al. 2016)
	Diverse and complex aquatic, floating and emergent vegetation (including flooded grasses and herbs).	1	Not clear? No evaluation available, but seems possible.
	Broad scale inundation of riparian vegetation to support dispersal and	3	Yes. Predicted a +0.5 m raise would inundate 50–200 additional hectares (depending on flow) at Lock 1 and

Ecological Asset	Principles or Driving objective (DEWNR 2012a)	Likelihood of WPM being able to achieve objective without additional flow-management (0=unachievable or not-applicable, 1=possible, 2=probable, 3=likely)	Hypothesis tested in a research context? If so, key learnings
	optimise recruitment and population connectivity		40–100 additional hectares at Lock 2 (DEWNR 2014). Depends on definition of “broad-scale”
Fish	Open wetland infrastructure August–April to promote connectivity	1	Not clear? Should be achievable operationally.
	Open structures during rise in river flow	1	Not clear? Should be achievable operationally.
	Begin drawdown during falling river with a brief period of open structures at wetlands to allow fish to exit	1	Drawdown only followed surcharge to-date.
	Preserve refuge habitat in some wetlands on a regional scale (don’t dry them all out together)	2	Yes. Not all weir pools manipulated in any year.
	Only use partial drawdown in wetlands containing rare and threatened species.	3	Not clear? Controllable through use of infrastructure.
Waterbirds (Provide a range of wetland habitats at a landscape scale including)	Exposed mudflats near the wetland edge with fringing reed beds	3	Not clear? No evaluation available, but seems likely.

Ecological Asset	Principles or Driving objective (DEWNR 2012a)	Likelihood of WPM being able to achieve objective without additional flow-management (0=unachievable or not-applicable, 1=possible, 2=probable, 3=likely)	Hypothesis tested in a research context? If so, key learnings
	Islands of reeds and trees in some wetlands for protected-edge habitat.	1	Not clear? No evaluation available, but seems possible.
	Maintain water under nesting trees until nestlings fledge	1	Not clear? No evaluation available, but seems possible. Likely to vary strongly by species.
	Fluctuating water levels to provide complex, diverse habitat for nesting and foraging	2	Not clear?
	Water to support large, dense stands of reeds, lignum and River red gums for colonial nesting waterbirds (particularly known rookeries)	1	Not clear?
	Water to support large stands of *Phragmites sp.* And *Typha spp.* For bitterns, rails and crakes	1	Not clear?
	Water to support a mosaic of shallow margins, deep water and diverse vegetation.	1	Not clear?
Water quality	Limiting salinisation of wetland surface water / groundwater.	3	Groundwater recharge and freshening variable but detectable during small WPM of short duration (Gehrig et al. 2016; Hanisch et al. 2017b)

Ecological Asset	Principles or Driving objective (DEWNR 2012a)	Likelihood of WPM being able to achieve objective without additional flow-management (0=unachievable or not-applicable, 1=possible, 2=probable, 3=likely)	Hypothesis tested in a research context? If so, key learnings
	Beneficial nutrient cycling & managing risk of cyanobacteria & anoxia	2	Some evidence of input of nutrients from small WPM of short duration but little evidence of heterotrophic response and no strong evidence of risk to water quality (Hanisch et al. 2017b). Unlike negative water-quality responses observed in earlier large-amplitude drawdowns (McCarthy et al. 2004).

Appendix 2: A summary of ecological objectives (Draft in development, April 2018) for assets in the NSW Lower Murray Darling Long Term Watering Plan (planning units 9–14) and an assessment of the role of WPM in achieving these objectives in these planning units.

Ecological asset	Ecological Objective	Role of WPM alone being able to achieve objective. (0=unachievable or not-applicable, 1=partially , 2=completely)	Rationale for rating and supporting evidence
Native fish	Improved distribution and abundance of generalist fish species (Australian Smelt, Carp Gudgeon, Murray-Darling Rainbowfish, Unspecked Hardyhead, Western Carp Gudgeon and Bony bream)	1	Improved productivity and habitat (vegetation cover) in littoral zone of weir pools (DEWNR 2012b; Gehrig et al. 2015) can lead to improved small fish abundance (Bice et al. 2014)

Ecological asset	Ecological Objective	Role of WPM alone being able to achieve objective. (0=unachievable or not-applicable, 1=partially , 2=completely)	Rationale for rating and supporting evidence
	Improved distribution and abundance of short lived floodplain specialist fish (Olive perchlet)	0	Probably extinct in NSW, River Murray. Unachievable unless species reintroduction implemented.
	Improved population structure of moderate to long lived flow specialists (Golden Perch, Silver Perch, Spangled Perch, Hyrtl's Tandan)	1	Could improve survival of recruits (GP and SP in Murray R.) through improved primary and secondary productivity. Evidence for recruitment success, not linked strongly to WPM (Ye et al. 2008), and evaluation confounded by increased flows.
	Expand the population of Silver Perch from Walgett to Louth	0	Out of geographic scope of WPM
	A 10-15% increase of mature Golden Perch and Murray Cod (of legal take size) from Walgett to Wilcannia	0	Out of geographic scope of WPM.
Native vegetation	Improve the condition of forest and woodland vegetation communities near river channels and on low-lying areas of floodplain	1	WPM may improve vegetation condition near river channels or low-lying areas of floodplain as a result of inundation or lateral bank recharge through WPM (DEWNR 2012b)
	Maintain the extent of forest and woodland vegetation communities near river	1	WPM may help to maintain extent of forest and woodland t vegetation near river channels or low-lying areas of floodplain as a result of inundation or later

Ecological asset	Ecological Objective	Role of WPM alone being able to achieve objective. (0=unachievable or not-applicable, 1=partially , 2=completely)	Rationale for rating and supporting evidence
	channels and on low-lying areas of floodplain		bank recharge through WPM (DEWNR 2012b)
	Support the recruitment of trees within River Red Gum and black box communities – achieving a greater range of tree ages in the longer term	1	WPM may support recruitment of long-lived woody species near river channels. Mainly River Red Gum communities (DEWNR 2012b)
	Improve the condition of lignum shrubland on low-lying areas of floodplain	1	WPM can affect vegetation near river channels (DEWNR 2012b). But some uncertainty (Souter & Walter 2014).
	Maintain or increase the extent of lignum shrubland on low-lying areas of floodplain. Maintain a viable, functioning lignum population	1	WPM can affect vegetation near river channels (DEWNR 2012b). But some uncertainty (Souter & Walter 2014).
	Maintain or increase the extent of non-woody native wetland vegetation fringing and within channel and on low-lying areas of floodplain	1	WPM can affect vegetation near river channels (DEWNR 2012b)
	Maintain diverse and viable non-woody native wetland vegetation communities fringing	1	WPM can affect vegetation near river channels (DEWNR 2012b)

Ecological asset	Ecological Objective	Role of WPM alone being able to achieve objective. (0=unachievable or not-applicable, 1=partially , 2=completely)	Rationale for rating and supporting evidence
	and within channel and on low-lying areas of floodplain		
Waterbirds	Maintain the number and type of waterbird species present	1	Potential for shallow inundation of riparian wetlands to enhance diversity and abundance (Taft et al. 2002)
	Increase total waterbird abundance	1	Potential for shallow inundation of riparian wetlands to enhance diversity and abundance (Taft et al. 2002)
	Increase breeding activity in non-colonial nesting waterbirds	1	WPM influence on rehabilitating nesting habitat such as dense reed beds, and trees adjacent to river (MDBA 2009)
	Increase opportunities for colonial waterbird breeding events	1	As above, but more limited scope. Most large breeding events occur in large wetlands beyond the reach of WPM
Functions/Connectivity	Provide and protect a diversity of refugia across the landscape	0	Limited spatial scope
	Create quality in-stream, floodplain and wetland habitat	1	WPM can increase primary production in habitats near river channel (Souter et al. 2012), but weak evidence that secondary production also benefits (Bice et al. 2016)
	Provide movement and dispersal opportunities for	1	Seed-bank germination and hatching of dormant resting stages of macro and microinvertebrates

Ecological asset	Ecological Objective	Role of WPM alone being able to achieve objective. (0=unachievable or not-applicable, 1=partially , 2=completely)	Rationale for rating and supporting evidence
	water-dependent biota to complete major life stages		
	Support instream and floodplain productivity	1	WPM can increase primary production in habitats near river channel (Souter et al. 2012), but weak evidence that secondary production also benefits (Bice et al. 2016)
	Support nutrient and carbon exchange along channels, and between channels and floodplains/wetlands	1	Wetting and drying of river margins and wetlands near river may promote transition between amphibious and terrestrial vegetation types (Gehrig 2018; Gehrig et al. 2015, 2016), increase carbon turnover and exchange between aquatic and terrestrial habitats (Baldwin et al. 2013)
	Support groundwater conditions to sustain groundwater-dependent biota	1	WPM can influence groundwater recharge and affect salinity of groundwater.