Commonwealth Environmental Water Office: Lower Murray Monitoring, Evaluation and Research Plan (2019–2022)

Draft plan prepared by the Lower Murray Selected Area Consortium: SARDI, University of Adelaide and DEW

October 2019

This project was commissioned and funded by Commonwealth Environmental Water Office (CEWO) with additional in-kind support from South Australian Research and Development Institute (SARDI) and South Australian Department for Environment and Water (DEW). The authors of this report as well as the CEWO respectfully acknowledge the traditional owners of Country in the Murray-Darling Basin, their Elders past and present, their Nations, and their cultural, social, environmental, spiritual and economic connection to their lands and waters. In particular, the Ngarrindjeri Nation and the First Peoples of the River Murray and Mallee as traditional owners of the land and water on which this publication is focused.

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This report should be attributed as 'Commonwealth Environmental Water Office: Lower Murray Monitoring, Evaluation and Research Plan (2019–2022), Commonwealth of Australia 2019'.

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Summary

This Plan informs the implementation of the Commonwealth Environmental Water Office (CEWO) Monitoring, Evaluation and Research (MER) Project in the Lower Murray Selected Area from 2019-20 to 2021-22. The MER Project aims to meet the key monitoring and research needs for the CEWO, extending and integrating services previously delivered by the five-year CEWO Long-term Intervention Monitoring (LTIM) and Environmental Water Knowledge and Research (EWKR) projects. As for LTIM, the Project will continue to be implemented at seven Selected Areas within the Murray-Darling Basin over the next three years with the key objectives of evaluating and demonstrating ecological outcomes of Commonwealth environmental water delivery and informing adaptive management.

This MER Plan has been prepared by the Lower Murray Selected Area Consortium, which includes the: South Australian Research and Development Institute, University of Adelaide and Department for Environment and Water. The Plan outlines a range of core monitoring and evaluation activities, with indicators to inform the evaluation of Commonwealth environmental water at the Lower Murray Selected Area (Category 3) and support the evaluation at Basin-scale (Category 1). These are:

Category 1

- Hydrology (Channel)
- Stream Metabolism and Water Quality
- Fish (Channel)

Category 3

- Hydraulic Regime
- Matter Transport and Coorong Habitat
- Littoral Vegetation Diversity and Productivity
- Microinvertebrate Assemblage
- Flow-cued Spawning Fish Recruitment
- Murray Cod Recruitment.

As well as these core services, a range of additional services will be delivered by the project. An integrated research project is proposed to explore the links between key indicators and improve our understanding of how flow influences the ecological processes that drive recruitment of key fish species (Murray cod). Additional contingency monitoring activities are also proposed to be undertaken under different flow scenarios. Section 8 constitutes the Engagement and Communication Plan, which describes core operational activities and proposed additional activities for enhancement. The MER Plan also outlines the project management arrangements for implementing the Plan, while Section 13 (removed from public version) summarises the budget for all activities.

This MER Plan has been developed in accordance with the contract and guidelines as required, and has been assessed and agreed by the CEWO. It will underpin the implementation of the three-year MER Project in the Lower Murray Selected Area, commencing in 2019-20.

1 Introduction

The Commonwealth Environmental Water Holder (CEWH) is responsible under the *Water Act 2007* for managing Commonwealth environmental water holdings. The holdings must be managed to protect or restore the environmental assets of the Murray–Darling Basin (MDB), and other areas where the Commonwealth holds water, so as to give effect to relevant international agreements. The Basin Plan (2012) further requires that the holdings must be managed in a way that is consistent with the Basin Plan's Environmental Watering Plan. The *Water Act 2007* (Cth) and the Basin Plan also impose obligations to report on the contribution of Commonwealth environmental water to the environmental objectives of the Basin Plan. Monitoring and evaluation are critical for supporting effective and efficient use of Commonwealth environmental water, and provide important information to support the CEWH in meeting their reporting obligations.

In June 2014, the Commonwealth Environmental Water Office (CEWO) commenced two, five-year projects; the Long-Term Intervention Monitoring (LTIM) and Environmental Water Knowledge and Research (EWKR) projects. The LTIM Project involves monitoring and evaluating the contribution of Commonwealth environmental water delivery in the MDB to support improved decision-making through the application of the principles of adaptive management. The LTIM Project was implemented at seven Selected Areas and at Basin-scale over a five-year period from 2014-15 to 2018-19 to deliver five high-level outcomes (in order of priority):

1. Evaluate the contribution of Commonwealth environmental watering to the ecological objectives of the Murray–Darling Basin Plan
2. Evaluate the ecological outcomes of Commonwealth environmental watering at each of the seven Selected Areas
3. Infer ecological outcomes of Commonwealth environmental watering in areas of the MDB not monitored
4. Support the adaptive management of Commonwealth environmental water
5. Monitor the ecological response to Commonwealth environmental watering at each of the seven Selected Areas.

The EWKR project provides research to improve the understanding of how environmental flow management influences ecosystem function and thereby sustains biodiversity. The knowledge developed will inform complementary water and natural resource management to enhance the outcomes of environmental flow management for ecological and human communities throughout the MDB.

On ground monitoring and research activities for the LTIM and EWKR projects end in June 2019. The current CEWO Monitoring, Evaluation and Research (MER) Project aims to extend the LTIM and selected EWKR project activities to June 2022, with improvements under an integrated project. Over the next three years, a Monitoring, Evaluation, Reporting and Improvement (MERI) Framework will continued to be implemented through the CEWO MER Project to facilitate the adaptive management of Commonwealth environmental water. The Project will continue to include an evaluation at the Basin-scale and in seven Selected Areas within the Basin. Monitoring data collected from the Selected Areas will contribute to the Basin-scale evaluation.

1.1 The MER Plan

The Lower Murray is one of seven Selected Areas for the MER Project. For Stage 1 of the Project, a three-year MER Plan has been developed for the Lower Murray Selected Area to guide the monitoring, evaluation and research activities from 2019-20 to 2021-22 (this document). This Plan builds on the LTIM Monitoring and Evaluation Plan (SARDI *et al.* 2018) for the Lower Murray (2014–15 to 2018−19), and the learnings from the LTIM Project. The following details are included in the MER Plan:

- A description of the Selected Area
- Commonwealth environmental watering in the Selected Area
- Monitoring and research priorities of the Selected Area
- Monitoring indicator methods and evaluation protocols, including standard operating procedures
- A description of research proposals
- A monitoring and research schedule
- An engagement and communication plan
- A reporting schedule and requirements
- A project management plan, including project governance, risk assessment and quality planning
- Data management procedures
- A workplace health and safety plan.

The MER Plan has been developed and will be implemented in the Lower Murray Selected Area for the next three years (Stage 2) by the Lower Murray Selected Area Consortium, led by the South Australian Research and Development Institute (SARDI).

2 Lower Murray description

A detailed description of the Lower Murray River is provided in Ecological Associates (2010) and summarised here. For the purposes of this study, the Lower Murray Selected Area (herein, Lower Murray) focuses on the main channel of the Lower Murray River between the South Australian border and Wellington, with only one targeted investigation (i.e. *Matter Transport and Coorong Habitat*) extending to the Lower Lakes and Coorong (Figure 2.1).

The natural flow regime of the Lower Murray is highly variable because of the variable rainfall within the MDB associated with the El Niño Southern Oscillation and other atmospheric phenomena (McMahon *et al.* 1992). In addition, as the end of the MDB system, flow to the Lower Murray is affected by flow from both the northern and southern basins. The hydrology of the Lower Murray, however, has been altered significantly by regulation and diversions (Maheshwari *et al.* 1995). The ecologically significant effects of regulation and diversions are:

- Loss of flowing water habitat
- Habitat fragmentation
- Permanent inundation of wetlands, the river channel and low-lying floodplain areas in the vicinity of the weir pools
- Reduction in the frequency of inundation in higher wetlands and floodplain areas
- Reduced connectivity and end of system flows at the Murray Mouth and to the Coorong.

Despite these changes, the Lower Murray has high habitat and biological diversity and includes important habitat for a number of species listed as requiring protection by state or federal legislations, including:

- Large-bodied native fish (Murray cod, freshwater catfish, silver perch)
- Small-bodied native fish (Murray hardyhead, southern pygmy perch, purple spotted gudgeon)
- Southern bell frog
- Numerous state and nationally listed migratory and other waterbird species.

The Lower Murray Selected Area covers three riverine geomorphic zones (floodplain, gorge and swamplands) and the Lower Lakes and Coorong (Wellington to Murray Mouth) (Figure 2.1). More details are provided below.

2.1 The Floodplain zone

The Floodplain zone is between the South Australian border and Lock 3. Here, the river meanders through a broad floodplain up to 8 kilometres (km) wide, with high geomorphic diversity including anabranches, backwaters and wetlands (Walker and Thoms 1993). The Floodplain zone includes the Riverland Ramsar site and a number of large wetlands, including Lake Bonney, Wachtels Lagoon, Gurra Lakes, Lake Merreti, Lake Woolpolool, Coombool Swamp, Clover Lake, Lake Littra and Bulyong Island. Small wetlands, less than 50 hectares (ha) in area, make up the majority of total wetland area. Increasing river flow does not significantly increase the inundation of the floodplain area (including floodplain vegetation communities) until flows of approximately 50,000 megalitres per day (ML/d) are reached.

2.2 The Gorge zone

The Gorge zone is between Lock 3 (Overland Corner) and Mannum. Here, the channel is characterised by long, straight reaches within a 30 metre deep limestone gorge with a narrow floodplain (2–3 km wide) with geomorphology that is largely undisturbed. The Gorge zone includes numerous wetlands including the Banrock Station Ramsar site. As in the Floodplain zone, significant floodplain inundation commences at flows above 50,000 ML/d.

2.3 The Swamplands zone

The Swamplands zone is between Mannum and Wellington. Here, the river corridor remains confined with a narrow floodplain (1–2 km wide), but a large proportion of the floodplain has been developed for irrigated agriculture with levee banks constructed that have largely isolated the floodplain from the main river channel. This has resulted in a loss of floodplain habitat, native vegetation and natural geomorphic characteristics. There are eight wetlands more than 50 ha in size and these represent approximately two-thirds of the total wetland area, but less than 10 percent of the total number of wetlands. Most wetlands are permanently inundated, with a small additional area inundated by flows exceeding 30,000 ML/d. Greater floodplain inundation commences at flows exceeding 50,000 ML/d.

2.4 The Lower Lakes and Coorong

The Lower Lakes and Coorong is the terminal system of the MDB, and is heavily impacted by river regulation and water extractions. A detailed description of the region, hydrology and hydrodynamics was provided by Gibbs *et al.* (2018). The Lower Lakes comprise two large, shallow, freshwater lakes, Lake Alexandrina (~65,300 ha; 1,620 GL) and Lake Albert (~17,300 ha; ~280 GL). They are physically separated from the Coorong estuary and Murray Mouth by five barrages, constructed between a series of islands from 1935 and 1940. The hydrology of the Lower Lakes is primarily influenced by inflows from the Murray River. Water levels in the Lower Lakes are managed to fluctuate seasonally, and are generally higher in winter and lower in summer following the pattern of Murray River and tributary inflows and climatic factors, such as wind, tides and evaporation (Phillips and Muller 2006).

The Coorong is a shallow (typically <3 metre), narrow (<4 km) and long (about 110 km) estuarine lagoon system with a constricted channel connection (Murray Mouth) to the sea (Figure 2.1). The North and South lagoons are 'separated' at Parnka Point with a narrow width down to ~100 m. The average width of North and South lagoons are 1.5 km and 2.5 km, respectively, whereas the average depths are 1.2 m and 1.4 m, respectively. There is a strong north-south salinity gradient in the Coorong, generally ranging from brackish/marine in the Murray Estuary near the Murray Mouth to hypersaline in the North and South lagoons (Geddes and Butler 1984; Geddes 1987). Salinities are spatio-temporally variable and highly dependent on the freshwater flows from the Murray River, with varied salinities supporting different ecological communities (Brookes *et al.* 2009). In addition, the southern end of the South Lagoon receives small volumes of fresh to brackish water (2,100–43,700 ML/year from 2007-08 to 2016-17) from a network of drains (the Upper South East Drainage Scheme) through Salt Creek (Ye *et al.* 2018b).

Figure 2.1. Map of the Lower Murray Selected Area, showing the floodplain (blue), gorge (green) and swamplands (orange) zones, and the Lower Lakes, Coorong and Murray Mouth (yellow).

3 Commonwealth environmental watering

3.1 What types of watering are proposed?

The MDB Plan and Gawne *et al*. (2013a) outline a number of generalised flow types, illustrated in Figure 3.1. *Cease-to-flow* events do not occur in the Lower Murray, as minimum water levels and flows are maintained by river regulation and South Australian entitlement flows (3,000−7,000 ML/d), which are considered as *baseflows*. Environmental water contributes significantly to *baseflows* in the Lower Murray, particularly in dry years where it may contribute up to half of total flows for the year. *Freshes* to *bankfull flows* (~7,000−45,000 ML/d) remain in the main channel and only result in minor additional inundated area in the Lower Murray. Herein, *freshes* and *bankfull flows* are both described as *freshes*, noting the magnitude of discharge will influence the hydraulic regime in the main channel.

During the LTIM Project (2014-15 to 2018-19), Commonwealth environmental water was delivered to the Lower Murray, in conjunction with other environmental flows (i.e. The Living Murray (TLM) Initiative, Victorian Environmental Water Holder and River Murray Increased Flows), largely as return flows through coordinated watering events across the southern connected Basin to achieve multi-site environmental outcomes. Direct orders of environmental water to the South Australian border also occurred for specific purposes, often during summer−autumn, to provide flow for the Lakes and Coorong.

In four out of the last five years, environmental water contributed to *freshes*, particularly as winter and spring−summer flow pulses in the Lower Murray. The exception was 2016-17, when high unregulated flows, resulting in overbank inundation (peak ~94,600 ML/d at the South Australian border) during spring/early summer, delayed the majority (~96%, excluding South Australian held entitlement flow) of environmental flow delivery until after mid-December 2016. In this high flow year, environmental watering assisted in slowing and extending the flood recession in summer. Over the last five years, Commonwealth environmental water played a critical role in maintaining barrage releases, particularly during dry autumn periods. In addition, environmental water has been used for other complementary management actions to achieve environmental outcomes in the Lower Murray (e.g. weir pool manipulation, operation of environmental regulators, pumping).

For the period of the MER Project (2019−20 to 2021−22), it is expected that the majority of the Commonwealth environmental water deliveries to the Lower Murray will continue to be used to contribute to *baseflows* and *freshes*. Commonwealth environmental water can be delivered, with other sources of environmental water, to create *freshes* or to complement *natural freshes* and in doing so increase the magnitude and/or duration of an event. Should suitable climatic and hydrological conditions transpire during the coming three years, Commonwealth environmental water may also be used to complement *natural overbank flows* and in doing so increase the magnitude or duration of these events.

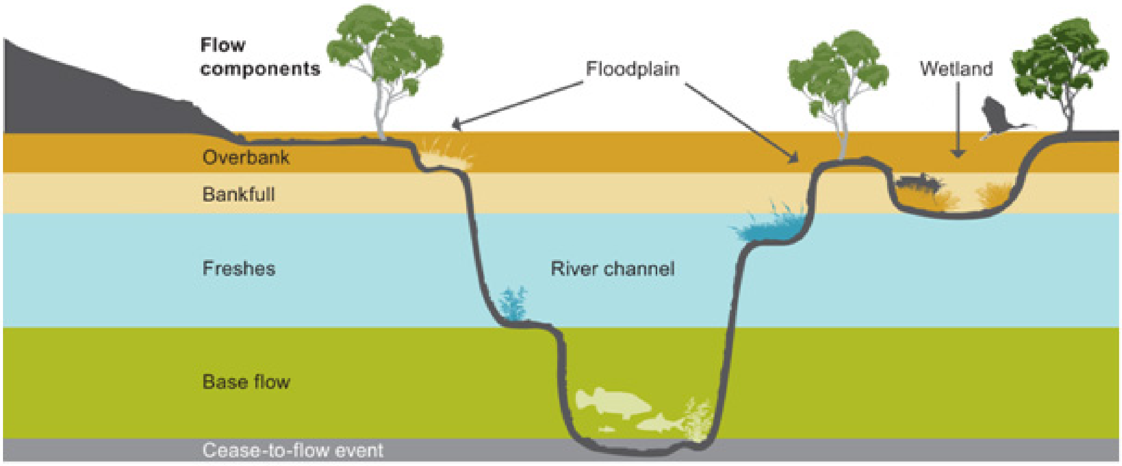


Figure 3.1. The various flow types as described by the Murray–Darling Basin Plan and Gawne *et al*. (2013a).

3.2 Practicalities of watering

Environmental water deliveries to the Lower Murray are sourced from multiple locations, including the Murray River, key tributaries (Goulburn, Murrumbidgee and Darling rivers) Lake Victoria. Environmental water will be delivered across the South Australian border in addition to the South Australian entitlement and any unregulated flows. Commonwealth environmental water available for use in the Lower Murray will depend on the system inflows, water available in the Commonwealth environmental water holdings, and delivery constraints.

The volume of environmental water delivered to the Lower Murray is constrained by risks associated with the potential inundation of property and infrastructure in upstream locations, the need to share limited channel capacity with deliveries for consumptive water use, impacts to river and floodplain work programs, and the practical feasibility of contributing water to natural high flow events. The basin states, in consultation with the MDBA, are developing a constraints management strategy, but over the next three-year evaluation period it is expected that environmental flow delivery at the South Australian border would be limited to events of less than 60,000 ML/d (see Gawne *et al*. 2013a for further details).

The implementation of watering options in the Lower Murray is undertaken through the coordination of river operations across the Southern Connected Basin, through consultation among the South Australian Department for Environment and Water (DEW), CEWO, MDBA and other jurisdictional operations units via the Southern Connected Basin Environmental Watering Committee (SCBEWC). To effectively implement the Lower Murray MER Plan, information on planned flow to South Australia and river flow management would need to be available to the project team, with regular updates provided as information becomes available. This information will continue to be provided by CEWO and DEW managers, as during the LTIM Project.

3.3 Water holdings for the Lower Murray

Water has been recovered by the Australian Government through a combination of investments in water-saving infrastructure, water purchases and other water recovery programs. This water becomes part of the Commonwealth's environmental water holdings. From 2014-15 to 2017-18, a substantial amount of environmental water was delivered to the Lower Murray (Table 3.1). Information on current Commonwealth environmental water available and security in the southern-connected Basin is in Table 3.2.

Table 3.1. Environmental water (gigalitres) delivered to Lower Murray at the South Australian border from 2014-15 to 2017-18. Volumes do not include the South Australian entitlement held by the Commonwealth Environmental Water Holder, TLM and the South Australian Minister for the Environment and Water, or wetland pumping. CEW = Commonwealth environmental water, TLM = The Living Murray, VEWH = Victorian Environmental Water Holder, NSW OEH = New South Wales Office of Environment and Heritage, RMIF = River Murray Increased Flows.

E-water holder	**Year**			
	2014-15	**2015-16**	**2016-17**	**2017-18**
CEW	581	798	618	894
TLM	107	101	234	176
RMIF			100	53
VEWH	26	15	43	29
NSW OEH				9
Total	**714**	**914**	**995**	**1162**

Table 3.2. Southern-connected Basin Commonwealth environmental water holdings (gigalitres) at 30 April 2019 (source: http://www.environment.gov.au/water/cewo/about/water-holdings).

Security	**Registered entitlements**	**Long term average annual yield**
High	883	828
General/Low	753	480
Conveyance	57	50
Supplementary[1]	415	186
Total	**2,108**	**1,544**

[1] For supplementary entitlements, no 'carryover' or 'water account balance' is reported. 'New allocations' and 'available water transferred for delivery or delivered directly' are accounted at the time of take.

Within the southern-connected Basin, water allocations to catchments can, with some restrictions, be traded to other catchments. This gives the Commonwealth the capacity to move water between catchments of the southern-connected Basin to get the best outcomes for the environment.

Southern connected basin includes the following hydrologically connected catchments: Goulburn, Campaspe, Loddon, Murray (SA, Victoria, and NSW), Lower Darling, and Murrumbidgee.

3.4 What are the expected outcomes?

Commonwealth environmental water deliveries to the Lower Murray aim to achieve a range of environmental outcomes, including those related to fish, vegetation, bird, water quality and river function. As identified previously, it is expected within the next three years (MER Project period), Commonwealth environmental water will primarily be used to contribute to elevated baseflows and freshes in the main channel and maintain river flows to the Lower Lakes and Coorong. These water deliveries are expected to contribute to the following ecological outcomes in the Lower Murray including:

- Improved hydraulic conditions with increased water velocities and increased variability in water levels in the main channel
- Increased inundated area of low-lying littoral zone, wetlands, channels and floodplains

- Improved longitudinal and lateral connectivity, including the connectivity between freshwater, estuarine and marine environments
- Maintaining dissolved oxygen and water quality
- Increased instream productivity to support riverine food webs
- Increased transport of nutrients and phytoplankton, likely stimulating primary and secondary productivity in downstream ecosystems
- Increased littoral understorey vegetation diversity, productivity and community resilience
- Increased diversity and abundance of microinvertebrates and their egg-bank
- Improved quality of food resources (microinvertebrates)
- Improved spawning, recruitment and population resilience of flow-cued spawning fish species (golden perch)
- Improved recruitment and population resilience of main channel specialist fish species (Murray cod)
- Increased salt export out of the MDB; and reduced salinities and improved fish habitats in the Coorong, and *Ruppia tuberosa* habitats in the Coorong at higher flow discharges.

It is anticipated that, over the long-term, environmental water delivery will make a significant contribution to achieving ecological outcomes in the Lower Murray, through restoring ecological processes and improving habitat for biota in the main channel and floodplain/wetlands. A consolidated view of the expected outcomes for the Lower Murray is presented in Figure 3.2 below, which includes core monitoring indicators of the MER Project.

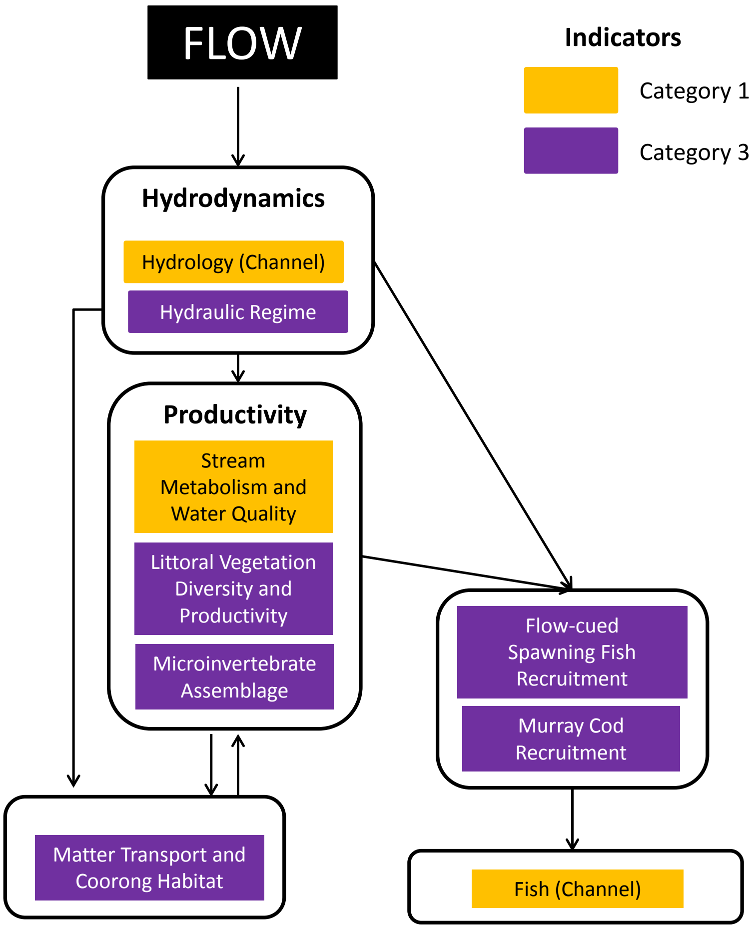


Figure 3.2. Cause and effect diagram of flow for the main channel of the Lower Murray Selected Area with respect to the proposed category indicators (core monitoring). Category 1 (Basin-scale) indicators are highlighted in orange and Category 3 (Selected Area) indicators in purple. Magnitude, timing and duration are factors of flow (in black).

4 Monitoring and research priorities

4.1 Prioritisation process

In the Lower Murray Selected Area, a range of indicators were used during LTIM to address objectives and evaluate ecological outcomes from Commonwealth environmental water deliveries (SARDI *et al.* 2018). This included targeted investigations driven by hypotheses, which were developed based on our conceptual understanding of the life histories of relevant biota and ecological processes and the effect of flow on them. The MER Project will continue to monitor most of these indicators in the Lower Murray (SARDI *et al.* 2018), and aim for improvements by integrating research (see Section 6), incorporating new indicators and improving evaluation based on knowledge from the LTIM Project. The MER indicators largely focus on the main channel of the Lower Murray River because it is expected Commonwealth environmental water delivery will continue to be limited to events of less than 60,000 ML/d due to a number of constraints (see Section 3.2).

During the planning phase of the LTIM Project, indicators of the Lower Murray were selected through a prioritisation process in consultation with key stakeholders, particularly CEWO and DEW. The selection criteria for indicators considered their capacity to: evaluate Basin-scale and Selected Area ecological objectives; support adaptive management; detect response to changes in flow; evaluate Commonwealth environmental water contribution; and cost. These were also used when considering new indicators and reviewing and refining LTIM indicators for the MER Project. Furthermore, existing monitoring programs and activities in the Lower Murray have been considered to avoid duplication and ensure programs be complementary (see Section 7.3).

As part of the prioritisation process, an evaluation framework was established to identify and align key ecological objectives, targets and expected outcomes at Basin-scale and Selected Area scale with indicators' evaluation questions. These questions were adapted from those developed previously by CEWO and DEW to facilitate reporting on environmental outcomes of the Basin Plan in the Lower Murray Selected Area. It was expected that the framework will also help to aggregate evaluation outcomes from the Lower Murray Selected Area to the Basin-scale. This framework has been reviewed and updated for the MER Project (Appendix D).

4.2 Outline priorities and evaluation questions

For evaluating the ecological outcomes of Commonwealth environmental water deliveries in the Lower Murray Selected Area, the overall question is 'What did Commonwealth environmental water contribute to water quality, ecosystem function, biodiversity and population resilience?' A summary of the indicators of the Lower Murray for the MER Project, and related objectives and CEWO evaluation questions are presented in Table 4.1. The Lower Murray indicators include:

Category 1

- Hydrology (Channel)
- Stream Metabolism and Water Quality
- Fish (Channel)

Category 3

- Hydraulic Regime
- Matter Transport and Coorong Habitat
- Littoral Vegetation Diversity and Productivity
- Microinvertebrate Assemblage
- Flow-cued Spawning Fish Recruitment
- Murray Cod Recruitment.

Category 1 (Basin-scale) indicators are mandatory (Hale *et al.* 2014). These indicators utilise standard protocols to inform quantitative Basin-scale evaluation, and, where applicable, support Selected Area evaluation. Category 3 (Selected Area) indicators are targeted investigations specific for the Lower Murray. These indicators are assessed using hypothesis-driven monitoring of flow-related ecological responses in the Lower Murray, to answer evaluation questions at the Selected Area scale. There are no Category 2 indicators for the Lower Murray, which aim for Selected Area evaluations but follow Basin-wide standard protocols.

In addition, identification of ecosystem type (the ANAE classification) and field validation is required for Basin-scale evaluation of ecosystem diversity for the MER Project. For the Lower Murray Selected Area, the field sampling will be focused on channel habitats, which are classified as permanent lowland rivers. As the river typology that applies to all in-channel sites is very coarse, this classification will not change during the current MER Project and ongoing validation is not required.

The evaluation questions for each indicator (Table 4.1) were adapted from CEWO's Basin-scale questions (see Appendix D) to better cater for indicators within the Lower Murray Selected Area, particularly for Category 3 indicators. The CEWO questions that are evaluated for the Lower Murray include:

Questions for evaluating short-term responses to watering:

- What did Commonwealth environmental water contribute to:
  - Hydraulic diversity within weir pools?
  - In-channel variability in water levels?
  - Dissolved oxygen levels?
  - Patterns and rates of primary productivity and decomposition?
  - Water quality?
  - Salinity levels and transport?
  - Concentrations and transport of nutrients and phytoplankton?
  - Biological and functional diversity of littoral vegetation?
  - Productivity and above-ground biomass produced by littoral vegetation?
  - Microinvertebrate diversity and abundance?
  - Microinvertebrate communities (via lateral and longitudinal connectivity)?
  - Quality of food resources (microinvertebrates) for higher trophic organisms?
  - Murray cod growth and condition?
  - Native fish recruitment (i.e. Murray cod, golden perch and silver perch)?

Questions for evaluating long-term outcomes from watering:

- What did Commonwealth environmental water contribute to:
  - Hydrological connectivity?
  - Meeting Environmental Water Requirements (of the South Australian Murray River Long-Term Watering Plan) in the main channel of the Lower Murray River?
  - Salinity regime?
  - Resilience of Murray cod, golden and silver perch populations?

The cumulative evaluation of the annual short-term responses to watering will also form the evaluation of long-term outcomes. Furthermore, questions were developed for DEW for each indicator (Appendix D), in line with targets from the Long-Term Environmental Watering Plan for the South Australian River Murray (LTWP) and Matter 8 expected outcomes. These serve as additional evaluation questions for the Lower Murray.

4.3 Evaluation process

Each year, data collected through the MER Project will be analysed in detail, with Selected Area reporting and evaluation conducted for each indicator (see details for indicator outputs in Section 5). LTIM data from relevant indicators will also be included in the analysis and evaluation. A technical report will be produced annually, which consolidates indicator outputs and synthesises results, identifying potential linkages between key indicators in context of cause and effect of flow on the ecological responses and broader ecosystem outcomes in the Lower Murray (as illustrated in Figure 3.2). The report will describe the ecological outcomes of environmental watering, with the primary aim to evaluate the contribution of Commonwealth environmental watering within the Lower Murray Selected Area. However, as Commonwealth environmental water is often delivered in conjunction with other environmental water sources (e.g. TLM, Victorian Environmental Water Holder), with river operations applied to achieve environmental benefits, the evaluation process for the Lower Murray will consider the influence of all environmental water, and in some cases, the overall flow regime. This will broaden our learnings of ecological responses to inform adaptive management of water use and river operations. Furthermore, other management interventions (e.g. weir pool manipulations, regulated floodplain inundations) that occurred within or upstream of the Lower Murray may also affect ecological responses in this region. Potential effect of these events will be considered when evaluating the outcomes of environmental watering. Nevertheless, the MER Project is not designed to evaluate specific outcomes from such river management actions.

Concurrently with environmental water deliveries described above, there were other management interventions that occurred within or upstream of the LMR, such as manipulations of Weir Pools 2, 5, 6, 7, 8, 9 and 15 (refer to Appendix B for more information). These events may also have affected ecological responses in the LMR.

In annual reports, the evaluation questions for the Lower Murray, including both CEWO and DEW questions (Table 4.1 and Appendix D) will be addressed, along with key findings summarised in simple evaluation tables (see Executive Summary Table 1.1, Ye *et al.* 2016a). The findings will be disseminated to CEWO and water managers in this Selected Area to inform the adaptive management of Commonwealth environmental water, and made publically available. Ongoing engagement of key stakeholders through the Selected Area Working Group assists with the review of the MER Project in the Lower Murray, and knowledge/information exchange to improve our understanding of ecosystem response to environmental watering within the MDB.

Table 4.1. Indicators, monitoring objectives and CEWO key evaluation questions for the Lower Murray Selected Area. Evaluation questions are sourced and/or adapted from Gawne *et al.* (2014). Refer to Appendix D for DEW evaluation questions, which serve as additional questions. CEW = Commonwealth environmental water. LTWP = South Australian Murray River Long-Term Watering Plan.

<table>
<tr><th>Indicator</th><th>Objectives</th><th>Evaluation questions for short-term responses</th><th>Evaluation questions for long-term outcomes</th></tr>
<tr><td colspan="4">Category 1</td></tr>
<tr><td>Hydrology (Channel)</td><td>• Provide discharge and water level data to inform other indicators.</td><td colspan="2">This indicator does not directly address specific evaluation questions but is important, providing fundamental information for analysis and evaluation of monitoring outcomes against hydrological conditions and environmental watering for all indicators.</td></tr>
<tr><td>Stream Metabolism and Water Quality</td><td>• Assess how environmental water influences water quality, primary production and ecosystem respiration in the river channel.</td><td>What did CEW contribute to:
• patterns and rates of decomposition?
• patterns and rates of primary productivity?
• dissolved oxygen levels?
• water quality?</td><td>What did CEW contribute to:
• patterns and rates of decomposition?
• patterns and rates of primary productivity?
• dissolved oxygen levels?
• water quality?</td></tr>
<tr><td>Fish (Channel)</td><td>• Determine presence or absence, relative abundance and age or size structure for selected key species.
• Determine temporal variation in large-bodied and small-bodied fish assemblage structures as well as the size/age compositions of key species.
• Consolidate Fish (Channel) condition monitoring data to evaluate DEW's Long Term Watering Plan targets.</td><td colspan="2">The analyses of Basin-scale community response to CEW will be carried out by the MER Basin-scale Provider. There are no CEWO evaluation questions for this indicator at Selected Area scale, therefore no evaluation will be undertaken.</td></tr>
<tr><td colspan="4">Category 3</td></tr>
<tr><td>Hydraulic Regime</td><td>• Assess how CEW has contributed to an increase in discharge, area, velocity and depth of flow at a high spatial and temporal resolution.</td><td>What did CEW contribute to:
• hydraulic diversity within weir pools?
• in-channel variability in water levels?</td><td>What did CEW contribute to:
• hydrological connectivity?
•Meeting Environmental Water Requirements (of the LTWP) in the main channel of the Lower Murray?</td></tr>
</table>

Indicator	Objectives	Evaluation questions for short-term responses	Evaluation questions for long-term outcomes
Matter Transport and Coorong Habitat	• Assess whether CEW has increased the transport and export of salt, nutrients and suspended solids through the Lower Murray. • Assess whether CEW has enhanced *Ruppia tuberosa* and fish habitats in the Coorong, through reduced salinity and increased water levels.	What did CEW contribute to: • concentrations and transport of phytoplankton? • salinity levels and transport? • nutrient concentrations and transport? • water quality? • improving *Ruppia tuberosa* habitat in the Coorong? • improving fish habitat in the Coorong?	What did CEW contribute to: • concentrations and transport of phytoplankton? • the salinity regime? • nutrient concentrations and transport? • water quality? • improving *Ruppia tuberosa* habitat in the Coorong? • improving fish habitat in the Coorong?
Littoral Vegetation Diversity and Productivity	• Compare and contrast the response of the littoral vegetation to different environmental water deliveries. • Compare the response of the littoral vegetation across the elevation gradient. • Compare understorey vegetation biomass across the elevation gradient. • Use flood inundation modelling to identify the differences in water level and inundation duration with and without CEW (and other environmental water) to identify the contribution of environmental water to littoral vegetation diversity and productivity by comparison across the elevation gradient.	What did CEW contribute to: • littoral understorey vegetation diversity and productivity? • above-ground biomass produced by understorey littoral vegetation?	See additional questions in contingency monitoring (Section 5.3)*.
Micro-invertebrate Assemblage	• Assess changes in pelagic potamoplankton assemblages during Commonwealth environmental water deliveries. • Relate changes in pelagic potamoplankton assemblages to longitudinal connectivity achieved through upstream watering events. • Relate changes in the density and diversity of pelagic potamoplankton assemblages to lateral connectivity between the main river channel and adjacent littoral, backwater habitats and connected floodplain during environmental water deliveries. • Relate changes in the ratios of defined microinvertebrate categories to in-channel hydraulics, water residence time, lateral and longitudinal connectivity and season and discuss about trophic ecology implications.	What did CEW contribute to: • microinvertebrate diversity and abundance (density)? • communities of the Lower Murray Selected Area (via longitudinal and lateral connectivity)? • the expected quality of food resources (microinvertebrates) for higher trophic organisms?	What did CEW contribute to: • the expected quality of food resources (microinvertebrates) for higher trophic organisms? See additional questions in contingency monitoring (Section 5.3)*.

Indicator	Objectives	Evaluation questions for short-term responses	Evaluation questions for long-term outcomes
Flow-cued Spawning Fish Recruitment	• Relate golden perch and silver perch recruitment to flow.	Did the flow regime (including environmental water) contribute to recruitment of golden perch and silver perch? See additional questions in contingency monitoring (Section 5.3)*.	Did the flow regime (including environmental water) contribute to the resilience of golden perch and silver perch populations?
Murray Cod Recruitment	• Compare and contrast growth rates and morphometric condition in response to annual flow regimes, including environmental water • Identify potential associations between recruitment, hydraulic habitat (e.g. flow velocities), and food resources (productivity). • Compare and contrast recruitment success (abundance of YOY) in response to annual flow regimes, including environmental water	What did CEW contribute to: • growth and morphometric condition of Murray cod? • recruitment of Murray cod?	What did CEW contribute to the resilience of Murray cod populations?

The capability of addressing long-term outcomes is limited for newly developed indicators for the MER three-year Project due to the length of time required to evaluate long-term outcomes (≥5 years).

*The capability to address evaluation questions for long-term outcomes from watering for *Microinvertebrate Assemblage* and *Littoral Vegetation Diversity and Productivity*, and additional evaluation questions for short-term responses to watering for *Flow-cued Spawning Fishes*, is dependent on contingency monitoring (see Section 5.3).

5 Indicators

This section provides further details for each indicator of the Lower Murray, including background information, cause and effect diagrams (also see Figure 5.1), objectives and hypotheses, general methodologies, outputs and key staff involved. Basin-scale (Category 1) indicators are presented in Section 5.1, and Selected Area (Category 3) indicators are in Section 5.2.

The cause and effect diagram for selected indicators in the following sections and the general diagram for the Lower Murray (Figure 3.2) illustrate our conceptual understanding of the ecological processes and life histories of relevant biota, and the expected responses from Commonwealth environmental water delivery. Hypotheses are based on these concepts, and monitoring is designed to assess flow responses and ecological outcomes. This intervention monitoring approach allows strong inferences to be drawn regarding the contribution of Commonwealth environmental water to ecological outcomes in the Lower Murray. Additional monitoring, evaluation (contingent upon flow) and research (see Sections 5.3 and 6) will be conducted in conjunction with the core monitoring program. Data and knowledge developed will inform the evaluation and underpin adaptive management of environmental flow in the Lower Murray.

More details of the Standard Operating Procedures (SOPs) for each indicator are available in Appendix B. An annual budget for each indicator, along with a more detailed breakdown of the budget is provided in Section 13. A matrix table linking indicators to the ecological objectives for the Basin Plan, CEWO and Selected Area evaluation questions is presented in Appendix D.

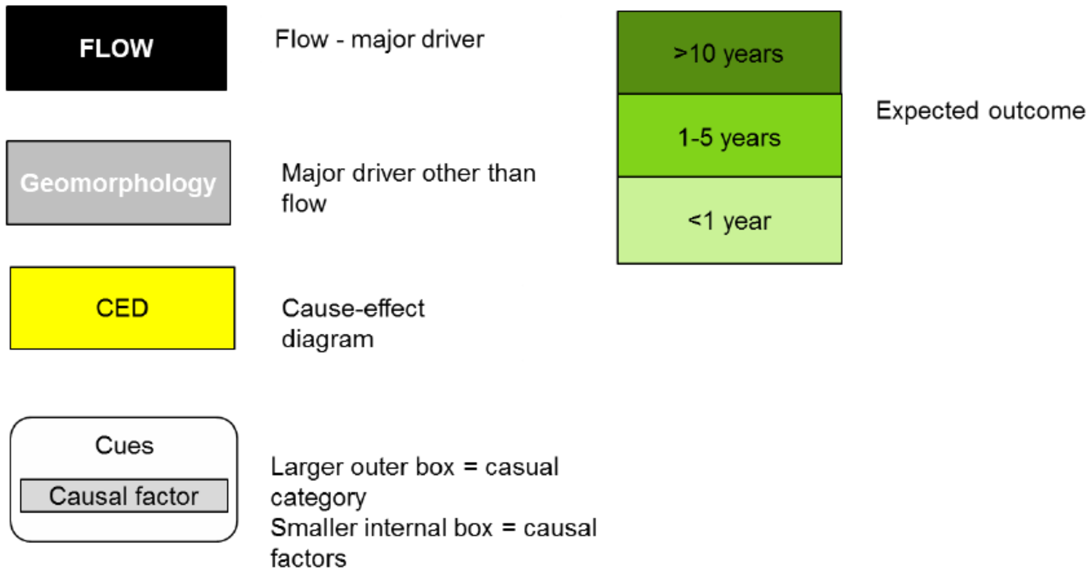


Figure 5.1. Key for cause and effect diagrams (taken from MDFRC 2013) that are provided in Sections 5.1 and 5.2.

5.1 Category 1.

5.1.1 Hydrology (Channel)

Indicators

- Recorded daily discharge and water level at available stations.

Background

The *Hydrology (Channel)* protocol describes a stage-based rating curve to determine daily discharge, using velocity measurements to derive the rating curve and the relationship between stage and discharge. The highly regulated Lower Murray Selected Area is not a free-flowing system where the downstream water level influences the discharge, so this approach is generally not appropriate. CEWO have advised that another approach can be used if the necessary accuracy can be achieved.

Daily discharge is currently calculated at all weirs (Locks 1–6) in South Australia within the necessary accuracy (within 10 percent), based on upstream and downstream water levels. A further station has recently been constructed on Katarapko Creek, and other sites may provide the necessary accuracy depending on the flow event, such as downstream of Chowilla regulator. Monitoring stations in the Lower Murray Selected Area that record water level, discharge or salinity at least daily can be seen in Figure 5.2. Given this existing coverage of stations, and the limited locations suitable for further stations to be installed, no further discharge stations are proposed as part of the MER Project.

Cause and effect diagram

No cause and effect diagram is provided for *Hydrology (Channel)*. Instead, hydrology can be seen to be present as a cause in all cause and effect diagrams and will be reported on as part of each indicator.

Key evaluation questions

This indicator does not directly address specific evaluation questions, rather it provides fundamental information for analysis and evaluation of monitoring outcomes against hydrological conditions and environmental watering for all indicators.

Objective

- Provide discharge and water level data to inform other indicators.

General methodology

Daily discharge will be monitored at each existing station using existing methods that provide the necessary level of accuracy (within 10 percent). Hydrological information collected from this part of the project will be used as an input for the analysis of many other indicators.

Refer to the Lower Murray Selected Area SOP for *Hydrology (Channel)* (Appendix B) for more information on the sampling protocol including sites, timing and equipment, and on data analysis and evaluation, data management and quality assurance/quality control measures. Refer to Section 7 for timing of monitoring activities and more information on sampling sites and zones.

Outputs

- A database of recorded daily discharge, provided if necessary. This data is already held in publicly available databases.

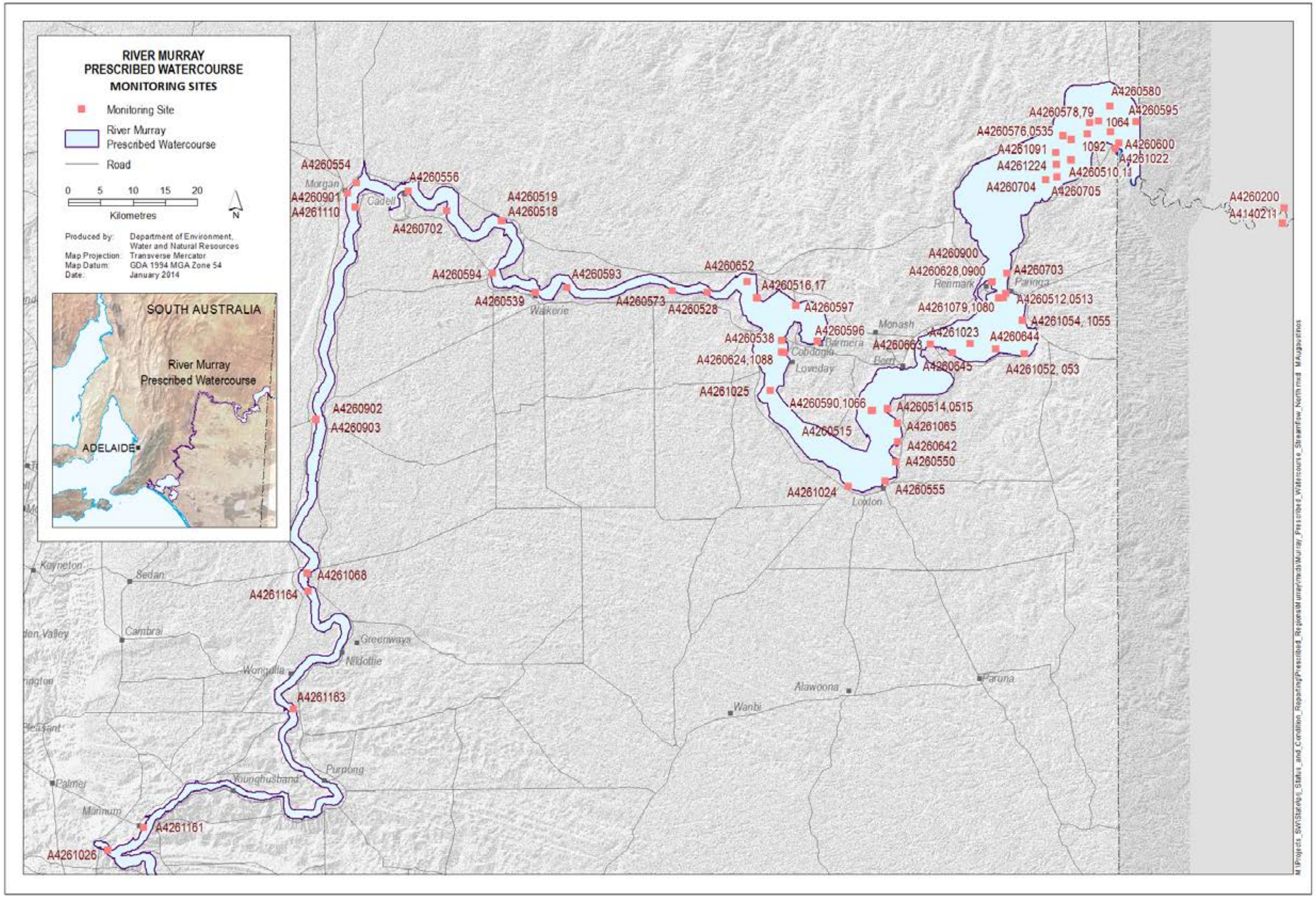


Figure 5.2. Monitoring stations in the Lower Murray Selected Area (SA border to Mannum). Most stations record level and salinity, and only some stations record daily discharge.

Staff

Dr Matt Gibbs ***University of Adelaide***

Dr Matt Gibbs is a hydrologist with 15 years' experience in the fields of water resources, modelling and optimisation techniques. As well as a Research Fellow at The University of Adelaide, he has a joint appointment as Principal Hydrologist at DEW. This joint appointment puts him in the unique position to have detailed knowledge of the progress of modelling and requirements within government, and of techniques and research developments to improve these methods. Matt has detailed knowledge of the River Murray and hydrological and hydraulic models available in South Australia, and has published recently in the fields of river restoration and hydraulics, uncertainty analysis, forecasting and salinity modelling.

5.1.2 Stream Metabolism and Water Quality

Indicators

Stream metabolism:

Dissolved oxygen concentrations and their diel fluctuations to assess the influence of environmental flows on:

- River dissolved oxygen concentrations supportive of biota
- Rates of photosynthesis
- Rates of ecosystem respiration including decomposition.

Water quality:

Concentrations of phytoplankton, nutrients, and organic carbon to identify:

- Phytoplankton contributions to photosynthesis and respiration
- Influence of organic carbon concentrations on ecosystem respiration
- Nutrient, phytoplankton and metabolism links to environmental flows

Background

Under the MER Project, stream metabolism is measured for two purposes (Hale *et al*. 2014):

- Inform the Basin-scale quantitative evaluation of fish responses to Commonwealth environmental water (see Lower Murray Selected Area SOP for *Fish (Channel)*, Appendix B)
- Detect changes in primary productivity and decomposition in the river in response to Commonwealth environmental water.

River metabolism measurements estimate the in-stream rates of photosynthesis and respiration and provide information on the energy processed through river food webs (Odum 1956; Young and Huryn 1996; Oliver and Merrick 2006). Metabolism measurements help identify whether the sources of organic material that provide the food resources have come from within the river (autochthonous) or from the surrounding landscape (allochthonous).

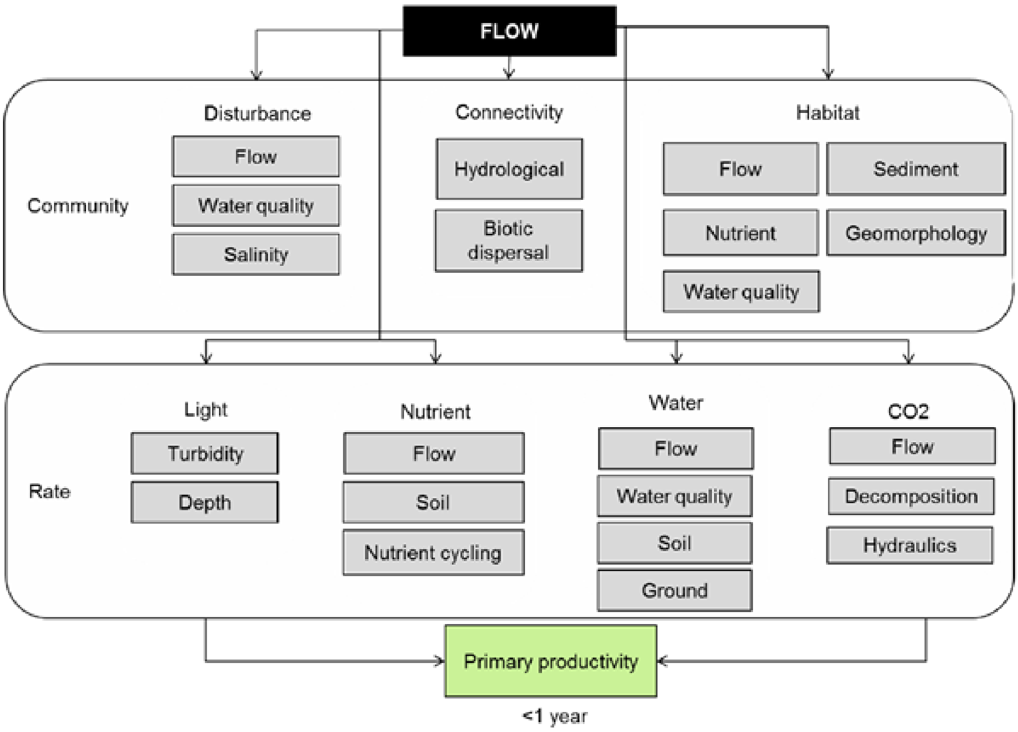
Stream metabolism can be measured by monitoring rates of change in the dissolved oxygen concentration over sequences of day and night cycles (diel changes). These changes in concentration are caused by the balance between photosynthetic oxygen production which occurs in the light, and oxygen depletion by respiration which occurs continuously. Suitable concentrations of dissolved oxygen are required for aquatic organisms to survive. Monitoring can inform on the mean oxygen levels, their changes in response to environmental flows, and likely impacts on the biota.

Measurements of stream metabolism describe the fundamental trophic energy connections that characterise different food web types (e.g. detrital, autotrophic). They indicate the size of the food web and its capacity to support higher trophic levels including fish and water birds (Odum 1956; Young and Huryn 1996; Oliver and Merrick 2006).

Water quality is included as a Basin Matter as it is one of the principal objectives of the Basin Plan, it is known to respond to changes in flow, and it can be a significant influence on the outcome of a watering action for biota (e.g. fish and waterbirds). There are instances where the objective of a watering action is the amelioration of reduced water quality (e.g. dissolved oxygen, salinity) to prevent disturbance to an ecosystem.

Cause and effect diagram

The cause and effect diagrams and background information presented in MDFRC (2013) for primary productivity and decomposition are applicable to this investigation. Refer to MDFRC (2013) for further details.



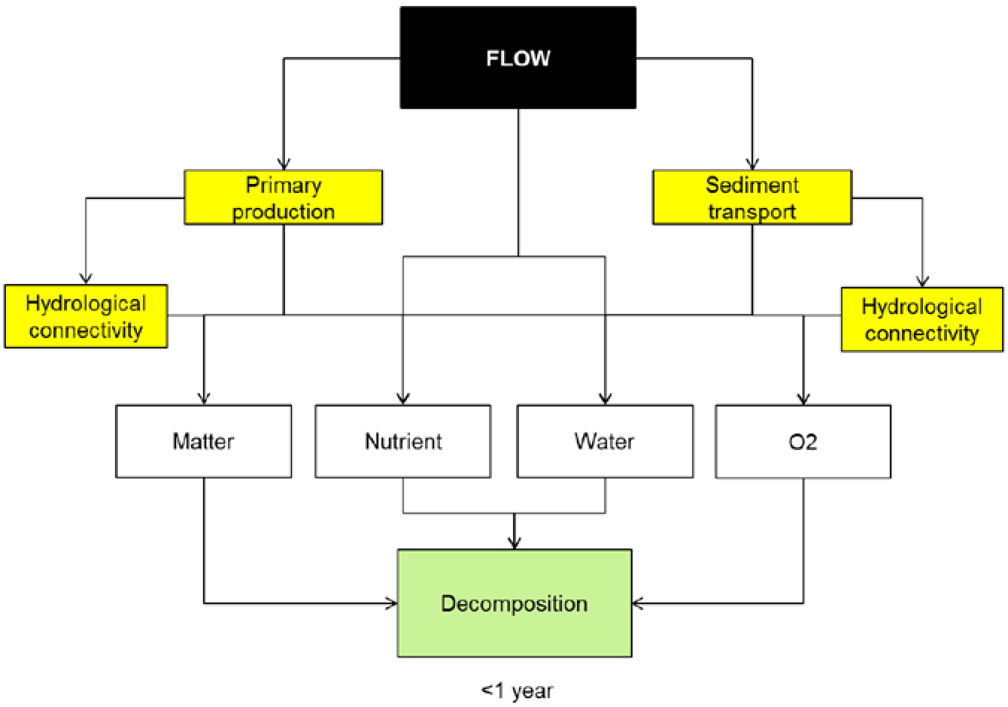


Figure 5.3. Cause and effect diagrams depicting the influence of flow on the components of *Stream Metabolism*, on primary productivity (top) and decomposition (bottom) (MDFRC 2013). Magnitude, timing and duration are factors of flow (in black).

Key evaluation questions

Basin and Selected Area evaluation questions (Hale *et al.* 2014):

- What did Commonwealth environmental water contribute to patterns and rates of decomposition?
- What did Commonwealth environmental water contribute to patterns and rates of primary productivity?
- What did Commonwealth environmental water contribute to dissolved oxygen levels?
- What did Commonwealth environmental water contribute to water quality?

Objectives and hypotheses

The objective of this indicator is to:

- Assess how environmental water influences primary production and ecosystem respiration in the river channel.

Major hypotheses are:

- During in-channel flows the transport of organic material from the floodplain is low and autochthonous carbon captured in-stream through photosynthesis is the major source of energy to the aquatic food webs.
- Water quality influences the growth of aquatic plants (microalgae and macrophytes) by modifying light and nutrient availability and influences the supply of autochthonous organic carbon to food webs.
- Increasing flow better connects the channel with riparian, wetland or floodplain areas and enhances the supply of allochthonous organic carbon to the river channel, leading to increased energy supplies and enhanced ecosystem respiration rates due to decomposition.
- Excessive loads of organic carbon increase respiration and decomposition rates and reduce dissolved oxygen concentrations to levels below those required by aquatic organisms, with potentially lethal effects.
- Increased energy supply due to enhanced aquatic photosynthetic production or enhanced supply of externally sourced organic carbon leads to increased food web size and complexity that can support larger populations of organisms dependent on aquatic systems for food supplies.

General methodology

This protocol is based on the single station open water stream metabolism method (Hale *et al.* 2014; Grace *et al. In Prep*).

Measurements of water level and stream characteristics including water velocity, channel cross-sectional area and average depth of sampling sites will be provided from established gauging stations in the Lower Murray in conjunction with site measurements during sampling trips. Discrete water quality samples will be collected for the analyses of chlorophyll-*a*, total nitrogen, NO_X, NH_4, total phosphorus, PO_4, and dissolved organic carbon. *In situ* logging of the dissolved oxygen concentration and temperature will provide data for estimating stream metabolism at two sampling sites selected to represent the two zones (Gorge and Floodplain) of the Lower Murray Selected Area, and an additional site situated between the two in the Floodplain zone. A terrestrial station logging photosynthetically active radiation (PAR) and barometric pressure to match the stream metabolism measurements will be established in a suitable nearby location.

Refer to the Lower Murray Selected Area SOP for *Stream Metabolism and Water Quality* (Appendix B) for more information on the sampling protocol including sites, timing and equipment, and on data analysis and evaluation, data management and quality assurance/quality control measures. Refer to Section 7 for timing of monitoring activities and more information on sampling sites and zones.

Data on water quality may be complemented by monitoring data collected through other relevant programs such as short-term monitoring instigated by CEWO and/or MDBA in response to planned watering actions or a potential water-quality event.

Outputs

- Annual reports on the stream metabolism in response to flow regime, including environmental water delivery, in the Lower Murray. The report will include:
  - Evaluation of the benefits of environmental flows to oxygen concentrations, primary production and ecosystem respiration
  - Assessment of the influences of water quality and connectivity on stream metabolism as related to environmental water
- Measurements of river metabolism suitable for Basin-wide comparisons
- Measurements of metabolism suitable for comparison with other aquatic indicators, especially fish population changes in response to environmental water.
- Data on pH, EC and turbidity in response to watering actions compiled from complementary sources.

Staff

Dr Rod Oliver ***University of Adelaide***

Rod Oliver was a senior Principal Research Scientist in CSIRO Land and Water for 30 years. Recently, he joined the University of Adelaide, and continues to contribute to the MER Project as the Stream Metabolism Task Leader. Rod has experience in aquatic ecology of reservoirs, lakes, rivers and wetlands. His research is aimed at understanding the effects of physical and chemical conditions on the population dynamics and community composition of phytoplankton, and how these interactions influence water quality, aquatic food webs, and ecosystem function. His current research is focussed on developing methods for assessing changes in the composition and activity of the micro-biota of riverine food webs using eco-physiological and molecular tools. This has included extensive use of stream metabolism measurements. He has numerous publications, including journal papers, articles, and book chapters.

Zygmunt Lorenz ***University of Adelaide***

Zygmunt Lorenz has an MSc in aquatic systems measurement and modelling with over 20 years experience working in the MDB. He recently played a critical role in the analysis of the Coorong Lower Lakes and Murray Mouth monitoring data for DEW through his computing and data management skills. The areas of direct research experience that are relevant to the MER Project are:

- Detailed knowledge of deploying, maintaining and managing electronic monitoring equipment including sensor systems, data loggers, GPS mapping, and remote communications. Experienced with design and construction of associated mounting frames and incubation chambers
- Experienced in aquatic sampling protocols for biota, water quality and physical attributes with extended experience measuring river metabolism and phytoplankton eco-physiology
- Extensive experience in planning and running complex field trips including operation of boats, vehicles, and sampling equipment
- Excellent computer programming skills in multiple languages including ‘R’, with experience in development and maintenance of large databases, large-scale statistical data analyses, and preparation of publication quality material

- Experienced with ecohydrological analyses of hydrographs and description of watering regimes (spell analyses, peak flows etc.).

5.1.3 *Fish (Channel)*

Indicators

- Fish diversity
- Fish population dynamics.

Background

River regulation and flow modification may have a profound impact on ecosystem processes and aquatic biota, including fish populations. In the MDB, declines in the abundance and distribution of native fish species have been associated with river regulation and other anthropogenic perturbations (MDBC 2013). This study was designed by the LTIM Basin-scale Provider (MDFRC) to address Basin-scale evaluation of the response of river fish (large- and small-bodied) to Commonwealth environmental water (for details see Hale *et al*. 2014). The standard method for fish sampling will continue to be applied during the MER Project.

Cause and effect diagram

The cause and effect diagram and background information presented in MDFRC (2013) for landscape fish diversity is applicable to this investigation (Figure 5.4). Refer to MDFRC (2013) for further details.

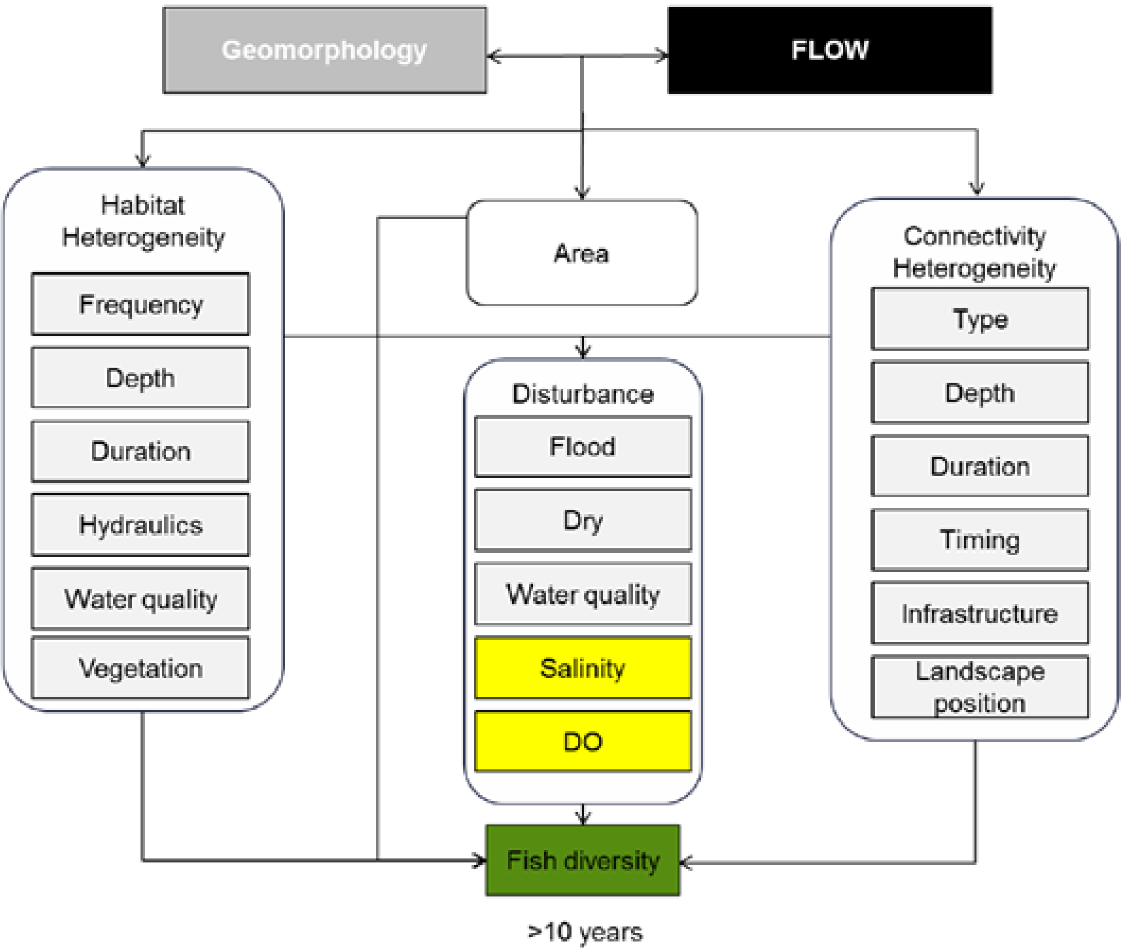


Figure 5.4. Fish (Channel) cause and effect diagram (MDFRC 2013). Magnitude, timing and duration are factors of flow (in black).

Key evaluation questions

This method does not include any Selected Area evaluation questions. Nevertheless, CEWO *Fish (Channel)* condition monitoring data will be consolidated to evaluate relevant fish targets of DEW's Long Term Watering Plan using the evaluation questions in Appendix D, which will be reported in an Appendix of the MER Annual Report.

Objective

The objectives of this indicator are to:

- Provide summary statistics of the catch rates and population demographics for key species.
- Determine temporal variation in large-bodied and small-bodied fish assemblage structures as well as the size/age compositions of key species.
- Discuss key findings based on published research and our current understanding of fish life histories and population dynamics in the Lower Murray.
- Consolidate CEWO *Fish (Channel)* condition monitoring data to evaluate relevant fish targets of DEW's Long Term Watering Plan.

General methodology

This protocol follows the methods outlined in Hale *et al.* (2014) with some modifications detailed in the most recent LTIM M&E Plan for the Lower Murray (SARDI *et al.* 2018). Sampling will occur in the Gorge zone each year using electrofishing (active sampling) and small-meshed fyke nets (passive sampling) to measure catch-per-unit-effort (CPUE) of fish species. Population structure (i.e. length, weight and age structure) data will be collected for target species. Target species include two equilibrium (Murray cod and freshwater catfish) and three periodic (golden perch, silver perch and bony herring).

Refer to the Lower Murray Selected Area SOP for *Fish (Channel)* (Appendix B) for more information on the sampling protocol including sites, timing and equipment, and on data analysis and evaluation, data management and quality assurance/quality control measures. Refer to Section 7 for timing of monitoring activities and more information on sampling sites within the zone.

Outputs

- Relative abundance estimation, population structure and community data will be submitted as described in Hale *et al*. (2014), complying with data standards as per Brooks and Wealands (2018).
- In the annual area evaluation reports, there will be quantitative analysis of data to determine temporal variation in large-bodied and small-bodied fish assemblage structures as well as the size/age compositions of key species.
- Patterns, based on outputs from above analysis, will be discussed based on published research and our current conceptual understanding of fish life histories and population dynamics in the Lower Murray River.
- Condition monitoring data will inform the evaluation of DEW's Long Term Watering Plan fish targets and Matter 8 expected outcomes.
- The analyses of Basin-scale community response to Commonwealth environmental water will be carried out by the MER Advisors. There are no CEWO evaluation questions for this indicator at Selected Area scale, therefore no evaluation will be undertaken. Our interpretations of the data for this indicator do not infer association with Commonwealth environmental water delivery.

Staff

Assoc. Prof. Qifeng Ye SARDI

Qifeng Ye is the Principal Scientist and Science Leader for the SARDI Inland Waters and Catchment Ecology (IWCE) Program. She has a range of skills and extensive research experience in fish and fishery biology and ecology and population dynamics, accumulated through 25 years of environmental and fishery related work. This has been done in freshwater, marine and estuarine systems in several countries. Qifeng has an excellent knowledge of the biology, habitat and environmental water requirements of native fish and the potential ecological impacts of river regulation. She has led and played a substantial role in a number of significant flow related ecology projects (including the CEWO LTIM and short-term intervention monitoring projects) in the MDB and the South East region of SA. Qifeng represents SA on the Murray-Darling Basin Fish Working Group. She is also a member of several science and management committees at State and national levels, including the national Murray Cod Fishery Management Group, National Carp Control Plan Science Advisory Group, and CLLMM Science Advisory Group.

Brenton Zampatti SARDI

Brenton is a Senior Research Scientist at SARDI Aquatic Sciences and has been conducting research on the flow-related ecology of freshwater and estuarine fish for the past 20 years. Brenton has a comprehensive understanding of the ecology and hydrology of rivers in the MDB and has published extensively on the ecology of fish throughout south-eastern Australia. Brenton has played a key role in a number of multi-disciplinary and cross-jurisdictional environmental water requirement (EWR) projects, including development of a multi-disciplinary technique for the establishment of EWRs for rivers in south-eastern Australian (FLOWS) and monitoring programs (VEFMAP) for the Victorian Government, and more recently the CEWO LTIM and EWKR projects. Brenton is currently undertaking large-scale research projects on the flow-related ecology of fishes throughout the Murray-Darling Basin, including the CLLMM region in SA. These projects are directly informing the management of water resources and river operations, including the delivery of environmental water by the MDBA and CEWO. Brenton is a member of numerous State and National working and advisory groups, including the MDB Fish Working Group, Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) Technical Advisory Group, MDBA EWKR fish leadership group, South Australia's River Murray Operations Working Group and the CLLMM Science Advisory Group.

George Giatas SARDI

George Giatas is a Research Officer at SARDI Aquatic Sciences (IWCE Program). Since 2012, he has contributed towards a variety of fish ecology research projects at SARDI in the Lower Murray and the CLLMM region. George has been involved in monitoring and evaluating the responses of ecological indicators to environmental water delivery through the CEWO short-term intervention monitoring (2012-13 and 2013-14) and LTIM (2014-15 to 2018-19) projects.

Arron Strawbridge SARDI

Arron Strawbridge is an experienced senior technical officer who has worked in the field of aquatic ecology and aquaculture for over 25 years. He has extensive experience running field, laboratory and mesocosm studies and has provided technical and field leadership on numerous projects including vegetation condition and intervention monitoring, seed bank assessments, electrofishing, fish condition monitoring and fish passage assessment. Arron also manages all project databases, field and laboratory equipment, vehicles and boats for the Plant Ecology Sub-program.

David Fleer ***SARDI***

David Fleer is a senior research services officer who has been working in the field of fisheries and environmental research for over 30 years. David is a highly experienced technical officer offering many skills and expertise in boating, fieldwork operations, and laboratory analyses including fish ageing and reproductive analysis. In the last six years, he has been the key technical support staff for the larval fish recruitment dynamics study, native fish monitoring and Murray River wetland surveys in the Lower Murray River for the Inland Waters research team.

Ian Magraith ***SARDI***

Ian Magraith is a senior technical services officer who has been working in the field of environmental research for over 25 years. Ian worked for the University of Adelaide Zoology and Botany Departments as a technical officer throughout the 1990s and early 2000s before joining SARDI in 2003. Ian is a highly experienced technical officer offering many skills and expertise in boating and fieldwork operations.

David Short ***SARDI***

David Short is a Senior Research Services Officer who has been working in the field of fisheries and environmental research for over 25 years. David is a highly experienced technical officer offering expertise in a large variety of fish sampling techniques including electrofishing, gill netting, seine netting and fyke netting, and holds a coxswains qualification. David is also highly skilled in database management and laboratory techniques including fish ageing and reproductive analysis. Over the last ten years, he has been the key technical officer for a number of important projects in the SA MDB, including the Coorong fish research and monitoring projects, the Sustainable Rivers Audit Project and Murray Fishway Program.

Luciana Bucater ***SARDI***

Luciana Bucater is an experienced fisheries ecologist, and has worked on a range of research over 15 years. She is particularly interested in fish biology, early life history of fish, and the application of GIS in fisheries research. She migrated from Brazil in 2004 and since then she has been involved in research both in NSW and SA. Since 2007 she has been part of the Inland Waters and Catchment Ecology team at SARDI Aquatic Sciences, having been involved in various projects assessing changes in fish assemblage associated with different flow scenarios in the Lower Murray River, Lakes and Coorong. Information generated from these work has been used extensively by the state government agencies in management of the region.

5.2 Category 3

5.2.1 Hydraulic Regime

Indicators

- Modelled daily discharge with and without Commonwealth environmental water
- velocity metrics with and without Commonwealth environmental water
- Modelled daily water level with and without Commonwealth environmental water
- Modelled area inundated at different durations with and without Commonwealth environmental water if appropriate (e.g. substantial overbank flows, exceeding 50,000 ML/d).

Background

The hydraulic characteristics (e.g. depth, water velocity, turbulence) of fluvial ecosystems result from the interaction of discharge and physical features (e.g. channel morphology, woody debris, man-made structures, etc.), and have a profound influence on river ecosystem structure and function (Statzner and Higler 1986; Biggs *et al.* 2005; Bice *et al.* 2017). Indeed, many riverine biota have life histories that are fundamentally linked to aspects of river hydraulics, and notably exhibit adaptations (e.g. drifting eggs and larvae) that confer dependence on *lotic* (flowing water) environments. Flow regulation in the Lower Murray, however, through a combination of reduction in overall discharge and construction of serial main channel weirs, has resulted in the transformation of a once lotic environment, to one that is predominantly *lentic* (lake-like) in character (Bice *et al.* 2017). In association, there have been declines and local extinction of lotic biota (Mallen-Cooper and Zampatti 2018). Promoting lotic habitats is critical to ecosystem rehabilitation in the Lower Murray, and may be achieved by two primary mechanisms: 1) increasing discharge volumes; and 2) lowering weir pools.

Ecological indicators that are likely to have detectable change in response to hydraulic characteristics (e.g. microinvertebrates, Murray cod, littoral vegetation) have been intentionally selected as part of this MER Plan. As such, detailed spatial and temporal information on the change in hydraulic regime due to changes in hydrology, i.e. flow and the delivery of Commonwealth environmental water, is beneficial to report on hydraulic indicators, as well as to inform the assessment and interpretation of the ecological responses.

Modelling will be used to upscale monitoring to the regional scale, to provide other variables such as velocity, and to simulate conditions with and without Commonwealth environmental water. Pre-processed outputs from hydrodynamic (MIKE FLOOD) models for the river channel between Lock 1 and Lock 5 will be used in combination with the hydrological (Source) model to simulate the with and without Commonwealth environmental water conditions that occur each year, simulating daily discharge, water levels and velocity for each weir pool. This modelling provides a direct indication of the contribution of environmental water to hydraulic changes in the river, which are one of the main drivers for biological responses to environmental water. This information will be reported as metrics (i.e. proportion of the reach in different velocity classes), as well as an input to the assessment of outcomes for other ecological indicators.

Cause and effect diagram

No individual cause and effect diagram is provided for *Hydraulic Regime*. Instead, the hydraulic regime can be seen to be present as a cause in all cause and effect diagrams.

Key evaluation questions

Selected Area questions for evaluating short-term responses (adapted from Hale *et al.* 2014):

- What did Commonwealth environmental water contribute to hydraulic diversity within weir pools?

- What did Commonwealth environmental water contribute to in-channel variability in water levels?

Selected Area questions for evaluating long-term outcomes (adapted from Hale *et al.* 2014):

- What did Commonwealth environmental water contribute to hydrological connectivity?
- What did Commonwealth environmental water contribute to meeting Environmental Water Requirements (of the South Australian Murray River Long-Term Watering Plan) in the main channel of the Lower Murray?

Objective and hypothesis

The objective of this indicator is:

- Assess how Commonwealth environmental water has contributed to an increase in discharge, area, velocity and water level at a high spatial and temporal resolution. Inundated area will also be reported if overbank flows occur.

The hypothesis is:

- Commonwealth environmental water will promote greater extent of lotic habitat as evidenced by increased water velocities and variability in water levels

General methodology

This indicator will make use of MIKE FLOOD hydrodynamic models that have been developed and used in the region (e.g. DHI 2014, McCullough *et al.* 2017). These models take the upstream flow and any structure settings (for example weir pool levels) as an input, and calculate hydraulic variables (e.g. velocity, water level) within the model domain. This is a very computationally demanding process, typically in the order of a number of days to simulate a period of a few months, over the domain of one weir pool.

This methodology used for this indicator will simulate a wide range of flow and structure settings, to calculate the hydraulic variables of interest in pre-processed tables that can be related to the hydrological conditions, both with and without environmental water. These tables also provide useful information to inform environmental watering decisions, where changes in hydraulic metrics due to changes in flow or infrastructure can be looked up directly, to inform the scale of changes that could be expected from a given management decision.

The Source hydrological model will be used to simulate flow hydrographs at the SA border throughout SA, accounting for travel time, losses and diversions. This model will also be used to interpolate the hydraulic lookup information each day, to provide time series representing the hydraulic regime. The metrics proposed to be included in proportion of each weir pool (weir pools 1 – 5) exceeding 0.3 m/s, representing lotic habitat, range in velocity within each weir pool (as the 10th, 50th and 90th percentiles) and the water level at the upper extent of each weir pool, as the most responsive location to changes in flow.

Outputs

- Annual reports including an assessment of the contribution of Commonwealth environmental water provisions to the variables above, presented as ecologically meaningful metrics (proportion of the reach in different velocity classes and variability in water level in association with discharge and weir pool manipulation)
- Model outputs of discharge, water level and velocity with and without the provision of Commonwealth environmental water provided in a format suitable for database entry.

<u>Staff</u>

Dr Matt Gibbs ***University of Adelaide***

Refer to Section 5.1.1 for staff capabilities.

5.2.2 Matter Transport and Coorong Habitat

Matter Transport

Indicator

Modelled concentrations and transport (loads) of:

- Salt
- Dissolved and particulate nutrients
- Phytoplankton biomass (chlorophyll *a*).

Background

Flow provides habitat and resources for aquatic organisms by altering the concentrations and transport of dissolved and particulate matter. Ultimately this governs the physiology, distribution and abundance of organisms. Here we consider dissolved and particulate matter to include:

- Salinity, which is a measure of total dissolved salts and is a particularly important parameter governing the distribution and abundance of aquatic biota. Salinity is strongly influenced by flow through the alteration of groundwater inputs, evapo-concentration and in estuarine habitats, incursions of seawater (Brookes *et al.* 2009; Aldridge *et al.* 2011; Aldridge *et al.* 2012; Mosley *et al.* 2012).
- Dissolved inorganic nutrients, which are readily assimilated by biota and are essential resources for growth and survival (Poff *et al.* 1997). Nitrogen, phosphorus and silica are particularly important because they often control the productivity of aquatic ecosystems. Flow results in the mobilisation and transport of dissolved nutrients through the leaching of nutrients from dried sediments and dead organic matter.
- Particulate organic nutrients (phosphorus and nitrogen), which are those nutrients incorporated into the tissue of living and dead organisms. Flow can influence particulate organic nutrient concentrations and transport through a number of mechanisms, including through increased productivity associated with elevated dissolved nutrient concentrations.
- Chlorophyll *a*, which is a measure of phytoplankton biomass, with phytoplankton being an important primary producer of riverine ecosystems. Flow can influence chlorophyll *a* concentrations and transport through increased phytoplankton productivity.

Altering the flow regime of riverine systems has significant consequences for the concentrations and transport of dissolved and particulate matter (Aldridge *et al.* 2012). For example, reduced flow can result in: salinisation through evapo-concentration and the intrusion of saline water; reduced nutrient concentrations due to decreased mobilisation of nutrients from the floodplain; and reduced primary productivity because of nutrient limitation, leading to reduced secondary productivity. Such observations have been made in the Lower Murray, including the Lower Murray Selected Area, Lower Lakes and Coorong (Brookes *et al.* 2009; Aldridge *et al.* 2011; Aldridge *et al.* 2012; Mosley *et al.* 2012). Environmental flow provisions may be used to reinstate some of the natural processes that control the concentrations and transport of dissolved and particulate matter, and may provide ecological benefits by doing so.

Relationships between flow and the transport of dissolved and particulate matter are relatively well established within the Lower Murray (Brookes *et al.* 2009; Aldridge *et al.* 2011; Aldridge *et al.* 2012; Mosley *et al.* 2012). Increased flows will lead to the mobilisation of dissolved and particulate matter from local and upstream sources through the inundation of the floodplain and resuspension of matter from the riverbed (Figure 5.5). This will influence dissolved oxygen levels, salinity levels, rates of nutrient and carbon cycling, primary production, decomposition and the occurrence of algal blooms

(Aldridge *et al.* 2012). Increased flows will also lead to increased channel mixing and flow velocities, which will transport this matter to downstream ecosystems (Figure 5.5).

Targets for salt export

There is approximately 10^{11} tonnes of salt in groundwater in the MDB and an additional 1.5 million tonnes of salt is deposited in the basin each year by rainfall (Herczeg *et al.* 2001). Unless salt is exported from the basin with flow there will be a net accumulation of salt within the basin. The Basin Plan sets out a salt export objective (section 9.09) to ensure adequate flushing of salt from the River Murray system into the Southern Ocean. The Basin Plan's indicative figure for salt export from the basin is 2 million tonnes per year.

The four years of salt export modelling enable the contribution of environmental flows to salt export to be scrutinised (Table 5.1). Flow was relatively low in three of the four years of LTIM monitoring. It is evident that in the low flow years (2014-15, 2015-16 and 2017-18) the Commonwealth environmental water plays a key role in salt export from the Basin. Commonwealth environmental water accounted for 64% of salt export in 2014-15, 87% of salt export in 2015-16 and 69% of salt export in 2017-18. In the high flow year (2016-17), 1.5 million tonnes was exported and the Commonwealth environmental water contributed 8% of salt export.

Table 5.1. Four year record of salt export (tonnes) over the barrages to the Coorong.

Flow scenario	**Year**			
	2014-15	**2015-16**	**2016-17**	**2017-18**
With all water	446,855	288,516	1,504,541	349,893
No CEW	161,791	36,884	1,383,674	109,171
No eWater	152,406	31,031	1,317,791	48,923

Cause and effect diagram

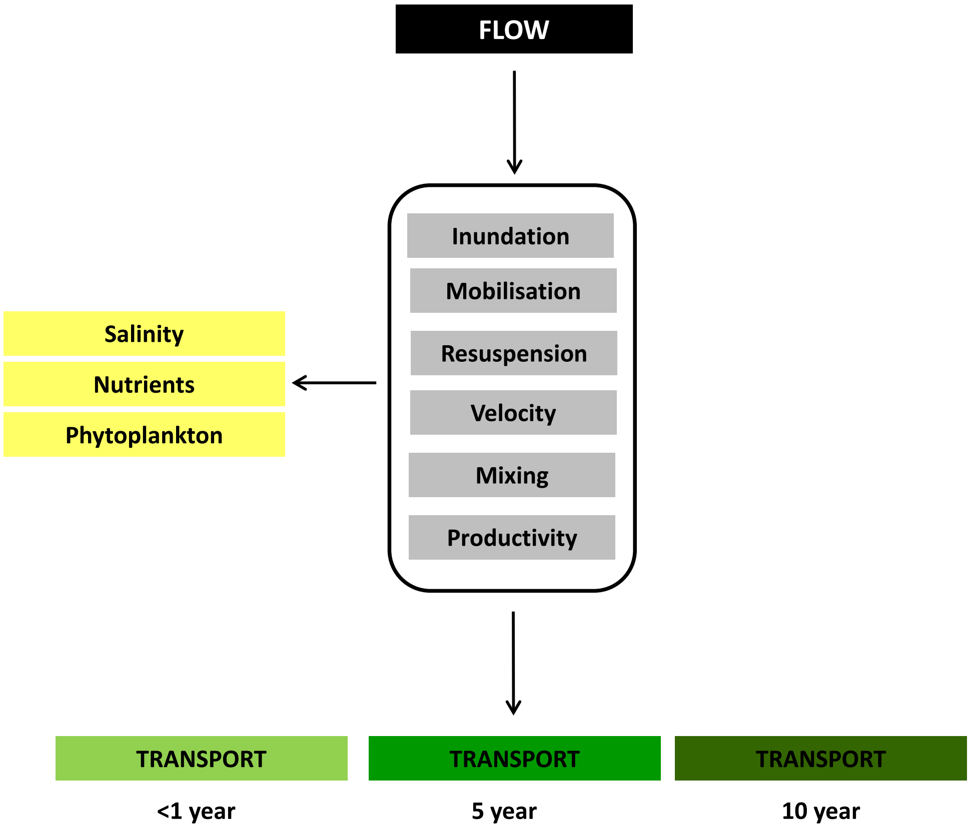


Figure 5.5. Matter Transport cause and effect diagram. Magnitude, timing and duration are factors of flow (in black).

Key evaluation questions

Selected Area evaluation questions (adapted from Hale *et al.* 2014):

- What did Commonwealth environmental water contribute to concentrations and transport of phytoplankton?
- What did Commonwealth environmental water contribute to salinity levels and transport?
- What did Commonwealth environmental water contribute to nutrient concentrations and transport?
- What did Commonwealth environmental water contribute to water quality?

Objectives and hypotheses

The objective of this indicator is to:

- Assess whether Commonwealth environmental water has increased the transport and export of salt, nutrients and phytoplankton through the Lower Murray.

Major hypotheses are:

- Commonwealth environmental water will increase the mobilisation of salts from the Basin and increase the transport of salt passing from Lock 1 through to the Lower Lakes and Murray Mouth
- Commonwealth environmental water will increase the mobilisation of nutrients from the Basin and increase nutrient loads passing from Lock 1 through to the Lower Lakes and Murray Mouth

- Commonwealth environmental water will increase the load of phytoplankton biomass passing from Lock 1 through to the Lower Lakes and Murray Mouth.

General methodology

This component will use the coupled hydrodynamic-biogeochemical model TUFLOW-FV-AED, developed by BMTWBM and the University of Western Australia. TUFLOW-FV is now used extensively in the region for hydrological purposes. A single model domain was applied spanning Lock 1 to the Southern Ocean, including the Coorong. For detailed information on the proposed modelling approach refer to Ye *et al.* (2016b). Although outside of the Lower Murray Selected Area, incorporation of Coorong, Lower Lakes and Murray Mouth increases the capacity of the MER Project to demonstrate outcomes within other areas and allows an assessment of exports to the Southern Ocean.

No data will be collected through this indicator, but validation of the models will rely solely on monitoring data (i.e. water temperature, electrical conductivity, dissolved oxygen, pH and turbidity, and water samples to be analysed for nutrients) that will be collected by complementary monitoring programs.

Refer to the Lower Murray Selected Area SOP for Matter transport (Appendix B) for more information on the sampling protocol including sites, timing and equipment, and on data analysis and evaluation, data management and quality assurance/quality control measures. Refer to Section 7 for timing of monitoring activities and more information on sampling sites and zones.

Outputs

- Annual reports describing changes in dissolved and particulate matter associated with river flows and environmental conditions between Lock 1 and the Southern Ocean, and an assessment of the contribution of Commonwealth environmental water delivery to those changes. Depending on the availability of validation data, model outputs may be limited to changes between Lock 1 and Wellington.
- A database to assess the response of dissolved and particulate matter to flows from Lock 1 to the Southern Ocean
- A validated hydrodynamic–biogeochemical model from Lock 1 to the Southern Ocean.

Staff

Professor Justin Brookes In Fusion Consulting/University of Adelaide

Justin Brookes is a limnologist with a broad interest in the biogeochemistry, primary productivity, phytoplankton and aquatic ecology, and the ecological functioning of stream, lake and estuarine ecosystems. Justin's research focuses on human impacts upon natural inland water ecosystems and on providing tools for better management of these systems. Justin has considerable experience in developing tools to assist determination of flow requirements and resource delivery to the Lower Murray Lakes and Northern Coorong. Justin has also been involved in numerous projects assessing changes in water quality in the Lower Murray Selected Area associated with river flows. Information generated from this work has been used extensively by state government agencies in management of the region.

Assoc. Prof. Matt Hipsey University of Western Australia

Matt Hipsey is an Associate Professor at the University of Western Australia and leads a research group active in the area of aquatic system modelling. He has a long history of developing coupled hydrodynamic–biogeochemical–ecological model platforms, particularly for lakes, rivers and estuarine environments. Since 2008 he has had an active role in developing 3D model systems for the region from Lock 1 to the Coorong, including assessing the impacts of drought and floods on water quality parameters such as nutrients, phytoplankton and geochemistry. These models have been used by state government agencies to manage the region and will be built upon for the MER Project.

Brendan Busch University of Western Australia

Brenton Busch is a Senior Research Engineer at the University of Western Australia. Brendan manages field and remote sensing data, and setup and assessment of computer models for the Aquatic Ecodynamic Research group (AED). His expertise was developed from extensive experience in the design and implementation of monitoring programs, which started as the Field Operations Manager for the Centre for Water Research (UWA) in 2006. In his current role, Brendan is also responsible for the design and creation of the AED group's data and model processing platforms, specialising in data analysis within the MATLAB computing environment.

Coorong Habitat

Indicators

- Modelled salinity concentrations
- Modelled water level
- Modelled extent of fish habitat, based on salinities
- Modelled extent of *Ruppia* habitat, based on environmental conditions.

Background

Freshwater flows are important in maintaining estuarine habitat and ecosystem health of the Coorong (Brookes *et al.* 2009). *Ruppia tuberosa* is an important macrophyte in the Coorong that provides habitat for fish and food for herbivorous birds in the Coorong (Phillips and Muller 2006). The germination and growth of *Ruppia* is known to be governed in large part by the salinity and water level regimes which are influenced by flows through the barrages (Kim *et al.* 2013). Other factors that influence *Ruppia* growth include nutrient availability, water temperature, sediment quality and interactions with algae, including shading of light and interference with flowers and fruits on the surface. Early summer flows are likely to be particularly beneficial as they delay the drop in water level in the South Lagoon and can prevent extreme salinities emerging, thereby encouraging a more complete reproductive cycle. In addition, salinity has also been identified as the key driver that influences fish assemblage structure and the extent of estuarine fish habitat in the Coorong (Ye *et al.* 2011). This sub-project aims to assess the benefits of environmental flows for the enhancement of *Ruppia* habitat, particularly those that are delivered in summer, as well as the improvement of estuarine fish habitat for several key species with different levels of salinity tolerance.

Cause and effect diagram

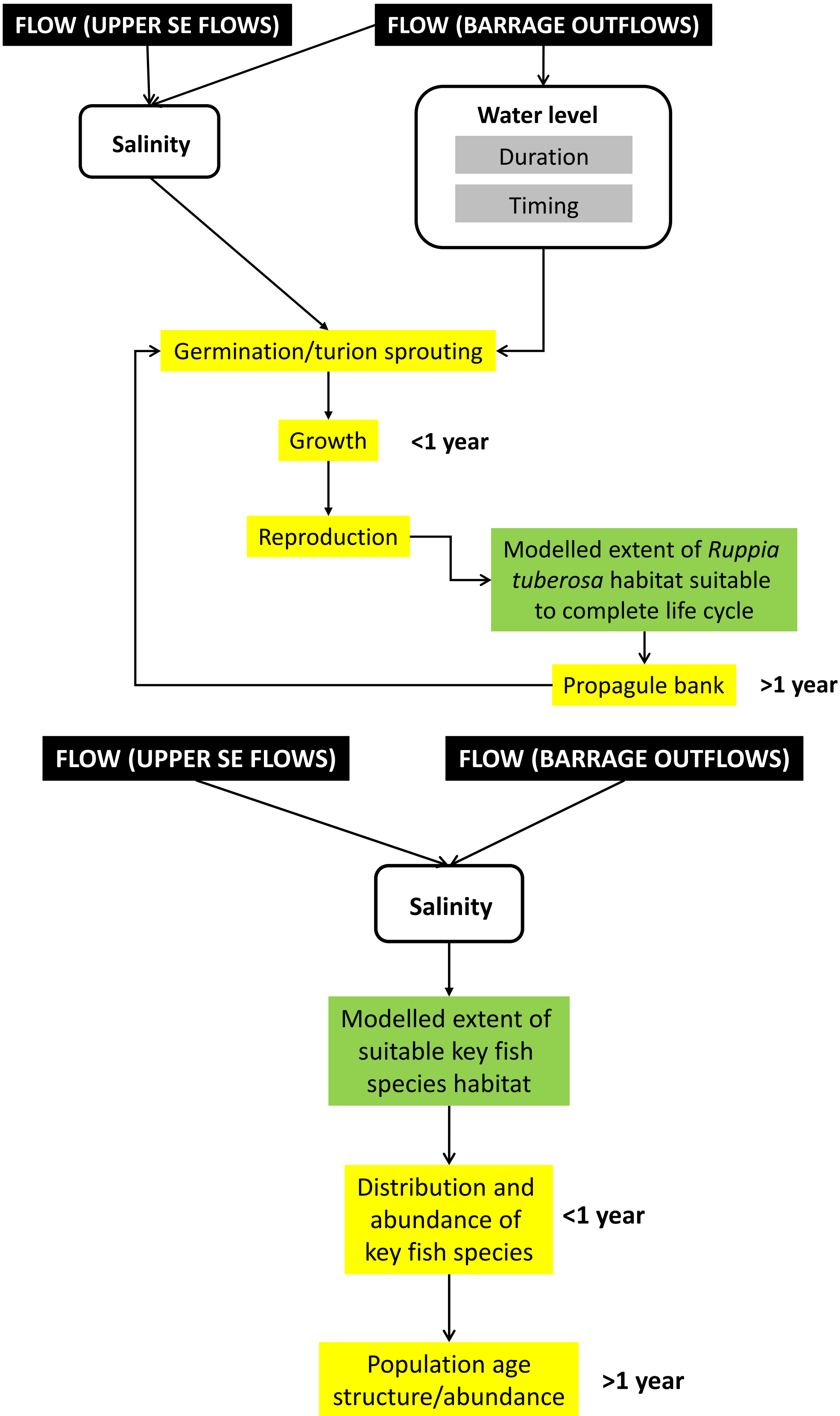


Figure 5.6. Coorong *Ruppia* (top) and fish (bottom) habitat cause and effect diagram. Magnitude, timing and duration are factors of flow (in black).

Key evaluation question

Selected Area evaluation questions:

- What did Commonwealth environmental water contribute to improving *Ruppia tuberosa* habitat in the Coorong?
- What did Commonwealth environmental water contribute to improving fish habitat in the Coorong?

Objectives and hypotheses

The objective of this indicator is to:

- Assess whether Commonwealth environmental water has enhanced *Ruppia tuberosa* and fish habitats in the Coorong, through reduced salinity and increased water levels.

The hypothesis is:

- Increased freshwater flow through the barrages and into the Coorong due to environmental watering will reduce salinity and increase water levels in the Coorong, thus enhancing the extent of *Ruppia tuberosa* and fish habitats.

General methodology

This project will use the 2D CLLMM model system based on the AED2 platform (Hipsey *et al.* 2019), to simulate water level and salinity, spanning from the Lower Murray to the southern end of the South Lagoon. The hydrodynamic model is based on daily river flows, oceanic and meteorological conditions, and barrage operation logic. Salinities and water level along the North and South Lagoon of the Coorong are calculated at a fine 2D resolution, allowing analysis of suitable areas of habitat. The model has been validated in detail against available water level and salinity monitoring across the Coorong in collaboration with DEW.

Results of salinities and water levels from simulations with and without environmental water scenario will be used to simulate habitat characteristics for *Ruppia tuberosa* as well as fish species based on *Ruppia tuberosa* and fish ecological response models (Collier *et al*. 2017; Ye *et al.* 2016b). As part of the Optimising *Ruppia* Habitat project (Collier *et al.* 2017), the *Ruppia* ecological response model has capability to account for habitat suitability of critical life stages, and is able to estimate the probability of replenishing the sediment seed-bank based, turion sprouting, seedling development to juvenile plants, and adult plant flowering and seed setting. Each stage is assigned a suitability based on cell specific light, depth, salinity and temperature, which in the end results in a combined probability of sexual or asexual life-cycle completion (e.g. Figure 5.7). A basic fish model calculates probabilities of habitat suitability for juveniles of key species based on salinity thresholds of key fish species including mulloway, black bream, greenback flounder, yelloweye mullet, congolli, Tamar goby and smallmouth hardyhead.

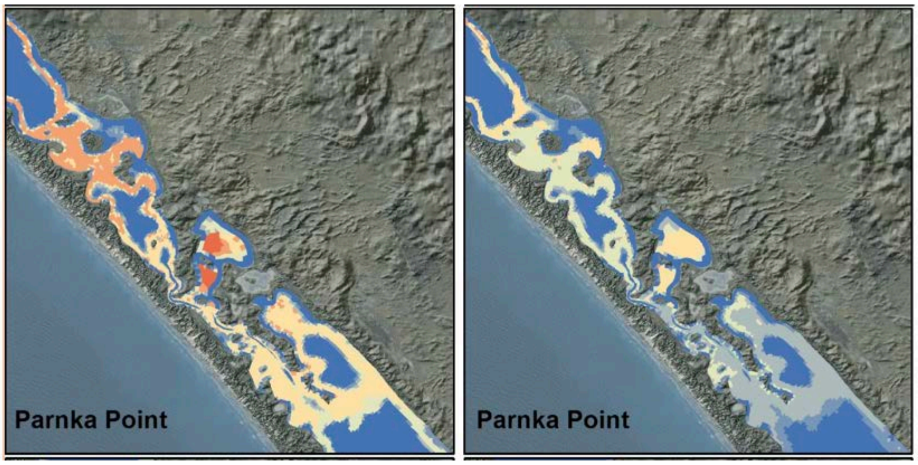


Figure 5.7. Coorong *Ruppia tuberosa* habitat suitability map under two different water level histories, generated by the AED2 model.

Refer to the Lower Murray Selected Area SOP for *Coorong Habitat* (Appendix B) for more information on the modelling protocol, data analysis and evaluation, data management and quality assurance/quality control measures.

Outputs

- Annual reports describing predicted changes in habitat suitability for *Ruppia* and fish (based on modelled salinity and water levels) in the Coorong associated with barrage flows and configurations, and an assessment of the contribution of Commonwealth environmental water delivery to those changes.
- Model outputs of salinity and water level with and without the delivery of Commonwealth environmental water provided in a format suitable for database entry.

Staff

Prof. Justin Brookes In Fusion Consulting/University of Adelaide

Assoc. Prof. Matt Hipsey University of Western Australia

See section above (Matter Transport) for staff capabilities.

Dr Matt Gibbs University of Adelaide/Department for Environment and Water

Refer to Section 5.1.1 for staff capabilities.

Assoc. Prof. Qifeng Ye SARDI Aquatic Sciences

Refer to Section 5.1.3 for staff capabilities.

Dr Jason Nicol SARDI Aquatic Sciences

Jason Nicol is an experienced aquatic and riparian plant ecologist who has worked extensively throughout south-eastern Australia over the past 21 years. He has excellent knowledge of the aquatic and riparian vegetation the lower Murray and Darling Rivers and current research activities in the Murray-Darling Basin include: impacts of altered hydrological regimes, plant recruitment, environmental water requirements, ecological risk assessment, restoration ecology, condition and intervention monitoring and seed banks. He has established two The Living Murray condition monitoring programs (Chowilla Floodplain commencing in 2006 and Lower Lakes commencing in 2008) and the intervention monitoring program at the Chowilla Floodplain Icon Site. Jason has authored or co-authored over 120 publications including book chapters, papers in peer review journals, conference presentations, technical reports and management plans and successfully delivered over 60 projects as principal investigator.

5.2.3 Littoral Vegetation Diversity and Productivity

Indicators

- Littoral understorey vegetation functional and biological diversity.
- Littoral understorey vegetation above-ground biomass.

Background

Littoral (streambank) vegetation is an important component of the biota of riverine ecosystems. Littoral vegetation is an important primary producer for both the riverine and terrestrial ecosystem (e.g. Roberts and Ganf 1986; Froend and McComb 1994), can improve water quality (e.g. Kadlec and Wallace 2009; Maddison *et al.* 2009; Li *et al.* 2010; Borin and Salvato 2012), oxygenate the sediment and water column (e.g. Blom *et al.* 1990; Sorrell and Hawes 2010; Dickopp *et al.* 2011) provide habitat for water birds (e.g. Jansen and Robertson 2001; Kapa and Clarkson 2009) and invertebrates (e.g. Papas 2007; Walker *et al.* 2013) and stabilise banks (e.g. Abernethy and Rutherfurd 1998). Littoral zones are also hot spots for biodiversity because they contain a specialised group of species adapted to wetting and drying not found in aquatic or terrestrial systems (Sabo *et al.* 2005).

Littoral vegetation responds rapidly to changes in water level (e.g. Nicol *et al.* 2018), with most species recruiting as water levels recede (e.g. Nicol 2004; Capon 2007). Maintaining stable water levels in lower weir pools can result in small increases in flow causing large water level rises in tailwaters immediately downstream of weirs (Maheshwari *et al.* 1995). Therefore, tailwaters represent areas where floodplain and amphibious vegetation can persist in the absence of over bank flows over a wide range of the elevation gradient (Blanch *et al.* 1999, Blanch *et al.* 2000). These water level changes make tailwaters an ideal location to evaluate the benefit of Commonwealth environmental water as the volumes available for delivery by the CEWO will have a significant impact on water levels. The response of the vegetation along the elevation gradient in tailwaters can then be exploited to evaluate the benefit of Commonwealth environmental water.

Cause and effect diagram

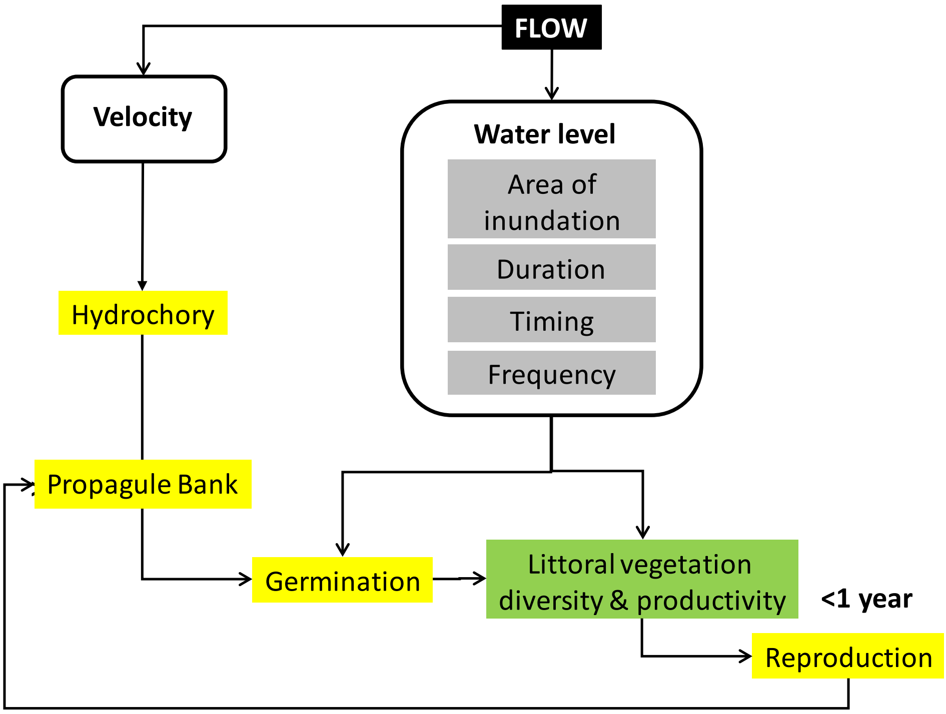


Figure 5.8. Littoral Vegetation Diversity and Productivity cause and effect diagram.

Key evaluation questions

Selected Area evaluation questions:

- What did Commonwealth environmental water contribute to littoral understorey vegetation diversity and productivity?
- What did Commonwealth environmental water contribute to above-ground biomass produced by understorey littoral vegetation?

See additional evaluation questions for long-term outcomes in contingency monitoring (Section 5.3).

Objectives and hypotheses

The objectives of this indicator are to:

- Compare and contrast the response of the littoral vegetation to different environmental water deliveries.
- Compare the response of the littoral vegetation across the elevation gradient.
- Compare understorey vegetation biomass across the elevation gradient.
- Use flood inundation modelling to identify the differences in water level and inundation duration with and without Commonwealth environmental water (and other environmental water) to identify the contribution of environmental water to littoral vegetation diversity and productivity by comparison across the elevation gradient.

Major hypotheses are:

- Increases in flow above regulated entitlement flow will result in increased water levels in the littoral zone that will facilitate the recruitment of floodplain and amphibious understorey species and in turn increase biological and functional diversity of the littoral zone plant community.
- The increase in water level due to increases in flow above regulated entitlement flow will result in increased productivity of littoral vegetation compared to areas not inundated.

General methodology

Sampling of littoral vegetation will occur in weir pool tailwaters downstream of Lock 4 and Lock 1 to correspond with sampling locations of other indicators. At each site, a transect running perpendicular to elevation contours will be established from normal pool level to the elevation inundated by flows of 40,000 ML/d (this flow level is the extent of the Channel PEA in South Australia but transects may extend beyond this elevation if flows exceed 40,000 ML/d). Quadrats will be positioned on the transect depending on water delivery. Figure 5.9 represents the impact on water levels when Commonwealth environmental water is delivered to increase flow magnitude. In this scenario, quadrats will be positioned at an elevation above the maximum water level, in the zone inundated by the addition of Commonwealth environmental water, in the zone inundated by the addition of other environmental water and in the zone inundated without the addition of any environmental water. Placing quadrats in these zones will give an indication of the benefit of Commonwealth environmental water comparing species richness and productivity between zones. It will also provide an estimate of littoral vegetation biomass produced by Commonwealth environmental water.

Figure 5.10 represents the predicted benefit of inundation duration on diversity or productivity of littoral vegetation. It is predicted that increased duration of inundation will result increased productivity and diversity to a point, after which there will be no further benefit (e.g. the soil profile is saturated and increased duration of inundation does not result in further water availability during draw down) (e.g. Ganf *et al.* 2010). In a scenario when Commonwealth environmental water is used to increase inundation duration, quadrats will be placed at regular intervals on the elevation gradient at elevations that correspond to a point that was inundated for a certain duration (Figure 5.11). For example, Figure 5.11 shows potential quadrat placement for a flow pulse of 50 days with quadrats positioned on points that were inundated between zero and 50 days with 5 day intervals. The number and position of quadrats would depend on the magnitude and duration of the flow pulse. The relationships between inundation duration and productivity and diversity will be determined and the benefit of Commonwealth environmental water will be estimated using this relationship comparing the inundation duration with and without Commonwealth environmental water.

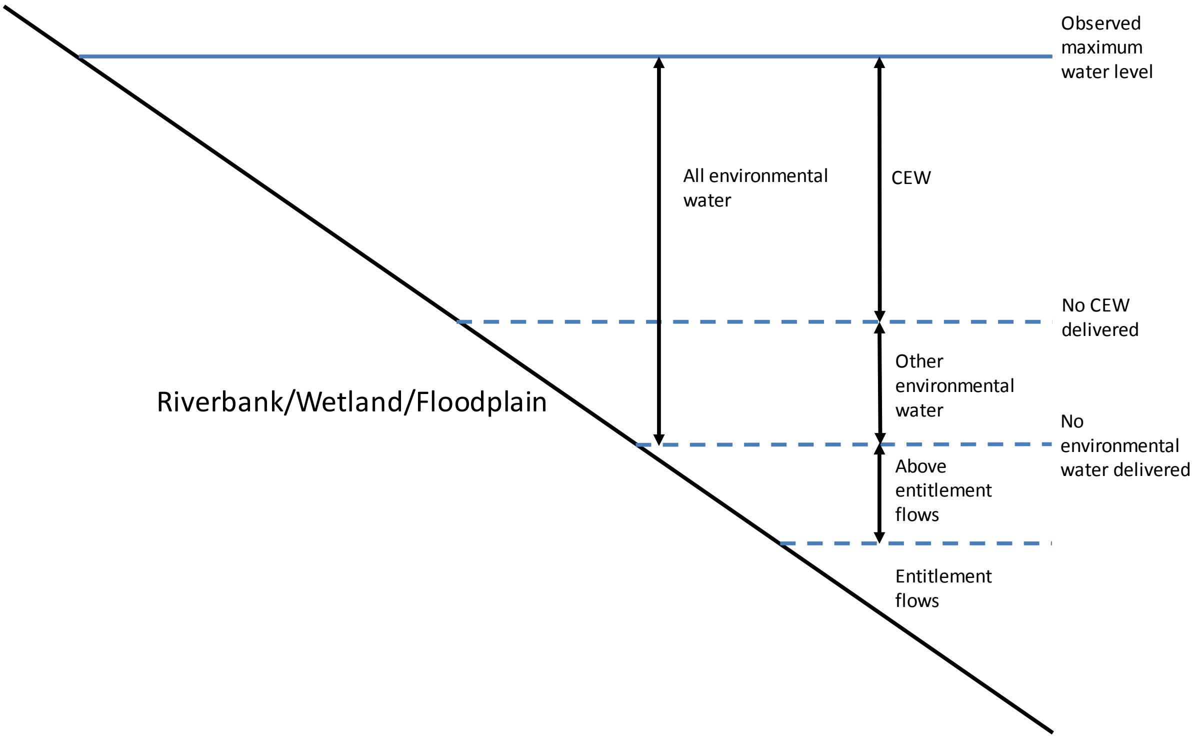


Figure 5.9. Vegetation sampling zones based on delivery of Commonwealth environmental water increasing flow magnitude.

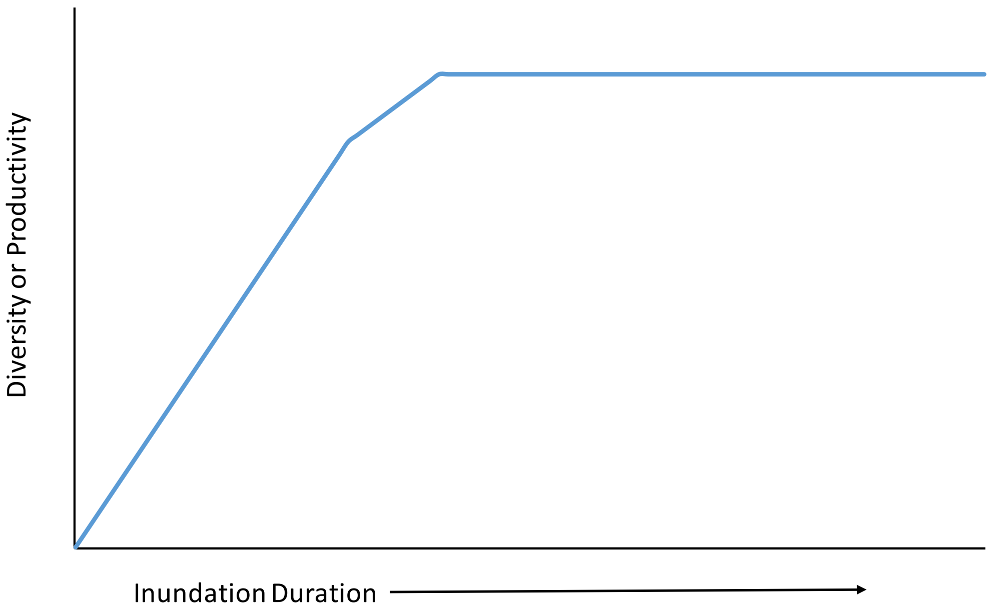


Figure 5.10. Predicted benefit of increased inundation duration on diversity or productivity of littoral vegetation.

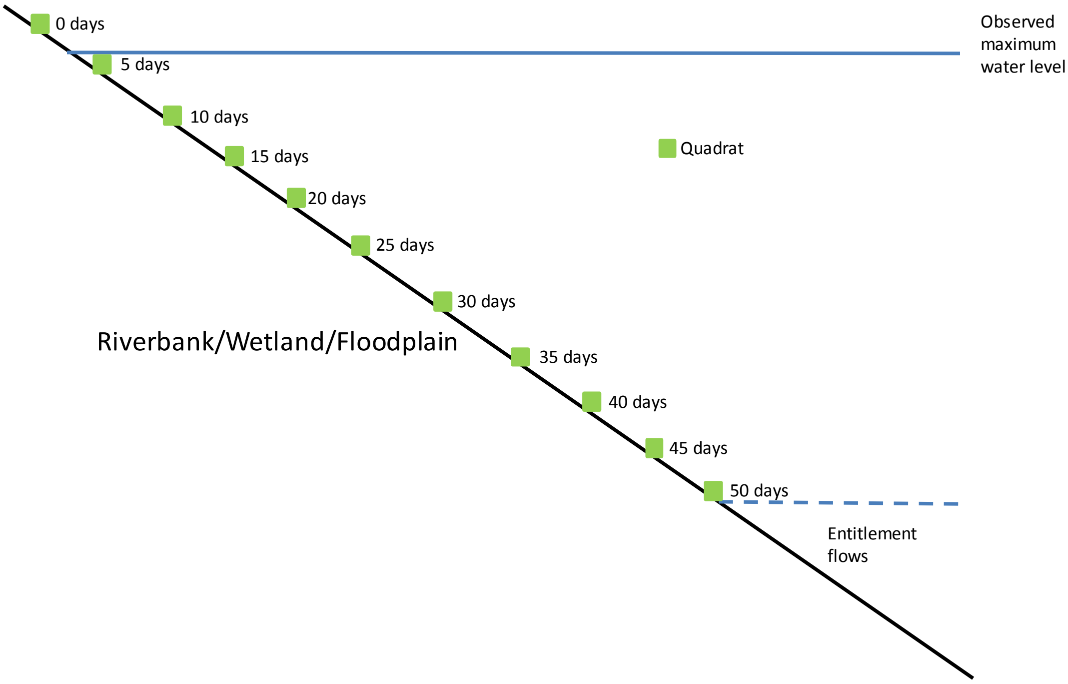


Figure 5.11. Potential position of quadrats on the elevation gradient when Commonwealth environmental water is delivered to increase duration of inundation. In this instance the total duration of flows above normal pool level was 50 days and quadrats were positioned on the elevation gradient to capture 5 day intervals but would change depending on magnitude and duration of flow.

Refer to the Lower Murray Selected Area SOP for *Littoral Vegetation Diversity and Productivity* (Appendix B) for more information on the sampling protocol including sites, timing and equipment, and on data analysis and evaluation, data management and quality assurance/quality control measures. Refer to Section 7 for timing of monitoring activities and more information on sampling sites and zones.

Outputs

Annual reports on the benefit of Commonwealth environmental water (and other environmental water) on the diversity (biological and functional) and productivity of littoral vegetation, in the Lower Murray Selected Area from 2019-20 to 2021-22. The report will include:

- Quantitative estimates of the benefit of Commonwealth environmental water (and other environmental water) on the diversity and productivity of littoral vegetation under different water delivery scenarios
- Data interpretation that considers the current conceptual understanding of the benefits of environmental water for littoral vegetation in the Selected Area

Staff

Dr Jason Nicol ***SARDI Aquatic Sciences***

See section 5.2.2 for staff capabilities.

Kate Frahn ***SARDI Aquatic Sciences***

Kate Frahn has worked at SARDI Aquatic Sciences since 2011 and worked extensively on vegetation monitoring, tree condition assessments, ecophysiology, seed bank assessments and plant identification. She has excellent knowledge of the flora of the lower River Murray, Mount Lofty Ranges and the south east of South Australia and has led the field component for numerous projects.

5.2.4 Microinvertebrate Assemblage

Indicators

- Microinvertebrate diversity and abundance
- Ratios of different flow categories of microinvertebrates (e.g. littoral, lentic or limnetic)

Background

To date, more than 400 species of planktonic and littoral microinvertebrates (protists, rotifers and microcrustaceans) have been identified in the Lower Murray Selected Area and Lower Lakes. This assemblage provides an important food resource for a range of higher order consumers (Shiel *et al.* 1982; Shiel and Aldridge 2011; Shiel and Tan 2013a; 2013b). Different habitat types promote different assemblages of microinvertebrates within riverine ecosystems, and at the simplest level can be classified as either littoral, limnetic, lotic or benthic.

Microinvertebrates are rapid responders to environmental flows, where within habitats that undergo wetting and drying cycles (e.g. the littoral zone and floodplains), organisms start to emerge from an egg-bank and begin to reproduce within hours of inundation (Tan and Shiel 1993). Therefore, a healthy egg-bank, which is primarily a result of long term flooding regime, is an important driver of the magnitude of response to inundation (Boulton and Lloyd 1992). Once inundated, longer water residence times (WRT) will result in higher abundance and biomass of organisms and result in a shift from rotifer to crustacean dominated communities (e.g. Basu and Pick, 1996; Baranyi *et al.* 2002; Obertegger et al. 2007). Therefore, slow flowing habitats such as littoral zones and floodplains favour the development of abundant microinvertebrate communities which can then be transferred between habitats, through hydrological mixing and exchange. Once in the main river channel, only some organisms will survive, with a component of the persistent community, reproducing within areas of the main river channel. Which component persists will largely depend on factors such as season and hydraulics.

Therefore, Commonwealth environmental water can facilitate the maintenance and development of microinvertebrate assemblages within the Lower Murray region by:

1. Creating slow flowing habitat adjacent to the main river channel and therefore sustaining populations that can act as a source to the main river channel community,
2. Improving lateral and longitudinal hydrological connectivity which promotes the dispersal of organisms,
3. Improving the flow regime over the long term to promote a more diverse and abundant egg-bank and thus more diverse and abundant community dispersed through lateral and longitudinal connectivity, and
4. Influencing instream environments (e.g. hydraulics) in a way that supports lower trophic level integrity.

To determine the responses of the microinvertebrate community to Commonwealth environmental water deliveries, it is proposed to quantify the diversity and abundance of assemblage(s), and changes in the ratios of key microinvertebrate flow categories during and after Commonwealth environmental water releases. Quantitative sampling of planktonic microinvertebrates will occur annually during spring and summer. Samples taken during the delivery of Commonwealth environmental water will permit the community responses to lateral and/or longitudinal connectivity (with the assistance of Commonwealth environmental water) to be identified.

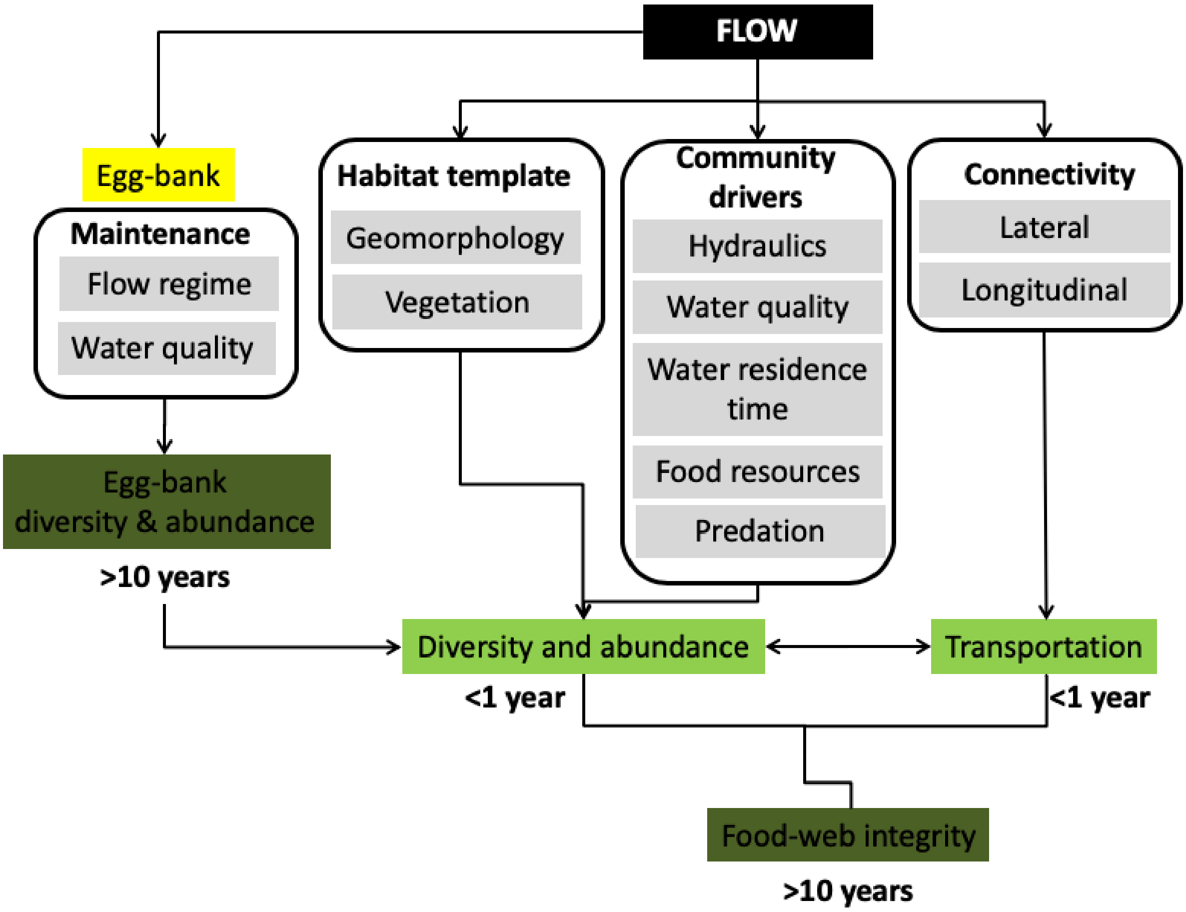


Figure 5.12. Microinvertebrate assemblage cause and effect diagram. Magnitude, timing and duration are factors of flow (in black).

Key evaluation questions

Selected Area evaluation questions:

- What did Commonwealth environmental water contribute to microinvertebrate diversity and abundance (density)?
- What did Commonwealth environmental water contribute via longitudinal (upstream) and lateral connectivity* and thus associated microinvertebrate communities of the Lower Murray Selected Area?
- What did Commonwealth environmental water contribute to the expected quality** of food resources (microinvertebrates) for higher trophic organisms?

*Our assessment of the influence of longitudinal connectivity will be based on comparing findings to the modelled (Bigmod) flow source data from the MDBA. We acknowledge there are assumptions with this approach, and it may be difficult to distinguish between the responses to environmental water and operational water.

** Assumptions will be made about the quality of specific groups of microinvertebrates as a food resource for higher trophic organisms based on what food types they are known to eat, which of those food types are present at the time of sampling and the quality of that food type based on findings in the literature. Due to these assumptions, the complexity of riverine ecosystems and the limited information on Australian specimens, it is important to note the potential inaccuracy in defining food quality.

See additional evaluation questions for long-term outcomes in contingency monitoring (Section 5.3).

Objectives and hypotheses

The objectives of this indicator are to:

- Assess changes in pelagic potamoplankton assemblages during Commonwealth environmental water deliveries
- Relate changes in pelagic potamoplankton assemblages to longitudinal connectivity achieved through upstream watering events
- Relate changes in the density and diversity of pelagic potamoplankton assemblages to lateral connectivity between the main river channel and adjacent littoral, backwater habitats and connected floodplain during environmental water deliveries
- Relate changes in the ratios of defined microinvertebrate categories to in-channel hydraulics, water residence time, lateral and longitudinal connectivity and season and discuss about trophic ecology implications.

Major hypotheses are:

- Microinvertebrate taxonomic diversity will increase due to flow induced transport of populations from upstream sources
- Microinvertebrate diversity and density will increase in the main channel during overbank flows or when increased flow leads to improved lateral connectivity with off-channel habitats
- Increased flow during spring will increase the abundance and diversity of littoral, diatom consuming zooplankton of higher quality food for higher trophic organisms.
- Reduced flow during summer will increase the abundance of cyanobacteria and abundance of lentic, bacteria consuming zooplankton communities of poorer quality food for higher trophic organisms.

General methodology

Sampling for potamoplankton will occur in the Gorge and Floodplain zones of the Lower Murray Selected Area. Sampling will occur three times during spring and three times during summer, approximately two weeks apart and will coincide with stream metabolism sampling. Pelagic sampling for potamoplankton will be conducted with a Haney trap (quantitative) and a pelagic plankton net tow (qualitative).

Refer to the Lower Murray Selected Area SOP for *Microinvertebrate Assemblage* (Appendix B) for more information on the sampling protocol including sites, timing and equipment, and on data analysis and evaluation, data management and quality assurance/quality control measures. Refer to Section 7 for timing of monitoring activities and more information on sampling sites and zones.

Outputs

Annual reports on the changes in microinvertebrate community response to flow regime, including environmental water delivery, in the Lower Murray Selected Area from 2019-20 to 2021-22. The report will include:

- Changes in the diversity and abundance of microinvertebrates to assess the influence of environmental flows on lateral and longitudinal connectivity.
- Changes in the ratios of different categories of microinvertebrates (e.g. littoral, lentic or limnetic) to assess the influence of environmental flows on driving and maintaining lower trophic level integrity.
- Data interpretation that considers the current conceptual understanding of the changes in relative abundance of microinvertebrate species and microinvertebrate categories in the

Selected Area with particular reference to community responses to flow, environmental water deliveries and potential ecological implications.

Staff

Dr Deborah Furst ***University of Adelaide***

Deborah completed her PhD in Freshwater Biology in 2014. Since then, Deborah has been involved in range projects investigating the impact of environmental water delivery on the ecology of the River Murray system. Key projects include the Commonwealth Environmental Water Office funded projects "Ecological response to the Lake Victoria bypass trial 2015–2017" and "The influence of flow translucency and integrity on resource availability in the River Murray"; and the Goyder Institute funded projects "An assessment of the research requirements to support effective provisions of environmental water in the South Australian Murray-Darling Basin"; "Science to inform operational decisions of major environmental infrastructure on the Chowilla Floodplain and other regulated floodplains in the SA River Murray", "Science to inform environmental water allocation in the Coorong: Investigation of productivity, microbiota community structure and trophic dynamics in the Coorong estuary in relation to low volume freshwater flows" and "Ecological connectivity: managing ecological outcomes and water quality risks through integrated river management".

Dr Russell Shiel ***Wetland Research & Management/University of Adelaide***

Russell Shiel completed a PhD on Murray River plankton ecology at the University of Adelaide in 1981, and has 45 years' experience researching zooplankton taxonomy and ecology, resulting in 170 publications and technical reports. Most recent projects include 'LTIM Project – monitoring microinvertebrates'; 'Monitoring zooplankton responses to the 2010–2012 Murray–Darling floods into the Lower Lakes and Coorong Lagoons (South Australia)'; 'Investigating impacts of mining on zooplankton in the Kimberley in Western Australia for ERISS (Northern Territory)', 'Investigating zooplankton responses to salinisation of wetlands in the Lower Muir region of the southwest of Western Australia'; and 'Investigating the downstream effects of the Ok Tedi mine in Papua New Guinea on Fly River oxbow microinvertebrate diversity in Western Australia'.

5.2.5 Flow-cued Spawning Fish Recruitment

Indicators

- Recruitment (presence of young of the year (YOY))
- Age structure.

Spawning (presence of eggs and larvae) and the natal origin of larvae/YOY will no longer be investigated as part of the core monitoring for this indicator (also see SARDI *et al.* 2018). Results from previous years of low, in-channel flows (<18,000 ML/d) during LTIM have consistently demonstrated poor recruitment success of golden perch (Ye *et al.* 2019). Larval sampling and associated analyses will, therefore, be contingent upon spring–summer flows exceeding 20,000 ML/d (see contingency monitoring, Section 5.3). Whilst this indicator will focus on two flow-cued spawning species (golden perch and silver perch), we acknowledge that low abundances of silver perch may preclude assessment.

Background

Flow regulation may impact fish directly through loss of spawning cues and barriers to dispersion, and indirectly through effects on habitat and food resources (Figure 5.13). Understanding the influence of flow and the mechanisms that facilitate fish reproduction will inform flow management to rehabilitate native fish populations.

In the southern MDB, spawning and recruitment of golden perch corresponds with increases in water temperature and discharge, either in-channel or overbank (Mallen-Cooper and Stuart 2003; Zampatti and Leigh 2013a; 2013b). Silver perch display similar life history characteristics and population dynamics, although in the lotic reaches of the River Murray, silver perch may spawn circa-annually (Tonkin *et al.* 2019). Within-channel increases in flow (*spring flow pulses*) were an annual feature of the hydrological regime of the unregulated River Murray (Mallen-Cooper and Zampatti 2018). In regions where these features remain intact (e.g. the mid River Murray), golden perch population display more consistent recruitment (Zampatti *et al.* 2018). In the lower River Murray (downstream of the Darling junction), spring flow pulses are compromised by river regulation, but restoration is potential with Commonwealth environmental water.

Through age structure analysis, the recruitment of golden perch and silver perch in the Lower Murray will be investigated to assess the impact of the flow regime (including environmental water) on the populations of flow-cued spawning fishes.

Cause and effect diagram

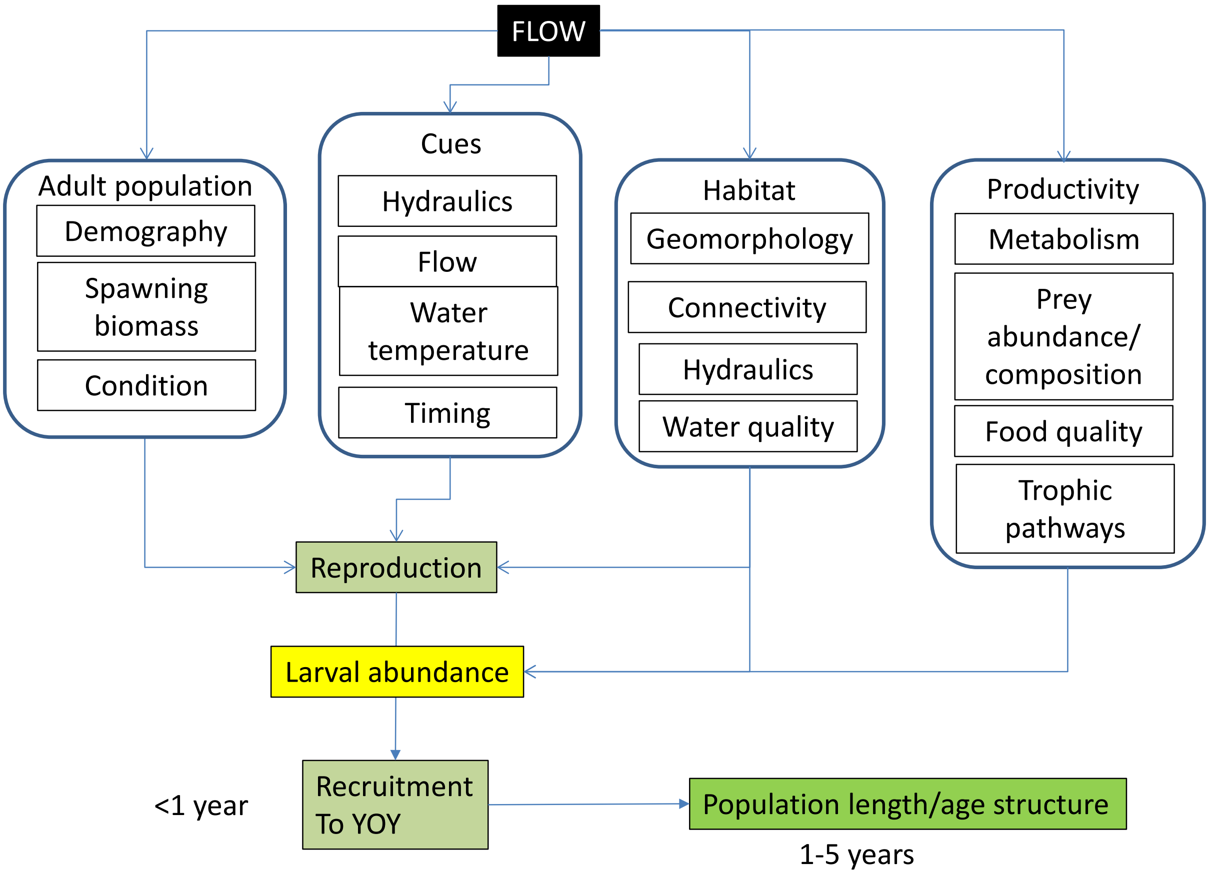


Figure 5.13. ***Flow-cued Spawning Fish Recruitment*** **cause and effect diagram (MDFRC 2013). Magnitude, timing and duration are factors of flow (in black).**

Key evaluation questions

Selected Area question for evaluating short-term responses (adapted from Hale *et al.* 2014):

- Did the flow regime (including environmental water) contribute to recruitment of golden perch and silver perch?

Selected Area question for evaluating long-term outcomes (adapted from Hale *et al.* 2014):

- Did the flow regime (including environmental water) contribute to the resilience of golden perch and silver perch populations?

There is limited capacity to evaluate the effect of Commonwealth environmental water on the reproduction (spawning and recruitment) of golden perch and silver perch under the current core monitoring as knowledge of hydrological conditions at the time and place of spawning is fundamental to explicitly relate spawning of flow-cued fishes to flow. The full evaluation of the reproduction (e.g. spawning) of golden perch and silver perch in response to Commonwealth environmental water is contingent upon spring–summer flows exceeding 20,000 ML/d (see contingency monitoring, Section 5.3).

Objective and hypotheses

The objective of this indicator is to:

- Relate golden perch and silver perch recruitment to flow.

Major hypotheses are:

- Increased spring–summer flow (nominally >20,000 ML/d), either in-channel or overbank, will promote the spawning and recruitment (to YOY) of golden perch and silver perch
- Multiple years of enhanced spring–summer flow will increase the resilience of golden perch and silver perch populations in the Lower Murray.

General methodology

Golden perch population structure data (i.e. length and age) will be collected annually to assess recruitment of golden perch. Juvenile and adult golden perch will be obtained through *Fish (Channel)* and *Murray Cod Recruitment* sampling in the Gorge and Floodplain zones. . Refer to the Lower Murray Selected Area SOP for *Flow-cued Spawning Fishes* (Appendix B) for more information on the sampling protocol including sites, timing and equipment, and on data analysis and evaluation, data management and quality assurance/quality control measures. Refer to Section 7 for timing of monitoring activities and more information on sampling sites and zones.

Outputs

- Annual report on the population structure of golden perch in the Lower Murray from 2019-20 to 2021-22 and comparison of contemporary age structure to prior years of LTIM.

Staff

Refer to Section 5.1.3 for staff and their capabilities.

5.2.6 Murray Cod Recruitment

Indicators

- Growth rates of larvae and juveniles
- Morphometric condition of larvae and juveniles
- Recruitment (abundance of young of the year (YOY))
- Age structure.

Background

Murray cod has great recreational and cultural significance in the MDB. Nonetheless, populations have declined as a result of human impacts including alteration of flow regimes, barriers to movement, overharvesting and habitat (hydraulic and physical) degradation (Lintermans and Phillips 2005). Murray cod is considered *vulnerable* under the Australian *EPBC Act* (1999) and *critical endangered* by the IUCN. In the lower River Murray (downstream of the Darling River junction), the fragmentation of the river by sequential weirs, alteration to hydraulics and loss of lotic habitats are considered primary threats to the persistence of Murray cod populations (Zampatti *et al.* 2014; Mallen-Cooper and Zampatti 2018). Indeed, under low flows, lotic environments that provide favourable juvenile and adult habitat, and support key life history processes (spawning and recruitment) can only be found in select anabranch systems (e.g. Chowilla) and lock and weir tailwaters. During elevated flows (e.g. >20,000 ML/d), however, lotic conditions are returned to considerable reaches of the Lower Murray.

Murray cod spawn annually over a well-defined period from October–December, irrespective of flow (Davis 1977; Rowland 1998), but recruitment in the lower Murray River main channel is positively associated with flow (Ye and Zampatti 2007; Zampatti *et al.* 2014). Indeed, from 2003–2010 during the Millennium Drought, Murray cod recruitment, measured as abundances of YOY in autumn, was limited in the predominantly lentic main channel habitats. Subsequently, recruitment was observed in association with spawning that occurred in high flow years from 2010–2013 (Zampatti *et al.* 2014). In more recent years (2015–2019), regular recruitment of Murray cod has been observed in the Lower Murray, including following an in-channel flow pulse (15,000–18,000 ML/d) and a high, overbank flow (>90,000 ML/d) (Ye *et al.* 2016a; 2017; 2018a; 2019; SARDI unpublished data), but also during three years of low, stable, in-channel flows (<12,000 ML/d). Furthermore, these cohorts have generally persisted in the population (Ye *et al.* 2019).

The mechanisms that facilitate recruitment of Murray cod (to YOY) in the Lower Murray likely relate to enhanced survival of early life stages associated with riverine hydraulics and productivity (Figure 5.14). Survival is likely mediated by enhanced growth rates and condition, and will ultimately determine recruitment and population abundance. This indicator will explore these mechanisms, in association with the proposed research project, by assessing aspects of Murray cod recruitment (e.g. abundance, growth, condition) in association with flow. Understanding the magnitude of recruitment, and causal links between recruitment and flow, are critical for informing future environmental flow management and will help evaluate ecological outcomes of Commonwealth environmental water.

Cause and effect diagram

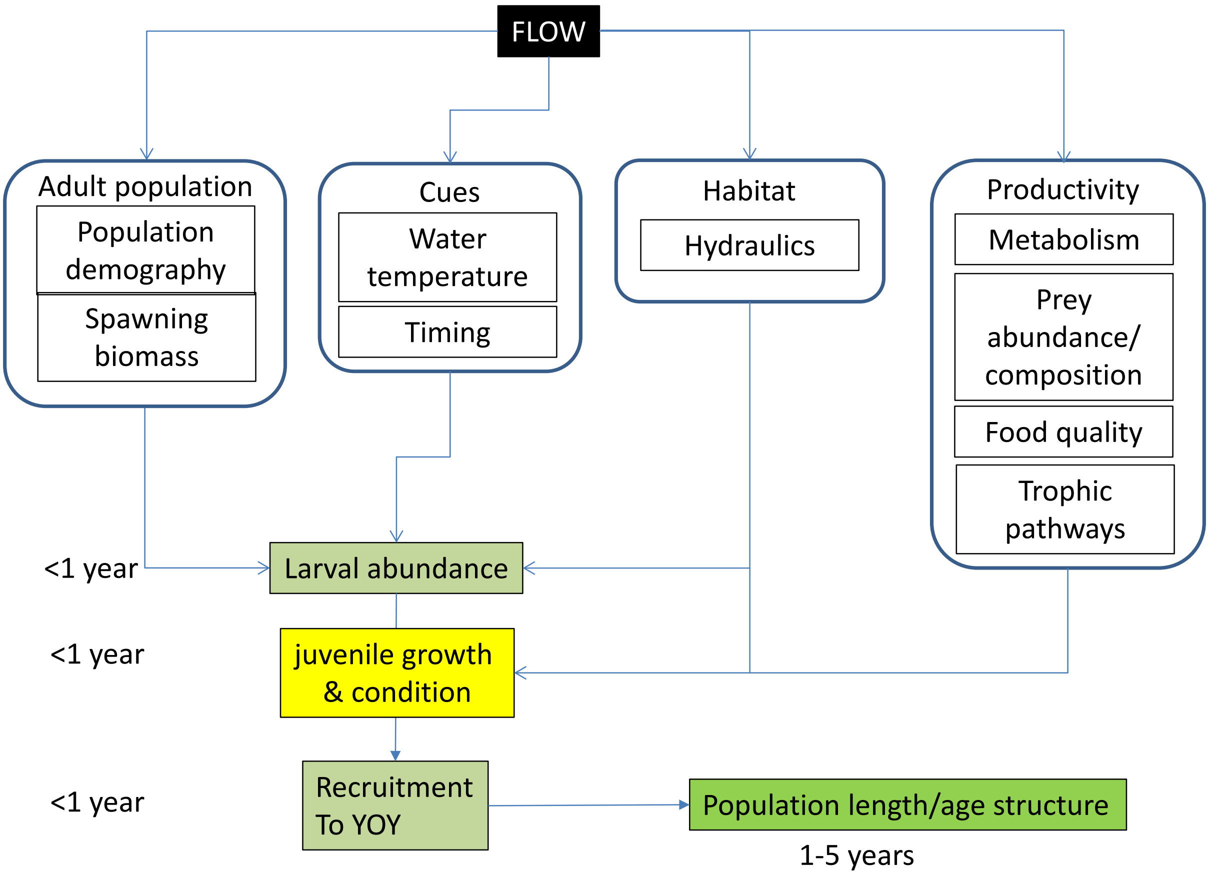


Figure 5.14. ***Murray Cod Recruitment*** **cause and effect diagram (modified from MDFRC 2013). Magnitude, timing and duration are factors of flow (in black).**

Key evaluation questions

Selected Area question for evaluating short-term responses (adapted from Hale *et al.* 2014):

- What did Commonwealth environmental water contribute to the growth and morphometric condition of Murray cod?
- What did Commonwealth environmental water contribute to recruitment of Murray cod?

Selected Area question for evaluating long-term outcomes (adapted from Hale *et al.* 2014):

- What did Commonwealth environmental water contribute to the resilience of Murray cod populations?

Objectives and hypotheses

The objectives of this indicator are to:

- Compare and contrast growth rates and morphometric condition in response to annual flow regimes, including environmental water
- Compare and contrast recruitment success (abundance of YOY) in response to annual flow regimes, including environmental water
- Identify potential associations between recruitment, hydraulic habitat (e.g. flow velocities), and food resources (productivity).

Major hypotheses are:

- Elevated spring–summer flow, either in-channel or overbank, and associated increase in lotic habitat, will enhance recruitment (to YOY) of Murray cod
- Elevated spring–summer flow, either in-channel or overbank, and associated increase in lotic habitat, will be associated with enhanced growth rates and morphometric condition of Murray cod
- Multiple years of enhanced spring–summer flow will result in broad size/age distributions of Murray cod and increased population resilience in the Lower Murray.

General methodology

To quantify abundance and collect samples for further analyses, Murray cod will be sampled at several stages during early ontogeny, from larvae through to YOY (>120 d of age).

Sampling for larvae (<30 mm) will be conducted in the main channel of the Lower Murray using a combination of techniques, including light traps and net tows. Juvenile Murray cod will be sampled during three different sampling occasions to capture a broad size range of individuals ~30–150 mm. Sampling methods (e.g. light traps and electrofishing) will depend on the expected fish size at the time of sampling. Juvenile Murray cod will also be obtained through complementary Fish (Channel) sampling in the Gorge zone. In addition to YOY, larger sub-adult and adult Murray cod will be sampled during electrofishing to collect size/age information on the broader population.

Otolith microstructure analysis, and measurements of length and weight, will support investigations of growth and morphometric condition. This will include, where possible, estimation of daily age and spawn dates (increment counts), as well as daily (increment width analysis) and seasonal growth rates. Morphometric condition will be determined by investigating length-weight relationships and associated metrics (e.g. condition factor, see Froese 2006), and comparison with reference data.

Refer to the Lower Murray Selected Area SOP for *Murray Cod Recruitment* (Appendix B) for more information on the sampling protocol including sites, timing and equipment, and on data analysis and evaluation, data management and quality assurance/quality control measures. Refer to Section 7 for timing of monitoring activities and more information on sampling sites and zones.

Outputs

- Annual report on the recruitment, growth rates and morphometric condition of Murray cod in response to flow regimes, including environmental water delivery, in the Lower Murray Selected Area from 2019-20 to 2021-22. The report will include:
    - Spatial and temporal variation in abundance of YOY (recruitment) Murray cod
    - Spatial and temporal variation in growth rates and morphometric condition of juvenile Murray cod
    - Data interpretation in the context of flow and hydraulics that considers the current conceptual understanding of the life history, spawning and recruitment of Murray cod in the Lower Murray, with comparison to prior years (e.g. LTIM).
    - Comparison of contemporary size/age structure of Murray cod in the Lower Murray Selected Area to prior years, including LTIM.

Staff

Refer to Section 5.1.3 for staff and their capabilities.

5.3 Contingency monitoring

In addition to the core monitoring (Sections 5.1 and 5.2) proposed for this Selected Area, additional resources have been made available for contingency monitoring. These additional services will be ordered by the CEWO when a need is identified, in response to opportunities and conditions that arise during the project. Contingency monitoring will allow for greater flexibility in undertaking short-term monitoring as needs and priorities evolve over time, and to allow the CEWO to obtain additional scientific advice as needed to inform environmental water use planning and management. Summaries of potential contingency monitoring activities are presented below, and in Table 5.2, including background, the need, monitoring approach and indicative budget. Contingency monitoring, however, is not limited to these proposals; any activities proposed to be undertaken will be further outlined and submitted for approval at the request of the CEWO via the work order template and process set out in the MER Project contract.

5.3.1 Spawning and natal origin of flow-cued Spawning Fishes

Under LTIM, the contribution of environmental water to the reproduction of flow-cued spawning fishes was investigated. Low, in-channel flows (<18,000 ML/d) occurred for four of the five years and were associated with negligible recruitment of golden perch. High, overbank flows (>90,000 ML/d) that occurred in the remaining year were also associated with negligible recruitment, although survival of eggs and larvae may have been impacted by hypoxia.

Spring–early summer 'in-channel' increases in discharge (20,000–45,000 ML/d) were once a key feature of the natural hydrograph, but are conspicuously absent from the contemporary flow regime. We hypothesise that increased spring–summer flow (nominally >20,000 ML/d) will promote the spawning and recruitment (to YOY) of golden perch and silver perch.

We propose to assess recruitment of golden perch and silver perch through annual electrofishing as a core monitoring activity (*Flow-cued Spawning Fish Recruitment,* Section 5.2.5), but assessment of spawning and natal origin of new recruits would be contingent upon receiving flows that are likely to promote recruitment (i.e. >20,000 ML/d). Collecting data at flows of these magnitude will address a substantial hydro-ecological knowledge gap for golden perch and silver perch population dynamics in the Lower Murray. Under the scenario of a higher spring–summer in-channel or overbank flow (>20,000 ML/d), golden perch spawning and recruitment monitoring is a priority for contingency monitoring in the Lower Murray.

The additional question for evaluating short-term responses to Commonwealth environmental water delivery for the *Flow-cued Spawning Fish Recruitment* indicator is: What did Commonwealth environmental water contribute to the spawning of golden perch and silver perch?

If flows remain <20,000 ML/d over the three-year MER Project period, natal origin and migration history of dominant cohorts of golden perch and silver perch in the Lower Murray may be investigated by analysing $^{87}Sr/^{86}Sr$ from the otolith core to edge using otoliths collected through *Fish (Channel)* and *Murray Cod Recruitment* electrofishing. We would compare these transects to water $^{87}Sr/^{86}Sr$ measured at sites across the southern MDB during spring–summer 2021-22 and from 2011–2018. See the last LTIM annual report for the Lower Murray (Ye *et al.* 2019) for details.

5.3.2 Stream metabolism (high flow)

Increased flows that result in expanding connections between the river and its littoral zone and floodplain have major impacts on stream metabolism. Under some scenarios, the movement of shallow waters across the floodplain can enhance the production of microorganisms that form a potential food source for larger organisms, either directly on the floodplain or on return to the river. However, if the conditions within the river are not conducive to the continued growth of these organisms then their decomposition can remove oxygen from the water column. If oxygen loss is not replaced by gas transfer from the atmosphere, or the production of oxygen by photosynthesis then dissolved oxygen concentrations decline. This process is enhanced if the floodplain inflows contain dissolved and particulate organic matter of terrestrial origin. This detrital material is not often a useful food resource for microorganisms and instead is decomposed by microbes including bacteria and fungi. The decomposition of organic materials from the floodplain can greatly enhance reductions in dissolved oxygen concentrations and may result in "black water" events where oxygen concentrations are below levels required for the support of aquatic plants and animals.

If these conditions are expected to occur, there is potential to increase the dissolved oxygen monitoring to include an extra site below the entry of Chowilla Creek, which is expected to reflect the influence of the return flow from the Chowilla Floodplain. This extra site, along with the below Lock 4 site, will require more detailed information on water quality and the associated communities of micro-organisms than the standard monitoring sites (i.e. below Lock 1 and 6). Data collected will inform on the influence of overbank flows on production and decomposition within the river channel.

5.3.3 Hypoxia risk

Hypoxia risk can eventuate under low flow when sediment oxygen demand and biological oxygen demand from microbes and phytoplankton in the pelagic zone exceed the rate of supply of oxygen from photosynthesis and the atmosphere to the water column.

If low flow conditions persist, then contingency monitoring could occur at key sites in the main channel of the Lower Murray Selected Area, for example the weir pools above the locks where the water velocity is lowest. Monitoring would include deployment of oxygen loggers and routine depth-profiles to determine if there is oxygen stratification at the key sites. Data collected will inform real time and future management of flow and environmental water delivery to mitigate hypoxia risk in the weir pools of the Lower Murray, and will contribute to the evaluation of ecological outcomes from Commonwealth environmental water delivery.

5.3.4 Cyanobacteria risk

Cyanobacteria risk can also occur when flow is low enough to allow stratification to persist in the main river channel. Under calm, stable, stratified conditions gas vesicles in the cyanobacteria enable the colonies to flow to the surface where they can access adequate light to grow, while denser phytoplankton tend to sediment away from the illuminated surface waters.

The critical flow velocity necessary to disrupt temperature stratification has been determined in a number of rivers through both deployment of thermistors and by modelling the hydrodynamics. This monitoring would include depth distributed thermistors at key sites including weir pools and key connected wetland complexes where thermal stratification may occur and cyanobacterial blooms may originate. In collaboration with SA Water the phytoplankton community would be monitored and when problematic cyanobacteria are detected more intensive sampling would commence. Data collected would inform real time and future management of flow and environmental water delivery to mitigate cyanobacteria risk in the weir pools of the Lower Murray, and contribute to the evaluation of ecological outcomes from Commonwealth environmental water delivery.

5.3.5 Seed/egg bank baseline assessment

Evaluation questions for long-term outcomes for the *Littoral Vegetation Diversity and Productivity* and *Microinvertebrate Assemblage* (see below) involve measuring Commonwealth environmental water contribution to resilience. The ability of plant and microinvertebrate communities to respond to changes in water level and recover after disturbance is largely due to seed and dormant or resting eggs deposited on dry areas of the river bank and floodplain. Under low flow conditions, only limited areas of the littoral zone and floodplain are inundated. It is anticipated that improved flow regime contributed by Commonwealth environmental water over years will help replenish seed and egg banks in these areas either by facilitating seed/egg dispersal into 'new' areas or by improved reproduction of mature organisms locally.

Sediment samples could be collected in the first year of the project at vegetation monitoring sites by the vegetation team, dried and stored to be assessed at a later date to gain an indication of the "baseline" seed and egg bank. Sediment samples could be collected at a later date to compare with the "baseline" to determine how the seed and egg banks have changed and evaluate the contribution of Commonwealth environmental water.

Evaluation questions for long-term outcomes for *Littoral Vegetation Diversity and Productivity* and *Microinvertebrate Assemblage* are: What did Commonwealth environmental water contribute to:

- the resilience of littoral plan communities? and
- increasing the diversity and abundance of the microinvertebrate egg-bank (via improvement of the flow regime)?

5.3.6 Lamprey migration

The anadromous life histories of pouched lamprey (*Geotria australis*) and short-headed lamprey (*Mordacia mordax*), characterised by long distance migrations between marine and freshwater habitats, are unique among the fishes of the MDB. This life history is dependent upon discharge to facilitate connectivity (e.g. fishway operation) and stimulate migrations into the Murray River (e.g. olfactory cues). Anecdotally, lamprey were common prior to regulation, with migrations extending up to 2000 km upstream in the Murray River and tributaries (e.g. the Goulburn, the Murrumbidgee), but altered flow regimes and obstruction by barriers likely led to population declines. However, in recent years, delivery of Commonwealth environmental water from the Murray barrages during key upstream migration periods (winter–spring) has provided opportunities for lamprey migration. Indeed since 2013, lamprey have been regularly detected entering the Murray, with migration observed as far upstream as Lock 11 (Mildura). Lamprey are thus a useful indicator of the influence of CEW on connectivity with the ocean and throughout the Lower Murray.

Monitoring of lamprey migration at the Murray Barrages is typically supported by the MDBA's TLM program. This meets TLM Icon Site reporting requirement, but also provides information on the influence of Commonwealth environmental water delivery. In certain years when adequate funds are not available, MER contingency monitoring may facilitate an appropriate level of monitoring to assess abundance, and movement of lamprey (assessed by movement of tagged fish through fishways). See Attachment A for the 2019 Work Order and Project Scope.

5.3.7 Winter stream metabolism

The timing (spring–summer) of the core stream metabolism monitoring in the Lower Murray follows that of the LTIM Project (see Section 5.1.2). In recent years, return flows from upstream watering events (e.g. Goulburn River) have produced in-channel flow pulses (up to ~12,000 ML/d) in the Lower Murray, prior to the monitoring period. Understanding of how these winter flows influence stream metabolism in the Lower Murray is currently limited. By adding another three sampling trips to the current sampling regime, stream metabolism and water quality monitoring can be extended forward to late June/early July to capture winter pulses delivered down the main channel of the Lower Murray.

5.3.8 Egg/larval drift and hydraulic modelling

The dispersal of eggs and larvae (hereafter referred to as propagules) is dependent upon their inherent sinking or swimming characteristics/abilities, the hydrodynamic conditions which keep the propagules entrained and the flow which transports the propagule. Flow and hydrodynamics are variable within a reach between locks. For example the water depth in the tailwater displays greater variability than in the weir pool, where water levels are fairly constant. Similarly hydrodynamics change through the reach with tailwater having greater turbulence, which is dampened downstream as the weir pool backs up water. This means that weir pools are more prone to stratification than the tailwater. As water slows and turbulence decreases propagules are more likely to be disentrained, increasing sedimentation losses.

Understanding the range of flow velocities and turbulence intensities through the river reach is critical to understanding how propagules are dispersed or lost. Profiling for velocity and turbulence along weir pool reaches over the spawning season coupled with laboratory experiments of the intrinsic settling velocity of various propagules with different swimming/floating abilities will facilitate a new level of refinement on the environmental flows required for propagule entrainment and dispersal.

5.3.9 Review of nutrient export – is nutrient export a good thing?

For the past four years of the LTIM Project, the *Matter Transport* indicator has modelled the export of salt and nutrients over the barrages to the Southern Ocean. There is a target for salt export set by the Murray-Darling Basin plan of average 2 million tonnes of salt per annum. The hydrodynamic and biogeochemical modelling enables an estimate of salt export attributable to unregulated river flow and environmental water including the Commonwealth environmental water. Nutrient export is also determined, however, it is not currently clear whether what levels of nutrient export from the basin will be optimal considering both water quality and ecological implications. Nutrient delivery to the estuary will drive productivity and so provide energy at the base of the food web, however this also means that nutrients are being eroded from the catchment, which will affect soil productivity. This contingency monitoring program would measure nutrients concentrations at the barrage overflow to validate the hydrodynamic modelling and use a literature review and biogeochemical modelling to determine an appropriate nutrient export target that considers both estuarine productivity and appropriate nutrient levels to maintain water quality and productivity in the catchment.

Table 5.2. Flow scenario trigger and indicative budget for contingency monitoring during the three-year MER Project in the Lower Murray.

Flow scenario trigger	Year 1	Year 2	Year 3	Indicative annual budget	Comments
Flow > 20,000 ML/d	Flow-cued Spawning Fishes (spawning and natal origin of new recruits)			$155k	
	Stream metabolism high flow			$70k	
Flow <20,000 ML/d	Microinvertebrate egg bank sample collection (via vegetation monitoring)	Microinvertebrate egg bank baseline assessment		$55k	Help address question relating to long-term outcomes in future
	Vegetation seed bank sample collection (via vegetation monitoring)	Vegetation seed bank baseline assessment		$50k* or $100k	Help address question relating to long-term outcomes in future
		Nutrient evaluation review (Value add to Matter Transport evaluation)		$40k	
		Hydrodynamic modelling (egg/larval dispersion)			
			Flow-cued Spawning Fishes (natal origin - adults)	$53k	
	Lamprey migration			$25k	Co-funded by DEW/MDBA
		Winter stream metabolism		$25k	
Flow < entitlement Or flows < 10,000 ML/d when risks are higher		Cyanobacteria risk		$60k	
		Hypoxia risk		$40k	

*If engaging a student to conduct the experiment.

6 Integrated research

The following research proposal has been provided for consideration by CEWO as a potential use of research funding and will be subject to a subsequent work order approval process. This proposed research project will integrate monitoring from several indicators in a cost-effective manner and provide a holistic view of ecosystem response to flow (including Commonwealth environmental water) and a mechanistic understanding of ecological processes that lead to improved recruitment of key fish species (Murray cod).

6.1 From primary productivity to Murray cod recruitment

6.1.1 Background

The early life stages of fishes (eggs, larvae and juveniles) often suffer high levels of mortality, and subsequently, survival through this vulnerable period can influence recruitment, abundance and population resilience (Houde 1997). Survival through early life stages is influenced by types and densities of food, levels of predation and competition, and physico-chemical conditions (e.g. temperature). The Fundamental Triad fish recruitment hypothesis (Bakun 1996), and its recent extension to riverine environments, The Riverscape Recruitment Synthesis Model (Humphries *et al.* In Press), propose that processes critical to fish recruitment are the sources and amount of energy available (productivity), nutrient and prey enrichment and concentration, as well as dispersal to, and retention of, fish in favourable nursery habitats. Assuming these functions are met or enhanced, individuals will likely exhibit improved growth rates and condition that will mediate greater survival and thus abundance (see Section 5.2.6, *Murray Cod Recruitment*). In the context of river flow regimes and environmental water delivery, monitoring ecological patterns associated with fish recruitment (e.g. growth rates, abundance) is needed for evaluating outcomes and informing future delivery via adaptive flow management. A range of indicators, from hydraulic regime, productivity to fish, are monitored in the Lower Murray Selected Area. Nonetheless, holistic understanding of the relationship between flow-induced environmental changes and fish response can only be gained by understanding how key ecosystem processes connect to influence these patterns.

The amount and sources of energy available in riverine ecosystems vary as a function of discharge and hydraulics. During low flow, autochthonous local sources are dominant, but as discharge and inundation increases, so too do carbon loads and longitudinal transport of material, to a point when broad-scale floodplain inundation occurs and these habitats may contribute substantial energy inputs (Vannote *et al.* 1980; Junk *et al.* 1989). In the Lower Murray, lower ranges of flow variability may also be associated with changed energy sources and pathways. For instance, changes in discharge that remain in-channel, and attendant changes in water velocity and turbulence, result in shifts in phytoplankton communities between cyanobacteria and diatom dominance (Aldridge *et al.* 2012). Diatoms are better quality food for higher trophic levels than cyanobacteria (Guo *et al.* 2017), and thus, this switch in in-channel basal food resources may influence the abundance and nutrition of microinvertebrate communities and trophic upsurge, including supporting fishes like Murray cod. Understanding the mechanisms that drive improved growth rates, condition, survival and ultimately recruitment, is key knowledge required to support Commonwealth environmental water delivery and flow management in the Lower Murray.

6.1.2 Research questions

The overarching question is:

- How is the recruitment of Murray cod influenced by variability in the amount, quality and pathways of energy transfer, and how is this mediated by flow (hydrology and hydraulics)?

Detailed questions may include:

- What is the diet of larval Murray cod in the Lower Murray, relative to ambient microinvertebrate communities, and how does this vary with flow?
- How does the basal food web (autochthonous v allochthonous, pelagic v benthic) change with flow, and is this reflected in the ambient microinvertebrate communities and the growth and condition of Murray cod?
- What is the diet of juvenile Murray cod in the Lower Murray, and does diet and/or nutrition of prey items vary with flow?

6.1.3 Methods

This research project will integrate and be supported by data collected through several other indicators including *Hydraulic Regime*, *Stream Metabolism and Water Quality*, *Microinvertebrate Assemblage* and fish indicators (Category 1 and 3). Some additional sampling (e.g. phytoplankton) will occur in conjunction with pre-existing sampling trips. This research project will also use multiple lines of evidence. Murray cod (larvae and juveniles) collected as part of the *Murray Cod Recruitment* indicator for analyses of age, growth and condition, will also provide samples for potential gut content and tissue analyses. Microinvertebrate samples may also provide a means of characterising ambient assemblages for assessing larval diets.

Assessing whether the pathways of energy leading from primary productivity vary with flow will require the use of chemical techniques, potentially including stable isotope, fatty acid and/or molecular analyses. Data on energy pathways can then be integrated with data on growth rates and condition of individual fish.

6.1.4 Informing monitoring outcomes and adaptive management

This component will integrate monitoring outcomes from several indicators in this Selected Area to present a holistic view on ecosystem response. This integrated research could also improve evaluation by understanding mechanisms driving monitoring outcomes (e.g. Murray cod juvenile growth rates). By elucidating the ecological processes that underlie the patterns observed in monitoring, this project will provide a mechanistic understanding of system function to support Commonwealth environmental water delivery and flow management. See Attachment B for the 2019–2021 Work Order and Project Scope.

7 Summary of monitoring, evaluation and research activities

7.1 Overview of monitoring

This plan proposes nine indicators for the Lower Murray Selected Area, including three Category 1 (Basin) and six Category 3 (Selected Area) indicators. It is expected that Commonwealth environmental water delivery to the Lower Murray Selected Area over the next three years will be limited to events of less than 60,000 ML/d, therefore the monitoring activities in this Selected Area will be focused on the in-stream environment for all indicators. Whilst the indicators proposed are complementary, field sampling regimes are aligned, within the constraints of CEWO standard methods/protocols, and sampling activities will be coordinated to maximise efficiencies. Further details of the monitoring schedule and sampling zones and sites are provided below.

7.2 Monitoring schedule

Table 7.1 provides a detailed monitoring schedule (timing, duration and sampling frequency) for all indicators for the Lower Murray Selected Area from July 2019 to December 2022. Sampling sites and zones for each indicator are shown in Table 7.2. For three of the indicators, monitoring will not be confined to any specified schedule, mostly due to relying on complementary data: *Hydrology (Channel)*, *Hydraulic Regime and Matter Transport and Coorong Habitat*.

7.2.1 Stream Metabolism and Water Quality

Stream metabolism measurements will be conducted annually between September and February below Lock 1 in the Gorge zone, and below Lock 4 and Lock 6 in the Floodplain zone (Table 7.1 and Table 7.2).

The *in-situ* water quality (WQ) monitoring commences in September and is continued at ca. 4 weeks intervals during field trips to maintain the dissolved oxygen (DO) probes.

Ten field trips are planned for the deployment period so that on average the DO monitoring stations will be maintained (batteries changed, mountings checked, sensors cleaned and re-calibrated) and data downloaded every 2 weeks. Light and barometric pressure loggers will also be downloaded and maintained and water quality samples taken. Field trips will not be longer than 3 weeks apart to ensure the reliability of data from the logging systems.

Equipment will be retrieved at the end of February unless further environmental flows are forecast, in which case monitoring will continue as long as resources are available to support the associated field trips. The resources available will depend on the prior sampling effort.

7.2.2 Fish (Channel)

Annual sampling will take place during autumn as described in Hale *et al.* (2014) and in the SOP (Appendix B) (Table 7.1). The Gorge is the chosen zone for this indicator, and sampling (electrofishing and fyke-netting) will be conducted at 10 sites within an approximately 100 kilometre reach between Locks 1 and 3 (Table 7.2). Ageing of target species will be carried out following Hale *et al*. (2014), including annual ageing for periodic and equilibrium species in the third year.

7.2.3 Littoral Vegetation Diversity and Productivity

Vegetation sampling will be conducted using the same methods as TLM vegetation monitoring for the Chowilla Floodplain (and most floodplain and wetland monitoring undertaken in the South Australian River Murray upstream of Wellington) (e.g. Nicol *et al.* 2018). Sites will be located in tailwaters in the floodplain and gorge zones on the riverbank or in temporary wetlands if they are present and likely to be inundated by Commonwealth environmental water. Elevations sampled will be determined by flood inundation modelling or inundation duration (depending on whether Commonwealth environmental water was used to increase the height or duration of inundation). A fixed area of each quadrat will be harvested to determine above ground biomass of understorey vegetation. Sampling will be undertaken after environmental water has been delivered and water levels at normal pool level.

7.2.4 Microinvertebrate Assemblage

Microinvertebrate sampling will be conducted in conjunction with *Stream Metabolism and Water Quality* sampling, at sites approximately 5 km below Lock 1, Lock 4 and Lock 6 (Table 7.2). Sampling will occur three times during spring and three times during summer, approximately two weeks apart (Section 7.2.2).

7.2.5 Flow-cued Spawning Fish Recruitment

Sampling of golden perch and silver perch for assessing recruitment to young of the year (YOY) and population age structure will be conducted annually (2019-20 to 2021-22) in autumn through *Murray Cod Recruitment* and *Fish (Channel)* electrofishing.

7.2.6 Murray Cod Recruitment

Murray cod will be sampled at several points during early ontogeny from larvae through to YOY (>120 days old). Larval sampling will occur once during the peak period of larval presence (November, SARDI unpublished data), whilst early stage juvenile sampling will occur during mid-summer and early autumn. Sites will be located in the tailwaters (<15 km downstream) of Lock 4 (Floodplain zone) and another Lock (to be determined) (Table 7.2). Population and YOY sampling will occur annually at a number of sites in the Gorge and Floodplain zones during autumn. Samples of YOY fish will be complemented with those collected in the Gorge zone as part of *Fish (Channel)* sampling. Murray cod growth and condition will be investigated using morphometric and otolith microstructure analyses.

Table 7.1. MER Project monitoring schedule for Category 1 (Basin) and 3 (Selected Area) indicators in the Lower Murray Selected Area from September 2019 to December 2022.

Indicator	Activities	2019						2020											
		J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Category 1																			
Hydrology (Channel)	Modelling																		
	Reporting																		
Stream Metabolism and Water Quality	Deploy equipment																		
	Data logging/water quality sampling																		
	Equipment maintenance & data download																		
	Collect equipment																		
	Data entry, analysis & reporting																		
Fish (Channel)	Field sampling (electrofishing)																		
	Field sampling (fyke netting)																		
	Lab fish ageing																		
	Data entry, analysis & reporting																		
Category 3																			
Hydraulic Regime	Modelling																		
	Reporting																		
Matter Transport and Coorong Habitat	Physical–chemical data collection																		
	Modelling and scenario runs																		
	Reporting																		
Littoral Vegetation Diversity and Productivity	Field sampling																		
	Lab sample processing																		
	Data entry, analysis & reporting																		
Microinvertebrate Assemblage	Field sampling																		
	Lab sample sorting and id																		
	Data entry, analysis & reporting																		
Flow-cued Spawning Fish Recruitment	Lab ageing																		
	Data entry, analysis & reporting																		
Murray Cod Recruitment	Field sampling																		
	Lab larval sorting/fish processing																		
	Lab ageing/otolith measurements																		
	Data entry, analysis & reporting																		

Indicator	Activities	2021												2022											
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Category 1																									
Hydrology (Channel)	Modelling																								
	Reporting																								
Fish (Channel)	Field sampling (electrofishing)																								
	Field sampling (fyke netting)																								
	Lab fish ageing																								
	Data entry, analysis & reporting																								
Stream Metabolism and Water Quality	Deploy equipment																								
	Data logging/water quality sampling																								
	Equipment maintenance & data download																								
	Collect equipment																								
	Data entry, analysis & reporting																								
Category 3																									
Hydraulic Regime	Modelling																								
	Reporting																								
Matter Transport and Coorong Habitat	Physical-chemical data collection																								
	Modelling and scenario runs																								
	Reporting																								
Littoral Vegetation Diversity and Productivity	Field sampling																								
	Lab sample processing																								
	Data entry, analysis & reporting																								
Microinvertebrate Assemblage	Field sampling																								
	Lab sample sorting and id																								
	Data entry, analysis & reporting																								
Flow-cued Spawning Fish Recruitment	Lab ageing																								
	Data entry, analysis & reporting																								
Murray Cod Recruitment	Field sampling																								
	Lab larval sorting/fish processing																								
	Lab ageing/otolith measurements																								
	Data entry, analysis & reporting																								

Table 7.2. Summary of sampling sites and zones for indicators for the MER Project in the Lower Murray Selected Area from July 2019 to June 2022.

Indicator	Zones				Sites	Comments
	Floodplain	Gorge	Swamplands	Lower Lakes and Coorong		
Hydrology (Channel)	Y	Y			8	Flow at SA Border, Chowilla Anabranch, and all 6 Locks within SA. New discharge monitoring stations commissioned over the life of the project may be included as sampling sites if necessary.
Stream Metabolism and Water Quality	Y	Y			3	Methods follow Hale *et al.* 2014 (1 continuously recording station per site). Sites approx. 5 km below Lock 1 (Gorge zone), Lock 4 and Lock 6 (Floodplain zone).
Fish (Channel)		Y			10	Follow Hale *et al.* (2014).
Hydraulic Regime	Y	Y	Y		1–2 as needed	Swamplands covered by *Matter Transport and Coorong Habitat* modelling.
Matter Transport and Coorong Habitat		Y	Y	Y	N/A	Modelling covers Lock 1 to Wellington, the Coorong and Lower Lakes.
Littoral Vegetation Diversity and Productivity	Y	Y			2 with a minimum of 5 transects/ site	Sampling will focus on weir tailwaters. Timing of sampling will depend on timing and volume of environmental water delivery and will be undertaken after water levels have returned to pool level.
Microinvertebrate Assemblage	Y	Y			3	This will be conducted in conjunction with *Stream Metabolism and Water Quality* at sites approx. 5 km below Lock 1 (Gorge zone), Lock 4 and Lock 6 (Floodplain zone).
Flow-cued Spawning Fish Recruitment	Y	Y			>6/zone	Samples collected through *Fish (Channel)* and *Murray Cod Recruitment* sampling. Sites spread throughout Gorge and Floodplain zones.
Murray Cod Recruitment a) larvae and juveniles	Y	Y			2	Sampling for larval and juvenile life stages of Murray cod will be conducted at two locations in the main channel of the Lower Murray: in the tailwaters (<15 km downstream) of Lock 4 (Floodplain zone) and another Lock (to be determined).
b) YOY and population	Y	Y			>6/zone	Sites spread throughout Gorge and Floodplain zones.

7.3 Complementary monitoring

In addition to the monitoring activities outlined in this plan, a number of complementary monitoring programs are undertaken within the South Australian MDB (Table 7.3). The monitoring programs listed in Table 7.3 were identified by DEW for the MDB Monitoring, Evaluation and Information Coordination project, and through contact with the relevant staff. In many cases, achievement of environmental outcomes from Commonwealth environmental water will be supported by management actions and monitoring in these programs. The outputs of these programs may be used to increase the capacity of the MER Project to evaluate environmental outcomes within Lower Murray Selected Area and the South Australian area of the MDB more broadly.

Findings from complementary monitoring programs may be used to complement or aid in the interpretation and evaluation of environmental outcomes of Commonwealth environmental water as part of MER Project annual reporting. However, in most cases, the raw data from these programs are unlikely to be used as they may not be consistent with MER Project requirements, and collation and analysis of this data for MER Project purposes may consume significant resources. Many of the programs have limited funding security or short timeframes, or indicators are not yet known (see Table 7.3). The potential use of this complementary data will be explored as further information about the programs becomes available, and this will be resourced within the evaluation component of the MER Project.

The exception is water quality monitoring by SA Water, MDBA, DEW and the EPA. These data sources are suitable for use in analysis and evaluation within the *Matter Transport and Coorong Habitat* and *Stream Metabolism and Water Quality* indicators of this project and will be incorporated when available for relevant sites. However, funding sources for these programs are not secure. Such circumstances have been considered in the risk assessment and the overall level of risk to the project was low (Section 10.2).

Table 7.3. Complementary monitoring programs for potential use in evaluating ecological outcomes in the Lower Murray Selected Area associated with Commonwealth environmental water.

Funding source	Description of site(s)	Indicators	Planned monitoring timeframe	Security of funding	Contact person
SA MDB NRM Board	Approximately 50 wetlands along the Lower Murray Selected Area that are actively managed through operation of regulators or pumping	Site (wetland) specific, dependent on objectives. Includes water quality, groundwater, frogs, macroinvertebrates, birds, vegetation, fish	Ongoing	Unknown	Rebecca Turner
The Living Murray (TLM)	Chowilla	Water quality, vegetation, fish, birds	Ongoing	Condition and Intervention Monitoring $ available in 2019-20. TLM monitoring funding is approved annually	Jan Whittle

Funding source	Description of site(s)	Indicators	Planned monitoring timeframe	Security of funding	Contact person
TLM	Coorong, Lower Lakes and Murray Mouth	Vegetation, fish, birds, macro-invertebrates	Ongoing	Condition and Intervention Monitoring $ available in 2019-20. TLM monitoring funding is approved annually	Rebecca Turner/ Adrienne Rumbelow
SA Riverland Floodplains Integrated Infrastructure Project	Pike and Katarapko Floodplains, weir pool manipulation	Still to be determined, focus on fish, vegetation, dissolved oxygen.	2019–2021	Funded	Benita Dillon
Healthy Coorong Healthy Basin Project	CLLMM, with a focus on the Coorong South Lagoon	Still to be determined, focus on aquatic vegetation (*Ruppia*), water quality, water birds, phytoplankton	2019–2021	Likely funded	Jody O'Connor
SA Water and MDBA (selected sites and parameters)	Lock 9, Lake Victoria Outlet, Murray River (MR) DS Rufus River Gauging Weir, MR 8 km downstream of Lock 6, MR Renmark, Lock 5, MR Berri, MR Loxton, MR Moorook, MR Cobdogla, MR Woolpunda, MR Waikerie, MR Cadell, MR Morgan, MR Lock 1, MR Swan Reach, MR Cowirra, MR Mypolonga, MR Mannum, MR Murray Bridge, MR Tailem Bend, Goolwa Barrage u/s, Lake Alexandrina – Milang	Key parameters include phytoplankton count, chlorophyll *a*, metals, basic phys/chem., colour, DOC, DO, nutrients, colifoms/*E. Coli*, turbidity. Not all of these are monitored at each site	Ongoing	Unknown (annual review)	Thorsten Mosisch

8 Engagement and communication Plan

8.1 Purpose

The Engagement and Communication Plan for the Lower Murray Selected Area is designed to ensure that the broader community are effectively informed about project activities and outcomes from environmental watering, and to ensure appropriate information exchange between parties involved in environmental watering and monitoring/research. Through various communication and engagement activities, we aim to continue to communicate the purpose and outcomes of the project with stakeholders (including the broader community), and seek their support for the MER activities and adaptive management of flows where appropriate. Engagement with the broader community will build on existing stakeholder engagement processes of CEWO and the consortium partners, and extend and improve communication activities since the commencement of LTIM Project in 2014.

The objectives of the Engagement and Communication Plan are to:

- Engage effectively with key stakeholder groups including the broader community to support the MER Project and adaptively manage water for the environment in the Lower Murray.
- Work effectively with the Flow-MER team (Basin-scale, Selected Area and CEWO) to integrate communication outputs and outcomes of specific environmental flow outcomes in the Lower Murray.
- Engage with aboriginal groups and recreational fishing groups via targeted and relevant activities in an appropriate manner.
- Have fun, engage thoughtfully, engage early, value knowledge, develop trusting relationships through time, celebrate and promote the wins, and respect cultural and local contexts.

The Engagement and Communication Plan is guided by the International Association for Public Participation's (IAP2) Public Participation Spectrum.

8.1.1 Principles for communicating information about the project

Community and stakeholder engagement requires a strong foundation. To create this foundation the Lower Murray Selected Area Consortium has adopted the seven principles outlined within 'Better Together: Principles of Engagement', developed by the South Australian Government to provide a consistent approach to community engagement. It has been developed using the values and practices of IAP2.

- We begin early.
- We know what we want to achieve and we communicate it clearly.
- We know who to engage.
- We know the background and history.
- We are genuine.
- We recognise and celebrate.
- We are creative, relevant and engaging.

8.1.2 Protocols for good communication

While it is important to allow robust debate and discussion about processes, methodologies and interpretation, it is important for the credibility of the overall MER program that information delivered by the project team is accurate and consistent.

As a standard process, we'll seek CEWO's approval for all communications (e.g. a blanket approval for general communications and additional approvals for specific communications or events), and consult with the Lower Murray Selected Area Working Group where appropriate. If there are any findings that could be construed as criticisms of or concerns about the MER Project, they will be discussed between CEWO Project Manager(s) and the Project Leader to gain agreement on appropriate language.

The Project Leader will advise CEWO Project Manager(s) of any meetings she organises for the MER Project, and offer them the opportunity to contribute to relevant discussions.

Any written recording of meetings should accurately reflect the content of the discussion, but remove any emotive language.

If there are any issues or concerns of the Project raised by stakeholders, they will be communicated to CEWO through the Project Leader. It is expected that any concerns presented to CEWO will be responded to in a timely manner, through the Project Leader back to the stakeholders.

All requests for media communications will be referred to CEWO Project Manager (s) with oversight of the Lower Murray MER Project. Approval will also be sought from appropriate research director and communication manager at PIRSA-SARDI.

In all communications related to the MER Project (both internal operational and external), the Lower Murray Selected Area Consortium members agree to comply with the Code of Conduct developed by CEWO.

8.1.3 Stakeholder groups

Clients

Clients are those who are affected by the outcomes of the MER Project and are critical to the success of the project.

Table 8.1. Clients for engagement

Client	Role and benefit to the project	Primary method of engagement
CEWO	Purchasing client Defines the deliverables Approves milestone payments Knowledge adoption in adaptive management of environmental flows	Contract with SARDI Reporting (see Section 1) Meetings of the Selected Area Working Group Regular meetings between CEWO project manager(s) and Project Leader and relevant team member(s) Steering Committee meetings
MER Basin-scale Provider	Provides technical advice on the design of the Basin-scale MER indicators	Communication through CEWO MER Annual Forum MER Thematic Working Group meetings
Partners of the project consortium	Collaborate in the project team for the delivery of MER in the Lower Murray Selected Area. Support for annual reporting and evaluation and communication and engagement activities.	Sub-Contracts Meetings of the Selected Area Working Group Project meetings Collaborative monitoring and research activities

Stakeholders

Stakeholders are those whose input or involvement may be required for the MER Project to be successful, or who are likely to play a key role in supporting the outcomes of the project.

Table 8.2. Stakeholders for engagement

Stakeholder	Role and benefit to the project	Primary method of engagement
DEW	Contribute to identifying and prioritising MER requirements for the South Australian Government Data curation Advice on engagement and support Knowledge adoption in adaptive management of environmental flows	Membership on the Selected Area Working Group Partner of the project delivery team during Stage 1 for MER Plan development
MDBA	Contribute to identifying and prioritising MER requirements for the effective operation of the River Information on river operations	Membership on the Selected Area Working Group Communications with MDBA Regional Engagement Officer
SCBEWC	Play a key role in supporting the outcomes of the project Support adaptive management	Membership on the Selected Area Working Group Communications through Project Leader
SA Water	Contributing relevant water quality data for evaluation and research Information on river operations	Membership on the Selected Area Working Group
Natural Resources South Australian Murray–Darling Basin, DEW Local Action Planning	Provide advice on MER needs of community stakeholders in the Lower Murray region Community engagement	Membership on the Selected Area Working Group Partner of the project delivery team during Stage 1
PIRSA Fisheries and Aquaculture	Contribute to identifying and prioritising MER requirements for the South Australian Government Advice on engagement and communication	Membership on the Selected Area Working Group
Aboriginal groups	Targeted engagement with Aboriginal groups to support MER	Engagement with • Ngarrindjeri Regional Authority (NRA) • First Peoples of the River Murray and Mallee (FPRMM) • Mannum Aboriginal Community Association Inc. (MACAI) Regular face-to-face meetings to discuss project activities, findings and analysis. Development of a targeted project in conjunction with Aboriginal groups. Existing DEW processes will be used to support engagement where appropriate.

Stakeholder	Role and benefit to the project	Primary method of engagement
Recreational fishers	Targeted engagement with recreational fishers to support MER	Via Recreational Fishing Council inland fishery representative and support from PIRSA Fisheries and Aquaculture Designed project for targeted engagement
Affected landholders	Supportive landholders ensure strong community support for the MER Project	Engagement and interaction with affected landholders will comply with the Code of Conduct developed by CEWO

__Interested communities__

Interested communities are the broader public and community groups that may have an interest in the MER Project, but do not have significant influence or impact on the outcomes.

Table 8.3. Interested communities for engagement

Interested Communities	Desired Relationship	Primary Method of Engagement
Community of people who have a connection to the River	Support for and interest in the Program Promotion of the Program	External communication and engagement activities will be through, and building on, CEWO and DEW's existing engagement processes related to the management of environmental water. These include setting up MER Lower Murray websites, linking to Basin-scale Flow-MER project, social media and promotion materials.
Media	Promotion of the Program	
Broader community	Support for and interest in the Program Promotion of the Program	

8.2 Plan for key activities

The Lower Murray engagement and communication plan for MER Project includes activities that continue from the LTIM Project (e.g. Selected Area Working Group, see Section 8.3) and new activities targeting key stakeholders (e.g. Aboriginal groups, recreational fishers and landowners) to improve engagement. The Lower Murray team will work closely with CEWO Local Engagement Officer (LEO) to implement the plan, with strong support from the Basin Flow-MER Engagement and Communication team, PIRSA Communication Unit, Lower Murray Communication Coordinator (SARDI) and DEW Natural Resources (SA MDB). Details of our planned core and additional activities are presented in below Table 8.4 and Table 8.5, respectively. A subset of these listed additional activates will be selected in consultation with CEWO at a later stage.

Table 8.4. Operational engagement and communication plan (core activities)

Activity	Purpose	Timing / frequency	Responsibility	Indicative attendees
Project Meetings – CEWO and MER Selected Area Provider	*Project progress and outcomes* Regular meetings between CEWO and the MER Selected Area Provider will serve to monitor project progress, ensure the project remains on track to deliver against the project outcomes, report early observations/outcomes and discuss and resolve project risks, issues and actions.	Fortnightly during Stage 1 Monthly during Stage 2	SARDI	CEWO MER Lower Murray Selected Area Provider (Project Leader plus others as required)
Project Meetings and communications – internal Lower Murray team	*Internal project team communications to review and share project progress and early findings* Regular/frequent catch up with Lower Murray team task leaders and key scientists.	Quarterly catch up plus 2 project team meetings per year	SARDI	MER Lower Murray team (task Leaders/key scientists etc)
MER Project Steering Committee meetings	*Project direction, collaboration and consistency* The whole-of-project Steering Committee will provide for exchanging information and intelligence that supports the implementation of the MER Program, through effective coordination and issues resolution. Consistency across all Selected Areas is essential. Regular meetings between the MER Provider Project Leaders (Basin-scale and Selected Areas) and CEWO will help achieve this. Such meetings will also provide an opportunity for the Project Leaders to collaborate and share knowledge and experiences.	Biannually from 2019-20	CEWO	CEWO MER Provider Project Leaders for each Selected Area and the Basin scale project
Thematic Working Group meetings	*Theme approach, methods and technical guidance* Thematic working groups (TWG's) for hydrology, fish, vegetation, stream metabolism and biodiversity will be organised and attended by Basin Matter Leads and attended by the Selected Area Providers' thematic experts for the purposes of discussing progress and resolving issues in relation to ecological indicators evaluated at the Basin-scale. TWG's will ensure consistency in monitoring and evaluation approach within themes across all Selected Areas.	Initial MER Project Inception workshop – 2–3 April 2019 Others as required (~1–2 per year)	MER Basin Matter Leads	CEWO MER Basin-scale Provider (Project Leader plus matter Leads) MER Providers (Project Leader plus Task Leaders for fish, stream metabolism and vegetation)

Activity	Purpose	Timing / frequency	Responsibility	Indicative attendees
Selected Area Working Group meetings	*Information and knowledge exchange* The Selected Area Working Group meetings will discuss issues and progress relating to the implementation of the MER plan. SAWG meetings will also provide a forum for all parties involved in environmental water delivery to exchange knowledge, information and observations.	At least 2 times during Stage 1 3 times per year from 2019-20	SARDI	Selected Area Working Group members
MER Providers Annual Forum	*Technical collaboration* A face-to-face annual workshop organised by the Basin-scale Provider and attended by representatives from across the Basin-scale and Selected Area Providers as well as the CEWO. As MER activities proceed, adaptations will be required in response to practical experiences. Annual workshops will provide a forum to discuss lessons learned and collaborate on adapting the MER activities. The workshops will also help to build relationships between the MER Providers (both Basin and Selected Area teams) and create opportunities for efficiencies.	Annually	Basin-scale Provider	CEWO MER Basin-scale Provider (Project Leader plus Matter leads) MER Selected Area Providers (Project Leader plus Task Leaders)
Quarterly outcomes newsletter	*Communicating project outcomes* Newsletters will be written in plain English for a public audience and will communicate MER activities, preliminary observations and findings relevant to environmental watering, and case studies about environments and people. It will contain opportunistic photos of outcomes from environmental watering and other visual aids relevant to demonstrating outcomes to the public. It will also include a description of the monitoring and research activities undertaken in this quarter. Regular communication to CEWO by the MER Selected Area Provider will serve to keep water managers up-to-date with the latest findings, observations and trends from the monitoring.	Quarterly Due by end of March, June, September and December	SARDI	N/A
Quarterly project progress report	*Project progress and outcomes* Regular reporting to CEWO by the MER Selected Area Provider to monitor project progress, ensure the project remains on track to deliver against the project outcomes, report early observations/outcomes, and identify project risks, issues and actions.	Quarterly Due by end of March, June, September and December	SARDI	N/A

Activity	Purpose	Timing / frequency	Responsibility	Indicative attendees
Project pictures and images	*High resolution pictures and images of the monitoring activities and outcomes* High resolution pictures will be taken during field sampling (e.g. for stream metabolism, fish, vegetation and microinvertebrates), showing sampling methods/monitoring team in action, Lower Murray habitats and/or specimens. These images will be used in communication materials (e.g. reports, hard copy items, newsletters and social media). For modelling indicators, high resolution images of graphs will be produced for reporting and other communication materials. Pictures and images will be provided to CEWO.	Per sampling season	SARDI Lower Murray team	N/A
Annual MER reports	*Monitoring, evaluation and research annual reporting* Lower Murray will produce a technical report and a summary report annually. The summary report will be prepared for a general public audience.	Annually	SARDI Lower Murray team	N/A

Table 8.5. Operational engagement and communication plan (additional activities*)

Activity		Purpose - details	Timing / frequency	Responsibility (Attendees)
Activity 1 – Collaborate as an effective team	Interact with Basin-scale team and other Selected Area teams	*Collaborate effectively – Both Basin- and Area- scales for MER Project* Interact with Basin Engagement and Communication team Collaborative activities with other Selected Areas Presenting MER outcomes to CEWO, MDBA etc	Regularly Annual event Annually	SARDI (Basin-scale and other Selected Area teams, Lower Murray team) SARDI Project Leader
Activity 2 – Engagement and Communications infrastructure	Website	*Project information, progress and outcomes* Set up an MER website for the Lower Murray Selected Area and link to Basin Flow-MER website to better inform interested communities with knowledge of the project. Calendar of events: regular updates.	Ongoing At least two stories per year, and an aboriginal story.	SARDI (Supported by PIRSA Communication Unit and Basin Flow-MER Engagement and Communication team)
	Social media	*Project progress and outcomes* Communicate findings/learnings and progress to interested communities e.g. via Twitter, Facebook, You tube clips and/or other forms of social media.	Quarterly	SARDI (Supported by PIRSA Communication Unit and Basin Flow-MER Engagement and Communication team)

Activity		Purpose - details	Timing / frequency	Responsibility (Attendees)
	Hard copy items or products	*Project information* Communication products such as post cards, fact sheets, guides and other hard copy items to better inform interested communities with knowledge of the project. Powerpoint slides for communication of key outcomes to the general public – one for the top outcome/finding for each indicator each year (at a minimum). Each slide will include an image or graph, supported by key statistics/facts in the notes section Other ‘innovative’ products, e.g. building a small 3D model of the river, to show things like fish migration, salt import/export etc	Annually	SARDI (Supported by PIRSA Communication Unit and Basin Flow-MER Engagement and Communication team)
Activity 3 – Capacity building for Lower Murray team	Engagement and communication training	*Capacity building to improve skills in communication and engagement for the Lower Murray team.* A training course	First year Training Day	SARDI (Lower Murray team; supported by Basin Flow-MER Engagement and Communication team)
Activity 4 – Strong and meaningful Aboriginal engagement	Targeted engagement with Aboriginal groups	*Collaboration and information exchange* Better engage Aboriginal groups with the MER Project in the Lower Murray Selected Area. To be planned with support from CEWO, DEW and Brad Moggridge. Activities may include: - Project Leader, with CEWO LEO, attending and presenting at Aboriginal group meetings (FPRMM, MACAI and NRA). - Working with Brad Moggridge and DEW-NR SAMDB on processes to improve engagement - Development of a targeted aboriginal engagement project(s) in consultation with key groups, and to be implemented following processes/protocols developed for the project. The project is expected to provide opportunities for aboriginal groups to be directly involved in project monitoring, research and/or evaluation activities.	Attend and present at three meetings annually Targeted project TBA	SARDI (supported by CEWO LEO, DEW-NR SAMDB and Basin Flow-MER Engagement and Communication team; aboriginal groups)

Activity		Purpose - details	Timing / frequency	Responsibility (Attendees)
Activity 5 – Engaging recreational fishing and regional communities	Targeted engagement with recreational fishers	*Collaboration and information exchange* Better engage recreational fishers with the MER Project in the Lower Murray Selected Area. Seek support from PIRSA Fisheries and Aquaculture and South Australian Recreational Fishing Council representative (Inland Fishery).	Targeted events during MER Project	SARDI (Supported by PIRSA Fisheries and Aquaculture and SA Recreational Fishing Council; representative recreational fishers)
	Community Forum	*Present the outcomes and learnings from on the Lower Murray MER Project* *E.g. Fish and Flow Science Forum, Science in the Pub etc.*	At least two during MER Project	SARDI (Supported by CEWO and SAWG; broader range of interested parties and regional community)
Activity 6 – Practitioner Forum/workshops/gatherings	Participate and contribute to Practitioner Forum	*Improved engagement with practitioners of environmental water management and river operators.* Attend annual forum and present MER outcomes and learnings to support environmental water planning and adaptive management	Annually	Basin-scale Provider (Selected Area teams, at least 2 from Lower Murray)

*Subject to funding approval by CEWO for Engagement and Communication funding.

8.3 Selected Area Working Group

8.3.1 Purpose

The Selected Area Working Group for the Lower Murray will provide a forum for the exchange of information and intelligence that supports the implementation of the MER Project, through effective coordination of environmental watering and monitoring, evaluation and research.

8.3.2 Authority

The Selected Area Working Group will be organised, operated and Chaired by Project Leader, A/Professor Qifeng Ye (MER Provider), under the Terms of Reference approved by CEWO.

The Working Group has no executive powers, supervisory functions or decision-making authority in relation to the MER Project. It is an operational group tasked with a general support and advisory role.

8.3.3 Objectives

The Selected Area Working Group will facilitate:

- Effective coordination between environmental water delivery partners and other relevant monitoring and evaluation projects
- Communication to environmental water managers of any information that would improve environmental water management
- Exchange of information and intelligence relevant to improving the implementation of the MER Project and the efficacy of environmental watering activities, to support adaptive management on both a short-term (preliminary observations during watering events) and longer-term (evaluation outcomes) basis
- The identification, communication and management of any issues, risks or opportunities relevant to the MER Project.

8.3.4 Membership

The Selected Area Working Group includes organisations involved in environmental water planning and delivery, which are directly or indirectly responsible for the successful delivery of the Lower Murray Selected Area MER Project.

The Working Group comprises the following members who have been nominated by the Project Leader and agreed to by CEWO:

Table 8.6. Membership of the Selected Area Working Group

Name	Agency/position	Role
Qifeng Ye	**SARDI** – Lower Murray Selected Area lead organisation	Working Group Chair Project Leader – MER Lower Murray
George Giatas	**SARDI** – Lower Murray Selected Area lead organisation	Working Group member Project Officer – MER Lower Murray
Rod Oliver	**University of Adelaide –** Lower Murray Selected Area consortium partner	Working Group member Task Leader – *Stream Metabolism and Water Quality*

Name	Agency/position	Role
Matt Gibbs	**University of Adelaide/DEW** – Lower Murray Selected Area consortium partner	Working Group member Task Leader – *Hydrology (Channel)* and *Hydraulic Regime*
Brenton Zampatti	**SARDI** – Lower Murray Selected Area lead organisation	Working Group member Task Leader – *Fish (Channel)*, *Flow-cued Spawning Fish Recruitment* and *Murray Cod Recruitment*
Deborah Furst	**University of Adelaide** – Lower Murray Selected Area consortium partner	Working Group member Task Leader – *Microinvertebrate Assemblage*
Justin Brookes	**University of Adelaide –** Lower Murray Selected Area consortium partner	Working Group member Task Leader – *Matter Transport and Coorong Habitat*
Jason Nicol	**SARDI** – Lower Murray Selected Area lead organisation	Working Group member Task Leader – *Littoral Vegetation Diversity and Productivity*
Chris Bice	**SARDI** – Lower Murray Selected Area lead organisation	Working Group member Task Leader – Research
Michelle Campbell	**CEWO** – Local Engagement Officer (MER Project Contact)	Working Group member CEWO MER Project Contact
Alana Wilkes	**CEWO** – Southern Basin Section (MER Project Contact)	Working Group member CEWO MER Project Contact
Anthony Moore	**CEWO** – Southern Basin Section (MER Project Contact)	Working Group member CEWO MER Project Contact
Janet Pritchard/Gill Whiting/Andrew Lowes/Adam Sluggett	**MDBA** – *SCBEWC and The Living Murray Initiative*, Environmental Management Division	Working Group member
Jacqui Hickey/Sarah Commens/Tom Zouch	**MDBA** – River Murray Operations	Working Group member
Michelle Bald Rebecca Quin	**DEW –** LMR Selected Area consortium partner (Stage 1)	Working Group member
Tony Herbert / Jan Whittle	**DEW** – LMR Selected Area consortium partner (Stage 1)	Working Group member
Tracey Steggles	**DEW** – Lower Murray Selected Area consortium partner (Stage 1)	Working Group member
Jarrod Eaton	**DEW** – Lower Murray Selected Area MER	Working Group member
Tumi Bjornsson/ Andrew Rettig	**DEW** – LMR Selected Area consortium partner (Stage 1)	Working Group member
Keith Rowling	**PIRSA Fisheries and Aquaculture**	Working Group member

Name	Agency/position	Role
Darren Willis/ Rebecca Turner	**DEW/SAMDB NRMB**	Working Group member
Gary Fyfe	**SA Water**	Working Group member

8.3.5 Terms of reference

The Selected Area Working Group is responsible for providing strategic direction for the MER Project and exchanging information and intelligence to support project delivery and adaptive management. It will:

- Actively support and promote the MER Project within partner organisations
- Review key project documentation where appropriate, including evaluation reports
- Exchange operational intelligence relevant to the MER Project, including intelligence on upcoming watering or monitoring activities
- Exchange intelligence relevant to adaptive management of environmental water, including operational observations and monitoring and evaluation outcomes
- Consider stakeholder expectations of the MER Project where appropriate
- Exchange intelligence on any actual or perceived risks to the MER Project
- Communicate key messages of the MER Project to organisations involved in environmental water planning and delivery
- Document key discussion points and outcomes of Working Group meetings and distribute these to members in the form of minutes.

Meetings

Working Group meetings will be held at least twice during Stage 1 (2018-19) and three times per year in Stage 2 (from 2019-20). Meetings will be held primarily at SARDI Aquatic Sciences, 2 Hamra Avenue, West Beach, South Australia.

Minutes and agendas

The MER Provider will prepare and distribute meeting agendas and minutes. Agendas and minutes from the previous meeting and any papers for consideration will be distributed no later than five days prior to the meeting (where practical). Meeting minutes and action items will be distributed within two weeks of the meeting. Immediate actions may be circulated earlier.

Agenda items

The standard agenda items for the Working Group are listed below. Members can submit additional items to be included on the agenda at the discretion of the Chair.

Table 8.7. Standard agenda items and responsibilities for the Working Group

Item	Responsibility
Review and accept minutes from last meeting	MER Provider (Chair)
Update on action items from last meeting	Chair and members
Update on planned watering activities	Delivery partners, environmental water planning organisations
Update on planned monitoring activities	MER Provider lead
Update on monitoring observations and evaluation outcomes to support adaptive management	MER Provider lead

Item	Responsibility
Update on community engagement	MER Provider lead
Other business	All
Confirmation of next meeting	MER Provider (Chair)

Grievances

Grievances identified within the Working Group will be mediated by the Chair. Where a grievance is deemed significant, a member or members of the Working Group may be removed from the Working Group, at the discretion of CEWO.

9 Reporting

The timetable for reporting to CEWO is described in the table below, relating to core activities for the MER Project. Additional information exchange through communication and engagement activities will be provided (see Table 8.4 and Table 8.5).

Table 9.1. Summary of engagement, reporting and information transfer activities

What	Frequency	Timing / due date	Responsibility	Receiver	Description and high level requirements	Inputs
Selected Area MER Plan	One-off	Draft – 21 June 2019 Final – 30 June 2019	MER Providers	CEWO	A plan for monitoring, evaluation and research in each Selected Area over the three-year period from 2019-20 to 2021-22.	LTIM M&E Plan, LTIM reports, BWS, LTWP, and input from researchers and managers
Selected Area evaluation report	Annual	Draft – 30 Nov Final – 30 Dec First report – 2020 Final report – 2022	MER Providers	CEWO	A cumulative evaluation of the outcomes of Commonwealth environmental water at each Selected Area, prepared in accordance with the MER Plan. The report must be prepared in plain English with simple science and be suitable for publication on CEWO website.	MER Plan Monitoring data for the Selected Area
Progress reports – 2019-20 onwards	Quarterly	Sep, Dec, Mar and Jun (last business day of month) for the duration of the MER Project	MER Providers	CEWO	A written progress report, summarising tasks completed since the last report, tasks planned for the upcoming period, emerging issues etc.	Progress report template (Appendix C)

What	Frequency	Timing / due date	Responsibility	Receiver	Description and high level requirements	Inputs
Quarterly outcomes newsletter	Quarterly	Sep, Dec, Mar and Jun (last business day of month) for the duration of the MER Project	MER Providers	CEWO	Newsletters for MER Project written for a public audience will communicate MER activities, preliminary observations and findings relevant to environmental watering, and case studies about environments and people. It will contain opportunistic photos of outcomes from environmental watering and other visual aids relevant to demonstrating outcomes to the public. It will also include a description of the monitoring and research activities undertaken in this quarter.	MER data, learnings, outcomes, photos, etc.
Monitoring data entry	Monthly Or as appropriate for indicators agreed by CEWO	Monthly (or appropriate frequency agreed by CEWO) for the duration of the MER Project	MER Providers	Monitoring Data Management System	Processed monitoring data uploaded to the Monitoring Data Management System in accordance with data management protocols, as outlined in the MER Plans.	Data management protocols
Information exchange	At least three times via Selected Area Working Group, and as appropriate during the MER Project to support delivery of environmental water	As appropriate	MER Providers	CEWO and other delivery partners	Information exchange on project activities (monitoring undertaken, observations, evaluation) and any information that is available to MER Providers that would support the delivery of environmental water. This could be written and/or verbal. The Selected Area Working Group is an appropriate forum.	MER data, learnings, outcomes, etc.

10 Project management

10.1 Project governance and personnel

The **Project Leader**, A/Professor Qifeng Ye, SARDI Aquatic Sciences, leads the development and implementation of the MER Plan, oversees the MER Project and ensures project performance, coordination, reporting and communication. The Project Leader will report to **CEWO Project Manager(s)**, and be the contact for any communication between the project delivery team and CEWO.

The Project Leader will be supported by **Project Officer** George Giatas (SARDI) and following **Task Leaders** for the delivery of MER Project in the Lower Murray (Table 10.1), including:

- Matt Gibbs (University of Adelaide)
- Rod Oliver (University of Adelaide)
- Justin Brookes (In Fusion Consulting/University of Adelaide)
- Jason Nicol (SARDI)
- Deborah Furst (University of Adelaide)
- Brenton Zampatti (SARDI)
- Chris Bice (SARDI)

The **Project Officer** will assist with coordinating monitoring and reporting activities, provide executive support for Selected Area Working Group meetings and project meetings, support project communication and engagement (where appropriate), and be responsible for data management, uploads to MDMS and liaison with CEWO data managers.

Task Leaders will be responsible for leading the technical delivery teams that will undertake indicator monitoring, evaluation and research activities and contribute to annual reports for the Lower Murray Selected Area.

Furthermore, a **Communication Coordinator** (SARDI, ~0.12 FTE) (if supported by CEWO Contingency Funding for Engagement and Communication) will provide additional support for engagement and communication activities in the Lower Murray Selected Area and interact/collaborate with CEWO LEO and Basin-scale Flow-MER engagement and communication leadership team, to promote the MER Project and effectively engage with key stakeholders, Aboriginal groups, recreational fishing community and general public. Further support to this role will be provided by PIRSA Communication Unit.

The **Project Leader** will be part of a high level **Steering Committee**, which is the whole-of-project committee for the CEWO MER Program. This committee will be chaired by CEWO director and attended by Provider representatives (both Basin- and Selected Area scales) for the purposes of contributing to a forum for the exchange of information and intelligence that supports the implementation of the CEWO MER Program, through effective coordination and issues resolution.

The **Selected Area Working Group** involves key stakeholders in the Lower Murray, with membership approved by CEWO and meetings chaired by the **Project Leader**. This group will provide a forum for the exchange of information and intelligence that supports the implementation of the MER Project, through effective coordination of environmental watering and monitoring, evaluation and research. More details are provided Section 8.3.

Table 10.1. Project and task leaders and delivery team for Category 1 and 3 indicators, research and key activities in the Lower Murray.

Matters/activities	Indicators (Cat.)	Task Leader	Delivery Team
Project leadership and management	N/A	Qifeng Ye, SARDI	George Giatas, SARDI
Hydrology	*Hydrology (Channel)* (1) *Hydraulic Regime*(3)	Matt Gibbs, UoA/DEW	DEW representatives
Ecosystem function	*Stream Metabolism and Water Quality* (1)	Rod Oliver, UoA	Zygmunt Lorenz, UoA
Ecosystem function	*Matter Transport and Coorong Habitat* (3)	Justin Brookes, In Fusion Consulting/UoA	Matt Hipsey, Univ. WA Matt Gibbs, UoA/DEW Jason Nicol, SARDI Qifeng Ye, SARDI
Ecosystem function	*Microinvertebrate Assemblage* (3)	Deborah Furst, UoA	Russell Shiel, WRM/UoA
Vegetation	*Littoral Vegetation Diversity and Productivity* (3)	Jason Nicol, SARDI	Kate Frahn (SARDI)
Fish	*Fish (Channel)* (1) *Murray Cod Recruitment* (3) *Flow-cued Spawning Fish Recruitment* (3)	Brenton Zampatti, SARDI	George Giatas, Qifeng Ye, Chris Bice and other SARDI researchers
Research	Integrated research	Chris Bice, SARDI	Lower Murray team
Synthesis and evaluation	N/A	Qifeng Ye, SARDI	George Giatas (SARDI) Task Leaders
Engagement and communication	N/A	Qifeng Ye, SARDI	Communication Coordinator (SARDI) Supported by: Flow-MER Engagement and Communication Team Rebecca Turner, SAMDB NRM/DEW PIRSA Communication Unit

10.2 Risk assessment

Only the risks for which the MER Provider for the Lower Murray Selected Area is fully or partly responsible have been assessed in this section. There may be other risks to this project that CEWO is solely responsible for managing. This Plan does not assess those risks.

Table 10.2 identifies risks to the project, including:

- Communication risks – risks to the project if communication is ineffective or inadequate

- Project risks – risks to the ability of the project team to undertake all of the required tasks to an acceptable standard within the timeframe and budget of the project and to meet project objectives.
- Environmental risks – risks to the environment from carrying out monitoring tasks
- Health and safety risks – risks to the health and safety of the project team members as a result of their involvement in the project
- Political risks – risks of political issues being raised because of the project design, delivery or outcomes.

An assessment of the likelihood and consequence of these risks has been made (Table 10.3 and Table 10.4). A combination of these two assessments is used to make an overall assessment of risk to the project and its partners. A strategy for mitigation is proposed. The order of preference of how to mitigate the risks is:

1. Avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk
2. Accepting or reducing the risk in order to pursue an opportunity
3. Removing the risk source
4. Changing the likelihood
5. Changing the consequences
6. Sharing the risk with another party or parties (including contracts and risk financing)
7. Retaining the risk by informed decision.

Table 10.2. Project risks, their level of significance, and a proposed mitigation strategy

Risk	Likelihood	Consequence	Level	Mitigation
Communication Risks				
Tight timeframes for consultation on the development of the MER Plan. Stakeholders may not all feel that they have had the opportunity to be adequately involved. The project team may not be aware of all of the key issues.	Possible	Moderate	Moderate	Provide more than one opportunity for engagement. Personally invite key stakeholders to contribute advice and review methodologies. Build on LTIM priorities and is largely an extension of LTIM.
Failure to engage key stakeholders. The project team is not aware of key issues and intelligence.	Unlikely	Minor	Low	Form the Selected Area Working Group. Communicate widely with infrastructure support. Improve engagement and communication with additional funding support from CEWO.
Failure to be clear about what people can influence, and to what degree. Stakeholders spend time trying to influence non-negotiable issues.	Unlikely	Minor	Low	Continually reinforce the scope of the project. Clear Terms of Reference for the Selected Area Working Group.

Risk	Likelihood	Consequence	Level	Mitigation
Perception by stakeholders that project has not been successful because outcomes are not what they expected.	Possible	Moderate	Moderate	Clearly communicate the role, scope and expected outcomes of the project and how issues will be managed. Ongoing engagement with key stakeholders via Selected Area Working Group meetings and other processes.
Project Risks				
Category 1 methods may not enable ecological effects of CEW to be adequately evaluated in the Lower Murray Selected Area	Possible	Moderate	Moderate	Clarify the purpose of Category 1 indicators, which is to follow standard methods for data collection to support Basin-scale evaluation to be conducted by Basin-scale Provider. Evaluate annual outcomes and adapt approach if required (for Category 1 indicator applicable for Lower Murray Selected Area evaluation)
Category 3 methods do not enable ecological effects of CEW to be adequately evaluated in the Lower Murray Selected Area	Possible	Moderate	Moderate	These indicators are designed by matter experts who have extensive experience in ecological research in the Lower Murray, and building learnings from LTIM. Evaluate annual outcomes and adapt approach if required.
For Category 3 *Hydraulic regime* Permission is not given to obtain data for the hydrodynamic models from the DEW, SA Water and Bureau of Meteorology.	Rare	Minor	Low	The task leader is in a joint position with DEW as the Principal Hydrologist. Permission to use validation data will be actively sought from relevant organisations prior to use. Essential information such discharge and water level is freely available through DEW's open data policy. Additionally data such as velocity measurements are not essential; as models are well established and previously validated, and a modelled comparison between with and without Commonwealth environmental watering can still be provided.

Risk	**Likelihood**	**Consequence**	**Level**	**Mitigation**
For *Matter Transport and Coorong Habitat* Permission is not given to obtain data for matter transport modelling for the Murray River, Coorong, Lower Lakes and Murray Mouth from relevant agencies.	Rare	Moderate	Low	Essential information such discharge, water level and salinity data is freely available through DEW's open data policy. Additionally data such as other water quality parameters or ecological monitoring are useful but not essential; as models are well established and previously validated, and a modelled comparison between with and without Commonwealth environmental watering can still be provided.
Not receiving timely and reliable MDBA hydro data (including timing, volumes and source) flow, CEW and other environmental water to the Lower Murray for modelling, reporting and evaluation.	Possible	Minor	Moderate	Project Leader and Lower Murray Hydrologist will work with CEWO Project Manager(s), who will help obtain data from MDBA through a formal request with a clear timeline. Lower Murray Hydrologist will work with MDBA modeler(s), facilitated by CEWO, to ensure appropriate modelling approach is used and assumptions are clearly identified and communicated. Regular communication between CEWO manager(s) and Project Leader to allow timeline adjustment for reporting in case of delayed data.
Unexpected delays to the project (e.g. due to weather)	Rare	Minor	Low	Regular reporting mechanisms identified in Table 9.1. Regular communication between CEWO manager(s) and Project Leader to allow timeline adjustment for reporting due to unforeseen events.
No environmental watering events occur in any one year.	Rare	Moderate	Low	Clarify expectation and accept that monitoring results in any one year may not demonstrate an impact of environmental watering, but will still learn ecological response to flows to inform future environmental water and flow management.

Risk	Likelihood	Consequence	Level	Mitigation
Failure of individual Task Leaders or project participants to deliver on their requirements.	Unlikely	Moderate	Moderate	Sub-contracts include a clause linking payments to delivery of milestones. Reporting outlined in Table 9.1. Regular communication between Project Leader and Task Leaders to review of project progress.
Loss of key staff.	Unlikely	Major	Moderate	Seek replacement from within the employing organisation. If a suitable individual cannot be found, seek an appropriate replacement from across the consortium partners, then externally.
Environmental Risks				
Damage to environmental assets from field or laboratory work.	Rare	Major	Moderate	Seek environmental approvals for any field or laboratory work that may put environmental assets at risk.
Health and Safety Risks				
Injury resulting from field or laboratory work.	Rare	Major	Moderate	Staff are required to follow the health and safety rules and guidelines of their host organisation.
Political Risks				
Evaluation does not adequately meet the objectives of the Federal and State Government.	Rare	Major	Moderate	Key agencies are represented on the Selected Area Working group (Table 8.6). Regular communication and reporting, see Table 8.4 and Table 9.1.
Criticism of methodology by scientists not involved in project delivery.	Rare	Moderate	Low	Most of the methods have been tested in LTIM and other monitoring/research projects in the Lower Murray. Implement publication review process. Refer criticisms to CEWO and MER Basin-scale Provider.
Media criticism of the investment made into the MER Project (too low or too high).	Rare	Moderate	Low	Improve engagement and communication to demonstrate the purpose, value and outcomes of the project. Refer criticisms to CEWO.

Table 10.3. Criteria for assessing the risks for which the MER Provider for the Lower Murray Selected Area is fully or partly responsible for.

Likelihood	
Almost Certain	Almost certain to occur in most circumstances.
Likely	Is likely to occur in most circumstances.
Possible	Possible to occur in most circumstances.
Unlikely	Unlikely to occur in most circumstances.
Rare	May occur but only in rare and exceptional circumstances.

Consequence	Risk				
	Communication	Project	Environmental	Health and safety	Political
Critical	Complete lack of awareness and/or support for the project and outcomes. No uptake of project learnings.	Failure on the delivery of project objectives.	Long-term, irreversible damage to the environment.	Fatality or irreversible severe disability or impairment, where a worker is unable to return to the workplace.	The project would cease due to political sensitivities or lack of credibility.
Major	Limited awareness and/or support for the project and outcomes. Partial update of project learnings.	Major impact on the delivery of project objectives.	Long-term damage to the environment that would require considerable rehabilitation.	Lost Time Injury (LTI) - Extensive injuries, where a worker sustains permanent partial disability or time lost from work of one day/ shift or more.	Major impact on the credibility of the project and the ability to inform environmental water management.
Moderate	Reasonable awareness and/or support for the project and outcomes. Sufficient update of project learnings.	Moderate impact on the delivery of project objectives.	Short-term, widespread damage to the environment.	Medical Treatment Injury (MTI) - Significant non-permanent injury with limited period of disability, where medical treatment is required from a health practitioner.	Moderate impact on the credibility of the project and the ability to inform environmental water management
Minor	Good awareness and/or support for the project and outcomes. Effective update of project learnings.	Minor impact on the delivery of project objectives.	Short-term, localised impact on the environment.	First Aid Injury (FAI) – Insignificant non-permanent injury/ illness, where treatment is administered by a first aider.	Minor impact on the credibility of the project and the ability to inform environmental water management.
Insignificant	Full awareness and/or strong support for the project and outcomes. Maximum update of project learnings.	Little or minimal impact on the delivery of project objectives.	Little or minimal impact on the environment	Report Only – No injury/ illness	Little or minimal impact on the credibility of the project and the ability to inform environmental water management.

Table 10.4. Risk assessment matrix for assessing the risks of the MER Project in the Lower Murray.

		Consequence				
		Insignificant	Minor	Moderate	Major	Critical
Likelihood	Almost Certain	Moderate	Moderate	High	Extreme	Extreme
	Likely	Moderate	Moderate	High	High	Extreme
	Possible	Low	Moderate	Moderate	High	High
	Unlikely	Low	Low	Moderate	Moderate	High
	Rare	Low	Low	Low	Moderate	High

10.3 Quality assurance plan

This Quality Assurance Plan documents quality control and quality assurance procedures for activities at the Selected Area. The plan has been developed in accordance with relevant standards such as AS/NZS ISO 10005:2006 Quality management systems – Guidelines for quality plans; and ANZECC and ARMCANZ (2000) Australian Guidelines for Water Quality Monitoring and Reporting. Further information on data management and health and safety procedures are provided in Section 11 and Appendix A.

10.3.1 Field sampling and equipment

Stream Metabolism Water Quality **samples and equipment maintenance**

Quality control and quality assurance protocols have been developed for *Stream Metabolism and Water Quality*. In terms of this method, the Quality Plan has been addressed by the descriptions of:

- Requirements for NATA accreditation for water quality analyses: Water quality samples will be collected following the described protocol using methods detailed by the Australian Water Quality Centre, a NATA registered laboratory that will undertake the sample analyses. Water quality samples will be by pooling multiple, depth-integrated tube samples and analysed along with field blanks. Holding times for water quality samples will follow AWQC and NATA requirements (Appendix B, Table B.3).

- Calibration and maintenance of sensors and loggers: Sites for stream metabolism measurements will be located within the two zones of the Lower Murray Selected Area that are proposed for fish assessments. At one site within each zone, stream metabolism will be measured continuously over the period September to February. Due to the risk of vandalism and the preference for regular cleaning and maintenance to ensure reliable data sets, field trips will be made at least every four weeks to service and calibrate the water quality logger and to collect associated water quality samples.

- Preservation and transport of water quality samples: Samples will be filtered in the field and kept on ice until transported to the analytical laboratory within two days either by the collection staff or by courier. Chlorophyll samples will be filtered in the field and the filter stored frozen until analysed.

Vegetation sampling

Quality control and quality assurance protocols have been developed for littoral vegetation diversity and productivity. In terms of this method, the Quality Plan has been addressed by the descriptions of:

- It is the sole responsibility of the provider to have specific permits from DEW with them while sampling.

- Herbarium samples of all unknown or species where the identification is doubtful observed in quadrats will be collected and retained for identification.

Fish sampling

Fish sampling for Category 1 and 3 indicators will be undertaken using electrofishing. SARDI Inland Waters and Catchment Ecology has two electrofishing boats*, Frank* and *Henri*. The primary difference between these is hull size (5.8 and 4.3 metres respectively) and the capacity of the electrofishing units (7.5 and 5.0 kW, respectively). Both boats are operated and maintained in accordance with the *Australian Code of Electrofishing Practice 1997* and SARDI SOPs. Comprehensive details on operation, maintenance and risk management can be found in these documents, which can be supplied if required.

QA/QC activities specific to this fish sampling include:

- Electrofishers will be experienced operators of units. They will be supervised by Senior Operators on-site, and have obtained their electrofishing certificates through a reputable course.
- Monitoring and Evaluation Providers will have relevant boat licenses.
- It is the sole responsibility of the provider to have specific fisheries and ethics permits with them while sampling. All sampling will be conducted under an exemption of section 115 of the *Fisheries Management Act 2007*.
- All personnel involved in field work will be professionally trained and have a Senior Operator supervising on-ground work.

10.3.2 Data collection, storage and management

Written field data will be recorded in waterproof field books using pencil, scanned on return to the laboratory to ensure safe copies, and data written to a file that meets the LTIM Project data standard. Refer below to Section 11 for QA/QC procedures relation to the storage and management of data.

10.3.3 Training

The team assembled to undertake this project are all highly experienced field operators, and it is not envisaged that they will require any training.

Should anyone require training, it will be at the instruction of the Project Leader. Under such circumstances, the Project Leader will require written confirmation from the trainer that the trainee has demonstrated competency in the required skills before that individual is permitted to undertake the relevant monitoring.

10.3.4 Auditing

CEWO has advised that they will be establishing whole-of-project audit procedures. The Lower Murray Selected Area Consortium has also identified the following self-auditing protocols.

Table 10.5. Self-auditing plan

Input/output	Audit procedure
Project partner sub-contracts	Payments made on delivery of milestones listed in the sub-contract, to be approved by the Project Leader
Technical reports and papers	Every technical report/paper and Annual Report will be independently reviewed
Data management protocols	Data quality will be audited by SARDI staff
Project risk assessment and mitigation plans	Mitigation of risks as per the risk management strategy will be audited quarterly by the Executive Committee
Health, safety and environmental risk assessment and mitigation plans	Each partner organisation of the consortium will sign off that they have audited the project for consistency with internal health and safety procedures
Communication and engagement plans	Delivery of communication and engagement plans will be audited quarterly by the Executive Committee

11 Data management

11.1 Data collection

Monitoring teams will be led by experienced scientists who are skilled to appropriately perform sampling using standard, repeatable methods (gear, sample size, sample preparation and preservation). The SARDI Project Leader will ensure that Task Leaders develop suitable Quality Plans (Section 10.3) to ensure the data and measurements taken in the Lower Murray Selected Area are of high quality and appropriately scaled to be able to report against questions with suitable error estimates if required. For Category 1 indicators, consultation will occur with the MER Basin-scale Project Provider.

Relevant standards and guidelines will be considered, equipment records will be maintained, calibration directions provided with each instrument will be followed, and for each instrument the meter errors for each parameter will be documented and reported (Section 10.3). Details about data collection have been developed in negotiation and agreement with the MER Project Adviser during LTIM.

The Lower Murray Selected Area Consortium partners provide research and monitoring services as part of our core business. We all have established QA/QC processes for field sampling, laboratory analysis, experimental data collection, data entry and reporting. Specific QA/QC plans are provided for relevant activities in the Quality assurance plan (Section 10.3).

11.2 Data storage and management

Individual sub-contractors will be responsible for management of all primary (raw) data including governance, storage, backup, version control and custodianship. Data will be made available to the MER Provider lead agency (SARDI) as necessary for Selected Area and Basin-scale analyses and reporting purposes.

- Hydrology data will be entered into DEW’s hydrological database
- Water quality and stream metabolism data will be entered to various Adelaide University databases including Excel and R-based data systems
- Fish and microinvertebrate data will be entered into SARDI inland waters databases (Access)

Complementary monitoring

Some indicators (e.g. *Hydraulic Regime* and *Matter Transport and Coorong Habitat* modelling) will utilise data collected by complementary monitoring programs (see Section 7.3). All organisations providing complementary monitoring data (SA Water, EPA and SA Water) have appropriately trained staff and procedures for obtaining and managing data to a suitable standard. In any case, the project team includes personnel highly experienced with handling and interpreting the type of data (parameters and locations) that will be considered within this study. As such, the project team will ensure that all data obtained from complementary monitoring programs are interrogated for potential errors.

Any potential errors will be investigated and if necessary removed. Quality of modelling outputs will be assessed through validation against observed data. Through this process, any potential errors will be identified and fixed the models will be rerun until the outputs are of a suitable scientific output. As part of the quality assurance and quality control, observed data will be compared to the ranges in the indicator-specific data definitions for the Monitoring Data Management System (MDMS). Although all raw data will be stored on databases of the intellectual property owners, compiled data will also be stored and managed by the project team.

The Monitoring Data Management System

In addition to storage of data in individual sub-contractor and MER Provider lead agency (SARDI) databases, data will be entered into the Monitoring Data Management System (MDMS), which is maintained by CEWO. All data provided for indicators into this database will conform to the data structure defined in the LTIM Data Standard (Brooks and Wealands 2018) to ensure data is consistent and comparable across Selected Areas to enable Basin-scale evaluation.

The spatial unit for which data is reported for each indicator is known as an 'assessment unit'. The assessment unit for this indicator is: the site (river section). Each row of data provided for each indicator will identify the assessment unit, the temporal extent of the data and a number of additional variables (as guided by the standard method in Brooks and Wealands 2018).

The exact data structure (template) for each Category 1 (Basin-scale) indicator is maintained and communicated in the LTIM Data Standard and will be enforced by the MDMS when data is submitted. The data templates for Category 3 (Selected Area) indicators have been developed in consultation with CEWO and conform to data standards (Brooks and Wealands 2018). These templates, including a description of the variables, their type and range, are provided in the SOPs for each Category 3 indicator (Appendix B). Data formats are subjected to change throughout the project's three-year operation in consultation with CEWO.

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13 Detailed budgets

To be provided to CEWO separately during the submission of the final draft.

Appendices

Appendix A – Workplace Health and Safety Plan

The Lower Murray Selected Area Consortium is unable to present a single health, safety and environment plan because staff within each organisation are required to follow their own internal rules and guidelines. Each partner organisation of the consortium will sign off that they have audited the project for consistency with internal health and safety procedures.

This section outlines how SARDI will manage work, safety and environment for this project.

Site Safety Management Plans have been implemented across PIRSA, including SARDI. They are a tool designed to assist PIRSA worksites to meet minimum Work Health Safety and Injury Management (WHS) legislative and *PIRSAFE* requirements.

Under these plans, activities are scheduled and responsibilities allocated to ensure that obligations are met. Completing the activities contained within the plan supports the site's compliance with WHS legislation and PIRSAFE policies and procedures. Evidence of completed activities is registered to meet compliance and audit requirements.

The SSMP provides the guidance and tools to meet the work health and safety requirements for the LTIM Project, along with PIRSA's other WHS policies and procedures.

Objective

To ensure that project risks are eliminated or mitigated through the identification of hazards, assessment of risk and the application of effective control measures.

Identification and control of risks

Risk management is conducted in accordance with PIRSAFE Risk Management Policies and Procedures. Risks are identified through the Job Task Risk Register - Aquatic Science Research Operations (attached separately). A job task register is a document that compiles information relating to work tasks, the associated risks and controls.

The Project Leader will work with SARDI staff to identify and control workplace health and safety related risks, and develop a plan for controlling these risks.

Significant Risks

All job tasks that have a residual risk of high or extreme are captured as a significant risk extract. This risk extract is developed following the completion of the job task register. A review of the job task register and significant risks is undertaken annually.

Safe work procedures

SARDI conducts safe work practices in accordance with the PIRSAFE WHS Management System (WHSMS). In addition to the WHSMS, task specific Job Safety Analysis (JSA) or Safe Operating Procedures (SOP) are developed for specific hazards. These documents are identified and developed through the job task register. Hazards are reported across PIRSA through rthe Hazard and Incident Reporting System (HIRMS), then analysed to identify corrective actions. Reporting from HIRMS provides trends and assists in implementing preventative measures. As a result, PIRSA has explicit Policies and Procedures relating to:

- Bushfire safety
- Driving

- Drug and Alcohol
- Energy Isolation
- Events
- Fatigue Management
- Field Work
- Hazard & Incident Reporting and Investigation
- Hazard Management
- Hazardous Manual Tasks
- Hazardous Substances Management
- Inclement Weather
- Injury Management
- Work Health and Safety Planning
- Plant and Equipment
- Risk management
- Site Safety Management Plans.

Procedures for site visits

SARDI conduct safe work practices for site visits and field trips in accordance with PIRSAFE Procedures. Site visit and field trip procedures are managed through our trip itinerary form (attached separately).

Fieldwork checklists

SARDI staff must complete a trip itinerary form for a field trip. A Scheduled Call Officer is the land-based contact for field trip staff to ensure safety during field trips. The requirements for Field Operations is outlined in the SARDI Aquatic Sciences Field Communications Manual (attached separately). Specific checklists have been developed for research and monitoring projects. Checklists will be developed for fieldwork relevant to monitoring indicators when the final list of indicators has been approved.

Legal and other requirements

- *Work Health and Safety Act 2012*
- *Work Health and Safety Regulations 2012*
- *Return to Work Act 2014*
- *Return to Work Regulations 2015*

Related documents

- PIRSAFE WHS Management System
- Site Safety Management Plan
- Job Task Risk Register
- Training Needs Analysis

WHS roles and responsibilities

The Chief Executive of PIRSA is required to identify, audit and demonstrate compliance with WHS legislation and the Return to Work Performance Standards for Self-insurers through the PIRSAFE systems.

SARDI is required to integrate WHS within its business, performance and goals. SARDI assigns its own objectives, targets and key performance indicators to meet its business needs, in addition to PIRSA-wide objectives.

Site managers are appointed at each of SARDI's regional sites, who coordinate WHS site activities. PIRSA provides these site managers with standard practices, guidance and assistance, tools, systems and education.

In this particular project, the Project Leader from SARDI is responsible for ensuring that the objectives and goals of the WHS plan are met by SARDI staff. The Project Leader will require each consortium partner to sign a WHS Plan when they agree that it is consistent with their internal health and safety procedures.

The Project Leader will be responsible for implementing the agreed WHS Plan for the SARDI staff involved in the project. Where two organisations are involved in the same field trip, they will each have developed their own WHS Plan that meets their own internal WHS requirements.

Training and competency

Training and competency is managed in accordance with PIRSA WHS Training Procedures (attached separately). Training needs are identified through the Training Needs Analysis, which is a process that identifies, plans, implements and reviews WHS training programs specifically related to job tasks. This includes training on hazards, risks, controls and associated tasks, SOPs, licence requirements, and competency and certification requirements.

Contractor/sub-consultant management

The Project Leader will require each consortium partner to sign off that they have audited the project for consistency with internal health and safety procedures.

Contractors are managed in accordance with PIRSA WHS Contractor Management Procedures (attached separately).

Induction procedures for visitors and contractors are adhered to and documented in accordance with PIRSAFE Induction Procedures.

Contractors involved in this project will have individual policies and guidelines for workplace health and safety. An outline of how policies and guidelines are managed within The University of Adelaide is outlined below.

The University of Adelaide is committed to maintaining the highest possible standard of health, safety and well-being for all employees and students (and others) while they are at work at the University. The University recognises the importance of integrating the continuous improvement of health and safety into all organisational activities, ranking this equal with all other operational considerations.

The University's Health, Safety and Wellbeing Team provide support to the University community on all safety, injury management and wellbeing issues. Services include:

- Management of the University Occupational Health & Safety Management System (OHSMS) and consultative framework
- Support in developing, implementing and reviewing of OH&S Policies, Procedures and Instructions
- Development of the Corporate OH&S Action Plan to ensure continuous improvement in OH&S
- Injury Management (workers compensation, rehabilitation, employee assistance program)
- Investigation of major incidents and implementation of improved hazard control measures
- Coordination of staff wellbeing initiatives and programs
- Management of the University OH&S Audit program.

Appendix B – Standard Operating Procedures for the Lower Murray

Introduction

Standard Operating Procedures (SOPs) of Category 1 (Basin) and 3 (Selected Area) indicators are provided in this document for the Lower Murray Selected Area. Protocols for Category 1 indicators follow the LTIM Standard Protocols detailed in Hale *et al.* (2014) (Table B.1). Category 3 indicators mostly follow the Lower Murray Selected Area protocols from LTIM (SARDI *et al.* 2018), or have newly developed protocols (e.g. new indicators). Changes to Standard Operation Procedures, such as modifications to methodology or data analysis, may have occurred since the first M&E Plan was developed in 2014. Additionally, there is potential for further changes to be made throughout the LTIM Projects operation.

Table B.1. Category 1 (Basin) and 3 (Selected Area) indicators of the Lower Murray Selected Area.

Category	Indicator	Comments re. LTIM Standard Protocol in Hale *et al.* (2014) and Lower Murray Selected Area protocol from LTIM (SARDI *et al.* 2018)
1	Hydrology (Channel)	Follows the standard protocol for *Hydrology (Channel)**
	Stream Metabolism and Water Quality	Follows the standard protocol for *Stream Metabolism**
	Fish (Channel)	Follows the standard protocol for *Fish (Channel)**
3	Hydraulic Regime	Follows Lower Murray LTIM protocol for *Hydraulic Regime*
	Matter Transport and Coorong Habitat	Follows Lower Murray LTIM protocol for *Matter Transport*, with addition of Coorong Habitat modelling component.
	Littoral Vegetation Diversity and Productivity	Newly developed protocol for MER.
	Microinvertebrate Assemblage	Modified version of Lower Murray LTIM protocol for *Microinvertebrates*. Haney trap is used in preference to the bucket method for potamoplankton sampling. Does not follow standard Category 2 riparian protocols.
	Flow-cued Spawning Fish Recruitment	Closely follows Lower Murray LTIM protocol for *Fish Spawning and Recruitment (Flow-cued Spawning Fishes)*.
	Murray Cod Recruitment	Newly developed protocol for MER.

*Standard protocols for the MER Project may be modified from the LTIM protocol described in Hale *et al.* (2014).

Category 1

1 Hydrology (Channel)

1.1 Evaluation questions

This protocol does not directly address specific Basin-scale evaluation questions, rather it provides fundamental information for analysis and evaluation of monitoring outcomes against hydrological conditions and environmental watering for all indicators. It indirectly addresses Basin-scale evaluation questions for *Fish (Channel)* and *Stream Metabolism and Water Quality* (Figure B.1).

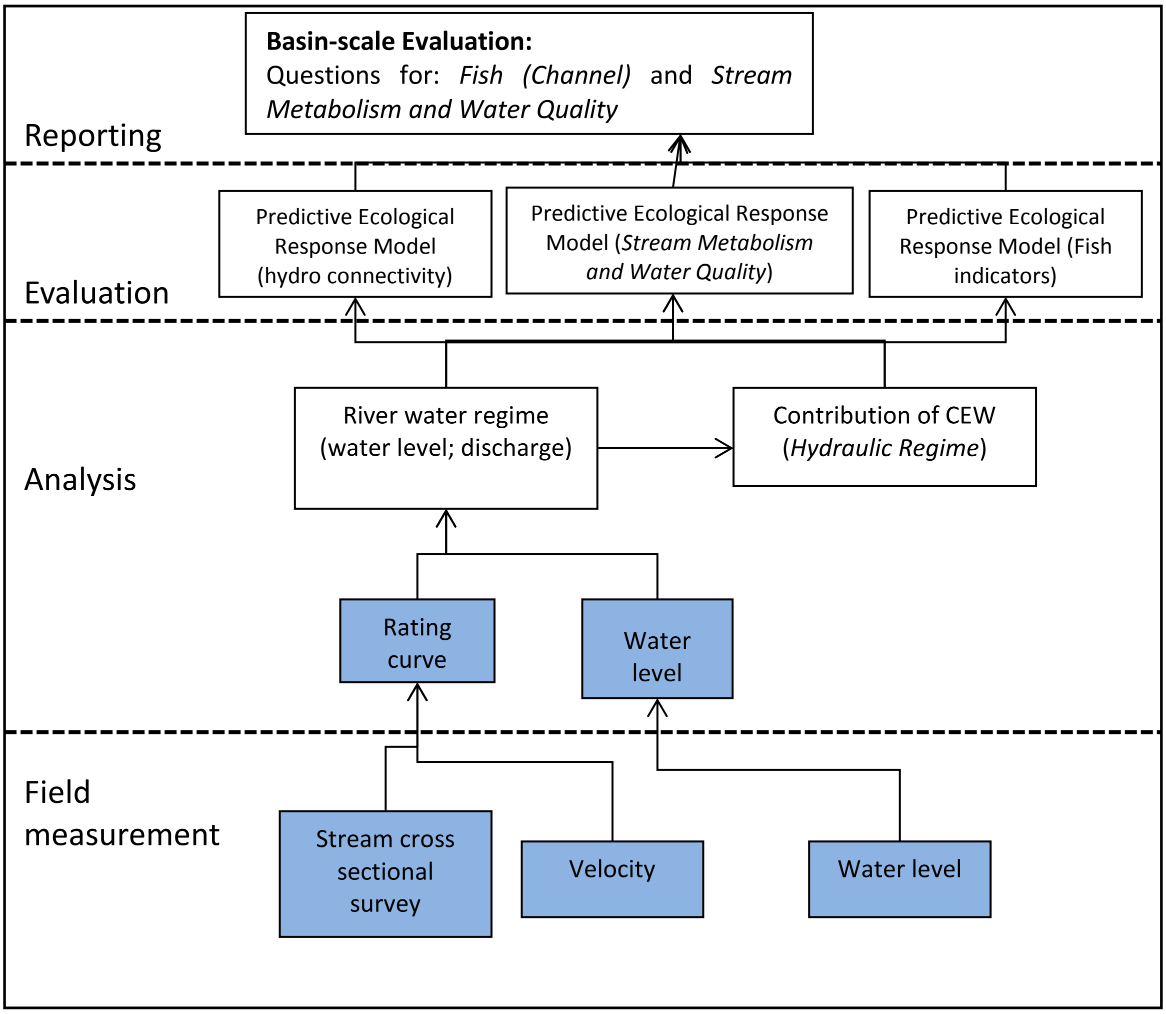

Figure B.1. Schematic of key elements of the LTIM Standard Protocol: *Hydrology (Channel)*, which has been adapted from the schematic of *Hydrology (Channel)* in Hale *et al.* (2014).

1.2 Relevant ecosystem types

Rivers.

1.3 Relevant flow types

All – baseflow, freshes, bankfull and overbank.

1.4 Overview and context

Hydrology (Channel) is a continuous monitoring protocol designed to capture aspects of a rivers water regime that influence behaviour and condition of native fish, stream metabolism, and water quality. In particular, this protocol aims to quantify the effect of Commonwealth environmental water on aspects of river hydrology that are most important for native fish, stream metabolism, and water quality. This protocol is based on a combination of field measures and hydrological modelling and comprises:

- Cross sectional survey
- Velocity measurements and development of a rating curve
- Daily Mean 'Stage' Height.

Refer to Section 5.1.1 in the MER Plan for background information, objectives, outputs and staff involvement for *Hydrology (Channel)*.

1.5 Complementary monitoring and data

For the Lower Murray Selected Area, the river hydrology monitoring is available from local gauging stations. These records are considered appropriate as they are just upstream and within the zone and if no tributaries exist between the site and the gauging station. It should be noted there are some anabranches around some of the stations that are within the zone, but the necessary upstream flow gauge is considered accurate.

1.6 Monitoring locations and timing

1.6.1 Locations

The discharge upstream of the Lower Murray Selected Area is recorded at the Flow to South Australia (A4261001) station. This record is calculated based on two stations, Murray River D/S Rufus River (AW426200) and the flow through the Lindsay–Mullaroo Anabranch (AW414211), with allowances made for losses and extractions in this anabranch. This station is considered high quality, and used for multiple reporting purposes. Within the Lower Murray Selected Area, discharge over each weir is calculated based on the upstream water level, downstream water level, and a rating curve relationship to calculate discharge. The relationship was derived using multiple velocity cross sections downstream of each weir. Based on current data availability discharge records available in the area are outlined in Table B.2.

Table B.2. Station data available

Station Number	Station Name
A4261001	Flow to SA
A4261091	Chowilla Creek DS Monoman
A4260511	Lock 6 DS
A4260513	Lock 5 DS
A4260663*	Lyrup PS
A4260515	Lock 4 DS
A4260517	Lock 3 DS
A4260528*	Overland Corner
A4260619	Lock 2 DS
A4260903	Lock 1 DS

* Flow data only valid for high flows

1.6.2 Timing

Water level and calculated discharge data at the stations outlined in Table B.2 is collected on a daily, or sub-daily basis. Data is readily available in DEW's hydrological database, and can be exported at any time.

1.7 Monitoring protocol

1.7.1 Equipment

Monitoring data in Table B.2 is collected using infrastructure in place, typically stilling wells or mounted pressure transducers for water level, and the conversion to flow using existing relationships.

1.7.2 Protocol

Monitoring data collected by complementary monitoring programs (Table B.2) will continue to adopt current best practice protocols, as monitored and maintained by the DEW Resource Monitoring Unit based at Berri, as well as SA Water at each Lock.

1.8 Data analysis and evaluation

No reporting or analysis is included in this indicator. However the data collected is important, providing fundamental information for analysis and evaluation of monitoring outcomes against hydrological conditions and environmental watering for all indicators.

1.9 Data management

See Section 11 in the MER Plan for data management procedures. The data structure for all Category 1 (Basin-scale) indicators will follow standard templates decided upon by the MER Basin-scale Providers, in consultation with CEWO.

1.10 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

1.11 Health, safety and environment plan

See Appendix A.

1.12 References

Hale, J., Stoffels, R., Butcher, R., Shackleton, M., Brooks, S. and Gawne, B. (2014). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project – Standard Methods. Final Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre. Murray–Darling Freshwater Research Centre, MDFRC Publication 29.2/2014.

2 Stream Metabolism and Water Quality

2.1 Evaluation questions

This monitoring protocol addresses the following Basin-scale evaluation questions:

- What did Commonwealth environmental water contribute to patterns and rates of decomposition?
- What did Commonwealth environmental contribute to patterns and rates of primary productivity?
- What did Commonwealth environmental water contribute to dissolved oxygen levels?
- What did Commonwealth environmental water contribute to water quality?

The process for evaluating these questions is illustrated in Figure B.2.

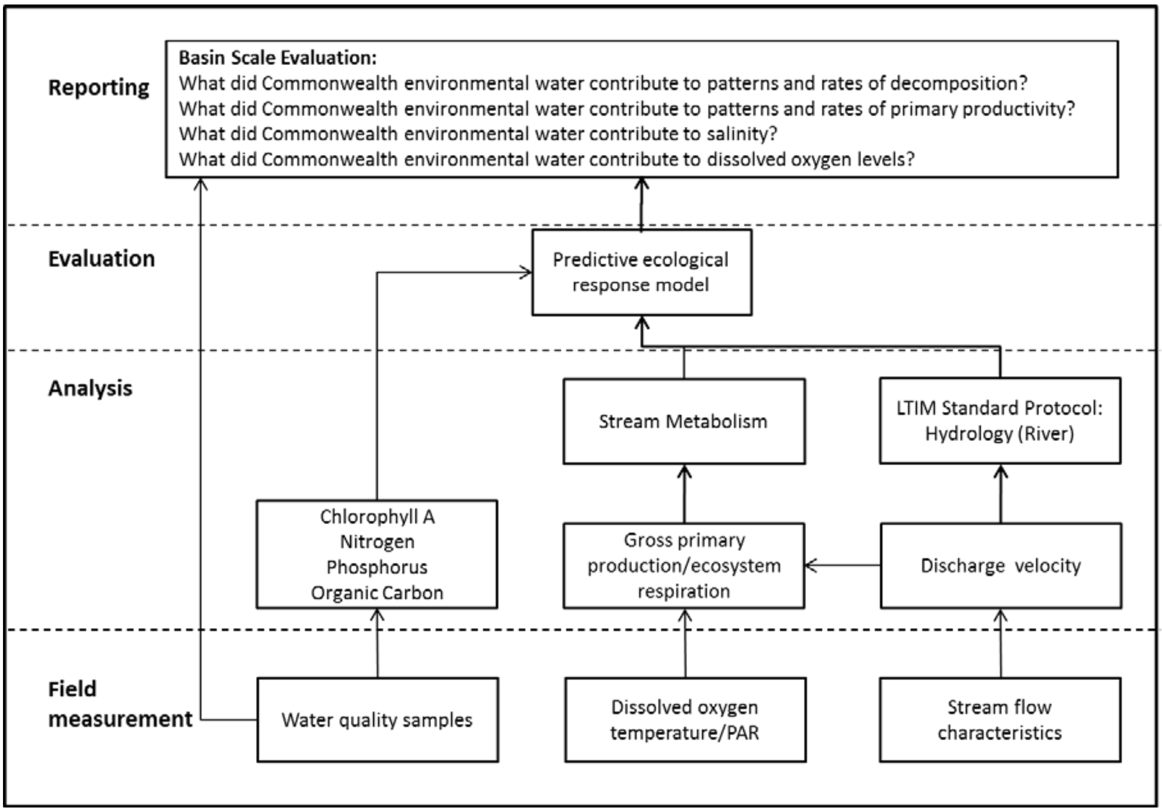

Figure B.2. Schematic of key elements of the LTIM Standard Protocol: *Stream Metabolism and Water Quality* (taken from Grace *et al. In Prep*).

2.2 Relevant ecosystem types

Rivers.

2.3 Relevant flow types

All – baseflow, fresh, bankfull, overbank.

2.4 Overview and context

Under the MER Project, stream metabolism is measured for two purposes:

1. To inform the Basin-scale quantitative evaluation of fish responses to Commonwealth environmental water (see *Fish (Channel)* SOP); and
2. To detect changes in primary productivity and decomposition in river in response to Commonwealth environmental water.

This protocol uses the replicate single station open water method and comprises:

- *In situ* logging of the dissolved oxygen concentration and temperature at ten minute intervals between September and February, which will provide data for estimating stream metabolism at three sampling sites in the Lower Murray Selected Area.

Covariates measures are:

- **Gauged water level related to cross-sectional area and flow velocity:** Measurements of water level and stream characteristics including water velocity, channel cross-sectional area and average depth of sampling sites. This information will be provided from established gauging stations in the Lower Murray in conjunction with site measurements during sampling trips.
- **Water quality samples including chlorophyll concentrations:** Collection of discrete water quality samples for the analyses of chlorophyll-*a*, total nitrogen, NO_X, NH_4, total phosphorus, PO_4, and dissolved organic carbon will be collected routinely at intervals ≤6 weeks duration.
- **Photosynthetically active radiation:** A terrestrial station logging photosynthetically active radiation (PAR) and barometric pressure at ten minute intervals to match the stream metabolism measurements will be established in a suitable nearby location.

This protocol is based on the single station open water stream metabolism method as detailed in Oliver and Merrick (2006), Oliver and Lorenz (2010) and Grace and Imberger (2006). Refer to Section 5.1.2 in the MER Plan for background information, objectives and hypotheses, outputs and staff involvement for *Stream Metabolism and Water Quality*.

2.5 Complementary monitoring and data

Hydrological data on stream discharge will be provided from the existing permanent stream gauging network associated with the weirs and managed flows of the Lower Murray. Mean velocity will be determined from the discharge data using existing information held by DEW, supplemented with site measures of cross-sectional area and gauged water level measurements. Estimates of water depth will be calculated from discharge and cross-sectional area and used to convert volumetric rates of metabolism to areal rates for comparison across zones and Selected Areas.

Data on water quality may be complemented by monitoring data collected through other relevant programs such as short-term monitoring instigated by CEWO and/or MDBA in response to planned watering actions or a potential water-quality event.

2.6 Establishing sites

2.6.1 Overview

MER for Basin-scale evaluation has adopted a hierarchical approach to sample design (Hale *et al.* 2014). Briefly, the spatial hierarchy for *Stream Metabolism and Water Quality* is as follows:

- Selected Area (Lower Murray)
  - Zone (*Gorge*)

- Site

A 'zone' is a subset of a Selected Area that represents a spatially, geomorphological and/or hydrological distinct unit at a broad landscape scale. For example, separate river systems, sub-catchments or large groups of wetlands. A site is the unit of assessment nested within a zone and in this instance will be a section of river.

2.6.2 Sites

In the Lower Murray, three sites have been identified for measurements of stream metabolism, which are situated downstream of Lock 6, downstream of Lock 4 and downstream of Lock 1. The sites downstream of Lock 6 and 1 are long-term LTIM sites that were selected to represent the two major geomorphological zones of the Lower Murray Selected Area, the *Floodplain* zone and the *Gorge* zone. These two zones respond differently to increases in flow, as the *Floodplain* has an open floodplain while the *Gorge* has a constrained floodplain. Because of these differences, hydrological characteristics such as connectivity differ markedly between them. The additional site (downstream of Lock 4) for the MER Project is hydrologically distinct from the other two long-term sites, and situated between the two in the *Floodplain* zone. This site has been identified as important for Murray cod recruitment and will complement the research project (See Section 6 of the MER Plan).

Between September and February of each year a single water quality (WQ) station will be deployed within the water column at each of the three sites, downstream of Lock 6, Lock 4 and Lock 1, continuously recording dissolved oxygen and temperature at ten minute intervals. The stations for stream metabolism measurements will be located within each site as follows:

- Open water, with sufficient depth that the sensors will not be exposed to air or touch the sediment
- Well mixed (non-stratified) water column to ensure measurements are representative of each site
- Constantly flowing reach
- No interference from tributaries, drains or significant groundwater inflows
- Safe to access
- Protected from vandalism to the extent possible
- Probes not located within macrophyte beds.

Measurements of light (PAR) and barometric pressure will be collected from nearby terrestrial locations. Light sensors will be located in an open area, not impacted by tree canopy or shading near to each of the three sites for careful matching with river metabolism measurements. A single barometric probe will be deployed at one of these stations as no significant differences in ambient conditions are expected across the region, or alternatively data from a nearby BOM station will be used.

2.6.3 Timing

Stream metabolism measures are to be collected continuously between September and February as this is the period of active growth of organisms within the river and also the period when enhanced environmental flows to the Lower Murray are likely. It is important to obtain one or two weeks of metabolism and water quality measurements prior to any major flow event to provide a starting level for assessing changes associated with larger events. Stations will be serviced and calibrated at a frequency of no longer than 4 weekly intervals where possible, but more frequent servicing will be required during environmental flow periods to ensure successful operation of probes during key times, and also to collect water quality samples. Increased servicing will be necessary during periods of high productivity due to increased likelihood of sensor fouling. Refer to Section 7.2 in the MER Plan for a monthly monitoring schedule for *Stream Metabolism and Water Quality*.

2.7 Water quality samples

Water quality variables are important for interpreting the stream metabolism results and are an input to the ecological response model for Basin-scale evaluation. Water samples will be collected for: chlorophyll-*a*, total nitrogen (TN), total phosphorus (TP), nitrate–nitrite (NOx), ammonium (NH4), filterable reactive phosphorus (FRP) and dissolved organic carbon (DOC). In-situ spot measurements will be taken of pH, turbidity and electrical conductivity (EC) using a multi-probe water quality meter. As a minimum, water quality samples will be collected when sensors are deployed and at each time the station is serviced and calibrated (≤ 6 weekly intervals).

Filtering for dissolved nutrients (NOx, NH_4, FRP, DOC) and chlorophyll will take place on site and samples frozen for transport to the analytical laboratories. Sample analyses will be undertaken by the Australian Water Quality Centre (AWQC, NATA registered) and sampling protocols will meet NATA requirements. All sample bottles will be supplied by AWQC and sample handling will be in accordance with preservation requirements as per the Australian Standard. AWQC will supply the syringes and 0.2 µm membrane filters used for filterable nutrient concentrations. Information on the methods including bottles, holding times and limits of detection are listed in Table B.3.

Table B.3. Information on the water quality analysis methods to be used by the AWQC. Reference method refers to American Public Health Association (APHA), International Standards Organisation (ISO) and the Standard Methods for Examination of Water and Wastewater (SM). Holding time is the length in hours that a sample can be stored using the reference method. Bottle = type of bottle for sample collection. LOR = limit of reporting.

Test Code	Reported Name	Matrix	Reference Method	Holding Time (hours)	Bottle	Units	LOR
AMMN_COL_5	Ammonia as N	FRESH-WATER	APHA 4500-NH3 G	672	PT120	mg/L	<0.005
CHLPHA95ET	Chlorophyll a & Phaeophytin a	WATER	ISO 10260 (1992)	24	BLKPT1	µg/L	<0.1
DOC_1	Dissolved Organic Carbon	WATER	SM5310C	336	PT350	mg/L	<0.3
FILTP_2	Phosphorus - Filterable Reactive as P	WATER	APHA 4500-P G	672	PT120	mg/L	<0.003
OXN_2	Nitrate + Nitrite as N	WATER	APHA 4500-NO3-I	672	PT120	mg/L	<0.003
TKNN_COL_1	TKN as N	WATER	APHA-N org A	672	PT120	mg/L	<0.05
P_TOT_2	Phosphorus - Total	WATER	APHA-N org A	672	PT120	mg/L	<0.005
TN_CALC_1	Nitrogen - Total	WATER	APHA-N org A	672	NONE	mg/L	<0.06

2.7.1 Equipment

- Sample containers and appropriate preservatives (sourced from AWQC NATA laboratory)
- 0.2 µm filters and suitable filtering device (e.g. syringe filter) for dissolved nutrients and carbon (sourced from AWQC NATA laboratory)

- 47 mm glass fibre (GFC) filters and suitable filtering device for chlorophyll-a
- Water quality meter(s) with pH, turbidity and electrical conductivity probes
- Deionised water for sample blanks
- Integrated sampling tube and collecting bucket
- Eskies and ice for sample preservation and storage
- Datasheets, data book and/or field computer.

2.7.2 Protocol

1. Integrated samples are collected mid stream and *in-situ* measurements made at the same location mid depth.
2. Samples are collected upstream and away from the side of the boat.
3. Surface films are avoided, but if present, a description is entered onto the field sheet.
4. Filtering for dissolved nutrients (NOx, NH_4, FRP, DOC) and chlorophyll-a takes place on site as samples are collected.
5. Samples are stored on ice for transport to field base and then frozen for transport to laboratory.

2.8 In-situ logging

Stream metabolism measures for temperature, dissolved oxygen, light (PAR) and barometric pressure are to be continuously logged at ten minute intervals during the deployment period. To ensure reliable measurements the loggers require regular downloading of data to minimise loss, and also regular maintenance, cleaning and battery replacement. Ten trips are planned between deployment of the *in-situ* logging stations in September and their retrieval in February (although retrieval could be extended if environmental flows were to be delivered later in the season). This ensures that the deployed probes are checked, cleaned and calibrated at regular intervals (approximately 2 weeks) and that water quality measurements are representative of changing conditions; and that there is capacity to respond to environmental watering events. The probes may be checked more frequently at critical times during the rise, fall and duration of an event when fouling may increase the need for cleaning and when detailed metabolism and water quality measurements are critical. To accommodate increased field trip frequencies during flow events, probe maintenance may need to be extended in the absence of environmental watering to the maximum 6 week period set in the standard method (Hale *et al.* 2014). This flexible protocol will aid improved data capture during critical stages of events so that changes associated with environmental watering can be identified.

2.8.1 Equipment

- Dissolved oxygen logger consisting of a multi-parameter water quality probe with integrated optical (fluorescence) dissolved oxygen probe and water temperature
- PAR sensor and loggers measuring µmol photons/m^2/s
- Barometric pressure sensor and logger
- Tool kit and spare parts for the multi-parameter probe; including spare batteries and spare probes
- Probe calibration log
- Field sheets
- Laptop and data cables for connecting to probes / logger
- Air bubbler with battery (e.g. one suitable for a large fish tank) and a large bucket (e.g. 20 L), for probe calibration.

2.8.2 Protocol

1. Prior to deployment in the field, and on each occasion in the field the probe(s) will be calibrated according to the manufacturer's instructions and results of calibration entered into a calibration log.
2. Before leaving the office/laboratory for deployment and on each occasion in the field the following should be checked for all electronic measurement equipment:
   - Batteries are charged and properly inserted
   - Previous data downloaded and memory cleared
   - Cable and cable connections checked
   - Obvious/minor faults on sensors including growth or dirt on the probes or tubing checked
   - All equipment listed above is in functional order.

2.8.3 Field method – water column measures

1. Record the following on the field sheet:
   - Date and time
   - GPS coordinates (latitude and longitude; GDA94)
   - Name(s) of survey team.
2. Collect water quality samples and spot measures according to instructions above.
3. Calibrate dissolved oxygen sensor on site:
   - On-site calibration of 100% saturation is achieved by placing the probe in a bucket of stream water which itself is sitting in the stream to ensure thermal control. Air is bubbled through the water in the bucket for at least 45–60 minutes. This should result in a stable reading from the probe. It is important that the probe is not in the direct line of air bubbles.
4. Set the dissolved oxygen, temperature, PAR and barometric pressure loggers to record at ten minute intervals. Synchronise loggers so as to obtain corresponding readings.
5. Select an appropriate place for the deployment of sensors and loggers noting:
   - Dissolved oxygen and temperature sensors must be placed in open water, and at a depth that will not expose sensors for the entire deployment period. Sensors should not be placed in eddies, backwaters or where flow is influenced by structures.
   - PAR sensor should be deployed above the water surface (and remain so for entire deployment) as described above.
   - Sensors will be deployed on suitable existing structures, these are a DEW equipment raft downstream of Lock 6 and Lock 4, and a permanent channel pole marker downstream of Lock 1.
6. Deploy loggers.
7. Leave loggers deployed for between three and six weeks.
8. Perform servicing, cleaning and calibration of loggers at each repeat visit.
9. Take water quality samples and spot measures at each repeat visit.
10. Repeat 100% saturation value check (water saturated air) and note the value of any drift.
11. Record any relevant information, such as changes in site characteristics since deployment.
12. Upload data onto laptop following manufacturer's instructions.
13. Calibrate all sensors and loggers and perform routine maintenance / cleaning as necessary.

2.9 Data analysis and evaluation

This method adopts the approach of determining gross primary production (GPP), ecosystem respiration (ER) and re-aeration rate (K_{O2}) from a series of diel dissolved oxygen curves. Curve fitting models estimating these parameters require data for dissolved oxygen in mg O_2/L, temperature in ^oC, PAR in µmoles photons/m^2/sec, and barometric pressure (in atmospheres) all at ten minute intervals. The salinity can be approximated as 0 unless the electrical conductivity is above 500 µS/cm in which case salinity = 6×10^{-4} x EC (Based on conversion factor of 1 µS/cm = 0.6 mg/L TDS). Analyses provide estimates of GPP and ER in mg O_2 /L/Day with uncertainties for each and goodness of fit parameters. These parameters are converted to areal measurements by multiplying by the average reach depth.

Evaluation of this data will be based on two approaches:

- A comparison of changes in dissolved oxygen concentrations and stream metabolism in response to environmental water events, approximating a before and after or time series assessment.
- An approach described in the LTIM Project evaluation plan as *counterfactual*, where a comparison is made between observed conditions and the conditions that would have occurred in the absence of environmental water (Gawne *et al.* 2014). In this approach the unperturbed conditions are modelled from established relationships between stream metabolism and environmental conditions derived over time from the LTIM/MER Project data collection, or in this case also from previous studies (Oliver and Merrick 2006, Oliver and Lorenz 2010).

2.10 Data management

See Section 11 in the MER Plan for data management procedures. The data structure for all Category 1 (Basin-scale) indicators will follow standard templates decided upon by the MER Basin-scale Providers, in consultation with CEWO.

2.11 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

2.12 Health, safety and environment plan

See Appendix A.

2.13 References

Gawne, B., Hale, J., Butcher, R., Brooks, S., Roots, J., Cottingham, P., Stewardson, M. and Everingham, P. (2014). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Evaluation Plan. Final Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre. MDFRC Publication 29/2014.

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3 *Fish (Channel)*

3.1 Evaluation questions

This monitoring protocol addresses the following Basin-scale evaluation questions:

- What did Commonwealth environmental water contribute to native fish community resilience?
- What did Commonwealth environmental water contribute to native fish survival?
- What did Commonwealth environmental water contribute to native fish populations?

The process for evaluating these questions is illustrated in Figure B.3, with components covered by this protocol highlighted in blue.

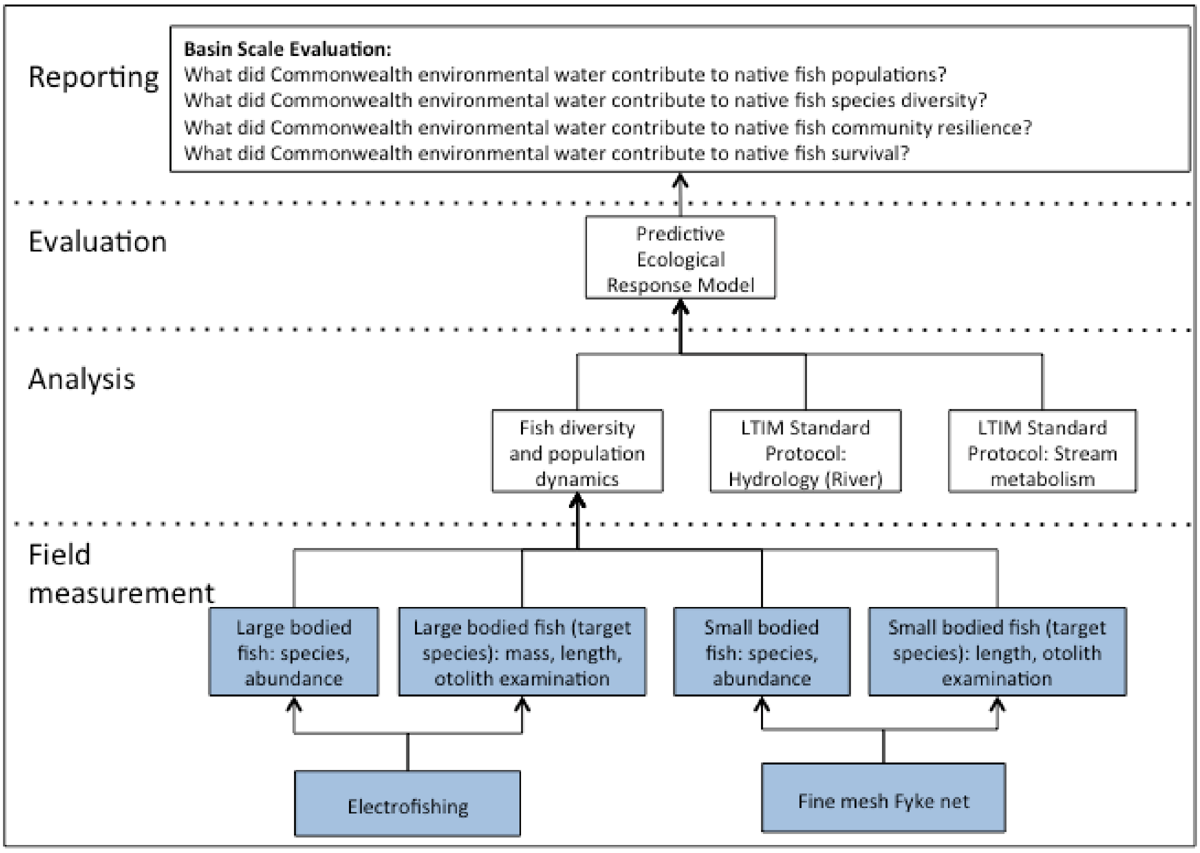

Figure B.3. Schematic of key elements in LTIM Standard Protocol: *Fish (Channel)* (taken from Hale *et al.* 2014).

3.2 Relevant ecosystem types

Rivers.

3.3 Relevant flow types

These methods describe annual monitoring conducted during March–May of each year independent of specific watering events. The methods are therefore relevant to all flow types – baseflow, fresh, bankfull and overbank.

3.4 Overview and context

These standard methods describe monitoring required for the Basin-scale evaluation of the response of river fish to Commonwealth environmental water. Refer to Section 5.1.3 in the MER Plan for background information, objectives, outputs and staff involvement for *Fish (Channel)*. The methods describe the sampling design and protocol for small- and large-bodied fishes in river channels for the LTIM Project.

This protocol describes sampling once each year during autumn to measure:

- Catch-per-unit-effort (CPUE) of each fish species for:
  - Electrofishing
  - Small-meshed fyke nets.
- Population structure data for target species:
  - Length
  - Weight
  - Approximate age structure (from otolith examination).

Covariates may include:

- Dissolved oxygen
- Salinity/electrical conductivity
- Discharge/flow
- Water temperature
- Turbidity
- Relative water level.

3.5 Sites

3.5.1 Equipment

- Boat
- GPS

3.5.2 Protocol

LTIM for Basin-scale evaluation has adopted a hierarchical approach to sample design (see Hale *et al.* 2014). The spatial hierarchy for *Fish (Channel)* monitoring is as follows:

- Selected Area (Lower Murray)
  - Zone (*Gorge*)
    - Site (river km 286, 302, 323, 326, 336, 376, 392, 400, 419, 426).

<u>Zone placement within Selected Areas</u>

The Lower Murray Selected Area is comprised of two distinct geomorphological units, namely the *Gorge* and the *Floodplain*. The *Gorge* zone has been selected as a subset of a Selected Area that represents a spatially, geomorphological and/or hydrological distinct unit at a broad landscape scale.

<u>Site placement within zones</u>

Ten long-term sites, located between Lock 1 and 3, were selected for the Lower Murray Selected Area at the commencement of the LTIM Project (Table B.4). These sites followed the following Basin-scale criteria from Hale *et al.* (2014), including:

- An **800 m reach of channel within a zone**.
- Located on a single channel
- Where appropriate, coincide with a pre-existing discharge and river height gauging station.
- Not within 1 km of a significant tributary and/or distributary.
- Distributed randomly throughout the zone selected for Basin-scale data collection, such that the samples collected are representative of that zone.

Table B.4. *Fish (Channel)* site information for the Lower Murray Selected Area. Site ID incorporated distance from the river mouth in kilometers.

Selected Area	Zone	Site No.	Site Name	Site ID	Latitude	Longitude
Lower Murray	Gorge	1	Blanchetown	LK2DS_286km	-34.271	139.62602
Lower Murray	Gorge	2	Scott Creek	LK2DS_302km	-34.1484	139.66095
Lower Murray	Gorge	3	Morgan	LK2DS_323km	-34.0209	139.69016
Lower Murray	Gorge	4	Cadell	LK2DS_326km	-34.0437	139.78645
Lower Murray	Gorge	5	Qualco	LK2DS_336km	-34.1019	139.87569
Lower Murray	Gorge	6	Waikerie	LK3DS_376km	-34.1582	139.9241
Lower Murray	Gorge	7	Lowbank DS	LK3DS_392km	-34.1645	140.03712
Lower Murray	Gorge	8	Lowbank US	LK3DS_400km	-34.1825	140.11108
Lower Murray	Gorge	9	Overland Corner DS	LK3DS_419km	-34.1801	140.27827
Lower Murray	Gorge	10	Overland Corner US	LK3DS_426km	-34.1594	140.33556

Sample placement within sites

A sampling grid was established within each site to ensure individual samples can be randomly sampled from that site, and are therefore representative of that site as a whole (Hale *et al.* 2014). Each 800m site was subdivided by fixed transects spaced 50 m apart. Points of intersection between the transects and the river bank define the sampling grid (Figure B.4).

The sample design specified in Figure B.4 defines two key sampling locations: electrofishing (EF) units (16 in total), and passive-gear sample (PS) waypoints (34 in total). Use of these EF units and PS waypoints will be explained in Section 3.7 below.

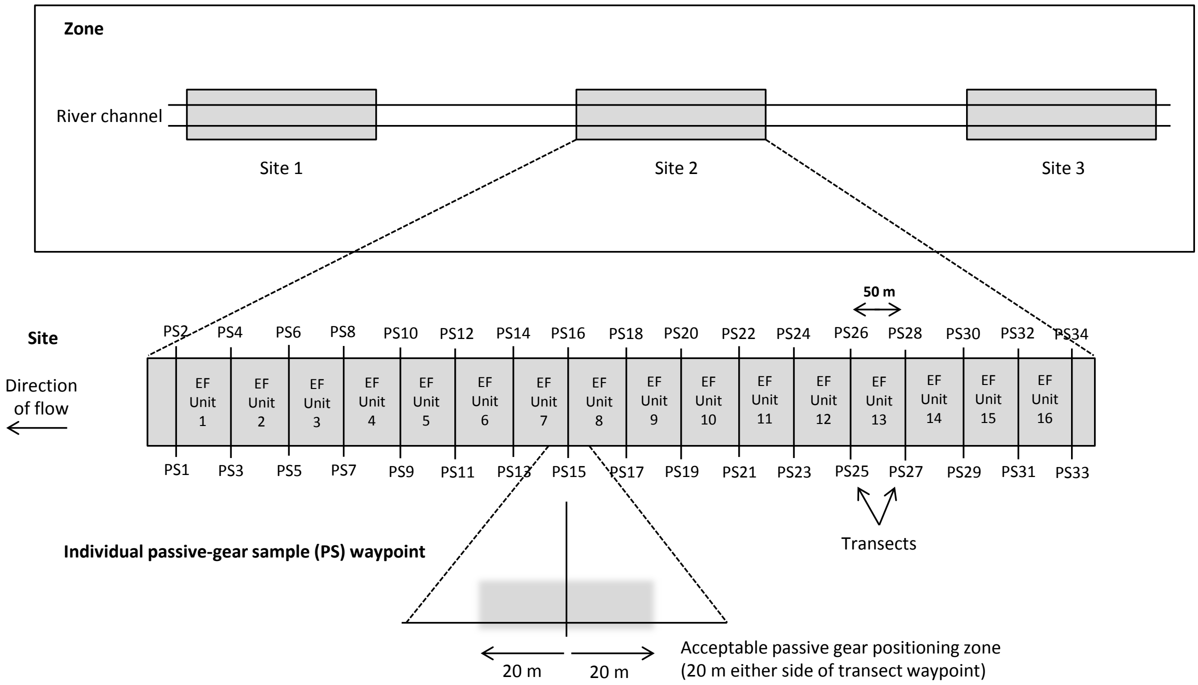

Figure B.4. Diagram of hierarchical sample design illustrating zones, sites and sample locations (taken from Hale *et al.* 2014).

3.6 Representative species from life-history guilds

3.6.1 Overview

Fishes belonging to different life history guilds may respond in different ways to managed and natural flows. Towards a more complete knowledge of fish population response to flows, monitoring will target representatives of the three primary life history guilds: equilibrium, periodic and opportunistic. CEWO/Basin-scale Provider request additional data collected from these target species.

3.6.2 Protocol

Within each Selected Area CEWO/Adviser request providers identified target species. Within each guild, some species were fixed, and common to all Selected Areas (as much as practicable), while the identity of the other species was flexible across Selected Areas.

Across all Selected Areas the equilibrium life history species targeted for detailed data collection will be Murray cod. The second equilibrium species in the Lower Murray will be freshwater catfish.

Across all Selected Areas periodic life-history species targeted will continue to be golden perch and bony herring. The third and only other known periodic species in the Lower Murray will continue to be silver perch.

Across all Selected Areas the opportunistic life-history species targeted are carp gudgeon, *Hypseleotris* spp. The second opportunistic species in the Lower Murray will be Murray rainbowfish.

3.7 Sampling protocol

3.7.1 Equipment

- Boat electrofisher, including nets, storage and processing equipment
- Ethics and fisheries permits from relevant institutions

- GPS
- GPS coordinates of site structure (PS waypoints and EF units; Figure B.4)
- PS waypoints determined using random number generator (sample locations within sites)
- 12 fine-mesh fyke nets (10 for use; 2 spare) per site
- Anchoring devices for fyke nets (stakes, chains, etc.)
- Large (1000 mm) and small (300 mm) measuring boards
- Scales, either quality hanging scales with bag or bench scales with bucket/tray for fish
- Water quality multimeter
- Data sheets.

3.7.2 Protocol

Timing of sampling

The channel sites of each Selected Area will be sampled once each autumn (March–May inclusive). Refer to Section 7.2 in the MER Plan for a monthly monitoring schedule for *Fish (Channel)*.

Large-bodied species

Sampling

Large-bodied species will be sampled using boat electrofishing.

Sustainable Rivers Audit (SRA) electrofishing protocol will be a subset of what is described here, so that data collected as part of the CEWO LTIM Project can be compared and contrasted with SRA large-bodied fish data. Small-bodied species will not be collected for processing using electrofishing, but collect all stages (including juveniles) of large-bodied species for processing.

Herein, 'small-bodied' species are those belonging to the following families:

- Galaxiidae
- Retropinnidae
- Atherinidae
- Melanotaeniidae
- Ambassidae
- Nannopercidae
- Eleotridae
- Gobiidae
- Poecilidae.

All other fish families of the Basin are considered 'large-bodied'.

The entire 800 m site will be electrofished. Within each electrofishing unit of a site (EF unit Figure B.4) two 'shots' of 90 s 'on-time' should be carried out. This results in a total of 2880 s (48 min on-time) for each site. No more than 180 s of shocking should be allocated to each EF unit, such that electrofishing effort is spread out across the entire site, thus giving a more random sample with respect to the (site's) environment. Note that, *within* EF units the location of shots is left to the discretion of the service provider.

Processing - electrofishing

For every individual belonging to a target large-bodied species, the following will be obtained or implemented:

1. Identified to species.

2. Total (TL; round or square caudal fin species) OR fork (FL; fork-tailed species) lengths, in millimetres (mm).
3. Mass in grams (g) (use scales that have been recently calibrated).

If > 20 individuals are obtained within a 90 s shot, the above information on a random sub-sample of 20 individuals will be recorded. The random sub-sample will be the first 20 individuals sampled during a 90 s shot.

Non-target species will be identified and enumerated. All species will be returned to the water.

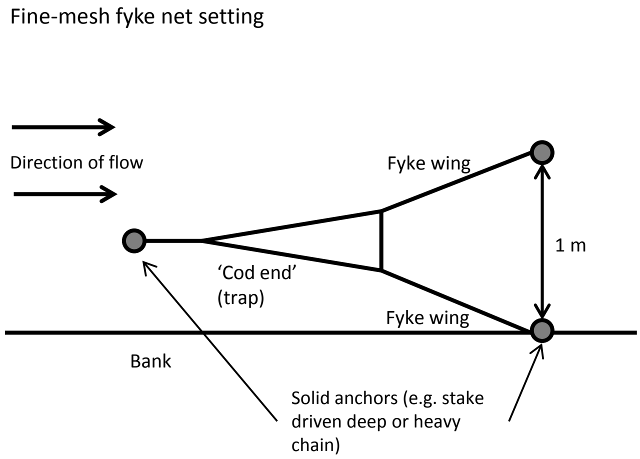

Figure B.5. Diagram indicating the positioning of fine-mesh fyke nets in river channels, relative to the bank and direction of water flow. Cod-end should face upstream so as to not collect debris and act as a water velocity 'parachute' (taken from Hale *et al.* 2014).

<u>**Small-bodied species**</u>

Sampling

Small-bodied species will be sampled using a passive technique only; fine-mesh fyke nets. The fine-mesh fyke nets (2 mm mesh) should be double wing (Figure B.5) (each wing: 2.5 m × 1.2 m), with a first supporting hoop covered by a plastic grid (5 cm x 5 cm) to keep large aquatic vertebrates out of the trap.

A random number generator will be used to randomly select a subset of 10 PS waypoints (Figure B.4) from the total of 34. As noted in Figure B.4, a waypoint encompasses a total of 40 m of bank (20 m either side of specific waypoint), so providers should endeavour to find the point on the bank as close to the exact waypoint as possible. If it is impossible (in the strict sense, not just inconvenient) to set a fyke net at a certain waypoint (current is too fast; bank is far too steep; water too deep; too many emergent macrophytes to be an effective fish sample), then an adjacent, unoccupied waypoint will be used.

Fine-mesh fyke nets will be set in the afternoon and retrieved the following morning. Set and retrieval times will be recorded for each individual net.

Fine-mesh fyke nets will be set with the cod end facing the current, so that water velocity is deflected around the net and wings (Figure B.5). For the net to be effective both wings and the cod end will be anchored to the bottom. So that sampling effort is held constant across nets, the wings will have an aperture of 1 m (Figure B.5).

Processing

The following measurements will be made for non-target, small-bodied species:

1. Identify (to species) and enumerate all individuals. Random sub-samples may be used if nets capture too many fish for complete processing, as long as proportion of total sample sub-sample represents is recorded.

Further measurements are required for those small-bodied species targeted as part of the opportunistic guild (see Section 3.6):

2. Obtain total (TL; round or square caudal fin species) OR fork (FL; fork-tailed species) lengths, in millimetres (mm), of up to the first 10 individuals from both target species, from each net. Ensure ten are randomly selected from the overall sample. This may be achieved, for example, by using an aquarium net to 'blindly' sub-sample from a bucket until 10 individuals have been measured.

Covariates

Water quality parameters will be measured at each site during all sampling times. Dissolved oxygen (ppm), electrical conductivity (µS), water temperature (°C) and turbidity (NTU) will be measured using a water quality multimeter. Discharge data (ML day^{-1}) and relative water level (m AHD, relative to the Australian Height Datum) from the closest gauging station will be obtained from the DEW Surface Water Archive (www.waterconnect.sa.gov.au).

Otolith collection and analysis

Otoliths will be collected from periodic and opportunistic target species (Section 3.6) populations for the following purposes:

1. Estimation of von Bertalanffy (vB) growth parameters, such that we have a vB model for each target species, for each area. These models will be used to coarsely approximate the age distribution (in years) of target species, based on their lengths, within each of the monitoring years. Age distributions will subsequently be used to coarsely approximate survivorships, hence year-class strength, in the absence of capture-mark-recapture data. Furthermore, otoliths may be used to back-calculate temporal variance in growth rates, in response to changes in flow.
2. Determine the relationship between age and length of (approximate, or what one assumes to be) 0+ and 1+ individuals within each year, to reduce uncertainty of age prescription during early life history.

The otolith collection and reading protocol is dependent on which life-history guild the species belongs to:

Periodic and Equilibrium species

One comprehensive otolith sample will be collected at the end (2021-22) of the three-year program from equilibrium and periodic target species. We will use these data to obtain vB growth curves for each of the target species of an area.

Where possible, otoliths from at least 50 individuals of each target species will be collected. Samples for estimating the parameters for vB curves will not be random with respect to the structure of the population. Samples containing representatives across the full range of lengths within the population (ideally), and approximately equal numbers of individuals within each length-class will be collected.

3.8 Data analysis and evaluation

3.8.1 Relative abundance estimation

Abundances will be recorded as 'catch-per-unit-effort' (CPUE). Data will be structured in spreadsheets by individual 'samples', which are individual net hauls, or abundances within discrete electrofishing shots (see Section 3.7). Units will depend on sampling method—electrofishing versus fyke netting. Electrofishing CPUE will have units number of individuals per second on-time for each shot. Fyke netting CPUE units will be number of individuals per net per hour.

3.8.2 Population structure data for target species

Additional data is required for equilibrium and periodic target species:

- Total length or fork length (mm), depending on species (see Section 3.7).
- Mass (gm).
- Length–age data:
  - o Year 3 data sets;
  - o Raw data required, not just vB parameter estimates.
  - o Yearly ages of fish (0+, 1+,…x+), will be tagged by their species identity, place and date of capture, total or fork length (mm), and mass (g).

3.8.3 Community data

No evaluation will be undertaken for the Selected Area. For the analyses of Basin-scale community response to Commonwealth environmental water to be carried out by the MER Advisors. CPUE data at the level of the site (species by site matricies) corresponding to each sampling method will be provided:

1. Electrofishing (large-bodied species; target + non-target).
2. Fine-mesh fyke nets (small-bodied species; target + non-target).

3.9 Data management

See Section 11 in the MER Plan for data management procedures. The data structure for all Category 1 (Basin-scale) indicators will follow standard templates decided upon by the MER Basin-scale Providers, in consultation with CEWO.

3.10 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

3.11 Health, safety and environment plan

See Appendix A.

3.12 References

Hale, J., Stoffels, R., Butcher, R., Shackleton, M., Brooks, S. and Gawne, B. (2014). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project – Standard Methods. Final Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre. Murray–Darling Freshwater Research Centre, MDFRC Publication 29.2/2014.

Category 3

4 Hydraulic Regime

4.1 Evaluation questions

This monitoring protocol addresses the following Selected Area scale evaluation questions for:

Short-term responses:

- What did Commonwealth environmental water contribute to hydraulic diversity within weir pools?
- What did Commonwealth environmental water contribute to in-channel variability in water levels?

Long-term outcomes:

- What did Commonwealth environmental water contribute to hydrological connectivity?
- What did Commonwealth environmental water contribute to meeting Environmental Water Requirements (of the South Australian Murray River Long-Term Watering Plan) in the main channel of the Lower Murray?

The process for evaluating these questions is illustrated below in Figure B.6.

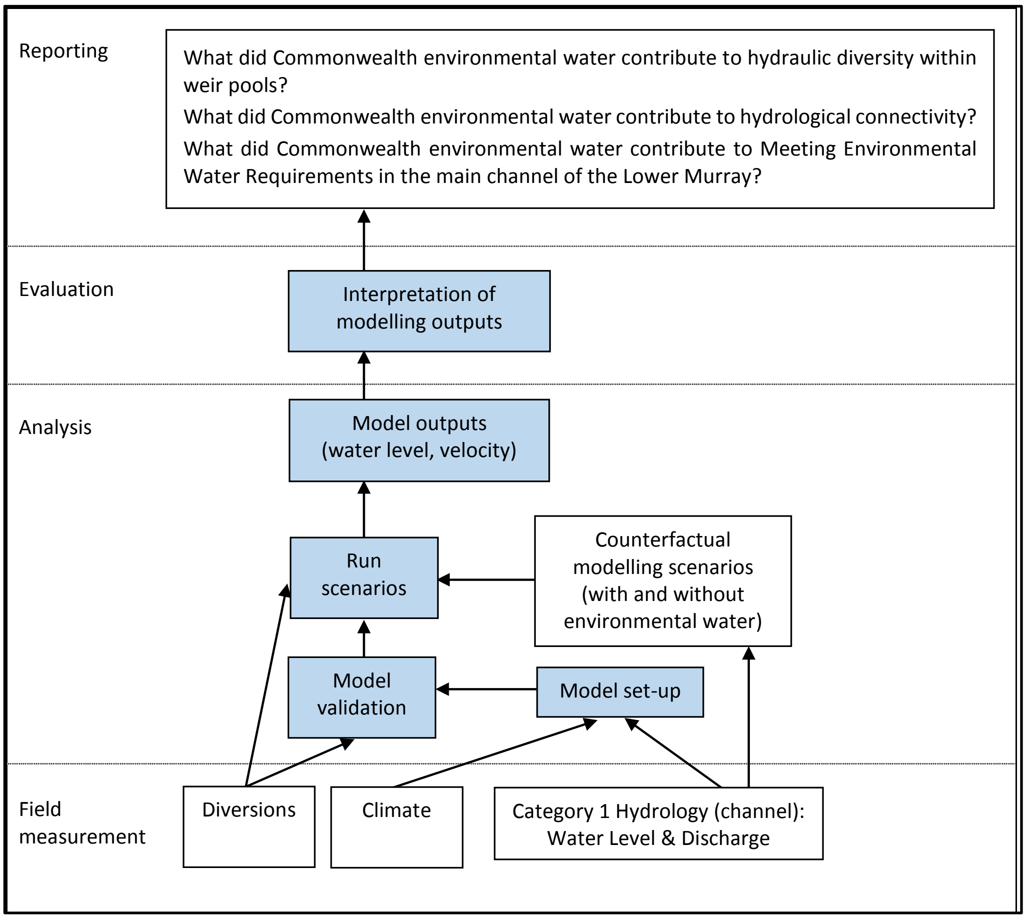

Figure B.6. Schematic of key elements of the LTIM Standard Protocol: *Hydraulic Regime* (adapted from the *Hydrology (Channel)* schematic in Hale *et al.* 2014).

4.2 Relevant ecosystem types

All – rivers, wetlands and floodplains.

4.3 Relevant flow types

All – baseflow, freshes, bankfull and overbank.

4.4 Overview and context

This component will use outputs from three 1D–2D coupled hydrodynamic models that have been developed and used extensively in the region (DHI 2014, McCullough *et al.* 2017). The models represent the majority of the Lower Murray Selected Area: Lock 6 to Lyrup (between Lock 5 and Lock 4) including the Pike River anabranch, Lyrup to Lock 3 including the Katarapko River anabranch, and the main river channel from Lock 3 to Lock 1. These hydrodynamic model outputs will be used in combination with the hydrological (Source) model to simulate the with and without Commonwealth environmental water conditions that occur each year, simulating daily discharge, stage and velocity. These results from this indicator supports the evaluation for all other indicators, as it is recognised that hydraulic characteristics have a profound influence on river ecosystem structure and function (Statzner and Higler 1986, Biggs *et al.* 2005, Bice *et al.* 2017). Refer to Section 5.2.1 in the MER Plan for background information, objectives and hypotheses, outputs and staff involvement for Hydraulic regime.

4.5 Complementary monitoring and data

Input data will be sought from DEW, SA Water and the Bureau of Meteorology. Variables required include discharge, water level, extractions, rainfall and Morton's Lake evaporation. Permission to use this data will be obtained from these organisations prior to use. If permission is not given, adjustments to the budget would be needed to validate the model. Modelling undertaken by the MDBA of the without environmental water scenario (counterfactual modelling) at the SA border is critical to undertaking this work.

4.6 Monitoring locations and timing

4.6.1 Locations

No specific monitoring is undertaken as part of this indicator. Model outputs for the with and without environmental water scenarios will be output at the locations outlined in Table B.5.

Table B.5. Station data available for model validation.

Variable	Station Number	Station Name
WL, Q	A4260511	Lock 6 DS
WL[1]	A4260512	Lock 5 US
WL,Q	A4260513	Lock 5 DS
WL[1]	A4260514	Lock 4 US
WL,Q	A4260515	Lock 4 DS
WL[1]	A4260516	Lock 3 US
WL,Q	A4260517	Lock 3 DS
WL[1]	A4260518	Lock 2 US
WL,Q	A4260619	Lock 2 DS

Variable	Station Number	Station Name
WL[1]	A4260902	Lock 1 US
V	-	Weir pool 5
V	-	Weir pool 4
V	-	Weir pool 3
V	-	Weir pool 2
V	-	Weir pool 1

* Flow data only valid for certain flow ranges

[1] Data used as an input to the models, hence cannot be used for validation

4.6.2 Timing

All model outputs in Table B.5 will be output on a daily basis over the whole water year each reporting year.

4.7 Monitoring protocol

4.7.1 Equipment

Complimentary monitoring data is collected using infrastructure in place, typically moored buoy or structure mounted pressure transducers for water level, and the conversion to flow using existing relationships.

4.7.2 Protocol

Monitoring data collected by complementary monitoring programs will continue to adopt current best practice protocols, as monitored and maintained by the DEW Resource Monitoring Unit based at Berri, as well as SA Water at each Lock. Velocity monitoring will also be undertaken by the DEW Resource Monitoring Unit, again using best practice methods and is considered of high quality, and high spatial resolution, for the purposes of model validation.

4.8 Data analysis and evaluation

The combination of MIKE FLOOD and eWater Source models will run scenarios to assess hydraulic variables with and without the contribution of environmental water, to make a direct comparison of outcomes with and without Commonwealth environmental water provisions. It is not possible to replicate the scenarios, so no statistical analyses are possible and validation of the model outputs is essential. Some data collected (outlined in Section 4.6) will be used as necessary inputs to the modelling, with the remaining data used to validate the model for the observed, with Commonwealth environmental water provisions, scenario. This will involve comparing observed and modelled flows, water levels and velocities. In an iterative process, any issues identified will be corrected to minimise errors in modelled outputs. The validation process is essential to allow for an adequate assessment of the contributions of Commonwealth environmental water provisions to hydrology in the Lower Murray Selected Area.

This comparison of modelled outputs for each flow scenario (with and without Commonwealth environmental water) will provide the basis for the evaluation and reporting. The difference between the scenarios can be attributed to Commonwealth environmental water, although uncertainty in model outputs will be appropriately acknowledged. This will be reported annually, with reports building on knowledge and results gained from previous watering years, including CEWO short-term intervention monitoring where it makes sense to do so.

4.9 Data management

See Section 11 in the MER Plan for data management procedures. The data templates for Category 3 (Selected Area) indicators will be developed by the Selected Area, in consultation with CEWO, and will conform to data standards. The template for *Hydraulic Regime* is provided below.

Variable	Description	Type	Req	Range	Example
samplePointName	a single reach of the Lower Murray River in either the *Gorge* or *Floodplain* zone represented by either a name or polygon within which observations are made	String	Y		LK6DS_616km
samplingTime	The date/time that water variables are measured	Date Time	Y		03/10/2019 00:00
discharge	Water discharge in megalitres per day	Number (0 decimals)	Y	[0,+]	12,042 ML/d
velocityMedian	Median daily velocity in weir pool in metres per second	Number (2 decimals)	Y	[0,+]	0.86 m/s
velocityLotic	Percentage of reach with velocity exceeding 0.3 m/s	Number (0 decimals)	Y	[0,+]	31%

4.10 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

4.11 Health, safety and environment plan

See Appendix A.

4.12 References

Bice, C. M., Gibbs, M. S., Kilsby, N. N., Mallen-Cooper, M., & Zampatti, B. P. (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(2), 108-131.

Biggs, B. J. F., V. I. Nikora and T. H. Snelder (2005). Linking scales of flow variability to lotic ecosystem structure and function. Regulated Rivers: Research & Mangement 21: 283–298.

DHI (2014) *Lower Murray Hydrodynamic Model – Model development and calibration report.* Final Report to Department For Water, Dec 2014

Hale, J., Stoffels, R., Butcher, R., Shackleton, M., Brooks, S. and Gawne, B. (2014). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project – Standard Methods. Final Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre. Murray–Darling Freshwater Research Centre, MDFRC Publication 29.2/2014.

McCullough DP, Montazeri M & Esprey L (2017). *Refinement and calibration of Pike and Katarapko floodplain flexible mesh models*. DEWNR Technical note 2017/11, Government of South Australia, Department of Environment, Water and Natural Resources, Adelaide.

Statzner, B. and B. Higler (1986). Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. Freshwater Biology 16: 127–139.

5 Matter Transport and Coorong Habitat

5.1 Matter Transport

5.1.1 Evaluation questions

This monitoring protocol addresses the following Selected Area scale evaluation questions:

- What did Commonwealth environmental water contribute to concentrations and transport of phytoplankton?
- What did Commonwealth environmental water contribute to salinity levels and transport?
- What did Commonwealth environmental water contribute to nutrient concentrations and transport?
- What did Commonwealth environmental water contribute to water quality?

The process for evaluating these questions is illustrated in Figure B.7, with components covered by this protocol highlighted in blue.

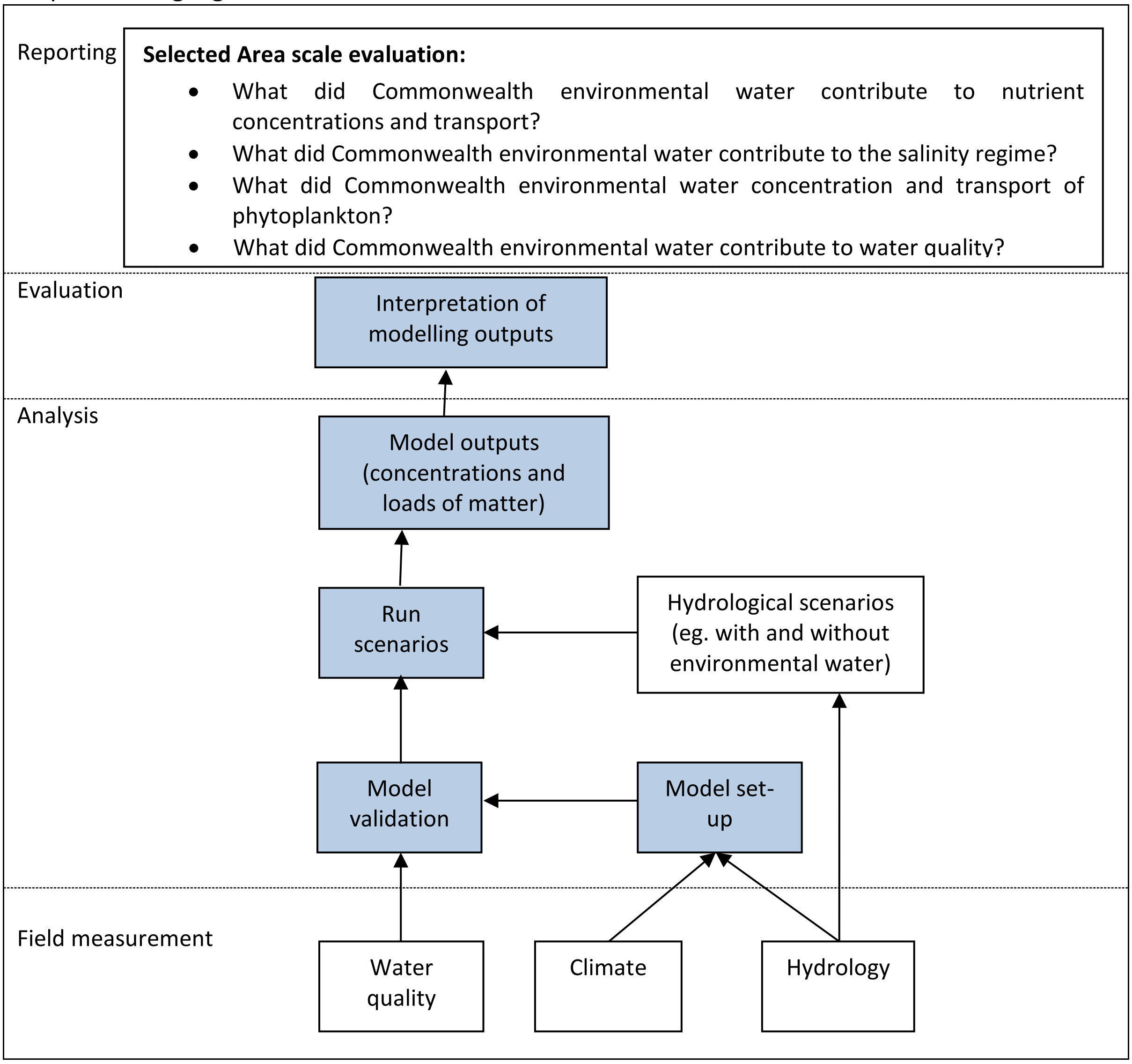

Figure B.7. Schematic of key elements of the LTIM Protocol: Matter transport.

5.1.2 Relevant ecosystem types

All – rivers, wetlands and floodplains.

5.1.3 Relevant flow types

All – baseflow, fresh, bankfull and overbank.

5.1.4 Overview and context

This component will use a 3D hydrodynamic–biogeochemical model to evaluate the response of concentrations and transport of dissolved and particulate matter (salt, nutrients and organic matter) to environmental water provisions in the Lower Murray River, Lower Lakes and Coorong (see Section 5.2.2 in the MER Plan for more details). The model platform used was the coupled hydrodynamic-biogeochemical model TUFLOW-FV-AED, developed by BMTWBM and the University of Western Australia. TUFLOW-FV is now used extensively in the region for hydrological purposes. A single model domain was applied spanning Lock 1 to the Southern Ocean, including the Coorong. Although outside of the Lower Murray Selected Area, incorporation of Coorong, Lower Lakes and Murray Mouth increases the capacity of the MER Project to demonstrate outcomes within other areas and allows an assessment of exports to the Southern Ocean. No data will be collected through the MER program, but validation of the models will rely solely on complementary monitoring data. Water quality monitoring is likely to cease within the Lower Lakes and Coorong during 2015-16. This will limit the model validation and may mean that for some parameters model outputs will not be provided for the Lower Lakes and Coorong. Refer to Section 5.2.2 in the MER Plan for background information, objectives and hypotheses, outputs and staff involvement for Matter transport.

The contribution of environmental water to the transport of salt, nutrients and phytoplankton will be assessed with a coupled hydrodynamic-biogeochemical model for the reach below Lock 1 to the Murray Mouth (TUFLOW-FV-AED). The model runs will be initialised with data from a range of data sources. Inflow data (Lock 1), used to drive the main river domain, will be provided by the MDBA for three scenarios: (1) 'with all water' (i.e. observed, including all environmental and consumptive water); (2) without Commonwealth environmental water ('no CEW'); and (3) without any environmental water ('no eWater'). These simulations were run for the period between July in one year and June the following year.

The influence of environmental water on the concentrations of matter will be assessed through a comparison of modelled concentrations for the various scenarios for the Murray River Channel (Wellington), Lower Lakes (Lake Alexandrina Middle) and Coorong (Murray Mouth). Modelled concentrations will be presented as medians of modelled cells within areas surrounding sampling sites.

The transport of matter will be assessed through modelled exports from the Murray River Channel (Wellington), Lower Lakes (Barrages) and Coorong (Murray Mouth) for salinity, ammonium, phosphate, dissolved silica, organic nitrogen, organic phosphorus and chlorophyll *a*.

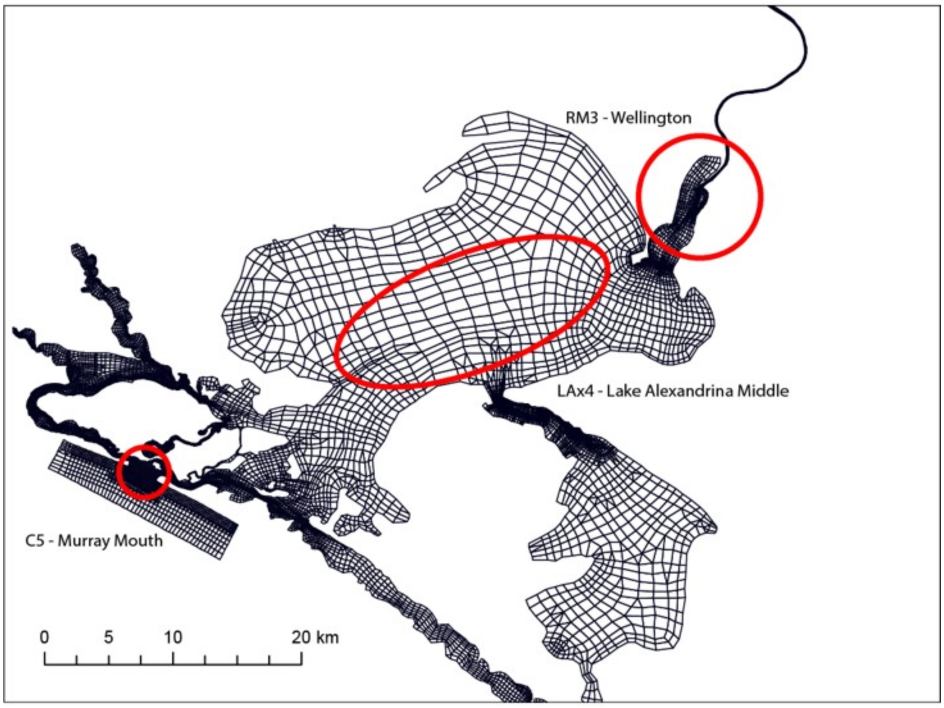

Figure B.8. Modelled cells (circled) used for calculating the modelled concentration of nutrients or salt at the Wellington, Lake Alexandrina Middle and Murray Mouth sites.

5.1.5 Complementary monitoring and data

Essential information such discharge, water level and salinity data are freely available through DEW's open data policy. Additional climatic and hydrological input data will be sourced from the Bureau of Meteorology (climate), MDBA (inflow) and Flinders Ports (Southern Ocean water level). Further validation data for the Coorong, Lower Lakes and Murray River will be sought from relevant State organisations (EPA, DEW and SA Water), such as other water quality parameters or ecological monitoring data. Permission to use these data will be sought from these organisations prior to use. These information are useful but not essential; as models are well established and previously validated.

5.1.6 Monitoring sites and timing

Sites

The modelling of matter transport will conducted for the area between Lock 1 and the Southern Ocean in the *Gorge* zone of the Lower Murray River and the Lower Lakes and Coorong. As all monitoring data for validation will be collected by complementary monitoring programs and the exact sites of these monitoring programs have not been finalised, it is impossible to provide final locations of sampling sites. However, a list of likely sites is provided below (Table B.6), based on sampling sites used in previous years. Water quality monitoring of nutrients ceased within the Lower Lakes and Coorong during 2015-16.

Table B.6. Possible sites where data is available for model validation. Exact sites will depend on data availability.

Waterbody	Site name	X	Y	Zone
Lower Murray Selected Area	Blanchetown (Lock 1)	373768.9	6195837	UTM 54S
	Wellington	353152.5	6086654	UTM 54S
Lower Lakes	Lake Albert Middle	346724.2	6056213	UTM 54S
	Lake Alexandrina Opening	348468.4	6080369	UTM 54S
	Lake Alexandrina Middle	331761.4	6077836	UTM 54S
	Point McLeay	324379.4	6068672	UTM 54S
Coorong	Goolwa Barrage	302100.7	6066302	UTM 54S
	Murray Mouth	308001.3	6063098	UTM 54S
	Ewe Island	315228.9	6062110	UTM 54S
	Mark Point	325761.5	6054914	UTM 54S
	Parnka Point	355250.6	6025735	UTM 54S

Timing

All monitoring data for validation was collected by complementary monitoring programs during the LTIM Project. The exact timing of sample collection cannot be determined for the next three years of the MER Project. However, it is anticipated that sampling will vary between weekly (Murray River) and quarterly (Coorong and Lower Lakes).

5.1.7 Monitoring protocol

Equipment

Additional monitoring data may be available from complementary monitoring programs and so the exact equipment to be used cannot be defined in the MER Plan. However, broadly, the equipment will likely include:

- water samplers
- water quality probes
- various laboratory apparatuses.

Protocol

As all monitoring data may be collected by complementary monitoring programs. Broadly, it is anticipated that:

1. Measurements of water temperature, electrical conductivity, dissolved oxygen, pH and turbidity will be taken at 0.5 metre intervals through the water column.
2. Integrated-depth water samples will be collected and sent to the Australian Water Quality Centre, a NATA accredited laboratory for analysis.
3. Samples will be analysed for filterable reactive phosphorus, total phosphorus, nitrate, ammonium, total Kjeldahl nitrogen, dissolved silica, and chlorophyll *a* concentrations, using standard techniques (Aldridge *et al.* 2013).

5.1.8 Data analysis and evaluation

The model will run scenarios to assess the response of concentrations and transport of dissolved and particulate matter, making a direct comparison of outcomes with and without Commonwealth environmental water provisions. It is not possible to replicate the scenarios and so no statistical analyses are possible and validation of the model outputs is essential. The model incorporates a large number of complicated biogeochemical processes, for which there is often no data available, and at a relatively fine spatial scale. The detailed nature of the model means that it is only validated for a given set of climatic conditions, so it is essential that validation is conducted routinely. Information collected from field and laboratory work through existing monitoring programs will be used to validate the model. This data, and permission to use it, will be sought from the Environment Protection Authority, DEW and SA Water. Additional climatic and hydrological input data will be sourced from the Bureau of Meteorology (climate), MDBA/CEWO (inflow) and Flinders Ports (Southern Ocean water level). The model validation will involve comparing observed and modelled concentrations of the various parameters for each flow scenario. In an iterative process, any issues identified will be corrected to minimise uncertainty with modelling outputs. The validation process is essential to allow for an adequate assessment of the contributions of Commonwealth environmental water provisions to matter transport in the Lower Murray Selected Area.

Following validation, the model will be run for defined (flow) scenarios to assess the response of concentrations and transport of dissolved and particulate matter. The comparison of modelled concentrations of the various parameters for each flow scenario (with and without Commonwealth environmental water) will provide the basis for the evaluation and reporting. The difference between the scenarios can be attributed to Commonwealth environmental water, although uncertainty in model outputs will be appropriately acknowledged. The model outputs will be presented as changes in concentrations and cumulative loads (at Lock 1, Wellington, Barrages and Murray Mouth) throughout the watering year. This will be reported on annually, with reports building on knowledge and results gained from previous watering years, including from CEWO short-term intervention monitoring.

5.1.9 Data management

See Section 11 in the MER Plan for data management procedures. The data templates for Category 3 (Selected Area) indicators will be developed by the Selected Area, in consultation with CEWO, and will conform to data standards. The *Matter* Transport templates for concentrations and loads are provided below.

Concentrations

Variable	Description	Type	Required	Range	Example
Sample Point Name	A specific location within water-bodies represented by either a name or polygon within which observations are made	string	Y		LK1DS_8km
sampleDate	Specific dates for outputs of modelled scenarios (each day within a watering year)	date	Y		12/09/2019
salinity	A measure of salinity in practical salinity units	Number (2 decimals)	Y	0–42 PSU	10.16 PSU

Variable	Description	Type	Required	Range	Example
phosphateConcentration	A measure of dissolved inorganic phosphorus concentration in milligrams per litre	Number (3 decimal)	Y	0–0.3 mg/L	0.010 mg/L
particulate OrganicPhosphorusConcentration	A measure of dissolved organic phosphorus concentration in milligrams per litre	Number (3 decimal)	Y	0–1 mg/L	0.053 mg/L
ammoniumConcentration	A form of dissolved nitrogen concentration in milligrams per litre	Number (3 decimal)	Y	0–0.300 mg/L	0.054 mg/L
particulateOrganicNitrogenConcentration	A measure of particulate organic nitrogen concentration in milligrams per litre	Number (3 decimal)	Y	0–5.000 mg/L	1.193 mg/L
dissolvedSilica concentration	A measure of inorganic silica concentration in milligrams per litre	Number (0 decimal)	Y	0–10 mg/L	8 mg/L
chlorophyll-*a*Concentration	A measure of algal biomass concentration in milligrams per litre	Number (1 decimal)	Y	0–200 µg/L	54.6 µg/L

Loads

Variable	Description	Type	Required	Range	Example
samplePointName	A specific location within water-bodies represented by either a name or polygon within which observations are made	string	Y		LK1DS_8km
sampleDate	Specific dates for outputs of modelled scenarios (each day within a watering year)	date	Y		12/09/2019
salinityLoad	A measure of dissolved solid load in kilograms per day	Number (0 decimal)	Y	[0,+]	2659847 kg/day
phosphateLoad	A measure of dissolved inorganic	Number (0 decimal)	Y	[0,+]	254 kg/day

Variable	Description	Type	Required	Range	Example
	phosphorus load in kilograms per day				
particulateOrganicPhosphorusload	A measure of dissolved organic phosphorus load in kilograms per day	Number (0 decimal)	Y	[0,+]	1984 kg/day
ammoniumLoad	A form of dissolved nitrogen load in kilograms per day	Number (0 decimal)	Y	[0,+]	254 kg/day
particulateOrganicNitrogenLoad	A measure of dissolved organic nitrogen load in kg per day	Number (0 decimal)	Y	[0,+]	1984 kg/day
dissolvedSilicaLoad	A measure of inorganic silica load in kilograms per day	Number (0 decimal)	Y	[0,+]	2238 kg/day
chlorophyll-*a*Load	A measure of algal biomass load in kilograms per day	Number (0 decimal)	Y	[0,+]	5650 kg/day

5.1.10 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

5.1.11 Health, safety and environment plan

See Appendix A.

5.1.12 References

Aldridge, K.T., Busch, B.D. and Hipsey, M.R. (2013). An assessment of the contribution of environmental water provisions to salt and nutrient dynamics in the lower Murray, November 2011–July 2012. Prepared for the Commonwealth Environmental Water Office, Department of Sustainability, Environment, Water, Populations and Communities, Canberra.

5.2 Coorong Habitat

5.2.1 *Evaluation questions*

This monitoring protocol addresses the following Selected Area scale evaluation questions:

- What did Commonwealth environmental water contribute to improving *Ruppia tuberosa* habitat in the Coorong?
- What did Commonwealth environmental water contribute to improving fish habitat in the Coorong?

The process for evaluating these questions is illustrated below in Figure B.9.

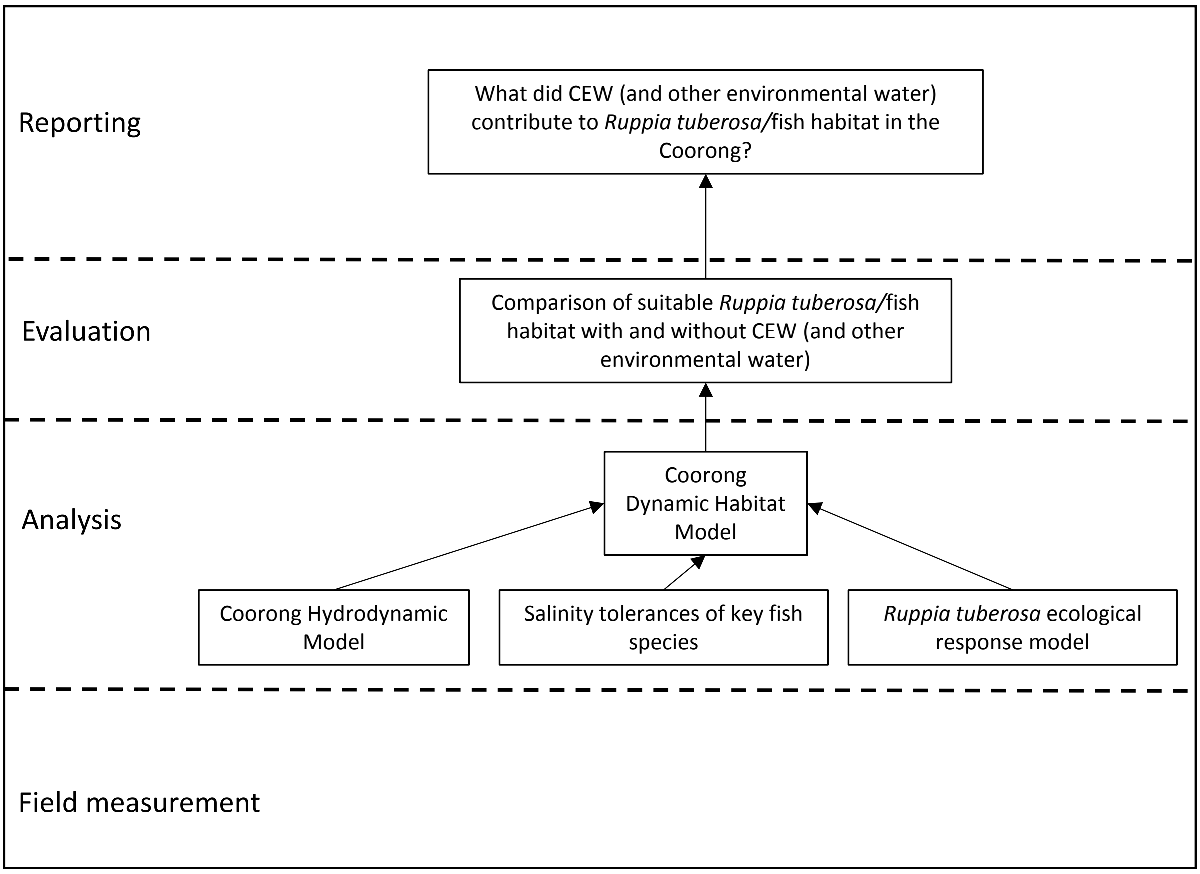

Figure B.9. Schematic of key elements of the LTIM Standard Protocol: Coorong Habitat.

5.2.2 *Relevant ecosystem types*

All – rivers, wetlands and floodplains.

5.2.3 *Relevant flow types*

All – baseflow, freshes, bankfull and overbank.

5.2.4 *Overview and context*

This component will use outputs from a hydrodynamic-biogeochemical model that have been developed and used in the region. The hydrodynamic model outputs will be used to simulate the 'with and without Commonwealth environmental water' conditions that occur each year, simulating habitat characteristics for *Ruppia tuberosa* and fish species. Refer to Section 5.2.2 in the MER Plan for background information, objectives and hypotheses, outputs and staff involvement for Coorong Habitat.

5.2.5 Complementary monitoring and data

Input data will be sought from DEW, SA Water and Bureau of Meteorology. Variables required include barrage discharge and water level. Permission to use this data will be obtained from these organisations prior to use. Modelling undertaken by the MDBA of the without environmental water scenario (counterfactual modelling) at the South Australian border is critical to undertaking this work.

5.2.6 Monitoring locations and timing

Locations

The habitat modelling will be conducted for the Coorong from the Murray Mouth to the southern end of the South Lagoon (102 km). All monitoring data will be collected by complementary monitoring programs and so no specific monitoring is undertaken as part of this indicator.

Timing

All model outputs will be simulated on a sub-daily basis over the whole water year, with reporting for the relevant period for each species summarised over the growing season.

5.2.7 Monitoring protocol

Equipment

N/A

Protocol

N/A

5.2.8 Data analysis and evaluation

This project will use the TUFLOW-FV – AED2 modelling system that has been developed form the CLLMM system. Salinities and water level along the North and South Lagoon of the Coorong will be calculated with a hourly time step with fine (2D) resolution driven, in response to forcing by datasets describing tidal forcing, wind velocity, evaporation and precipitation.

To evaluate the effect of environmental watering on ecosystems, three scenarios will be calculated for each watering year:

- 'with all water' (i.e. observed, including all environmental and consumptive water);
- without Commonwealth environmental water ('no CEW'); and
- without any environmental water ('no eWater').

Results of salinities and water levels from the scenario runs will be subsequently used to simulate habitat characteristics for *Ruppia tuberosa* as well as fish species based on *Ruppia tuberosa* and fish ecological response models (Collier *et al.* 2017; Ye *et al.* 2016b). This comparison of modelled outputs for each flow scenario (with and without Commonwealth environmental water) will provide the basis for the evaluation and reporting. The difference between the scenarios can be attributed to Commonwealth environmental water, although uncertainty in model outputs will be appropriately acknowledged. This will be reported annually, with reports building on knowledge and results gained from CEWO short-term intervention monitoring, where it makes sense to do so.

5.2.9 Data management

See Section 11 in the MER Plan for data management procedures. The data templates for Category 3 (Selected Area) indicators will be developed by the Selected Area, in consultation with CEWO, and will conform to data standards. The proposed template for *Coorong Habitat* is provided below.

Variable	Description	Type	Req	Range	Example
samplePointName	Spatial grid (km) where the modelled data is for.	String	Y		Coo55km
sampleDate	The date that water variables are modelled.	Date	Y		12/09/2019
salinity	Modelled salinity concentration in grams per litre.	Number (2 decimals)	Y	[0,+]	32.15 g/L
waterLevel	Modelled water level in metres above height datum (AHD).	Number (2 decimals)	Y	[0,+]	0.22 m AHD

5.2.10 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

5.2.11 Health, safety and environment plan

See Appendix A.

5.2.12 References

Collier, C., van Dijk, K.-J., Erftemeijer, P., Foster, N., Hipsey, M., O'Loughlin, E., Ticli, K. and Waycott, M. (2017). Optimising Coorong *Ruppia* habitat: Strategies to improve habitat conditions for *Ruppia tuberosa* in the Coorong (South Australia) based on literature review, manipulative experiments and predictive modelling. In: Waycott, M. (Ed.), Reports to Department of Environment and Natural Resources (DEWNR). The University of Adelaide, School of Biological Sciences, Adelaide, South Australia, p. 169 pp.

Ye, Q., Livore, J., Aldridge, K., Giatas, G., Hipsey, M., Joehnk, K., Nicol, J., Wilson, P. and Zampatti, B. (2016b). Monitoring the ecological response to Commonwealth environmental water delivered to the Lower Murray River in 2013-14. Final Report prepared for the Commonwealth Environmental Water Office. South Australian Research and Development Institute.

6 Littoral Vegetation Diversity and Productivity

6.1 Evaluation questions

This monitoring protocol addresses the following Selected Area scale evaluation questions:

- What did Commonwealth environmental water contribute to littoral understorey vegetation diversity and productivity?
- What did Commonwealth environmental water contribute to above-ground biomass produced by understorey littoral vegetation?

See additional evaluation questions for long-term outcomes in contingency monitoring (Section 5.3 in the MER Plan).The process for evaluating these questions is illustrated below in Figure B.10

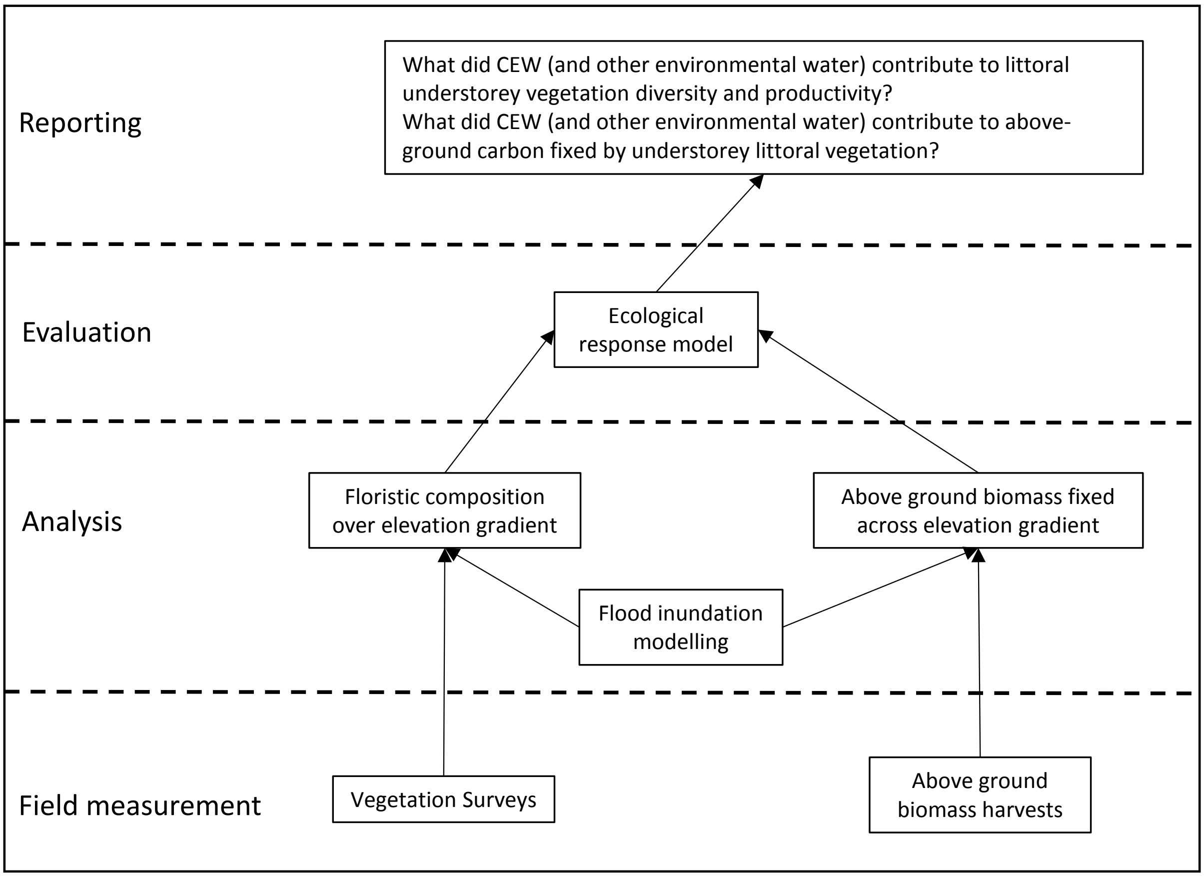

Figure B.10. Schematic of key elements of the MER Standard Protocol: *Littoral Vegetation Diversity and Productivity*.

6.2 Relevant ecosystem types

Rivers.

6.3 Relevant flow types

These methods describe monitoring to be conducted annually after environmental water has been delivered and water levels are at or close to normal pool level. The methods are therefore relevant to all flow types except baseflow (e.g. freshes, bankfull and overbank).

6.4 Overview and context

This method was developed specifically to determine the benefit of Commonwealth environmental water on littoral vegetation in the in the Lower Murray Selected Area. Refer to Section 5.2.3 in the MER Plan for background information, objectives and hypotheses, outputs and staff involvement for littoral vegetation diversity and productivity.

Sampling of littoral vegetation will be conducted in two tailwaters on the banks of the main channel of the Lower Murray or temporary wetlands that were inundated the previous spring.

Covariates include:

Discharge/flow

- Water level.
- Rainfall

6.5 Complementary monitoring and data

Sampling for this indicator will be conducted at two locations corresponding to where other indicators will be monitored. This indicator is closely related to the hydrology indicator and will use flood inundation modelling outputs.

6.6 Monitoring locations and timing

6.6.1 Locations

Vegetation surveys will be conducted at two locations on the banks of the main channel of the Lower Murray (or adjacent temporary wetlands inundated the previous spring) in the tailwater sections downstream of Locks 4 and 1. At each location a minimum of five transects will be established and elevations sampled will depend on how Commonwealth environmental water was delivered.

Timing

Surveys will be conducted after environmental water is delivered and water levels have returned to normal pool level.

6.7 Monitoring protocol

6.7.1 Vegetation surveying protocol

A minimum of five transects will be established at each location and quadrat dimensions will be 1 x 15 m, split into 15 1 x 1 m cells to determine species frequency in each quadrat. Quadrat placement and numbers will be determined by, magnitude and duration of flow and delivery of Commonwealth environmental water. Quadrats with these dimensions, using frequency as a surrogate for abundance have been used extensively throughout the lower Murray and shown to be effective in detecting differences in floodplain plant communities (e.g. Nicol *et al.* 2013; Nicol *et al.* 2018). Furthermore, it will allow comparison with other data sets and enable data to be used to assess DEW targets. Above ground biomass will also be measured in each quadrat by harvesting a fixed area with the area determined by the biomass present (i.e. a smaller area will be harvested from quadrats with high biomass).

Equipment

- Measuring tapes
- GPS

- Dumpy or laser level
- Quadrats
- Battery operated hedge clippers for biomass harvests
- Paper bags
- Marker pens
- Field data sheets.

Protocol

1. Transect locations will be determined in year 1 of the project.
2. Extent of inundation determined and quadrat locations along the transects determined by either flood inundation modelling or elevations corresponding to different inundation durations.
3. Quadrat boundaries established using measuring tapes and vegetation survey data collected.
4. Biomass harvest area selected and all above ground material collected and placed in paper bag(s).
5. Harvested material dried at 40° C to a constant weight and weighed to determine above ground biomass.

6.7.2 Covariates

Water level (m AHD, relative to the Australian Height Datum) from the closest gauging station will be obtained from the DEW Surface Water Archive (www.waterconnect.sa.gov.au).

6.8 Data analysis and evaluation

Species abundances will be expressed as a frequency (0–15) within each quadrat and above ground biomass g dry weight m^{-2}. Comparisons of the floristic composition over the elevation gradient will be analysed using multivariate statistics (NMDS ordination, Clustering, PERMANOVA and Indicator Species Analysis). Species richness and biomass will also be compared over the elevation gradient to evaluate the benefit of Commonwealth environmental water.

6.9 Data management

See Section 11 in the MER Plan for data management procedures. The data templates for Category 3 (Selected Area) indicators will be developed by the Selected Area, in consultation with CEWO, and will conform to data standards. The proposed template for *Littoral Vegetation Diversity and Productivity* is provided below.

Variable	Description	Type	Req	Range	Example
samplePointName	a single reach of the Lower Murray River in either the *Gorge* or *Floodplain* zone represented by either a name or polygon within which observations are made	String	Y		LK6DS_616km
sampleDateStart	Start date (inclusive) that these measures were observed	dateTime	Y		15/05/2019 11:35
sampleDateFinish	End date (exclusive) that these measures were observed	dateTime	Y		16/05/2019 2:35
speciesName	Latin name for species of plant	String	Y		*Phragmites australis*

Variable	Description	Type	Req	Range	Example
speciesFrequency	Frequency of species in each quadrat	Number (0 decimals)	Y	[0, 15]	14
abovegBiomass	Above ground biomass harvested from each quadrat	Number (3 decimals)	Y	[0,+]	13.158 g m^{-2}
waterLevel	Water level at nearest gauging station	Number (2 decimals)	Y	[0,+]	16.72 m AHD

6.10 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

6.11 Health, safety and environment plan

See Appendix A.

6.12 References

Nicol, J.M., Frahn, K.A., Fredberg, J.F., Gehrig, S.L., Marsland, K.B. and Weedon, J.T. (2018). Chowilla Icon Site – Floodplain Vegetation Monitoring 2018 Interim Report, p. 70, South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Nicol, J.M., Gehrig, S.L., Frahn, K.A. and Strawbridge, A.D. (2013). Resilience and resistance of aquatic plant communities downstream of Lock 1 in the Murray River, p. 57, Goyder Institute for Water Research, Adelaide, South Australia.

7 Microinvertebrate Assemblage

7.1 Evaluation questions

This monitoring protocol addresses the following Selected Area scale evaluation questions:

- What did Commonwealth environmental water contribute to microinvertebrate diversity and abundance (density)?
- What did Commonwealth environmental water contribute via longitudinal (upstream) and lateral connectivity* and thus associated microinvertebrate communities of the Lower Murray Selected Area?
- What did Commonwealth environmental water contribute to the expected quality** of food resources (microinvertebrates) for higher trophic organisms?

*Our assessment of the influence of longitudinal connectivity will be based on comparing findings to the modelled (Bigmod) flow source data from the MDBA. We acknowledge there are assumptions with this approach, and it may be difficult to distinguish between the responses to environmental water and operational water.

** Assumptions will be made about the quality of specific groups of zooplankton as a food resource for higher trophic organisms based on what food types they are known to eat, which of those food types are present at the time of sampling and the quality of that food type based on findings in the literature. Due to these assumptions, the complexity of riverine ecosystems and the limited information on Australian specimens, it is important to note the potential inaccuracy in defining food quality.

See additional evaluation questions for long-term outcomes in contingency monitoring (Section 5.3 in the MER Plan).

The process for evaluating these questions is illustrated in Figure B.11.

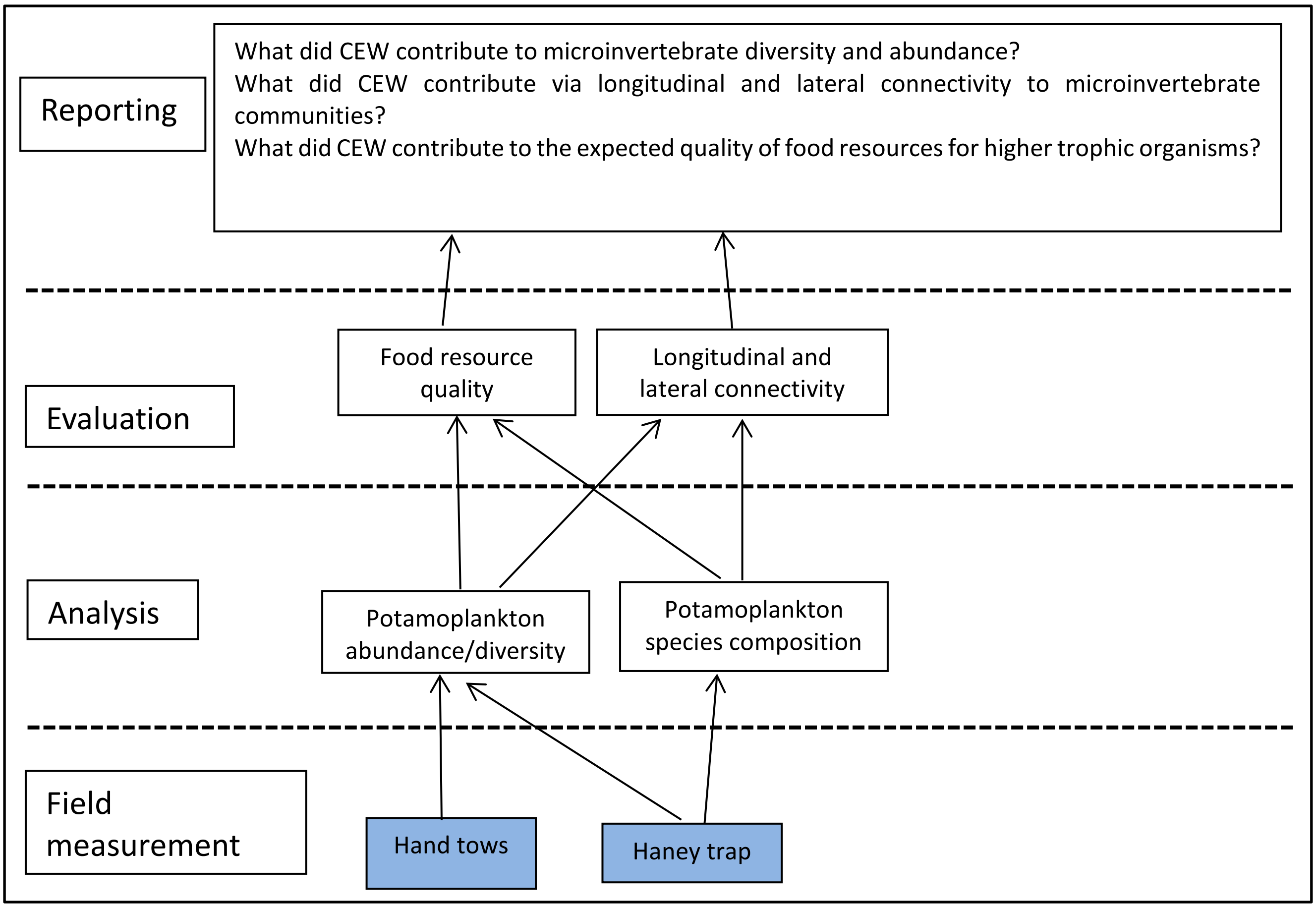

Figure B.11. Schematic of key elements of the LTIM Standard Protocol: *Microinvertebrate Assemblage*.

7.2 Relevant ecosystem types

Rivers.

7.3 Relevant flow types

These methods describe annual monitoring conducted during the period October to January of each year independent of specific watering events. The methods are therefore relevant to all flow types (baseflow, freshes, bankfull and overbank).

7.4 Overview and context

These methods describe monitoring required for the Selected Area evaluation of the microinvertebrate assemblage in response to Commonwealth environmental water. The methods describe the sampling design and protocol for main stream potamoplankton sampling in the Lower Murray. Refer to Section 5.2.4 in the MER Plan for background information, objectives and hypotheses, outputs and staff involvement for *Microinvertebrate Assemblage*.

Sampling will be from October through to late January each year in conjunction with *Stream Metabolism and Water Quality* sampling (see SOP for *Stream Metabolism and Water Quality*). Pelagic habitats will be sampled with a 4-l Haney trap (quantitative, 3–5 bulked trap volumes) and a 37 µm-mesh plankton tow (qualitative). The trap provides a site-specific density, but the small volume underestimates zooplankton diversity. The net tow samples a greater volume, and thereby provides a more representative diversity estimate.

Covariates include:

- Dissolved oxygen
- Salinity/electrical conductivity
- Discharge/flow
- Water temperature
- Turbidity
- Relative water level.

7.5 Complementary monitoring and data

Phytoplankton assemblage information will be collected via *Stream Metabolism and Water Quality* indicator and as part of the research component of the MER Project. Larvae of large-bodied species will be collected through *Murray Cod Recruitment* and contingency monitoring larval sampling. These data or samples may be used during the microinvertebrate assemblage assessment.

7.6 Monitoring locations and timing

7.6.1 Locations

Sampling for microinvertebrates will be conducted at one site within three locations in the main channel of the Lower Murray, approximately 5 kilometres below Lock 1 (*Gorge* zone), Lock 4 and Lock 6 (*Floodplain* zone).

7.6.2 Timing

At each site, sampling will occur three times during spring and three times during summer, approximately two weeks apart and will coincide with stream metabolism sampling. Refer to Section 7.2 in the MER Plan for a monthly monitoring schedule for *Microinvertebrate Assemblage*.

7.7 Monitoring protocol

7.7.1 Collection of potamoplankton

Composite trap (Haney trap) samples and a pelagic net tow will also be collected at each site. Three to five replicate 9 L (4.5 L combined top and bottom depth) Haney trap samples will be taken at each site. Each sample is filtered through the standard plankton net, which is then flushed using a squeeze bottle into the terminal 200 ml PET collecting bottle to provide a 9-litre filtrate of potamoplankton, which is then topped up with 90% ethanol. The accompanying net tow will be 3 hauls of a 5-metre line plankton net, the catch decanted through the net to reduce the filtrate volume to approximately 30–40 ml in the PET bottle, then topped up with 90% ethanol.

<u>Equipment</u>

- 4.5-litre butterfly door Perspex Haney trap
- Standard plankton net
- Squeeze bottle
- 200 mL PET collecting bottle
- 90% ethanol
- Field sheets.

<u>Protocol</u>

1. Three to five replicate 9 L (4.5 L combined top and bottom depth) Haney trap samples will be taken per site.

2. Samples will be filtered through the standard plankton net.
3. Samples will be then flushed using a squeeze bottle into the terminal 200 ml PET collecting bottle to provide a 9-litre filtrate of potamoplankton, which is then topped up with 90% ethanol.
4. Three hauls of a 5-metre line plankton net will be taken.
5. Samples then will be decanted through the net to reduce the filtrate volume to approximately 30–40 ml in the PET bottle, then topped up with 90% ethanol.

7.7.2 Covariates

Water quality parameters (e.g. dissolved oxygen and water temperature) will be measured during Stream Metabolism sampling (See *Stream Metabolism and Water Quality* SOP). Discharge data (ML/d) and relative water level (m AHD, relative to the Australian Height Datum) from the closest gauging station will be obtained from the DEW Surface Water Archive (www.waterconnect.sa.gov.au).

7.7.3 Processing

Entire samples will be preserved individually in 90% ethanol and returned to the laboratory for microinvertebrate identification and enumeration. Quantitative samples will be subsampled (3 x 1 ml Sedgewick-Rafter cell counts to provide an SD and SE of the subsampling method), microinvertebrates identified to species, and counts expressed as density/L. For the net tows, the settled volume will be decanted into a 125 mm square gridded Greiner tray, the first 200–300 individual microinvertebrates encountered identified to species, and the counts recorded as proportional composition. The remainder of the tray will be scanned for missed taxa, which will be recorded as 'present'.

7.8 Data analysis and evaluation

Spatio-temporal variability in microinvertebrate abundance, diversity and species composition (e.g. ratios of different categories of microinvertebrate) will be investigated using parametric (ANOVA) or non-parametric (e.g. permutational analysis of variance), depending on the nature of the data. To model relationships between abundance/species composition and one or more water quality (WQ) predictor variables, we will use distance-based linear model techniques. Evaluation of the microinvertebrate community responses to Commonwealth environmental water will be qualitative.

7.9 Data management

See Section 11 in the MER Plan for data management procedures. The data templates for Category 3 (Selected Area) indicators will be developed by the Selected Area, in consultation with CEWO, and will conform to data standards. The proposed template for *Microinvertebrate Assemblage* is provided below.

Variable	Description	Type	Req	Range	Example
SamplePointName	A single reach of the Lower Murray River in either the *Gorge* or *Floodplain* zone represented by either a name or polygon within which observations are made	String	Y		LK6DS_616km
SampleDateStart	Start date (inclusive) that these measures were observed	dateTime	Y		03/10/2019 17:55
SampleDateFinish	End date (exclusive) that these measures were observed	dateTime	Y		03/10/2019 18:10
SpeciesName	Latin name for species of microinvertebrate	String	Y		*Brachionus novaezealandiae*

Variable	Description	Type	Req	Range	Example
HaneyTrapCatch	Mean number of individuals per litre	Number (0 decimals)	Y	[0,+]	3,000 ind. L^{-1}

7.10 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

7.11 Health, safety and environment plan

See Appendix A.

7.12 References

None.

8 Flow-cued Spawning Fish Recruitment

8.1 Evaluation questions

This monitoring protocol addresses the following Selected Area scale evaluation questions for:

Short-term responses:

- Did the flow regime (including environmental water) contribute to recruitment of golden perch and silver perch?

Long-term outcomes:

- Did the flow regime (including environmental water) contribute to the resilience of golden perch and silver perch populations?

The process for evaluating these questions is illustrated below in Figure B.12.

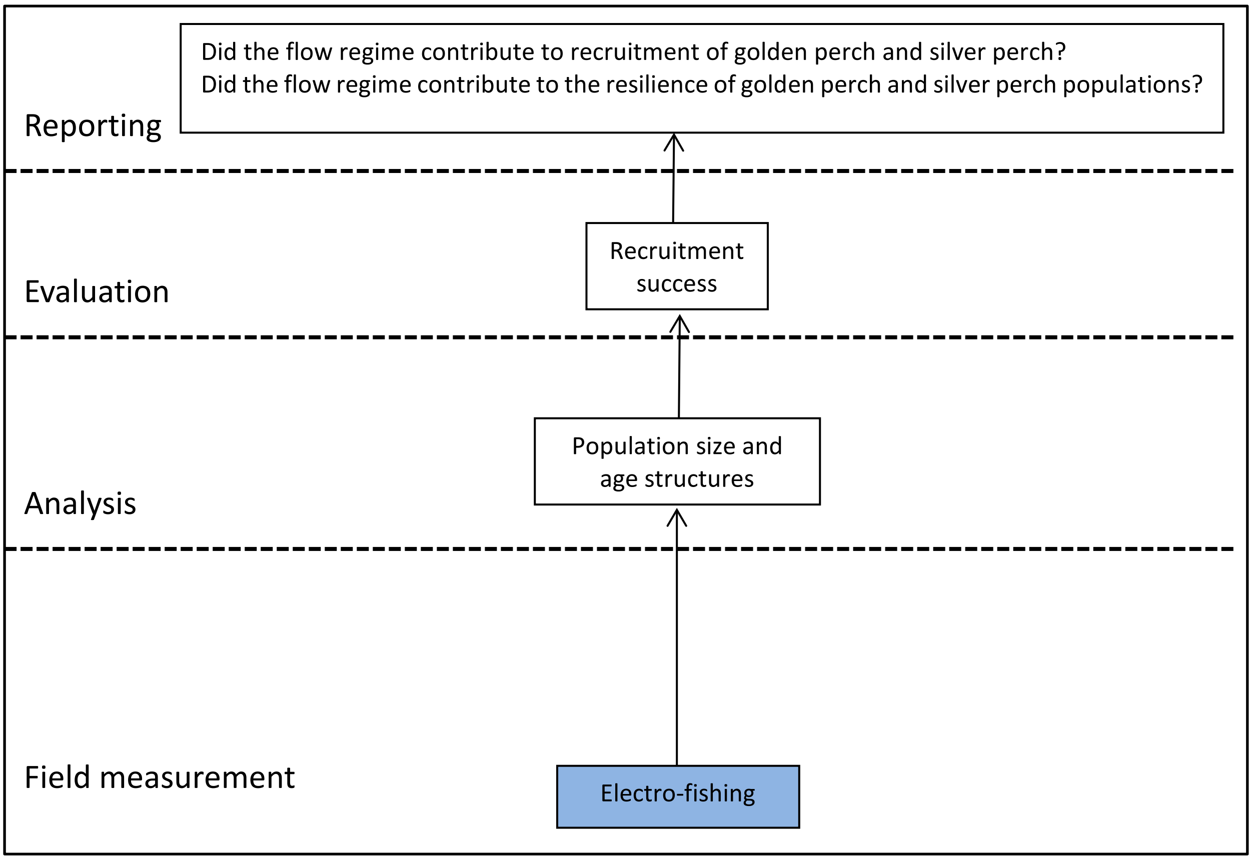

Figure B.12. Schematic of key elements of the LTIM Standard Protocol: *Flow-cued Spawning Fish Recruitment*.

8.2 Relevant ecosystem types

Rivers.

8.3 Relevant flow types

Sampling is independent of specific watering events and therefore relevant to all flow types (baseflow, freshes, bankfull and overbank).

8.4 Overview and context

This protocol has been developed by the Selected Area and describes the monitoring required for the evaluation of the response of recruitment (flow-cued species) to flow, including environmental water. This indicator will focus on two flow-cued spawning species; golden perch and silver perch. We acknowledge that not enough silver perch may be sampled in the Lower Murray for assessment.

Juvenile and adult golden perch and silver perch will be obtained annually through *Fish (Channel)* and *Murray Cod Recruitment* sampling (see each indicator SOPs) to collect information on golden perch population demographics (length and age).

Spawning (presence of eggs and larvae) and the natal origin of larvae/YOY will no longer be investigated as part of the core monitoring for this indicator (also see SARDI *et al.* 2018). Results from previous years of low, in-channel flows (<18,000 ML/d) during LTIM have consistently demonstrated poor recruitment success of golden perch (Ye *et al.* 2019). Larval sampling and associated analyses will, therefore, be contingent upon spring-summer flows exceeding 20,000 ML/d (see contingency monitoring, Section 5.3). Refer to Section 5.2.5 in the MER Plan for background information, objectives and hypotheses, outputs and staff involvement for *Flow-cued Spawning Fish Recruitment*.

8.5 Complementary monitoring and data

Juvenile and adult golden perch will be obtained through *Fish (Channel)*, *Murray Cod Recruitment* and complementary electrofishing conducted by SARDI.

8.6 Monitoring locations and timing

8.6.1 Locations

Juvenile golden perch will be collected through *Fish (Channel)* sampling in the *Gorge* zone and by *Murray Cod Recruitment* sampling at a minimum of six sites in the *Floodplain* zone of the Lower Murray Selected Area.

8.6.2 Timing

Juvenile and adult golden perch and silver perch will be sampled in March/April of each year from 2020–2022. Refer to Section 7.2 in the MER Plan for a monthly monitoring schedule for *Flow-cued Spawning Fish Recruitment*.

8.7 Monitoring protocol

8.7.1 Collection of larval fish

Larval fish sampling will be conducted using paired bongo nets towed behind a boat. Samples will be fixed in ethanol and preserved for analysis in the lab. Refer to the net tow monitoring protocol in the *Murray Cod Recruitment* SOP.

8.7.2 Collection of juvenile and adult golden perch

Juvenile (including young-of-year) and adult golden perch will be sampled by boat electrofishing in the littoral zones of main channel and anabranch habitats of the Lower Murray using a boat mounted 7.5kVA Smith-Root electrofishing unit through sampling for other indicators.

8.7.3 Covariates

Discharge data (ML/d) and water temperature from the closest gauging station will be obtained from the DEW Surface Water Archive (www.waterconnect.sa.gov.au).

8.8 Data analysis and evaluation

Collection and ageing of otoliths from a representative subsample of the golden perch population in the Lower Murray will enable determination of age structures and successful recruitment of strong cohorts and association with hydrology.

8.9 Data management

See Section 11 in the MER Plan for data management procedures. The data templates for Category 3 (Selected Area) indicators will be developed by the Selected Area, in consultation with CEWO, and will conform to data standards. The data template for *Flow-cued Spawning Fish Recruitment* will follow the standard template for individual fish data for *Fish (Channel*) (Brooks and Wealands 2018).

8.10 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

8.11 Health, safety and environment plan

See Appendix A.

8.12 References

Brooks, S. and Wealands, S. (2018). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Data Standard. Report prepared for the Commonwealth Environmental Water Office by La Trobe University, Publication 29.3/2013 Revised November 2018.

Ye, Q., Giatas, G., Aldridge, K., Busch, B., Gibbs, M., Hipsey, M., Lorenz, Z., Maas, R., Oliver, R., Shiel, R., Woodhead, J. and Zampatti, B. (2019). Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project: Lower Murray River Selected Area 2017-18 technical report. A report prepared for the Commonwealth Environmental Water Office. South Australian Research and Development Institute, Aquatic Sciences.

9 Murray Cod Recruitment

9.1 Evaluation questions

This monitoring protocol addresses the following Selected Area scale evaluation questions for:

Short-term responses:

- What did Commonwealth environmental water contribute to the growth and morphometric condition of Murray cod?
- What did Commonwealth environmental water contribute to recruitment of Murray cod?

Long-term outcomes:

- What did Commonwealth environmental water contribute to the resilience of Murray cod populations?

The process for evaluating these questions is illustrated below in Figure B.13.

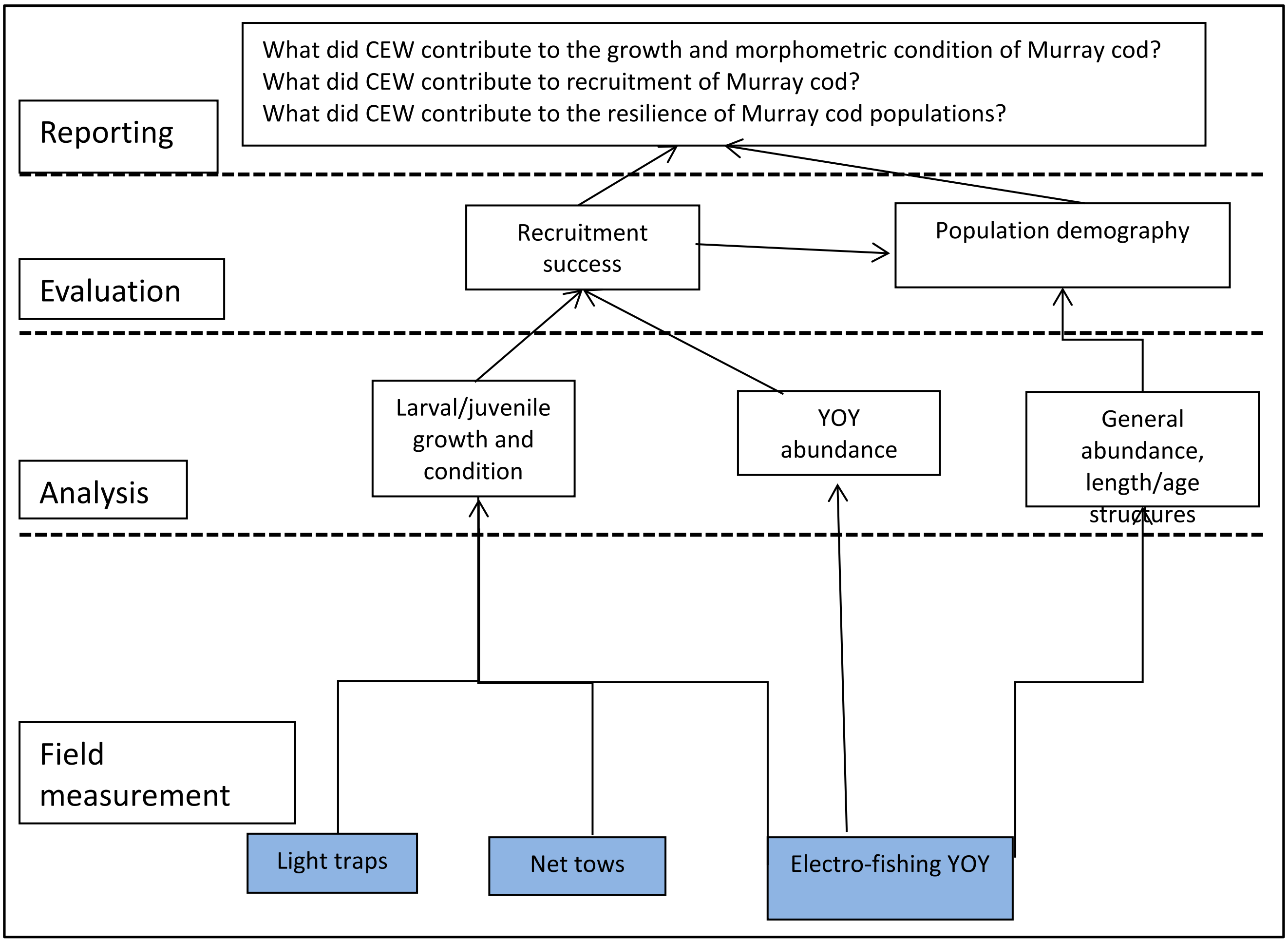

Figure B.13. Schematic of key elements of the LTIM Standard Protocol: *Murray Cod Recruitment*.

9.2 Relevant ecosystem types

Rivers

9.3 Relevant flow types

These methods describe monitoring to be conducted annually during the period November to May, independent of specific watering events. The methods are therefore relevant to all flow types (baseflow, freshes, bankfull and overbank).

9.4 Overview and context

This protocol describes the monitoring required for the evaluation of the response of Murray cod recruitment to flow, including Commonwealth environmental water. The protocol has been developed by the Selected Area. Refer to Section 5.2.6 in the MER Plan for background information, objectives, outputs and staff involvement for *Murray Cod Recruitment*.

Field sampling:

- Net tows (larvae)
- Light traps (larvae and early juveniles)
- Electrofishing (juveniles and adults)

Laboratory analyses:

- Age (otolith increment examination)
- Growth rates (daily and seasonal, otolith examination)
- Morphometric condition (length-weight relationships and associated metrics)

Covariates may include:

- Water velocity
- Discharge/flow
- Water temperature
- Turbidity
- Relative water level.

9.5 Complementary monitoring and data

This indicator will use complementary samples and data collected through the *Fish (Channel)* electrofishing and other complementary electrofishing conducted by SARDI. Murray cod larvae might also be collected during spring sampling trips for stream metabolism and microinvertebrates, or golden perch contingency sampling (flows >20,000 ML/d). Analyses will include data from previous work in the Lower Murray, including LTIM.

9.6 Monitoring locations and timing

9.6.1 Locations

Sampling for larval and juvenile life stages of Murray cod will be conducted at two locations in the main channel of the Lower Murray: in the tailwaters (<15 km downstream) of Lock 4 (*Floodplain* zone) and another Lock (to be determined).

Young-of-year and adult Murray cod electrofishing will occur in the Gorge and Floodplain zones, throughout the Lower Murray Selected Area. Abundance and length data, and YOY samples will also be collected through *Fish (Channel)* sampling in the Gorge zone.

9.6.2 Timing

Murray cod will be sampled on four occasions as follows:

1) November – Larval sampling: This will involve an intensive week of collecting larvae (light traps and net tows) during the peak period of larval presence in the Lower Murray (SARDI unpublished data). Further larvae may also be collected during spring sampling trips for stream metabolism and microinvertebrates, or golden perch contingency sampling (flows >20,000 ML/d).
2) December/January – Juvenile sampling trip 1: This will involve sampling of early stage juveniles using multiple techniques (e.g. light traps, electrofishing, etc.)
3) February/March – Juvenile sampling trip 2: This will involve sampling of early stage juveniles using multiple techniques (e.g. light traps, electrofishing, etc.)
4) April/May – Population and YOY sampling: This will involve monitoring of all life stages of Murray cod using boat electrofishing to assess size/age distributions, and also service to provide data on YOY abundance and collect samples for analysis.

Refer to Section 7.2 in the MER Plan for a monthly monitoring schedule for *Murray Cod Recruitment*.

9.7 Monitoring protocol

9.7.1 Larval fish net tows

Larval fish sampling will be conducted using paired bongo nets towed behind a boat. Samples will be fixed in ethanol and preserved for analysis in the lab. Volume of water through the net will be estimated with a flow-meter attached to the front of the net. Larval fish sorting and enumeration will be conducted in the laboratory.

Equipment

- Paired bongo net (500 µm mesh; square-framed 0.5 x 0.5 m and 3 m long)
- Ethanol
- 32µm mesh sieve
- Sample containers
- Squeeze bottle (for sample rinsing)
- Flow meter
- Water quality multimeter
- Field sheets.

Protocol

6. Bongo net to be towed behind boat for 15 minute tows.
7. Nets are towed in zig-zag using a 20 m rope, in the river main channel in areas with a depth greater than 1 m. The volume of water filtered through each net is determined using a flow meter (General Oceanics), fitted in the centre of the mouth openings.
8. Plankton tows are conducted using a pair of square-framed, 0.5 x 0.5 m, 3 m long bongo nets of 500 µm mesh. Nets are equipped with a 60 cm pneumatic float in the centre of the frame, so the frame sat five cm below the water surface.

9. Once the tow is completed, samples from each net are rinsed into containers and preserved in 95% ethanol.
10. Water quality parameters (dissolved oxygen, electrical conductivity, water temperature and turbidity) are recorded at each site.
11. Samples are transported to a laboratory for sorting under magnification lamps.

9.7.2 Light traps

Larvae and YOY will be targeted using light traps. The design of these traps are similar to those described in Hale *et al.* (2014), although modifications to the design are expected for the capture of larger juveniles in summer. Light traps will be set in the afternoon along the bank of the river, in habitats deemed favourable for Murray cod larvae (i.e. slackwaters within broader areas of flowing habitat), and retrieved the following morning. Set and retrieval times will be recorded to calculate catch-per-unit-effort (CPUE). Each trap will be 'baited' with a yellow 12 h light sticks (yellow in colour). Samples will be fixed in 95% ethanol and preserved for analysis in the lab. Larval fish sorting and enumeration will be conducted in the laboratory.

9.7.3 Electrofishing

Juvenile (including YOY) and adult Murray cod will be sampled by boat electrofishing in the littoral zones of main channel habitats of the Lower Murray using a boat mounted 7.5kVA Smith-Root electrofishing unit. During December/January and February/March sampling, electrofishing may be complemented with light traps. Catch and length information, and YOY samples for analysis, will also be obtained through sampling for *Fish (Channel)* and other complementary electrofishing.

9.7.4 Age, growth and body condition

Otoliths will be removed from larval and juvenile Murray cod collected from all sampling trips and sites. Otolith microstructure analysis will be used to estimate otolith diameter, and daily ages of larvae and early stage juveniles (i.e. collected during juvenile sampling trips 1 and 2), and potentially YOY (sampled in April/May). Otolith preparation and daily age estimation will follow methods used for larval and juvenile golden perch in LTIM (see Ye *et al.* 2019). Estimated age, together with known length and weight, will provide a measure of seasonal growth, whilst otolith increments widths will also be analysed (*sensu* Tonkin *et al.* 2008) to allow interpretations of daily growth rates.

Morphometric condition will be assessed in several ways. Length, weight and estimated age data will be used to determine: 1) length–weight relationships; 2) condition factors; and 3) length–age relationships for juvenile Murray cod sampled in each year and at each site. This data will be compared with reference models for these relationships for Murray cod from the Lower Murray to allow association of annual flow regimes with patterns of growth and condition.

9.7.5 Covariates

Stream metabolism and water quality parameters (e.g. dissolved oxygen, water temperature and turbidity) will be measured below Lock 4 during sampling for the *Stream Metabolism and Water Quality* indicator (see SOP). Discharge data (ML/d) and relative water level (m AHD, relative to the Australian Height Datum) from the closest gauging station will be obtained from the DEW Surface Water Archive (www.waterconnect.sa.gov.au). Hydraulic data will be provided through the Hydraulic regime indicator.

9.8 Data analysis and evaluation

Spatio-temporal variability in the abundance of YOY (recruitment) collected in April/May will be investigated using parametric (ANOVA) or non-parametric (e.g. permutational analysis of variance), depending on the nature of the data (i.e. assumptions of parametric statistics are meet or not).

Data on length-weight and length-age (i.e. seasonal growth) relationships for Murray cod collected in each year, and in past years, will be modelled using linear and non-linear functions to assess the model of best fit for fish from the Lower Murray. Subsequently, the accepted models will be applied for each year, and residuals from these models used as an index of condition or deviation from average seasonal growth, for each individual. Means will then be compared among years and sites. In addition, the relative condition factor (K_{rel}) (Froese 2006) will be calculated from length-weight relationships and compared among years and sites as a further means of assessing differences in morphometric condition (*sensu* Tonkin *et al.* 2012).

Measurements of otolith daily increment widths will be used to investigate differences in daily growth of juvenile Murray cod among years and sites. Mixed-effects modelling will be used to predict otolith derived measures of fish analysed. Models may include various fixed (year, site) and random effects, including water quality (e.g. temperature), and metrics to describe aspects of hydrology and hydraulics. In this way the approach will associate growth with hydrology experienced over the study period.

All data will be integrated to develop an understanding of Murray cod recruitment dynamics and response to flow regimes and water delivery, including Commonwealth environmental water.

9.9 Data management

See Section 11 in the MER Plan for data management procedures. The data templates for Category 3 (Selected Area) indicators will be developed by the Selected Area, in consultation with CEWO, and will conform to data standards. The proposed template for *Murray Cod Recruitment* is provided below.

Catch

Variable	Description	Type	Req	Range	Example
SamplePointName	A single reach of the Lower Murray River in either the *Gorge* or *Floodplain* zone represented by either a name or polygon within which observations are made	string	Y		LK6DS_616 km
SampleDateStart	Start date (inclusive) that these measures were observed	dateTime	Y		03/05/2020 17:55
SampleDateFinish	End date (exclusive) that these measures were observed	dateTime	Y		03/05/2020 18:10
SpeciesName	Latin name for species of fish	String	Y		*Macquaria ambigua*
Type	Gear type used to sample the fish	string	Y		Electrofishing

Variable	Description	Type	Req	Range	Example
Effort	Number of net sets or electrofishing effort (seconds on time)	Number (0 decimals)	Y	[0,+]	4400 s
Catch	Number of individuals	Number (0 decimals)	Y	[0,+]	15

Individual fish

Variable	Description	Type	Req	Range	Example
SamplePointName	A single reach of the Lower Murray River in either the *Gorge* or *Floodplain* zone represented by either a name or polygon within which observations are made	string	Y		LK6DS_616km
SampleDateStart	Start date (inclusive) that these measures were observed	dateTime	Y		03/05/2020 17:55
SampleDateFinish	End date (exclusive) that these measures were observed	dateTime	Y		03/05/2020 18:10
Type	Gear type used to sample the fish	string	Y		Light trap
SpeciesName	Latin name for species of fish	string	Y		*Macquaria ambigua*
FishNumber	Arbitrary name/number that identifies the net, trap or electrofishing unit within the assessment unit	string	Y		3
TotalLength	Fork length (in mm), where necessary	number (0 decimal)	Y	[0,+]	54 mm
Weight	Weight (in grams) of individual	number (2 decimal)	Y		6.82 g

9.10 Quality Assurance/Quality Control

See Section 10.3 in the MER Plan for quality assurance and control measures.

9.11 Health, safety and environment plan

See Appendix A.

9.12 References

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Appendix C – Progress report template

Name of Project

Project Leader:

Report period:

Project Health Summary

Indicator	Traffic light	Comment
Overall Rating		*Traffic light question: Is this Project going to achieve its objective as committed?*
Time (schedule)		*Traffic light question: Is this project (and its elements) forecast date of completion tracking to the baseline schedule?*
Scope (change)		*Traffic light question: Is this Project delivering outcomes directly associated with the agreed project scope?*
Engagement		*Traffic light question: What is the current status of the relationship with project and other stakeholders*
Safety		*Traffic light question: Has there been a safety incident, or have any inadequacies been identified in the safety planning (note, details on any incidents or inadequacies must be communicated to the CEWO as soon as practical)*
Risks		*Traffic light question: Are there any risks that may impact our ability to achieve committed outcomes?*
Issues		*Traffic light question: Are there any issues that may impact our ability to achieve committed outcomes?*

Traffic light legend:

Tasks are completed or on track and there are no issues

Tasks are delayed or under pressure, but not influencing the outputs of the project

Tasks are delayed and are influencing the projects ability to meet its commitments

Summary of Progress towards Milestones

Milestone	Due Date	% Complete	Comment

Critical Risks, Opportunities & Issues

Risk / issue	Action

Outstanding Information

Information required	From Whom	Date required	Urgency
			High
			Medium
			Low

Appendix D – Objectives, evaluation questions, hypotheses and outcomes for each component (indicator) of the MER Project.

CEWO Basin- (Category 1) and Selected Area-scale (Category 3) evaluation questions relating to Basin Plan environmental and water quality objectives for water-dependant ecosystems (adapted from Gawne *et al.* 2014).

Basin Plan level 1 objectives	Basin outcomes		Short-term expected outcomes	Long-term expected outcomes	Basin-scale evaluation questions	Selected Area evaluation questions	MER indicator
Biodiversity	Species diversity	Fish	• Condition • Larval abundance • Reproduction	• Fish diversity • Larval and juvenile recruitment	What did CEW contribute to native fish reproduction? What did CEW contribute to native fish survival? What did CEW contribute to sustaining native fish populations?		Category 1 Fish (Channel)
						Did the flow regime (including environmental water) contribute to recruitment of golden perch and silver perch?	Category 3 Flow-cued Spawning Fish Recruitment
						What did CEW contribute to the growth and morphometric condition of Murray cod? What did CEW contribute to the recruitment of Murray cod?	Category 3 Murray Cod Recruitment
		Micro-invertebrates	• Micro-invertebrate diversity			What did CEW contribute to microinvertebrate diversity? What did CEW contribute to microinvertebrate abundance (density)?	Category 3 Micro-invertebrate Assemblage
		Vegetation	• Vegetation diversity • Vegetation productivity	• Plant community resilience	What did CEW contribute to understorey vegetation diversity across sites with vegetation indicators?	What did CEW contribute to littoral understorey vegetation diversity and productivity? What did CEW contribute to above-ground biomass produced by understorey littoral vegetation?	Category 3 Littoral Vegetation Diversity and Productivity
Ecosystem function	Hydrological Connectivity		• Hydrological connectivity			What did CEW contribute to hydraulic diversity within weir pools?	Category 3 Hydraulic Regime

Basin Plan level 1 objectives	Basin outcomes	Short-term expected outcomes	Long-term expected outcomes	Basin-scale evaluation questions	Selected Area evaluation questions	MER indicator
		including end of system flows • Hydraulic diversity • Sediment transport			What did CEW contribute to in-channel variability in water levels? What did CEW contribute to hydrological connectivity? What did CEW contribute to meeting EWRs in the Channel of the Lower Murray?	
	Functional connectivity	• Biotic dispersal and movement			What did CEW contribute via longitudinal (upstream) and lateral connectivity and thus associated microinvertebrate communities in the Lower Murray?	Category 3 Micro-invertebrate Assemblage
	Process	• Primary productivity (of aquatic ecosystems) • Decomposition • Nutrient and carbon cycling		What did CEW contribute to patterns and rates of primary productivity and decomposition?	What did CEW contribute to patterns and rates of primary productivity and decomposition? What did CEW contribute to concentrations and transport of phytoplankton? What did CEW contribute to the quality of food resources (microinvertebrates) for higher trophic organisms?	Category 1 Stream Metabolism and Water Quality Category 3 Matter Transport and Coorong Habitat Category 3 Microinvertebrate Assemblage
Resilience	Ecosystem resilience	• Individual survival and condition (individual refuges) • Individual condition (ecosystem resistance)	• Population condition (individual refuges) • Population condition (landscape refuges) • Population condition (ecosystem recovery)	What did CEW contribute to native fish community resilience?	Did the flow regime (including environmental water) contribute to the resilience of golden perch and silver perch populations? What did CEW contribute to the resilience of Murray cod populations?	Category 1 Fish (Channel) Category 3 Flow-cued Spawning Fish Recruitment Category 3: Murray Cod Recruitment

Basin Plan level 1 objectives	**Basin outcomes**	**Short-term expected outcomes**	**Long-term expected outcomes**	**Basin-scale evaluation questions**	**Selected Area evaluation questions**	**MER indicator**
Water quality	Chemical	• Salinity • Dissolved oxygen • pH • Dissolved organic carbon		What did CEW contribute to dissolved oxygen levels? What did CEW contribute to water quality?	What did CEW contribute to dissolved oxygen levels? What did CEW contribute to water quality? What did CEW contribute to salinity levels and transport? What did CEW contribute to nutrient concentrations and transport? What did CEW contribute to improving *Ruppia tuberosa* habitat in the Coorong? What did CEW contribute to improving fish habitat in the Coorong?	Category 1 Stream Metabolism and Water Quality Category 3 Matter Transport and Coorong Habitat

DEW evaluation questions relating to ecological targets for the SA River Murray Channel Priority Environmental Asset (adapted from DEW's Long Term Watering Plan, DEWNR 2015) and Matter 8 expected outcomes. Evaluation questions will be reviewed when expected outcomes for Matter 8 reporting are further developed for LTWP targets.

Type	Ecological objective	Ecological targets	Short-term expected outcome (2019)	Intermediate expected outcome (2029)	Evaluation questions	MER indicator
Ecosystem processes	Provide for the mobilisation of carbon and nutrients from the floodplain to the river to reduce the reliance of in-stream foodwebs on autochthonous productivity.	Open-water productivity shows a temporary shift from near zero or autotrophic dominance (positive Net Daily Metabolism) towards heterotrophy (negative Net Daily Metabolism) when QSA >30,000 ML.day^{-1}.	Outcome being developed – can be updated once complete	Outcome being developed – can be updated once complete	Year 1 only: To what extent did CEW contribute to achieving the short-term expected outcome for open-water productivity in the Lower Murray? All years: To what extent did CEW contribute to progress toward the intermediate expected outcome for open-water productivity in the Lower Murray?	Category 1 Stream Metabolism and Water Quality
	Provide diverse hydraulic conditions over the range of velocity classes in the lower third of weir pools so that habitat and processes for dispersal of organic and inorganic material between reaches are maintained.	Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep–Mar, at a maximum interval of 2 years.			To what extent did CEW contribute to meeting the EWRs (all metrics) for the Lower Murray Channel?	Category 1 Hydrology (Channel)
			Between 2013 and 2019, the majority of lower third weir pools will have median cross-sectional velocities of > 0.3 m/s for at least 60 consecutive days between September-March in 2 of the 7 years.	Between 2013 and 2029, the majority of lower third weir pools will have median cross-sectional velocities of > 0.3 m/s for at least 60 consecutive days between September-March in 5 of the 17 years.	Year 1 only: To what extent did CEW contribute to achieving the short-term expected outcome for velocity in the Lower Murray? All years: To what extent did CEW contribute to progress toward the intermediate expected outcome for velocity in the Lower Murray?	Category 3 Hydraulic Regime
	Maintain habitats and provide for dispersal of organic and inorganic material and organisms between river and wetlands.	Inundation periods in temporary wetlands have unrestricted lateral connectivity between the river and wetlands in >90% of inundation events.			To what extent did CEW contribute to increased dispersal of organisms between river and wetlands in the Lower Murray?	Category 3 Micro-invertebrate Assemblage
Water Quality	Maintain water quality to support aquatic biota and normal biogeochemical processes.	Biovolume <4 mm^3 L^{-1} for all Cyanobacteria, where a known toxin producer is dominant.			To what extent did CEW contribute to managing the concentrations of cyanobacteria.	Category 1 Stream Metabolism and Water Quality
		Biovolume <10 mm^3 L^{-1} for all Cyanobacteria, where toxins are not present.				

Type	Ecological objective	Ecological targets	Short-term expected outcome (2019)	Intermediate expected outcome (2029)	Evaluation questions	MER indicator
		Basin Plan Target: Maintain dissolved oxygen above 50% saturation throughout water column at all times.			To what extent did CEW contribute to maintaining dissolved oxygen levels above 50% saturation throughout the water column at all times in the Lower Murray?	Category 1 Stream Metabolism and Water Quality
Fish[1]	Restore resilient populations of Murray cod (a long-lived apex predator).	Population age structure of Murray cod includes recent recruits[2], sub-adults and adults in 9 years in 10.	Between 2013 and 2019, the population age structure of Murray cod will include recent recruits, sub-adults and adults 5 of the 7 years.	Between 2013 and 2029, the population age structure of Murray cod will include recent recruits, sub-adults and adults 10 of the 17 years.	Year 1 only: Was the short-term expected outcome achieved in the Lower Murray? All years: Is the intermediate expected outcome on track to being achieved in the Lower Murray?	Category 1 Fish (Channel) Category 3 Murray Cod Recruitment
		Population age structure of Murray cod indicates a large recruitment[3] event 1 year in 5, demonstrated by a cohort representing >50% of the population.			Did the length-frequency distribution for Murray cod indicate at least 1 large recruitment event in the last 5 years, demonstrated by a YOY cohort representing >50% of the population from the Lower Murray?	Category 1 Fish (Channel) Category 3 Murray Cod Recruitment
		Abundance (CPUE[4]) of Murray cod increases by ≥50% over a 10-year period.			Did the abundance of Murray cod in the Lower Murray increase by ≥20% over the last 5-year period?[6]	Category 1 Fish (Channel) Category 3 Murray Cod Recruitment
	Restore resilient populations of golden perch and silver perch (flow-dependent specialists).	Population age structure of golden perch and silver perch includes YOY with sub-adults and adults in 8 years in 10.	Between 2013 and 2019, the population age structure of golden perch will include adults and sub-adults[5] 5 of the 7 years.	Between 2013 and 2029, the population age structure of golden perch will include adults and sub-adults 11 of the 17 years.	Year 1 only: Was the short-term expected outcome achieved in the Lower Murray? All years: Is the intermediate expected outcome on track to being achieved in the Lower Murray?	Category 3 Flow-cued Spawning Fish Recruitment

[1] Population age structure is inferred from length-frequency distributions and validated by otoliths where appropriate. YOY = Young of Year, age 0+.
[2] Age classes defined as recent recruits (<200 mm, including YOY and 1+ fish), sub-adults (200–600 mm) and adults (>600 mm)
[3] 'Recruitment' refers to survival and growth of the larvae and juveniles to YOY (young of year)
[4] Abundance is measured by CPUE, which is 'catch per unit effort' resulting from formal surveys using standard techniques (e.g. boat-mounted electrofishing, fyke nets)
[5]Age classes defined as YOY <1+, sub-adult 1+–3+, adult 4+

Type	Ecological objective	Ecological targets	Short-term expected outcome (2019)	Intermediate expected outcome (2029)	Evaluation questions	MER indicator
		Population age structure of golden perch and silver perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.	Between 2013 and 2019, large recruitment events of golden perch have occurred in 3 of the 7 years.	Between 2013 and 2029, large recruitment events of golden perch have occurred in 8 of the 17 years.	Year 1 only: Was the short-term expected outcome achieved in the LM Selected Area? All years: Is the intermediate expected outcome on track to being achieved in the LM Selected Area?	Category 3 Flow-cued Spawning Fish Recruitment
		Abundance (CPUE) of golden perch and silver perch increases by ≥30% over a 5-year period.			Did the abundance of golden perch in the *Gorge* zone increase by >30% over a 5-year period? Did the abundance of silver perch in the *Gorge* zone increase by >30% over a 5-year period?[6]	Category 1 Fish (Channel)
	Restore resilient populations of freshwater catfish.	Abundance (CPUE) of freshwater catfish increases by ≥30% over a 5-year period.			Did the abundance of freshwater catfish in the *Gorge* zone increase by ≥30% over a 5-year period?[6]	Category 1 Fish (Channel)
	Restore and maintain resilient populations of foraging generalists (e.g. Australian smelt, bony herring, Murray rainbowfish, unspecked hardyhead, carp gudgeons, flathead gudgeons).	The length-frequency distributions for foraging generalists include size classes showing annual recruitment.[7]			Did the length-frequency distribution for bony herring in the *Gorge* zone include size classes representing YOY? Did the length-frequency distribution for Murray rainbowfish in the *Gorge* zone include size classes representing YOY? Did the length-frequency distribution for carp gudgeon in the *Gorge* zone include size classes representing YOY?	Category 1 Fish (Channel)
	Minimise the risk of carp recruitment.	The relative abundance and biomass of common carp does not increase in the absence of increases in abundance and biomass of flow-dependent native fish.			Did the relative abundance of common carp in the *Gorge* zone increase during the current year, relative to the previous year, whilst the relative abundances of flow-dependent native species decreased? Did the estimated biomass of common carp in the *Gorge* zone increase during the current	Category 1 Fish (Channel)

[6] Capability to answer the question is dependent on adequate sample size.

[7] During high flow years (e.g. >30 000 $ML.day^{-1}$), Murray rainbowfish and carp gudgeon may be rare or absent from main channel environments as in-channel habitats become unsuitable. As fish sampling for LTIM is not being undertaken in off-channel habitats, the absence of YOY in the main channel should not be seen as a failure to achieving the target.

Type	Ecological objective	Ecological targets	Short-term expected outcome (2019)	Intermediate expected outcome (2029)	Evaluation questions	MER indicator
					year, relative to the previous year, whilst the estimated biomass of flow-dependent native species decreased?	
Vegetation	Throughout the length of the Channel asset (i.e. SA border to Wellington), establish and maintain a diverse native flood-dependent plant community in areas inundated by flows of 10,000–40,000 ML/day QSA. Throughout the length of the Channel asset (i.e. SA border to Wellington), establish and maintain a diverse macrophyte community in wetlands inundated by flows up to 40,000 ML/day QSA.	Species from the Plant Functional Group 'flood-dependent/responsive' occur in 70% of quadrats spanning the elevation gradient in the target zone at least once every 3 years. Native macrophytes from the emergent, amphibious and flood-dependent functional groups occur in 70% of quadrats spanning the elevation gradient in the target zone at least once every 3 years.			To what extent did CEW (and other environmental water) contribute to littoral understorey vegetation diversity and productivity?	Category 3 Littoral Vegetation Diversity and Productivity

Acronyms

ANAE	Interim Australian National Aquatic Ecosystem
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AS/NZS ISO	Australian/New Zealand Standard International Organisation for Standardisation
CED	Cause and effect diagram
CEW	Commonwealth Environmental Water
CEWH	Commonwealth Environmental Water Holder
CEWO	Commonwealth Environmental Water Office
CLLMM	Coorong Lower Lakes and Murray Mouth
CPUE	Catch Per Unit Effort
CR	Community Respiration
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DO	Dissolved Oxygen
DEW	Department for Environment and Water
EPA	Environment Protection Authority
EPBC Act	Environment, Protection and Biodiversity Conservation Act
EWKR	Environmental Water Knowledge and Research
EWR	Environmental Water Requirement
GPS	Global Positioning System
IAP2	International Association of Public Participation
LMRIA	Lower Murray Reclaimed Irrigation Area
LTIM	Long Term Intervention Monitoring
LTWP	Long Term Watering Plan
MDB	Murray–Darling Basin
MDBA	Murray–Darling Basin Authority
MDBC	Murray–Darling Basin Commission
MDBNRMS	Murray–Darling Basin Natural Resources Management Strategy
MDFRC	Murray–Darling Freshwater Research Centre
MER	Monitoring, Evaluation and Research
MERI	Monitoring, Evaluation, Reporting and Improvement
NATA	National Association of Testing Authorities

NRM	Natural Resources Management
NRMB	Natural Resources Management Board
PAR	Photosynthetically Active Radiation
PIRSA	Primary Industries and Regions South Australia
QA/QC	Quality assurance/quality control
RRP	Riverine Recovery Project
SAMDB	South Australian Murray–Darling Basin
SARDI	South Australian Research and Development Institute
SCBEWC	Southern Connected Basin Environmental Watering Committee
SOP	Standard Operating Procedures
SSMP	Site Safety Management Plans
TLM	The Living Murray
UoA	University of Adelaide
VEWH	Victorian Environmental Water Holder
WHS	Work Health Safety and Injury Management
WQ	Water Quality
YOY	Young-of-the-year (with reference to newly recruited 0+ year old fish)

Attachment A: 2019 Lamprey migration contingency monitoring Work Order and Project Scope

Schedule 6 –Work Order

Order
The parties have agreed in accordance with clause 7 the Agreement that the Provider will provide the Additional Project Services specified in this Work Order.

Item	Description	Clause	Details
1.	Agreement description	N/A	Agreement for Additional Project Services in respect of Monitoring lamprey migration at the Murray Barrages in winter–spring 2019
2.	Names of Parties to the Agreement	N/A	The Commonwealth of Australia as represented by the Department of the Environment and Energy ABN 34 190 894 983 SARDI Aquatic Sciences ABN: 53 763 159 658
3.	Additional Project Start Date	1.1	Date work order approved by CEWO
4.	Additional Project Timeframe	1.1	From the Additional Project Services Start Date until 30 March 2020
5.	Category of Services	7	Contingency Monitoring
6.	Additional Project Services	7	Pouched lamprey and short-headed lamprey are the only anadromous fishes in the MDB. Their life history is reliant on discharge and connectivity to stimulate and facilitate upstream spawning migrations from the ocean. Thus, they are a useful indicator of the influence of Commonwealth environmental water on connectivity with the ocean and throughout the Murray. The current service will involve supplementing of existing monitoring of lamprey migration (funded under the Murray-Darling Basin Authority (MDBA) The Living Murray program) to ensure an appropriate level of monitoring to assess abundance and movement. This involves the use of cage traps to sample lamprey migrating through fishways during the winter–spring migration season. All lamprey will be tagged with PIT (passive integrated transponder) tags to monitor subsequent movement through fishways on the River Murray.

			A data summary will be provided to the CEWO, as well as the SA DEW, and MDBA, by 15 November 2019 detailing numbers of lamprey sampled. A short summary report will be provided to the CEWO, as well as the SA DEW, and MDBA, by 30 March 2020 outlining details of lamprey abundance and movement. This will include addressing the following evaluation question: - What did Commonwealth environmental water contribute to connectivity and the migration of lamprey at the Murray Barrages in winter–spring 2019. [*See 'Research project scope and costing' for details of services*]
7.	**Subcontractors**	**6.5**	Not applicable
8.	**Progress meetings and reports**	**11**	Communication of findings will occur by email or teleconference as required throughout the project. Work progress will also be reported in the quarterly report of the MER project. A short summary report will be provided to CEWO, DEW and MDBA by 30 March 2020. This monitoring will also be incorporated as a section into the annual CEWO MER report.
9.	**Performance Criteria**	**12**	The following Performance Criteria will apply to this Additional Project Services specified in the Work Order: - Must be in accordance with the Work Order. - Must be completed to a professional standard. - Must address relevant feedback previously provided by the Department. - Must be undertaken in accordance with the dates and timeframes specified the Work Order - Summary report must be submitted in accordance with a standard format and template to be agreed by the Department
10.	**Project Officers**	**1.1**	**Department** Name: Anthony Moore Position: Southern Basin Section Commonwealth Environmental Water Office Physical address: 51 Allara Street, Canberra Postal Address: GPO Box 787, Canberra ACT 2601 Phone: 02 6275 9795 Email: anthony.moore@environment.gov.au

			Provider Name: A/Professor Qifeng Ye Position: Principal Scientist/Science Leader (Inland Waters & Catchment Ecology), SARDI Aquatic Sciences Ph: (08) 8429 0774 Email: qifeng.ye@sa.gov.au
11.	**Specified Personnel**	**1.1 and 13**	Chris Bice – Senior Research Officer Brenton Zampatti – Senior Research Scientist Arron Strawbridge – Senior Research Services Officer Ian Magraith – Senior Research Services Officer
12.	**Department Material**	**1.1**	Not applicable
13.	**Pre-existing Material of the Provider**	**1.1**	Not applicable
14.	**Payment Schedule**	**7 and 16**	All costings have been removed from this version
15.	**Expenses**	**16**	No change
16.	**Other**	**1.1**	This funding application is for a co-contribution to a 'jointly funded lamprey monitoring project' with the MDBA The Living Murray Program.

Research Project Scope and Costing

SERVICE SCHEDULE

SCHEDULE 1 - RESEARCH PROJECT SCOPE

1. PROJECT DETAIL

1.1 Title

CEWO Barrage lamprey monitoring 2019

1.2 Client Contact Details

Department:	Commonwealth Environmental Water Office
Branch:	Southern Basin Section
Attention:	Anthony Moore
Position:	CEWO Southern Delivery Section
Address:	GPO Box 787, Canberra ACT 2601
Email:	anthony.moore@environment.gov.au
Telephone:	(02) 6275 9795
Facsimile:	(08) 8463 7688

1.3 Principal Investigator

Name:	Qifeng Ye
Position:	Principal Scientist/Science Leader (Inland Waters & Catchment Ecology), SARDI Aquatic Sciences
Address:	SARDI Aquatic Sciences PO Box 120 HENLEY BEACH SA 5022
Email:	Qifeng.Ye@sa.gov.au
Telephone:	(08) 8429 0774
Facsimile:	(08) 8207 5415

1.4 Subcontractor/Collaborator

Not applicable.

1.5 Timeframe

Commencement Date:	On signing of agreement
Completion Date:	30 March 2020

Research Project Scope and Costing

1.6 Summary

This project brief defines the scope of work for assessing the migration of lamprey at the Murray Barrage fishways in winter–spring 2019, and the influence of Commonwealth environmental water (CEW) in facilitating connectivity and migration. This project will supplement existing monitoring under the Murray Darling Basin Authority's The Living Murray Program. This brief provides a description of the project background, objectives, milestones, deliverables, and budget and resource requirements.

2. PROJECT DESCRIPTION

2.1 BACKGROUND

Pouched lamprey (*Geotria australis*) and short-headed lamprey (*Mordacia mordax*) are the only anadromous fish species native to the Murray-Darling Basin. Their life-history is characterised by a parasitic marine life-stage, followed by large-scale adult upstream spawning migrations into freshwater habitats (McDowall 1996). Juveniles (ammocoetes) live in freshwater riverine habitats prior to metamorphosis and downstream migration to marine habitats. Whilst there is limited knowledge on Australian lamprey species, evidence from the northern hemisphere suggests that upstream migration of sea lamprey (*Pteromyzon marinus*) is mediated by olfactory cues in river outflows, particularly odours from conspecific juveniles (Bjerselius et al. 2000, Vrieze et al. 2010). The life-history strategy of lamprey is thus highly dependent upon connectivity between marine and freshwater environments, and the provision of freshwater flows (including environmental water) and resulting olfactory migratory cues. As such, these species are vulnerable to the obstruction of migratory pathways by flow regulating structures and diminished freshwater flows to estuaries as a result of water abstraction.

Anecdotal evidence suggests pouched and short-headed lamprey formally migrated upstream in large numbers to spawn in the River Murray (Lintermans 2007), whilst recent data suggests contemporary upstream migrations still occur over 100s of kilometres (unpublished data). Additionally, lamprey may migrate over relatively narrow time periods, and when coupled with low abundance, both species may be difficult to detect using standard fish sampling techniques in a large river like the lower Murray. Trapping of fishways on barriers to migration, during the migration season, alleviates some of these issues as individuals are forced to pass upstream through the fishways.

The fishways on the Murray Barrages have been sampled annually since 2006, which has confirmed that winter–spring (July–October) is the key upstream migration period for lamprey. Under historical operation, the provision of freshwater discharge at the Murray Barrages during this period was rare. Nonetheless, the delivery of flow to the lower River

Research Project Scope and Costing

Murray following return flows from upstream watering actions during winter is an increasingly common outcome of CEW water delivery. Correspondingly in recent years, CEW has been released from the barrages in winter–spring with the objective of facilitating and stimulating lamprey migration. Monitoring of migration during these events is required to evaluate the contribution of CEW to migration outcomes for lamprey.

2.2 NEED

This project will contribute to the collection of essential data on the migration of pouched and short-headed lamprey at the Murray Barrages, and more broadly in the lower River Murray, in association with CEW delivery in winter–spring 2019. This data is fundamental in to underpin future management, in particular, the delivery of CEW, and barrage and fishway operation. Specifically the data will be used to assess the following evaluation questions:

- What did Commonwealth environmental water contribute to connectivity and the migration of lamprey at the Murray Barrages in winter–spring 2019?

2.3 OBJECTIVES

The objective of the current study is to investigate the upstream movement of pouched and short-headed lamprey at the Murray Barrages in winter–spring 2019. Using the barrage fishways as a sampling tool, we aim to:

1) Determine the number of pouched lamprey and short-headed lamprey migrating upstream at fishways on Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere Barrages, and Hunters Creek causeway, over in winter–spring 2019;
2) Surgically implant lamprey with PIT tags to allow detection of individuals on the Murray fishway PIT reader systems should these fish migrate upstream in the lower River Murray; and
3) Assess the contribution of CEW to connectivity and migration of lamprey.

2.4 METHODS

The current project will supplement existing monitoring and follow the same methods. Lamprey attempting to move between the Coorong and the Lower Lakes will be captured from the entrances of a subset of the Murray Barrage fishways using specifically designed and constructed cage-traps. Sampling will be undertaken at the following barrages and fishways: Goolwa (two vertical-slot fishways), Mundoo (dual vertical-slot fishway), Boundary Creek (small vertical-slot fishway), Ewe Island (dual vertical-slot fishway) and Tauwitchere barrages (2 vertical-slot fishways), and the Hunters Creek causeway (vertical-slot fishway).

Research Project Scope and Costing

The peak period for upstream migrations of lamprey is in winter–spring. Together with monitoring funded by the MDBA and administered by the South Australian Department of Environment and Water, approximately 20 sampling nights (as per method described above) are scheduled to occur during appropriate weather conditions in July–October 2019. All lamprey captured will be implanted with a PIT (passive integrated transponder) tag prior to release. All fishways on main channel weirs have been fitted with PIT tag reader systems as part of the 'Sea to Hume Fishway Program' and these PIT reader systems will record the passage of lamprey through the fishways. Based on past data, movements on fishways may be detected until the following summer.

3. DELIVERABLES

3.1 Service Provided:

As above

3.2 Outcomes:

This project will enable assessment of the following evaluation question,

- What did Commonwealth environmental water contribute to connectivity and the migration of lamprey at the Murray Barrages in winter–spring 2019.

Ultimately, this data will provide empirical evidence to support the future delivery of CEW and underpin operation of the barrages and fishways.

3.3 Outputs and Extension:

During this project, all tasks will include regular liaison with the project manager, including in quarterly report for the MER project. Sampling of lamprey at the Barrage fishways will commence in July 2019 and continue until October 2019. A data summary, detailing numbers of lamprey captured, will be provided by 15 November 2019. Movements through fishways on the River Murray may continue until January 2020, and thus the MDBA PIT reader database will be interrogated at this time. A brief summary report, detailing sampling and subsequent movement of lamprey will be provided to the CEWO, as well as the SA Department of Environment and Water (DEW), and Murray-Darling Basin Authority, by 30 March 2020. A section on this monitoring will also be incorporated in the annual CEWO MER report later in 2020.

Attachment B: 2019–2021 Research Work Order and Project Scope

Schedule 6 –Work Order

Order
The parties have agreed in accordance with clause 7 the Agreement that the Provider will provide the Additional Project Services specified in this Work Order.

Item	Description	Clause	Details
1.	**Agreement description**	**N/A**	Agreement for Additional Project Services in respect of to the Research component of MER in the Lower Murray selected area. Project is titled *From productivity to Murray cod recruitment*
2.	**Names of Parties to the Agreement**	**N/A**	The Commonwealth of Australia as represented by the Department of the Environment and Energy ABN 34 190 894 983 SARDI Aquatic Sciences ABN: 53 763 159 658
3.	**Additional Project Start Date**	**1.1**	Date work order approved by CEWO
4.	**Additional Project Timeframe**	**1.1**	From the Additional Project Services Start Date until 30 December 2021* **The end date will be December 2022 if the second field season occurs in 2021-22 due to flow scenario.*
5.	**Category of Services**	**7**	Contingency Funding - Research
6.	**Additional Project Services**	**7**	The current research project aims to investigate the influence of the source, pathways and quality of energy transfer through the lower River Murray trophic web on the recruitment of Murray cod, and ultimately, how this process is mediated by flow (hydrology and hydraulics). Specific questions related to this objective include: - What is the composition of ambient prey communities and how does this vary with flow? - What is the diet of larval and juvenile Murray cod in the Lower Murray in relation to ambient prey communities, and how does this vary with flow? - What is the nutritional quality of key prey items of larvae/juvenile Murray cod, is this reflected in the condition of Murray cod, and how does this vary with flow? - What basal components of the food web (e.g. autochthonous v allochthonous, pelagic v

			benthic) support the growth of early life stage Murray cod, and how does this vary with flow? - How do these flow-related trophic processes relate to Murray cod growth, condition and recruitment? The research project will integrate monitoring from several pre-existing indicators (*Hydraulic Regime, Stream Metabolism and Water Quality, Microinvertebrate Assemblage, Fish* and *Murray Cod Recruitment*) in a cost-effective manner and provide a holistic view of ecosystem response to flow (including Commonwealth environmental water) and a mechanistic understanding of ecological processes that lead to improved recruitment of Murray cod. The research project will occur over two field sampling seasons (2019/20 plus 2020/21 or 2021/22, aiming for a contrasting flow scenario year with the first year), and have a spatial focus on the Lock 4 tailwater. This is due to the greatest likelihood of sampling adequate numbers of Murray cod from this region. Existing fieldwork and sampling largely supports the current project, but in some instances additional monitoring and sampling will occur, as well as a range of further laboratory analyses outlined below. - Stream metabolism: An additional stream metabolism site (see Lower Murray MER Plan 2019-22 for methods) will be added to downstream of Lock 4 to aid interpretation of productivity and trophic dynamics. This component will also be supported by molecular analyses outline below, which will seek to quantify prey species availability, but also provide insight on microbial community dynamics that influence productivity; - Murray cod diet and ambient prey: this will include traditional (dissection and microscopy) and DNA metabarcoding approaches to assess diet throughout early ontogeny. Ambient prey assemblages (zooplankton), and the abundance of critical prey species (i.e. shrimp) will be quantified using traditional (i.e. netting, microscopy) and DNA metabarcoding approaches to assess selection for/against certain taxa and resource availability; - Nutrition: the nutritional value, that is polyunsaturated fatty acid (PUFA) profiles and calorific content, of key prey species, and juvenile Murray cod will be quantified.

			- Basal food sources: Sources of basal carbon supporting juvenile Murray cod will be investigated using compound-specific stable isotope analyses (CSIA). CSIA will be used to firstly determine the $\delta^{13}C$ signatures for several amino acids of distinct end-members in the Lower River Murray (preliminarily riparian trees, macrophytes, periphyton and seston (including isolated diatoms and cyanobacteria)) before investigating which of these sources of carbon support early life stages of Murray cod, and how this varies within and between years, as a function of flow. An interim report detailing fieldwork and analyses undertaken in 2019/20 will be included in the annual MER report for the Lower Murray selected area in December 2020. A final report detailing fieldwork from both 2019/20 and the second field season (2020/21 or 2021/22), as well as all analyses, will be delivered in December 2021 or December 2022 (if work is fieldwork is conducted in 2021/22). This integrated research will improve evaluation by enhancing understanding of mechanisms that promote ecological patterns (e.g. Murray cod juvenile growth rates and recruitment). Consequently, the project will provide a mechanistic understanding of system function to support Commonwealth environmental water delivery and flow management. [*See attached 'Research project scope and costing' for details of services*]
7.	**Subcontractors**	6.5	Not applicable
8.	**Progress meetings and reports**	11	Communication of findings will occur by email or teleconference as required throughout the project. Work progress will also be reported in the quarterly report of the MER project. Quarterly reports delivered in June of 2020 and 2021 will serve as milestones for the current project. A progress report, detailing fieldwork and analyses from the 2019-20 season, will be provided to the CEWO in December 2020, as a part of the Lower Murray MER annual report. A final report, detailing all fieldwork and analyses from two field seasons, will be provided to CEWO in December 2021 if the second field season occurs in 2020/21 or December 2022 if the second field season occurs in 2021/22 as a part of the Lower Murray MER annual report

9.	**Performance Criteria**	**12**	The following Performance Criteria will apply to this Additional Project Services specified in the Work Order: - Must be in accordance with the MER Contract. - Must be in accordance with the Work Order. - Must be completed to a professional standard. - Must address relevant feedback previously provided by the Department. - Must be undertaken in accordance with the dates and timeframes specified the Work Order - Summary report must be submitted in accordance with a standard format and template to be agreed by the Department
10.	**Project Officers**	**1.1**	**Department** Name: Anthony Moore Position: Southern Basin Section Commonwealth Environmental Water Office Physical address: 51 Allara Street, Canberra Postal Address: GPO Box 787, Canberra ACT 2601 Phone: 02 6275 9795 Email: anthony.moore@environment.gov.au **Provider** Name: A/Professor Qifeng Ye Position: Principal Scientist/Science Leader (Inland Waters & Catchment Ecology), SARDI Aquatic Sciences Ph: (08) 8429 0774 Email: qifeng.ye@sa.gov.au
11.	**Specified Personnel**	**1.1 and 13**	Qifeng Ye – Principal Scientist, SARDI Chris Bice – Research Scientist, SARDI George Giatas – Research Officer, SARDI Sarah Catalano – Senior Research Officer, SARDI Arron Strawbridge – Senior Research Services Officer, SARDI Ian Magraith – Senior Research Services Officer, SARDI David Fleer – Senior Research Services Officer, SARDI Mark Gluis – Senior Research Services Officer, SARDI

			Rod Oliver – Principal Research Scientist, UoA Zygmund Lorenz – Senior Research Services Officer, UoA Deborah Furst – Research Scientist, UoA Andy Revill – Research Scientist, CSIRO Brenton Zampatti – Principal Research Scientist, CSIRO
12.	**Department Material**	**1.1**	Not applicable
13.	**Pre-existing Material of the Provider**	**1.1**	Not applicable
14.	**Payment Schedule**	**7 and 16**	All costings have been removed from this version
15.	**Expenses**	**16**	No change
16.	**Other**	**1.1**	

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SERVICE SCHEDULE

SCHEDULE 1 - RESEARCH PROJECT SCOPE

1. PROJECT DETAIL

1.1 Title

From productivity to Murray cod recruitment

1.2 Client Contact Details

Department:	Commonwealth Environmental Water Office
Branch:	Southern Basin Section
Attention:	Anthony Moore
Position:	CEWO Southern Delivery Section
Address:	GPO Box 787, Canberra ACT 2601
Email:	anthony.moore@environment.gov.au
Telephone:	(02) 6275 9795
Facsimile:	(08) 8463 7688

1.3 Principal Investigator

Name:	Qifeng Ye
Position:	Principal Scientist/Science Leader (Inland Waters & Catchment Ecology), SARDI Aquatic Sciences
Address:	SARDI Aquatic Sciences PO Box 120 HENLEY BEACH SA 5022
Email:	Qifeng.Ye@sa.gov.au
Telephone:	(08) 8429 0774
Facsimile:	(08) 8207 5415

1.4 Subcontractor/Collaborator

University of Adelaide

- Rod Oliver
- Zygmunt Lorenz
- Deborah Furst

CSIRO

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- Andy Revill
- Brenton Zampatti

1.5 Timeframe

Commencement Date:	On signing of agreement
Completion Date:	December 2022

1.6 Summary

This project brief defines the scope of work for investigating the influence of variability in the source, pathways and quality of energy transfer through the lower River Murray food web on the recruitment of Murray cod (*Maccullochella peeli*), and ultimately, how this process is mediated by flow (hydrology and hydraulics). This project represents the *research* component of the Commonwealth Environmental Water Office (CEWO) Monitoring, Evaluation and Research (MER) project for the Lower Murray Selected Area. The project will integrate monitoring from several pre-existing indicators in a cost-effective manner and provide a holistic view of ecosystem response to flow (including Commonwealth environmental water) and a mechanistic understanding of ecological processes that lead to improved recruitment of a key fish species (Murray cod). This brief provides a description of the project background, objectives, milestones, deliverables, and budget and resource requirements.

2. PROJECT DESCRIPTION

2.1 BACKGROUND

The early life stages of fishes (eggs, larvae and juveniles) often suffer high levels of mortality, and subsequently, survival through this vulnerable period can influence recruitment, abundance and population resilience (Houde 1997). Survival through early life stages is influenced by food density and type, predation and competition, and water physico-chemistry (e.g. temperature). The Fundamental Triad fish recruitment hypothesis (Bakun 1996), and its recent extension to riverine environments, The Riverscape Recruitment Synthesis Model (Humphries et al. 2019), propose that processes critical to fish recruitment are the sources and amount of energy available (productivity), nutrient and prey enrichment and concentration, as well as dispersal to, and retention of, fish in favourable nursery habitats.

Assuming these functions are enhanced (e.g. by discharge), individuals will exhibit improved growth rates and condition, that will mediate greater survival and thus abundance (see

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Category 3 *Murray Cod Recruitment* section of Lower Murray Monitoring, Evaluation and Research Plan). In the context of river flow regimes and environmental water delivery, monitoring ecological patterns associated with fish recruitment (e.g. growth rates, abundance) is needed to evaluate outcomes and inform future delivery via adaptive management. In the Lower Murray Selected Area, a range of indicators are monitored, including the hydraulic regime, stream metabolism, microinvertebrates and fish. Nonetheless, holistic understanding of the relationship between flow-induced environmental changes and fish response can only be gained by understanding how these key ecosystem processes connect, to influence observed patterns.

The amount and sources of energy available in riverine ecosystems, and how energy propagates through food webs, vary as a function of discharge and hydraulics. During low flow, autochthonous local sources are dominant, but as discharge and inundation increases, so too do allochthonous carbon loads, and longitudinal and lateral transport of material, to a point when broad-scale floodplain inundation occurs and these habitats may contribute energy inputs (Vannote *et al.* 1980; Junk *et al.* 1989). In the Lower Murray, flow variation that remains within the river channel may also be associated with changed energy sources and pathways, and low trophic level communities (e.g. zooplankton). For instance, changes in discharge that alter water velocity and turbulence, result in shifts in phytoplankton communities between cyanobacteria and diatom dominance (Aldridge *et al.* 2012). For higher trophic levels, diatoms present better quality food than cyanobacteria (Guo *et al.* 2017), and thus, a switch in in-channel basal food resources may influence the abundance and nutrition of microinvertebrate communities and trophic upsurge, including supporting fishes like Murray cod. Understanding the mechanisms that drive improved growth rates, condition, survival and ultimately recruitment, is key knowledge required to support Commonwealth environmental water delivery and flow management in the Lower Murray.

2.2 NEED

This project will generate data and improve understanding regarding the trophic dynamics in the Lower River Murray that ultimately lead to the recruitment of Murray cod, and how this process is influenced by flow, including Commonwealth Environmental Water. The project will be supported by various data collected under the core monitoring of Category 1 and 3 indicators of the broader MER project. This data and knowledge is fundamental to underpin future management, in particular the delivery of Commonwealth environmental water.

2.3 OBJECTIVES

The objective of the current project is to investigate the influence of variability in the source, pathways and quality of energy transfer through the lower River Murray food web on the recruitment of Murray cod, and ultimately, how this process is mediated by flow (hydrology and hydraulics). Specific questions related to this objective include:

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- What is the composition of ambient prey communities (e.g. zooplankton), and how does this vary with flow?
- What is the diet of larval and juvenile Murray cod in the Lower Murray in relation to ambient prey communities, and how does this vary with flow?
- What is the nutritional quality of key prey items of larvae/juvenile Murray cod, is this reflected in the condition of Murray cod, and how does this vary with flow?
- What basal components of the food web (e.g. autochthonous v allochthonous, pelagic v benthic) support the growth of early life stage Murray cod, and how does this vary with flow?
- How do these flow-related trophic processes relate to Murray cod growth, condition and recruitment?

2.4 METHODS

This research project will integrate and be supported by data collected through several other core monitoring indicators of MER, including *Hydraulic Regime*, *Stream Metabolism and Water Quality*, *Microinvertebrate Assemblage* and *Fish* indicators (Category 1 and 3). In particular, this research project is directly linked to the Category 3 *Murray Cod Recruitment* evaluation component, which will determine relative abundance and collect samples of early life stage Murray cod on four occasions during early ontogeny (larvae–YOY, >120 days old) annually from 2019–2022.

Larval sampling will occur during the peak period of larval presence (November, SARDI unpublished data), whilst early stage juvenile sampling will occur in January and February–March. The focal site will be located in the tailwater (<15 km downstream) of Lock 4 (Floodplain zone) and Lock 3 (Gorge zone). Population and YOY sampling will also occur annually at a number of sites in the Gorge and Floodplain zones during autumn (March/April). Larvae/juvenile Murray cod collected will be assessed for condition based on morphometrics and otolith based growth parameters as part of the Category 3 *Murray cod recruitment* component. The same individuals will be used for investigations of diet, nutrition and basal food sources under this research component, and ultimately, inform on links between trophic and recruitment dynamics.

The research project will occur over two field sampling seasons from 2019–2021, and have a particular spatial focus on the Lock 4 tailwater, due to the greatest likelihood of sampling adequate numbers of Murray cod from this region. Whilst existing fieldwork and sampling for the core monitoring of MER supports the current project, in some instances additional sampling will occur using specific methods for this targeted research to investigate diet, nutrition and basal food resources. Details are described below.

Stream metabolism

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The Category 1 *Stream Metabolism and Water Quality* indicator is focused on the reaches downstream of Lock 1 and 6. Given the focus of the current research project on the reach downstream of Lock 4, an additional *Stream Metabolism and Water Quality* site has been added to investigate ecosystem production and respiration in this reach (see Lower Murray Monitoring, Evaluation and Research Plan 2019–2022 for methods), and aid interpretation of trophic dynamics influencing Murray cod growth and recruitment. In addition to standard stream metabolism methods, DNA metabarcoding will be used to further investigate temporal variability in microbial communities that drive stream metabolism. The DNA metabarcoding approach involves the collection and filtering of water samples before amplification (polymerase chain reaction, PCR) and sequencing of diagnostic DNA sequences obtained from specimens held within. The DNA barcode genes CO1 (mitochondrial cytochrome oxidase subunit 1), 16S (mitochondrial) and 18S (nuclear) are commonly used to cover DNA of both eukaryotes and prokaryotes, and provide appropriate taxonomic resolution, and will be applied in the current study. Ultimately, amplified DNA sequences are compared with reference collections to determine taxonomy, and a semi-quantitative measure of abundance is determined. This understanding will support interpretation of trophic pathways through to Murray cod.

Murray cod prey and diet

The ambient prey assemblages available to larval and early juvenile Murray cod in the littoral zone will be assessed using traditional (i.e. zooplankton sampling) and DNA metabarcoding techniques. Characterisation of ambient prey assemblages will enable assessment of the frequency of occurrence of given taxa in Murray cod guts, and in the ambient environment, and provide a measurement of selectivity for or against given taxa. DNA metabarcoding will follow the methods described above, but will be limited to the CO1 gene, as this gives greatest taxonomic resolution for metazoans, and has most commonly been used for assessments of zooplankton community structure and fish gut content. With regard to later stage juvenile (February–March sampling) and YOY Murray cod (March-April sampling), preliminary evidence suggests that shrimp (e.g. *Macrobrachium australiense*) form a dominant prey item (SARDI unpublished). As such, the abundance of shrimp will be quantified during February–March and March–April sampling events using baited box traps and subsamples collected to assess food quality (see below).

The diet of early life stage Murray cod (i.e. species identity, frequency, abundance) will be investigated for individuals sampled across all four sampling occasions, using a combination of traditional gut content analyses (i.e. dissection, microscopy and identification) and DNA metabarcoding. DNA metabarcoding will follow the methods described above using the CO1 gene.

Nutrition

The nutritional quality and energy content of key prey items of Murray cod will be assessed by analyses of fatty acid and calorific content. Polyunsaturated fatty acids (PUFA) are primarily produced by certain taxa of algae, including diatoms, and many PUFA are essential for physiological functions that support consumer growth and reproduction (Guo et al. 2017). Specifically, the PUFA and calorific content of shrimp will be analysed from samples collected during February–March and March–April sampling events, and potentially from zooplankton samples collected during November and January events. The same parameters will also be measured in samples of Murray cod as an additional measure of condition and to assess the reflection of prey PUFA in consumers.

Basal carbon sources supporting Murray cod

Sources of basal carbon supporting juvenile Murray cod will be investigated using compound-specific stable isotope analyses (CSIA). This approach uses specific compounds, particularly amino acids (AA), to trace carbon flow in food webs. Most primary producers and algae can synthesise essential AA's, but animals cannot, and therefore must incorporate essential AA's from the diet. Importantly, due to differences in the metabolic pathways of synthesis for these AA's, unique isotopic signatures or 'fingerprints' are generated for different source end-members (e.g. terrestrial plants verse algae; Larsen et al. 2009). These signatures propagate through food webs unmodified allowing determination of contribution of different sources to supporting higher level biota.

The current project will apply CSIA to firstly determine the $\delta^{13}C$ signatures for several amino acids of distinct sources in the lower River Murray (preliminarily riparian trees, macrophytes, periphyton and seston (including isolated diatoms and cyanobacteria)) before investigating which of these sources of carbon support early life stages of Murray cod, and how this varies as a function of flow.

This approach involves the collection and preservation of samples in the field, before multiple laboratory processes are undertaken (for specific detail see McMahon et al. 2016). These analyses will not be performed on larval Murray cod, as nutrition that has driven growth to this point in the life cycle is likely dominated by yolk supply, but will be performed on juvenile and YOY life stages, as well as samples of shrimp collected in February–March and March–April sampling events. The contribution of different basal carbon sources to Murray cod growth will then be analysed using a Bayesian stable isotope mixing-model approach (McMahon et al. 2016).

Integrating condition, growth and trophic dynamics with hydrology and hydraulics

Mixed effects modelling will be used to explore the relationship between diet, nutrition and basal food sources, as well as the hydraulic regime, and the condition and growth of individuals. Ultimately, data concerning these parameters will be integrated with data from several Category 3 indicators including *Murray Cod Recruitment, Hydraulic Regime, Stream Metabolism and Water Quality and Microinvertebrate Assemblage* to investigate flow-related causal mechanisms that promote Murray cod recruitment.

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3. DELIVERABLES

3.1 Service Provided:

As above.

SARDI Staff

- Chris Bice: Research Scientist, Inland Waters and Catchment Ecology Program
  - Project management, data analysis and interpretation (all), report writing
- George Giatas: Research Officer, Fish Ecology Sub-program
  - Sample processing (gut content, CSIA), data analysis and interpretation (all), and report writing
- Qifeng Ye: Principal Scientist, Inland Waters and Catchment Ecology Program, SARDI Aquatic Sciences
  - Project management and report writing
- Sarah Catalano: Senior Research Officer, Aquaculture Sub-program
  - Molecular analysis, data analysis and interpretation (molecular analyses), and report writing
- David Fleer: Senior Research Services Officer, Inland Waters and Catchment Ecology Program
  - Fieldwork and sample processing (gut content, CSIA)
- Arron Strawbridge: Senior Research Services Officer, Inland Waters and Catchment Ecology Program
  - Sample processing (otolith, gut content, CSIA)
- Mark Gluis: Senior Research Services Officer, Aquaculture Sub-program
  - sample preparation (CSIA)

Contractors

- Rod Oliver: Principal Scientist, University of Adelaide
  - Project management, data analysis and interpretation (stream metabolism, molecular analyses), report writing.
- Zygmunt Lorenz: Senior Research Services Officer, University of Adelaide
  - Fieldwork and sample processing (stream metabolism)

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- Deborah Furst: Research Scientist, University of Adelaide
  - Sample processing (microinvertebrates, gut content), data analysis and interpretation (microinvertebrates, gut content, molecular analyses), and report writing

- Andy Revill: Research Scientist, CSIRO
  - CSIA, data analysis (CSIA) and report writing.

- Brenton Zampatti: Research Scientist, CSIRO
  - Data interpretation (all) and report writing

3.2 Outcomes:

This component will integrate monitoring outcomes from several indicators in the Lower Murray Selected Area to present a holistic view on ecosystem response. This integrated research will improve evaluation by enhancing understanding of mechanisms that promote ecological patterns (e.g. Murray cod juvenile growth rates and recruitment). Consequently, the project will provide a mechanistic understanding of system function to support Commonwealth environmental water delivery and flow management.

3.3 Outputs and Extension:

During this project, all tasks will include regular liaison with the project manager, including in the quarterly report for the MER project. Sample collection will be supported by monitoring already scheduled to occur in spring–summer 2019/20 and 2020/21 (or 2021/22 aiming for two contrasting flow scenarios) for multiple indicators, as outlined in the Lower Murray Monitoring, Evaluation and Research Plan 2019–2022. Laboratory analyses (i.e. DNA metabarcoding, nutrition, and CC-SIA) will be conducted in two batches and occur in May–November of both 2020 and 2021 (or 2022). An interim report will be delivered as a section of the annual CEWO MER report in December 2020. A final report, detailing two years of sampling and analyses will be delivered by December 2021 if the second field season occurs in 2020/21 or by December 2022 if the second field season occurs in 2021/22.

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Larsen, T., D. L. Taylor, M. B. Leigh and D. M. O'Brien (2009). Stable isotope fingerprinting: a novel method for identifying plant, fungal, or bacterial origins of amino acids. *Ecology* **90**: 3526-3535.

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