Australian Government
Commonwealth Environmental Water Office

UNIVERSITY OF CANBERRA

INSTITUTE FOR APPLIED ECOLOGY

COMMONWEALTH ENVIRONMENTAL WATER OFFICE LACHLAN SELECTED AREA MONITORING, EVALUATION AND RESEARCH PLAN (2019-2022)

APPENDIX A: STANDARD OPERATING PROCEDURES

FINAL: JUNE 2019

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ACRONYMS AND ABBREVIATIONS

Accepted Acronym	Standard Term (capitalisation as specified)
ANAE	Australian National Aquatic Ecosystem
CC	Crown cover
CED	Cause and Effect Diagrams
CEWO	Commonwealth Environmental Water Office
CO	Canopy openness
CPUE	Catch per unit effort
DEM	Digital elevation model
ER	Ecosystem respiration
FC	Foliage cover
GPP	Gross Primary Production
IMEF	Integrated Monitoring of Environmental Flows
LTIM Project	Long Term Intervention Monitoring Project
LTIM Project	Long Term Intervention Monitoring Project
M&E	Monitoring and Evaluation
MDB	Murray-Darling Basin
MDMS	Monitoring Data Management System
MER Proram	Monitoring, Evaluation and Research Program
NSW DPI	New South Wales Department of Primary Industry
QA/QC	quality assurance / quality control
SARDI	South Australian Research and Development Institute
SRA	Sustainable Rivers Audit
SYSID	A unique number for each polygon (wetland, lake, floodplain) or line (river, creek, stream) used in the ANAE classification
WHS	Workplace Health and Safety

A1. STANDARD OPERATING PROCEDURES FOR INDICATORS MONITORED

This appendix contains the standard operating procedure for the indicators monitored as part of the Lachlan Monitoring, Evaluation and Research Program (MER Program). The standard operating procedures are based on those developed within the LTIM project (Dyer et al. 2014) and have been updated to reflect the current needs of the MER Program.

A1.1 ZONES AND REACHES

Under the MER Program, monitoring may be conducted within Zones that occur across the Selected Area. These Zones are described in Table 1 and Figure 1. Monitoring sites for Core monitoring and evaluation activities are shown in Figure 2.

Table 1. Zones for the Lachlan Selected Area.
To maintain continuity of the data set and approach, the original number of zones for the LTIM program are retained, but appended with an L to denotes zones within the lower Lachlan river system. Zones appended with an M are new zones within the mid Lachlan river system.

ZONE	LOCATION	CHARACTER
Zone M1	Lachlan River channel between Forbes and Brewster Weir	This zone contains populations of target species of fish, including freshwater catfish and is likely to regularly receive Commonwealth environmental water.
Zone L1	Lachlan River channel between Brewster Weir and Booligal	This zone contains relatively high abundances of the required target species of fish (with potentially limited numbers of freshwater catfish). Situated in the upper reaches of the selected area, this zone also is likely to regularly receive Commonwealth environmental water.
Zone L2	Lachlan River channel between Booligal and Corrong	Located downstream of Booligal Weir and similar to Zone 1 in geomorphology. This zone differs hydrologically because of water diversion and extraction above Booligal Weir.
Zone L3	Lachlan River channel between Corrong and its terminus in the Great Cumbung Swamp	This zone starts at the point at which the mid-Lachlan wetland system re-enters (drains into) the main Lachlan channel, providing an increase in riverine productivity, stimulating food webs. The fish assemblages are currently dominated by alien species.
Zone L4	Merrowie Creek	A distributary creek that receives intermittent regulated stock and domestic flows as well as targeted environmental flows at Tarwong Lake and Cuba Dam. No data exist on the fish assemblage present within Merrowie Creek.
Zone L5	Torringanny, Box, Merrimajeel and Muggabah Creek system	The largely ephemeral, effluent streams of the Merrimajeel and Muggabah system north of the Lachlan main channel and Merrowie creek. This complex system is fundamentally different to main channel zones acting more like linear wetlands that are likely to only retain water for limited periods during and following environmental flow deliveries.

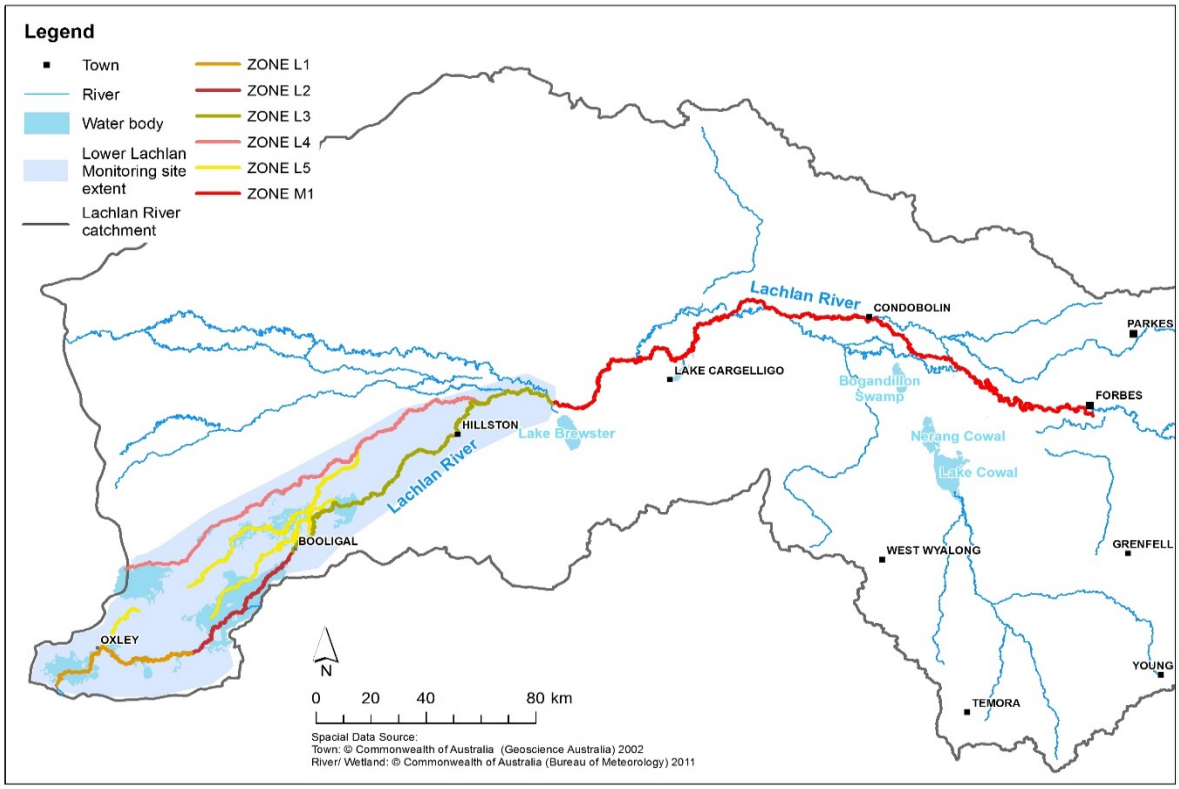

Figure 1. The Lachlan Selected Area showing the monitoring zones of the MER Program. The grey shaded area shows the core monitoring zones.

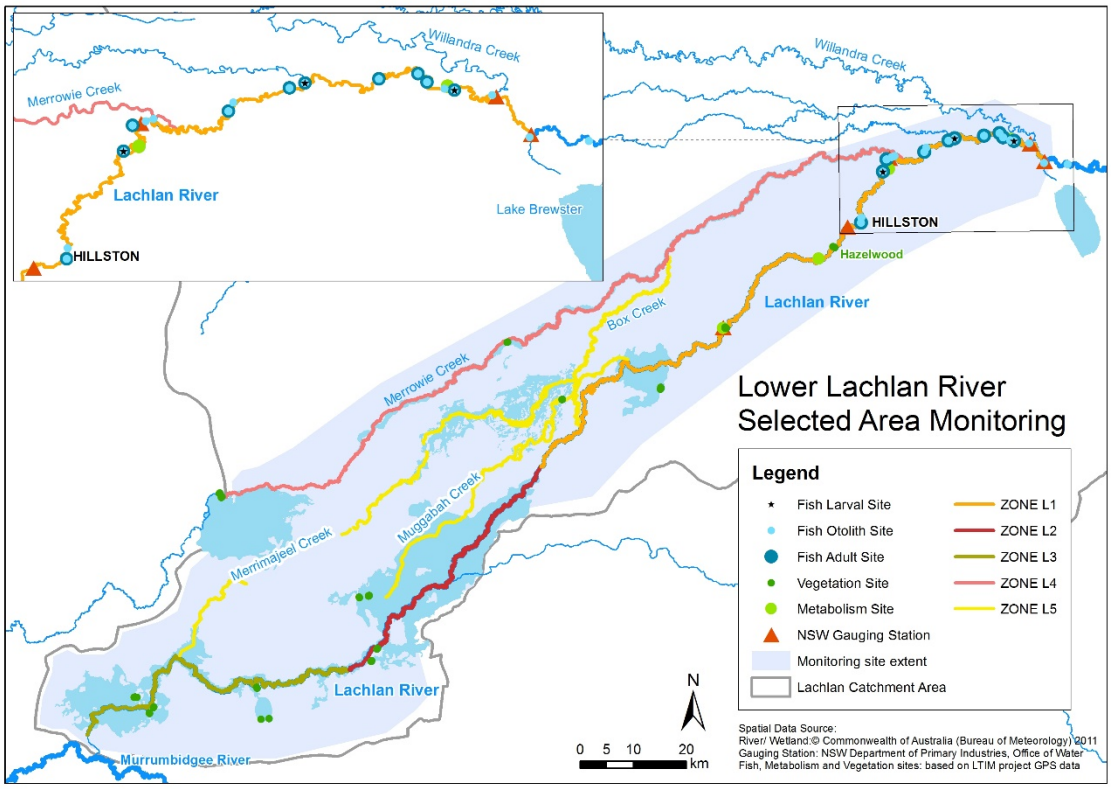

Figure 2. The lower Lachlan Selected Area showing the monitoring zones and core monitoring sites of the MER Program.

A1.2 ECOSYSTEM TYPE

A1.2.1 EVALUATION QUESTIONS

This is a protocol to validate the interim Australian National Aquatic Ecosystems (ANAE) classification at monitoring sites. The interim ANAE ecosystem typology and classification are relevant to the following Basin evaluation questions:

- **Short-term (one-year) and long-term (five year) questions:**
  - What did Commonwealth environmental water contribute to sustainable ecosystem diversity?
  - Were ecosystems to which Commonwealth environmental water was allocated sustained?
  - Was Commonwealth environmental water delivered to a representative suite of ecosystem types?

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

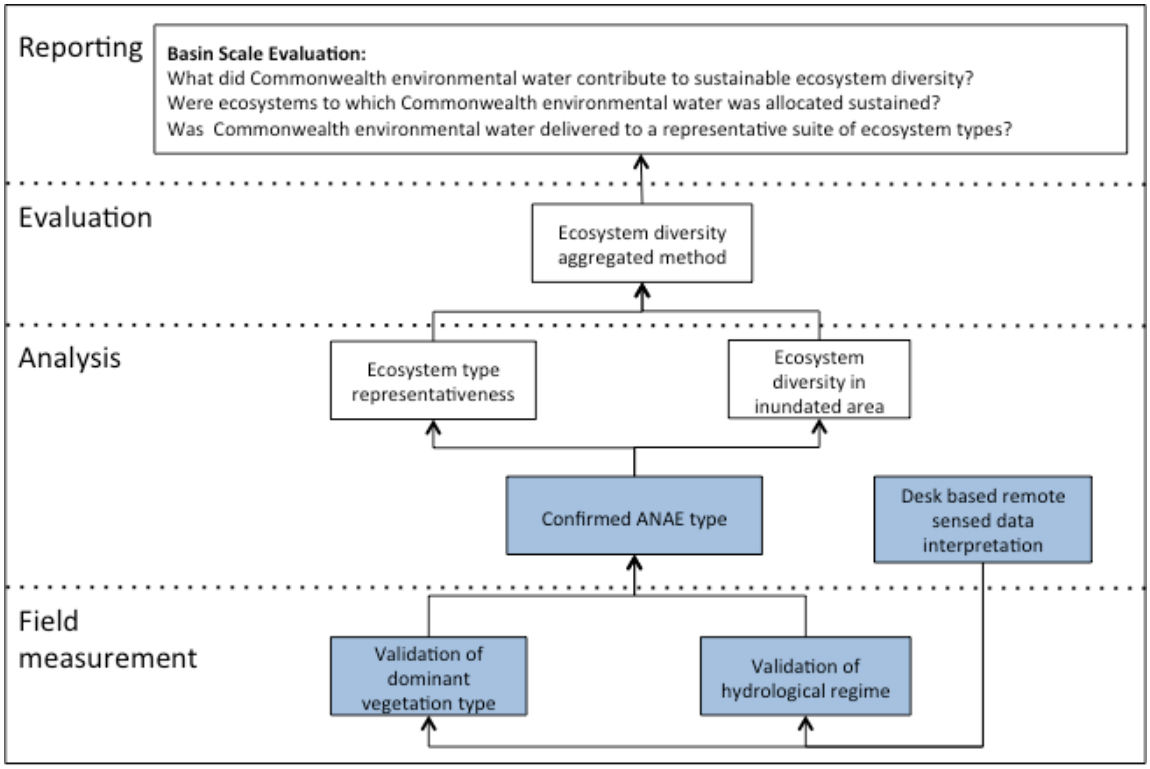

Figure 3. Schematic of key elements of the Standard Protocol: Ecosystem type.

A1.2.2 RELEVANT ECOSYSTEM TYPES

Rivers and wetlands. Note that the definition of wetland used in the Logic and Rationale for the LTIM project incorporates palustrine and lacustrine systems as defined in the interim Australian National Aquatic Ecosystem (ANAE) classification. Also note, that while the protocol is to be applied to wetlands on floodplains, it is not currently recommended for broader areas of the floodplain surface.

A1.2.3 RELEVANT FLOW TYPES

All flow types are relevant to ecosystems.

A1.2.4 OVERVIEW AND CONTEXT

This method is the field validation if the ANAE classification that is required for the Basin Scale evaluation of ecosystem diversity for the LTIM project. Brooks et al. (2013) applied the interim ANAE framework to aquatic ecosystems across the Murray Darling Basin using the best available mapping and attribute data. Wetland polygons, riverine polygons, and river centre lines were attributed with the majority coverage of each attribute without dividing them further. The scale and coverage of available mapping and attribute data varied considerably across the MDB has not yet been validated by the contributing jurisdictions. There is a need to validate the mapping outputs from Brooks et al. (2013) as they relate to specific sampling sites, and the Selected Areas. The current mapping may be useful within the LTIM project but should not be relied upon until validated. This validation must be carried out at all Selected Areas for each ecosystem type that falls within an assessment unit for all other on-ground monitoring programs:

- LTIM Standard Protocol: Fish (River)
- LTIM Standard Protocol: Fish (Wetland)
- LTIM Standard Protocol: Fish (Larvae)
- LTIM Standard Protocol: Hydrology (River)
- LTIM Standard Protocol: Hydrology (Wetland)
- LTIM Standard Protocol: Macroinvertebrates
- LTIM Standard Protocol: Stream metabolism
- LTIM Standard Protocol: Tree stand condition
- LTIM Standard Protocol: Vegetation diversity
- LTIM Standard Protocol: Waterbirds breeding
- LTIM Standard Protocol: Waterbirds diversity
- LTIM Standard Protocol: Water quality

A1.2.5 COMPLEMENTARY MONITORING AND DATA

- **Floodplain systems** are those aquatic systems that are either seasonally or intermittently flooded flat areas that are outside the riverine channels or palustrine/lacustrine systems but that display characteristics of hydric soils or vegetation that are characteristically adapted to the seasonal or intermittent presence of water. ***Excluded from this protocol.***
- **Lacustrine systems** (lakes) are open-water dominated systems, characterised by deep, standing or slow-moving water with little or no emergent vegetation (<30% cover). (Included as wetlands in Logic and Rational document).
- **Palustrine systems** are primarily shallow, vegetated, non-channel environments, including billabongs, bogs, swamps, springs, soaks etc. (Included as wetlands in Logic and Rational document).
- **Riverine systems** are those that are contained within a channel and its associated streamside vegetation. This definition refers to both single channel and multi-

channel systems e.g. braided channel networks. The beds of channels are not typically dominated by emergent vegetation, may be naturally or artificially created, periodically or continuously contain moving water, and may form a connecting link between two bodies of standing water (Aquatic Ecosystem Task Group 2012). (Includes riparian systems).

The typology used to assign ecosystem types is presented as a dichotomous key and as an extract from Brooks et al. (2013) in Supplement B: Key to MDB interim ANAE Typology (Page 10).

An example of the mapping output from Brooks et al (2013) for some saline Victorian systems is shown in Figure 4. This highlights some of the potential validation issues that may be encountered. In some cases the data provided for the MDB mapping project included situations were multiple polygons were sub-units of larger polygons. In most cases this is likely to represent a different habitat/vegetation type within a single wetland. In this case, as illustrated below, it is advised to use the larger ecosystem and unique identifier as the assessment ecosystem. Attribute mapping that overlays these polygons (e.g. vegetation, hydrological regime, salinity) may also contain inaccuracies. Confidence measures included in the Brooks et al (2013) mapping product should be used to guide interpretation. Note that it is expected that updated mapping will be made available in coming years as attribute data improves, however the ecosystem typology is considered robust and is less likely to change significantly.

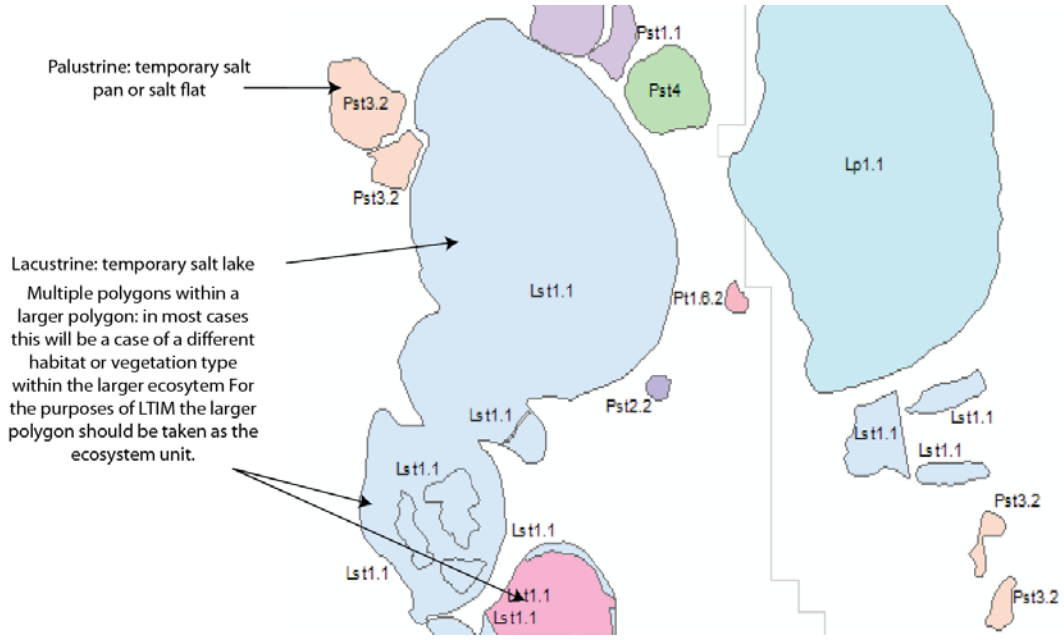

Figure 4. Example of mapping output from Brooks et al. (2013) with areas requiring validation.

A unique number (SYSID) for each polygon (wetland, lake, floodplain) or line (river, creek, stream) identifies each mapped unit (Brooks et al. 2013). On ground validation of the interim ANAE classification is required to confirm the aquatic ecosystem types for use in the MER program.

A1.2.5.1 Validation Sites

Validation sites include all sites for other monitoring protocols (i.e. waterbird breeding sites, tree stand condition sites, fish sites, etc.). Where a site has not been mapped the typology developed by Brooks et al. (2013) should be used to assign an ecosystem type *de novo* (Protocol step 3 below).

A1.2.5.2 Equipment

- Maps of Selected Area including assessment site information.
- Aerial imagery should be as current as possible and of sufficient resolution to identify vegetation.
- Satellite imagery – e.g. SPOT6.
- GPS.
- Datasheets and/or field computer.
- Appropriate safety gear.
- Copy of this protocol.
- Appropriate plant identification field guides.

A1.2.5.3 Protocol

1. Prior to field visit, source and review all relevant information relevant to the potential area of influence of Commonwealth environmental water.
    - This will include, but not necessarily be limited to, mapping output from Brooks et al. (2013) for the selected area, current aerial imagery (e.g. Google Earth), satellite imagery and fine scale mapping (aquatic ecosystem type and or vegetation mapping) from state agency partners.
2. Identify the ecosystems to be assessed and record/locate their unique identifier code.
    - If mapped by Brooks et al. (2013) use the SYSID as the unique identifier for each mapped ecosystem.
    - If the ecosystem is not mapped then record coordinates (GDA94) of the centre of the ecosystem and either locate compatible GIS mapping or delineate the boundary of the ecosystem using remote sensed data. Contact your Selected Area M&E Advisor to obtain a unique identifier for the ecosystem.
3. Using the dichotomous key presented in Supplement B assign an ecosystem type and code to each assessment ecosystem, noting any knowledge gaps that relevant unambiguous classification
    - If the aquatic ecosystem is mapped then check if the interim ANAE type allocated to the polygon/line feature representing the ecosystem (see Supplement B) is correct. (Note that is it possible to have lacustrine and palustrine systems located on floodplains and some, or potentially many, of these may not have been captured in the interim ANAE mapping).
    - Record the correct interim ANAE type as per the typology in Supplement B.
4. Determine locations for ground-truthing, mark on map and note GPS co-ordinates. The ground truthing should be designed to:
    - Confirm / identify dominant vegetation type (note the typology is based on dominant vegetation type only, so not all habitat/ vegetation types require ground-truthing).
    - Fill any knowledge gaps identified in step 2.

- Be easily and safely accessible.

5. Use the information collected in the field to update (if necessary) the ecosystem type as identified in step 4.

A1.2.6 QUALITY ASSURANCE/QUALITY CONTROL

The dominant vegetation type at each site will be recorded during the initial field campaign. Prior to field assessments, staff will be trained in the methods and a field site used to verify the ability of staff to determine the dominant vegetation. All sites will be verified by a team of two staff and where the classification differs from that of Brooks et al., (2013) standardised photographs of the site will be provided as evidence of the classification.

A1.2.7 DATA DESCRIPTION

The spatial unit for which data is reported for this validation is an ANAE feature identified by the ANAE SYSID.

Each row of data provided for this validation will identify the ANAE SYSID, the original classification, and the revised classification. The exact data structure for this indicator is maintained and communicated in the LTIM Data Standard and will be enforced by the MDMS when data is submitted.

All data provided for this indicator will conform to the data structure defined in the MER Data Standard which is based on the LTIM Data Standard (Brooks and Wealands 2014). The data standard provides a means of collating consistent data that can be managed within the CEWO's Monitoring Data Management System (MDMS).

A1.2.8 HEALTH AND SAFETY

For details on health and safety please refer to the Workplace Health and Safety Plan for the Lachlan Selected Area (WHS 202.1) in Appendix C.

SUPPLEMENT A: EXAMPLE ECOSYSTEM TYPE VALIDATION FIELD SHEET

ECOSYSTEM TYPE VALIDATION FIELD SHEET: Page ---------- of ----------			Selected Area:	
Date:			Name of recorder:	
Mapped ecosystems				
SYSID	ANAE Type (code and name)	Valid Y/N	Correct ANAE type (code and name)	Relevant assessment protocol
e.g. 123456	Lst1.1: Temporary saline lakes	N	Lst1.2: Temporary saline lakes with aquatic beds	Waterbird breeding

ECOSYSTEM TYPE VALIDATION FIELD SHEET: Page ---------- of ----------			Selected Area:	
Date:			Name of recorder:	
New ecosystems (not mapped by Brooks et al. 2013)				
Unique identifier	Location GDA94	ANAE Type (code and name)	Relevant assessment protocol	

SUPPLEMENT B: KEY TO MDB INTERIM ANAE TYPOLOGY

The following terminology explains some of the descriptors used in the typology, and some of the assumptions made in order to simplify the naming convention (modified from Brooks et al. 2013):

Energy (high, low) – pertains to the relative energy of riverine flows resulting from the slope or steepness of the terrain.

Fen and bogs – peatlands (bogs and fen) are created under a range of hydrological and physical conditions. Fens are formed where mineral rich groundwater flows sustain vegetation such as grasses, sedges, reeds, shrubs and trees (Batzer and Sharitz 2006). The alkaline nature of fens and the fact that their primary water source is groundwater, with some surface and rainfall inputs, distinguishes them from bogs, which are dominated by surface water inputs. Bogs are further characterized as supporting Sphagnum moss.

Freshwater – unless specified, aquatic ecosystems are assumed to be freshwater (salinity <3000 mg/L).

Intermittent – used to describe the water regime of periodically inundated types in which inundation is known to be less frequent than annual or seasonal inundation, but more frequent than episodic and ephemeral inundation. Flooding may persist from months to years (Boulton and Brock 1999). Only used in the type name when the inundation requirements of the dominant vegetation associated with the system are able to inform the frequency of inundation, or when waterholes have been identified as being present in a stream.

Lake – an inland body of water, predominantly still or lentic in nature. Cowardin et al. (1979) defines them as being situated in a topographic depression or a dammed river channel, and having less than 30 per cent emergent vegetation. Size may vary but most will exceed eight hectares; those with similar habitats but less than eight hectares can also be included, however, if active wave-formed or bedrock shoreline features makes up all or part of the boundary, or their depth is greater than 2 meters. Ocean-derived salinity is always less than 0.5 parts per thousand, thus separating them from lagoons.

Marsh – a wetland dominated by non-woody emergent vegetation such as sedges, reeds and rushes. Marshes can be shallow or deep with a combination of emergent and submergent vegetation types. They may also have areas of open water in deeper systems, up to 70 per cent of wetland area. Marshes are typically between 0.5 to 2 meters depth, but depth can be highly variable.

Meadow – a wetland dominated by grasses (excluding Phragmites which is typically found in deeper marsh environments) and forbs. Meadows typically have shallow depths in the order of 10 to 50 centimeters. They are rarely permanent, often being filled on a seasonal basis.

Permanent – used to describe the water regime of commonly wet systems (wet >70 per cent of the time). This assumes that for commonly wet lakes, for example, that they have water all year round except during extreme droughts, when they can dry out. Permanent is used as a commonly accepted term (e.g. Ramsar and Queensland typologies).

Saline – ecosystems with a salinity >3000 mg/L.

Streams – 'streams' is taken to include rivers, streams and creeks for the purposes of simplifying the naming convention. Rivers are large natural in-channel bodies of moving water (lotic) which have the capacity to structure the surrounding landscape (i.e. alluvial processes). This includes large anabranching systems (e.g. Edward-Wakool Rivers are major anabranches of the River Murray). Streams and creeks, both of which are typically smaller in-channel bodies of moving water, can be either a tributary or distributary of a river.

Swamp – a wetland dominated by woody vegetation, either shrubs and or trees.

Temporary – used to describe the water regime of periodically inundated types when the frequency of inundation is not known, but is less than commonly wet (wet <70% of the time).

Key to MDB interim ANAE types

This typology can be used to validate ecosystem types at which assessments are made for both mapped and unmapped features. It can also be used to identify ecosystems that have not been mapped. For greater detail see section A1.2.

1a	Ecosystem being validated/classified is a line feature, has flowing water and a defined channel	***Riverine systems*** got to 2
1b	Ecosystem being validated/classified is a polygon feature, typically lacks flowing water and a defined channel	go to 5
2a	Water regime permanent (surface water >70% of time) .	go to 3

2b	Water regime temporary (surface water present <70% of time)	go to 4
3	Landform for ANAE was derived in GIS by intersecting features with the 3sec CSIRO Valley Bottom Flatness and does not require field validation	
		Rp1.1: Permanent high energy upland streams
		Rp1.2: Permanent transitional zone streams
		Rp1.3: Permanent low energy upland streams
		Rp1.4: Permanent lowland streams
4	Landform for ANAE was derived in GIS by intersecting features with the 3sec CSIRO Valley Bottom Flatness and does not require field validation	
		Rt1.1: Temporary high energy upland streams
		Rt1.2: Temporary transitional zone streams
		Rt1.3: Temporary low energy upland streams
		Rt1.4: Temporary lowland streams
5a.	Ecosystem with less than 30% emergent vegetation, large enough to support wave action	***Lacustrine systems*** go to 6
5b.	Ecosystem with more than 30% emergent vegetation, or no vegetation. If no vegetation typically shallow and doesn't develop wave action (i.e. deflation basins, salt flats, clay pans etc.).	go to 17
6a	Water type: fresh	go to 7
6b	Water type: saline	go to 10
7a	Permanent (surface water >70% of time)	go to 8
7b	Temporary (surface water <70% of time)	go to 9
8a	Permanent floodplain lakes, with or without submergent aquatic macrophyte	
		Lp2.1: Permanent floodplain lakes

	Lp2.2: Permanent floodplain lakes with aquatic beds	
8b	Permanent non-floodplain lakes, with or without submergent aquatic macrophytes	
	Lp1.1: Permanent lakes	
	Lp1.2: Permanent lakes with aquatic beds	
9a	Floodplain lakes, with or without submergent aquatic macrophytes	
	Lt2.1: Temporary floodplain lakes	
	Lt2.2: Temporary floodplain lakes with aquatic beds	
9b	Non- floodplain lakes, with or without submergent aquatic macrophytes	
	Lt1.1: Temporary lakes	
	Lt1.2: Temporary lakes with aquatic beds	
10a	Permanent saline lakes (surface water >70% of time)	go to 11
10b	Temporary saline lakes (surface water <70% of time)	go to 12
11a	Floodplain saline lakes, with or without submergent aquatic macrophytes	
	Lsp2.1: Permanent saline floodplain lakes	
	Lsp2.2: Permanent saline floodplain lakes with aquatic beds	
11b	Non-floodplain saline lakes, with or without submergent aquatic macrophytes	
	Lsp1.1: Permanent saline lakes	
	Lsp1.2: Permanent saline lakes with aquatic beds	
12a	Temporary saline floodplain lakes, with or without submergent aquatic macrophytes	
	Lst2.1: Temporary saline floodplain lakes	
	Lst2.2: Temporary saline floodplain lakes with aquatic beds	

12b	Temporary saline non-floodplain lakes, with or without submergent aquatic macrophytes	**Lst1.1: Temporary saline lakes** **Lst1.2: Temporary saline lakes with aquatic beds**
13a	The ecosystem is a wetland depression	***Palustrine systems*** go to 14
14a	Water type: fresh	go to 15
14b	Water type: saline	go to 20
14c	Unspecified, no data	**Pu1: Unspecified wetland**
15a	Permanent springs	**Pp5: Permanent springs**
15b	Permanent (surface water >70% of time), non-springs.	go to 16
15c	Temporary (surface water <70% of time)	go to 23
16a	Permanent floodplain wetlands	go to 19
16b	Permanent non-floodplain wetlands	go to 18
17a	Floodplain swamps - dominated by woody vegetation	**Pp1.1.1: Permanent floodplain paperbark swamps**
17b	Floodplain marshes – dominated by non-woody vegetation	
(e.g. Typha, Phragmites, Baumea, Juncus: tall spp typically>1m)		**Pp2.1.1: Permanent floodplain tall emergent marshes**
(species typically <1m)		**Pp2.2.1: Permanent floodplain sedge/grass/forb marshes**
		Pp2.3.1: Permanent floodplain grass marshes
		Pp2.4.1: Permanent floodplain forb marshes
17c	Floodplain wetland, unspecified vegetation	**Pp4.1: Permanent floodplain wetland**
18a	Non-floodplain swamps- dominated by woody vegetation	**Pp1.1.2: Permanent paperbark swamps**
18b	Non-floodplain marshes, bogs and fens – dominated by non-woody vegetation	

(e.g. Typha, Phragmites, Baumea, Juncus: tall spp typically>1m)	**Pp2.1.2: Permanent tall emergent marshes**
(species typically <1m)	**Pp2.2.2: Permanent sedge/grass/forb marshes**
	Pp2.3.2: Permanent grass marshes
	Pp2.4.2: Permanent forb marshes
(fen marshes dominant water source is groundwater)	**Pp3: Peat bogs and fen marshes**
18c Non-floodplain wetland, unspecified vegetation	**Pp4.2: Permanent wetland**
19a Temporary floodplain swamps and marshes, identified by dominant vegetation type	
	Pt1.1.1: Intermittent River red gum floodplain swamp
	Pt1.2.1: Intermittent Black box floodplain swamp
	Pt1.3.1: Intermittent Coolibah floodplain swamp
	Pt1.4.1: Intermittent River Cooba floodplain swamp
	Pt1.5.1: Temporary paperbark floodplain swamp
(tree species unidentified)	**Pt1.6.1: Temporary woodland floodplain swamp**
	Pt1.7.1: Intermittent Lignum floodplain swamps
(e.g. Typha, Phragmites, Baumea, Juncus: tall spp typically>1m)	**Pt2.1.1: Temporary tall emergent floodplain marsh**
(species typically <1m)	**Pt2.2.1: Temporary sedge/grass/forb floodplain marsh**
(water typically <50cm, often seasonally inundated)	**Pt2.3.1: Floodplain freshwater meadow**
	Pt3.1.1: Floodplain clay pan
(unspecified vegetation)	**Pt4.1: Temporary floodplain wetland**
19b Temporary non-floodplain swamps, marshes, identified by dominant vegetation type	
	Pt1.1.2: Intermittent River red gum swamp

	Pt1.2.2: Intermittent Black box swamp
	Pt1.3.2: Intermittent Coolibah swamp
	Pt1.4.2: Intermittent River Cooba swamp
	Pt1.5.2: Temporary paperbark swamp
(tree species unidentified)	**Pt1.6.2: Temporary woodland swamp**
	Pt1.7.2: Intermittent Lignum swamps
(e.g. Typha, Phragmites, Baumea, Juncus: tall spp typically>1m)	**Pt2.1.2: Temporary tall emergent marsh**
(species typically <1m)	**Pt2.2.2: Temporary sedge/grass/forb marsh**
(water typically <50cm, often seasonally inundated)	**Pt2.3.2: Freshwater meadow**
(lacks vegetation, shallow)	**Pt3.1.2: Clay pan**
(unspecified vegetation)	**Pt4.2: Temporary wetland**
20a Permanent saline palustrine systems (surface water >70% of time), identify by dominant vegetation type	
	Psp1.1: Saline paperbark swamp
(e.g. samphire)	**Psp2.1: Permanent salt marsh**
	Psp3.1: Permanent seagrass marsh
	Psp4: Permanent saline wetland (vegetation not specified)
20b Temporary saline palustrine systems (surface water <70% of time) identify by dominant vegetation type	
	Pst1.1: Temporary saline swamp
(e.g. samphire)	**Pst2.2: Temporary salt marsh**
	Pst3.2: Salt pans and salt flats
(vegetation unspecified)	**Pst4: Temporary saline wetland**

TYPOLOGY (EXTRACT FROM BROOKS ET AL. 2013)

Water regime, water type and vegetation are the main attributes used throughout the typology developed by Brooks et al. (2013). It should be noted that only vegetation structure (not dominant vegetation) has been used to help distinguish types for lacustrine and riverine classes. 'Non-vegetated' is a valid category for riverine systems as it can represent areas of settlement, or cleared areas. As lacustrine systems are defined on the basis of having less than 30 per cent emergent vegetation, 'only water' is considered as a valid attribute category for the dominant vegetation attribute in the typology for lakes. For example, it would not be appropriate to describe a type on vegetation that only occurred over, say, 5 per cent of the site.

Lacustrine systems

The typology proposed for lacustrine systems (Table 2) is based on the following Level 3 ANAE attributes:

- Water type;
- Water regime (water permanency);
- Dominant vegetation (water only);
- Finer vegetation (aquatic bed).

The typology for lacustrine systems also captures if the system is located on a floodplain. A number of types can be aggregated (for example permanent lakes with or without submerged macrophytes can be aggregated up to being called just permanent lakes) and this is explained in the descriptions for each combination of attributes in Table 2. In the typology lacustrine systems are considered freshwater unless stated otherwise in the naming convention. Also lakes are assumed to have no submergent vegetation unless stated in the name convention.

Table 2. Lacustrine types using Level 3 attributes and a location descriptor (floodplain) (from Brooks et al. 2013).

Note: Dominant vegetation and fringing vegetation do not provide any greater separation of types. Codes: Lp = permanent freshwater lacustrine/lakes, Lt = temporary freshwater lacustrine/lakes, Lsp = permanent saline lacustrine/lakes, Lst = temporary saline lacustrine/lakes

WATER TYPE	WATER REGIME	DOMINANT VEGETATION	FINER SCALE VEGETATION	LOCATED ON FLOODPLAIN	TYPE			DESCRIPTION
Fresh	Commonly wet	Water	No vegetation	No	Lakes	Lp1: Permanent lakes	Lp1.1: Permanent lakes	Includes volcanic lakes, dune lakes, crater lakes, alpine lakes and other inland lakes. Typically greater than 2 metres deep with substantial areas of open water – may have fringing vegetation in littoral zone, but are defined as having less than 30 per cent emergent vegetation and no to limited submergent vegetation. Often greater than 8 ha in size, but smaller systems are also included if they are greater than 2m deep and support wave action.
			Aquatic bed				Lp1.2: Permanent lakes with aquatic beds	As for Lp1.1 but have substantial areas of submergent macrophytes (e.g. Hattah Lakes). This type of lake is likely to be shallow in areas which support macrophytes.
			No vegetation	Yes		Lp2: Permanent floodplain lakes	Lp2.1: Permanent floodplain lakes	As for Lp1.1, but lakes located on floodplains.
			Aquatic bed				Lp2.2: Permanent floodplain lakes with aquatic beds	As for Lp1.2, but lakes located on floodplains.
	Periodic inundation	Water	No vegetation	No		Lt1: Temporary lakes	Lt1.1: Temporary lakes	As for Lp1.1 but tend to be shallower and periodically dries (temporary).
			Aquatic bed				Lt1.2: Temporary lakes with aquatic beds	As for Lp1.2; but lakes are temporary.

WATER TYPE	WATER REGIME	DOMINANT VEGETATION	FINER SCALE VEGETATION	LOCATED ON FLOODPLAIN	TYPE			DESCRIPTION
			No vegetation	Yes		Lt2: Temporary floodplain lakes	Lt2.1: Temporary floodplain lakes	As for Lt1.1, with main distinction being location on floodplain with dominant water source assumed to be from parent stream.
			Aquatic bed				Lt2.2: Temporary floodplain lakes with aquatic beds	As for Lt1.2, with main distinction being location on floodplain with dominant water source assumed to be from parent stream.
Saline	Commonly wet	Water	No vegetation	No	Saline lakes	Lsp1: Permanent saline lakes	Lsp1.1: Permanent saline lakes	As for Lp1.1, but saline.
			Aquatic bed				Lsp1.1: Permanent saline lakes with aquatic beds	As for Lp1.2, but saline. Examples of typical aquatic vegetation include systems with *Ruppia*.
			No vegetation	Yes		Lsp2: Permanent saline floodplain lakes	Lsp2.1: Permanent saline floodplain lakes	As for Lp2.1 but saline.
			Aquatic bed				Lsp2.2: Permanent saline floodplain lakes with aquatic beds	As for Lp2.2 but saline.
	Periodic inundation	Water	No vegetation	No		Lst1: Temporary saline lakes	Lst1.1: Temporary saline lakes	As for Lt1.1, but saline
			Aquatic bed				Lst1.2: Temporary saline lakes with aquatic beds	As for Lt1.2, but saline.
			No vegetation	Yes		Lst2: Temporary saline floodplain lakes	Lst2.1: Temporary saline floodplain lakes	As for Lt2.1, but saline.
			Aquatic bed				Lst2.2: Temporary saline floodplain lakes with aquatic beds	As for Lt2.2, but saline.

Palustrine systems

The typology proposed for palustrine systems (Table 3) is based on the following Level 3 ANAE attributes:

- Water type;
- Water regime;
- Dominant vegetation (structure);
- Finer scale vegetation (dominant species) **(Note this equates to vegetation type/habitat type in MER).**

The typology for palustrine systems also captures if the system is located on a floodplain. The typology for palustrine systems includes a greater number of types as the potential range of vegetation associations/attributes is greater, as these reflect the greater range or variability in water regime encountered in this ecosystem class. Springs were assigned to individual features as designated in jurisdictional data sets and were assumed to be commonly wet.

Table 3. Palustrine types using Level 3 attributes (from Brooks et al. 2013).

Codes Pp = permanent wetland types, Pt = temporary wetland types, Psp = permanent saline wetland types, Pst = temporary saline wetland types, Pu = unknown

WATER TYPE	WATER REGIME	DOMINANT VEGETATION	FINER SCALE VEGETATION	LOCATED ON FLOODPLAIN	TYPE			DESCRIPTION
Fresh	Commonly wet	Tree	Paperbark	Yes	Pp1: Permanent swamp forest	Pp1.1: Permanent paperbark swamps	Pp1.1.1: Permanent floodplain paperbark swamps	Permanent wetlands on floodplains; vegetation is emergent and dominated by paperbark.
				No			Pp1.1.2: Permanent paperbark swamps	As for Pp1.1.1, but not on floodplains.
		Sedge	Tall emergent aquatic	Yes	Pp2: Permanent marsh	Pp2.1: Permanent tall emergent marshes	Pp2.1.1: Permanent floodplain tall emergent marshes	Permanent wetlands on floodplains; vegetation is dominated by emergent aquatic species, including *Typha*, *Phragmites*, *Eleocharis*, some *Juncus* species, Includes species ≥1m in height.
				No			Pp2.1.2: Permanent tall emergent marshes	As for Pp2.1.1, but not on floodplains.
		Sedge	Aquatic sedge/grass/forb	Yes		Pp2.2: Permanent sedge/grass/forb marshes	Pp2.2.1: Permanent floodplain sedge/grass/forb marshes	Permanent wetlands on floodplains; vegetation is emergent, but can also include submergent species as well. Height of emergent species is typically ≤1m – can include species from *Carex*, *Cyperus*, *Myriophyllum*, *Triglochin*, *Eleocharis, Sporobolus, Amphibromus, Pseudoraphis spinescens etc*. Includes obligate aquatics as

WATER TYPE	WATER REGIME	DOMINANT VEGETATION	FINER SCALE VEGETATION	LOCATED ON FLOODPLAIN	TYPE			DESCRIPTION
								well as amphibious species in littoral zones.
				No			Pp2.2.2: Permanent sedge/grass/forb marshes	As for Pp2.2.1, but not on floodplains.
		Grass/forb	Freshwater grasses	Yes		Pp2.3: Permanent grass marshes	Pp2.3.1: Permanent floodplain grass marshes	Permanent wetlands on floodplains; vegetation is emergent grass species.
				No			Pp2.3.2: Permanent grass marshes	As for Pp2.3.1, but not on floodplains.
		Grass/forb	Freshwater forb	Yes		Pp2.4: Permanent forb marshes	Pp2.4.1: Permanent floodplain forb marshes	Permanent wetlands on floodplains; vegetation is emergent forb species.
				No			Pp2.4.2: Permanent forb marshes	As for Pp2.4.1, but not on floodplains.
		Sedge/Grass/ forb	Bogs and fen	No	Pp3: Peat bogs and fen marshes			Permanent wetlands with emergent sedge, grass or forb. Fen marshes are separated from bog by the presence of Sphagnum and groundwater being the dominant water source.
		All remaining	Not specified	Yes	Pp4.1: Permanent floodplain wetland			Permanent wetlands on floodplains with unspecified vegetation.
				No	Pp4.2: Permanent wetland			As per Pp4.1 but not on floodplains.

WATER TYPE	WATER REGIME	DOMINANT VEGETATION	FINER SCALE VEGETATION	LOCATED ON FLOODPLAIN	TYPE			DESCRIPTION
			Not specified	All	Pps5: Permanent springs			Permanent freshwater wetlands in groundwater discharge areas.
	Periodic inundation	Tree	River red gum	Yes	Pt1:Temporary swamps	Pt1.1:Intermittent River red gum swamp	Pt1.1.1: Intermittent River red gum floodplain swamp	Intermittent River red gum wetland on floodplains; can include both woodland and forest forms.
				No			Pt1.1.2: Intermittent River red gum swamp	As for Pt1.1.1, but not on floodplains.
		Tree	Black box	Yes		Pt1.2:Intermittent Black box swamp	Pt1.2.1: Intermittent Black box floodplain swamp	Intermittent Black box wetlands on floodplains; have predominantly woodland structure. Occurs on infrequently flooded outwash areas, as a narrow fringe around intermittent lakes, as a woodland across the floor of some deflation basins and as a string of trees following a palaeo-channel (Roberts and Marston 2011).
				No			Pt1.2.2: Intermittent Black box swamp	As for Pt1.2.1, but not on floodplains.
		Tree	Coolibah	Yes		Pt1.3:Intermittent Coolibah swamp	Pt1.3.1: Intermittent Coolibah floodplain swamp	Intermittent Coolibah wetlands on floodplains; mainly restricted to the north-west of the Basin. Often the dominant tree in infrequently inundated floodplains of northern rivers such as the Darling and

WATER TYPE	WATER REGIME	DOMINANT VEGETATION	FINER SCALE VEGETATION	LOCATED ON FLOODPLAIN	TYPE		DESCRIPTION
							Gwydir; forming extensive woodlands. This type may also occur as a riparian fringe beside river channels and around waterholes (Roberts and Marston 2011).
				No		Pt1.3.2: Intermittent Coolibah swamp	As for Pt1.3.1, but not on floodplains.
		Tree	River Cooba	Yes	Pt1.4:Intermittent River Cooba swamp	Pt1.4.1: Intermittent River Cooba floodplain swamp	Intermittent River Cooba wetlands on floodplains. River Cooba is also known as Belalie and Eumong (Roberts and Marston 2011). Common in the northern Basin.
				No		Pt1.4.2: Intermittent River Cooba swamp	As for Pt1.4.1, but not on floodplains.
		Tree	Paperbark	Yes	Pt1.5:Temporary paperbark swamp	Pt1.5.1: Temporary paperbark floodplain swamp	As for Pp1.1.1 but temporary.
				No		Pt1.5.2: Temporary paperbark swamp	As for Pp1.2.1 but temporary.
		Tree	Other aquatic trees	Yes	Pt1.6:Temporary swamp	Pt1.6.1: Temporary woodland floodplain swamp	Temporary wetlands on floodplain with a range of aquatic trees such as *Casuarina*, *Allocasuarina*, *Eucalyptus ovata*.
				No		Pt1.6.2: Temporary woodland swamp	As for Pt1.6.1, but not on floodplains.

WATER TYPE	WATER REGIME	DOMINANT VEGETATION	FINER SCALE VEGETATION	LOCATED ON FLOODPLAIN	TYPE			DESCRIPTION
		Shrub	Lignum	Yes		Pt1.7:Intermittent Lignum swamps	Pt1.7.1: Intermittent Lignum floodplain swamps	Temporary Lignum swamps on floodplains.
				No			Pt1.7.2: Intermittent Lignum swamps	As for Pt1.7.1, but not on floodplains.
		Sedge	Tall emergent aquatics	Yes	Pt2: Temporary marshes	Pt2.1: Temporary tall emergent marshes	Pt2.1.1: Temporary tall emergent floodplain marsh	Temporary floodplain wetlands dominated by *Phragmites*, *Juncus Typha*, *Eleocharis*, *Baumea,* etc.
				No			Pt2.1.2: Temporary tall emergent marsh	As for Pt2.1.1, but not on floodplains.
		Sedge/grass/ forb	Aquatic sedge/grass/forb	Yes		Pt2.2: Temporary sedge/grass/forb marsh	Pt2.2.1: Temporary sedge/grass/forb floodplain marsh	Temporary sedge/grass/forb marshes on floodplains. Marshes tend to be deeper than meadows, ranging anywhere from 20-30 centimetres in depth to up to two metres in depth. Can be vegetated across the whole system or include areas of open water (deeper areas). Includes systems with *Eragrostis*, *Eleocharis*, *Carex*, *Cyperus*, *Paspalum*, etc
				No			Pt2.2.2: Temporary sedge/grass/forb marsh	As for Pt2.2.1, but not on floodplains.
		Grass/forb	Freshwater grasses, Freshwater forbs	Yes		Pt2.3: Freshwater meadow	Pt2.3.1: Floodplain freshwater meadow	Temporary meadows on floodplains, which tend to be shallow typically ranging between 20 to 40

WATER TYPE	WATER REGIME	DOMINANT VEGETATION	FINER SCALE VEGETATION	LOCATED ON FLOODPLAIN	TYPE			DESCRIPTION
								centimetres in depth. Meadows are typically vegetated across whole system, may have scattered trees, shrubs, and or sedges, but are dominated by grasses and forbs.
				No			Pt2.3.2: Freshwater meadow	As for Pt2.3.1, but not on floodplains.
		No vegetation/ Water	n/a	Yes	Pt3: Freshwater playas	Pt3.1:Clay pans	Pt3.1.1: Floodplain clay pan	Floodplain clay pans typically less than eight hectares and less than two metres deep. Lack wave action characteristic of lacustrine systems
				No			Pt3.1.2: Clay pan	As for Pt3.1.1, but not on floodplains.
		All remaining	Not specified	Yes	Pt4.1: Temporary floodplain wetland			Temporary wetlands on the floodplain with unspecified vegetation.
				No	Pt4.2: Temporary wetland			As for Pt4.1, but not on floodplains.
Saline	Commonly wet	Tree	Paperbark	All	Psp1: Saline swamps	Psp1.1: Saline paperbark swamp		Permanent saline paperbark swamps, including *Melaleuca halmaturorum.*
		Shrub/sedge/ grass/forb	Saltmarsh	All	Psp2: Salt marsh	Psp2.1: Permanent salt marsh		Permanent inland saltmarsh.
		Grass	Seagrass	All	Psp3: Seagrass marsh	Psp3.1: Permanent seagrass marsh		Permanent saline marshes dominated by seagrass.

WATER TYPE	WATER REGIME	DOMINANT VEGETATION	FINER SCALE VEGETATION	LOCATED ON FLOODPLAIN	TYPE		DESCRIPTION
		All remaining	Not specified	All	Psp4: Permanent saline wetland		Permanent saline wetlands with unspecified vegetation.
	Periodic inundation	Tree	All trees	All	Pst1: Saline swamp	Pst1.1: Temporary saline swamp	Temporary saline wetlands with tree species.
		Shrub/sedge/ grass/forb	Saltmarsh	All	Pst2: Salt marsh	Pst2.2: Temporary salt marsh	Temporary inland saltmarsh wetlands.
		No vegetation/ water	n/a	All	Pst3: Saline playas	Pst3.2: Salt pans and salt flats	Temporary saltpans and playas typically less than eight hectares and less than two metres deep. Lack wave action characteristic of lacustrine systems.
		All remaining	Not specified	All	Pst4: Temporary saline wetlands		Temporary saline wetlands with unspecified vegetation.
Unknown	Unknown	Unknown	Unknown	All	Pu1: Unspecified wetland		There is no information with which to assign a type.

Riverine systems

The typology for palustrine systems (Table 3) is based on the following Level 3 ANAE attributes:

- Water source,
- Water regime, and
- Landform.

The riverine confinement attribute was also considered for the typology but was found to be highly correlated with the landform attribute and so provided no additional ecological information.

Waterholes are assumed to have been identified in temporary or periodically inundated streams. However, approaches such as designating permanent palustrine features that intersect steams as 'waterholes' resulted in a vast (unrealistic) number of features being so assigned. The designation of a feature as a 'waterhole' therefore relies on designations from jurisdiction databases.

Including substrate as an attribute in the typology for riverine systems would be informative; however, there is insufficient information available for the MDB to include it at this stage. It may be considered in future iterations of the ANAE framework as it would add useful information on the characteristics of a riverine system (e.g. help define sandy bottom, cobble, boulder or bedrock streams).

Table 4. Riverine types using Level 3 attributes(from Brooks et al. 2013).
Codes: Rp = riverine – permanent streams, Rt = riverine – temporary streams, Rw = riverine – waterholes, Ru = unspecified streams.

WATER SOURCE	WATER REGIME	LANDFORM	TYPE		DESCRIPTION
Surface	Commonly wet	High energy upland	Rp1: Permanent streams	Rp1.1: Permanent high energy upland streams	Fast flowing streams with steep gradient (>6%), and dominated by riffles and runs. Often with coarse substrate. Base flow typically maintained except in extreme droughts.
		Transitional		Rp1.2: Permanent transitional zone streams	Intermediate slope (4-6%) with long runs and riffle zones; pools are infrequent.
		Low energy upland		Rp1.3: Permanent low energy upland streams	Low gradient (<4%), slow flowing systems, often with a narrow channel on relatively flat land. May lack extensive riffle areas.
		Lowland		Rp1.4: Permanent lowland streams	Low gradient (<4%),systems that can include both narrow and relatively shallow flowing systems with pool, riffle, run sequences, and large deeper lowland systems with slow flow and no riffle areas. Base flow is maintained in dry periods, except in extreme drought.
	Periodic inundation	High energy upland	Rt1: Temporary streams	Rt1.1: Temporary high energy upland streams	As for Rp1.1, but may be systems which rise and fall rapidly, wetting and drying for varying lengths of times.
		Transitional		Rt1.2: Temporary transitional zone streams	As for Rp1.2, but are only periodically wet.
		Low energy upland		Rt1.3: Temporary low energy upland streams	As for Rp1.3, but are only periodically wet.
		Lowland		Rt1.4: Temporary lowland streams	As for Rp1.4, but are only periodically wet.
All	Commonly wet	All	Rw1: Waterholes		Commonly wet remnant pools that are located on periodically wet riverine segments.
	Unknown	Unknown	Ru1: Unspecified river		There is no information with which to assign a type.

A1.3 HYDROLOGY (RIVER): SELECTED AREA METHODS

A1.3.1 OVERVIEW

This protocol describes the methods that will be used for the Selected Area Evaluation.

A1.3.2 EVALUATION QUESTIONS

A1.3.2.1 Selected Area Evaluation questions

Within the Selected Area, changes in the duration, timing and magnitude of flow caused by the management of environmental water will allow the assessment of a range of evaluation questions.

1. What did Commonwealth environmental water contribute to hydrological connectivity?
    a. How was longitudinal and lateral connectivity changed by the use of Commonwealth environmental water?
    b. What proportion of the flow in the river was environmental water and how did this change throughout the year?
2. What did Commonwealth environmental water contribute to habitat for native fish and other water dependent vertebrate species?
    a. How did river levels differ from those under normal operations?
3. What did Commonwealth environmental water contribute to hydrological variability?
    a. Did the provision of Commonwealth environmental water modify low flow variability?
    b. Did the provision of Commonwealth environmental water change the number of freshes in the river?

The process for evaluating these questions is illustrated in Figure 5, with components covered by this protocol highlighted in green.

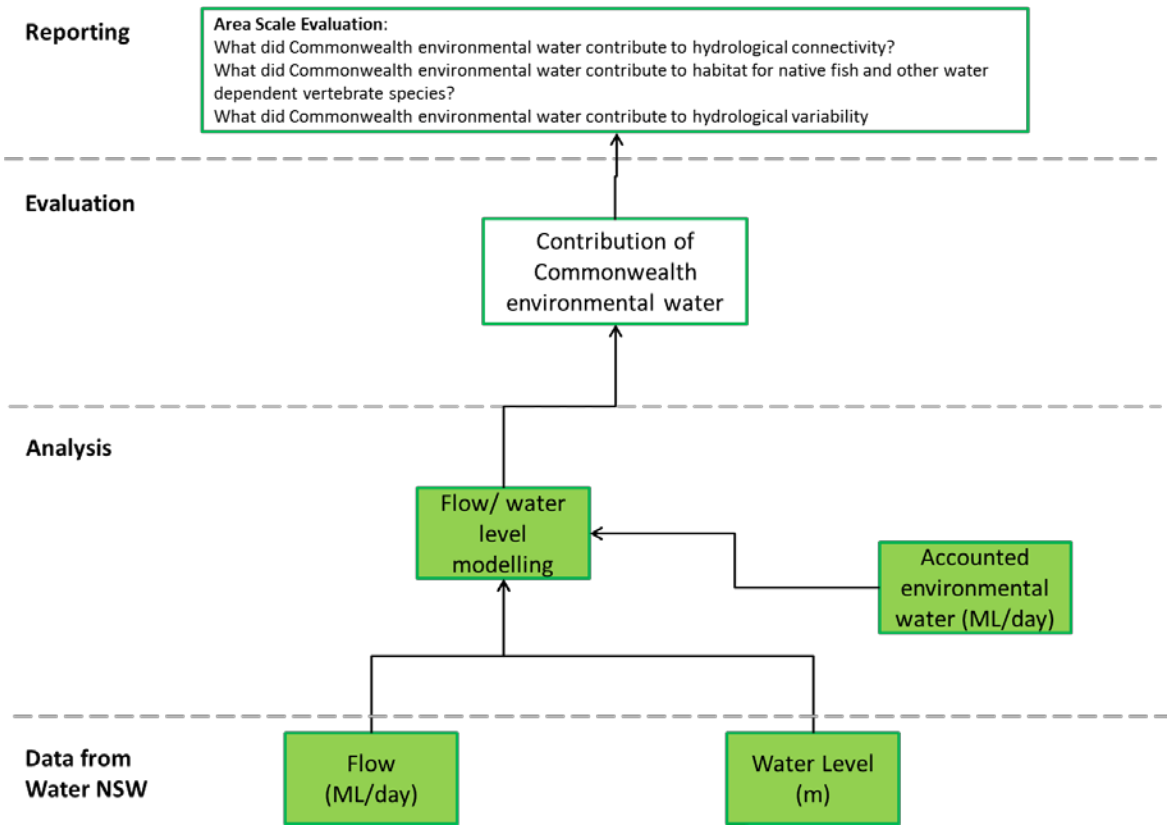

Figure 5. Schematic of key elements of the MER protocol for Area evaluation: Hydrology (River).

A1.3.3 RELEVANT ECOSYSTEM TYPES

Rivers.

A1.3.4 RELEVANT FLOW TYPES

All.

A1.3.5 OVERVIEW AND CONTEXT

A1.3.5.1 Area scale

At the area scale, hydrology (river) is a continuous monitoring protocol designed to capture aspects of a rivers flow regime that will be used to evaluate the effect of Commonwealth environmental water. This protocol is based identifying the attributes that will be used in the evaluation for each of the key indicators within the Lachlan Selected Area and comprises a combination of gauge data and hydrological modelling. Key hydrological attributes required are:

- Daily flow data:
  - Frequency and duration of watering
- River height.
  - Presence/absence of water at a site

A1.3.6 COMPLEMENTARY MONITORING AND DATA

Twelve gauging stations currently operate on the Lower Lachlan River system. The locations are listed in Table 4 and are shown in Figure 6. Historical monitoring activities have relied on gauging data to evaluate outcomes of environmental watering.

Table 5. Location of gauging stations in the Lower Lachlan River system.

NUMBER	NAME	LAT	LONG
412005	LACHLAN RIVER @ BOOLIGAL	-33.8695	144.8811
412038	LACHLAN RIVER U/S WILLANDRA WEIR	-33.3497	145.876
412039	LACHLAN RIVER @ HILLSTON WEIR	-33.4873	145.504
412045	LACHLAN RIVER @ CORRONG	-34.2176	144.4638
412078	LACHLAN RIVER @ WHEALBAH	-33.6544	145.2488
412163	MERROWIE CREEK DOWNSTREAM OF OFFTAKE WEIR	-33.3676	145.6017
412194	LACHLAN RIVER @ FOUR MILE WEIR	-34.248	144.1987
412196	LACHLAN RIVER DOWNSTREAM GANOWLIA WEIR (LANES BRIDGE)	-33.3716	145.5925
412012	WILLANDRA @ ROAD BDG	-33.3452	145.8803
412042	WILLANDRA HOMESTEAD	-33.1954	145.1217
412187	WILLANDRA @ YILGA	-33.2222	145.5053
412154	CUMBUNG SWAMP @ END OF SYSTEM	-34.1541	-143.5950

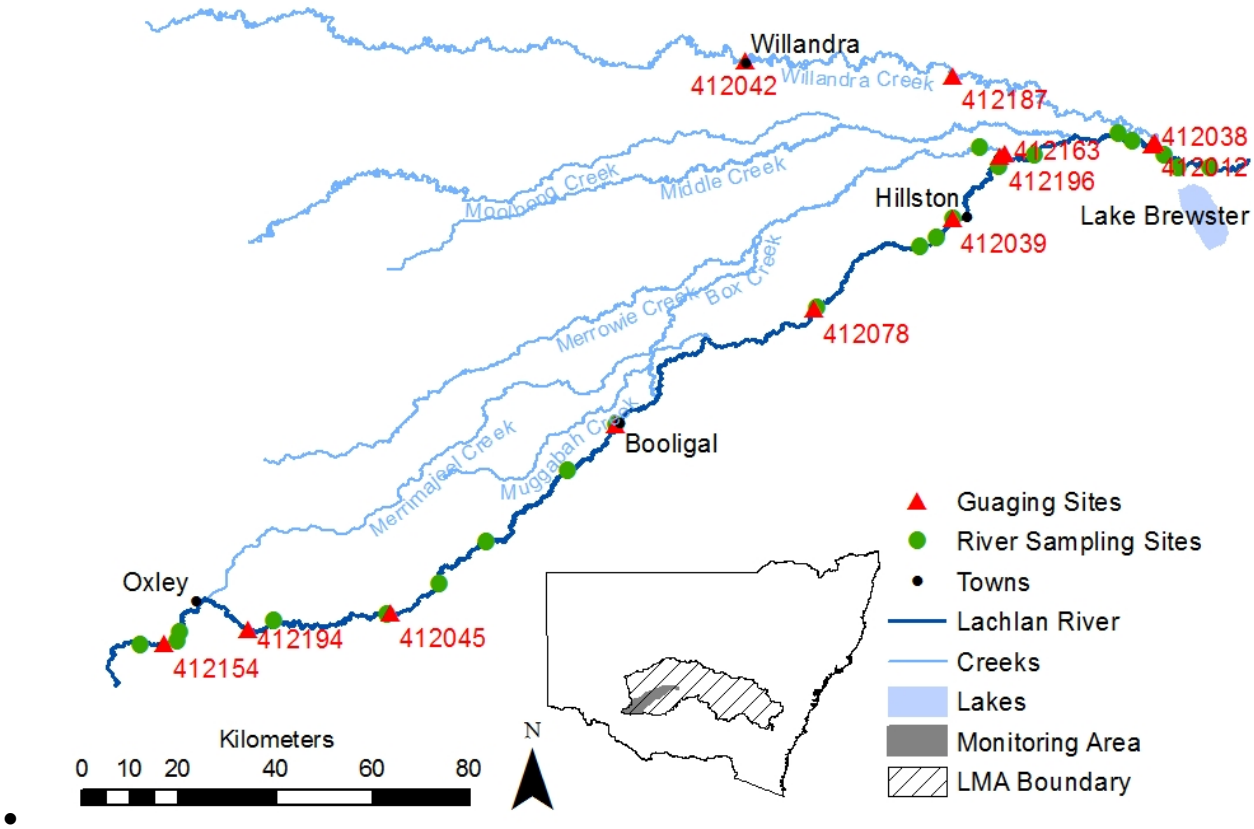

Figure 6. Map of the Lower Lachlan Rivers showing the region that is the focus for the long term intervention monitoring investment from the Commonwealth Environmental Water Office including the location of the gauging stations.

A1.3.7 ESTABLISHING SITES

A1.3.7.1 Zones and sites

The MER project for Basin-scale evaluation has adopted a hierarchical approach to sample design (Gawne et al. 2013). Briefly, the spatial hierarchy is as follows:

Selected Area → Zone → 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 for River Hydrology it will be a section of river.

A1.3.7.2 Area scale site establishment

Selected Area scale site establishment is linked to the area scale evaluation methods for riverine fish, stream metabolism, vegetation condition and diversity with sites matched to the sampling locations.

A1.3.7.3 Selected Area evaluation

Locations will be matched to the sampling locations for fish, stream metabolism, vegetation diversity as well a. These sites are summarized in Table 6.

A1.3.8 TIMING OF MONITORING

The use of existing gauge data means that monitoring data are available throughout the year and records the passing of Commonwealth environmental water.

Table 6. River monitoring sites and the source of hydrological data for use in evaluation.

SITE	RIVERINE FISH	LARVAL FISH	META-BOLISM	HYDROLOGY DATA SOURCE
Lachlan River @ Benson's Drop				Lachlan River at Willandra weir (412038) verified using releases from Lake Brewster Water Level: Gauging site data
Lachlan River @ Willanthry	Y	Y	Y	Flow based on Lachlan River at Willandra weir (412038) and the Willandra Creek at the bridge (412012)
Lachlan River @ Site 9	Y			Flow based on Lachlan River at Willandra weir (412038)
Lachlan River @ Site 11	Y			Flow based on Lachlan River at Willandra weir (412038)
Lachlan River @ Riama	Y			Flow based on Lachlan River at Willandra weir (412038)
Lachlan River @ Moora Farm	Y			Flow based on Lachlan River at Willandra weir (412038)
Lachlan River @ Hunthawang	Y			Flow based on Lachlan River at Willandra weir (412038)
Lachlan River @ Lane's Bridge	Y	Y	Y	Modelled flow based on Lachlan River at Willandra weir (412038) and the Willandra Creek at the bridge (412012)
Lachlan River @ Riverview	Y			Flow based on Lachlan River at Willandra weir (412038)
Lachlan River @ U/S Lane's Bridge	Y			Flow based on Lachlan River at Willandra weir (412038)
Lachlan River @ Hillston	Y	Y		Flow: Gauge at Hillston (412039) Water Level: Gauging site data
Lachlan River @ Hazelwood				Modelled data between Hillston and Whealbah
Lachlan River @ Cowl Cowl			Y	Modelled data between Hillston and Whealbah
Lachlan River @ Whealbah			Y	Flow: Gauge at Whealbah (412078) Water Level: Gauging site data
Lachlan River @ Booligal				Flow: Gauge at Booligal (412005) Water Level: Gauging site data
Lachlan River @ Corrong				Flow: Gauge at Corrong (412045) Water level: gauging site data
Merrowie Creek				Flow: Gauge at top end of Merrowie Creek downstream of offtake weir (412163) Water level: gauging site data

A1.3.9 DATA COLLECTION

Flow and water level data from gauging stations will be downloaded from NSW Waterinfo (https://realtimedata.waternsw.com.au/).

A1.3.10 QUALITY ASSURANCE/QUALITY CONTROL

A1.3.10.1 Flow Data from gauging stations

Quality assurance and quality control protocols implemented by the hydrographic agencies responsible for the gauging stations will be relied up for flow data from existing gauging stations.

A1.3.11 DATA ANALYSIS AND REPORTING

A1.3.11.1 Daily Mean 'Stage' (Water Height)

From gauging sites: The daily mean 'stage' will be downloaded from the NSW WaterInfo site (http://waterinfo.nsw.gov.au/). This will be the water level in metres above sea level.

A1.3.11.2 Daily mean river discharge

From gauging sites: The daily mean discharge (ML/day) will be downloaded from the NSW WaterInfo site (http://waterinfo.nsw.gov.au/).

A1.3.11.3 Presence/absence of water at a site

Water height (stage) data will be used to determine the presence/absence of water at a site.

A1.3.11.4 Frequency and duration of watering

The frequency and duration of watering event will be established from the flow records at the sites and linked to.

A1.3.12 DATA MANAGEMENT

All data for this indicator is publicly available and will not be uploaded through the Monitoring Data Management System (MDMS).

A1.4 VEGETATION DIVERSITY

This monitoring protocol encapsulates the Category 3 monitoring of vegetation diversity.

A1.4.1 EVALUATION QUESTIONS

This monitoring protocol addresses the following Evaluation questions in relation to vegetation diversity:

A1.4.1.1 Basin Evaluation

Short (one-year) and long term (five year) evaluation questions

- What did environmental water contribute to species diversity?
    - How did Commonwealth environmental water affect the presence, distribution and abundance of individual plant species?
- What did environmental water contribute to vegetation community diversity?
    - How did Commonwealth environmental water affect the composition and structure of particular vegetation communities?
    - How did Commonwealth environmental water affect the presence, distribution and abundance of particular vegetation communities?

A1.4.1.2 Area Evaluation

Short (one-year) and long term (five year) evaluation questions

- What did Commonwealth environmental water contribute to native riparian and wetland vegetation communities?
    - What did Commonwealth environmental water contribute to populations of long-lived organisms (measured by cover and recruitment of tree species)?
    - What did Commonwealth environmental water contribute to individual plant species across the Selected Area including changes to species presence, distribution and cover?
    - What did Commonwealth environmental water contribute to vegetation communities within ANAE vegetation types, including changes in species richness, composition, cover and structure?

The process for evaluating these questions is illustrated in Figure 7 and with components covered by this protocol highlighted in blue. The brown boxes for tree recruitment and structure will be implemented in the Lachlan Selected Area as they form part of historical monitoring protocols. This information can be collected with little additional field time cost and recruitment of floodplain and riparian species is known to be a key outcome of environmental watering in the region.

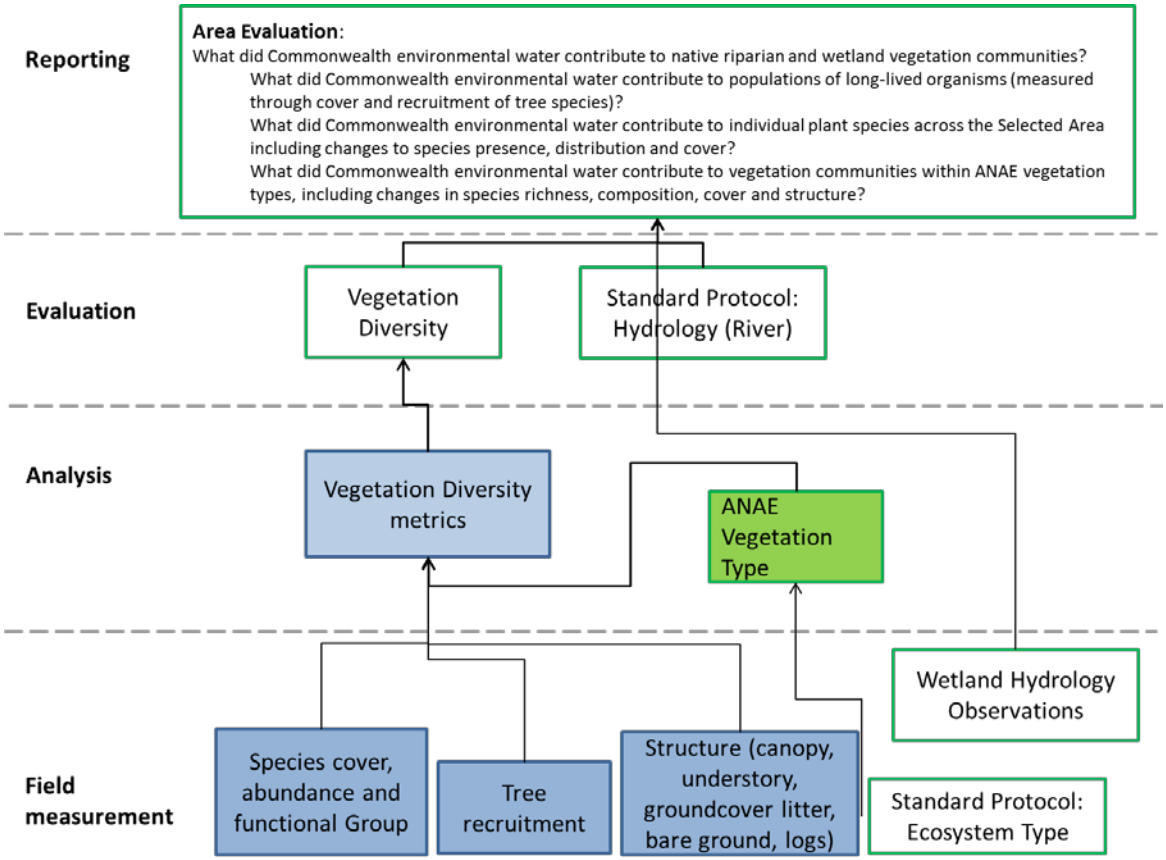

Figure 7. Schematic of key elements of the MER Protocol for the evaluation of Vegetation Diversity for the Lachlan Selected Area.

A1.4.2 RELEVANT ECOSYSTEM TYPES

Rivers and wetlands are the relevant ecosystem types for evaluating vegetation diversity.

A1.4.3 RELEVANT FLOW TYPES

Fresh, bankfull, overbank (infrastructure assisted) are the relevant flow types for evaluating diversity.

A1.4.4 OVERVIEW AND CONTEXT

The condition, type and diversity of riparian and wetland vegetation communities are strongly influenced in by the frequency and extent of inundation (Brock and Casanova 1997, Kingsford 2000). Floodplain wetlands are major repositories of biodiversity (Kingsford 2000) and support distinct biological communities (Hillman and Shiel 1991). Wetlands are a major target for ecological rehabilitation driven, at least in part, by environmental water allocations. Wetland vegetation is critical for carbon cycling and provision of food and habitat for water birds, amphibians, fish, terrestrial vertebrates and a variety of other biota (Hillman and Shiel 1991, Kingsford and Thomas 1995, Kingsford and Johnson 1998, Kingsford and Thomas 2001, Leslie 2001).

Flooding frequency is associated with wetland biota structure and function on the floodplain (Boulton and Lloyd 1992, Jenkins and Boulton 1998). Flooding interacts with plant life-history processes such as dispersal, germination, recruitment, survival, growth, and reproduction.

Although some native wetland species can thrive in permanently wetted habitats, flooding of previously dry habitats is a major stimulus to production of water plants and their associated biota such as invertebrates, both of which are important food sources for some waterbird species (Maher 1984, Maher and Carpenter 1984, Briggs and Maher 1985).

The Lachlan river system in the study region, is low gradient and includes many paleochannels, anabranches and distributaries, such as Merrowie, Middle and Willandra creeks. There are abundant swamps, lagoons and billabongs associated with the distributaries of the lower river, culminating in the terminal Great Cumbung swamp. The predominant land uses in cleared areas of the floodplain are grazing and dryland and irrigated cropping (cereals, cotton, grapes, wheat and vegetables). However, there are significant areas of native vegetation, including three wetlands of national importance, listed in the Directory of Important Wetlands in Australia; Booligal Wetlands, the Great Cumbung Swamp and Lachlan Swamp. In addition there are other significant wetlands along Merrowie Creek, at Lake Brewster and Lake Cowal (Department of Land & Water Conservation (DLWC) 1997, Driver et al. 2010).

High-value wetland plant communities present include black box *Eucalyptus largiflorens*, river cooba (*Acacia stenophylla*), extensive reed beds (*Phragmites australis*) and extensive areas of riparian fringing river red gum forest (*Eucalyptus camaldulensis*) and woodland, including one of the largest stands of river red gum in NSW at the Great Cumbung Swamp. These vegetation communities support breeding events for tens of thousands of colonial nesting birds including straw-necked ibis and glossy ibis, birds listed under international migratory bird agreements including great egret, glossy ibis, sharp-tailed sandpiper, common greenshank, Latham's snipe, painted snipe and white-bellied sea-eagle and birds listed as vulnerable including the Australasian bittern, blue-billed duck and freckled duck.

The vegetation diversity and condition methods will quantify and interpret the response of key plant species and communities e.g. black box, cooba, river red gum and reed beds in terms of condition, extent and life history responses to the provision of Commonwealth environmental water, taking into account the effects of landscape context, historical flows and land use. Function will be represented by measures of wetland vegetation response, focussed on condition and extent (assessed on-ground). Diversity is assessed on ground through surveys, and validation of these surveys as diversity-assessment tools. The resulting data will build on existing capacity to predict responses of different plant communities and species to alternative environmental flow scenarios delivered to the Lachlan floodplain.

For the Lachlan Selected Area, much of the purchased environmental water delivered is combined with other flows, (e.g., translucent flow, natural events or irrigation delivery). The capacity of Commonwealth environmental water to be delivered to specific locations will be similar to other forms of environmental water. In dry years this becomes more difficult, except at locations such as Booligal Swamp where structures such as Lake Brewster and Torrigany Weir enable local, controlled delivery (modelled in Driver et al. 2005).

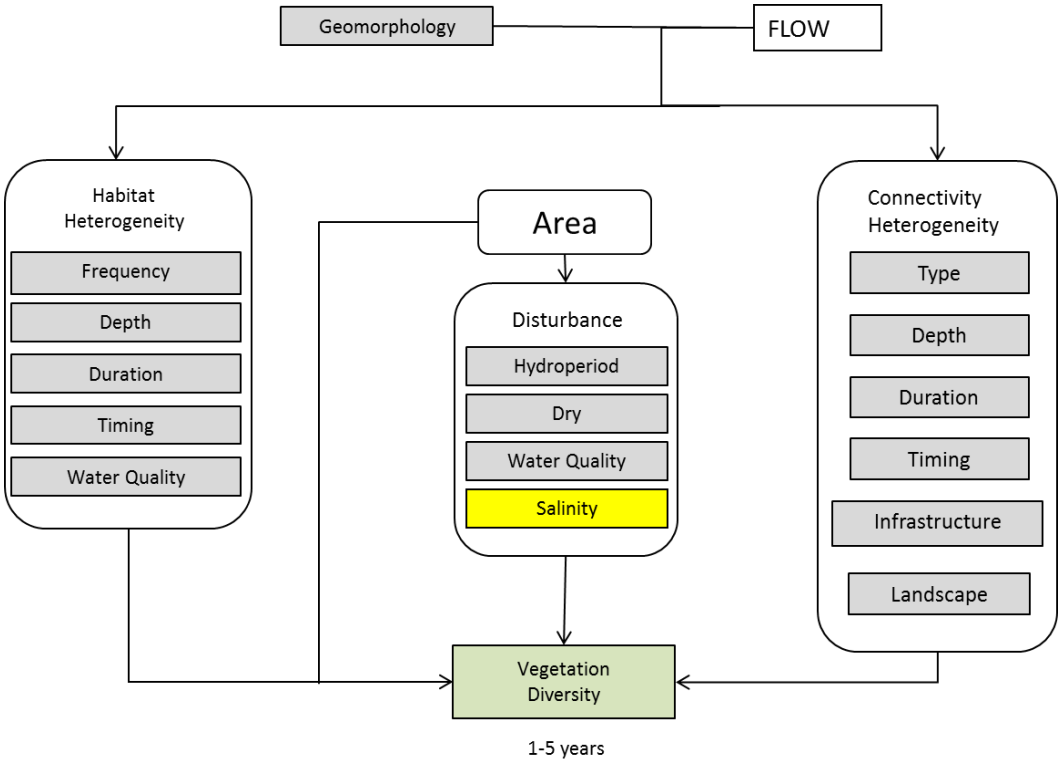

Figure 8. Cause and effect diagram for Vegetation diversity.

A1.4.5 MONITORING LOCATIONS

A1.4.5.1 Overview

The LTIM Project for Basin Evaluation has adopted a hierarchical approach to sample design (see Gawne et al. 2013). Briefly, the spatial hierarchy for vegetation monitoring is as follows:

Selected Area → Zone → Site → Habitat (vegetation type, open water)

A1.4.5.2 Selection of zone(s)

The vegetation community in the Lachlan river system Selected Area is dominated by woodland communities, with River red gum and Black box/River red gum communities prevalent in areas inundated by Commonwealth environmental water. Lignum and River Cooba are found in mixed stands with Black box and aquatic reeds, grasses and sedges are represented in some wetland sites. There is no way to draw a line along or across the study area that neatly splits the study area for vegetation.

The lack of clear delineation of vegetation types across the Selected Area means that the selection of zones is not supported. Instead, the vegetation response will be measured across the Selected Area and the evaluation stratified by Australian National Aquatic Ecosystem (ANAE) type (Brooks et al. 2013) and by the classification of Green (1997).

A1.4.5.3 Selection of sites

The Selected Area contains several wetlands of national and regional significance as listed in the Directory of Important Wetlands (Environment Australia 2001).

Many or all of these wetlands will be targets of CEWO, MDBA or NSW OEH environmental flow deliveries. The criteria used to select sites are:

1) Accessibility: Each site should be accessible under a range of watering conditions so that monitoring can occur each year.
2) Representative: Each site should not be an obvious ecological aberration and in combination, the sites should adequately represent the range of inundation dependent vegetation characteristic of the Selected Area.
3) Likelihood of watering: The site must be highly likely to receive Commonwealth environmental water at least once in the next five years. Sample locations will be selected to cover the range of water dependent vegetation communities likely to be affected by Commonwealth Environmental Water within a given Selected Area.
4) Bathymetry: Preference should be given to sites with known bathymetry (or DEM: Digital elevation model) and water level recording infrastructure.

Table 7. Vegetation type and applicability to the Lachlan category 3 vegetation diversity method.

COMMONWEALTH CRITERIA	APPLICABILITY TO THE LACHLAN CATEGORY 3 VEGETATION DIVERSITY METHOD (FOR SITE SPECIFIC DETAILS, SEE APPENDIX 1).
River red gum forest	N/A
River red gum woodland	Yes
Black box forest	N/A
Black box woodland	Yes, but not pure stands, more mixed RRG/BBX woodland in the areas inundated by the CW water.
Coolibah	Not in the Lachlan
River Cooba	Yes, but in mixed stands as with BBX (e.g., at Whealbah Lagoon).
Unidentified aquatic trees	N/A
Lignum	Yes, in mixed stands, often under RRG (e.g., Murrumbidgil Swamp).
Other shrub	N/A
Tall emergent aquatic (reeds, Phragmites, cumbungi, etc)	Yes. Represented (e.g., in Marrool, currently club rush]).
Aquatic sedge/grass/forb	Yes
Freshwater grasses	Warrego Summer Grass is often common, but not dominant
Freshwater forb	No

A1.4.5.4 Fixed site locations among years

Aquatic ecosystems are notoriously variable in space, so if sample size is not large and the sites selected change among years, inter-annual differences may be caused by spatial heterogeneity, not temporal effects. The method presented below relies on the use of fixed sites within and among years with sites monitored during the LTIM project providing foundational sites for on-going monitoring.

A1.4.5.5 Site locations

Unpublished IMEF analyses indicate that 12 sites represent about 90% of catchment diversity within the Lachlan floodplain (with the study area defined within the site selection criteria described above). Twelve sites along the length of the Lower Lachlan River system Selected Area have been monitored during the LTIM Project (Table 8). Recommendations from the LTIM program was that some of the less frequently watered sites be replaced by sites which are more frequently watered.

At each site data from replicate plots and transects will be collected.

Table 8. Sites selected for monitoring vegetation diversity and condition in the Lachlan river system Selected Area.
Optional sites; which will be surveyed where possible. The clusters include sites from nationally significant wetland complexes (Environment Australia 2001): Booligal Wetlands, Merrowie/Box Creek, Great Cumbung Swamp (GCS) and Lachlan Swamp.

WETLAND COMPLEX	SITE	CORE (C) OPTIONAL (O)	WETLAND TRANSECTS	RIPARIAN PLOTS
Booligal Wetlands	Moon Moon swamp	C	2	2
	Booligal National Park	C	2	2
	Booligal Ibis Colony	O		3
Merrowie/Box Creek	Merrowie Creek on Cobb Hwy	C		2
	Lake Tarwong Red Gum	C	2	2
	Lake Tarwong Black Box	C		2
Lachlan Swamp	Lake Bullogal Red Gum	C	2	2
	The Ville Red Gum	C	2	2
	The Ville mixed stand	C		2
Great Cumbung Swamp	Marrool Lake	C	2	2
	Nooran Lake	C	2	2
	Clear Lake	C	2	2
	Lake Ita inlet channel (BBX)	O		2
	Lake Ita RRG	O		2
Lachlan River Floodplain	Whealbah Billabong	C	2	2
	Hazelwood Billabong	C	2	2

A1.4.5.6 Plot size /No of transects

This part of Australia has no forest-level densities of trees (see Specht 1970) and so only woodland communities are recorded. The non-tree community sampling design captures different non tree vegetation communities that occur at different elevations and locations within the wetland and / or river from submerged communities in the river or wetland bed through to emergent or littoral vegetation at the edges of aquatic ecosystems. The tree community sampling design is a minimum of 2 replicate 0.1 ha plots located entirely within the tree community and not encroaching into the adjoining aquatic or littoral vegetation communities (see Bowen 2013, Supplement: B).

For tree communities overstorey tree health plots are 20x50 m (0.1ha) is the plot size used in the NSW Office of Environment and Heritage (NSW OEH) method for tree health (Bowen 2013; Supplement B) and is derived from Siverston (2009). For understory floristic survey 20x20 m (0.04ha) is the standard OEH method for floristic vegetation survey (Sivertsen 2009).

A1.4.6 TIMING OF FIELD SAMPLING

Sampling will occur in spring and autumn. This is expected to, where possible; correspond with before and after watering, with the fixed timing accounting for seasonal variation in species present.

A1.4.7 MONITORING PROTOCOL: NON-TREE COMMUNITY

This is largely based on the transect method (Driver et al. 2003), partly modified for consistency with LTIM and OEH methods applied in the Lachlan. It is applied to the riparian zones of billabongs, just below or within the tree fringe, and starting at the top of the bank for billabongs and finishes within the deeper sections of billabongs (or other floodplain wetlands).

A1.4.7.1 Equipment

- GPS
- 100 m Tape
- Sample bags/project books
- Permanent markers
- Pens
- Hand lens
- Site poles
- Fluorescent spray paint
- Mallet
- 1 x 1 m quadrat
- Field data sheets.
- Camera (with inbuilt GPS)
- Boat (for wide or deep streams).
- Life Jackets
- Waders/wetsuit & boots
- Wetsuit gloves
- A copy of this protocol.

A1.4.7.2 Preparation

- Before leaving the office / laboratory the following should be checked:
  - Batteries are charged and properly inserted.
  - Previous data downloaded and memory cleared.
  - GPS camera recording correctly
  - All equipment listed above is present and in functional order.

A1.4.7.3 Site Establishment

1) Find the site using the point location established in the Monitoring and Evaluation Plan.
2) Record the following on the field sheet:
   a) River or wetland name and ANAE ID.
   b) Date and time.
   c) GPS coordinates (latitude and longitude; GDA94).
   d) Name(s) of installation team.
3) Install the initial site marker pole at the high water mark, ensuring that it is solidly fixed.
4) Run a tape perpendicular to the bank 100m into the wetland. Install the 2nd marker pole at the end of the tap (or known distance if more practical)

A1.4.7.4 Data Collection

1) Each person who will be entering the water is to put on protective clothing (e.g. life jacket plus waders with an external belt, or wetsuits and boots and wetsuit gloves).
2) Always start the survey at the highest elevation.
3) Attach a 100 m tape to the site marker pole at the start of the first transect and run the tape out towards the end marker pole
4) Standing at the starting site marker pole, photograph along the line of the tape, to the right and left of the tape and take a panorama photograph (or set of panoramas)
5) Place the one metre square quadrat on the ground or water surface in front of you record the direction from the tap of the quadrat
6) For each quadrat, record the following details on the field data sheet:
   a) Transect number;
   b) Quadrat number;
   c) Distance from the start of the transect;
   d) Water depth (m);
   e) Stock pug (hoof) marks per square metre;
   f) Estimated percentage cover of litter/debris;
   g) Estimated percentage cover of bare ground/mud;
   h) Name of each plant species (if known). If unknown record a Temporary code (e.g., unknown sedge # 1);
   i) Estimated percentage cover of each plant species (nearest 10 %, or below about 5 % cover, the nearest 1 % [~ %PFC]), and;
   j) the number of individual plants in a quadrat
   k) The linear length of fallen timber > 10 cm
   l) Median height of individual plant species in a quadrat
   m) The life stage of each plant species (Vegetative (V), Flowering (FL), Fruiting (FR), Seeding (S) or Dead (D);
7) If you are unsure of taxonomic status remove a specimen, including flowers and fruits if present, and place it in a plastic bag. Ensure that the destructive effects of sampling are minimised, especially with less common species. Label the bag with:
   a) Site Number.
   b) Site/Wetland Name.

c) Collectors Name(s).
d) Date collected.
e) Temporary code (e.g., unknown sedge # 1).

8) Please note these 'unknown specimens' should be pressed and preserved as soon as possible for later identification.
9) When you return to the office, remove specimens from their bags and tape each plant to a specimen sheet. Label the sheet appropriately. Allow specimens to dry completely before pressing.
10) Place the specimen sheets into a plant press.
11) Carefully place pressed specimens into a specimen box.
12) Contact the NSW Herbarium and advise them in advance of the number of specimens that you will be sending them and the type of analysis that you require.
13) Send specimen boxes to the NSW Herbarium for identification, to species level. Naphthalene or toilet soap may be added to the specimen box to prevent specimens being eaten by insects.

A1.4.8 MONITORING PROTOCOL: TREE COMMUNITY

This method is based on the NSW OEH method for survey and monitoring of flood dependent vegetation (Bowen 2013). It is designed to capture quantitative measures of the condition, structure and species composition of flood dependent vegetation communities. It includes measures of:

- Measures of cover.
- Tree recruitment.
- Community Structure.
- Species abundance.
- Functional group.

A1.4.8.1 Equipment

- GPS
- 2 x 100 m Tape
- 4 x hooked sand tent pegs for marking corners of the plot
- Sample bags/project books for collecting plant samples
- Permanent markers
- Pens
- Hand lens
- Site poles
- Fluorescent spray paint
- Mallet
- Aluminium tags
- Galvanised roofing nails
- Hammer
- DBH tape
- Field data sheets
- Field ID books

- Camera (with inbuilt GPS)
- Gumboots or waders
- A copy of this protocol.

A1.4.8.2 Preparation

- Before leaving the office / laboratory the following should be checked:
  - Batteries are charged and properly inserted.
  - Previous data downloaded and memory cleared.
  - GPS camera recording correctly
  - All equipment listed above is present and in functional order.

A1.4.8.3 Site Establishment

1) Find the site using the point location established in the Monitoring and Evaluation Plan.
2) Record the following on the field sheet:
   a) River or wetland name and ANAE ID.
   b) Date and time.
   c) GPS coordinates (latitude and longitude; GDA94).
   d) Name(s) of installation team.
3) Install the initial site marker pole at the NE corner of the 0.1 ha plot.
4) Plot is oriented north/south (i.e. tape is run 50 m S and 20 m W, starting from the NE corner). Alternate orientation is allowable but must be recorded.
5) Install the second site marker pole at the SW corner of the plot
6) Mark the corners of the plot with sand pegs and also place markers at the 20m point on the long side of the plot to mark out a nested 0.04 ha plot
7) Tag and number each live tree of diameter at breast height (dbh) greater than 10 cm within the 0.1ha plot using aluminium tags and galvanized nails, starting with the tree closest to the NW corner of the plot.

A1.4.8.4 Data Collection: Floristic Data

1) Mark out the site using the site establishment protocol (section A1.4.7)
2) For the 0.04ha plot record the following details on the field data sheet for all vascular species and each structural component of the vegetation (Tallest stratum, mid-stratum (>1m) and lower (<1 m) stratum).
   a) % plot flooded
   b) % plot wet soil
   c) % open water (including % submerged litter; % submerged bare ground; % submerged vege)
   d) % unsubmerged litter
   e) % unsubmerged bare ground
   f) Average water depth (cm)

g) Species Cover recorded as **Foliage Cover**[1][2] (FC) and is the percentage of the sample plot occupied by the vertical projection of *foliage and branches* (if woody) of a species for in each stratum in which it occurs.
h) **Crown Extent**[3] (CE) and **Canopy openness (CO)** for all tree species in the tallest stratum in tree communities
i) the percentage of the sample plot occupied by **litter** (non-attached plant matter e.g. leaves and branches less than 10 cm diameter) and is recorded as the sum of submerged and non-submerged litter in flooded plots (Note: where plants are dry or dead but can still be identified to species and are attached to the base of the plant, their cover is included in the species cover not in per cent litter)
j) the percentage of the sample plot occupied by bare earth and is recorded as the sum of submerged and non-submerged **bare ground** in flooded plots.
k) Number of individuals of each species (actual count or estimated number from sub quadrats for superabundant species) in each stratum in which it occurs.
l) **Strata type** (T=tallest, M=mid (>1m), L = lower (<1 m)
m) **Upper height** (average) of each species (metres).
n) **Lower height** (average) of each species (metres)
o) **Linear length of fallen timber at site** – the total length of fallen timber of diameter >10 cm is recorded.

3) If you are unsure of taxonomic status remove a specimen, including flowers and fruits if present, and place it in a plastic bag. Ensure that the destructive effects of sampling are minimised, especially with less common species. Label the bag with:
   a) Site Number.
   b) Site/Wetland Name.
   c) Collectors Name(s).
   d) Date collected.
   e) Temporary code (e.g., unknown sedge # 1).
4) Please note these 'unknown specimens' should be pressed and preserved as soon as possible for later identification.
5) When you return to the office, remove specimens from their bags and tape each plant to a specimen sheet. Label the sheet appropriately. Allow specimens to dry completely before pressing.
6) Place the specimen sheets into a plant press.
7) Carefully place pressed specimens into a specimen box.

[1] Foliage cover (FC) is the percentage of the sample site occupied by the vertical projection of foliage and branches (if woody). This is sometimes also termed per cent foliage cover or projected canopy cover. (Ayers et al. 2009)
[2] Projective Foliage Cover is the percentage of the sample site occupied by the vertical projection of foliage only (Walker and Hopkins 1998). Not to be confused with Foliage Cover.
[3] Crown cover (CC) is the percentage of the samples site within the vertical projection of the periphery of crowns. In this case, crowns are treated as opaque. (Ayers et al. 2009).

8) Contact the NSW Herbarium and advise them in advance of the number of specimens that you will be sending them and the type of analysis that you require.
9) Send specimen boxes to the NSW Herbarium for identification, to species level. Naphthalene or toilet soap may be added to the specimen box to prevent specimens being eaten by insects.

A1.4.8.5 Data Collection: Tree Data

1) Mark out the site using the site establishment protocol (section A1.4.8)
2) **Linear length of fallen timber at site** – the total length of fallen timber of diameter >10cm both within the 0.04 ha and remainder of the 0.1 ha plot.
3) **Total number of seedlings** - stems that are <10 dbh and < 1 m tall and are not sprouting from a coppiced rootstock, are treated as seedlings and the number is recorded separately for the 0.04 ha and remainder of the 0.1 ha plot.
4) **Total number of saplings** - stems that are <10cm dbh and > 1 m tall and are not sprouting from a coppiced rootstock, are treated as saplings and the number is and the number is recorded separately for the 0.04 ha and remainder of the 0.1 ha plot.

A1.4.9 DATA ANALYSIS

Once data have been collected from each site, the following additional steps need to occur

1) Check the Calculation of Total Foliage Cover (FC)

Total FC for lower stratum (<1 m) + ∑Species Cover + % litter + %bare ground = 100%, unless lower stratum space is occupied by mid storey emergent tussock form graminoid or spreading shrub species >1m tall (e.g. Lignum, rushes or reeds). Thus ground stratum the FC lower (ground) stratum = ∑Species Cover + % litter + %bare ground = 100% - total ∑FC of these mid stratum species.

In flooded sites total FC lower (ground) stratum includes; submerged vegetation, submerged bare ground and submerged litter.

2) Assign functional groups

Plant species are to be grouped into the four following functional groups (Brock and Casanova 1997, Casanova and Brock 2000, Casanova 2011):

- Amphibious responders (AmR) – plants which change their growth form in response to flooding and drying cycles.
- Amphibious tolerators (AmT) – plants which tolerate flooding patterns without changing their growth form.
- Terrestrial damp plants (Tda) – plants which are terrestrial species but tend to grow close to the water margin on damp soils.
- Terrestrial dry plants (Tdr) - those which are terrestrial species which don't normally grow in wetlands but may be encroaching into the area due to prolonged drying.

The use of these 'Brock and Casanova' functional groups has been commonly employed in NSW state reporting (e.g. IMEF, NSW OEH, Mawhinney 2003, Driver et al. 2010, Driver et al. 2011, Bowen 2013) and this will carry through to this method. Variations to the above method, consistent with state methods, will include:

- Measures of diversity based on the % cover of plant species recorded in the field. At least one level of correction will be required because the transect method records on average about 60% of the diversity that would be recorded in ocular surveys (Driver et al. 2014);
- For analysis and survey design vegetation species and communities are also grouped within "functional groups" (described in terms of the response to flooding of their dominant or canopy species) consistent with the definition of a wetland in the NSW Wetlands Policy (2010, following Bowen and Simpson 2010, Thomas et al. 2010, Bowen 2013).

Functional Group can be generated automatically from species name during data analysis from master list.

3) Calculate Crown Cover

Crown cover is a measure used to classify vegetation structural type and is used in the OEH Vegetation Type Standard (Siverston 2009). It is derived for each species in the over storey stratum of the plot by dividing the sum of canopy extent of all trees of that species by the area of the plot.

Where there are $j = 1$ to n_i trees of species i in the plot

A1.4.10 EVALUATION

To address the Selected Area evaluation questions, the vegetation data from each year will be analysed both separately and in combination with the data collected over preceding years. Analysis will consider the prevailing weather patterns and the watering history of each site.

For each survey occasion, the measures of species richness, abundance, cover will be analysed with respect to the duration of watering using univariate and graphical methods to determine the contribution of Commonwealth environmental water to riparian and wetland species. Measures of community composition (species composition, functional types and nativeness) will similarly be analysed to determine the contribution of Commonwealth environmental water to vegetation communities. Multivariate analyses (using measures of dispersion from MDS plots) will be used to detect changes across multiple elements of the vegetation community in relation to the duration of watering.

The contributions to populations of long-lived organisms (the floodplain and riparian trees such as river red gum, black box and river cooba) means ensuring that there are new cohorts in the population. The recruitment of key riparian species (river red gum, black box, coolabah and river cooba) will be analysed with respect to the duration of watering using univariate and graphical methods to determine the contribution of Commonwealth environmental water to populations of long-lived organisms.

A1.4.10.1 Data management

Following identification of the species that were unknown, data will be transferred from field data sheets to intermediate tables within a Microsoft Access database. Data in intermediate tables will be verified by QA/QC staff. The original datasheets will be scanned and copies of the data stored at the University of Canberra.

A1.4.11 HEALTH AND SAFETY

For details on health and safety please refer to the Workplace Health and Safety Plan for the Lachlan Selected Area (WHS 202.1) in Appendix C.

SUPPLEMENT A: WETLAND GROUNDCOVER SURVEY DATA SHEETS.

MER-VEGETATION FIELD SURVEY FORM

Wetland transect survey – Location and inundation

Location

Site Code			
Date		**Recorders**	

Transect 2		
Code		
Transect on side		
Transect Direction		
GPS coordinates START		
GPS coordinates END		

Photo Notes

Panoramic photo series taken from long-term photo point? y / n

Number of photos_____

Start and finish time of photos _____

Site Sketch

(provide a detailed site sketch including distances of bare, vegetated and wet areas; note location and orientation of transects within broader landscape features)

Recruitment (between transects: indicate meter mark and abundance**)**

Species name	m	#	m	#	m	#	m	#	m	#	m	#	m	#	m	#	m	#	m	#	m	#	m	#	m	#	m	#	m	#	m	#

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* Stage = Vegetative (V), Flowering (FL), Fruiting (FR), Seeding (S), Senescent (Se)
# = number of individual plants in 1 x 1 m quadrat;
C = % cover to nearest 10% (or 1% for < 10%)
H = average height of plants in cm

1% > 10x10cm
0.25% > 5x5cm
0.1% > 2x5cm
0.01% > 1x1cm

Site Code	
date	

Structure/ Coverage	Transect #	0m	10m	20m	30m	40m	50m	60m	70m	80m	90
% Water/ Water depth (m)		/	/	/	/	/	/	/	/	/	
% Litter											
% Bareground											
% Vegetation Cover (exact calculation in office)		~	~	~	~	~	~	~	~	~	
% Basal Area (live / dead)		/	/	/	/	/	/	/	/	/	
% Dead wood on ground (fallen)/ Dead wood linear length		/	/	/	/	/	/	/	/	/	
% Canopy Coverage (live / dead)		/	/	/	/	/	/	/	/	/	
% Disturbance											
Soil Moisture (dry, damp, waterlogged, submerged)											

bag	press	No	Species name	Stage	0m			10m			20m			30m			40m			50m			60m			70m			80m			90m		
					#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H
		1																															
		2																															
		3																															
		4																															
		5																															
		6																															
		7																															
		8																															
		9																															
		10																															

MER-VEGETATION FIELD SURVEY FORM Wetland transect survey

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* Stage = Vegetative (V), Flowering (FL), Fruiting (FR), Seeding (S), Senescent (Se) C = % cover to nearest 10% (or 1% for < 10%) H = average height of plants in cm # = number of individual plants in 1 x 1 m quadrat;	1% > 10x10cm 0.25% > 5x5cm 0.1% > 2x5cm 0.01% > 1x1cm	**Site Code**	
		date	

✓ Bag	✓ Pressed	Field No	Species name	Stage*	0m			10m			20m			30m			40m			50m			60m			70m			80m			90m		
					#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H	#	C	H
		11																															
		12																															
		13																															
		14																															
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		23																															
		24																															
		25																															

SUPPLEMENT B: MEASURES OF COVER

In this study cover is measured as "percent foliage cover" and is the area that is covered by a vertical projection of the plants foliage and small branches or the shadow cast on the ground rather than "projected foliage cover" that was suggested in the MER standard method. This is applied to **ALL** vegetation measures in the monitoring (e.g. trees, shrubs, ground, individual species, etc.). An example of "percent foliage cover" is provided in Figure 9.

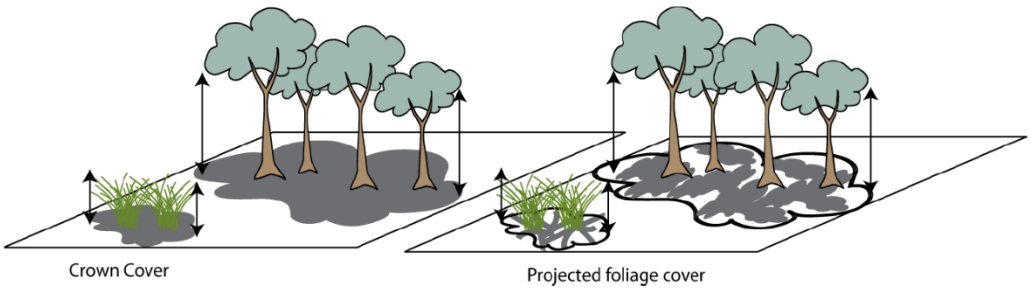

Figure 9. Crown (or canopy) cover (CC, left) and Percent Foliage Cover (%FC, right).
The picture (from Roberts and Hale 2013) was intended to represent projected foliage cover on the right but – for the detail shown in this picture – equally well represents %FC; which is what is ultimately reported in this study. CC is a function of crown extent and plot area. CC and Crown Openness at the plot scale are then used to calculate %FC (see Appendix 1).

Percent foliage cover (%FC) has been chosen as the measure of cover used in this method as projective foliage cover is difficult to measure in the field especially for understorey species.

Note: Difference between projective foliage cover and percent foliage cover:

- Projective foliage cover (fpc) is equivalent to the vertical shadow cast by an individual crown's **photosynthetic material only** (leaves, phyllodes, needles
- Percent foliage cover (%FC) , is equivalent to the amount of shadow that would be cast on the ground if there were a light source directly overhead and consists of both photosynthetic material and small twigs and branches

SUPPLEMENT C: CANOPY OPENNESS (CO) ESTIMATE

In some river red gum communities the canopy openness (CO) will be much less than 40 % especially in poor (>80% dead canopy) and intermediate poor (41-80% dead canopy) communities.

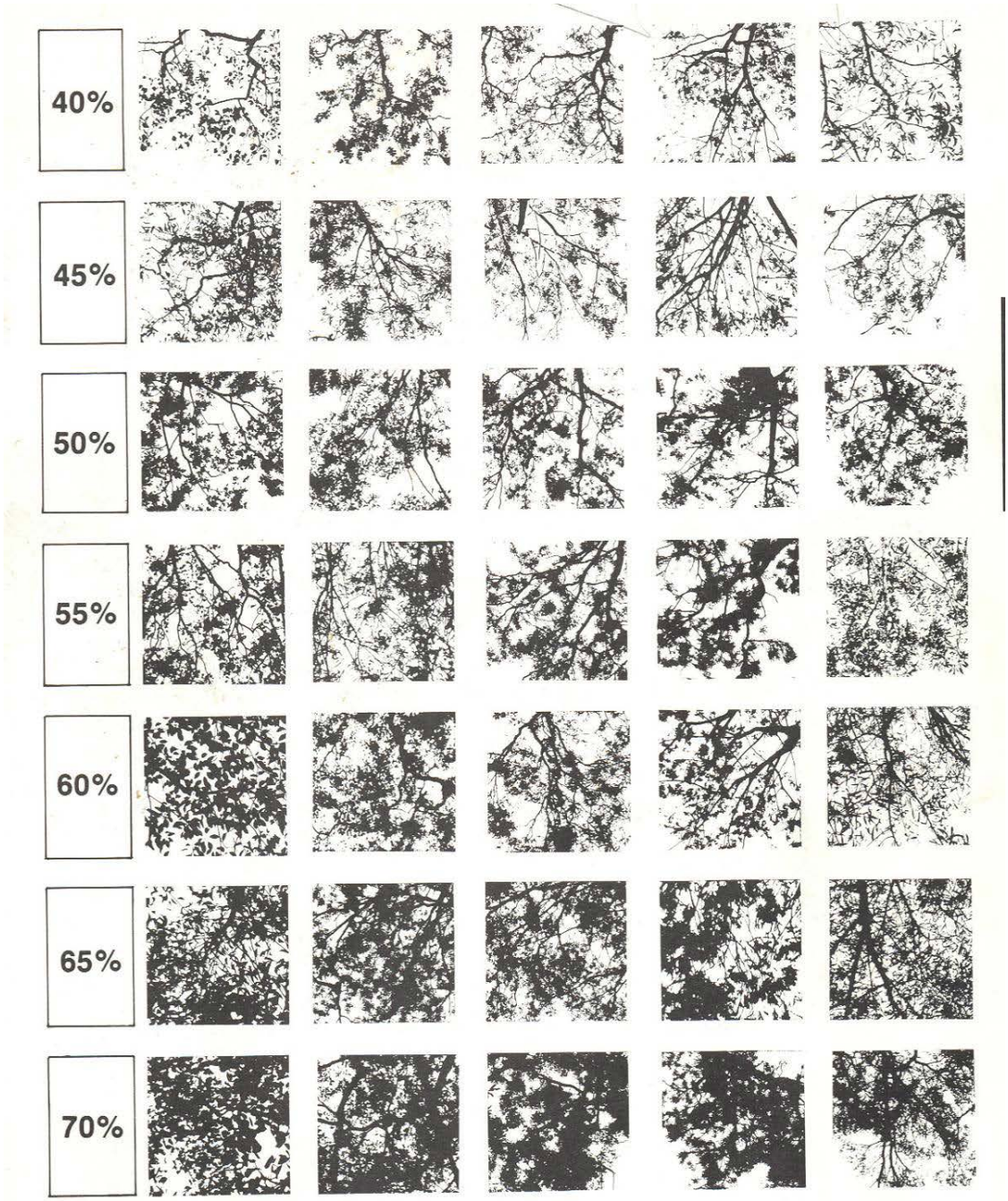

Figure 5 Crown types. Estimate the openness of individual tree or shrub crowns by matching the crown with a photograph. The rows show similar crown types for different leaf sizes (large to small, left to right); *Acacia* phyllodes are in the right hand row. Most Australian woody plants are in the range 40 per cent to 70 per cent.

Figure 10. Cown types and estimates of openness.
Source: DECC (2011) pg. 86. from Figure 6, p. 71 of Walker and Hopkins (1998)

SUPPLEMENT D: FLOOD DEPENDENT VEGETATION DATA SHEETS

MER-VEGETATION FIELD SURVEY FORM

Flood-dependent vegetation communities – Location, history and disturbance

Location

Site Code		date		Recorders	

Land use and Cover, Age Structure

Land Use (dominant)	grazing	nature conservation	travelling stock route	forestry	grazing	grazing / cropping	cropping	other:
Land Cover (upper stratum)	native	none	native	environmental planting	native plantation	exotic plantation	exotic/ native	other:
Land Cover (ground stratum)	native (native/ exotic)	none	native	environmental planting	native plantation	exotic crop	exotic/ native	other:
Age structure	uneven age	early regeneration	advanced regeneration	uneven age	mature	senescent		

Site History	Freq. code[1]	Age code[1]	Land Manager Survey: categories, quantities, comments
Grazing management			not grazed set stocked rotational / cell grazing
Grazing intensity [3]			high medium light none
Farming management			none direct drill disc plough tyned implement mouldboard rotary hoe
Erosion control			none contour cultivation contour banks mulching other
Timber extraction (incl. firewood)			
Regrowth management			
Weed control			
Pest animal control			
Burning			
Other			

[1] Frequency:
0=no record,
1=rare (>5yrs),
1=occasional (1-5yrs),
3=frequent (<1yrs).

[1] Age:
R=recent (<3yrs),
NR=not recent (3-10yrs),
P=old in the past (>10yrs)

[3] Grazing intensity:
high =<10% ground cover (in communities that you would normally expect >10) and/or – evidence of grazing to stubble over >50% of area , and or evidence of pug marking and scats over >30% of plot,
medium = evidence of grazing to stubble over >30% of area or to mid stem over >50% , and or evidence of pug marking and scats over >10% of plot.
light =evidence of grazing to stubble over >10% of area or to mid stem over >30% , and or evidence of pug marking and scats over >05% of plot.

Plot Disturbance	Severity code[4]	Age code[5]	Observational evidence:
Clearing (inc. logging)			
Cultivation (incl. pasture)			
Firewood collection			
Grazing			
Fire damage			
Storm damage			
Other			

[4]Severity: 0=no evidence, 1=light, 1=moderate, 3=severe	[5]Age: R=recent (<3yrs), NR=not recent (3-10yrs), P=old in the past (>10yrs)

MER-VEGETATION FIELD SURVEY FORM

Flood-dependent communities – Floristics 1

(within 0.04 ha quadrat)

Site Code	
date	

coverage and soil moisture of 0.04 ha	**% of plot, m or category**
Open Water: % / depths in m	/
% Litter	
% Bare ground	
% Vegetation [1]	~
Dead wood on ground: % / length in m (assumption Ø10cm: 40m>1%)	/
% Disturbance	/
Soil moisture [1]	

[1] exact calculation for % Veg. coverage will happen in the office (plus: canopy cover and basal area)
[1] dry, damp, waterlogged, submerged

Coverage in %	**Area**
1	1x1 m
0.5	1x1m
0.15	1x1 m
0.115	1x0.5 m
0.1	70x70 cm
0.06	50x50 cm
0.01	10x10 cm
0.001	7x7 cm
0.0001	1x1 cm

✓ Bag	✓ Pressed	No	Field name	Species name	Strata G or U[6]	% Cove-rage	# Indivi-duals	Ht (cm
		1						
		1						
		3						
		4						
		5						
		6						
		7						
		8						
		9						
		10						
		11						
		11						
		13						
		14						
		15						
		16						
		17						
		18						
		19						
		10						
		11						
		11						
		13						
		14						
		15						

[6]G (ground cover <1m), U (understorey cover 1-5m)

MER-VEGETATION FIELD SURVEY FORM

Flood-dependent communities – Floristics 1

(within 0.04 ha quadrat)

Site Code	
date	

✓ Bag	✓ Pressed	No	Field name	Species name	Strata: G or U[6]	% Cove-rage	# Indivi-duals	Ht (cm
		33						
		34						
		35						
		36						
		37						
		38						
		39						
		40						
		41						
		41						
		43						
		44						
		45						
		46						
		47						
		48						
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		51						
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		54						
		55						
		56						
		57						
		58						
		59						
		60						
		61						
		61						
		63						
		64						
		65						

[6]G (Ground cover: heights <1m), U (Understorey cover: heights 1-5m)

MER-VEGETATION FIELD SURVEY FORM –
Flood-dependent communities –Tree health data 1

(within 0.04 ha and 0.1 ha quadrat)

Site Code	
date	

Plot: 0.04/ 0.1 ha	Tree No	Tag No	Species name (RRG, BBX, RC, unk.)	Stem No	DbH (cm)	Ht (m)	Crown Extent (m^1)	% Crown out of	% Canopy Openness	% Dead	Dead limb/ live limbs	Fruit/ Flower/ buds	# of Hol-lows	# of Nests

*

CE CO DC **!! Stems** **!! Limbs**	Crown extent in m^1 (of each tree) Canopy openness the % of the sky obscured by leaves and small branches Dead canopy in % of present foliage that is dead Measure DBH separate for each major stem with DBH ≥10 cm (separation must be below 1.30 m, otherwise they are limbs) Count main limbs (DBH ≥ 10 cm) from common trunk or for each stem at the first separation (ie if tree has 4 and 1 are dead =(1/1)	1 stem, 4 limbs 	3 stems = 3 limbs 	1 stem , 6 limbs 

Site Recruitment (within 0.04 ha and 0.1 ha)

(While counting, please be consistent either use numbers or lines, or sum lines up afterwards!)

Plot	Species Name	Tree seedling <10 cm	Tree seedling 10-50 cm	Tree seedling 50-130 cm	Tree seedling 1.3–3 m	Tree seedling >3 m
0.04 ha						
0.1 ha						

Site Code	

date	

MER-VEGETATION FIELD SURVEY FORM –
Flood-dependent communities –Tree health data 1

(within 0.04 ha and 0.1 ha quadrat)

Plot: 0.04/ 0.1 ha	Tree No	Tag No	Species name (RRG, BBX, RC, unk.)	Stem No	DbH (cm)	Ht (m)	Crown Extent (m[1])	% Crown out of	% Canopy Opennes	% Dead	Dead limb/ live limbs	Fruit/ Flower/ buds	# of Hol-lows	# of Nests

A1.5 STREAM METABOLISM

A1.5.1 EVALUATION QUESTIONS

This monitoring protocol addresses the following Basin and Area evaluation questions:

- **Short-term (one-year) and long-term (five year) 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?

The process for evaluating these questions is illustrated in Figure 11 with components covered by this protocol highlighted in blue.

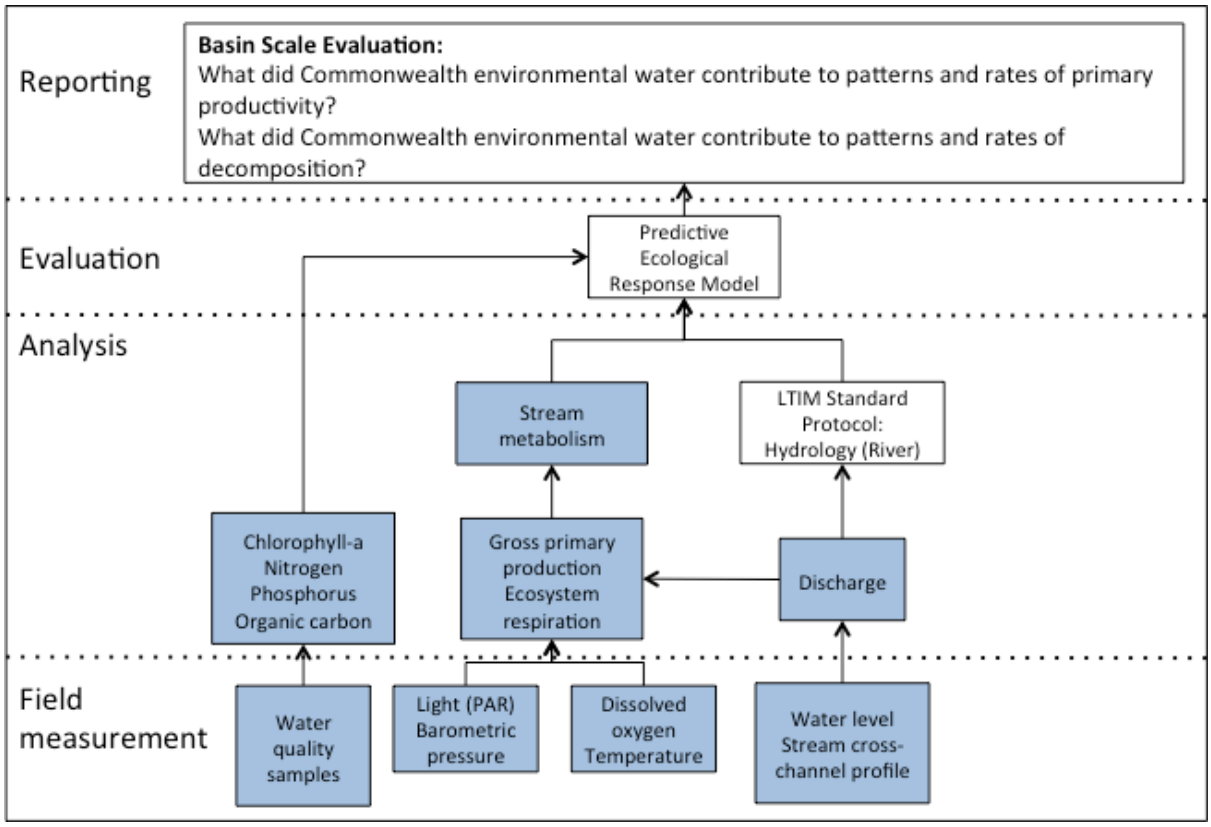

Figure 11. Schematic of key elements of the LTIM Standard Protocol: Stream metabolism.

A1.5.2 RELEVANT ECOSYSTEM TYPES

River.

A1.5.3 RELEVANT FLOW TYPES

Fresh, bankfull, overbank.

A1.5.4 OVERVIEW AND CONTEXT

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

1. To inform the Basin-scale quantitative evaluation of fish responses to Commonwealth environmental water (see MER Standard Protocol: Fish (River)).
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:

- Water level and stream characteristics (which may be available from an established gauging station).
- Discrete water quality samples (chlorophyll-a, total nitrogen, NOx, NH_4, total phosphorus, PO_4, dissolved organic carbon).
- *In situ* logging within the water column (dissolved oxygen, temperature) at every stream metabolism site.
- Logging of photosynthetically active radiation (PAR) and barometric pressure in a nearby terrestrial location, with the potential for a single PAR / barometric pressure station to capture all stream metabolism sites within 100 km.

This protocol is based on the single station open water stream metabolism method as detailed in Grace, M.R. and Imberger, S (2006). Stream Metabolism: Performing and Interpreting Measurements, Monash University (available to read online at: http://www.yumpu.com/en/document/view/5585175/stream-metabolism-faculty-of-science-monash-university) and Grace, M.R. et al. (2015).

A1.5.5 COMPLEMENTARY MONITORING AND DATA

Hydrological measures of stream discharge will be used to inform the interpretation of stream metabolism. Details of the methods used to collect hydrological information are included within the River Hydrology standard operating procedure.

A1.5.6 MONITORING LOCATIONS

A1.5.6.1 Protocol

MER for Basin-scale evaluation has adopted a hierarchical approach to sample design (Gawne et al. 2013a). Briefly, the spatial hierarchy for stream metabolism is as follows:

Selected Area → Zone → 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.

Zones have been matched to the fish monitoring sites, as these sites are known to have good access and will be visited monthly. The monitoring of stream metabolism has been mandated for sites at which fish monitoring occurs. We have selected Zone L1 as the zone for the monitoring of Basin-scale indicators as it is likely to receive Commonwealth Environmental Water during every year of the program (see Figure 1, page 2).

A1.5.6.2 Sites placement within zones.

A site is the unit of assessment nested within a zone and in this instance will be a section of river.

Stream metabolism is required to inform the Basin-scale quantitative evaluation of fish responses to Commonwealth environmental water (see MER Standard Protocol: Fish (River)). The sample design for the fish protocol involves a minimum of a single zone with ten sites within a zone distributed over < 100 km of single channel. It is mandated that stream metabolism measurements are located at river sites used for fish monitoring. This may also provide adequate data to assess changes in stream metabolism as a result of Commonwealth environmental water and will be used to provide an evaluation of the zone response to watering.

Four sites have therefore been selected for Stream metabolism monitoring. These are shown in Figure 2, page 2 and are:

- Willanthry
- Lane's Bridge
- Cowl Cowl
- Whealbah

With the mobility of fish and the extent over which the metabolism measures integrate, we have coverage over the extent of the 10 fish sites.

It is proposed to establish additional short-term sites in the mid Lachlan River associated with fish monitoring sites in those areas.

A1.5.6.3 Placement of stations

Stations for stream metabolism measures from the water column will be located within a site as follows:

- Open water, mid stream, with sufficient depth that the sensors will not be exposed, nor touch the sediment.
- Well mixed (non-stratified) water column to ensure sample is representative of reach.
- Constant flow (small streams with rocky / riffle or waterfall areas are not appropriate).
- No interference from tributaries, drains or significant groundwater inflows. For the Lachlan system we have identified sites with no major tributary for at least 4 km upstream of the logger location.

- Safe to access.
- Protection from vandalism (sampling locations on private property, with landholders permission are preferable).
- Probes should not be located within a macrophyte bed.

Measures of light (PAR) and barometric pressure are to be collected from a nearby terrestrial location (e.g. a fence post within an adjacent property). These measures are to capture the ambient conditions of the surrounding landscape and so should be located in an open area, not impacted by tree canopy or shading. A single station for the measurement of light and barometric pressure may be sufficient to cover the requirements for multiple stream metabolism (water column) sites within a 100 km radius, providing there are no significant differences in ambient conditions (e.g. vastly different altitudes). The Lachlan system is low gradient and for the study reaches chosen, there are no major inflows in the area immediately (within 5km) upstream. As a consequence single station methods are appropriate for measuring metabolism responses to environmental flows.

One important consideration is 'how far upstream is integrated by a probe in a day?' A reasonable estimate is provided by 3 v/K, where v is the mean water velocity in m/Day and K is the reaeration coefficient in /Day. As an example, a mean water velocity of 5 cm/s (0.05 m/s) equates to 4.3 km/Day. A typical value for K in a slow flowing river might be 5 /Day. Hence the distance upstream integrated by the probe will be 3 x 4.3/5 = 1.6 km. Both mean water velocity and K are dependent upon discharge, so the upstream distance integrated will change in a non-linear fashion with discharge. Flow at the study sites in the Lachlan system which have been collected as a part of previous work are in the range of 4-8 cm/s , meaning that the distance upstream integrated by each probe will be 1-4km. We have chosen sites where there are no significant inflows or other features (such as significant backwater areas) for >4km upstream.

A1.5.6.4 Timing

Stream metabolism measures will be collected continuously over the period for which water is flowing within the selected river site. Loggers will be maintained continuously in the Lachlan system at all sites, with downloads of data occurring approximately monthly, associated with maintenance of loggers.

A1.5.7 FLOW AND STREAM CHARACTERISTICS

River discharge (ML/day) and mean velocity (m/s) are required to interpret the stream metabolism measures and inform Basin evaluation. The monitoring locations are located such that a permanent stream gauging station adequately captures discharge (refer to Hydrology (River) methods), these data can be accessed and used to inform the modelling.

Mean velocity is calculated as discharge / cross sectional-area. In some circumstances, this may be able to be derived from the nearest gauge (supplemented with some site measures of cross sectional area and water level)

However, if an existing stream gauge does not adequately capture discharge and / or velocity, then a cross-section survey and water level logger will need to be installed (see MER Standard Method: Hydrology (River)).

A1.5.8 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 are collected for: chlorophyll-a, total nitrogen (TN), total phosphorus (TP), nitrate-nitrite (NOx), ammonium (NH_4), filterable reactive phosphorus (FRP) and dissolved organic carbon (DOC). In-situ spot measurements are taken for pH, turbidity and electrical conductivity (EC). At a minimum, these water quality samples and measures are collected when sensors are deployed and at each time the station is serviced and calibrated (≤ 6 weekly intervals).

Further samples can be collected during site visits for other purposes. Water quality meters will be provided to community groups to enable weekly sampling of conductivity and pH, and sampling associated with events such as fish kills, natural spates, environmental flows and blackwater events.

A1.5.8.1 Equipment

- Nalgene acid-washed 150mL containers.
- Pre-combusted amber-glass jars (DOC).
- 31% HCl (for DOC samples).
- 0.1 μm filters (Advantec; Dublin, USA), filter stage and hand vacuum pump for dissolved nutrients and carbon.
- 47 mm glass fibre (Watman GFC) filters, filter stage and hand vacuum for chlorophyll-a.
- Horiba U-10 water quality meter for pH, turbidity and electrical conductivity measurements.
- Deionised water for sample blanks.
- Eskies and ice for sample preservation and storage.
- Datasheets and/or field computer.
- Chain of custody sheets.
- Copy of this protocol.

A1.5.8.2 Protocol

- Samples and measurements will be collected mid stream and mid depth on a monthly basis.
- The sampler will stand downstream of sample collection point.
- Sampling will avoid surface films, but if present, a description will be entered onto the field sheet.
- For dissolved nutrients (NOx, NH_4, FRP) 150mL water samples will be filtered on site through 0.1 μm filters into Nalgene bottles and then stored on ice for return to the laboratory. Samples will be frozen within 11 hours of collection and analysed within 14 days. Grab samples were collected seasonally for one year. Concentrations of FRP and NOx will be determined using flow-injection analysis; NH4+ NH3 concentration will be measured using the phenate method (American Public Health Association (APHA) 2005).
- Chlorophyll-a will be measured using duplicate 250 millilitre samples. Samples will be filtered on site through GFC-50 and the filters stored on ice and in the dark. Samples will be frozen within 11 hours of collection and analysed within 14 days. Frozen filter

papers will be extracted in 10mL of acetone in the dark at 4 degrees Celsius for 11 hours. At the end of this time the acetone will be filtered through a GF-C filter to remove any sediment and then chlorophyll-a measured spectrophotometrically (Shimadzu UV-200, Shimadzu, Japan) using standard methods (American Public Health Association (APHA) 2014).

- For DOC, samples will be filtered on site on to 0.1 μm glass fiber filters into pre-combusted amber-glass jars and acidified (to pH < 1) with 31% HCl. All samples will then be refrigerated immediately and organic carbon concentration analyzed using a Shimadzu TOC-V CPH/CPN Total Organic Carbon analyzer (Shimadzu; Tokyo, Japan) upon return to the laboratory (within 71 hours).
- All analyses will be undertaken by NATA accredited lab, ALS.

A1.5.9 *IN-SITU* LOGGING

Stream metabolism measures for temperature, dissolved oxygen, light (PAR) and barometric pressure are logged at ten-minute intervals. Loggers are deployed continuously as it is expected that all sites in the Lachlan system will be continuously flowing. Loggers will be maintained continuously in the Lachlan system at all sites, with downloads of data occurring monthly, and associated with maintenance of loggers.

A1.5.9.1 Equipment

- Dissolved oxygen (DO) and water temperature will be logged using miniDOT (PME Sensors). Photosynthetic active radiation (PAR) will be measured using an Odyssey PAR logger (Odyssey; Christchurch, New Zealand).
- Barometric pressure will be logged with a Silva Atmospheric Data Centre Pro (Silva; Sollentuna, Sweden).
- Tool kit and spare parts for the multi-parameter probe; including spare batteries
- Metal star pickets and star picket driver or mallet
- Means to attach probe to star picket or permanent structure
- GPS
- Probe calibration log
- Field sheets
- Laptop and data cables for connecting to probes / logger

A1.5.9.2 Protocol

Preparation

- Prior to deployment in the field, all probes will be calibrated according to manufacturer's instructions and results of calibration entered into a calibration log.
- Before leaving the office / laboratory the following will be checked for all electronic equipment (probes, loggers, GPS):
    - Batteries are charged and properly inserted.
    - Previous data downloaded and memory cleared.
    - Check cable and cable connections.
    - Check for any obvious/minor faults on sensors including growth or dirt on the probes or tubing.
    - Check contents and condition of probe toolkit.

- All equipment listed above is present and in functional order.

Field method – PAR, barometric pressure

- PAR will be measured at 10 min intervals using a logger placed in full light adjacent to the upstream site.
- Barometric pressure will be will be logged at 10 min intervals using a logger placed adjacent to the upstream site.

Field method – water column measures

- Record the following on the field sheet:
  - River name and ANAE Streamid.
  - Date and time.
  - GPS coordinates (latitude and longitude; GDA94).
  - Name(s) of survey team.
- Record site characteristics:
  - Substrate type.
  - Width of channel.
  - Presence of any geomorphic features.
  - Percent canopy cover.
  - Land use immediate adjacent to site.
- Collect water quality samples and spot measures according to instructions in A1.5.8 above.
- The dissolved oxygen sensor will be calibrated prior to deployment and annually on site thereafter.
  - Calibration will be according to PME Sensors instructions, calibrating to oxygen free water (1% sodium sulfite Na_1SO_3 solution) and 100% saturation (air saturated water). Calibration to 100% saturation will be carried out by placing the probe in a bucket of stream water which itself is sitting in the stream to ensure thermal control. Air will be bubbled through the water in the bucket for at least 45-60 minutes until a stable reading is found from the probe.
- Loggers will be set to record at ten-minute intervals.
- Loggers will be deployed at each site in open water, mid stream and at a depth that will not expose sensors for entire deployment period. Sensors will not be placed in eddies, backwaters or where flow is influenced by structures.
- Deploy loggers.
- Loggers will be downloaded, serviced, cleaned and calibrated monthly.
- Any changes in site conditions will be noted.

A1.5.10 QUALITY ASSURANCE/QUALITY CONTROL

All water quality samples will be taken in duplicate, collected stored and analysed according to APHA (2014) protocols. All water quality samples will be taken and analysed in duplicate. All laboratory analyses will be carried out to NATA standards including analysis of blanks. Samples will be held for a maximum time as indicated in the appropriate protocols above. All loggers will be calibrated seasonally.

A1.5.11 DATA ANALYSIS AND REPORTING

This method adopts the approach of determining gross primary production (GPP), ecosystem respiration (ER) and reaeration rate (K_{O1}) from the diel dissolved oxygen curves. These parameters will be calculated from the raw data using curve fitting software (Grace and Imberger 2006, Grace et al. 2015) as provided to the MER project via the Govdex website.

The model uses data for dissolved oxygen in mg O_1/L, temperature, PAR and barometric pressure (in atmospheres) at 10 minute intervals, together with information on salinity which will be derived from the monthly EC values. The program provides estimates of GPP and ER in mg O_1 /L/day with uncertainties for each and goodness of fit parameters.

Patterns in ER are indicative of decomposition, while GPP indicates primary production. Correlations between GPP, ER and likely key predictors will be assessed. In particular the effects of 1) water quality parameters and 1) stream height/provision of environmental flows on ER and GPP will be assessed. These relationships are highly non-linear and typified by thresholds in other systems. The majority of analyses are likely to be descriptive based on responses to changes in flow, and illustrated using scatterplots. If the data are available, non-linear multiple regression may be applied to identify key drivers of GPP and ER. Analyses will be stratified seasonally and by antecedent flow conditions to determine contingent responses.

- **Short-term (one-year) and long-term (five year) 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?

Expected relationships between environmental flows deliver and water quality and stream metabolism parameters for the Lachlan system are consistent with the cause and effect diagrams provided in the Program Logic for Basin Level evaluation. ER provides an estimate of patterns and rates of decomposition, while GPP provides an estimate of patterns and rates of primary productivity.

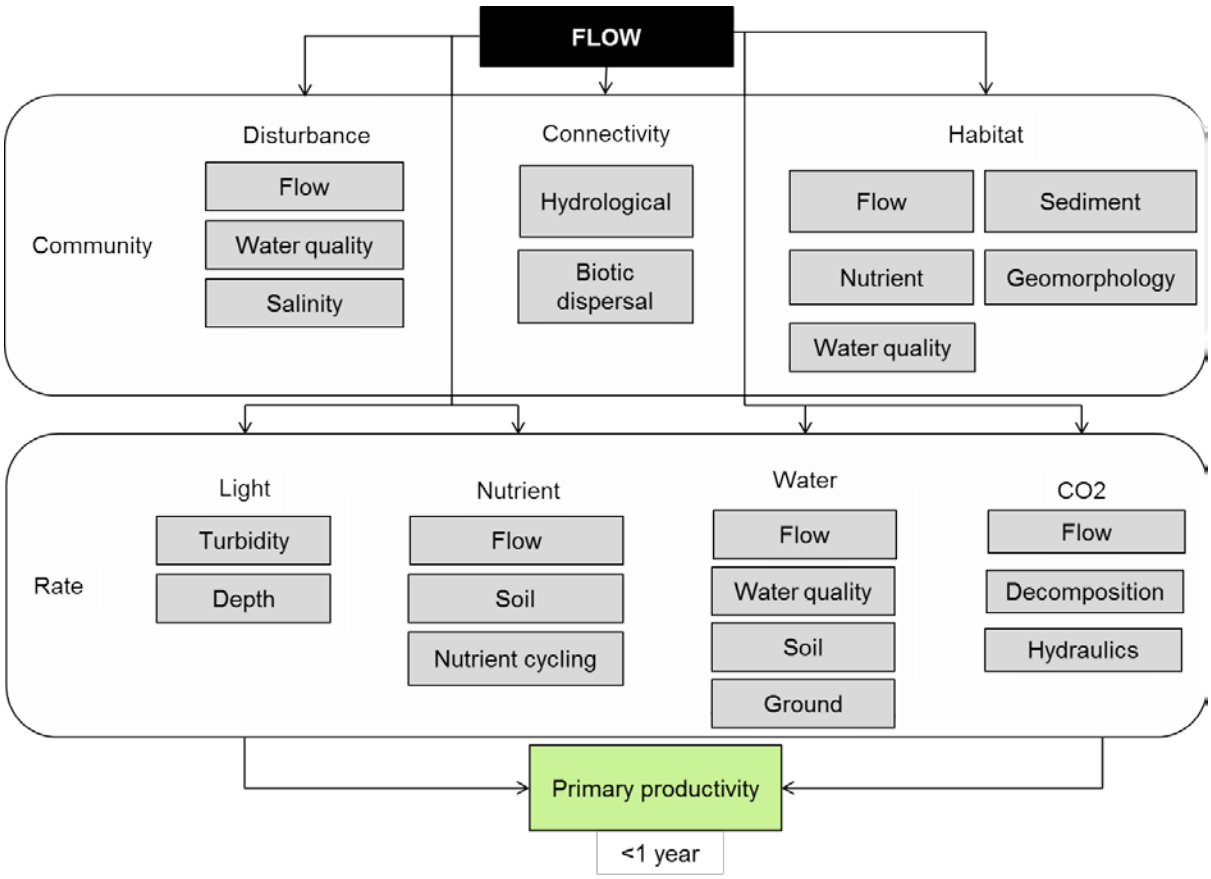

Figure 12. Cause and effect diagram depicting the influence of flow on primary production.

Environmental flows may be expected to influence water quality and stream metabolism in a number of ways.

- Inundation of terrestrial habitat may increase concentrations of N, P and DOC which may in turn support increased GPP (N, P) and ER (DOC).
- Extensive and prolonged inundation of terrestrial habitat may greatly increase DOC and therefore ER, resulting in depleted surface water oxygen levels (a 'blackwater event').
- Increased channel depth may act to shade benthic biofilms and macrophytes, reducing GPP.
- Increased water volumes may dilute phytoplankton cells (resulting in lower GPP) but then provide increased habitat and nutrients that may then allow a 'rebound' effect resulting in higher GPP.

These effects act to alter the amount of energy flowing into aquatic food webs and thus to higher consumers such as invertebrates and fish.

A1.5.12 DATA MANAGEMENT

All data provided for this indicator will conform to the data structure defined in the MER Data Standard. The data standard provides a means of collating consistent data that can be managed within the MER Monitoring Data Management System (MDMS).

The assessment unit for this indicator is the site (river section). Each row of data provided for this indicator will identify the assessment unit, the temporal extent of the data and a number of additional variables (as guided by this standard method). The exact data structure for this indicator is maintained and communicated in the MER Data Standard and will be enforced by the MDMS when data is submitted.

A1.5.13 HEALTH AND SAFETY

For details on health and safety please refer to the Workplace Health and Safety Plan for the Lachlan Selected Area (WHS 202.1) in Appendix C of the M&E Plan.

SUPPLEMENT A: EXAMPLE: STREAM METABOLISM DATA COLLECTION SHEET

Streamid:		River name:		Date:	
Observers:			Deployment / retrieval		
Stream characteristics:					
Stream width (m):					
Substrate type:					
Geomorphic features:					
Canopy cover (%)					
Adjacent land use:					
Notes:					

Water quality samples (check if collected)

Chlorophyll-a		Total P		FRP	
Total N		NOx		NH_4	
DOC					

In-situ logging

DO calibration (% saturation):			
Oxygen free water		100% saturation	
Logging commence / finish time:			
DO / Temperature sensor depth:			
Notes:			

A1.6 RIVERINE FISH

A1.6.1 OVERVIEW

Different categories of methods will be employed for the following evaluations;

- Basin evaluation (Category 1) of the response of river fish to Commonwealth environmental water delivery
- Area evaluation (Category 3) of the response of river fish to Commonwealth environmental water delivery for:
    - Option 1: within the selected channel reach (Zone L1).
    - Option 2: Zone L1 and mid-Lachlan River (M1)

Only Basin evaluation Category 1 methods will be used in the Lachlan Selected Area. Data collected using these methods are reported to and analysed by the Basin Scale Reporting Team in order to answer the Basin evaluation questions. They will also provide Selected Area specific information to answer Selected Area evaluation questions.

A1.6.2 EVALUATION QUESTIONS

A1.6.2.1 Basin evaluation questions

Small and large-bodied fish

Long term (five year) questions:

- What did Commonwealth environmental water contribute to sustaining native fish populations?

Short-term (one-year) questions:

- What did Commonwealth environmental water contribute to sustaining native fish reproduction?
- What did Commonwealth environmental water contribute to sustaining native fish survival?

These questions are taken from the revised fish foundation report (Stoffels et al. 2016).

A1.6.2.2 Selected Area evaluation questions

Small and large-bodied fishes

- **Long-term (five-year) questions:**
    - How does the fish community vary in the lower Lachlan Selected Area on an annual time step in relation to abundance, biomass and size? Does this link to sequential flow events and the hydrological regime?
- **Short-term (one-year) questions:**
    - Do commonwealth environmental water delivery events result in detectable changes in the abundance, biomass and size (length) of the fish community in the lower Lachlan Selected Area?

The process for evaluating these questions is illustrated in Figure 13, with components covered by this protocol highlighted in blue.

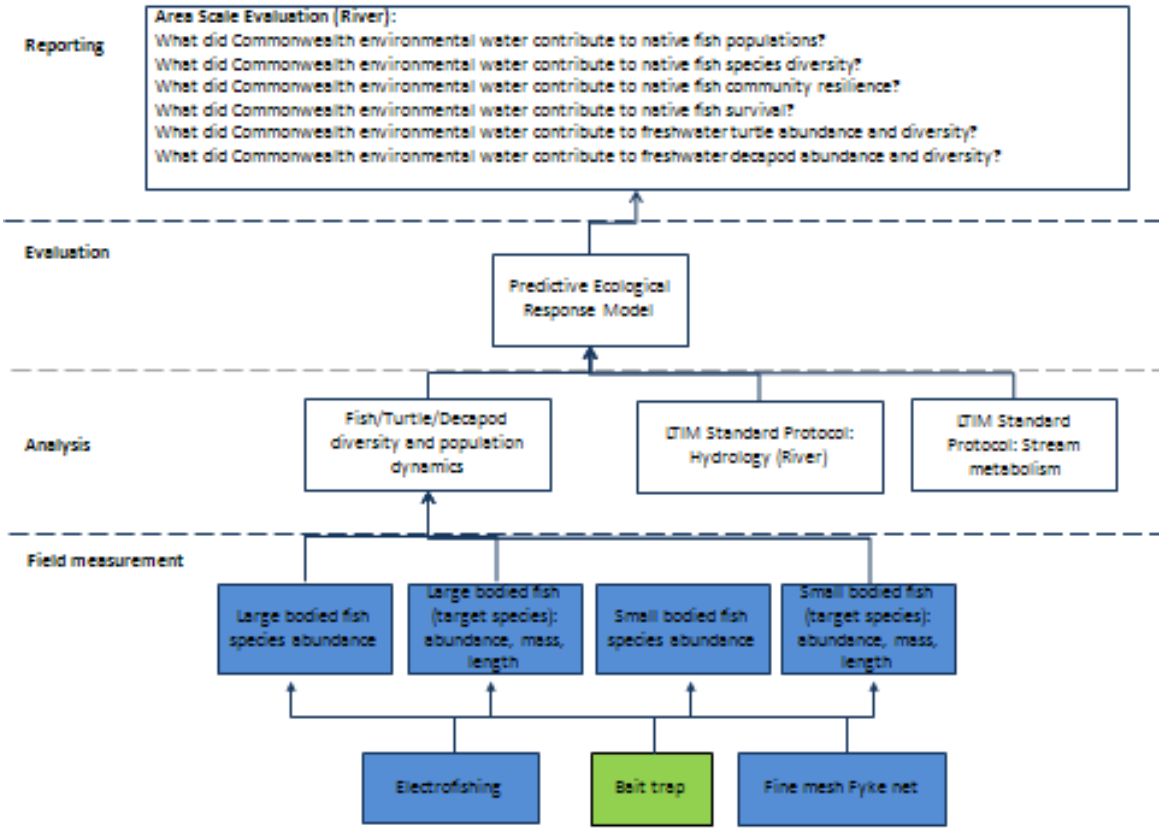

Figure 13. Revised schematic of key elements of the MER Standard Protocol: Riverine Fish Sampling.

A1.6.3 RELEVANT ECOSYSTEM TYPES

Rivers are the ecosystems relevant to fish.

A1.6.4 RELEVANT FLOW TYPES

All flow types are relevant to fish.

Annual sampling in Zone L1 for Basin-scale assessment (following Category 1 riverine fish sampling methods, Hale et al. (2014) will not allow an assessment of the outcome of any specific single fresh, bankfull or overbank flow event, but represents the overall response of fish assemblages to the combination of natural and managed hydrological conditions experienced within a single zone on an annual basis.

A1.6.5 OVERVIEW AND CONTEXT

Fish are an integral component of aquatic ecosystems and have been used as an indicator of aquatic ecosystem health in several large river health monitoring programs in south-east Australia (Davies et al. 2010, Muschal et al. 2010). The advantages of incorporating fish as indicators of aquatic ecosystem condition include (Harris 1995); i) fish are relatively long-lived and mobile, reflecting both short and longer-term and local to catchment scale processes, ii) they occupy higher trophic levels within aquatic ecosystems, and in turn, express impacts on lower trophic level organisms, iii) they are relatively easily and rapidly collected and can be sampled non-destructively, iv) they are typically present in most

waterbodies, and v) biological integrity of fish assemblages can be assessed easily and interpretation of indicators is relatively intuitive. Further, as fish have a high public profile, with significant recreational, economic and social values, they foster substantial public interest (MDBC 2004).

Aspects of native fish diversity, abundance, reproduction, growth and survival and dispersal were identified by Gawne et al. (2013b) as priority indicators relevant to monitoring the outcomes of environmental flow delivery in the lower Lachlan Selected Area.

Historically, 14 species of native fishes occupied the lower Lachlan catchment. Recent monitoring indicates that 10 of these species are still present, with four species locally extinct or exceedingly rare: The critically endangered flat-headed galaxias (*Galaxias rostratus*), endangered southern pygmy perch (*Nannoperca australis*) and southern purple spotted gudgeon (*Mogurnda adspersa*) and the non-threatened Murray-Darling rainbowfish (*Melanotaenia fluviatilis*). Of the 10 extant species, the threatened olive perchlet (*Ambassis agasizzii*), silver perch (*Bidyanus bidyanus*) and freshwater catfish (*Tandanus tandanus*) are at very low abundance and/or have a very restricted distribution. Only two species; carp-gudgeons (*Hyseleotris* spp) and bony herring (*Nematalosa erebi*) could be considered widespread and abundant. The natural fish assemblage is dependent on a range of habitat types within the system. Many of the smaller-bodied and most highly threatened species are wetland dependant while the larger-bodied species are largely (but not entirely) restricted to river channel habitats. All are dependent on flow events to provide spawning triggers, boost primary and micro-invertebrate production, provide connectivity between habitats (both lateral and longitudinal connectivity). All are dependent on the maintenance of quality refugia during drought periods to ensure resilience of the system.

Flow plays an important role in the life-cycle of native fishes from larval through to adult life stages. Water may inundate habitat needed for reproduction, triggering a spawning response, create a boost in primary production that improves recruitment success, improve habitat condition through maintaining natural geomorphic processes or stimulate in-stream migration (Figure 13, Figure 15).

River channel dependent species require flow triggers to initiate spawning (golden perch and silver perch), or recruitment success may be heavily dependent on nutrient inputs to the river channel following overbank flows (Figure 16). The seasonality of these flow triggers is critically important. Further, sediment transport and scouring during high flow events is essential to maintenance of deep pools and the input of large woody debris habitat. Freshes also provide movement triggers and facilitate longitudinal connectivity within the system. Persistence of these species is dependent on the provision of natural spawning triggers and subsequent boosts in primary production to facilitate successful recruitment as well as longitudinal connectivity within the river channel network.

For all fish species, access to high quality refugia during drought periods is critically important for ecosystem resilience, as unlike vegetation, many species of invertebrates, waterbirds and turtles, fish have no mechanisms to cope with the loss of water for even very brief periods of time.

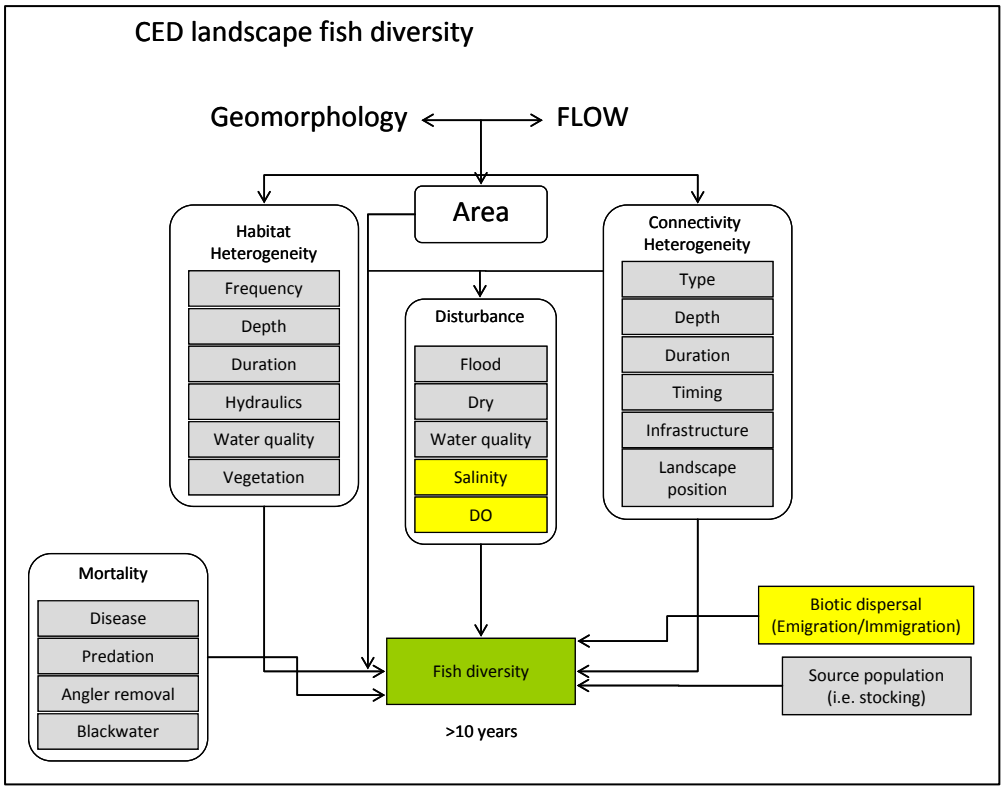

Figure 14. Revised landscape fish diversity CED. Yellow boxes indicate other CEDs.

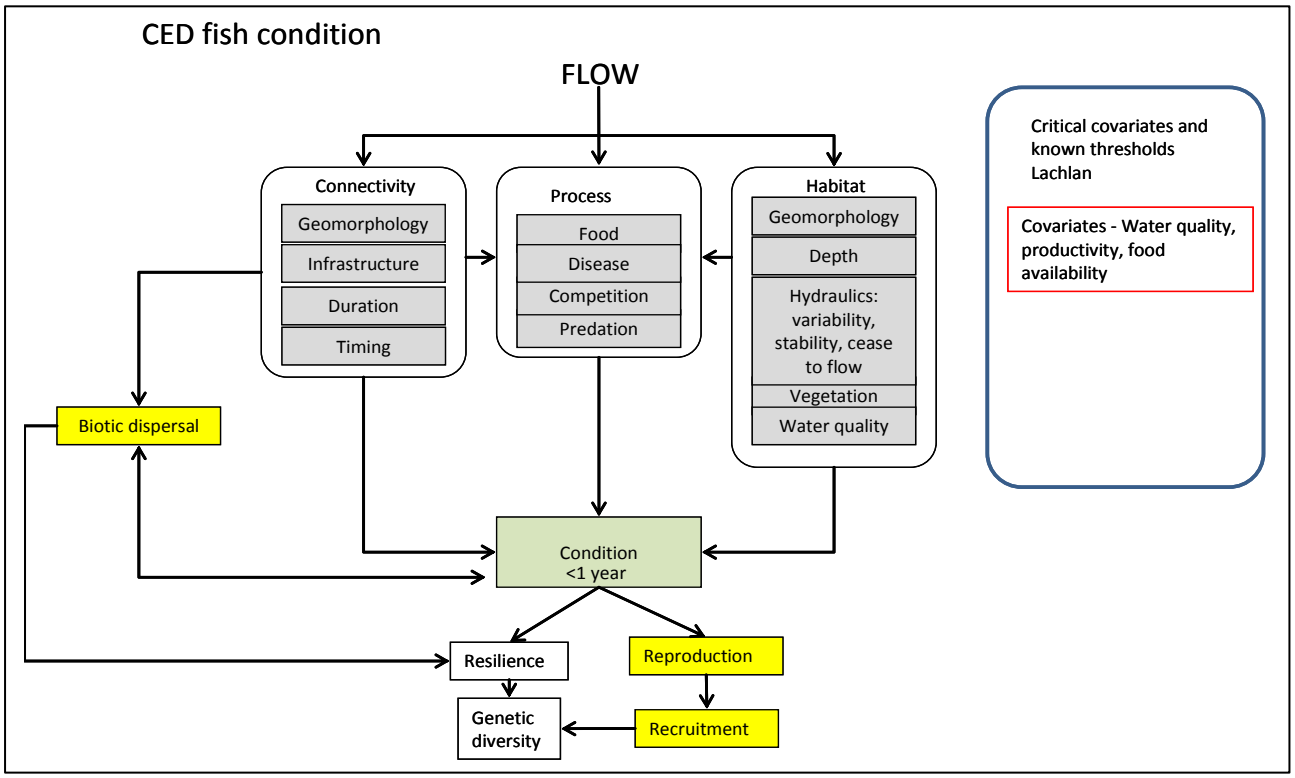

Figure 15. Revised fish condition CED. Yellow boxes indicate other CEDs.

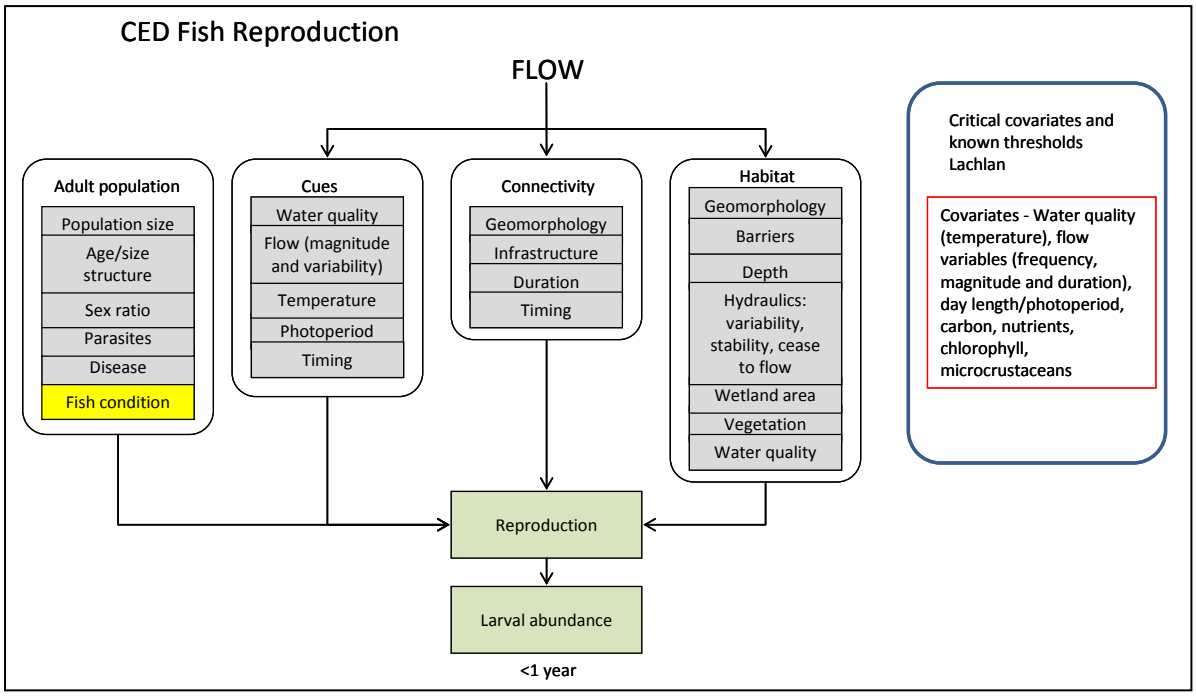

Figure 16. Revised fish reproduction CED. Yellow boxes indicate other CEDs.

A1.6.6 COMPLEMENTARY MONITORING AND DATA

Whilst older Museum records exist, the collection of standardised data on fish populations within the lower Lachlan catchment did not commence until 1994 (Harris and Gehrke 1997). Numerous projects have been undertaken since then (Growns 2001, 2008, McNeil et al. 2008, Price 2009, Davies et al. 2010, Gilligan et al. 2010, Wallace and Bindokas 2011) and additional unpublished data collected by NSW Department of Primary Industries (Fisheries) are available. Most of these data are held by NSW DPI (Fisheries). The remainder is available in technical reports published by MDFRC and SARDI (South Australian Research and Development Institute). Most significant are samples collected annually at seven sites within the lower Lachlan River channel (see Gilligan et al. 2010) between 2007 and 2012. These data are accompanied by data on water quality, micro-invertebrates, benthic and epi-benthic macro-invertebrates, aquatic macrophyte cover and diversity and structural aquatic habitat variables collected over a portion or all of the same period. Even longer time-series of fish assemblage data (commencing in 1994 and 1998) are available from two of these locations. Only a limited amount of fish assemblage data are available from distributary channels and floodplain wetland systems within the Lachlan.

We are aware of two other projects which plan to collect fish data from within the study area over the study period. The Invasive Animals CRC plans to continue to collect data from the seven sites established by Gilligan et al. (2010) between 2015 and 2017 as part of its carp biocontrol M&E program. This project adheres to SRA sampling protocols. The second is a NSW DPI olive perchlet monitoring program in the Lake Brewster area which samples annually to determine the local status of this population. Sampling for this project occurs within the outlet channel of Lake Brewster (Mountain Creek) and in the Lachlan River immediately downstream of Brewster Weir.

A1.6.7 REPRESENTATIVE SPECIES FROM LIFE-HISTORY GUILDS

The six 'representative' species we propose to target are:

- Equilibrium: Murray cod (*Maccullochella peeli*) and freshwater catfish (*Tandanus tandanus*)
- Periodic: golden perch (*Macquaria ambigua*) and bony herring (*Nematalosa erebi*)
- Opportunistic: carp-gudgeons (*Hypseleotris* spp) and unspecked hardyhead (*Craterocephalus stercusmuscarum*).

All six species are present within Zone L1 of the lower Lachlan Selected Area. Both of the periodic and opportunistic species, and one of the equilibrium species (Murray cod) are present in sufficient abundance to ensure required sample sizes are collected (for age and age-structure data). However, freshwater catfish are currently uncommon within the study area (listed as an endangered population under the *NSW Fisheries Management Act 1994*) and while we propose to collect population information on catfish we will not be undertaking destructive sampling of catfish to determine age. No other equilibrium species are present in the focal reach.

A1.6.8 MONITORING LOCATIONS

The lower Lachlan Selected Area can be partitioned into five spatially, geomorphologically and hydrologically distinct river channel zones at a broad landscape. Core monitoring undertaken within Zone L1 (Lachlan River channel between Brewster Weir and Booligal, see Figure 1, page 2). Representative of the main Lachlan River channel, this zone contains relatively high abundances of the required target species (with potentially limited numbers of freshwater catfish). Situated in the upper reaches of the selected area, this zone will also receive Commonwealth Environmental Water during each year of the MER project.

Contingency monitoring may be implemented on request within the mid-Lachlan River between Forbes and Lake Brewster (to continue short term monitoring undertaken in 2019). This zone has a similar fish assemblage but has the presence of the periodic species silver perch *Bidyanus bidyanus*.

The remaining zones differ significantly from Zone L1 and the mid-Lachlan in terms of fish assemblages and will not be monitored as part of the MER project.

NSW DPI has pre-existing data from 20 riverine sites within the lower Lachlan Selected Area, see Figure 6, page 33. Of these, 7 sites are established monitoring sites that have been sampled annually between 2007 and 2012. The remaining sites have been sampled between 1 and 3 times between 2001 and present. Sites required will be drawn from these existing sampling locations (where they were selected randomly), or, new randomly selected sampling locations will be generated in a GIS.

The 100 km reach specified as the maximum distance within which the 10 riverine fish monitoring sites can be selected (Hale et al. 2014) will extend for 100 km kilometres downstream from the Willandra Weir to the township of Hillston (see Figure 2, page 2)

A1.6.9 MONITORING TIMING

Annual sampling will be undertaken between March – May each year as specified by the standard methods (Hale et al. 2014).

A1.6.10 MONITORING PROTOCOL

A1.6.10.1 Equipment

- Electrofishing boat and equipment
- Backpack electrofisher and equipment
- 11 x fine meshed fyke nets (10 plus two spares) per site, with anchors and stakes
- Electrofishing and boating personal protective equipment
- GPS
- GPS coordinates of site structure (passive sample waypoints and electrofishing units)
- Passive sample waypoints determined using random number generator (sample locations within sites)
- Data sheets
- Large (1000 mm) and small (300 mm) measuring boards;
- Hanging scales with bag for large fish (1 - 50 kg capacity with 10 g accuracy) and bench scales with tray for smaller fish (0-1000 g capacity to 0.1 g accuracy)
- Water quality meter (pH, DO, Temperature, Conductivity, Turbidity)
- Eskies and ice for storing fish / fish heads for otolith analysis
- Sample jars, preservative and blank specimen labels
- Otolith dissection tools
- Otolith envelopes
- Ethics and sampling permits

Additional sampling equipment to Cat 1 requirements (see A1.6.10.2);

- 11 x collapsible shrimp traps (10 plus two spares) per site

A1.6.10.2 Protocol

Fish community annual assessment

Annual sampling for basin-scale analysis and selected area analysiswill follow the standard methods for riverine fish as specified by Hale et al. (2014). However, in order to improve comparability with historical data (SRA, NSW DPI) the following additional protocols and augmentations at each site have been proposed;

1. The amount of sampling effort per 90 second electrofishing ‘shot’ is to be partitioned between littoral/structural and open water habitats at a ratio of 5:1 in order to maintain comparability with CPUE data generated using the standard SRA protocol. This means that within any single electrofishing operation, 75 seconds should be used to sample littoral/structural habitats and 15 seconds of sampling should be undertaken in open-water habitats < 4 m deep.
2. Length data from all species is recorded for all operations of every gear type (with sub-sampling of 20 individuals per shot/net/trap) to allow generation of SRA metrics. This includes alien and both large and small bodied species.
3. The individual weight of the first 50 individuals measured for length of each non-target species will also be recorded.

4. Ten unbaited collapsible shrimp traps will be set for the duration of the electrofishing operations (minimum of 1.5 hours) to maintain consistency with SRA protocol.

Basin evaluation otolith analysis (Zone L1)

Basin evaluation otolith analysis within zone L1 will utilise published otolith procedural protocols (Secor et al. 1992, Campana 2001, Campana and Thorrold 2001) as specified by Hale et al. (2014).

- The five 'representative' species we propose to undertake otolith analyses are:
- Equilibrium: Murray cod (*Maccullochella peeli*)
- Periodic: golden perch (*Macquaria ambigua*) and bony herring (*Nematalosa erebi*)
- Opportunistic: carp-gudgeons (*Hypseleotris spp*) and unspecked hardyhead (*Craterocephalus stercusmuscarum*).

A1.6.11 QUALITY ASSURANCE/QUALITY CONTROL

QA/QC activities specific to this protocol include:

- NSW DPI staff are permitted to sample fish in NSW waters under a NSW Section 37 permit.
- University of Canberra staff apply for permission to sample using a NSW DPI scientific collection permit (if option 1 is selected).
- NSW DPI will apply to undertake research on fish under a research authority granted by the NSW Fisheries Animals Care & Ethics Committee.
- University of Canberra will apply to undertake research on fish under a research authority granted by the University of Canberra Animal Ethics Committee (if option 1 is selected).
- NSW DPI electrofishing operators are certified under the NSW DPI Electrofishing Training schedule (Wooden et al. 2013) and operate under the requirements of the Australian Code of Electrofishing Practice.
- University of Canberra electrofishing operators will operate under the requirements of the Australian Code of Electrofishing Practice.
- Electrofishing equipment is serviced by the manufacturer (Smith-Root Pty Ltd) on an annual basis.
- Fyke nets and collapsible shrimp traps are checked for holes or damage prior to every field trip and during each trip, and damaged nets either repaired or replaced.
- Scales are calibrated following manufacturers specifications prior to every field trip.
- A select sample of voucher specimens of those species groups typically difficult to identify in the field (see Muschal et al. 2010, Supplement: A, MDBA 2012) will be preserved for ID verification in the laboratory.
- A sub-sample of otoliths will be read twice to validate the readings.
- Following confirmation of the identity of those species where voucher specimens were collected, data will be transferred from field data sheets into intermediate tables within a Microsoft Access database (the I&I NSW Freshwater Fish Research Database - FFRD) and the original datasheets stored in fire-proof safes. Data in intermediate tables will be processed through a series of 50 range-checks to identify

any outliers and inconsistencies in data recording. All potential errors are referred to the senior operator responsible for data collection at that site for confirmation and/or correction. The corrected intermediate tables are then appended into the FFRD for storage. A level 3 data audit is also undertaken by the supervising scientist after each year's sampling in order to ensure compliance with sampling protocols.

A1.6.12 DATA ANALYSIS AND REPORTING

Relative abundance

Raw catch and effort data for each sampling operation (electrofishing shot or net/trap set) will be recorded. Processed data for fish abundances will be reported as standardised catch-per-unit-effort (CPUE) per method. Electrofishing CPUE will be standardised to catch per minute of electrofishing (power on time). Fyke net and shrimp trap CPUE will be standardised to catch per net hour.

Population structure data

Each individual measured/weighed will be assigned a unique identification code based on its sampling location, operation and sequence on the raw data sheets. This identifier will be used to label any otoliths collected and can subsequently be used to assign the ageing result from otolith analysis to each sample. Raw length, weight and age data for each individual will be provided to CEWO as required.

The abundance (CPUE) or proportion of new recruits within populations will be derived using a similar process to that applied to generate recruitment metrics for the SRA (Robinson 2012). For large bodied and generally longer living species (>three years), an individual will be considered to be a recruit if its body length is less than that of a one year old of the same species. For small bodied and generally short lived species that reach sexual maturity in less than 1 year, recruits will be considered to be those individuals that are less than the species known average length at sexual maturity. The recruitment length cut-offs used for both large and small bodied species will be derived from either length at age data generated by this program or from scientific literature.

The abundance (CPUE) or proportion of sexually mature adults within populations will be derived using a similar process as that above, but based on the length at sexual maturity of both large and small bodied species.

Individual body condition

Established length – weight relationships for each species (MDBC 2004, NSW DPI unpublished data) will be used to estimate the expected weight of individuals based on their length. Relative body condition of each individual will be calculated as = recorded weight/ expected weight.

Fish assemblage condition

Using the Sustainable Rivers Audit data analysis methods described by Robinson (2012), eight fish metrics will be derived from the data collected on each sampling occasion. The eight metrics will then be aggregated to produce three fish condition indicators and these indicators will then be used to derive an overall Fish Condition Index (ndxFS). The SRA derived Indicators will be: (1) *expectedness* (provides a comparison of existing catch composition with historical fish distributions), (2) *nativeness* (an indicator of the dominance of native versus alien fish in the assemblage), and (3) *recruitment* (an indicator of the extent of native fish recruitment within the zone). These indicator scores are scaled between 0 and 100 and are condition rated as (Extremely Poor (0-20), Very Poor (21-40), Poor (41-60), Moderate (61-80), Good (81-100). SRA condition scores can be compared across time and before and after flow events, with an overall expectation that condition ratings will improve over time.

A1.6.12.1 Data analyses

As has been conducted within the existing MER project running from 2014/15 to 2018/19, fish community data will be collected annually (March) from 10 pre-selected in-channel sites in the Lower Lachlan Selected Area, from Wallanthery to Hillston and for option 1 as was sampled as part of the short-term monitoring undertaken in the mid-Lachlan River between Forbes and Lake Brewster. At each site, single sampling events will involve a suite of passive and active gears including boat-electrofishing (*n*=31 operations, each consisting of 90 seconds 'on-time'), unbaited bait traps (n=10) and small fyke nets (n=10) (Hale et al. 2014). Additionally at each site, large fyke nets will be set to target freshwater catfish (n=4), and baited opera house traps will survey decapods (n=5).

All captures (fish and other non-target taxa) will be identified to species level and released onsite, with the exception of the periodic species bony herring which will be retained for annual ageing (n=100) (Hale et al. 2014). Individuals will be measured to the nearest mm and weighed to the nearest gram. Where large catches of particular species occur, a sub-sample of individuals will be measured and examined for each gear type. The sub-sampling procedure consists of firstly measuring all individuals in each operation until at least 50 individuals has been measured in total. The remainder of individuals in that operation will also be measured, although any individuals of that species from subsequent operations of that gear type will only counted. Fish that escaped capture, but could be positively identified will also be counted and recorded as "observed".

Total catch will be pooled for all sites and methods, with the exception of the calculation of SRA metrics where the first 11 electrofishing shots and bait trap data will be used (Davies et al. 2010). To determine differences between years, abundance and biomass data will be analysed separately using one-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al. 2008). Raw data will be fourth root transformed and the results will be used to produce a similarity matrix using the Bray-Curtis resemblance measure. Where significant differences are identified, pair-wise post-hoc contrasts will be used to determine which years differed. Similarity percentage (SIMPER) tests will be used to identify individual species contributions to average dissimilarities between years.

Sustainable Rivers Audit (SRA) fish community condition indices (Expectedness, Nativeness, Recruitment) will be calculated to quantify overall condition of the fish community

assemblage. Data will first be portioned into recruits and non-recruits. Large-bodied and generally longer lived species (maximum age >3 years) will be considered recruits when length is less than that of a one year old. Small-bodied and generally short-lived species, that reach sexual maturity in less than one year, will be considered recruits when length is less than the average length at sexual maturity. Recruitment lengths are derived from published scientific literature or by expert opinion when literature is not available Table 9. Eight fish metrics will be calculated using the methods described by Robinson (2012). These metrics will then be aggregated to produce three indicators (Nativeness, Expectedness and Recruitment), and to derive an overall fish community condition index. Metric and indicator aggregation use Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) (Davies et al. 2010, Carter 2012).

Table 9. Size limits used to distinguish new recruits for each species. Values represent the length at one year of age for longer-lived species or the age at sexual maturity for species that reach maturity within one year.

SPECIES	ESTIMATED SIZE AT 1 YEAR OLD OR AT SEXUAL MATURITY (FORK OR TOTAL LENGTH)
Native species	
Australian smelt	40 mm (Pusey et al. 2004)
Bony herring	67 mm (Cadwallader 1977)
Carp gudgeon	35 mm (Pusey et al. 2004)
Flatheaded gudgeon	58 mm (Pusey et al. 2004, Llewellyn 2007)
Freshwater catfish	83 mm (Davies 1977)
Golden perch	75 mm (Mallen-Cooper 1996)
Murray cod	222 mm (Gavin Butler, Unpublished data)
Un-specked hardyhead	38 mm (Pusey et al. 2004)
Alien species	
Common carp	155 mm (Vilizzi and Walker 1999)
Eastern gambusia	20 mm (McDowall 1996)
Goldfish	127 mm (Lorenzoni et al. 2007)
Redfin perch	60 mm (maximum reported by Heibo et al. 2005)

The Expectedness index is the proportion of native species found within the relevant catchment and altitudinal zone, compared to a historical reference condition. The index value is derived from two input metrics; the observed native species richness relative to the expected species richness at each site, and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (Robinson 2012). The Nativeness index is the proportion of native compared to alien fishes, and is derived from three input metrics; proportion of total biomass that is native, proportion of total abundance that is native and proportion of total species richness that is native (Robinson 2012). The Recruitment index represents the recent reproductive activity of the native fish community, and is derived from three input metrics; the proportion of native species showing evidence of recruitment, the average proportion of sites at which each species captured was recruiting (corrected for probability of capture

based on the number of sites sampled), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). The three indicators are aggregated to generate a weighted overall Fish Condition Index (Carter 2012). Overall condition is then partitioned into five equal categorical bands to rate the condition of the fish community as "Good" (80–100), "Moderate" (60–79), "Poor" (40–59), "Very Poor" (20–39), or "Extremely Poor" (0–19).

A1.6.13 DATA MANAGEMENT

Following confirmation of the identity of those species where voucher specimens were collected, data will be transferred from field data sheets into intermediate tables within a Microsoft Access database (the I&I NSW Freshwater Fish Research Database - FFRD). Data in intermediate tables will be processed through a series of 50 range-checks to identify any outliers and inconsistencies in data recording. All potential errors are referred to the senior operator responsible for data collection at that site for confirmation and/or correction. The corrected intermediate tables are then appended into the FFRD for storage. A level 3 data audit is also undertaken by the supervising scientist after each year's sampling in order to ensure compliance with sampling protocols.

The original datasheets will be scanned and copies of the data stored at the University of Canberra. The original data sheets will be stored in fire-proof filing cabinets at the Narrandera Fisheries Centre.

A1.6.14 HEALTH AND SAFETY

For details on health and safety please refer to the Workplace Health and Safety Plan for the Lower Lachlan Selected Area (WHS 202.1) in Appendix C.

SUPPLEMENT A: MURRAY DARLING BASIN AUTHORITY - SUSTAINABLE RIVERS AUDIT PROTOCOL FOR FISH THEME SAMPLING – IMPLEMENTATION PERIOD 8: 2011-13

INTRODUCTION

This protocol applies to the sampling of SRA sites as part of the Fish Theme. It was developed by the MDBA's SRA team in consultation with the SRA Joint Venture Committee, Independent Sustainable Rivers Audit Group, the Jurisdictional Managing Agencies (JMA) and the Fish Taskforce.

PREREQUISITES

The following prerequisites must be met before applying this protocol:

- a current sampling plan has been received from the Authority office
- the site has been validated in accordance with the Site Validation protocol
- field staff meet the requirements of their respective JMAs and agencies in applying this protocol, and
- field staff must comply with the requirements of the Australian Code of Electrofishing Practice.

SAMPLING PRINCIPLES

The staff undertaking sampling must adhere to following principles, which are fundamental to the application of this protocol

- Sampling is to take place between 1 November and 30 April. In the North of the Basin (specifically the Paroo, Warrego and Condamine) the sampling period may extend to the end of May if temperatures earlier in the season are too high to work.
- Sampling is not to take place during periods of high flow, either natural or from impoundment releases. High flows are those which in the judgement of the field operators would pose an occupation health and safety risk or compromise catch efficiency to unacceptable levels.
- The Authority office must be notified as soon as practicable by the sampling agency or the JMA of any change to the application of this protocol or methods deployed at a site during a site visit in the event of equipment malfunction, site abandonment or disruption to a sampling event.
- Each major habitat type present at a site must be sampled at least once and then remaining sampling effort should occur in the most abundant habitat types. Recognised habitat types are pool edges, middle portions of pools, runs and riffles, slow-flowing back waters, emergent vegetation, submerged vegetation, large woody debris and debris dams.
- Sites must be sampled using the most appropriate methods, as listed in Tables 6.1 and 6.1. It is likely that both backpack and boat electrofishing will be used at most sites.
- Data are only to be recorded for fish greater than 15 mm total length.

- All caught fish are released live, except where State noxious or alien fish policies require otherwise or where samples are required as voucher specimens (see Voucher specimens).

DEPLOYMENT OF SAMPLING METHODS

Fish sampling will be conducted by electrofishing (boat, bank-mounted and backpack) and by use of bait-traps. Given the wide variety of site conditions in the Basin (from small upland streams to large lowland rivers) the teams will need to make a site-specific assessment of conditions. This assessment will need to identify the type of habitats present and their relative abundance, after which a decision can be made on the appropriate mix of sampling methods. In particular, the site should be assessed to identify all habitats that can be electrofished by boat, bank-mounted and/or backpack methods, and the proportion suitable for each method should be determined.

Guidance on the selection and deployment of fish sampling methods is provided in the following tables.

The broad mix of sampling methods to be deployed under different site conditions is described in Table 10, and guidance on their application is provided in Table 11.

Table 10. Choice of fish sampling method under varying site characteristics.

SITE CHARACTER	APPROPRIATE METHODS
Large river sites: >15 m wetted channel width (as estimated by sampling teams)	• Adopt large boat electrofishing. • Include backpack shots as necessary to sample each wadeable habitat type at least once. • Deploy 10 bait-traps.
Small river sites: <15 m wetted channel width (as estimated by sampling teams)	• Adopt small boat electrofishing • Include backpack shots as necessary to sample each wadeable habitat type at least once • Deploy 10 bait-traps.
Wadeable habitats	• Adopt backpack electrofishing. However, bank-mounted electrofishers can be used instead of backpack electrofishers for sites with electrical conductivity levels between 1500 µS/cm and the detection limits of the bank-mounted unit, provided agencies accept their use. • Deploy 10 bait-traps.

Table 11. Application of fish sampling methods.

METHOD NAME	APPLICATION
Boat electrofishing	• Deploy 11 shots. • Note: A shot is 90 seconds of accumulated power-on time. • In portions of streams >15 m wetted channel width (as estimated by sampling teams), adopt alternate shots alongside both banks. • In portions of streams <15 m wetted channel width (as estimated by sampling teams), adopt zigzag coverage of sampled area. • Deploy two mid-channel shots when mid-channel water depth <4 m.
Backpack (and Bank-mount) electrofishing	• Deploy 8 shots. • Note: A shot is 150 seconds of accumulated power-on time. • In portions of streams <10 m wetted channel width (as estimated by sampling teams), adopt zigzag coverage of sampled area. • In streams >10 m wetted channel width (as estimated by sampling teams), adopt alternate shots alongside both banks. • Where electrical conductivity is >1500 µS/cm and where agencies accept their use, bank-mounted electrofishers can be used in place of backpack electrofishers using the same procedures.
Bait-trap	• Deploy 10 bait-traps for 1 hours (± ½ hour depending on duration of electrofishing effort). • Only deploy at locations with depth <1 m. • Do not use bait or chemical light sticks in the traps. • Set traps in slow-flowing or backwater areas independent of electrofishing sites. • Pool the catch from all traps and record as a single event.

Table 12. Number of electrofishing shots required with each type of electrofishing gear.

METHOD	PROPORTION OF SITE								
	<1/8	1/8	¼	3/8	½	5/8	¾	7/8	All
Boat	0	0	4	5	6	8	9	11	11
Backpack	0	1	1	3	4	5	6	8	8

BAIT-TRAP PLACEMENT

Sampling practices guided by Table 3 above and as adopted during Implementations Periods 1–6 should continue to be used.

MEASUREMENT OF INDIVIDUALS AND SUBSAMPLING

Fish smaller than 15 mm may be recorded, but should not be reported as core SRA data as they will not be used in the analysis. A subsample of 50 individuals per species captured by each method (i.e. boat electrofishing, backpack electrofishing and bait-traps) used at each site should be measured for the listed attributes below. The subsample begins with the first individual of each species collected from each method and continues until the 50th

individual. During electrofishing operations, in the shot/replicate where the 50th fish is found, all individuals present should be measured and recorded in order to avoid any bias in the size of fish selected for the subsample. For bait-traps the catch is pooled prior to counting and measuring, each fish is identified, and the first 50 of each species are measured. An effort should be made to reduce bias in sub-sampling the pooled catch, e.g. use a small aquarium dip-net to net the pooled catch. (Note: NSW DPI prefers to collect the data for each trap independently and then, using random sampling of the data, generate a compliant pooled data return for MDBA.) If the number of individuals captured by each sampling method is less than 50, all of them should be measured for the attributes listed below.

Data to be recorded for each individual are outlined below.

1. *Length:* Caudal fork length for species with a forked tail and total length for species with round tails are to be measured. Approximate length should be estimated for damaged fish and this will be considered equivalent to a measured length during data analysis. Length should be measured to the nearest mm using a measuring board.
2. *Weight:* If weight is to be recorded for that species, then each individual fish should be blotted dry and measured on a balance with a suitable range for individual being measured:
3. for fish >50 g, record weight to nearest gram, or
4. for fish 50 g or less, record weight to nearest 0.1 g.
5. *Health and condition:* For data requirements chapter: Fish health and condition.
6. *Voucher specimens:* These are to be collected if that species requires a voucher specimen (refer to Table A 1-8 and Voucher specimens).

SPECIES LIST

The species list is a combination of those species thought to have occurred in the Basin under reference conditions, those species caught during previous sampling events and those alien species expected to be caught in future sampling.

The list may be updated from time-to-time where new species are identified, taxonomy revised or data collection requirements change. Those species for which voucher specimens should be collected or weight recorded are indicated in this list. Requirements for voucher specimens are presented below.

When identifying alien species such as carp and goldfish, field teams should be aware that there is the possibility of hybridisation. Jurisdictions may decide whether or not they wish to record the presence of hybrids. However, in doing so they should be aware that when the data are received by the MDBA, any hybrids will be assigned to a single parent taxon (e.g. carp or goldfish) based on which parent stock the body dimensions of the hybrid most resemble. This will therefore require that jurisdiction field teams either record hybrids as a single parent taxa (e.g. carp or goldfish) immediately in the field, **OR** record in the field as hybrids and take appropriate notes to allow matching to either parent taxa prior to transmission of data to MDBA.

Table 13. Murray–Darling Basin SRA fish taxa, including whether they require voucher specimen collection and/or weighing.

TAXA CODE	SCIENTIFIC NAME	COMMON NAME	GET VOUCHER SPECIMEN	RECORD WEIGHT
ACAFLA	*Acanthogobius flavimanus*	Yellowfin goby	YES	
ACABUT	*Acanthopagrus butcheri*	Black bream		
AFUTAM	*Afurcagobius tamarensis*	Tamar River goby	YES	
ALDFOR	*Aldrichetta forsteri*	Yellow-eyed mullet	YES	
AMBAGA	*Ambassis agassizii*	Olive perchlet	YES photo only	**YES**
AMOBIF	*Amoya bifrenatus*	Bridled goby	YES	
ANGAUS	*Anguilla australis*	Short-finned eel		
ANGREI	*Anguilla reinhardtii*	Long-finned eel	YES	
ARGHOL	*Argyrosomus hololepidotus*	Mulloway		
ATHMIC	*Atherinosoma microstoma*	Small-mouthed hardyhead	YES	
BIDBID	*Bidyanus bidyanus*	Silver perch	YES[a]	**YES**
BIDWEL	*Bidyanus welchi*	Welch's grunter	YES[a]	
CARAUR	*Carassius auratus*	Goldfish		
CARCAR	*Carassius carassius*	Crucian carp	YES	**YES**
CRAAMN	*Craterocephalus amniculus*	Darling River hardyhead	YES	**YES**
CRAFLU	*Craterocephalus fluviatilis*	Murray hardyhead	YES	**YES**
CRASTE	*Craterocephalus stercusmuscarum fulvus*	Unspecked hardyhead	YES	
CYPCAR	*Cyprinus carpio*	Common carp		
GADBIS	*Gadopsis bispinosus*	Two-spined blackfish		
GADMAR	*Gadopsis marmoratus*	River blackfish		
GALBRE	*Galaxias brevipinnis*	Climbing galaxias	YES	**YES**
GALMAC	*Galaxias maculatus*	Common galaxias	YES	
GALFUS	*Galaxias fuscus*	Barred galaxias	YES	
GALOLI	*Galaxias olidus*	Mountain galaxias	YES	
GALROS	*Galaxias rostratus*	Flat-headed galaxias	YES	**YES**
GALSP1	*Galaxias* sp1	Obscure galaxias	YES	
GALSP1	*Galaxias* sp1	Riffle galaxias	YES	**YES**
GALTRU	*Galaxias truttaceus*	Spotted galaxias	YES	**YES**
GAMHOL	*Gambusia holbrooki*	Gambusia		
GEOAUS	*Geotria australis*	Pouched lamprey	YES	**YES**
HYPGAL	*Hypseleotris galii*	Firetail gudgeon	YES[b]	
HYPSPP	*Hypseleotris* spp.	Carp gudgeons (lumped)	YES[b]	
LEIUNI	*Leiopotherapon unicolor*	Spangled perch		
LIZARG	*Liza argentea*	Flat-tailed mullet	YES	
MACAMB	*Macquaria ambigua ambigua*	Golden perch		
MACAUS	*Macquaria australasica*	Macquarie perch		
MACCOL	*Macquaria colonorum*	Estuary perch		**YES**
MACMAC	*Maccullochella macquariensis*	Trout cod / Bluenose cod	YES[c]	
MACPEE	*Maccullochella peelii peelii*	Murray cod	YES[d]	
MELFLU	*Melanotaenia fluviatilis*	Murray–Darling rainbowfish	YES[e]	
MELSPL	*Melanotaenia splendida tatei*	Desert rainbowfish	YES[e]	**YES**
MISANG	*Misgurnus anguillicaudatus*	Oriental weatherloach	YES	

MOGADS	*Mogurnda adspersa*	Southern purple-spotted gudgeon	YES photo only	
MORMOR	*Mordacia mordax*	Short-headed lamprey	YES	
MUGCEP	*Mugil cephalus*	Sea mullet	YES	
MYXELO	*Myxus elongatus*	Sand mullet	YES	
NANAUS	*Nannoperca australis*	Southern pygmy perch		
NANOBS	*Nannoperca obscura*	Yarra pygmy perch		**YES**
NEMERE	*Nematalosa erebi*	Bony herring		
NEOHYR	*Neosilurus hyrtlii*	Hyrtl's tandan		
ONCMYK	*Oncorhynchus mykiss*	Rainbow trout	YES[f] <100 mm	
PERFLU	*Perca fluviatilis*	Redfin perch		
PHIGRA	*Philypnodon grandiceps*	Flathead gudgeon	YES	
PHIMAC	*Philypnodon macrostomus*	Dwarf flathead gudgeon	YES	**YES**
PORREN	*Porochilus rendahli*	Rendahl's tandan		
PSEOLO	*Pseudogobius olorum*	Blue-spot goby		
PSEURV	*Pseudaphritis urvillii*	Congolli		
REDMAC	*Redigobius macrostoma*	Large-mouthed goby	YES	
RETSEM	*Retropinna semoni*	Australian smelt		
RUTRUT	*Rutilus rutilus*	Roach	YES	**YES**
SALTRU	*Salmo trutta*	Brown trout	YES[f] <100 mm	
TANTAN	*Tandanus tandanus*	Freshwater catfish		
TASLAS	*Tasmanogobius lasti*	Lagoon goby		
TINTIN	***Tinca tinca***	**Tench**		**YES**

[a] *Bidyanus bidyanus* and *Bidyanus welchi* may both be in the Paroo and voucher specimens and/or colour images are required for confirmation.

[b] *Hypseleotris* species should be collected in Queensland valleys to determine if *Hypseleotris galii* is present. For all other valleys the genus is lumped.

[c] *Maccullochella macquariensis* to be photgraphed when individual >110 mm and a voucher specimen collected when <100 mm.

[d] *Maccullochella peelii peelii* to have voucher specimen collected for small fish (<110 mm) in regions where *Maccullochella macquariensis* occurs.

[e] *Melanotaenia fluviatilis* and *Melanotaenia splendida tatei* may both be in the Paroo, Warrego and Middle to Upper Darling and voucher specimens and or colour images are required for confirmation.

[f] Small trout (<100 mm) should have voucher specimens collected to ensure *Salmo trutta* and *Oncorhynchus mykiss* are distinguished.

VOUCHER SPECIMENS

Voucher specimens are to be collected for rare species, uncertain species and for notable range extensions of any species. Required species are shown in the Get Voucher column of Table 5. Note the following recommendations for voucher collections.

- Collect at least three specimens where possible, covering a range of size and colouration.
- Preserve specimens in 90–100% alcohol.
- Label each voucher sample with the following information: SRA site ID, State, river name, date collected and collector's name.

- Use a container of adequate size so that fish are not bent or crammed in, and ensure adequate preservative concentration is maintained.
- Obtain good quality digital images of all live specimens depicting body colouration and fin shape.

Note: Good quality digital images of live specimens depicting body colouration and fin shape are an acceptable alternative when specimens are too large to be effectively preserved and for those species identified in Table A 1-10 above.

Identification of the specimen is a three-stage process.

1. Return specimens to the sampling team's laboratory and use collective knowledge and identification aids to confirm identification.
2. If uncertainty remains, use a known specialist in that particular taxon to confirm the specimen's identification.
3. If a specialist is not available or any uncertainty remains, send the specimen to the following fish taxonomist, who will confirm identification or, in conjunction with the Authority, determine a process to have the specimen identified.

Tarmo Raadik
Arthur Rylah Institute for Environmental Research
113 Brown Street
Heidelberg Vic 3084

FISH HEALTH AND CONDITION

The presence of any abnormality sighted on any part of a measured fish should be recorded on the field sheet. At least one side of the fish should be checked completely for abnormalities. Abnormalities are to be assessed only on the measured subsample of each species.

Those fish abnormalities that are considered reportable are listed in Table A 1-10. The fact that a handled fish exhibits one or more abnormalities must be indicated by listing the health code against attribute 'HealthCode' in the data return. A 'HealthCode' entry is recorded as a continuous sequence of the codes available in Table 14. Examples of valid entries include 'D', 'DWLP' and 'PLWD'. The codes 'yes' or 'true' can be used when an abnormality is observed but the descriptive health code has been misplaced, lost or forgotten. This ensures that the presence of all abnormalities is recorded even if the type of abnormality is lost.

Table 14. Reportable abnormalities exhibited by handled fish.

HEALTHCODE	ABNORMALITY DESCRIPTION
D	Deformity (skeleton deformities, blindness, fin deformities, asymmetrical, etc)
F	Fin condition poor (broken, eroded fins)
S	Lesions (skin abnormality with raised and or discoloured scales)
U	Ulcers (skin is broken, crater like, redness)
T	Tumour (localised abnormal growth)
W	Wounds (e.g. bird strikes, hook wounds)
G	Fungus
L	*Lernaea* spp. (but only where a notable number are present. This is defined as: If fish <100 m total length, report any *Lernaea* sp.; If fish >100 mm total length, report if more than 3 *Lernaea* sp.)
P	Other visible parasites
O	Other: the abnormality must be photographed and described and/or a specimen preserved
Yes True	Either of these codes can be used when an abnormality is observed but the above list has been misplaced, lost or the health code has been forgotten

A1.7 FISH (LARVAE)

A1.7.1 OVERVIEW

This protocol describes the methods that will be used to monitor larval fish for both Basin scale (specified by the CEWO) and the Area scale evaluation.

A1.7.2 EVALUATION QUESTIONS

A1.7.2.1 Basin evaluation questions

- **Short-term (one-year) questions:**
  - What did Commonwealth environmental water contribute to native fish reproduction?
  - What did Commonwealth environmental water contribute to native larval fish growth?
  - What did Commonwealth environmental water contribute to native fish survival?

- **Long-term (five-year) questions:**
  - What did Commonwealth environmental water contribute to native fish populations?
  - What did Commonwealth environmental water contribute to native fish species diversity?

The process for evaluating these questions is illustrated in Figure 17, with components covered by this protocol highlighted in blue. Note that the boxes marked in red for otolith examination and daily age and growth are optional (category 1) monitoring associated with this method.

A1.7.2.2 Selected Area evaluation questions

- **Short-term (one year) evaluation questions:**
  - What did Commonwealth environmental water contribute to native fish reproduction in the lower Lachlan River catchment?
  - What did Commonwealth environmental water contribute to native larval fish growth and survival in the lower Lachlan River catchment?

Long-term (five year) evaluation questions:

  - What did Commonwealth environmental water contribute to native fish populations in the lower Lachlan River catchment?
  - What did Commonwealth environmental water contribute to native fish species diversity in the lower Lachlan River catchment?

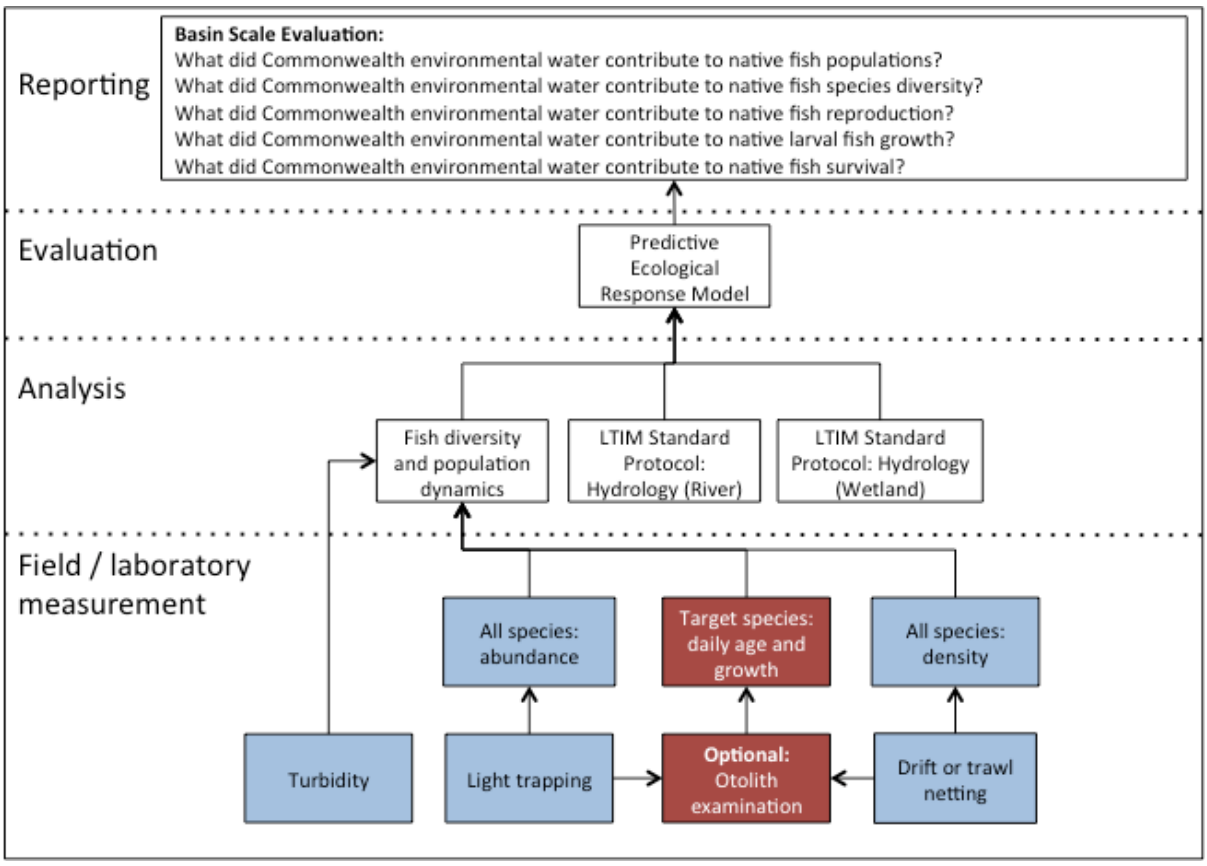

Figure 17. Schematic of key elements in LTIM Standard Protocol: Fish (Larvae).

A1.7.3 RELEVANT ECOSYSTEM TYPES

Rivers.

A1.7.4 RELEVANT FLOW TYPES

These methods describe annual monitoring conducted during the period August to February of each year independent of specific watering events. The methods are therefore relevant to all flow types.

A1.7.5 OVERVIEW AND CONTEXT

A common goal of many environmental flow regimes is the maintenance and enhancement of the native fish community (King et al. 2010). This strategy is based on the premise that aspects of the flow regime are linked to key components of the life history of fish, including pre-spawning condition and maturation, movement cues, spawning cues and behaviour, and larval and juvenile survival (e.g. Junk et al. 1989, Humphries et al. 1999, King et al. 2003, Balcombe et al. 2006). Since the strength of recruitment, is largely driven by spawning success and growth and survival of young, understanding how the flow regime influences the early life history of fishes is critical to managing fish populations (King et al. 2010). This document provides an overview of the methods of evaluating the contribution of Commonwealth Environmental Water releases to native fish spawning, larval fish growth and survival and recruitment to the population.

These methods describe monitoring required for the Basin Evaluation and Selected Area Evaluation of fish breeding in response to Commonwealth environmental water. The methods describe the sampling design and protocol for fish larvae in rivers for the LTIM project.

This protocol describes sampling fortnightly for 5 sampling events between September through to December each year to measure:

- Catch-per-unit-effort (CPUE) of each larval fish species in rivers using:
    - Light traps
    - Fixed position drift nets in flowing sites or towed trawl nets in low/no current sites.
- Collection of water quality sample or *in situ* measurement of turbidity

A1.7.6 MONITORING LOCATIONS

A1.7.6.1 Protocol

MER for Basin-scale evaluation and area scale evaluation has adopted a hierarchical approach to sample design (see Gawne et al. 2013). The spatial hierarchy for fish (river) monitoring is as follows:

Selected Area → Zone → Site

Please refer to MER Standard Protocol: Fish (River) for more detail on the nested hierarchical approach design adopted for MER fish sampling.

A1.7.6.2 Site placement within zones

Basin Methods

Larval fish monitoring for Basin scale analysis will take place at a subset of the same sites specified for monitoring of fishes in the channel (see MER Standard Protocol: Fish (River)). The rationale underlying this is to seek as much synergy as possible among the different monitoring components for fishes. For basin evaluation larval fish sampling will be undertaken in one zone at three sites:

- Three channel sites (also sampled for adult fish – see Figure 2, page 2)
    - Lanes Bridge
    - Hunthawang
    - Wallanthery

Selected Area Methods

Selected Area Evaluation will be made using the same sites as for basin methods with an additional option of three sites in a second zone (M1 in the mid-Lachlan, see Figure 1, page 2) which may be undertaken on request. The additional larval fish monitoring sites will be a subset of the 10 sites monitored in the additional option of monitoring the fish community in the mid-Lachlan zone. Specifically, this monitoring regime will be able to detect the contribution of Commonwealth Environmental Water to enhancing native fish spawning and recruitment in Zone L1 (where reasonable populations of the target native species are

already present) and the mid-Lachlan Zone where CEW has been delivered over the past three years.

- Three additional channel sites in the mid-Lachlan zone (also sampled for adult fish):
    - Kirkup Park
    - Techam
    - Euabalong

A1.7.6.3 Sample placement within sites

Equipment

- GPS
- Possibly a boat, depending on access

Up to three different larval sampling gears will be used within the three channel sites of the zone targeted for both basin and area evaluations: Light traps, drift nets, and larval tows/trawls. Upon inspection of field sites, it is most likely that drift nets will be employed in channel habitats as there will be sufficient flow. For further detail on why these three methods have been selected, and gear specifications, refer to section A1.7.7.

Ten **light traps** will be randomly allocated within each site. The same randomisation approach recommended in MER Standard Protocol: Fish (River) will be used, with the following caveat: light traps must be positioned within slackwater. The set of 10 random PS waypoints will be used (see MER Standard Protocol: Fish (River)). The closest slackwater to that waypoint will be used for positioning of light traps. If no slackwater is available within 20 m either side of the waypoint another random waypoint will be selected.

Light traps will be used for larval assemblage composition and potentially for relative abundance comparisons/contrasts among areas. Their efficacy is heavily dependent on turbidity, so any comparisons of relative abundance among areas will be dependent on the inter-area differences in turbidity levels.

Larval density is measured using stationary drift nets for higher current areas and towed nets for low current pools.

Three **Drift nets** per site (total of nine per zone, per sampling event) will be positioned in water with a moderate velocity, preferably where the discharge is concentrated through a narrow section of the river (a funnel effect). Ideally, drift nets will not be closer than 100 m to each other.

If a site does not contain suitable water for setting drift nets (too slow, wide, deep, etc.) then a boat will be used for taking **larval trawls**. Three replicate five-minute trawls at approximately ½ m per second will be allocated to each site (nine five-min trawls per area, per sampling event). To ensure samples are independent, the water column in any space must only trawled once.

A1.7.7 SAMPLING PROTOCOL

A1.7.7.1 Equipment

- Ethics and fisheries permits from relevant institutions.
- Light traps.
- Larval drift nets.
- Boat.
- Data sheets

A1.7.7.2 Protocol

Timing of sampling

At each site, larval sampling will take place over five sampling events between October and December inclusive. These sampling events may be event targeted during this time, though will be taking in consideration the seasonal requirements of the target native fish species in terms of other factors required for the onset of spawning (day length, temperature etc.). These are referred to as the five 'sampling events' below. Sampling will be undertaken following Commonwealth Environmental water released in the months between September and December. In the Lachlan river catchment selected area these flows are most likely to be released earlier in that period due to restrictions of releasing Commonwealth water associated other flow releases for irrigation.

Sampling

The sampling procedure is the same for Riverine fish.

The six 'representative' species we propose to target are:

- Equilibrium: Murray cod (*Maccullochella peeli*) and freshwater catfish (*Tandanus tandanus*)
- Periodic: Golden perch (*Macquaria ambigua*) and bony herring (*Nematalosa erebi*)
- Opportunistic: Australian smelt (*Retropinna semoni*) and flathead gudgeon (*Philypnodon grandiceps*).

All six species are present within the target Zones of the lower Lachlan catchment. *In situ* measurements of turbidity will be taken each fortnight via calibrated meter.

Modified quatrefoil light traps will be used, see Humphries et al. (2002). Mesh will be fitted around the light traps to eliminate larger fish from entering the trap, and eating the sample (3 mm knot-to-knot). The ten light traps set within each of the three sites will be set in the afternoon and retrieved the following morning. Set and retrieval times will be recorded, so that relative abundance can be expressed as catch-per-unit-effort (CPUE). Each light trap will be 'baited' with a yellow 11 h light stick.

If **drift nets** are appropriate for the site, they will be constructed of 500 µm mesh, have an opening diameter of 50 cm, tapering over 1.5 m to an opening of 9 cm, to which a reducing bottle fitted. Positioning of drift nets is explained earlier. Volume through the net will be estimated so that larval abundances in drift nets can be expressed as a density: number of individuals per m^3. Volume sampled by the net is estimated as $\pi r^2 \cdot v \cdot t$, where *r* is radius in metres, *v* is mean velocity in m s^{-1}, and *t* is time set in seconds.

If **larval trawls** are appropriate then larval tow nets will be exact dimensions to the stationary drift nets. Similarly, volume through the net will be estimated using a flow meter attached to the front of the net. Velocity of the boat will be no less than ½ m per second, to avoid fish swimming away from the net. Larval trawls will take place during the early evening in the channel (so that in channel drift nets will be comparable to trawl nets), and abundances will be expressed as number of individuals per cubic metre of water sampled.

Processing

Entire samples will be preserved individually in 90% ethanol and returned to the laboratory for larval identification and enumeration.

A1.7.8 DATA ANALYSIS AND REPORTING

A1.7.8.1 Basin-scale evaluation

Turbidity

Turbidity measures will be recorded as mean turbidity per site per sampling event and assessed against Light trap abundance data for all sites.

Relative abundance estimation

Light-trap abundances will be expressed as 'catch-per-unit-effort' (CPUE), where the units are number of individuals per trap per hour of deployment. Drift and trawl net abundances will be expressed as densities; number of individuals per cubic metre of water filtered (see Section A1.6.10.2).

Community data

CPUE data will be provided at the level of the site (species by site abundance matrices). Abundance data is reported for each species as the mean CPUE for the site. Data will be provided separately for each sampling method:

- Light-trap channel;
- Drift net OR larval trawl channel.

A1.7.8.2 Area-scale evaluation

Short-term (1 year) questions

- What did Commonwealth environmental water contribute to native fish reproduction in the lower Lachlan River catchment?

Larval fish abundance (described in chapter Protocol A1.7.7.2) will be analysed using parametric univariate ANOVA using year as the factor. In the same way, changes in larval fish assemblages will be analysed using non-parametric PERMANOVA (Primer 6). Interpret the differences between years based on flow components delivered and relative life history traits.

- What did Commonwealth environmental water contribute to native larval fish growth and survival in the lower Lachlan River catchment?

The contribution of commonwealth environmental water to larval fish growth (and hence recruitment) will be determined by analysing length frequency histograms of

larval fish across sampling events. . Interpretation of results will be set in the context of covariates relevant to growth and survival of larval fish in the Lachlan River system (see below). Analyse the effect size of changes in growth (age vs. length ratio) in relation to flow components (categorical variable) or hydrological parameters (continuous variables).

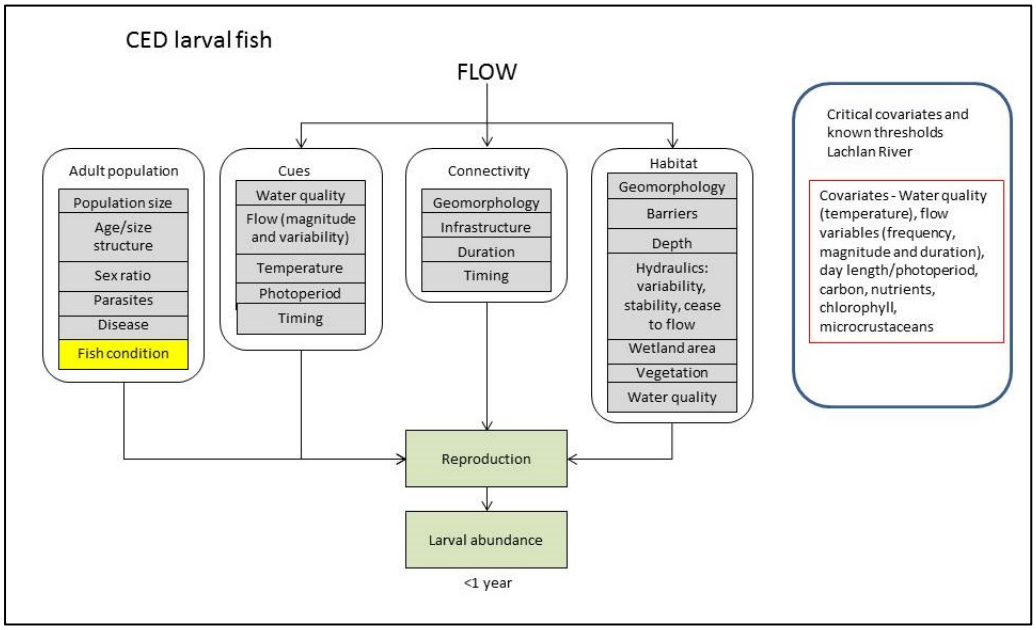

Figure 18. Larval fish abundance cause and effect.

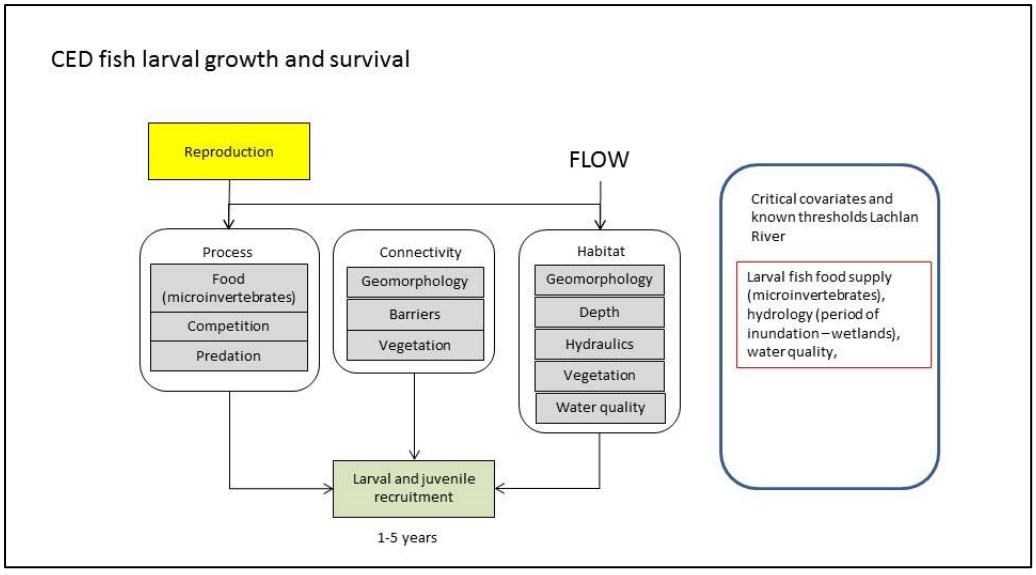

Figure 19. Larval fish growth and survival cause and effect diagram.

Long-term (five year) evaluation questions:

- What did Commonwealth environmental water contribute to native fish populations in the lower Lachlan River catchment?

Larval fish abundance (described above in chapter Protocol A1.7.7.2) will be analysed using parametric univariate ANOVA using year as the factor. In the same way, changes in larval fish assemblages will be analysed using non-parametric PERMANOVA (Primer 6). Interpret the differences between years based on flow components delivered and relative life history traits.

- What did Commonwealth environmental water contribute to native fish species diversity in the lower Lachlan River catchment?

Larval fish abundance (described above in chapter Protocol A1.7.7.2) will be analysed using parametric univariate ANOVA using year as the factor. In the same way, changes in larval fish assemblages will be analysed using non-parametric PERMANOVA (Primer 6). Interpret the differences between years based on flow components delivered and relative life history traits.

A1.7.8.3 Data management

All data provided for this indicator will conform to the data structure defined in the MER Data Standard (Brooks and Wealands 2014). The data standard provides a means of collating consistent data that can be managed within the MER Monitoring Data Management System (MDMS).

The spatial unit for which data is reported for this indicator is known as an 'assessment unit'. The assessment unit for this indicator is: the site (River section).

Each row of data provided for this indicator will identify the assessment unit, the temporal extent of the data and a number of additional variables (as guided by this standard method). The exact data structure for this indicator is maintained and communicated in the MER Data Standard and will be enforced by the MDMS when data is submitted.

It is strongly recommended that Monitoring and Evaluation Providers make themselves familiar with the data standard requirements for this standard method prior to detailed monitoring program design and implementation.

A1.7.9 QUALITY ASSURANCE/ QUALITY CONTROL

Quality control and quality assurance protocols are documented in the Quality Plan developed as part of the Monitoring and Evaluation Plan. QA/QC activities specific to this protocol include:

- It is the responsibility of the provider to have specific fisheries and ethics permits with them while sampling.
- 10% of samples will be re-processed by a different observer. If significant differences (>10%) are present between the two observers for a given sample, processing of 10 samples by both observers at the same time will be undertaken to ensure comparative abundance and identification between observers is achieved.

A1.7.10 HEALTH AND SAFETY

A complete WHS plan has been included in the monitoring and evaluation plan (Appendix C).

A1.8 WATERBIRD BREEDING

A1.8.1 EVALUATION QUESTIONS

This monitoring protocol addresses the following Basin and Area evaluation questions:

- **Long-term (five-year) question:**
  - What did Commonwealth environmental water contribute to waterbird populations?
  - What contribution did Commonwealth water in the Lachlan Selected Area make to Basin wide colonial waterbird breeding?

- **Short-term (one-year) and long-term (five year) questions:**
  - What did Commonwealth environmental water contribute to waterbird breeding?
  - What did Commonwealth environmental water contribute to waterbird chick fledging?
  - What were the colonial waterbird responses to Commonwealth environmental watering?

The process for evaluating these questions is illustrated in Figure 20, with components covered by this protocol highlighted in blue.

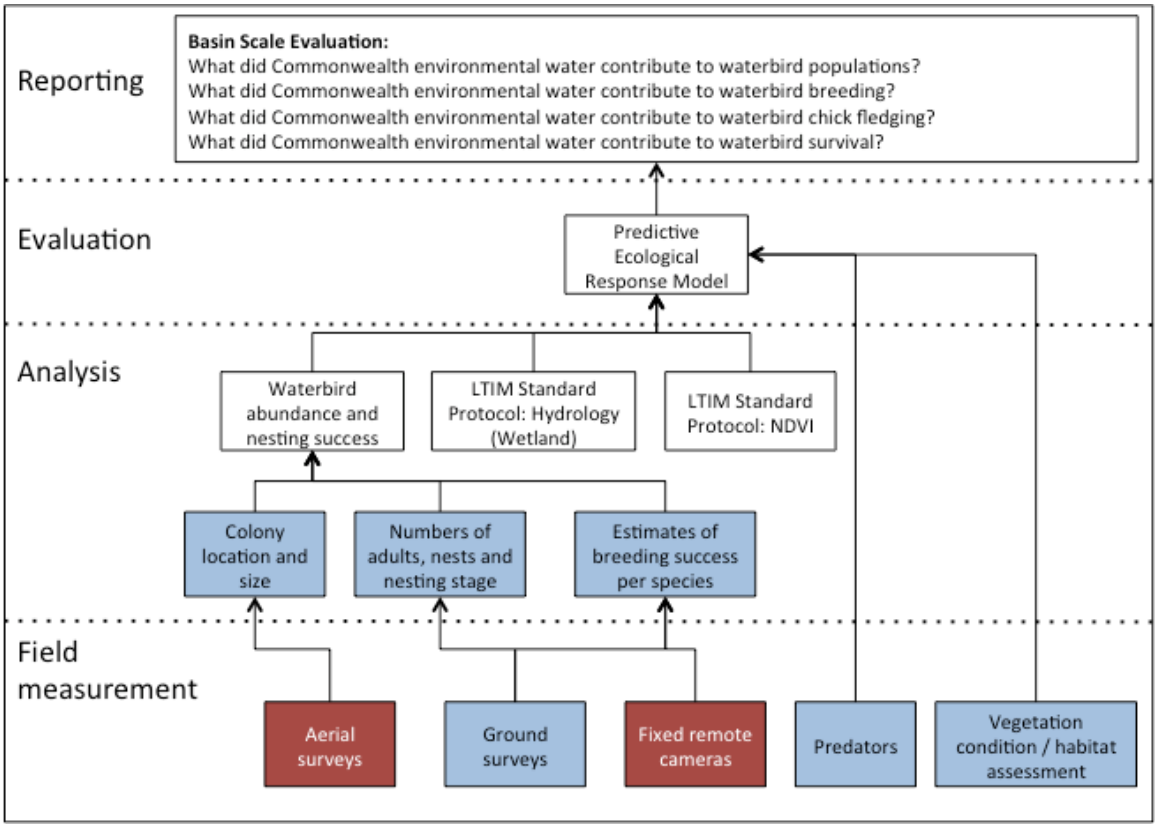

Figure 20. Schematic of key elements in LTIM Standard Protocol: Waterbird Breeding.

A1.8.2 RELEVANT ECOSYSTEM TYPES

Wetlands and floodplains.

A1.8.3 RELEVANT FLOW TYPES

Freshes, bankfull, overbank (infrastructure assisted)

A1.8.4 OVERVIEW AND CONTEXT

This protocol describes event based monitoring to detect the effect of Commonwealth environmental water on breeding of colonial nesting waterbirds for the Lachlan River system Selected Area.

However, to inform Basin scale evaluation the methods will also meet the minimum requirements detailed below with respect to:

- Site establishment.
- Frequency of ground surveys.
- Field measures.
- Reporting of results.

The measurements for this protocol comprise:

- Waterbird breeding measures (fortnightly over the duration of a breeding event):
  - Identity of species breeding.
  - Number of adults.
  - Number of nests.
  - Number of nests in stages: eggs, early stage nestling (< 1 weeks old); later stage nestling (1 – 5 weeks old).
  - Fledgling estimate.

- Covariates
  - Vegetation type.
  - Number of nests in each vegetation / habitat type.
  - Predators/disease.

Key references used in the development of this protocol include the Living Murray (TLM) program (e.g. MDFRC 2011); *Guidance on waterbird monitoring methodology: Field Protocol for waterbird counting* (Wetlands International 2010) and methods from the *National Waterbird Assessment* (Kingsford et al. 2011).

A1.8.5 COMPLEMENTARY MONITORING AND DATA

The field measures required for the assessment of waterbird breeding are specific to this protocol. However, existing breeding information for each Selected Area should be used in the first instance to aid in identifying potential monitoring locations (sites).

Records of colonial waterbird breeding in the Lachlan Catchment are available from as early as 1899 (Table 15). Site selection for the monitoring of waterbird breeding has been based upon expert knowledge and historical data. Species such as Ibis and Spoonbills which are most responsive to flooding and changes in hydrology have been recorded breeding in large

numbers (~160,000 in 1984; Marchant and Higgins 1990) in the Booligal Wetlands with a frequency of about 1:3.5 years.

Table 15. Historical records of colonial waterbird breeding in the Lachlan Catchment (source: (source: Brandis et al. 2014, National Colonial Waterbird Breeding Database).

SPECIES	YEAR BREEDING RECORDED	WETLANDS
Australian Pelican	1964, 1971, 1975, 1985, 1989, 2006, 2017,2018	Lake Cowal, Lake Brewster, Lake Cargelligo
Glossy Ibis	1984, 1985, 1990, 1991, 2010	Booligal Swamp, Lake Gunbar, Cuba Dam, Lignum Lake
Straw-necked Ibis	1964, 1978, 1984, 1985, 1989, 1990, 1991, 1991, 1993, 1996, 1998, 2000, 2010, 2016	Lake Cowal, Murrumbidgil Swamp, Booligal Swamp, Cuba Dam, Great Cumbung Swamp, Lignum Lake
Royal Spoonbill	1978, 1984, 1985, 1990, 1991, 2006, 2010	Murrumbidgil Swamp, Lake Cowal, Booligal Swamp, Cuba Dam, Peppermint Swamp, Lake Merrimajeel, Lignum Lake, Lake Cargelligo
Great Cormorant	1964, 1990, 2006	Lake Brewster, Lake Cowal, Cuba Dam, Lake Cargelligo
Intermediate Egret	1899, 1989, 1990	Lower Gum Swamp, Peppermint Swamp
Little Egret	1989, 1990	Booligal
White-necked (Pacific) Heron	1975, 1978, 1989, 1990, 2006	Murrumbidgil Swamp, Booligal Swamp, Peppermint Swamp, Lake Cargelligo

In addition, diversity data for non-breeding birds, including cryptic species, will also be opportunistically collected during waterbird breeding surveys. See the MER Standard Protocol: Waterbird Diversity.

A1.8.6 SITES, SURVEY TYPES AND TIMING

A1.8.6.1 Establishing sites

Monitoring of colonial waterbird breeding will be undertaken in the Booligal Wetlands. Historically, the Booligal Wetlands have been the site of frequent breeding events involving a diverse group of species (Table 16). The Booligal Wetlands are predominantly channelised Lignum with stands of River Red Gums, Black Box and River Cooba (Lachlan Riverine Working Group 2013). The methods for surveying colonial waterbird breeding that will be used the Lachlan have been chosen based upon previous studies and are specific to channelized lignum wetlands.

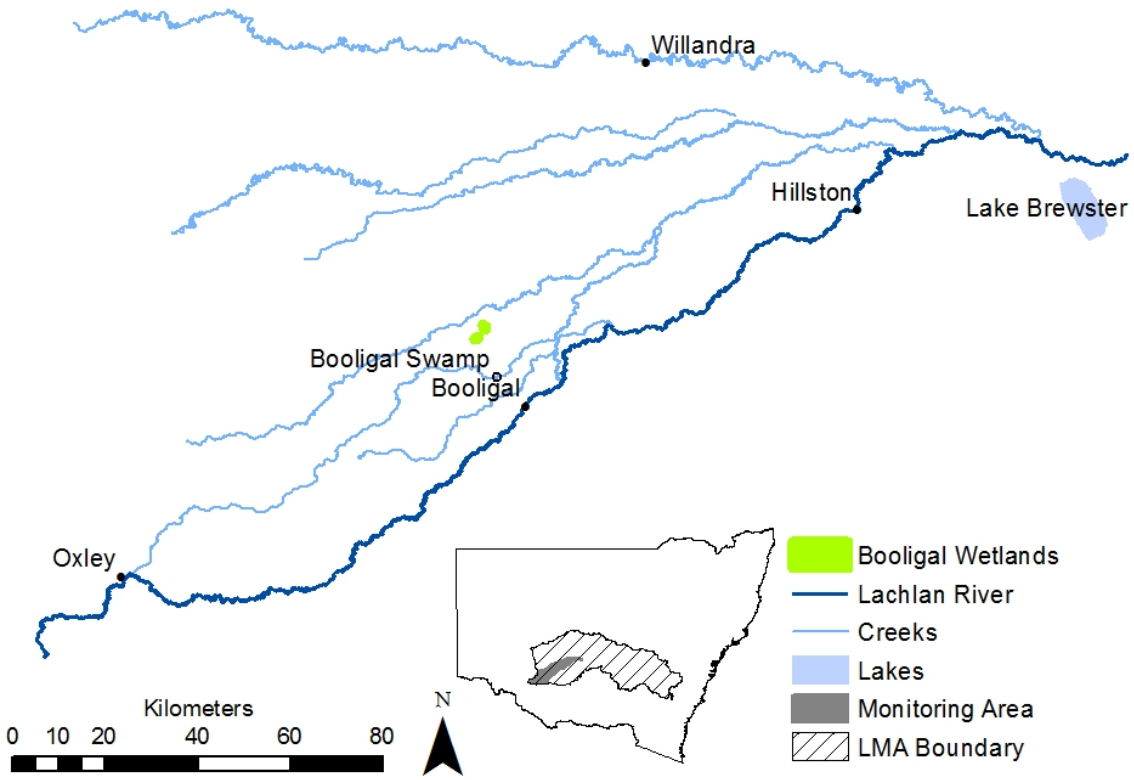

Figure 21. Map of lower Lachlan showing location of Booligal swamp (Booligal wetlands).

Table 16. Records of breeding by colonial waterbirds in the Lachlan catchment (source: Brandis et al. 2014, National Colonial Waterbird Breeding Database).

WETLAND COMPLEX	INDIVIUDAL WETLANDS	SPECIES RECORDED BREEDING	MONITORING CATEGORY	ZONE
Booligal Wetlands	Merrowie Creek	Glossy Ibis; Straw-necked Ibis; Little Egret, Royal Spoonbill; White-necked Heron	Cat 1	L4
	Booligal Swamp	Glossy Ibis; Straw-necked Ibis; Little Egret, Royal Spoonbill; White-necked Heron	Cat 1	L5
	Upper Gum Swamp	Glossy Ibis; Straw-necked Ibis; Little Egret, Royal Spoonbill; White-necked Heron	Cat 1	L5
	Lower Gum Swamp	Intermediate Egret	Cat 1	L5
	Merrimajeel Swamp	Glossy Ibis; Straw-necked Ibis; Little Egret, Royal Spoonbill; White-necked Heron	Cat 1	L5
	Murrumbidgil Swamp	Glossy Ibis; Straw-necked Ibis; Little Egret, Royal Spoonbill; White-necked Heron	Cat 1	L5

As this is an event based monitoring program, sampling locations and times are determined by the use or planned use of Commonwealth environmental water, and the likelihood of colonial nesting species establishing at a site that could receive Commonwealth environmental water. Species included in this protocol are:

- Ibis.
- Egrets.
- Herons.
- Cormorants, Darter.
- Pelicans.
- Spoonbills.

If breeding by colonial waterbirds is established in the Booligal Wetlands we will implement our breeding monitoring protocol. If the timing aligns with the annual October Waterbird Survey of Eastern Australia run by the Centre for Ecosystem Science, University of New South Wales, then an aerial survey of waterbird abundance and diversity will be undertaken as part of this survey. This data may then contribute to the Basin and Area scale data collection.

For Basin evaluation, data are reported on an assessment unit defined by a colony of nesting waterbirds. Colonies are defined as a single location supporting breeding birds located close enough in distance to interact socially; i.e. a clear aggregation of nesting waterbirds in the landscape. Therefore a site may comprise multiple assessment units (colonies) within a single wetland or wetland complex.

A1.8.6.2 Survey type and timing

Event based monitoring of colonial waterbird breeding will be undertaken at the Booligal Wetlands. A combination of aerial, drone and ground surveys will be used to identify the specific location of the colony or colonies. Aerial surveys will only be used if the timing corresponds with that of the Eastern Australia Aerial Survey of Waterbirds in October each year. Alternatively all surveys will be ground based either on foot or using small boats to get around the colonies. Ground surveys will be used, determine nesting vegetation type, waterbird species breeding and diversity, total number of nests and the stages of nesting. Drone imagery will be used to map colony boundaries, map and count nest numbers.

For the duration of breeding by Straw-necked ibis, Glossy ibis, Australian White ibis, or Royal Spoonbills a subset of marked nests will be visited fortnightly to measure reproductive success for these species. These species typically nest in colonies within the channelized lignum. These species have been shown to be sensitive to changes in water levels (Brandis et al. 2011), therefore regular monitoring at each stage of chick development (fortnightly visits) is crucial for assessing the contribution of Commonwealth Water contributed to waterbird breeding.

Surveys of tree nesting species such as Cormorants, Darters and Egrets will be timed to co-incide with development stages. Due to the difficulties associated with accessing nests in trees data collected will include nest activity i.e. adults on nest/eggs, presence of chicks and stage of chick development. Obtaining accurate chick counts may not be feasible but records of nesting and nest success will be collected. These species do not appear to be as

sensitive to changes in water depth. If possible, drones will be used to monitor tree nesting birds.

Estimates of total nests successfully fledged will be extrapolated from the monitored sub-set, assuming it is not feasible to monitor all nests in the colony.

To minimise disturbance to the colony All ground surveys of the colonies will be limited to two hour periods, either in early morning (6-11 am) or late afternoon (3-8 pm) to avoid causing heat stress to nesting birds and their offspring. This approach has worked effectively in previous studies of large waterbird colonies in the Lowbidgee which recorded high levels of nesting success (Brandis et al. 2011b).

A1.8.7 AERIAL SURVEYS (RECONNAISSANCE, DELINEATING COLONY BOUNDARIES)

A1.8.7.1 Reconnaissance flights

Aerial surveys can be undertaken to assist in identification of breeding occurrences and breeding success during watering or flooding events. In the first instance, these will be reconnaissance surveys and rely heavily on information compiled regarding nesting locations within the Selected Area prior to the first flight, under the premise that colonial nesting waterbirds are generally faithful to previously used sites. If reconnaissance flights capture early breeding stages, consideration should be given to a second aerial survey 4 – 6 weeks later to identify potential additional colonies.

Colony boundaries will be delineated during the first ground survey for waterbird breeding, and checked during subsequent survey trips. This will enable accurate mapping of boundaries, the ability to adjust boundaries as the colony progresses and provide a spatial template within which we can randomly select nests for monitoring.

A1.8.7.2 Aerial counting techniques

Prior to deploying to the field, flight paths must be established. These should be designed to most effectively capture all major breeding colonies (> 150 nests) within a site. There are a variety of techniques, dependent on the size and shape of the site and the distribution of colonies (Figure 22).

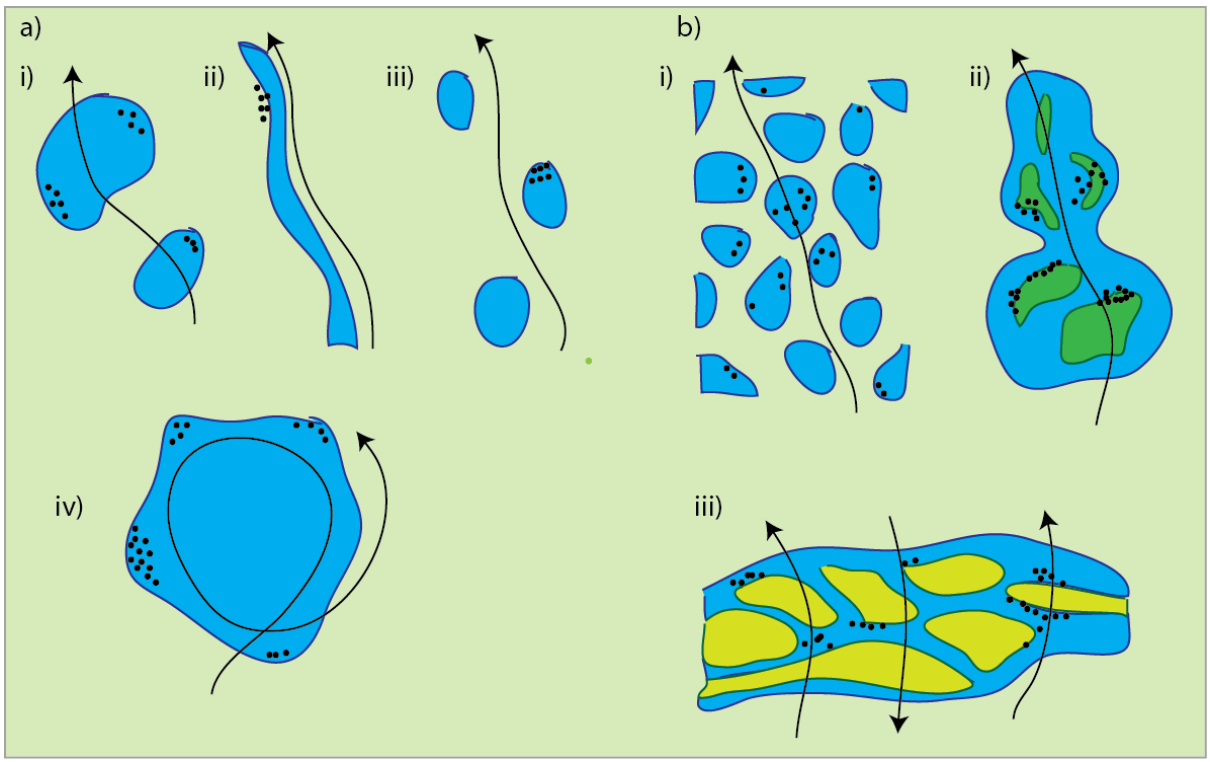

Figure 22. Illustration of aerial counting options for assessing nesting colonies (modified from Braithwaite et al. 1986).
a) total counts where an assessment is obtained for the total nesting colonies (indicated by the dots) on, for example i) discrete waterbodies of less than about 50 ha; ii) a river channel; iii) small impoundment; iv) large lake or impoundment with nesting predominantly along shorelines.
b). Transect counts with counting limited to nests within a band at ground level of 100m either side of the aircraft; i) on a landscape dotted with wetlands, each usually of less than 1 ha of surface water; ii) a floodplain with inter-dispersed water and land; iii) a braided river channel.

This protocol requires a minimum of two observers (in addition to the pilot) in the plane. The observers on each side of the plane estimate numbers of waterbirds on their side of the aircraft, recording the information on small tape recorders for later transcription (Kingsford et al. 2011). Care must be taken to ensure that nesting birds are not distressed leading to abandonment of nests.

The location (as a point or a polygon) of each colony must be recorded together with:

- Species composition.
- Estimates of the number of active nests.
- Breeding stage – i.e. eggs/chicks/ runners present?
- Colony boundary.
- Nesting vegetation type.

Observers (two for each flight) should independently identify and record species abundances and numbers of nests and broods. Where no birds, nests or broods are observed, a zero count is to be recorded (Kingsford et al. 2011).

Where the species of waterbird cannot be determined with confidence, record as categories: spoonbills, egrets, cormorants ('pied', or 'black'), ibis, and 'white birds' (egrets

and spoonbills), and be as specific as possible, e.g. 'unidentified breeding egrets (40 nests), seemed large' (which implies they were probably Eastern Great Egret).

A1.8.8 ON-GROUND SURVEYS

A1.8.8.1 Equipment: Identification guides

A good field guide must be taken on all field trips. Most waterbirds are quite conspicuous and, with notable exceptions, straightforward to identify in good conditions if care is taken. The most frequently encountered problem is identifying birds at long range in the extensive and flat terrain preferred by most congregatory waterbirds. This is when the additional power of a telescope is needed, but at some sites, a certain proportion of the birds will often remain unidentified because they are too distant to see properly (Wetlands International 2010), and because some colonial nesting species tend to 'hide' their nests in screening foliage, e.g. Nankeen Night Heron and Glossy Ibis.

The recommended field guides are: Simpson and Day (2010 - 8th edition), Slater et al. (2009), Morecombe (2003)and Pizzey and Knight (2007). We will use Simpson and Day (2010) and professional knowledge and experience in the identification of waterbirds.

A1.8.8.2 Equipment: Field survey

- Compass.
- Camera (35 mm format camera - dSLR - with 50–150 mm zoom lens, automatic exposure).
- Watch.
- Maps of Selected Area including assessment site information.
- 1B pencils, sharpener and eraser.
- Hand held tally counter.
- Simpson and Day (2010) Field Guide to the Birds of Australia.
- Binoculars or Telescope (for on-ground surveys/validation – see below).
- Field note book or datasheets and/or field computer.
- Appropriate field clothing/safety gear – first aid kit, hat, sunblock etc.

A1.8.8.3 Breeding surveys

Once breeding colonies have been identified at Booligal Swamp and monitoring has been requested, monitoring will occur every two weeks to obtain a measure of overall breeding success. Surveys will be undertaken either by small boat or foot. If the timing is suitable (see above) aerial surveys may be done by in conjunction with the Eastern Australia Aerial Waterbird Survey (UNSW). Surveys of lignum nesting species (Ibis, Spoonbills) will continue fortnightly until chicks have fledged and it is no longer possible to associate chicks with specific nests (Brandis et al. 2011b). Tree nesting species (Cormorant, Darters, Egrets, Herons) will be surveyed in conjunction with chick development stages (Table 17).

Depending upon the size of the colony or colonies that establish in the Booligal Wetlands, either a complete count will be undertaken or a subset will be surveyed and extrapolated to estimate the total abundance and reproductive success. Historical records of breeding at the Booligal Swamps range from colony sizes of 200 - 160,000 birds (Brandis et al. 2014).

Intensive waterbird breeding monitoring using the Category 1 standard methods will be restricted to previously used lignum wetlands in the Booligal Wetlands. Field measures specified in the LTIM Standard Protocol: Waterbird Breeding (Hale et al. 2014) include:

- Position of the colony (as a polygon).
- Number of nests of each colonial nesting waterbird species in each vegetation species in the following categories:
    - River red gum.
    - Black box.
    - River cooba.
    - Paperbark.
    - Other tree.
    - Lignum.
    - Other shrub.
    - Tall emergent aquatic (reeds, Phragmites, Typha, etc.)
    - Aquatic sedge/grass/forb.
    - Dead trees.
- Number of nests in breeding / chick development stage categories (see Table 17)
- Number of adults present in a colony.
- Dominant vegetation type and condition score (at the commencement of breeding - first survey only – see chapter A1.8.8.4 below).
- Observations of predators.

Table 17. Chick development stages recorded during each survey (Marchant and Higgins 1990, Brandis et al. 2011a).

DEVELOPMENT STAGE	CHARACTERISTICS	AGE (DAYS)
Egg	Whole egg, being incubated by adult	1-20
Chicks	Recently hatched (1-5 days old), downy feathers, immobile	21-25
Squirters	Early sheathed feathers starting on wings, still in nest, immobile	26-30
Runners	Development of pin feathers. Mix of down and feathers, walking awkwardly, can leave nest on foot	31-35
Flappers	Nearly fully feathered, cannot fly but flaps between nests	36-40
Flyers	Fully feathered, able to fly and leave nests, still attended by parents at nest	41-47
Fledged	Independent, does not return to nest but roosts in nearby trees	>48

These data will be collected through repeat ground surveys conducted by two field staff.

As straw-necked ibis are particularly sensitive to sudden changes in water level real-time information on the status of nesting birds and water levels is needed during breeding events to support adaptive management of environmental water (Brandis et al. 2011a, Brandis et al. 2011b).

Although the standard methods request monthly ground surveys, this survey intensity will not provide adequate information to address the short and long-term evaluation questions for waterbird breeding responses in the Lachlan. The breeding period for straw-necked ibis, from laying to chicks leaving their nests and taking short flights (flapper stage), is around 45-53 days (Brandis et al. 2011a). If monitoring is scheduled monthly and the first survey is at egg stage, the second survey a month later will be at a development stage where chicks are off the nests and success rates for individual nests cannot be measured. To ensure that Basin and Selected Area objectives can be evaluated, we plan to undertake ground surveys at fortnightly intervals, with the first survey taking place after eggs are laid, thus ensuring accurate estimates of the number of nests successfully fledged and mean number of chicks per nest for a subsample of nests. The three month breeding period is assumed to be a large enough window to cover the period from birds pairing up, laying and incubating eggs, rearing chicks and cover the period of post-fledging dependency in the three ibis species (Brandis et al. 2011a). These methods have been used since 2008 (Brandis et al. 2011b) and have been applied to waterbird colonies consistently across the Basin providing a consistent dataset with the ability to make comparisons between sites and years.

During the first colony survey, as close as possible to colony establishment, the boundary of the colony will be mapped using a differential GPS mounted on a boat to provide a framework for random sampling of a subset of nesting sites. Where a nesting site is defined as a group of nests on a clump of lignum separated from another clump of lignum by open water or non-flattened vegetation. A representative sub-set of nests will be monitored for the three month breeding period. All nests will be recorded with GPS and marked using coloured tape and given a unique identifier as per methods developed by Brandis et al. (2011a). Selected nests will be monitored throughout the breeding period from egg to fledgling development stages through repeat field surveys by trained observers. The deployment of fixed cameras (camera traps) for monitoring breeding success are included as an optional method for measuring reproductive success in the Category 1 standard methods. However, repeat visits by field personnel provide a number of advantages over the fixed cameras including eliminating the potential risk of camera failure; allowing for information to be collected on a larger number of nests; the presence of new starters and changes to the colony boundary. Brandis et al. (2014) demonstrated in a comparison of breeding success by repeat visits to straw-necked nests by investigators with the results from analysing images from camera traps that the presence of investigators did not impact breeding success or rates of predation.

In addition to reproductive success data hydrological indicators relevant to waterbird breeding will be measured in the Category 1 sites. These include continuous measurement of water depth (as per Hydrology (river): Selected Area methods) and replicate spot measurements of water quality (dissolved oxygen, turbidity, conductivity, and temperature) at each nesting site.

Drone imagery will be captured during the early stages of nesting, preferably while adults are incubating eggs on nests. This allows for a more accurate count of nests. Drone imagery will be used to map the colony boundary (in addition to ground based mapping), count and map nest locations. This provides an accurate count of the total number of nests and colony extent (Lyons et al. 2018).

As per tested survey methodology established by Lyons et al. (2018), the drone surveys will be conducted for a maximum of 20 minutes over an active waterbird colony, with a break of 1.5 hours between surveys and a maximum of three surveys per day. Survey timing will also take into consideration time of day and exposure effects (hot and cold daytime temperatures on eggs and young). The ideal time for capturing drone imagery is in the middle of the day when birds are less active and shadow effects are minimised.

A1.8.8.4 Covariates

Vegetation type and condition

The dominant vegetation type of the colony to be identified using the interim ANAE typology developed for the MDB (Brooks et al. 2013), and includes the following:

- Open water (no vegetation).
- River red gum forest.
- River red gum woodland.
- Black box forest.
- Black box woodland.
- Coolibah.
- Standing dead trees.
- River cooba.
- Paperbark.
- Lignum.
- Other shrub.
- Saltmarsh.
- Tall emergent aquatic (reeds, phragmites, Typha, cumbungi etc).
- Aquatic sedge/grass/forb.
- Freshwater grasses.
- Freshwater forb.

Each breeding colony will have the corresponding dominant vegetation class and condition score recorded during the first nesting survey. This is a qualitative ranking and is summarised in Table 18.

Table 18. Vegetation condition ranks for colonial nesting locations. Use only for live vegetation, not for species which prefer to nest in dead trees.

RANK	DESCRIPTION
Good	Vegetation structure in dominant layer healthy, good cover (>70%) with virtually no weeds evident. No obvious indication of altered processes which may affect vegetation condition.
Moderate	50-70% cover in dominant vegetation layer, some areas of dead branches present, or limited evidence of disease (i.e. die back), shrub layer more sparse, less connected and somewhat patchy. Some evidence of weeds and or indication of altered processes
Poor	Significant loss, <30%, of cover in dominant vegetation type, considerable amount of weeds, large number of dead branches, crown highly patchy. Stands of vegetation patchy and disconnected, considerable or obvious evidence of altered processes (i.e. drowned stumps).

Nest Desertion/Failure

Known predators at colonies are humans, dingos (wild dogs), foxes, cats, Australian raven, swamp harrier and wedge-tailed eagle. Any evidence or observation of nest contents or adult bird predation by these or other species should be recorded.

Disease is known to cause significant morality in waterbird colonies, particularly avian botulism. Observations of disease will also be recorded and estimates of mortality.

Also, mass nest desertion can occur if water levels drop suddenly around the nests or if the ground below the nest dries out (or if islands become connected to the main shore, for ground-nesting species), and these events and the likely triggers for desertion/nesting abandonment should be recorded.

A1.8.9 QUALITY ASSURANCE/QUALITY CONTROL

Quality control and quality assurance protocols are documented in the Quality Plan developed as part of the Monitoring and Evaluation Plan for all Selected Areas. QA/QC requirements specific to this protocol, which should be captured in the Quality plan are described briefly below.

All Waterbird Breeding assessments within a Selected Area, where possible, should be undertaken by the same experienced observers to maintain consistency over time. All observers must undergo training prior to undertaking monitoring surveys, including calibration against experienced observers to ensure standardisation of measurements. Training and calibration procedures must be documented in the MEP and relevant records maintained.

Identification of difficult to see species will often differ between observers. To minimise the variance associated with different observers, a minimum of two staff are assigned to Waterbird Breeding assessments, particularly when aerial methods are used. Where there are significant differences in original observer scores, observers will discuss their rationale and where appropriate adjust scores to mutually agreed values. For aerial surveys this should be done immediately after flights to get agreement on species identifications.

A1.8.10 DATA ANALYSIS AND REPORTING

The variables that will be reported for each colony for each survey are:

- Location (polygon of the colony).
- ANAE Wetlandid.
- Size of wetland surrounding colony (ha).
- Number of nests of each species per vegetation type / structural habitat.
- Number of nests in each nesting stage for each species.
- Estimate of number of nests successfully fledged for each species (i.e. one or more chicks fledged per nest) since last survey.
- Estimate of the mean number of chicks thought to have fledged per successful nest for each species, where possible (for nests fledged since last survey).
- Number of adults of each species.
- Vegetation type, condition scores.

- Observations of colony level disturbance (e.g. predators, other disturbance agents, or probable causes of colony desertion).

A1.8.11 EVALUATION

What did Commonwealth environmental water contribute to **waterbird populations and waterbird species diversity** at key wetlands in the Lachlan Catchment? (see Figure 23)

Expected outcomes:

- Local increases in waterbird abundance in response to Commonwealth environmental watering.
- Local increases in waterbird diversity in response to Commonwealth environmental watering
- Local increases in waterbird species of conservation significance (i.e. threatened species, JAMBA, CAMBA and ROKAMBA species, see) in response to Commonwealth environmental watering.

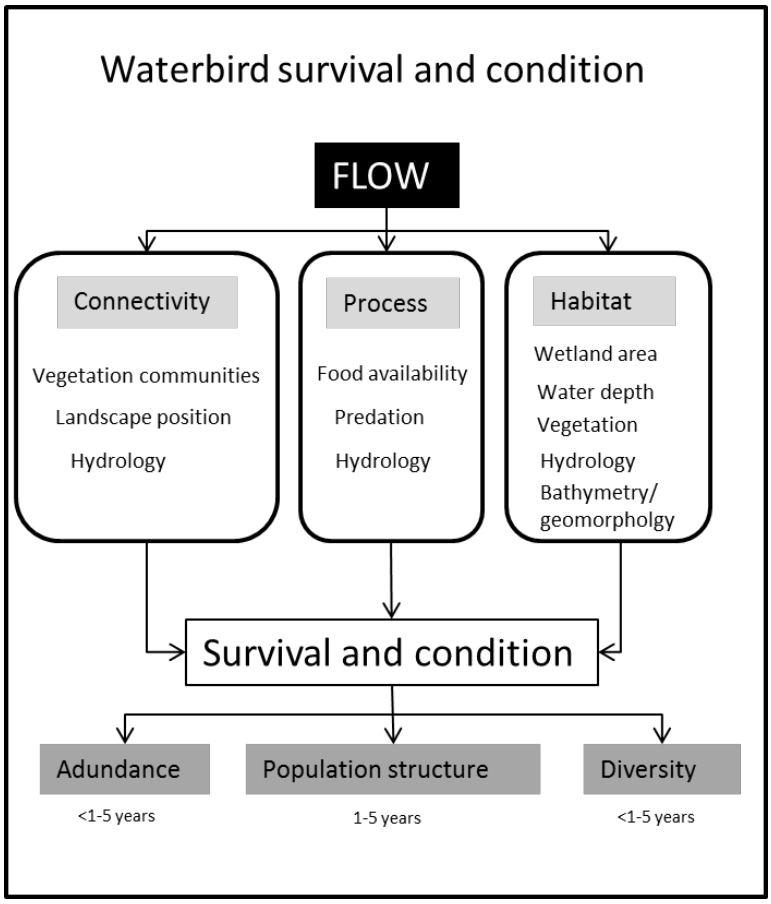

Figure 23. Waterbird survival and condition conceptual diagram.

What did Commonwealth environmental water contribute to **waterbird breeding**? (see Figure 24)

Expected outcomes:

- Local increases in non-colonial waterbird breeding activity (total number of breeding species and total number of broods) following Commonwealth environmental watering.
- Initiation of nesting activity in straw-necked ibis, glossy ibis and royal spoonbill colonies as a result of watering actions targeting known colony sites.
- Maintenance of stable water levels in colony sites using Commonwealth environmental water to support successful breeding of colonial waterbird species.
- Maintenance of water levels in feeding habitats using Commonwealth environmental water to support successful breeding and recruitment of colonial waterbird species.

What did Commonwealth environmental water contribute to **waterbird chick fledging and waterbird survival**? (see Figure 24)

Expected outcomes

- Maintenance of stable water levels in colony sites using Commonwealth environmental water to ensure successful fledging of chicks.
- Maintenance of water levels in feeding habitats using Commonwealth environmental water to support successful breeding and recruitment of colonial and non-colonial waterbird species.

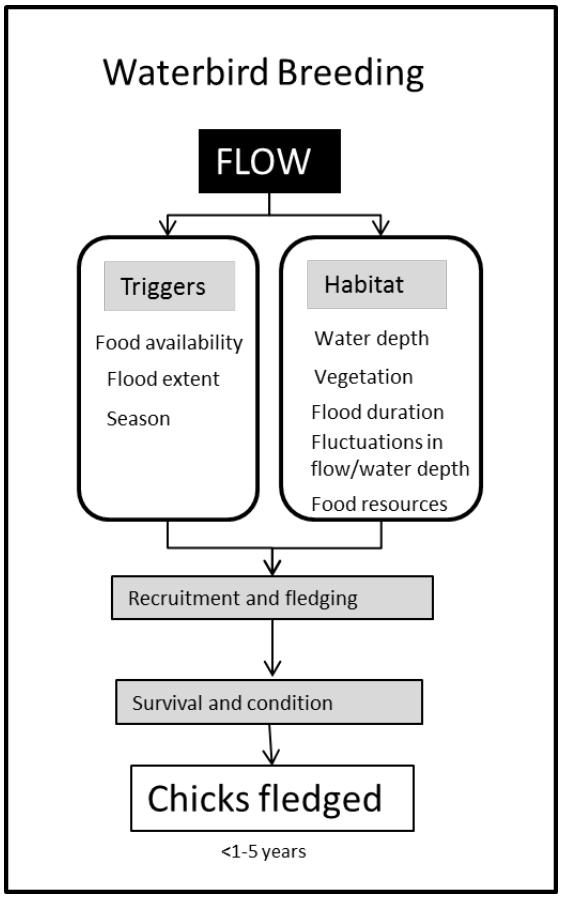

Figure 24. Waterbird breeding and conceptual diagram. Evaluation – area scale evaluation, how we will use these data to evaluate area scale questions.

A1.8.12 DATA ANALYSES

A1.8.12.1 Breeding data

The following metrics will be calculated for each colony:

- Estimates of total abundance by species breeding at each colony site.
- Identify phenology of breeding by tracking egg and chick development using survey data.
- Calculate mean clutch size for each species in each colony.
- Extrapolate results where reasonable to obtain and estimate for the entire colony.
- Colony extent and number of nests

These data will then contribute to answering the area and basin scale questions.

A1.8.12.2 Reproductive success

Calculated as the hatching rates for each species in each colony. Data will be categorised into three groups: egg, chick and nest. Success will be determined for periods between surveys. For example, if at the end of each time period between surveys the nest contained eggs or chicks it was scored 1, if neither then 0. Data will be further analysed based upon date of first survey of that site. All survey sites will be initially sampled at egg stage. Date of first survey will be used as a surrogate for laying period in data analyses. Analyses were grouped based upon date of first survey of that site.

A1.8.12.3 Breeding models

Generalised additive models (GAM) will be developed to understand the relationships between variables for breeding of ibis and spoonbills. Models will be developed including the relationship between between clutch sizes, lay date (relative to the delivery of water) and nest site size and hydrological variables including water depth.

A1.8.12.4 Colony conditions

We will also monitor water depth and water quality (pH, conductivity, dissolved oxygen, turbidity and temperature) at each colony at each survey time.

A1.8.12.5 Analysis Software

All statistical modelling will be undertaken using RStudio Version 0.98.501 and spatial analyses will be done using ArcGIS Version10.

A1.8.13 DATA MANAGEMENT

All data provided for this indicator will conform to the data structure defined in the LTIM Data Standard (Brooks and Wealands 2014). The data standard provides a means of collating consistent data that can be managed within the LTIM Monitoring Data Management System (MDMS).

The spatial unit for which data is reported for this indicator is known as an ‘assessment unit’. The assessment unit for this indicator is: the colony.

Each row of data provided for this indicator will identify the assessment unit, the temporal extent of the data and a number of additional variables (as guided by this standard method).

The exact data structure for this indicator is maintained and communicated in the LTIM Data Standard and will be enforced by the MDMS when data is submitted.

A1.8.14 HEALTH AND SAFETY

For details on health and safety please refer to the Workplace Health and Safety Plan for the Lachlan Selected Area (WHS 201.1) in Appendix C.

SUPPLEMENT A: WATERBIRD SPECIES AND CODES

Table 19. Census of Australian Vertebrate Species (CVAS) codes. Sourced from http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/search/biocode

TERM	DEFINITION
Colonial breeding waterbirds (based on Jaensch 2001)	***Target species*** CAVS: 0106: Australian pelican *Pelecanus conspicillatus* CAVS: 0179: Australian white ibis *Threskiornis molucca* CAVS: 0103: Black swan *Cygnus atratus* CAVS: 0977: Cattle Egret *Ardea ibis* CAVS 8731: Darter *Anhinga novaehollandiae** CAVS 8711: Eastern Great Egret *Ardea modesta* CAVS 0187: Glossy ibis *Plegadis falcinellus* CAVS 0096: Great cormorant *Phalacrocorax carbo* CAVS 0186: Intermediate Egret *Ardea intermedia* CAVS 0097: Little Black Cormorant *Phalacrocorax sulcirostris* CAVS 0185: Little Egret *Egretta garzetta* CAVS 0100: Little Pied Cormorant *Microcarbo melanoleucos* CAVS 0191: Nankeen Night Heron *Nycticorax caledonicus* CAVS 0099: Pied cormorant *Phalacrocorax varius* CAVS 0181: Royal spoonbill *Platalea regia* CAVS 0180: Straw-necked ibis *Threskiornis spinicollis* CAVS 0069: White-necked heron *Ardea pacifica** CAVS 0181: Yellow-billed spoonbill *Platalea flavipes** [* NB these species often nest 'singly' away from colonies] ***Other non-target colonial species*** CAVS 0060: Great crested grebe *Podiceps cristatus* CAVS 0061: Hoary-headed grebe *Poliocephalus poliocephalus* CAVS 0059: Eurasian coot *Fulica atra* CAVS 0146: Black-winged stilt *Himantopus himantopus* CAVS 0147: Banded stilt *Cladorhynchus leucocephalus* CAVS 0148: Red-necked avocet *Recurvirostra novaehollandiae* CAVS 0115: Silver gull *Chroicocephalus novaehollandiae* CAVS 0111: Gull-billed term *Gelochelidon nilotica* CAVS 0111: Caspian tern *Hydroprogne caspia* CAVS 0110: Whiskered tern *Chlidonias hybrida*
Waterbirds (from DSE 2009)	Anatidae (swans, geese, ducks) Podicipedidae (grebes) Anhingidae (darters) Phalacrocoracidae (cormorants) Pelecanidae (pelicans) Ardeidae (herons, egrets, night herons, bitterns) Threskiornithidae (ibises, spoonbills) Accipitridae (hawks, harriers) not included in aerial surveys Rallidae (crakes, rails, gallinules) Scolopacidae (snipe, godwits, curlews, sandpipers, stints, phalaropes) Recurvirostridae (stilts, avocets) Charadriidae (plovers, dotterels, lapwings) Laridae (gulls, terns) Alcedinidae (azure kingfisher), and Slyviidae (old world warblers)

SUPPLEMENT B: EXAMPLE WATERBIRD BREEDING FIELD SHEET

WATERBIRD BREEDING FIELD SHEET: Page ---------- of ----------					
Site name			**Total site wetland area (ha)**		
Date:			**Name of Recorder:**		
Survey start time:			**Survey end time:**		
WetlandID:		**WetlandID:**		**WetlandID:**	
WetlandID:		**WetlandID:**		**WetlandID:**	
WetlandID:		**WetlandID:**		**WetlandID:**	
Stream ID:		**Stream ID:**		**Stream ID:**	
Observer 1:			**Observer 1:**		
Approach type:	**A.** Aerial observer **B.** On-ground observer			**% of wetland of site/wetland wet……..%**	
Count method:	1. Total count 2. Proportion			**Proportion surveyed**:…….%	
GPS co-ordinates and/or tracks for site/sub-sampled area boundaries and survey route/location Attach a mud map as required:					

WATERBIRD BREEDING FIELD SHEET: Page ---------- of ----------					
Site name		**Total site wetland area (ha)**			
Date:		**Name of Recorder:**			
Survey area (ha):					
Notes: e.g. number of colonies, mixed species colonies, etc					
Key: Vegetation codes (dominant vegetation used in nesting): River red gum forest = RRGf; River red gum woodland = RRGw; Black box forest = BBf; Black box woodland = BBw; Coolibah = Cool; River cooba = RCb; Paperbark = Pb; Lignum = Lig; Other shrub = OS; Saltmarsh = SM; Tall emergent aquatic (reeds, phragmites, Typha, cumbungi etc) = TEA; Aquatic sedge/grass/forb = AqSGF; Freshwater grasses = FGr; Freshwater forb = FFb **Dominant vegetation code and area of colony (% and ha):**					
Vegetation condition (first nesting survey only): Assign ranking of Good, Moderate or Poor to each dominant vegetation type in which colonial nesting is occurring. Comments:					
Species	**Number of nests**	**Number of adults**	**Number of live young per successful nest**	**Number of fledging per nest**	**Vegetation condition rank**

WATERBIRD BREEDING FIELD SHEET: Page ---------- of ----------					
Site name			**Total site wetland area (ha)**		
Date:			**Name of Recorder:**		

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