

Riverine Recovery Project Wetlands Phase 2:

A summary of new information for managing South Australian
River Murray wetlands.

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Cover image: SARDI, (2017) [Installation of trail cameras at North Purnong]

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1. Executive Summary

Many years of water over-allocation and river regulation led to a decline in the health of the River Murray, exacerbated by an extended period of drought across the Murray-Darling Basin. This has had a significant impact on riverine habitats, with dying native vegetation, such as the iconic river red gums, and decreasing numbers of native fish, such as the Murray cod.

The Riverine Recovery Project (RRP) was a \$98 million joint Australian and South Australian Government initiative between the South Australian/Victorian border to Wellington, to improve the health of the River Murray and the resilience of its wetlands, floodplains and backwaters in a future of lower water availability. The project was delivered between 2011 to June 2019 and aimed to boost the ecological health of wetlands through the re-introduction of more natural wetting and drying cycles, while improving environmental water use by reducing evaporative losses. It set the foundations by installing infrastructure, undertaking ecological investigations, and engaging with landholders and regional communities at a selection of managed and un-managed wetlands within the South Australian portion of the River Murray.

This report is based on the works of the RRP Phase 2 Wetlands Project, conducted over a three year period from 2016-2019. This report summarises new and current information from the wetland monitoring program, and six ecological investigations. This work provides support for future management decisions, and recommendations for further works. Wetland monitoring and investigation projects demonstrated that the RRP Wetland Management Plans (WMPs) were generally adequate, and identified where required improvements to planned wetland management regimes were recommended.

2. Introduction and background to RRP Phase 2 Wetlands

River regulation and water extraction have dramatically altered the ecology of the Murray-Darling Basin (MDB), transforming the South Australian River Murray from a dynamic river into a series of stable pools. Most of the wetlands that fringe the river are now either too wet or too dry. These changes to river flow, together with a reduction in overbank flooding have reduced the river's resilience and increased its vulnerability to a range of stressors, evident in the death and dieback of riparian and floodplain forests during the Millennium drought (2006-10).

RRP is a \$98 million project that aimed to recover up to 15 GL of environmental water, maintain and improve water dependent ecosystem health, optimise conditions for ecological community recovery, increase community knowledge and improve the scientific knowledge and

understanding for the management of floodplains, wetlands and environmental river management.

Within the wetlands component of RRP, a phased approach was used. Wetlands Phase 1 included immediate works at small 'shovel ready' sites as well as revisions and updates to WMPs at existing managed wetlands (1A). Phase 1 also included larger construction works at new wetland sites where adequate data existed to inform management planning. The work included design, survey, community engagement and construction (1B). Finally, Wetlands Phase 1 also included a process to identify a suite of additional sites (1C) for investment to complement the 1A and 1B sites.

In total, 11 additional sites plus three reserve sites were identified for investment via the Phase 2 Wetlands Project Element. Ten of the total 14 sites were progressed to completion through the Phase 2 Wetlands Project Element. These sites covered 7301 ha of floodplain spanning 440 km of the river. Importantly these floodplains included 374 ha of wetlands that were ready for hydrological management, including more than 50 km of wetland fringe where the condition of the riparian zone was directly improved by reinstating a variable hydrograph. The works also facilitated pumping at 23 ha of wetlands and improved flow and fish passage through 47 km of anabranches and creeks.

All of the works which were undertaken at the ten Phase 2 Wetlands sites were designed to improve connectivity between the wetland, anabranches and main channel as well as increase the management potential to wet and dry the wetlands through improved regulation capacity. The ten wetland sites progressed were: Mutho-Weila, Woolenook Bend, Goat Island/Paringa Paddock, Pyap Horseshoe, Sugar Shack, Silver Lea, Big Bend, North Curnamont, Teal Flat and Teal Flat Hut. RRP Phase 2 Wetlands was delivered over a four year period from 2015 to 2019.

RRP Phase 2 Wetlands program logic

The monitoring and investigations component was a significant inclusion in RRP's Phase 2 Wetlands Project Element. The program logic for RRP Phase 2 Wetlands (Figure 1) was outlined in the South Australian Priority Project SA-05: Riverine Recovery Project Schedule. Five Priority Project Activities (A-E) were identified as the long-term outcomes (note that A, D, and E are not displayed here). The RRP Phase 2 Wetlands Monitoring and Investigations project contributed most significantly to two of the South Australian Priority Project long-term outcomes (activities B and C in Figure 1).

The program logic identifies the linkages between the activities undertaken within Phase 2 Wetlands in order to achieve short-term results, and the medium to long-term outcomes.

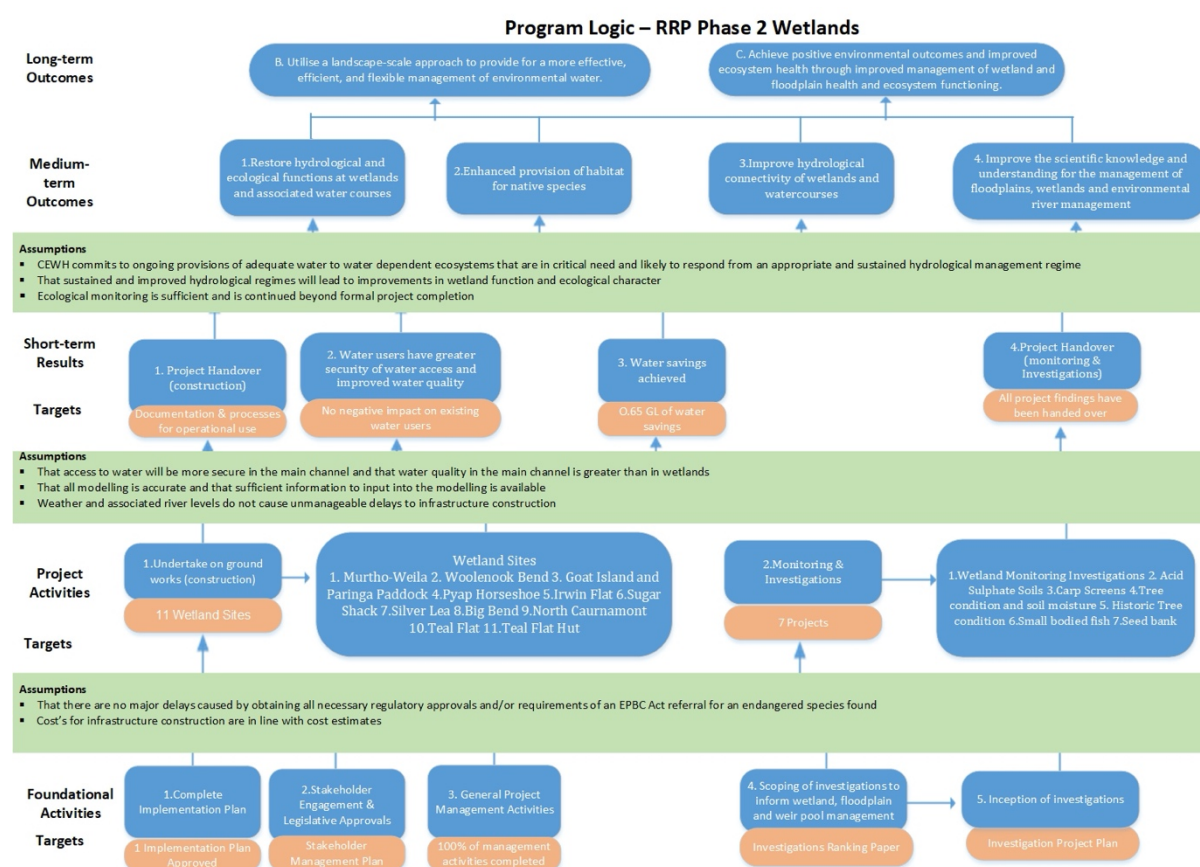


Figure 1. RRP Program Logic

RRP Phase 2 Wetlands program medium term outcomes

RRP Phase 2 Wetlands Monitoring and Investigations project activities contributed to achieving key medium term outcomes for RRP (see Figure 1) intended to:

- Restore hydrological and ecological functions at targeted wetlands and associated watercourses (e.g. through re-introduced wetting and drying regimes).
- Provide enhanced habitat for native species.
- Improve hydrological connectivity of targeted wetlands and watercourses with the River Murray and surrounding habitats, especially where existing infrastructure did not meet current best practice.
- Improve the scientific knowledge and understanding for the management of floodplains, wetlands and environmental river management.

RRP Phase 2 Monitoring and Investigations foundational and project activities contributing to short term results

The RRP Monitoring and Investigations component included seven distinct monitoring and investigation project activities designed to inform and improve management of all RRP wetland sites. Foundational activities supporting the monitoring and investigation project activities included consultation with a range of stakeholders, investigations scoping, procurement of services, project delivery and management.

Foundational and project activities contributed to the short-term result of project handover to the new business owners. Through the development of reports, workshops, and guidebooks, these activities enabled the identification of knowledge gaps, the generation of new knowledge and insight, and project ownership at the close of RRP. Through involvement with the monitoring and investigation activities, the knowledge of field officers, private wetland landholders, and community members has improved.

The outputs from the RRP Wetlands Phase 2 Monitoring and Investigations have supported the continued work of River Murray wetland management.

Wetland management and landholder engagement post RRP

RRP undertook extensive landholder engagement and built relationships with a significant number of landholders along the length of SA River Murray from the SA/Vic border to Wellington, SA. At the completion of RRP, the responsibility for landholder engagement, monitoring, and management at constructed wetlands will continue to reside within Department for Environment and Water (DEW). Figure 2 shows two teams involved in both monitoring, evaluation, and infrastructure management. Noting that as of July 1 2019, River Murray Operations branch was renamed Water

Infrastructure and Operations Branch. The investigations detailed in this report have been formally handed over to relevant business owners through the development of project closure reports (refer key short-term result of 'project handover', Figure 1).

The information contained in the monitoring and investigation reports contributes to addressing the identified knowledge gaps in wetland management into the 'post-construction landholder engagement period' (refer Figure 2). This knowledge transfer and incorporation is a fundamental component of the adaptive management cycle and further supports DEW's culture of continuous improvement.

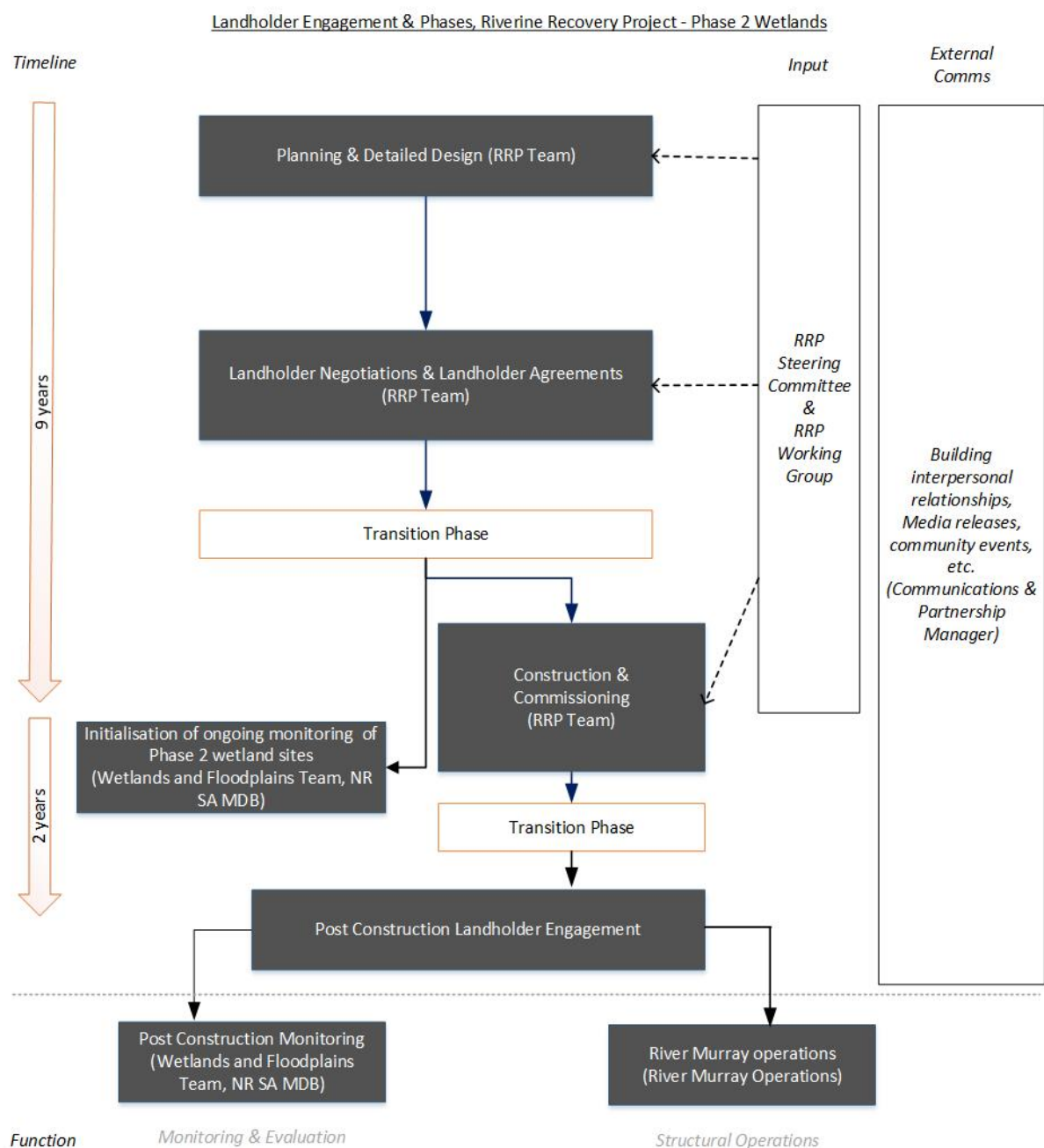


Figure 2. Landholder Engagement & Phases, Riverine Recovery Project - Phase 2 Wetlands, figure based on organisational structure in 2015.

3. RRP Phase 2 Wetlands Monitoring and Investigations

Investigations development and prioritisation

The experience and knowledge gained through the delivery of RRP Phase 1 enabled the RRP Ecology team to collate a list of approximately 25 potential investigations to improve understanding of wetland and weir pool management. Following the Phase 2 business case and due diligence process, a budget of \$1.37 million was allocated for investigations to better understand the use of RRP funded wetlands infrastructure to maximise environmental benefit. A DEW internal focus group consisting of Major Projects (RRP Ecology team), River Murray Operations (RMO), the Science Group and NR SAMDB reviewed the existing list, explored any up to date information on investigations needs and agreed on priority investigations. The process of ranking these investigations gave consideration to the following criteria:

- Extent of satisfaction of RRP objectives
- Likelihood of success
- Required delivery timeframe
- Current status of research into the field of investigation.

As a result of the prioritisation ranking process and combining several related investigations, the list was refined to six priority investigations colloquially known as:

- Carp Screen Efficiency
- Wetland Acid Sulfate Soils | Wetland Productivity | Wetland & Floodplain Soil Microbiology
- Wetland Seedbank Assessment
- Tree Condition Analysis
- Threatened Small Bodied Fish Habitat Optimisation
- Overstorey Vegetation vs. Soil Moisture | Geophysical Methods for Ground Watering.

The six investigation projects, as well as Wetland Monitoring, were progressed to inception and implementation from 2016 to 2019.

Multi-scalar approach of RRP Phase 2 Wetlands

RRP recognises the various planning and spatial scales at which monitoring and management occurs in the SA River Murray and the importance of choosing the right scale for effective management. In response to this, and in line with RRP goals, the six investigations and wetland monitoring undertaken in Phase 2 Wetlands were primarily focused at the scale of the wetland management unit. Furthermore, these investigations reflected the current scale of wetland management and monitoring activities undertaken by the SA MDB Regional Floodplain Wetland Team (FAWT). Several investigations

were applicable at various scales within the River Murray. Figure 3 shows the conceptual scale of the investigation, against the geographical (spatial) and organisational (planning) scales. There is a strong overlap of investigations at the wetland scale but it is clear from Figure 3 that the knowledge and recommendations (arising from the investigations) have implications for management from the 'habitat' and 'wetland' scale through to the 'reach' and 'floodplain' scale.

Multi-scalar approach of Riverine Recovery Project Phase 2 Wetlands – Monitoring and Investigations

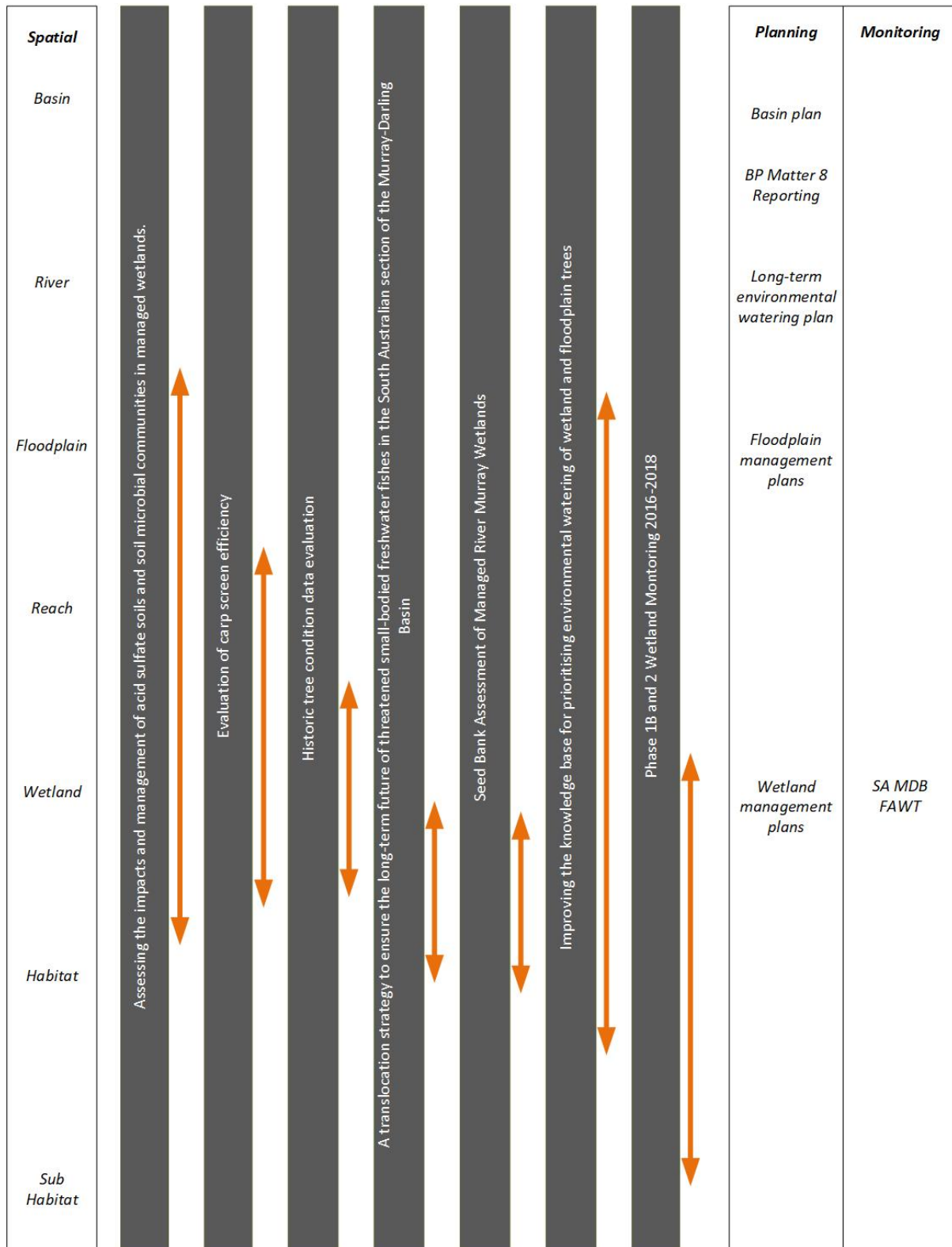


Figure 3. Multi-scalar approach of wetland investigations, monitoring and planning.

Monitoring and management program structure

The *RRP Monitoring and Program – Technical Design 2nd Edition* provides for a monitoring and evaluation framework. This framework uses a series of logic steps to identify current conditions, conceptual understandings, desired conditions, targets, management actions, data collection, and analysis methods to inform management regime changes. The framework supports the adaptive management approach as identified in the WMPs, and identifies review (evaluation) timeframes. The information delivered in this report could be incorporated within the review cycle in order to address and contribute to the evaluation questions as depicted in Figure 4 (see the blue dotted box top left).

Monitoring and adaptive management reviews can be conducted to assess progress and refine conceptual understanding, targets and monitoring effort. Where resources permit, the information provided in this report has been incorporated into departmentally stored and managed WMPs as an addendum. Information not incorporated into WMPs through an addendum could be incorporated in the next recommended five yearly review period.

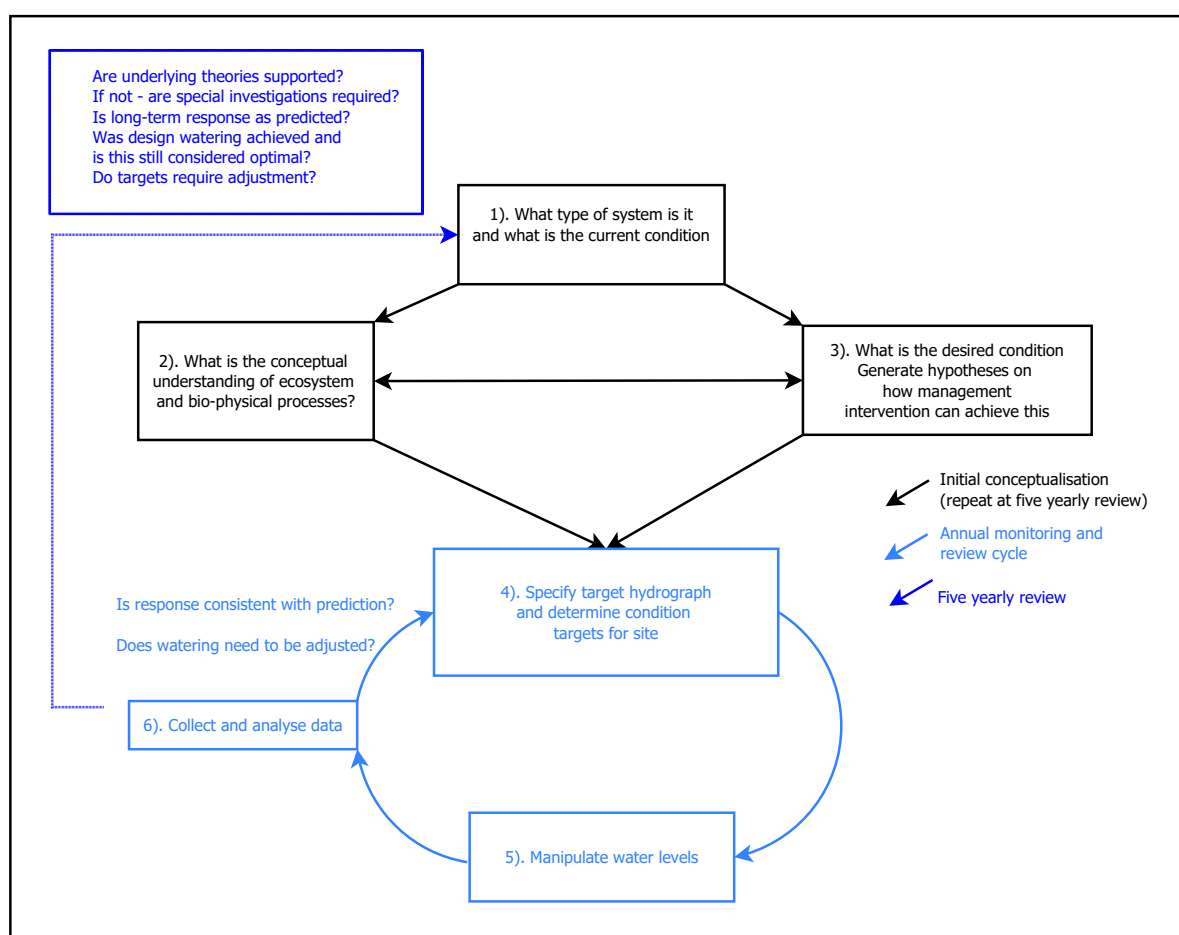


Figure 4. Monitoring and management program structure.

Investigation limitations

A summary of limitations identified within individual RRP Monitoring and Investigation activities are compiled below. These have been included due to the potential impact on ongoing agency business. These limitations are not unique to RRP, and could be considered as potential limitations for any scientific investigations conducted by the agency or private institutions within the SA River Murray.

- **Unable to evaluate complete hydrographs at most wetlands**

- Impact - unable to attribute ecological outcomes to management actions**

The planned five-year hydrological cycles, as contained within most WMPs, was a clear limitation to some of the investigations. The RRP delivery timeframe enabled project delivery from six months to almost two years, which represents only one part of a full hydrological cycle or almost half a hydrological cycle at most. This limitation could be addressed by extending key investigations into the impacts of wetting and drying to cover one, two, or more hydrological cycles (i.e. at least five years). The monitoring work supported the capture of one and a half years of operation (partial hydrological cycle) at Phase 1B sites.

- **Data not fit-for-purpose for some investigations**

- Impact – unable to answer some evaluation questions**

Historic data used in some of the investigations were found to be inconsistent, absent from corporate databases, or collected in a way that did not enable certain evaluation questions to be addressed. The reasons for diminished data utility can be attributed to a variety of causes including historical collection methods, changes in collections methods, improvements in technology, improvement in understanding (e.g. improved confidence in conceptual models) or data may have been collected to support management decisions with no data corresponding on a spatial and temporal co-occurrence. In some instances this has resulted in an inability to compile analyses to support all proposed evaluation questions. This limited the ability of the service providers and managers to answer select evaluation questions related to management effectiveness.

- **Infrastructure not operated as planned**

- Impact – unable to attribute ecological outcomes to management actions**

For reasons mostly related to construction timeframes, operation of wetland infrastructure in accord with WMPs had not yet occurred which limits the ability to infer response.

4. Summary of RRP Phase 2 Investigations

This section summarises the investigations and monitoring activities by listing the rationale and approach, key outcomes, management implications, recommendations and a statement on managing environmental knowledge. Information in the following section is drawn from both the investigations and monitoring publications, and from discussions held during DEW internal contract and project close out processes. External publications are available on the following websites:

Enviro Data SA, WaterConnect, SARDI, Aquasave–Nature Glenelg Trust.

1. Riverine Recovery Wetlands Monitoring 2016-2018 (Internal Report)

Full report: Donaldson, J., Monk, C., Hardy, S., Cheshire, D., Mason, K. and Turner, R. 2018. Riverine Recovery Project Monitoring Data Report 2016-17 and 2017-18. Department for Environment and Water, Berri, South Australia.

▪ Rationale and approach

This monitoring activity commenced in February 2017 and data collection were completed by May 2018, with a total of 353 monitoring activities conducted. Three rounds of ecological monitoring were undertaken over the 18 month period at five Phase 1B Wetland sites and 12 Phase 2 Wetlands (Table 1).

	Phase 1B	Phase 2
Wetland	Lake Merreti	Murtho-Weila
	Lake Woolpolool	Woolenook Bend
	Beldora Lagoon	Paringa Paddock
	Murbko South	Pyap Horseshoe
	North Purnong	Sugar Shack wetland 2
		Sugar Shack wetland 5
		Sugar Shack wetland 13
		Silver Lea
		Big Bend
		North Caurnamont
		Teal Flat
		Teal Flat Hut

Table 1. Phase 1B and 2 Wetlands

The NR SAMDB Floodplain and Wetlands Team (FAWT) undertook all ecological monitoring and remain the business owner at RRP closure. Monitoring at the five Phase 1B Wetlands aimed to collect post-construction data to support water management decision-making based on the WMP objectives and hydrographs. The data are intended to be used in the future to help assess if these objectives are being met and to help support the evaluation of ecological outcomes of management.

Monitoring at Phase 2 Wetland sites aimed to collect one annual round of 'pre-regulator construction' ecological data. This contributes to the baseline from which ecological responses to the post-construction hydrological regime can be evaluated.

The work also aimed to establish working relationships with relevant landholders and water managers. Data summaries were regularly distributed to engage and inform landholders (where appropriate) and other water managers. The general suite of parameters sampled at the wetlands included water levels, surface water quality, groundwater, vegetation (quantitative and photo-point), tree condition, waterbirds, fish and frogs (species composition and abundance). Turtle nesting was also monitored at Murbko South.

In parallel to this monitoring work, a Microsoft Access database was developed, which houses the ecological, surface water and groundwater data collected by the FAWT. An important function that has been built into the database is the capability to prepare the data into the correct format for direct upload to the appropriate corporate databases: Biological Database of South Australia (BDBSA, ecological data), Hydstra (surface water data) and SA Geodata (groundwater data).

▪ **Key outcomes from wetland monitoring**

- Secured an increase in operational and ecological response data relating to one or more cycles of management for the 1B Wetlands to inform ongoing management.
- Updated pre-construction ecological baseline data set for Phase 2 wetlands providing a point of comparison for evaluation of future operational and ecological response monitoring.
- Developed relationships with landholders at wetlands where the FAWT are likely to have ongoing responsibility beyond the life of RRP.
- Improved capacity for FAWT to deliver wetland monitoring.

▪ **Management implications**

Donaldson et al. (2018) details management implications on an individual wetland basis. In general, these include:

- Continue planned water level manipulation (wetting and drying) to improve water quality within wetlands, promote aquatic vegetation recruitment, reduce turbidity and consolidate wetland bed soils.

- Continue the use of carp screens for large carp after drying out the wetland temporarily to remove the existing carp.
- Monitor both tree health and groundwater gradients and salinities during drying phases to ensure tree health doesn't decline further or that the wetland bed doesn't salinize.
- Undertake hydrological variation (e.g. rewetting phases during spring/summer) to improve habitat, and encourage frog persistence and breeding over time within a complex.
- Identify and protect turtle nests from fox predation.
- Capitalise on the potential to expose extensive fringing habitats and mudflats for the shorebird-resident and shorebird-migrant functional groups.
- Monitor exotic plant species to ensure management does not increase their extent or diversity.
- Monitor rare species (e.g. swamp daisy - *Brachyscome basaltica*) to ensure its extent does not decrease over time in response to management.
- Monitor alien fish species (e.g. oriental weatherloach – *Misgurnus anguillicaudatus*) to ensure no increase over time.

▪ Recommendations for further work

- Continue to undertake monitoring at existing Phase 1B wetlands and at Phase 2 Wetland sites post commissioning of the new regulating structures.
- Develop a system of management that operates at the wetland unit but can be scaled up to inform and improve wetland management decisions across the whole Murray Darling Basin. This should be based on risks and opportunities as described in the latest version of the ISO31001 standard.

▪ Managing environmental knowledge

A Managing Environmental Knowledge (MEK) chart has been developed for this activity. The chart indicates the flow of data from the point of collection in the field, to the end authorised product. Monitoring data collected have been uploaded into the Access database. The Access database has prepared and uploaded data into relevant corporate databases.

2. Evaluation of carp screen efficiency

Full report: Thwaites, L. and Schmarr, D. (2019). Evaluating the effectiveness of carp exclusion screens at wetland inlets in the River Murray, South Australia. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2019/000113-1. SARDI Research Report Series No. 1017. 80pp.

▪ Rationale and approach

Managing the effects of carp is an important part of maximising the outcomes of wetland management. Following research and development by the University of Adelaide and the South Australian Research and Development Institute (SARDI), the RRP utilised a novel and improved carp exclusion screen (CES) design in new wetland management infrastructure. The CES incorporate horizontal 'jail' bars with a 31 mm aperture. They are designed to restrict the passage of carp ≥ 250 mm total length (TL), while allowing the passage of small-bodied native fishes, juveniles of large-bodied native fishes (e.g. golden perch) and $>95\%$ of bony herring (the most abundant large-bodied native fish in wetlands). The CES also incorporate a one-way finger style push gate within the lower section. The gate prevents the entry of carp ≥ 250 mm TL while allowing carp that entered the wetland as juveniles (<250 mm TL) to push out of the wetland and not return. These new CES designs allow more flexible wetland management practices to occur, reducing the need for full wetland drying, but still managing carp impacts.

The objectives of this investigation was to evaluate the effectiveness of the new and existing CES in the field and inform the ongoing management of CESs at various RRP managed wetlands. To achieve these objectives, the differences in the fish assemblage and relative abundance and size structure of carp between un-screened wetlands and wetlands fitted with new carp exclusion screens (NCES) and old carp exclusion screens (OCES) were assessed. This study was conducted over a 12 month period approximately one year following extensive overbank flooding where carp screens had subsequently been closed. The annual cycle of carp activity at screened wetland inlets under regulated conditions (i.e. non-flood, non-drought) was also monitored and recorded using remote trail cameras. Finally, the utility of one-way gates within NCES as a passive carp control measure was evaluated.

▪ Key outcomes and management implications

This study found that carp screens had no effect on fish assemblage abundances, but had a significant effect on the presence or absence of species within wetlands with golden perch, smelt and goldfish less prevalent in wetlands with NCES. NCES had a significantly higher abundance of carp in comparison to unscreened wetlands in sampling round one. No differences were detected for the remaining sampling rounds. The one-way gates appear to be working as intended and may even be allowing non-target native species to exit wetlands. However, it is difficult to estimate the precise numbers that exited via the gates as some counts are likely a result of carp and other fauna nudging a finger without exiting. Therefore, further investigation is required to assess which species and the total numbers of each species that are exiting. Long-term monitoring of wetland carp abundance and size structure will also aid in understanding the overall effectiveness of one-way gates.

This study also demonstrated that off-channel movements can occur during periods that do not align with some CES management protocols, suggesting protocols may need to be tailored to individual wetlands. As this study occurred over a 12 month period one year following flood, and off-channel movement may change annually, it is recommended monitoring continue at wetlands fitted with remote cameras and be expanded to other wetlands fitted with CES. If annually predictable migration patterns are observed then appropriate screen manipulation protocols can be developed.

▪ **Recommendations for further work**

- Prior to establishing long-term CES management protocols or installing further CES it is strongly recommended further investigations and monitoring be undertaken. This is particularly important as the results of the current study and previous research suggest CES have minimal impact on wetland carp abundances. Additionally, current wetland managers should consider reviewing how screens are opened and closed on a seasonal basis until further investigations can provide more information.
- Monitor changes in wetland fish assemblages and carp abundance that occur as a result of management practices according to the wetland management plans with CES (i.e. wetting/drying, screen manipulations).
- Continue to evaluate seasonal carp movements at wetlands using trail cameras in order to better inform screen manipulation protocols.
- Undertake further investigations to calibrate the one-way gate finger movement sensor using technology such as dual frequency identification sonar (DIDSON) in conjunction with netting or trapping. Once sensor calibration has been achieved, expand the number of wetlands inlets and sensors that are monitored (utilising current camera and one-way gate sensors). Evaluate the effect of horizontal 'venetian' and vertical 'jail' bar designs on fish passage.

▪ **Managing environmental knowledge**

A MEK chart has been developed for this investigation. The chart indicates the flow of data from the point of collection in the field, to the end authorised product. The data collected by the SARDI team as part of this investigation were uploaded into BDBSA.

3. Assessing the impacts and management of acid sulfate soils and soil microbial communities in managed wetlands

▪ **Rationale and approach**

Almost all pool-connected SA River Murray wetlands have the potential to form Acid Sulfate Soil (ASS) materials. Prior to the Millennium Drought, potential ASS (PASS) materials built up in the wetland, lake and river channel soils due to the presence of sufficient iron, sulfate, carbon and permanently

reducing conditions (due to almost permanent inundation since river regulation).

During the Millennium Drought, declining water levels led to the exposure and oxidation of accumulated PASS and formation of severely acidified actual ASS (AASS) throughout South Australia. Upon the break of the Millennium Drought, the AASS were re-flooded. The current state of ASS material (i.e. either AASS or PASS or a combination of both) in the wetlands is relatively unknown. Additionally, the pre-European 'baseline' vegetation state appears to have been lost from many lower River Murray wetlands.

Widespread and fundamental transitions in sediment and vegetation state driven by regulation may have already occurred resulting in wetlands that are fundamentally different to the 'natural' state and must now be managed as novel ecosystems. Significant transition from that 'natural' state means that interventions designed to colonise wetland sediments with non-woody amphibious and submerged plants (wetting and drying) will be creating novel ecosystems and will not be restoring damaged ecosystems. The pre-European 'baseline' sediment state has also been lost and again interventions to manage or reduce ASS hazards will be creating novel soil ecosystems that may behave differently to simply restoring a wetland that has not undergone an oxidation-reduction transition to release sulfuric acid. It is likely that the amount of ASS will remain the same over time (apart from where sediment erosion occurs). However, the chemical state or phase of ASS will change depending on the water regime, and wetting and drying cycles.

The objectives of this investigation were to:

- Primarily, assess the adequacy of RRP's WMP's consideration of ASS risk, impacts, mitigation and management.
- Improve RRP's understanding of the role that soils and soil microbial communities play in the condition of river-floodplain ecosystems and knowledge of ASS mitigation measures in RRP Wetlands.
- Further uncover links between soil microbial communities, bio-geochemical processes and acid sulfate soils in response to wetting/drying regimes.
- Address concerns raised by the Commonwealth Department of Agriculture and Water Resources (DAWR) during the Due Diligence assessment of RRP relating to the process of ASS 'burn-off', mitigation measures post construction, and impacts to the channel.

This investigation had multiple parts entailing five separate reports that were linked to separate milestones (see Figure 5). As part of the investigation, RRP WMPs were updated with addenda containing acid sulfate soils hazard maps. The different reports and outputs are briefly summarised below:

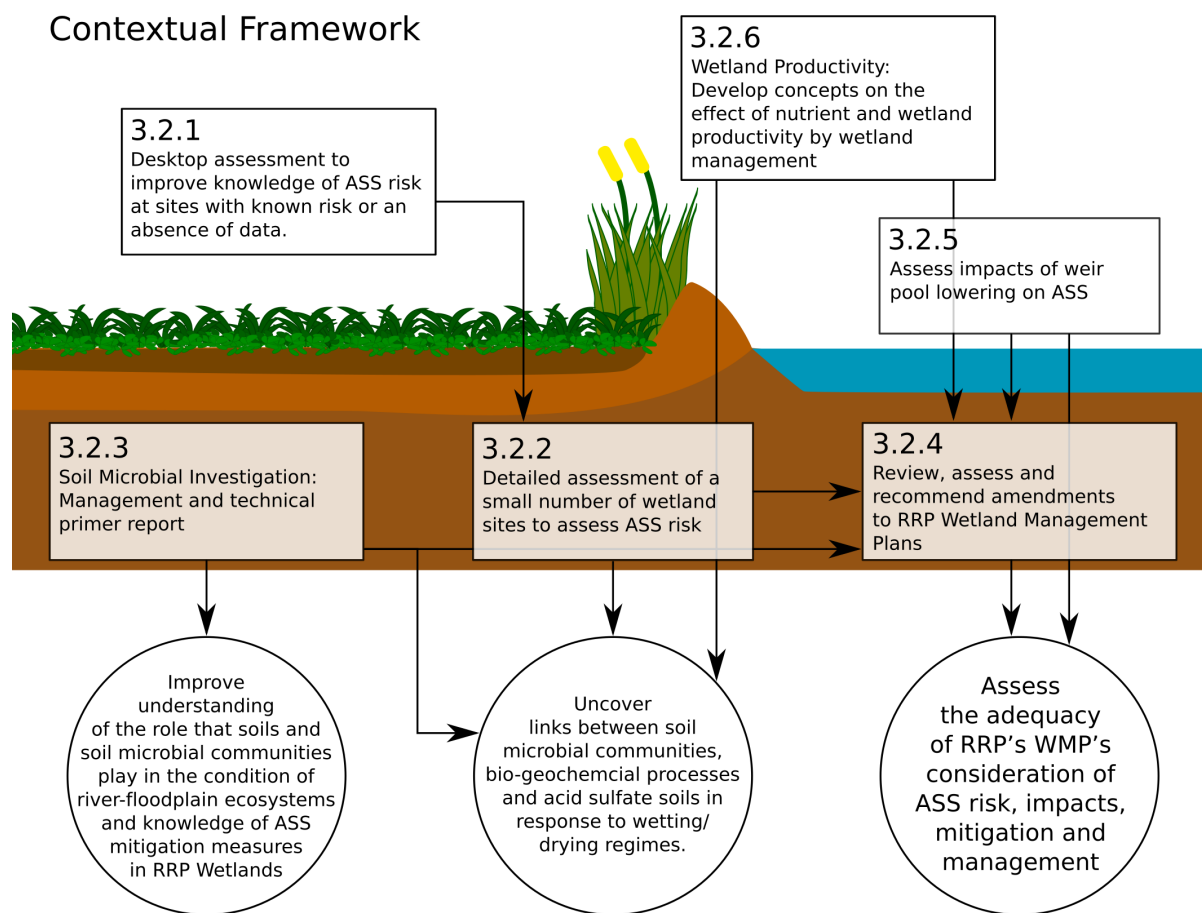


Figure 5. Acid sulfate soil investigation milestone outline and objectives.

▪ RRP ASS report 1: Desktop and detailed field assessment

Desktop review assessments (3.2.1 in Figure 5) were completed for seventeen South Australian wetlands. This was based on several previously published and unpublished reports covering the assessment and extent of ASS materials during the Millennium Drought between 2007 and 2010 to identify whether or not ASS materials were likely to be present and in what general location.

Wetlands were ranked according to the potential for disturbance and the potential for ASS to cause environmental harm via: (i) Acidification (ii) De-oxygenation, and/or (iii) Metal mobilisation. Where the review identified a risk or insufficient field-based information was available to determine the level of risk, wetlands were recommended for further assessment in Phase 2 of this investigation.

Nine wetlands were assessed in detail (3.2.2 in Figure 5). Fieldwork was carried out and soil samples analysed using a combination of standard methods. A database of field, laboratory, and photographic data was compiled and interpreted to determine, and update the hazard rankings for each wetland. This study also constructed maps for each of the 17 wetlands showing the ASS conditions at the various times of sampling, which includes conditions during both the Millennium Drought (between 2007 – 2010) and in 2018.

This investigation established that soil acidification, deoxygenation and metal mobilisation hazard ratings in the 17 wetlands were variable and ranged from high to low (see report for full details). The Gurra Gurra wetland was the only wetland with high soil acidification, deoxygenation and metal mobilisation hazard ratings. Hypersulfidic samples were identified from the following wetlands; Woolenook Bend (1 sample), Pyap Horseshoe (1 sample) Murtho Park (4 samples) and Gurra Gurra (10 samples). The lowest soil pH identified following 12 weeks of incubation was a pHinc 2.28, which was measured in a hypersulfidic sand sample from Gurra Gurra. Moderately acidic samples occurred at all wetlands with the exception of Lake Woolpolool and Lake Merreti. A total of 213 samples (30%) recorded a moderately acidic soil pH following incubation for 16 weeks, ranging pHinc 4<5.5, where trace elements such as aluminium can be mobilised to concentrations of environmental concern.

The findings and conclusions of this report have been used to review, assess and recommend amendments to the RRP WMP's, and to develop "A Guide to Managing Acid Sulfate Soil Risks in South Australian Wetlands" (see report below).

For more details, please see the full report:

Thomas B.P., Fitzpatrick R.W. and Mosley L.M. (2019). Technical Report – Acid Sulfate Soil Assessment for Riverine Recovery Program wetlands. Acid Sulfate Soils Centre, University of Adelaide. Acid Sulfate Soils Centre Report: ASSC_156.

▪ **RRP ASS Report 2: A guide to managing acid sulfate soils**

The second output from this investigation was a guide to managing acid sulfate soil risks. The aim of this guideline was to provide the basic rationale and describe a set of practical methods to assist environmental managers to identify and manage ASS risks in River Murray wetlands. The management guidance is particularly focused on wetlands in the RRP and the South Australian Riverland Floodplains Integrated Infrastructure Program (SARFIIP).

The accumulated knowledge incorporated into this guideline is drawn from over a decade of experience assessing and managing acid sulfate soil risk in key wetlands in the Murray-Darling Basin and elsewhere. There are various approaches, phases, stages and steps for ensuring acid sulfate soil risks are identified and managed but there is no "authoritative one-size-fits-all" approach.

This guideline provides specific information relating to acid sulfate soil management in RRP wetlands that have been recently re-assessed and key learnings, principles and options that can be used by environmental managers to identify and address existing or emerging acid sulfate soil hazards. This information is critical for managed wetlands in this region. However, each wetland needs to be considered and managed individually according to the characteristics of the particular site (e.g. known hazards, previous wetting and drying cycles, infrastructure operation, water

availability, infrastructure operations and climate). Many of these factors are dynamic and hence continual observation, assessment and adaptive management is required as RRP and SARFIIP infrastructure move into the operational phase.

For more details, please see the full report:

Mosley L.M., Thomas B.P. and Fitzpatrick R.W. (2019). A Guide to Managing Acid Sulfate Soil Risks in South Australian River Murray Wetlands. Acid Sulfate Soils Centre, University of Adelaide. Acid Sulfate Soils Centre Report: ASSC_155

▪ **RRP ASS Report 3: Wetland Productivity**

The overarching purpose of this report was to inform future decision-making on wetting and drying cycles to improve the native primary productivity of wetlands within the River Murray (3.2.6 in Figure 5). The aims were to: (i) assess how wetland productivity, nutrient cycling, and acid sulfate soil dynamics are likely influenced by managed wetting and drying cycles; (ii) assess how different frequencies of wetting and drying may influence each of these outcomes at different spatio-temporal scales; and (iii) identify any constraints and risks associated with managed wetting and drying for productivity in riverine wetlands.

A combination of stakeholder consultations (workshop and online evaluation), policy insights (co-design of project outcomes with RRP) and a systematic review of international literature on emerging priorities and best practice was used. The local wetland managers and policy makers extensive experience in combination with international best practice was then synthesised to develop management principles to enable improved productivity of River Murray wetlands.

Manuscript in preparation:

Packer, JG and Mosley, L. (2019) Review and synthesis of principles to enhance native wetland productivity in Riverine Recovery Project Wetlands, Technical Report prepared by Environment Institute, The University of Adelaide, on behalf of the Riverine Recovery Project, Department for Environment and Water.

▪ **RRP ASS Report 4: Soil microbial investigation - Assessing microbial functioning**

This specific report is a 'primer' document about the importance of soil microbial functions, and their interactions, to water management for ecological outcomes (3.2.3 in Figure 5). The information in this report is presented in two parts – Part 1 (management) and Part 2 (technical) as well as a second report (see report below). This report is an introduction to the importance of soil microbial functions for wetland managers. It is based on a review of literature, and synthesises knowledge and knowledge gaps. It also contains recommendations for priorities for managing significant ASS risks and future research.

For more details, please see the full report:

Stirling E, Packer J.G., Mosley L.M., and Cavagnaro T.R. (2018) Soil Microbial Investigation- Assessing microbial functioning in soils with different inundation contexts. Report prepared by the University of Adelaide, on behalf of the Riverine Recovery Project, Department for Environment and Water.

▪ **RRP ASS Report 5: Soil microbial investigation - Field report on microbial communities**

The goal of this report was to conduct a pilot assessment of soil microbial communities in a limited number of soil samples as part of the 'primer' document (3.2.3 in Figure 5). The intention was to provide information that will inform potential future work on a larger scale. Two key goals of the pilot assessment were to ascertain whether or not: (i) DNA could be successfully extracted from ASS within River Murray wetlands, and (ii) Next Generation DNA sequencing could provide a preliminary assessment on the microbial communities present within different wetlands containing a variety of ASS materials. Note: Next Generation DNA sequencing is a catch-all term for a number of modern sequencing techniques.

The study successfully examined microbial (bacterial and archaeal) species within all soil samples and generated estimates of species diversity. Factors known to drive microbial diversity within soil samples, such as landform, depth or pH, were identified and confirmed that the approach selected for this investigation was sensible and appropriate for future studies.

Differences in microbial diversity associated with ASS, defined by an alteration of the species that are present and an overall decrease in species diversity, were also observed. There was a significant difference in ASS soils compared to non-ASS soils, even when non-ASS soils were slightly acidic. Differences in microbial communities (alpha- and beta-diversity) unique to ASS soils were tightly associated with soil pH and electric conductivity, as well as iron oxide mottles (indicative of dynamic redox conditions), not associated/weakly associated the presence of nitrogen, carbon, monosulfide, etc.

Four unique taxa were identified in ASS soils. Known reference genome sequences for these species do not exist, indicating little is known about these microbial species. Importantly, this preliminary study demonstrates the potential to use Next Generation DNA sequencing to better understand ASS-affected soils, and the impacts of management factors on them. Additional microbial DNA analysis on a wider range of samples is required to confirm these pilot study findings. The report further suggests that a more detailed analysis using such approaches is likely to provide novel and useful insights (e.g. role of salinity in wetlands, wetting and drying, acid sulfate soil status) that cannot be gained using conventional methods of soil analysis and/or assessment.

For more details, please see the full report:

Weyrich L.S., Thomas B, Stirling E, Mosley L.M., and Cavagnaro T.R. (2018) Acid Sulfate Soils- Field report on microbial communities. Report prepared by the University of Adelaide, on behalf of the Riverine Recovery Project, Department for Environment and Water.

- **RRP ASS Report 6: Review, assess and recommend updates to RRP Wetland Management Plans**

The final output from this investigation was to update the WMP's with addendums containing an ASS management section (3.2.4 in Figure 5). The seventeen WMPs addendums include ASS Hazard Maps and drawdown maps. See individual WMPs below for details:

- Silver Lea
- Woolenook Bend
- Pyap Horseshoe
- Lake Woolpolool
- Gurra Gurra
- Caurnamont wetland
- North Caurnamont
- Paringa Paddock
- Teal Flat
- Sugar Shack
- Murtho-Weila
- Lake Meretti
- Spectacle Lakes
- Big Bend
- Murbko South
- North Purnong
- Teal Flat Hut

■ Key outcomes

This investigation was able to:

- Improve our understanding of the potential risk posed by ASS in selected RRP Wetlands.
- Identify that weir pool lowering will need to consider ASS impacts as part of its operational planning.
- Provide wetland managers with a handbook and acid sulfate soil hazard maps to manage wetlands while minimising risks associated with ASS.
- Synthesise the extensive experience of wetland productivity from local wetland managers, policy makers and international best practice into a document with the intention to develop a management principle for improving productivity of River Murray wetlands, while avoiding undesirable states.
- Improve our understanding of the importance and interaction of soil microbial function to water management for ecological purposes and give recommendations for management priorities and future investigation.
- Further explore the links between soil microbial communities, bio-geochemical processes and acid sulfate soils in response to wetting/drying regimes.
- Ascertain the potential to use Next Generation DNA sequencing to better understand ASS affected soils. Further suggesting that more analyses using similar approaches is likely to provide novel and useful insights (e.g. role of salinity in wetlands, wetting and drying, acid sulfate soil status) that cannot be gained using conventional methods of soil analysis/assessment.
- Produce a significant amount of 'in-kind' resources (e.g. a significant quantity of soil samples contained in freezers) which is deemed valuable for future investigations.

■ **Management implications**

The results from this investigation have substantially increased our knowledge and understanding of acid sulfate soils in River Murray wetlands and how to manage risks arising from these. Furthermore, the investigation collated and synthesised a multitude of unpublished reports and datasets. The “Desktop assessment” preserved information, especially from the Millennium Drought period, which was in danger of being lost. The reports and outputs developed during this investigation have great value for managers and stakeholders when managing for acid sulfate soils, particularly during periods of sustained low flows over the SA Border.

■ **Recommendations for further work**

- The effectiveness of using desktop reviews to develop preliminary ASS maps was confirmed. This methodology enables a rapid evaluation of data from existing data sets against Digital Elevation Models (DEMs) based on improved knowledge of ASS dynamics in SA River Murray wetlands. Simple but specific hazard maps could be generated for a number of other wetlands linked to the proposed hydrographs in their relevant WMP's. This site-specific approach is a more powerful management tool than a generic guidebook.
- The investigation has also uncovered strong links between wetland environmental variables (e.g. salinity, pH, and wetland type). Future microbial DNA analyses, coupled with biogeochemical process measurements, would be highly beneficial to understand these linkages further. This will be of increasing importance over coming decades given that river flows are expected to be lower and soil temperatures higher due to climate change, both of which are likely to present new and compounding ASS management challenges.
- One limitation identified was that the sampling period was not reflective of the full WMP's hydrological cycle, therefore the results tell only part of the story. To get full overview of the risk of ASS across the whole of the WMP's cycle a larger study across multiple years would have to be conducted.

■ **Managing environmental knowledge**

A MEK chart has been developed for this investigation. The chart indicates the flow of data from the point of collection in the field, to the end authorised products. The data collected by the University of Adelaide team as part of this investigation has been uploaded into Soil Sites SA, DEW GeoDatabase and FigShare.

4. Improving the knowledge base for prioritising environmental watering of wetland and floodplain trees

Full report: Wallace T, Gehrig SL, Doody TM (2019). Improving the knowledge base for prioritising environmental watering of wetland and floodplain trees.

■ Rationale and approach

Long-lived vegetation, particularly river red gum (*Eucalyptus camaldulensis*), and black box (*Eucalyptus largiflorens*), are a key attribute of wetland-floodplain complexes and the riparian zone adjacent to creek and river channels. Tree survival and growth is dependent on the availability of water in the soil profile which can be obtained from low salinity groundwater, rainfall, and soil recharge during periods of elevated flows and floods. Large areas of the floodplain in the lower Murray are underlain by groundwater that is too saline to support plant growth. A combination of river regulation and abstraction for consumptive use, and changes in rainfall-runoff patterns associated with drought and climate change have extended the duration of dry phases substantially beyond what has occurred historically. The combined effects of reduced rainfall, increases in the inter-flood period, decreases in flood duration and high groundwater salinity has caused long-term damage and tree death across large parts of the lower Murray floodplain and wetlands.

Access to soil moisture is the key determinant of floodplain tree condition. Measurement of soil moisture availability provides a direct assessment of likely tree response to a continued dry phase versus delivery of environmental water. However, soil moisture availability is not often directly measured but is typically inferred from visual assessments of crown condition. This makes it challenging for management agencies to make fully informed decisions on the priority of sites that may be competing for environmental water.

The focus of this investigation was on black box. The objective was to connect a suite of techniques ranging from low-cost, rapid visual assessment of tree crown condition, through labour intensive soil coring and laboratory analysis of soil samples, to technology intensive in-field measurement of tree physiology. The project addressed a number of key knowledge gaps in the links between tree visual condition, tree physiology, soil water availability and the decision-making process for prioritising sites for management action.

■ Key Outcomes

The results in this report can be used to define ecological targets and thresholds for management action based on soil condition. The approach of incorporating a scalable suite of techniques to support decisions on the priority of delivering water is not expected to replace existing assessment approaches, but to represent an appropriate combination of objective techniques that managers can draw upon to produce a scientifically defensible “multiple lines of evidence” approach for determining the prevailing and potential future condition of trees. Additionally, the study furthers our broader understanding of the impact of altered hydrological processes on floodplain vegetation and the management responses required to ensure tree water requirements are met.

▪ **Management implications and recommendations for further work**

The suite of techniques used in this investigation presents a multiple lines of evidence pathway to enable floodplain/wetland managers and environmental water holders to more confidently determine the priority to deliver environmental water. Utilisation of the full suite of approaches would not be cost effective at all sites, but would be most appropriate when there is a lack of site specific knowledge on condition trajectory or likely response to a localised management action. Increased confidence in ecological responses increases the ability of floodplain/wetland managers to optimise timing of environmental watering, and achieve the best possible ecological outcomes. This is expected to lead to (i) increased efficiency of environmental water use, and (ii) reduced risk profiles associated with site specific management actions. The approach used here could be extended to determined similar approaches to improved management of river red gum.

▪ **Managing environmental knowledge**

A MEK chart has been developed for this investigation. The chart indicates the flow of data from the point of collection in the field, to the end authorised product.

5. Securing the long-term future of threatened small-bodied wetland specialist fish across the SA Murray-Darling Basin

Full report: Whiterod, N. (2019). A translocation strategy to ensure the long-term future of threatened small-bodied freshwater fishes in the South Australian section of the Murray-Darling Basin. A report to Natural Resources, SA Murray-Darling Basin and the Riverine Recovery Project. Aquasave–Nature Glenelg Trust, Goolwa Beach.

▪ **Rationale and approach**

Small-bodied freshwater fishes are under threat across the Murray-Darling Basin. These species have experienced historical declines, which were compounded most recently by the prolonged and extreme Millennium Drought. The SA MDB region – representing a hotspot for small fishes – was profoundly impacted by the drought, with the significant deterioration and loss of aquatic habitat. Four threatened small-bodied freshwater fishes – Murray hardyhead (*Craterocephalus fluviatilis*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*) and Yarra pygmy perch (*Nannoperca obscura*) – were significantly impacted, with the latter two species believed at one stage to have become regionally extinct.

Local researchers and managers had the foresight to rescue small-bodied freshwater fishes from deteriorating habitats at this time to refuge habitats (e.g. dams, constructed wetlands). This has allowed breeding in captivity and translocations of fish back to their former habitats. It is unlikely that these

populations would have survived the Millennium Drought without these translocations given the severity of the impact on already threatened species and limited post-drought recovery.

During RRP Phase 1 the SA MDB NRM Board were funded to restore habitat for threatened small-bodied wetland specialists. This included the site of the only known remaining population of the southern purple-spotted gudgeon. The project successfully reinstated flow paths into and through the wetland that had become choked with growth of common reed when the wetland dried during the Millennium Drought. Water quality and plant diversity substantially improved as a result of the water management, which improved habitat condition and enabled the release of captive-bred fish back into the wetland. The success, learnings and importance of these past efforts is undoubted as both the Yarra pygmy perch and southern purple-spotted gudgeon are believed to have been lost to the region during the drought and now only persist as a direct result of reintroductions. Translocations like these, along with other environmental interventions (e.g. improved water management and alien fish control), will be necessary to re-establish resilient, connected populations of these four target species in the SA MDB region.

■ **Key Outcomes**

This report articulates a realistic translocation strategy, whilst acknowledging the potential severity of the problem and greater understanding of scope of efforts required. The strategy specifically documents the (i) present status of wild as well as captive and surrogate populations of each target species, (ii) overarching strategy outlining the necessary scope and extent, (iii) approach to implement the strategy; and (iv) preliminary application of the strategy to potential translocation sites.

■ **Management implications**

Central to any future widespread translocation strategies will be the requirement for suitable wild habitats as well as increased fish production, greater numbers are required for releasing and ongoing survival in their new habitat. In time, a network of wild subpopulation (known and re-established) are needed to reduce the risk of regional extinction of the four targeted species. Appropriate genetic management, monitoring, and evaluation is critical, as will be consideration of drought and future climates. Equally important will be the identification of high priority translocation sites, which maintain abiotic and biotic conditions, as well as appropriate management for the target species.

■ **Recommendations for further work**

- This strategy should undergo a recurrent review aiming at filling identified knowledge gaps and translating this into wetland management works and plans. Where identified, future opportunities to implement aspects of the translocation plan should be taken up and possibly added into future revisions of WMP's.

- Further identification of high priority translocation sites, which maintain abiotic and biotic conditions, as well as appropriate management, will be essential to support translocation and populations of small-bodied fish in the SA River Murray region.
- Any translocating will have to be done into wetlands with suitable habitat as well as a WMP purposefully intended for management of small-bodied fish. Apart from a suitable habitat this will require, at all times, a certain water level within the wetlands in order to avoid local extinctions.
- Promotion of the report should be undertaken in order to improve organisational priorities/obligations and the Strategy should be considered to be taken up at a higher level e.g. at a regional (NR SA MDB) and Departmental (DEW) level under the EPBC responsibilities.

▪ **Managing environmental knowledge**

A MEK chart has been developed for this investigation. The chart indicates the flow of information and data from the point of collection in the field, to the end authorised product. Most of the data were uploaded into BDBSA by the Aquasave – Nature Glenelg Trust team, some sensitive site information data of these endangered fish have conscientiously been left out of the public database. For access to all available data including redacted site information, please contact investigation author.

6. SAMDB wetland and floodplain seedbank status and response capability assessment

Full report: Nicol, J.M. and Frahn, K.A. (2019). Seed Bank Assessment of Managed River Murray Wetlands. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI. Publication no. F2019/000078-1. SARDI Research Report Series No. 1013. 34pp.

▪ **Rationale and approach**

In 2017, the RRP produced the *RRP Monitoring and Evaluation Program – Conceptual understanding of the ecological response to water level manipulation, 2nd Edition* (DEWNR, 2017a). This report was based on the assessment of historic data, literature reviews, expert opinion and observations. Major risks and factors related to expected vegetation responses included wetland drawdown rates, pest species, fire (riparian and floodplain zones), reduced availability of niche habitats, dry phase duration, water/soil quality, seed bank condition and seed bank depletion. The report noted that colonisation will only occur if seeds or propagules are present (or introduced) and conditions are suitable (habitat and resource availability). A review by Muller et al. (2017) of the above-mentioned report additionally recommended that a seedbank assessment should take place to further explain vegetation response to wetland management. The seed bank provides an important mechanism for the survival of species beyond unfavourable conditions. It contains a pool of propagules for establishment of

plant communities when favourable conditions return to wetland ecosystems. Unregulated arid and semi-arid Australian wetlands are subject to highly variable hydrology with both drought and flooding disturbances making survival of asexual propagules often unlikely; hence, the seed bank is the major source of propagules for establishment of plant communities following major disturbance.

The lower River Murray is a highly regulated system with largely stable water levels. Wetlands that were historically temporary, are now connected to the main river channel at pool level and permanently inundated. Vegetation monitoring of wetlands where drying cycles have been reinstated often showed a lack of response in the vegetation and it was proposed that this was due to a depauperate seed bank, the probable legacy of nearly 100 years of permanent inundation due to river regulation. The primary aim of this study was to determine whether the poor response of the vegetation was due to depauperate seed banks in managed wetlands, and assess the seed banks of wetlands where structures are being built.

The seed banks of 15 lower River Murray wetlands between the New South Wales border and Mannum were assessed using the seedling emergence technique. Sediment samples were collected from below normal pool level at ten sites with managed wetting and drying cycles and five sites where structures were under construction, unmanaged sites.

▪ Key Outcomes

This investigation contributed to further understanding of the factors that drive wetland vegetation response to water level manipulation. Data analysis showed that:

- Three out of ten managed wetlands had seed densities $>10,000$ seeds m^{-2} and species richness ≥ 8 .
- All of the unmanaged wetlands had a depauperate seed bank and low species diversity.
- No germination was observed in five wetlands (three managed and two unmanaged), furthermore, seed separation detected no seeds in the sediment in these wetlands.
- No statistical significant difference was found between seed density, species richness and seed bank composition between the managed and unmanaged wetlands, however, differences are likely to be ecologically significant.

This investigation did not specifically address the multitude of factors that could affect vegetation responses to water level manipulation, however it presented evidence to support the following conclusions:

- Poor response of vegetation is likely due to a depauperate soil seed bank.
- Response of the vegetation with regulators under construction initially is probably going to be poor.

- The legacy of 100 years of river regulation is a significant factor.
- Hydrological restoration is paramount for wetland restoration.

▪ **Management implications**

Poor response of the vegetation in managed wetlands is likely due to a depauperate seed bank and the unmanaged wetlands will probably respond in a similar manner if drying cycles are reinstated. However, reinstatement of a more “natural” hydrological regime is fundamental in wetland restoration. Without the appropriate hydrology, many floodplain and amphibious species will not recruit and a diverse seed bank will not develop. Many of the amphibious and floodplain species that require a drying cycle to recruit are prolific seed producers and it may only require one individual to complete its life cycle to provide a seed bank “hot spot” for that species which may significantly contribute to the regenerating plant community through time. The most important management action after hydrological manipulation is to implement a spatially and temporally appropriate monitoring program to detect changes in the vegetation through time and protect areas in wetlands where the vegetation has responded positively.

If the vegetation does not respond to hydrological manipulation through time active revegetation may be required. This can involve mixed planting, planting of keystone or nurse species that facilitate recruitment of other species, direct seeding of desirable species or sediment transplant.

Generally, managers should seek to:

- Maintain hydrological restoration and implement WMP's
- Protect areas where plants are present from grazing (e.g. exclosures)
- Undertake weed control
- Actively revegetate
- Transplant sediment from donor sites with healthy seed banks (noting potential issues with this process like introducing weed species to new areas).

▪ **Recommendations for further work**

- Consider exploring seed sourcing, and sediment transplant trials for aquatic vegetation.
- Identification of plant species from seeds can sometimes be difficult, monitoring and studies using eDNA methods could potentially overcome this hurdle and would possibly allow for discovery of hard to identify species.
- For aquatic revegetation consider finding a suitable nursery species to plant within wetlands with a number of trial sites that may enable non-pioneer plants to grow, for example *Schoenoplectus validus* has been used by the Coorong, Lower Lakes, and Murray Mouth Vegetation Program in the Lower Lakes.

- Explore potential methods for seed harvesting and release to improve seed bank stock. This work could include nursery based or managed wetland planting seed collection, and would be coupled with trials to determine optimum seed release timing in line with water regimes.

▪ **Managing Environmental Knowledge**

A MEK chart has been developed for this investigation. The chart indicates the flow of data from the point of collection in the field, to the end authorised product. The data collected by the SARDI team as part of this investigation were uploaded into BDBSA.

7. Historic tree condition data evaluation

Full report: Denny, M.L., Willoughby, N. and Wallace, T.A. (2019). Riverine Recovery Project Historic Tree Condition Data Evaluation. DEW Technical report 2019/09, Government of South Australia, Department for Environment and Water, Adelaide.

▪ **Rationale and approach**

This investigation followed on from the RRP 2016-17 review of conceptual understanding of the ecological response to water level manipulation (Muller et al., 2017). The 2016-17 project report recommended that, given the emphasis on tree condition in current wetland management, a similar investigation utilising data specific to tree condition, would be appropriate and valuable. DEW has collected tree condition data at River Murray wetlands and floodplains in various formats for at least two decades. Over this timeframe, opportunities to deliver environmental water to individual wetlands and broader wetland complexes have increased via engineering works and measures, and are foreseen to increase in the future. This brings a requirement for prioritising and delivering environmental water in the most efficient and effective way to maximise ecological outcomes from a given available volume of water.

The historic tree condition data evaluation investigation aimed to analyse and evaluate existing tree condition data to make recommendations about future data collection, and to inform hydrological management for floodplain tree outcomes. Floodplain tree response to environmental watering actions was analysed using data from visual assessments of tree crown condition collected using the method outlined in Souter et al. (2010) from approximately 2009 to 2018. The study was delivered in two phases. Phase 1 was a preliminary data scoping and investigation refinement phase that considered a series of draft evaluation questions that were proposed by investigation partners and stakeholders. The following was adopted as the key evaluation question to be assessed in Phase 2 of the investigation:

Are the trees at sites that received managed environmental water in the years preceding and between unregulated high flow, in better condition than those sites that only received water during unregulated flows?

The analysis aimed to group and compare sites that, over the last decade, were inundated by:

- Only the two unregulated floods that occurred in 2010-11 and 2016-17
- Unregulated floods in 2010-11 and 2016-17 and a series of smaller follow-on unregulated flows in 2011 and 2012
- Unregulated floods (2010-11 and 2016-17) + high flows AND inundated by pumping
- Unregulated floods (2010-11 and 2016-17) + high flows AND weir pool manipulation.

▪ **Key Outcomes and management implications**

Using these particular data, the analysis suggests that:

- When comparing areas with similar unregulated flooding history, tree condition index (TCI) was likely to be higher during dry periods at tree transects that had received additional environmental water, compared with tree transects that had not received additional environmental water.
- Tree condition across transects with varying watering history can converge following a large unregulated flow.
- Trees adjacent permanent waterbodies are more likely to maintain better condition and their condition is less variable over time compared with the condition of trees at temporary wetlands and floodplain transects.

The study supports delivery of environmental water as a means to improve tree condition and to maintain trees through dry inter-flood periods. However, the results are only valid for trees with comparable long-term hydrological regimes.

This investigation has improved our knowledge of the response of SA River Murray floodplain tree condition to environmental watering using various methods, including unregulated flows/pumping. In particular, a better understanding of tree condition response to the magnitude, timing, duration and frequency of flow (flow regime) was gained, however, the findings were limited by a lack of coupled, detailed watering history for sites where tree condition has been monitored.

▪ **Recommendations for further work**

- This tree condition modelling approach could be further developed as a tool to estimate theoretical reference condition for groups of trees subject to management. Such an exercise would however require coupled hydrological data for reference and monitored sites of interest. This only exists for an extremely limited number of sites because related environmental data are often not collected in a way that enables linkages between tree condition and environmental watering to be explored. Future work should ensure that tree condition data can

be coupled to watering history. Identification of co-occurring monitoring parameters can occur through the development of monitoring plans that are contained within a broader Monitoring, Evaluation, Reporting and Improvement (MERI) framework. Use of a tool such as MERI allows articulation of evaluation questions designed to measure the success of management objectives. Subsequently, planning includes the identification of monitoring methods and parameters before data are collected, and ensures monitoring provides data that supports evaluation questions.

- If evaluation questions similar to the question adopted for this project are to be utilised in the Department's current/draft/future monitoring programs/plans then during their review process, consideration should be given to identifying data and monitoring requirements that support answering such evaluation questions. E.g. Understanding the extent, duration, return intervals and frequency of managed inundations helps inform on the achievement of management actions. Identifying new/alternate data and monitoring requirements at the review phase (of the monitoring plans) would further contribute to the Department's ability to evaluate environmental watering activities and align with evaluation and reporting obligations under the Basin Plan.
- Revise DEW staff/team work-flows and embed the use of the tree condition data load template (for the TLM method) into practice. This will improve data standardisation and ease of retrieval from BDBSA.
- Review DEW agency staff work-flow and ensure adherence to established Monitoring Environmental Knowledge procedures prior to undertaking field monitoring activities. This includes the development of MEK charts, identification of approved corporate data storage locations, articulated monitoring rationale, and timely upload of collected data.
- Investigate opportunities to better associate data pertaining to watering actions with transect-scale tree condition monitoring observations. This includes exploring possibilities to utilise/integrate information from BDBSA and the Management Action Database (MAD) or the development of a purpose built information management solution.
- Continue to explore recent enhancements in remote sensing capabilities through Geoscience Australia to better capture watering history on the floodplains.

▪ **Managing Environmental Knowledge**

A MEK chart has been developed for this investigation. The chart indicates where to find the data, to the end authorised product.

5. Conclusions

The RRP has established a strong foundation for on-going maintenance and improvement of water dependent ecosystem health along the River Murray in South Australia. Key advances have been made in understanding how best to optimise conditions for ecological community response to watering and implications for the management of floodplains, wetlands and environmental river management. Strong relationships have been built with wetland landholders and communities and this has increased community knowledge of the risks and opportunities associated with managing wetlands.

Based on the investigations presented here, it is likely that RRP investment has and will continue to increase the ecological resilience of the wetland and floodplain areas under its influence compared to parts of the river system that are not actively managed. The legacy of the long-term view of riverine restoration taken by RRP and the management knowledge captured by RRP will extend decades into the future by supporting future managers when challenged by managing River Murray wetlands affected by limited environmental water allocations, global heating, continued consumptive use, and unpredictable water availability. Capturing the lessons learnt by implementing RRP during and after the Millennium Drought will be particularly important for managers to reflect on during future dry periods.

It is acknowledged that SA River Murray wetlands today are in a very different state/condition to that prior to river regulation and water resources development and in effect are novel ecosystems that will continue to provide management challenges. Achievement of the long-term vision of healthy and resilient wetlands will require a well-resourced, structured, flexible and adaptive management approach guided by robust evaluation of long-term data sets that have been collated, evaluated and improved by RRP.

It is also important to acknowledge that wetland management in South Australia faces the ongoing challenge of funding consistency, high staff turnover and resulting issues such as inconsistent transmission of knowledge, loss of corporate knowledge, and a decrease in field experience. Many of the investigations summarised here suffered from this loss of corporate knowledge. It is recognised that previously, the FAWT were managing a smaller number of wetlands, however, with an increase in the number of managed wetlands, it is reasonable to expect there will greater demand to actively coordinate and optimise the efficiency of management activities and ecological outcomes. On-going management, especially with the increased responsibility and complexity of additional infrastructure along the SA River Murray, will require additional resourcing to ensure that the legacy of RRP is as beneficial as possible.

The RRP experience has confirmed the importance of having an overarching monitoring program with clear objectives that is part of a comprehensive MERI framework. It has also become evident that development of an integrated management system that meets international standards (e.g. ISO31001, ISO9001 and ISO14001) could be used to operationalise the

concept of adaptive management in the SA River Murray, particularly as more infrastructure is commissioned and decision-making becomes more complex. Such a system could foreseeably increase the opportunity to obtain funding and allow rapid articulation of goals and objectives, and provide for transparent and accountable public service practice.

6. Recommendations

The following recommendations focus on building systems that support continual improvement in managing South Australia's River Murray wetlands and are underpinned by DEW's culture of continuous improvement. In this context, some but not all recommendations are scalable. Those that are not scalable can, however, be implemented incrementally to progressively build on the RRP foundation.

Evaluate wetland management outcomes for each RRP wetland that has gone through its full hydrological cycle (5 years)

An annual and five year review cycle is recommended by the RRP WMPs. This aligns with the RRP Monitoring and Evaluation Program – Technical Design 2nd Edition (DEWNR, 2017b). Data collected for Phase 1B and 2 wetlands can be used in this evaluation to assess if WMP objectives have been met, or are on track, to help determine the ecological impact of the management approach. This data analysis and review process specifically enables:

- evaluation of progress towards targets
- identification of drivers of change and attribution of change to management actions, where possible
- testing of whether observed responses matched the expected responses to intervention (hypotheses and assumptions) and thus whether our conceptual understanding in RRP Monitoring and Evaluation Program – Conceptual Understanding 2nd Edition (DEWNR, 2017a) was confirmed or not
- evaluation of risks and benefits, especially the appropriateness of management actions to mitigate risks and optimise benefits, as part of the adaptive management process
- continual improvement of operations towards targets and prevention of long-term damage
- justification of investment to achieve objectives
- communication of achievements to stakeholders, landholders and the broader community.

In addition, monitoring data will be used to answer a series of evaluation questions in each WMP. These answers then inform the refinement of the following hydrological cycles and other management activities (e.g. pest control, revegetation). Over time, wetland managers can use the monitoring

and evaluation approach as articulated in Figure 4 to better understand the extent of management influence over the wetland's ecological character and how best to utilise available management levers (e.g. wetland regulators, weir pool operations and environmental flows).

Review the approach to managing environmental knowledge in line with DEW's systematic corporate database management requirements

It is recommended to identify and establish wetland information management requirements in alignment with DEW's MEK framework and the state's Digital by Default Declaration. This will ensure consistency, resource efficiencies and continuity of service by alignment with other investment in River Murray tools and support systems. This may include:

- Determining information management requirements, and documentation using MEK charts
- Determination of data flows, inputs, outputs and storage
- Linkage to e-water planning and operations tools and system.

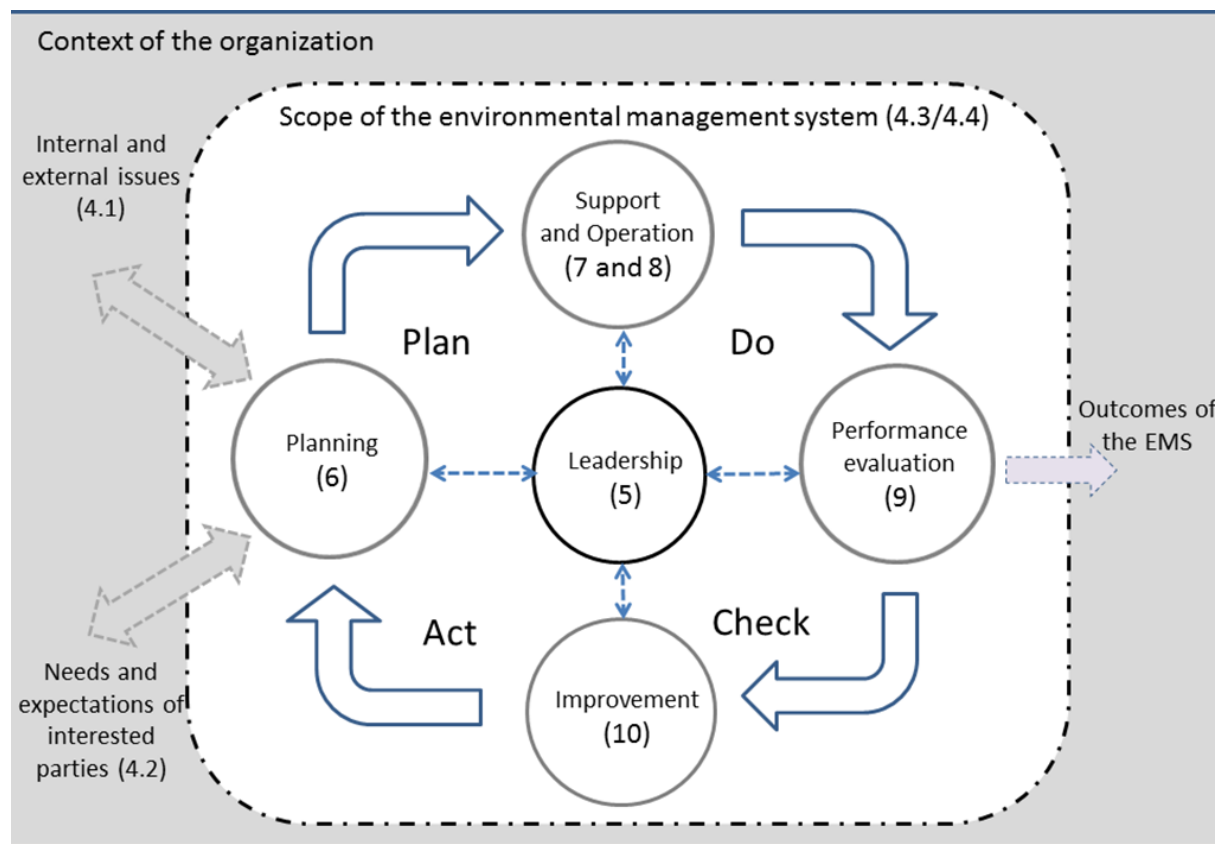
Develop a regional wetland management system incorporating adaptive management strategies

There was a challenge to incorporate the learnings from the investigations due to a lack of a regional wetland management system where the adaptive process is incorporated. While it is recognised that each WMP has been crafted to suit the specific wetland, there are management efficiencies and opportunities that could be better understood and enhanced by the establishment of an Environmental Management System (EMS) compliant with ISO14001 (2015) at the regional scale. Such a system may also assist with attracting funding for continuation of RRP Wetland monitoring activities by demonstrating due diligence and giving funding body's confidence that ecological outcomes will be achieved. An example of the concept of this approach is given in Figure 6.

By using a hierarchical approach and having regard to the objectives and assumptions stated in the WMPs, teams can prioritise monitoring activities from absolute must haves (e.g. critical evidence of ecological response to management; testing high risk assumptions) through to *nice to have* (e.g. ecological information that has appeal but does not inform management decision-making). This will focus the monitoring effort and provide a line of sight between data and management to improve funding application success.

The incorporation of adaptive management strategies through robust evaluation of monitoring data, and discussions with on-ground personnel, will help document and shift from risk-based monitoring (reactive) to monitoring for optimisation and making observations that drive creative exploration of

management opportunities (proactive). This approach would enable the wetland managers to evaluate data, and their operations, at a higher level.



Note: Numbers in brackets refer to the clauses in this International Standard.

Figure 6. Plan-Do-Check-Act Model that is the foundation of ISO14001 (2015).

Consider training for, and progressing the development of a MER framework as part of South Australia's wetland management system

The Department's guide to monitoring, evaluation and reporting on the effectiveness of programs is a key document in the establishment of the rationale and considerations for developing a MER framework (Markiewicz and Patrick, 2016, Scholz, 2016).

The Departments newly adopted method has not yet been implemented at the wetland scale. In-line with the Departments methods, and similar to other teams within DEW, the FAWT could endeavour to undertake training in the development of MER/MERI frameworks through a professional service provider (noting that funding would need to be provided). This would help provide a common language and linkages to broader MER/MERI frameworks related to environmental watering.

Early planning for a monitoring and evaluation program is essential for achieving efficient and effective outcomes.

WMP's focus on operations, ecological rationale, suggested management objectives, and monitoring. An important component of these plans, aiming to provide direction and context for adaptive management, are contained in the recommended approaches to the development of a management system that incorporates evaluation and reporting.

The MER framework identifies knowledge gaps, and enables managers, operators, monitoring personnel, landholders, and community members' transparent access to management information and data. Benefits of using the departmental approach to MER include; consistency with other programs operating in the River Murray (and broader SA MDB), clear and demonstrable decision making process, data sharing, and a pathway for practice improvement.

The RRP Monitoring and Evaluation: Technical Report 2nd edition (DEWNR, 2017b) provides a significant resource in support of the establishment of MERI framework.

Undertake further specific investigations to fill knowledge gaps

There is considerable merit in the development of a register of knowledge gaps in conjunction with other River Murray management/operators. Once knowledge gaps have been identified they can be prioritised with regard to the risk to the WMPs objectives of not knowing the information or process and/or the risk of making assumptions about the missing knowledge.

For example, there was some indication from the seedbank and the acid sulfate soils reports that wetlands would benefit from quick draw down and refilling. Identifying specific knowledge gaps associated with these management risks (e.g. acidification, lack of vegetation response) and undertaking detailed studies before and after managed inundations to fill these gaps will enable better understanding of how to manage the dynamics of timing, duration, depth, velocity, and magnitude of wetland wetting and drying regimes.

Continue to build the evidence base for on-going wetland management

Continue to develop the wetland monitoring program to build the scientific evidence of the risks and benefits of using wetting and drying cycles in wetland management, and for management of specific species and functional groups for the benefit of ecosystem health and function.

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