

2014–15 Basin-scale evaluation of Commonwealth environmental water – Stream Metabolism and Water Quality

Prepared by: Mike Grace

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2014–15 Basin-scale evaluation of Commonwealth environmental water – Stream Metabolism and Water Quality

Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre

Commonwealth Environmental Water Office
PO Box 787
Canberra ACT 2901

Ph: (02) 6274 1088

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For further information contact:

Ben Gawne

The Murray–Darling Freshwater Research Centre
PO Box 991
Wodonga VIC 3689

Ph: (02) 6024 9650

Email: Ben.Gawne@canberra.edu.au
Web: www.mdfrc.org.au
Enquiries: mdfrc@latrobe.edu.au

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Author(s): Mike Grace

Author affiliation(s): Water Studies Centre & School of Chemistry, Monash University

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The Murray–Darling Freshwater Research Centre offices are located on the land of the Latje Latje and Wiradjuri peoples. We undertake work throughout the Murray–Darling Basin and acknowledge the traditional owners of this land and water. We pay respect to Elders past, present and future.

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1 Introduction

Whole stream metabolism, usually abbreviated to 'stream metabolism', refers to the transformation of organic matter and is comprised of two key ecological processes — primary production and decomposition — which generate and recycle organic matter, respectively. Here, organic matter refers to living and dead animal and plant matter.

Stream metabolism measures the production and consumption of dissolved oxygen gas by photosynthesis (primary production) and respiration (Odum 1956). Primary producers use light to photosynthesise (producing oxygen) and respire (consuming oxygen), while decomposers (mostly bacteria and fungi) only respire. This enables daily rates of primary production and ecosystem respiration to be measured by monitoring changes in the dissolved oxygen (DO) concentration in the water column over short-term intervals (e.g. 10 minutes) over the full 24-hour period. Healthy aquatic ecosystems need both processes to generate new organic matter (which becomes food for organisms higher up the food chain) and to break down plant and animal matter to recycle nutrients to enable this growth to occur. Hence, metabolism assesses the energy base (organic carbon supply) underpinning aquatic foodwebs. The relationships between these processes are shown in Figure 1.

In essence, these processes have a profound effect on ecosystem character and condition through their influence on the capacity of plants to complete their life-cycles and the ability of animals to acquire the food resources needed to survive and reproduce.

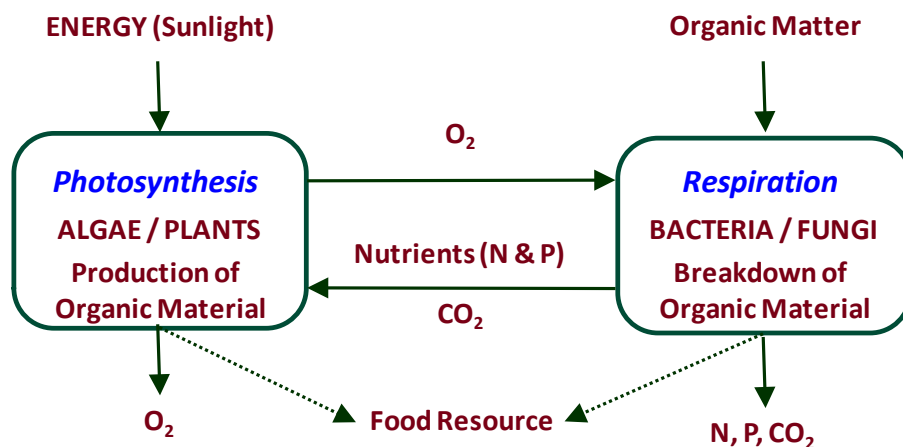


Figure 1. Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients.

Metabolism is expressed as the increase (photosynthesis) or decrease (respiration) of DO concentration over a given time frame; most commonly expressed as (change in) milligrams of dissolved oxygen per litre per day ($\text{mg O}_2/\text{L/day}$). Typical rates of primary production and ecosystem respiration range over two orders of magnitude, from around 0.2 to 20.0 $\text{mg O}_2/\text{L/day}$, with most measurements falling between 0.5 and 10.0 $\text{mg O}_2/\text{L/day}$.

As with many ecological processes, problems arise when rates of primary production or decomposition are too low or too high. If process rates are too low, this will limit the amount of food resources (bacteria, algae and water plants) for consumers. This limitation will then constrain populations of larger organisms, including fish, birds and frogs.

Problems also arise when rates of primary production or decomposition are too high. Greatly elevated primary production rates are associated with algal blooms or excessive growth of plants

such as duckweed and azolla. This excessive growth affects habitat and water quality for other plants and animals. Algal blooms are associated with depleted DO, particularly at night or when the bloom collapses. Abundant growth of plants such as azolla is associated with shading which influences other aquatic plants and also reduced oxygen levels.

The main environmental factors known to influence rates of primary production and decomposition include temperature and nutrient concentrations. For primary producers, light is a critical resource while for decomposers, the amount and type of organic matter are important. Rates of primary production are, therefore, expected to vary on a seasonal basis as warmer temperatures and more direct, and longer hours of, sunlight contribute to enhancing primary production. Warmer temperatures and a supply of organic carbon usually result in higher rates of ecosystem respiration (Roberts & Mulholland 2007). Flow also influences rates of primary production and decomposition, both directly through the provision of habitat for microbiota and plants, but also indirectly through changes in nutrient concentrations, organic matter availability and turbidity that affects light penetration into the water.

There is growing evidence to suggest that flow modification has influenced patterns and rates of primary production and decomposition and that these influences have contributed to the decline in the condition of aquatic ecosystems (Aristi *et al.* 2014). Therefore, understanding primary production and decomposition responses to environmental watering will be important if watering actions are to be optimised to contribute to the protection and restoration of water-dependent ecosystems. Within the broad objective of protecting or restoring water-dependent ecosystems, environmental flows may play a number of roles. The first of these is to restore more natural patterns of metabolism, including episodes of high productivity. A second may be to manage events associated with excessive rates of primary production or decomposition. Examples include flows to disrupt algal blooms or to dilute blackwater with low levels of oxygen. Third, flows may be used to disperse productivity from one area to another. Examples include returning flows from floodplains to main channels or transporting algae into the Lower Lakes and Coorong.

When seeking to restore natural patterns of productivity, there are three ways that flow may have an influence and these are summarised in the following conceptual models¹:

- i) Entrainment, in which flow introduces nutrients and organic carbon
- ii) Mixing, in which flow either mixes stratified water bodies or resuspends organically or nutrient-rich material
- iii) Disturbance, in which flow scours existing biofilms.

1.1 Entrainment — nutrient and organic carbon additions

Primary production requires nutrients, notably nitrogen (N) and phosphorus (P), in bioavailable forms (Borchardt 1996; Boulton & Brock 1999). When water column nutrients are all consumed, photosynthesis may be severely inhibited. Conversely, the microbial population undertaking ecosystem respiration requires cellular detritus from dead plants and animals (organic matter) as a food supply, and during this process nutrients (N and P) are regenerated. Once the supply of organic matter is diminished, nutrient regeneration is reduced. The two processes of primary production and ecosystem respiration are therefore closely linked. Figure 2 shows that when discharge levels increase, more nutrients and organic matter can be transported into the stream, potentially alleviating nutrient and organic matter limitation.

¹ Diagrams courtesy of Professor Ben Gawne
2014–15 Basin-scale evaluation of Commonwealth environmental water — Stream Metabolism and Water Quality

Flow and, in particular, lateral connectivity have long been recognised as important in facilitating the exchange of organic matter and nutrients between rivers and associated wetlands and floodplains (Junk *et al.* 1989; Tockner *et al.* 1999; Baldwin *et al.* 2013). The amount of nutrients and organic carbon added will depend on how high the water reaches up the bank (whether it inundates benches) and whether backwaters, flood runners and the floodplain itself are reconnected to the main channel (Thoms *et al.* 2005; McGinness & Arthur 2011; Southwell & Thoms 2011).

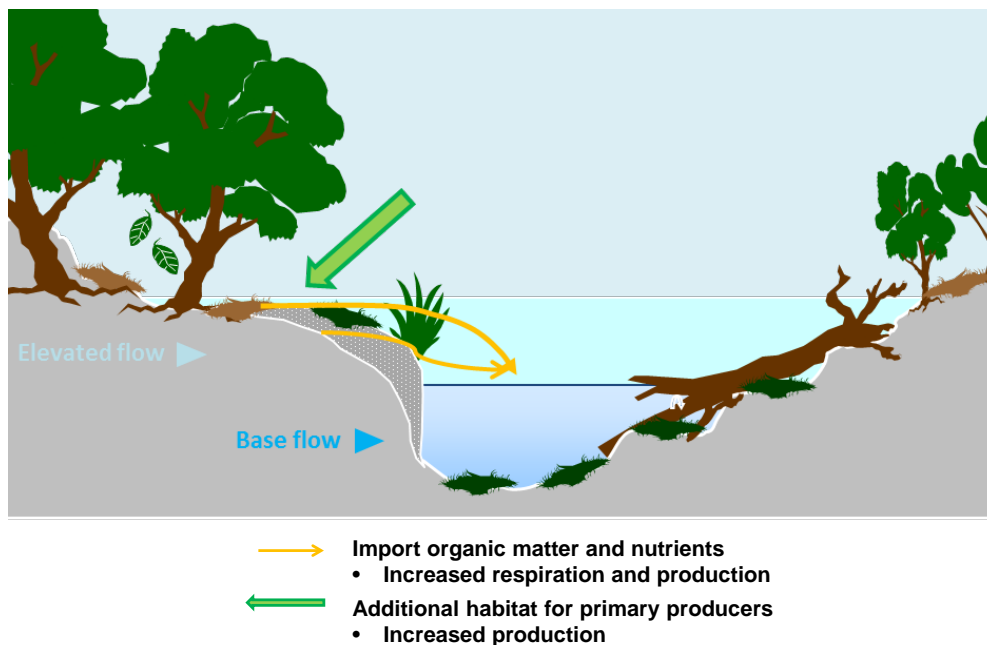


Figure 2. Conceptual model of increased flow effects on stream metabolism through increased nutrient and organic matter delivery (Entrainment Model).

1.2 Mixing or resuspending material

There are several situations in which high concentrations of material are created in rivers. Examples include:

1. organic matter in areas of low flow
2. nutrients within sediments (where oxygen from the overlying water does not reach)
3. nutrients and organic matter in stratified pools.

Within the channel, organic matter may accumulate in areas of low flow, such as slackwaters or the bottom of deep pools (Figure 3). In these areas, low flow limits the supply of oxygen and nutrients, slowing rates of decomposition. When flows increase, the accumulated material may be resuspended or mixed, relieving the limitation and this is often associated with a significant increase in metabolic activity (Baldwin & Wallace 2009).

In rivers exemplified by the Darling, where low water velocities combined with structures, such as weir pools, cause water impoundment with potentially long residence times, it is extremely likely that extended periods of thermal stratification will occur (Oliver *et al.* 1999). The stratification leads to a depletion of oxygen levels at the bottom of the pool and this results in the release of phosphate and ammonia from the sediments. The first flush that breaks down stratification may lead to the transportation downstream of large concentrations of these bioavailable nutrients and accumulated organic matter, which may then engender significant decomposition in the water column over

subsequent days and weeks, leading in some instances to depletion of oxygen in the water column (Baldwin & Wallace 2009). This occurred in the Darling River in 2004 and was associated with fish kills (Ellis & Meredith 2004).

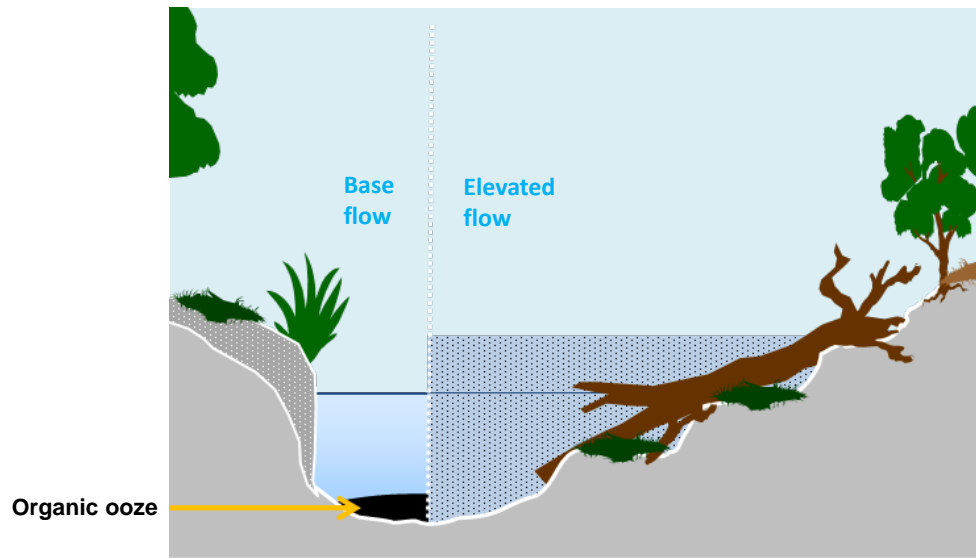


Figure 3. Conceptual model of increased flow effects on stream metabolism through resuspension of soft bottom sediments (Mixing Model).

1.3 Disturbance — scouring of existing biofilms

Biofilms — which grow on any surface, including sediments, plants or wood — can provide a substantial proportion of the primary production in a stream. Flow events with sufficient stream power (resulting from higher water velocities) to cause scouring of these biofilms (Ryder *et al.* 2006) can ‘reset’ primary production to very low rates which are then maintained until biomass of primary producers is re-established (Uehlinger 2000). Over a period of weeks, this can lead to higher rates of primary production if those biofilms that were washed away were ‘old’ and not growing substantially or even starting to decline (senesce).

Floating communities of algae and bacteria are also subject to disturbance by changes in flow (Reynolds 1991, 1992, 1996). Phytoplankton abundance is influenced by the residence time of water within the reach which in turn is affected by discharge and the relative volume of slackwaters within the reach. As discharge increases, existing slackwaters may be flushed out and the overall area of slackwaters may change, either increasing or decreasing. The flushing of slackwaters will lead to reductions in floating algae. The longer term effects will depend on populations building up in newly created slackwaters.

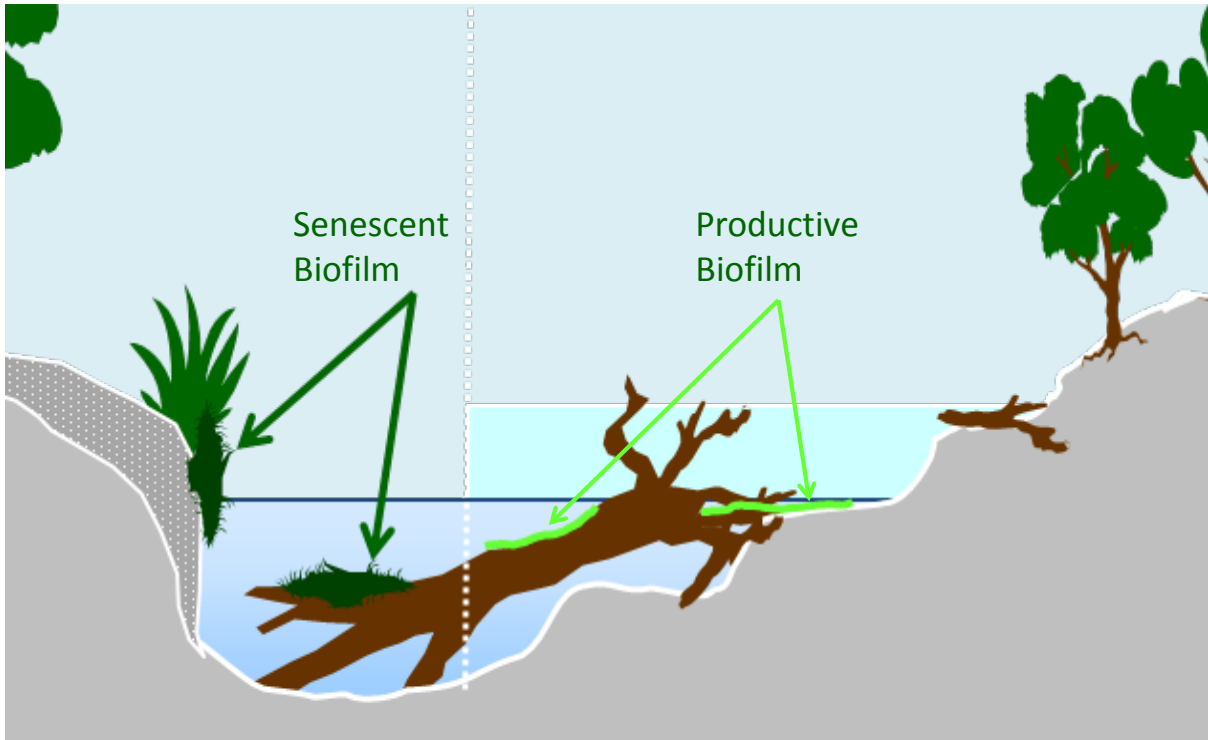


Figure 4. Conceptual model of increased flow effects on stream metabolism through scouring of biofilms (Disturbance Model).

This report also examines water quality data, especially in the context of drivers of ecosystem function and the avoidance of poor water quality as exemplified by low dissolved oxygen concentrations.

1.4 Short-term and long-term questions

This component of the Basin Evaluation will address the following short-term (1-year) and long-term (5-year) Basin-scale evaluation questions:

- What did Commonwealth environmental water contribute to patterns and rates of decomposition? Decomposition is measured as the rate of ecosystem respiration. The hypothesis is that increases in rates of decomposition that do not also cause adverse water quality outcomes are beneficial by making organic matter and nutrients available to the ecosystem.
- What did Commonwealth environmental water contribute to patterns and rates of primary productivity? The hypothesis is that increases in rates of primary production that do not lead to algal blooms or adverse water quality outcomes are beneficial by increasing the amount of organic matter available to the food web.
- What did Commonwealth environmental water contribute to pH and dissolved oxygen levels and to salinity and turbidity regimes?

These questions stem from the relevant Basin-scale objectives (as defined in Table 2 of Gawne *et al.* 2014):

- Stream metabolism/ecosystem function — ‘to protect and restore the ecosystem functions of water-dependent ecosystems’.

- Water quality — ‘to ensure water quality is sufficient to achieve the above objectives for water-dependent ecosystems, and for Ramsar wetlands, sufficient to maintain ecological character’.

2 Methods

2.1 The Stream Metabolism Basin Matter approach

The approach to evaluating stream metabolism to flows within the Basin Matter analysis is described in the foundation report (Grace 2015). The key points are summarised here.

All Monitoring and Evaluation (M&E) Providers will use the same statistical model (‘BASE’ — Bayesian Stream metabolism Estimation) to compute reach-scale metabolism based on changes in dissolved oxygen over the course of 24 hours to ensure a consistent approach to estimating rates of primary production and ecosystem respiration. The model also provides uncertainty estimates for each parameter.

Currently, there are no quantitative models that enable prediction of the metabolic rates expected at a specified flow, either with, or in the absence of, environmental watering. There are, however, conceptual models that describe the relationship between flow and metabolism that provide a starting point for making predictions to support evaluation. These conceptual models will be interrogated as far as possible with data collected during year 1 of the Long Term Intervention Monitoring (LTIM) Project.

During subsequent years (and based on experience with other models of complex ecological interactions over large spatial and temporal scales), quantitative models of stream metabolism will be developed that will:

- estimate the rate of stream metabolism in the absence of environmental watering at the reach scale for reaches that are monitored
- predict both environmental flow and non-flow rates of stream metabolism at the reach scale for reaches that are not monitored
- support estimation of Basin-scale changes to stream metabolism in response to environmental watering.

For this year 1 report, discussion of the effects of environmental water on stream metabolism will be confined to those sites where monitoring data are available as it is necessary to establish the baseline behaviour before being able to extrapolate to unmonitored sites. The evaluation considered all watering actions for which metabolism data were available and also provides a qualitative evaluation of watering actions that had expected outcomes for metabolism at unmonitored sites.

The LTIM Stream Metabolism monitoring sites are shown in Figure 5.

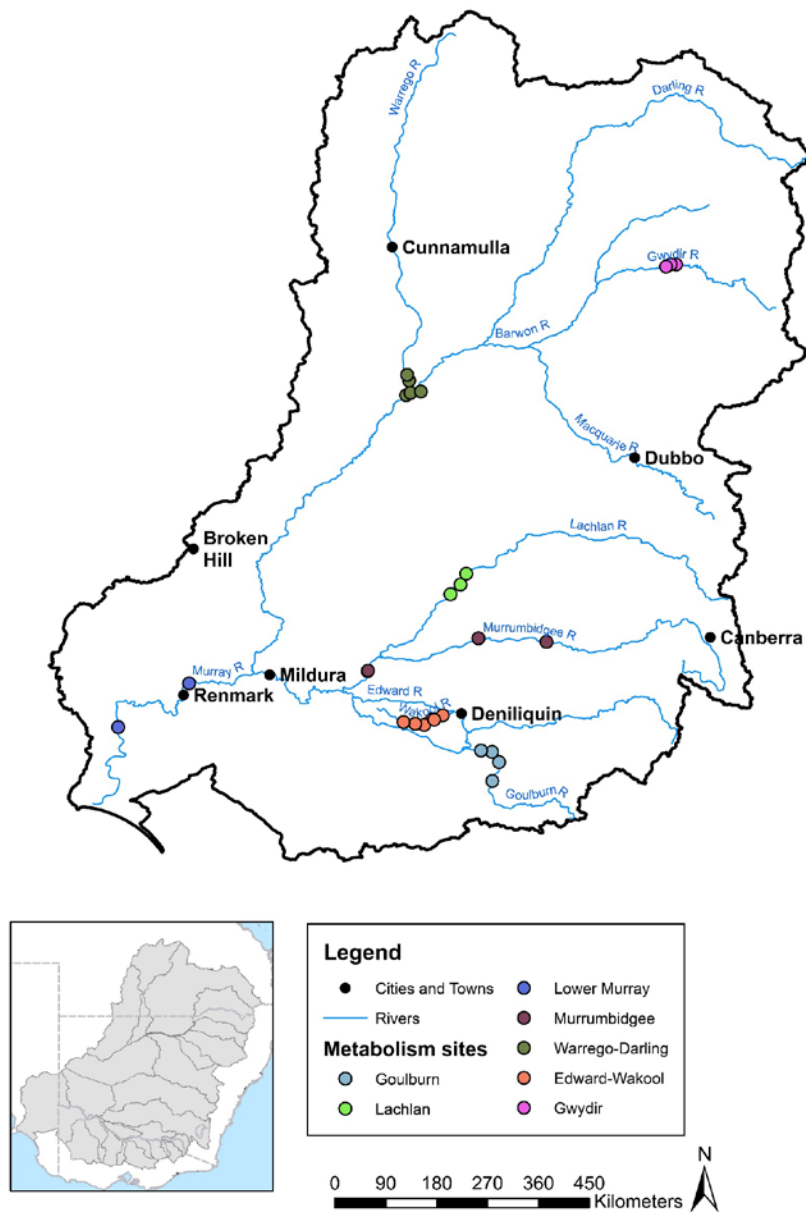


Figure 5. Location of LTIM Stream Metabolism monitoring sites. Delays in equipment installation precluded evaluation of flow effects on water quality or metabolism in the Warrego and Darling Rivers (Southwell *et al.* 2015b).

2.2 The Water Quality Basin Matter approach

Collection of water quality data to address both the short- and long-term questions was typically performed when accessing the sites for other purposes (e.g. dissolved oxygen (DO) logger downloading and maintenance). Hence, data collection for pH, turbidity, salinity (electrical conductivity), and nutrient and chlorophyll-a concentrations was sporadic and typically at frequencies of every 2–6 weeks. The lack of continuous monitoring (except for DO and

temperature²) is a constraint imposed by the overall project budget. Hence, it is effectively impossible to attribute the effects of watering actions on any parameter other than DO. Water quality data are useful to help explain patterns of metabolism at a catchment and Basin scale.

3 Synthesis of Selected Area outcomes

3.1 Selected Area outcomes

The stream metabolism data set collected for year 1 (2014–15) is summarised in Table 1. For each monitoring site in the seven Selected Areas, the table includes the total number of days for which metabolic parameters were calculated and the number of days for which the model fitted to the experimental data using the BASE model met or failed the criteria for subsequent meta-analysis. These two criteria, $R^2 \geq 0.90$ and coefficient of variation for gross primary productivity (primary production) $< 50\%$, were established during the LTIM Project meeting of Selected Area (Stream Metabolism Basin Matter) leaders in Sydney, 21–22 July 2015. The applicability of these criteria will be discussed in 2016 and revised if necessary. It is emphasised that this method of data collection and analysis using the BASE model is only appropriate for flowing waters, not wetlands. Analysis of wetland metabolism is much more difficult as water column stratification and heterogeneity in response mean multiple (as many as 6–10) loggers need to be deployed in a single wetland.

3.2 Highlights

3.2.1 Synthesis

In 2014–15, the Commonwealth Environmental Water Office (CEWO) contributed to 14 watering actions within Selected Areas to achieve expected outcomes associated with stream metabolism (including actions with expected outcomes for nutrient cycling and/or ecosystem function). Within the Selected Areas, 14 watering actions were monitored for Stream Metabolism as part of the LTIM Project, noting that several of the actions did not have CEWO-defined expected outcomes for ecosystem function. These are summarised in Table 2. An additional 28 watering actions targeted water quality (these are listed in Appendix A of this report).

² The availability of continuous salinity (EC) data from nearby gauging stations will be assessed as part of the LTIM Project year 2 data analysis.

Table 1. Summary of Stream Metabolism data records 2014–15.

Catchment	Logger site	Period of record		Days with metabolism data (no.)		
		First date	Last date	Pass	Fail	Total
Edward–Wakool	Barham Bridge	11/08/2014	16/03/2015	125	57	182
Edward–Wakool	Hopwood	11/08/2014	16/03/2015	109	68	177
Edward–Wakool	Llanos Park2	11/08/2014	16/03/2015	85	94	179
Edward–Wakool	Noorong2	11/08/2014	16/03/2015	48	134	182
Edward–Wakool	Widgee, Wakool River1	11/08/2014	16/03/2015	185	20	205
Edward–Wakool	Windra Vale	11/08/2014	16/03/2015	161	44	205
Goulburn	Darcy’s Track	22/11/2014	23/04/2015	101	52	153
Goulburn	Loch Garry Gauge	29/11/2014	23/04/2015	51	95	146
Goulburn	McCoys Bridge	11/10/2014	23/04/2015	128	67	195
Goulburn	Moss Road	11/10/2014	23/04/2015	11	184	195
Lachlan	CC	28/08/2014	06/11/2014	63	6	69
Lachlan	LB	27/08/2014	10/12/2014	46	11	57
Lachlan	WB	28/08/2014	12/11/2014	63	12	75
Lower Murray	LK1DS_265km	05/11/2014	24/02/2015	89	15	104
Lower Murray	LK6DS_616km	05/11/2014	23/02/2015	49	56	105
Murrumbidgee	1 km upstream Wynburn Escape	24/09/2014	25/02/2015	25	33	58
Murrumbidgee	3 km downstream Wynburn Escape	24/09/2014	25/02/2015	47	18	65
Murrumbidgee	McKennas	21/10/2014	29/04/2015	157	30	187
Murrumbidgee	Narrandera	23/10/2014	18/01/2015	74	12	86
Gwydir	nil	–	–			
Warrego–Darling	nil	–	–			

Note: a small amount of metabolism data was collected in at the Warrego–Darling site; however, the data were not collected from flowing river sites; hence, not appropriate for analysis using the BASE model.

3.2.2 Effects of Commonwealth environmental water on stream metabolism at Selected Areas

As noted above, relatively few of the over 50 watering actions that were delivered within Selected Areas in 2014–15 explicitly targeted outcomes associated with stream metabolism and ecosystem functioning in monitored locations. The following information is largely drawn from the respective individual Selected Area Synthesis and Technical reports, which are cited at the beginning of each section.

Edward–Wakool river system

This section is derived from the Edward–Wakool river system Selected Area Synthesis (Watts et al. 2015a) and Technical (Watts et al. 2015b) reports.

There was little variation in discharge in either Yallakool Creek or the Wakool River in September–December 2014; hence, it was not possible to assess discharge effects on metabolism during this period. There were small increases in both gross primary productivity (primary production) and ecosystem respiration (ER) over this period, suggesting that seasonal effects cannot be discounted when assessing potential longer term (weeks) metabolic responses to watering events. It is expected that longer, warmer days as spring becomes summer will increase the daily rates of primary production. Higher growth rates of primary producers, including benthic algae, will lead to more production of organic carbon and some of this will fuel increased rates of ecosystem respiration. The absence of significant flow change meant that scouring of extant biofilms was unlikely (Disturbance Model).

The most notable feature of the Edward–Wakool results was the much higher rates found at one site in the upper Wakool River (LTIM Project Zone 2, Site 4; Emu Park) which did not receive Commonwealth environmental water, but instead had accumulations of organic matter and filamentous algae. This may suggest that environmental watering actions that can introduce organic matter and nutrients will result in increased metabolic rates. It was only this site which had rates that were typical of those found in streams from other parts of the world (e.g. ER rates of 2–12 mg O₂/L/day).

One benefit of the constant and elevated flows was the maintenance of sufficient dissolved oxygen (DO) concentrations to avoid undesirable consequences (due to suboxic (low dissolved oxygen levels) or, in the worst case, anoxic (no dissolved oxygen) conditions). Low DO concentrations were recorded at the upper Wakool River site (Emu Park) and were attributed to both the extant low flow and the higher respiration rates. This point emphasises the ‘Goldilocks’ nature of metabolic rates: *sufficient* primary production and ER are required to ensure the production of basal food resources but if rates are too high then this might be the result of algal blooms (primary production) or cause anoxia, with resultant fish deaths. A better understanding of the ‘ideal target range’ for metabolism should emerge as the LTIM Project continues into year 2 and beyond.

Goulburn River

This section was derived from the Goulburn River Selected Area Evaluation Report (Webb et al. 2015).

There were eight watering actions (freshes and base flows) targeting stream metabolism in the Goulburn River during 2014–15. In all cases, the increased flows were contained within the main river channel, resulting in very little inundation/reconnection of backwaters. As shown in the Entrainment Model, this means only a small amount of nutrients and organic matter would have entered the river, primarily from the newly wetted banks and benches. Consequently, there was no discernible change to metabolic rates. Preliminary Bayesian modelling suggests that the initial diminution of respiration rates was due to dilution. More elaborate modelling (requiring further flow–metabolism data over subsequent years) will explore the critical relationship between flow events and any subsequent increase in metabolic rates — *this will be a common theme for all Selected Areas*.

The six sets of monthly chlorophyll data (at each site), which ranged between <5 and 19 µg/L, indicated low phytoplankton concentrations at these times, consistent with the low primary production rates. As per the Disturbance Model, it is likely that some of the primary production is performed by algae growing in the shallow, marginal areas of the river.

Table 2. Summary of watering actions monitored for Stream Metabolism.

Selected Area (Watering Action Reference) ¹	Water delivery dates (start – end) ¹	Flow component type ¹	Commonwealth environmental water volume delivered (GL) ¹	Expected ecological outcome ¹	Monitored site(s) ²	Observed ecological outcomes ²	Influences ²
Edward–Wakool (10008-01)	12/08/14 – 09/01/15	Base flow	34.563	None	Yallakool Creek	Metabolic rates comparable with many other streams	Constrained by very low concentrations of bioavailable nutrients and organic carbon
Goulburn (10002-01)	25/08/14 – 25/09/14	Base flow	12.986	Disrupt biofilms, move fine sediment, entrain organic matter in stream to support ecosystem function	Moss Rd, Darcy’s Creek, Loch Garry, McCoys Bridge	No major changes in stream metabolism as a result of flows	Flows retained within channel. Consequently, introduction of sufficient nutrients/organic carbon to stimulate primary production is unlikely
Goulburn (10002-01)	10/11/14 – 17/11/14	Base flow	1.315				
Goulburn (10002-01)	14/10/14 – 11/11/14	Fresh flow	67.46				
Goulburn (10002-01)	20/11/14 – 30/11/14	Fresh flow	14.472				
Goulburn (10002-01)	01/12/14 – 28/02/15	Base flow	18.291				
Goulburn (10002-01)	01/03/15 – 15/03/15 13/04/15 – 12/06/15	Base flow	21.103				
Goulburn (10002-01)	16/03/15 – 12/04/15	Fresh flow	13.321				
Goulburn (10002-01)	13/06/15 – 30/06/15	Fresh flow	65.444				

Selected Area (Watering Action Reference)¹	Water delivery dates (start – end)¹	Flow component type¹	Commonwealth environmental water volume delivered (GL)¹	Expected ecological outcome¹	Monitored site(s)²	Observed ecological outcomes²	Influences²
Gwydir (00016-01)	17/09/14 – 07/03/15	Fresh flow	30.000	Allow for sediment transport, nutrient and carbon cycling	Pallamalla on Gwydir River	Water quality parameters within normal ranges Reduced average pH, conductivity, and dissolved oxygen (DO); DO linked with low chlorophyll-a (algae) concentrations	Due primarily to dilution effects metabolism not monitored
Lachlan (10013-01)	03/10/14 – 29/10/14	Fresh flow	5.000	None	Wallanthery, Lanes Bridge, Cowl Cowl, Whealbah	Gross primary productivity and ecosystem respiration were both reduced in the target reach but increased in the weeks following	Dilution and light attenuation during flow Subsequent flow-independent increases require further research
Murrumbidgee (10023-01)	12/08/14 – 20/01/15	Wetland, return flows	40.000	Support ecosystem functions, such as mobilisation, transport and dispersal of biotic and abiotic material (e.g. macroinvertebrates, nutrients and organic matter) through longitudinal and lateral hydrological connectivity	Upper North Redbank	Rates of decomposition were not influenced by the release	Water volumes released were too small relative to the total river volume to drive primary productivity or environmental respiration downstream of the release

Selected Area (Watering Action Reference)¹	Water delivery dates (start – end)¹	Flow component type¹	Commonwealth environmental water volume delivered (GL)¹	Expected ecological outcome¹	Monitored site(s)²	Observed ecological outcomes²	Influences²
Warrego–Darling (Information from Appendix C, Selected Area Technical Report)	Oct–Nov 2014, Dec–Mar 2015, Apr–May 2015	Base flow (water is not specifically delivered, rather held as unregulated entitlement and reliant on upstream catchment availabilities)	None accounted	Assess response of primary productivity	Yanda & Akuna (above Warrego–Darling rivers junction)	Difficulties with oxygen profiles prohibited analysis of primary productivity	
Lower Murray River (10009-01)	04/09/14 – 31/12/14	Base flow	191.833 ~581 (2014–15)	Assess response of primary productivity, ecosystem respiration and dissolved oxygen levels	Gorge (downstream of Lock 1) and floodplain (downstream of Lock 6)	Enhanced respiration rates during return flows (from Chowilla Floodplain) Reduction in dissolved oxygen concentration associated with increased respiration rates	Increased organic material supplied in return flows back to the river Contributed to by the quality of returning water

¹ As reported by the Commonwealth Environmental Water Office.

² As reported by the Monitoring and Evaluation (M&E) team for each Selected Area in Selected Area reports for 2014–15.

Lachlan river system

This section was derived from the Lower Lachlan river system Selected Area 2014–15 Annual Monitoring and Evaluation Report (Dyer et al. 2015).

The ability to draw any inferences from flow–metabolism relationships was very limited as only one environmental water event (peak flow on 8 September 2014) coincided with the limited periods for which metabolism measurements were made during this first year. There was a reduction in both primary production and ER of 25–50% in the week or two after the peak discharge in early September, then the values of these parameters increased over the following 8 weeks. This behaviour is consistent with the Disturbance Model where existing biofilms were scoured (resulting in a decline in primary production) and then primary production increased again as new biofilms started to grow. Primary production was constrained within the narrow range of 1–3 mg O₂/L/day. ER showed a consistent increase from 2 weeks after the watering event peak until the end of October. There was a spike in ER (up to 6 mg O₂/L/day for a few days in late October, but this was not mirrored by an increase in primary production. However, at this stage, it is unclear whether the post-event increases (delayed by a week or two) in metabolic parameters were the result of the flow event or simply a response to warmer temperatures and longer days (more light) moving from early to late spring.

Of the spot measurements of water quality, the only unusual pH reading was 5.9 at Wallanthery on 10 December 2014. This seems to be an outlier as 5.9 is an unusually low pH value for these lowland river systems. pH values such as this may be associated with very high levels of respiration (respiration produces H⁺ (acidity)) but this seems unlikely here. Other readings (pH 7.3 to 8.2) were in the very conventional range for lowland rivers. Chlorophyll-a concentrations (24 readings over 6 sampling trips) were within the range 3–23 µg/L, indicating low phytoplankton abundance.

Lower Murray River

This section was derived from the Lower Murray River Selected Area 2014–15 Annual Report (Ye et al. 2016). (Note that there is additional information in this section related to the export of material to the mouth of the Murray.)

No simple relationships were found between flow and metabolic parameters in the Lower Murray River. This is a common finding across the Selected Areas and is most probably related to the lack of inundation of backwaters and other areas with high nutrients and organic matter as described in the Entrainment Model. The lack of entrainment appears to be confirmed by the observation that primary production and respiration were closely balanced (net production was close to zero), suggesting that there was a close coupling between autochthonous (originating in channel) production and respiration with little organic matter (and perhaps nutrient) supply from outside the main river channel. The constrained and uniform channel shape means that when higher flows do occur, there is little inundation of new areas; therefore, the absence of a significant allochthonous (external to the river) organic matter supply is not surprising.

One aspect that sets the Lower Murray aside from most other Selected Areas in 2014–15 is that for a period there was a significant portion of the river flow from a source other than directly upstream. Hence, it is worth highlighting (as did the authors of the Selected Area report) that inflows from these different sources could contribute to different water quality (and hence potentially metabolic rates if the different sources have, for example, higher nutrient concentrations to fuel primary production). In particular, it was noted that return flows from the Chowilla Floodplain (environmental water from The Living Murray) could supply elevated concentrations of organic carbon, consistent with the Entrainment Model. This would then lead to higher rates of ER. Further examination of the effects of different sources of water on rates of primary production and ER will

be conducted over subsequent years in the LTIM Project. Identification of water sources that can stimulate metabolic rates may lead to judicious use of these sources in future to boost base levels of primary production and ER.

The other model that may have been relevant in the Lower Murray was the Mixing Model. Floating algae (phytoplankton) are heavily influenced by flow conditions, with lower flows providing longer residence times and less mixing which support increased growth. It was noted that the water velocity 'downstream of Lock 6 was always less than 0.25 m s^{-1} ' (Ye *et al.* 2016). Velocities below this threshold value are insufficient to induce significant water column mixing; hence, would not represent a disturbance for floating algae. It is likely that higher flows may result in lower rates of metabolism as water residence times and flushing increase.

The low water velocities may also be insufficient to initiate any significant scouring of biofilms on large woody debris and in the shallow waters near the river banks (Disturbance Model).

From combined hydrodynamic–biogeochemical modelling, Commonwealth environmental water resulted in small but perhaps significant differences in dissolved and particulate nutrient concentrations, including higher ammonium, silica and particulate organic nitrogen concentrations within the Murray Mouth. This additional nutrient supply through the Commonwealth environmental water may then support increased productivity in the Coorong.

Modelling suggests that Commonwealth environmental water had no effect on in-channel salinity levels but these additional flows increased salt exports from the Murray River Channel, Lower Lakes and Coorong, contributing 21% and 64% of the total modelled export from the Lower Murray River Channel and Lower Lakes, respectively. Modelling suggests that Commonwealth environmental water greatly reduced the net import of salt to the Coorong during 2014–15 (from 3.2×10^6 tonnes down to 1.6×10^5 tonnes) (Ye *et al.* 2016).

The impacts of Commonwealth environmental water on exported nutrient loads from the Murray River Channel, Lower Lakes and Murray Mouth were largely driven by the increased discharge (as concentrations remained relatively constant). Commonwealth environmental water contributed 29%, 48% and 51% of the total silica exports from the Murray River Channel, Lower Lakes and Murray Mouth, respectively (Ye *et al.* 2016). Silica is an essential nutrient for diatom growth; these diatoms are of high nutritional quality in coastal and riverine systems, and therefore Commonwealth environmental water would be expected to support increased secondary productivity in the Coorong and near-shore environment.

As noted with nutrients, increased exports of phytoplankton biomass from the Murray River Channel, Lower Lakes and Murray Mouth are largely driven by increased discharge rather than increased concentration. Phytoplankton export provides benefits for the Lower Lakes, Coorong and near-shore environment as an energy source for secondary productivity (e.g. grazing by zooplankton).

Murrumbidgee river system

This section was derived from the Murrumbidgee river system Selected Area Synthesis (Wassens et al. 2016a) and Technical (Wassens et al. 2016b) Reports.

A total of eight watering actions were undertaken in the Murrumbidgee — five of these occurring over the period August 2014 to April 2015 with the remaining three being wetland inundation actions undertaken in May and June. The watering actions increased discharge in the main channel over the 4-month period from October 2014 to February 2015. The protracted influence of the watering actions makes identification of the outcomes of the actions problematic without models that would enable predictions of what would have happened in the absence of the environmental water. Data were collected at two sites — Narrandera, where the data record spanned November

2014 until February 2015, and Carrathool, where the data extended until May 2015. As a result, it was possible to examine responses to variations in flow that included Commonwealth environmental water.

Peaks in primary production and ER were highlighted in the data set and occurred both during periods of small increases in discharge within the main river channel and also under low flow conditions. The increases with small flow events coincided with increases in nutrient concentrations and are consistent with the Entrainment Model. However, metabolic increases during low flow conditions suggest that these might be simply associated with seasonal increases in light and temperature.

Water was also returned to the main channel of the Murrumbidgee after inundation of mid-North Redbank wetlands. Water quality monitoring detected changes in dissolved organic carbon and phosphorus; however, these were not associated with any detectable change in rates of decomposition within the main channel.

The most salient feature of the data is that the metabolic rates (around 1–3 mg O₂/L/day) were at the low end of the range expected for aquatic ecosystems globally. Hence, any flow-based effects are relatively small. It was noted that these metabolic rates in the Murrumbidgee were about half those reported by Vink *et al.* (2005) a decade earlier. The reason for this apparent decline remains unclear but is certainly a point of interest and warrants further attention, especially if there is an ongoing decrease in rates.

From a water quality perspective, there were no issues associated with any of the watering actions. Spot measurements of DO indicated that this parameter did not fall below 7 mg O₂/L; hence, the balance of respiration, primary production and re-aeration were such that there was no evidence of low oxygen conditions. (Such conditions can be highly ecologically harmful as high rates of ER coupled with very low flows (and hence reduced re-aeration) can result in suboxic or even anoxic water column conditions.) Turbidity values were moderate and typical for Australian lowland rivers in this region (30–70 nephelometric turbidity units; NTU). Despite the lack of response in metabolism, flow events did result in increases in in-stream nutrient concentrations, which may provide further opportunity for primary production enhancement over subsequent weeks and in locations downstream (as the higher nutrient water moves through the system). There is also the possibility that if water velocities are sufficient, then flow events may cause some scouring of biofilm communities and a resultant reduction in metabolic rates (Disturbance Model). Further data, matching nutrient concentrations to watering events and examining biofilm biomass, are needed to check these assertions.

Gwydir river system and Junction of the Warrego and Darling rivers

This section was derived from the Junction of the Warrego and Darling rivers Selected Area Report (Southwell et al. 2015b) and Gwydir river system Selected Area Report (Southwell et al. 2015a).

Delays in equipment installation precluded evaluation of flow effects on water quality or metabolism in the Warrego and Darling rivers. A few days' data were recorded at two sites on the Darling (Yanda and Akuna) towards the end of the monitoring period (February and May 2015) and demonstrated that data collection and analysis were viable for year 2 and beyond. There was a similar situation in the Gwydir where late delivery of equipment restricted in-channel measurements to a few days from mid-February to mid-April 2015. The very limited results showed low levels of primary production (typically 2 mg O₂/L/day or less) consistent with findings from other Selected Areas. Additional logger data were recorded in several wetland and dam sites in these catchments but such data are beyond the scope of stream metabolism modelling which assumes a unidirectional water flow and no substantial localised areas of static water. Whether the logger measurements are indicative of the behaviour of a wetland, pond or dam is very difficult to ascertain without multiple

point measurements across that water body. In particular, 'edge' effects due to benthic biofilms in shallow water might not be picked up by a logger in the middle of an unmixed pond.

There were insufficient data from both of these Selected Areas to undertake any assessment of the effects of Commonwealth environmental water although it is expected that this will be possible from year 2 onwards.

3.2.3 Overview of stream metabolism at monitored sites within Selected Areas

For the five Selected Areas for which there was sufficient data in 2014–15, the metabolic parameters primary production and ER are presented in Figures 6 and 7, respectively. The data are stratified into season (spring, summer and autumn) to briefly evaluate any seasonal patterns. The data are also summarised in Appendix B of this report. Only three Selected Areas had data available from across all three seasons (Edward–Wakool, Goulburn and Murrumbidgee). The typical trend was that both primary production and ER increased when moving from spring into summer. This is entirely consistent with longer (more hours of sunlight and more intense sunlight), warmer (higher cellular metabolic rates) days during summer. As algae double in number every 1–2 days, then highest algal populations are often found in late summer rather than earlier in the season. Moving from summer into autumn, there was no common pattern between the three Selected Areas for primary production, however ER decreased in all three (partially at least due to lower autumn temperatures). As more data become available over subsequent years of the LTIM Project, much better understanding of the seasonal dynamics of metabolism should become apparent within each Selected Area. This information is important for the LTIM Project as it will enable predictions of the counterfactual — what would the metabolic rates be if there was no added environmental water. The effects of added environmental water can then be modelled knowing the background behaviour of each river system.

For comparison on a global scale, a compendia of stream metabolism data collected worldwide (but mostly featuring the United States of America) indicate that primary production and ER values are typically in the range 2–20 mg O₂/L/day (Bernot *et al.* 2010; Marcarelli *et al.* 2011) — assuming an average water depth of 1 m to enable conversion of areal units to the volumetric units used in this report. Hence, the LTIM Project data fall towards the bottom end of this range. Again, as further data become available over subsequent years, it will be very informative to determine whether these Selected Area rates are consistent between years or whether 2014–15 was unusually low (or high). Questions relating to whether the fact that these rates are low on a global basis mean food webs (and hence native fish populations) are resource/energy limited will be a key focus of annual reports towards the end of the LTIM Project.

3.3 Unmonitored area outcomes

Over the 2014–15 watering period, the CEWO contributed to 12 watering actions to achieve expected outcomes associated with stream metabolism (including actions that targeted nutrient cycling and/or ecosystem function) in unmonitored sites. These actions are summarised in Table 3.

Based on results from year 1 of the monitored areas, it is anticipated that environmental watering actions that result in flow being confined within the defined river channels (e.g. the Campaspe and Ovens river systems) will not result in significant changes to metabolic rates. It is still hypothesised based on the Entrainment Model that in the southern Basin, metabolic rates are largely determined

by low nutrient concentrations (and specifically, low concentrations of ‘bioavailable’³ phosphorus for primary production and labile organic carbon for ER).

There are as yet no data to indicate the effects of watering actions at sites where nutrient concentrations are significantly higher. Hopefully, data from the Warrego–Darling system (and perhaps also the Gwydir) in 2015–16 and henceforth will provide some insights for future reports.

It is likely that unmonitored streams with low nutrient concentrations and relatively poor connection with backwaters and floodplains will have low metabolic rates.

For watering actions targeting stream metabolism and water quality in unmonitored sites, it is expected that water returning to the main river channel (e.g. Warrego–Darling, Gwydir, Macquarie) after inundating wetlands and floodplains is likely to affect water quality and rates of primary production and ER. On this basis, it appears likely that the watering actions undertaken in the Gwydir, Warrego–Darling and Macquarie rivers would have been associated with increases in metabolism based on the Entrainment Model.

The magnitude of the effects of these watering actions will be influenced by a number of factors. Timing will influence the temperature and amount of light and, as noted earlier, these are both major drivers of metabolism responses. Duration of inundation will also have an influence as longer duration inundation events provide more time for growth of key primary producers, such as algae. Finally, the area inundated and its associated vegetation community will influence the amount and type of organic matter and nutrients available for entrainment.

3.4 Synthesis of water quality findings

The Basin Plan objective in relation to water quality and salinity is to maintain appropriate water quality, including salinity levels, for environmental, social, cultural and economic activity in the Murray–Darling Basin. More specifically, for water-dependent ecosystems, the objective is to ensure water quality is sufficient to protect and restore ecosystems, their associated ecosystem functions and to ensure they are resilient to climate change and other risks and threats. In terms of an evaluation of the management of Commonwealth environmental water, there are three considerations:

1. the extent to which watering actions undertaken to achieve biodiversity, ecosystem function or resilience outcomes influenced water quality
2. the effectiveness of watering actions undertaken to ameliorate threats from acute water quality events, including blue-green algal blooms, oxygen-depleted blackwater and acidification
3. the effectiveness of watering actions undertaken to achieve long-term improvements in water quality, including the export of salt.

Within this context, the available data did not detect any water quality issues arising from the implementation of watering actions in 2014–15. The watering actions undertaken in the Lower Murray were effective in exporting salt and nutrients which would be expected to contribute to 1–5-year improvements in water quality in the Basin.

A review of water quality data from across the seven Selected Areas provides an important baseline that will inform the evaluation of watering actions undertaken in future years of the LTIM Project. Appendix C of this report lists the nutrient data from samples collected from the Selected Areas during 2014–15. Of particular importance to stream metabolism are the concentrations of the bioavailable forms of nitrogen (N) (nitrate+nitrite = ‘NOx’ and ammonia/ammonium) and

³ ‘Bioavailable’ refers to those forms of nitrogen (N), carbon and phosphorus (P) most readily taken up by organisms. This typically equates to phosphate for P and the combination of ammonia, nitrate and nitrite for N.

phosphorus (P) (filterable reactive P (FRP) which is usually equated to phosphate). The Edward–Wakool, Murrumbidgee and Goulburn sites in particular had very low median FRP concentrations (around 2–5 µg P/L; Table C5) which almost certainly constrained primary production. FRP was also relatively low in the Lower Murray and Lachlan. Median FRP was much higher in samples from the Gwydir and especially the Warrego–Darling samples, so it will be instructive to contrast metabolism from these two Selected Areas with the other five Selected Areas to assess the impact of nutrients. Bioavailable N concentrations (ammonia and nitrate; Tables C3 and C4, respectively) varied widely across the Selected Areas. It is anticipated that low bioavailable N may help limit primary production where P is also low or favour N-fixing cyanobacteria if P concentrations favour significant growth. It is expected that nutrient availability will perhaps be the dominant determinant of metabolism (especially primary production) across the Basin.

Dissolved organic carbon (DOC) concentrations (Table C6) also showed some variability between Selected Areas. DOC can be correlated with ER, as ER involves breakdown of organic matter. However, it must be stressed that the relationship between these two parameters is not straightforward as the lability of the organic carbon is just as important. DOC can be a reasonable estimate of organic matter but can also reflect the carbon remaining after all the labile fractions have been consumed. Continued assessment of lability of the DOC (and total organic carbon) samples, through techniques including fluorescence excitation and emission matrices (Watts *et al.* 2015a), is essential to tease these factors apart.

A key finding from 2014–15, however, was that in general, the water quality data (including nutrient concentrations) are likely to be of insufficient frequency to enable future determination of the effects of watering events on such concentrations (which in turn may drive subsequent increases in metabolism). Although beyond the financial and logistical constraints on the LTIM Project, it is recommended that each Selected Area investigate other sources of water quality data that can then be used in meta-analysis. Of particular importance will be information on how nutrients change over short time frames (hours to days) during and immediately after watering events (and natural flow increases).

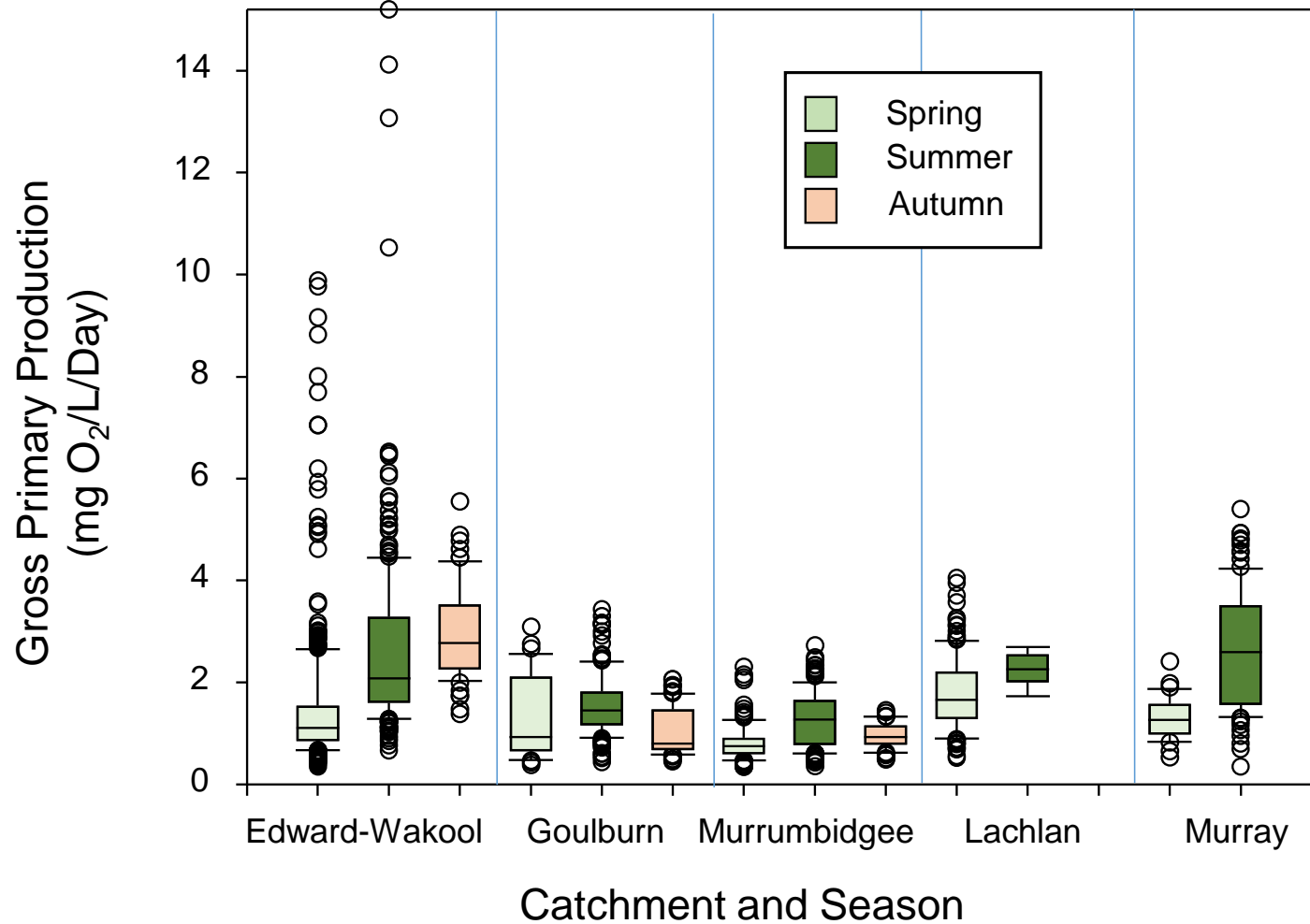


Figure 6. Box plot representing the seasonal dependence of gross primary productivity in the five Selected Areas for which data are available. Within each area, results from individual loggers (sites) have been composited. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. ‘Whiskers’ above and below the box indicate the 90th and 10th percentiles. Values beyond this, ‘outliers’ are plotted as individual circles.

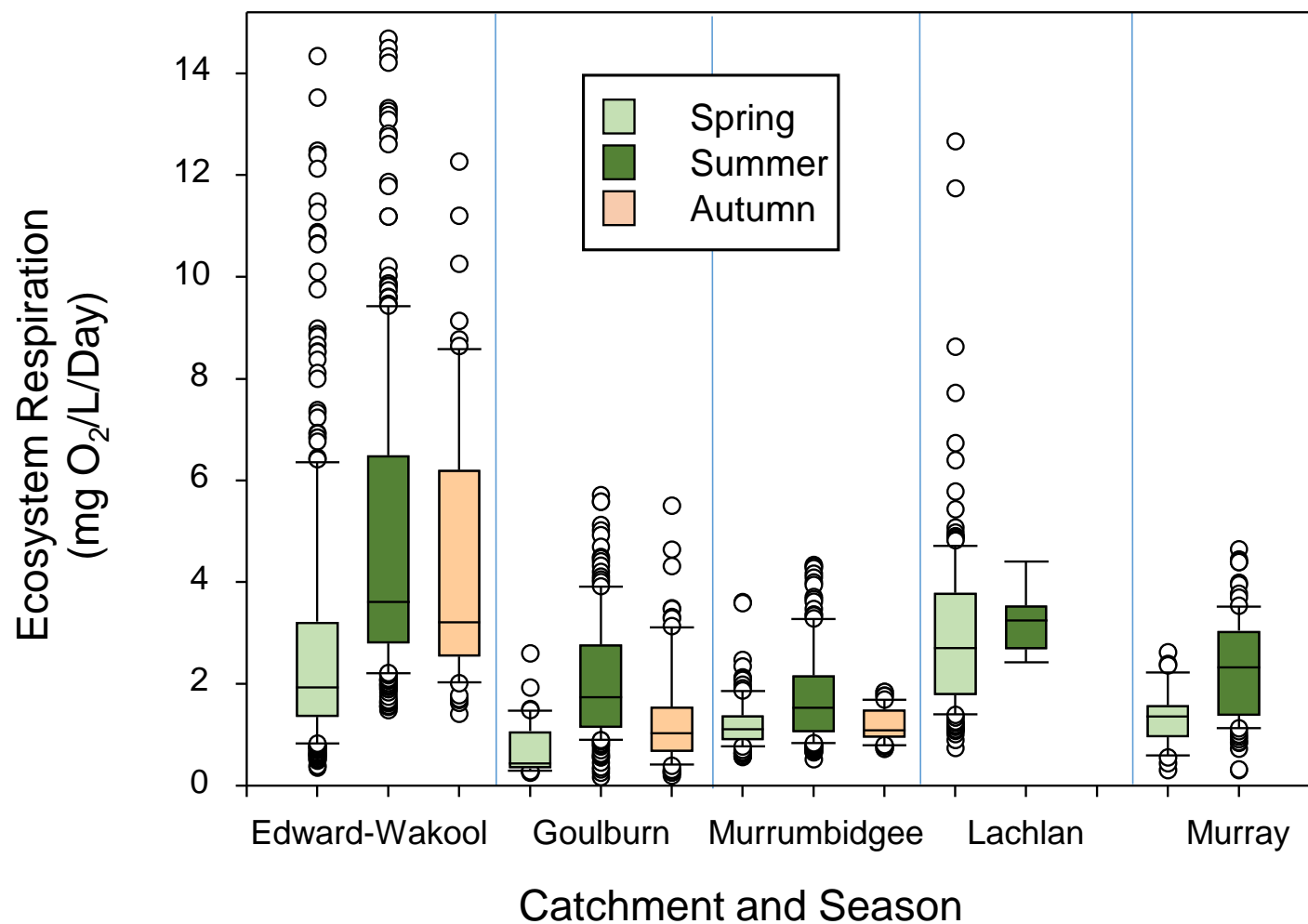


Figure 7. Box plot representing the seasonal dependence of ecosystem respiration (ER) in the five Selected Areas for which data are available. Within each area, results from individual loggers (sites) have been composited. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. 'Whiskers' above and below the box indicate the 90th and 10th percentiles. Values beyond this, 'outliers' are plotted as individual circles.

Table 3. Summary of watering actions targeting Stream Metabolism expected outcomes at unmonitored sites.

Selected Area (Watering Action Reference)	Actual water delivery dates (start – end)	Commonwealth environmental water delivered (GL)	Flow component type	Locations	Expected ecological outcomes
Campaspe (10003-01)	09/10/2014 – 22/10/2014	5.7914	Fresh flow	Campaspe river system (Reaches 2, 3 and 4) including floodplain	Flush organics from bank and benches to reduce the risk of blackwater events in summer
Macquarie (10015-01)	13/10/2014 – 12/12/2014	10	Base flow; fresh flow; wetland inundation	Macquarie river system including floodplain	Allow for sediment transport, nutrient and carbon cycling
Murray (10011-02)	x	0.2995	Wetland	Bullock Swamp	Provide freshwater inflows to reduce salinity levels and improve condition and diversity of wetland vegetation, improving ecological function
Gwydir (00016-03)	03/10/2014 – 29/10/2014	3.656	x	Carole Creek	Support in-stream ecological function and nutrient cycling contributing to health of in-stream habitat and maintaining water quality
Gwydir (00016-04)	02/10/2014 – 27/10/2014	13.316	x	Mehi River	Support in-stream ecological function and nutrient cycling contributing to health of in-stream habitat and maintaining water quality
Ovens (10004-01)	04/04/15 – 05/04/15 30/04/15 – 30/04/15	0.05 0.02	Base flow	Ovens river system including floodplain	Improve primary production through disruption of biofilms
QLD Border Rivers (00111-18)	29/01/15 – 05/02/15 06/04/2015	0.332 0.231	Fresh	Dumaresq–Macintyre River and fringing wetlands	Nutrient and sediment cycling (from inundation of upper channel areas, some anabranch channel and near-stream wetlands)
NSW Barwon–Darling (00111-24)	11/01/15 – 17/01/15 30/05/15 – 31/05/15 Late Feb & May 2015	1.2564 0.108 0.39636	Fresh	Barwon–Darling River and fringing wetlands (Mungindi to Menindee)	Nutrient and sediment cycling from inundation of lower level benches

3.5 Adaptive management

Based on the limited information from the first LTIM Project year in the five Selected Areas that recorded sufficient stream metabolism data, it appears that, in line with the Entrainment Model, rates of primary production and ER are unlikely to respond to base flows or freshes. It does appear likely that stream metabolism did respond to those watering actions that achieved significant floodplain or wetland inundation.

It is hypothesised that the lack of response to base flows and freshes is largely determined by the limited opportunities for entrainment that occur when water remains in-channel. Results suggest, however, that delivery of water from alternative sources (e.g. Chowilla into the Lower Murray) can induce higher metabolic rates. Nutrient increases may also be mediated through rewetting dried areas, as seen in the Murrumbidgee. In addition, there is a limited amount of evidence that higher nutrient concentrations do in fact stimulate primary production and ER (one site in the Edward–Wakool Selected Area, Entrainment Model). *There is emerging evidence that increasing nutrient concentrations will enhance what appear to be 'low' rates of primary production and ER on a world scale.* In many instances, the management of Commonwealth environmental water will be limited to freshes and base flows due to either the volumes of water available or delivery constraints within the system. In these instances, three options emerge in terms of future management:

1. If larger magnitude flows are out of scope due to limited volumes of environmental water, then two options may be worth consideration:
 - coordinated watering through either piggybacking on natural events, the delivery of consumptive water or collaboration with other environmental waterholders. The Hydrology evaluation revealed that many of the more significant outcomes were achieved collaboratively
 - re-evaluate the trade-off between magnitude and duration. In situations where stream metabolism responses are believed to be important, many of the key processes in terms of nutrient cycling occur within days of inundation. This may mean that larger, shorter flows may be more effective.
2. If stream metabolism is a priority outcome either in its own right or in order to achieve outcomes for fish or waterbirds, then opportunities to connect the river to potential sources of nutrients and organic matter should be explored. These may include upstream opportunities or through the use of infrastructure to inundate and then return water to the main channel.
3. Focus on other outcomes — environmental flows play a variety of roles in rivers and if stream metabolism outcomes are unlikely within the operational constraints, this requires that flow management focus on other outcomes such as provision of habitat or connectivity.

4 Expected 1–5-year outcomes

The relevant Basin Plan long-term objective for stream metabolism is water-dependent ecosystems able to support episodically high ecological productivity and its ecological dispersal. Within this context, the metabolism objective is similar to the hydrological connectivity objective that seeks to protect and restore more natural patterns of lateral and longitudinal connectivity. Like hydrological connectivity, there is no presumption that metabolism responses will lead a long-term metabolic legacy per se. Rather, the legacy will be manifest further up the food chain with improvements in the condition of fish and waterbird populations. As a result, the outcomes of each watering action contribute to long-term patterns of productivity and, given it is the first year of monitoring, considering 1–5-year outcomes is speculative.

A potential exception to the above is suggested by the Basin Plan objective; specifically, that water-dependent ecosystems' capacity to support episodically high productivity may vary — that is, ecosystems in good condition may show a stronger response to boom times than systems in poor

condition. There is little evidence to test this idea and as a consequence the underlying processes are not known, but may include variations in a system's ability to retain nutrients, the composition of the decomposer and primary producer communities or the influence of starting condition on the system's response to change. Over time, the LTIM Project monitoring data will provide valuable insight into this hypothesis and this would help guide future water management toward short-term improvements in condition that would underpin longer term outcomes during episodes of high ecological productivity.

Monitored outcomes of freshes and base flows in the first year (2014–15) did not detect any significant change in rates of gross primary production nor ER with the addition of environmental water. It should be noted that it is possible that environmental flows created additional habitat for primary producers and decomposers and that this will have had an influence on metabolism rates. The data required to evaluate this possibility were not available this year, but it is expected that this will be included in future evaluations.

Deconvoluting flow effects on primary production (and ER) from seasonal changes will be challenging and will require monitoring watering actions at various times throughout the year. The absence of flow events at various stages of the year will greatly assist with this deconvolution as these periods will enable study of the seasonal effects by themselves. This allows development of the 'counterfactual' — that is, the behaviour of stream metabolism, in the absence of watering events (both natural and anthropogenic).

It appears likely that unmonitored watering actions that inundated wetlands and floodplains were associated with increases in primary production and decomposition. It would appear from these results that using environmental flows to connect rivers to sources of nutrients and organic carbon (Entrainment Model) will make a contribution toward achievement of the Basin Plan objective.

5 Expected Basin-scale outcomes

5.1 Stream Metabolism

With essentially no long-term data on stream metabolism across the Murray–Darling Basin prior to the short-term monitoring projects in 2011 and onwards into this first year of the LTIM Project, it is difficult to determine whether the 2014–15 results provide typical rates of primary production and ER in these waterways and whether there is any longer term trend. As noted above, rates were lower in the Murrumbidgee than a decade ago, but it is uncertain whether these differences are perhaps due to differences in sites, methodology and/or analysis methods, rather than a real decline.

It has already been highlighted that the rates of primary production and ER in the five Selected Areas for which there were sufficient data are at the lower end of 'normal' compared with other waterways in several countries. However, it may be that the 2014–15 rates *are* 'normal' for waterways across the Murray–Darling Basin. One important difference when comparing systems between Australia and elsewhere is the higher turbidities found in Australian streams (due to the fine colloidal nature of the soils), which would be expected to inhibit primary production. These high turbidities persist for very long periods, often near permanently, meaning that primary production is dominated by plant growth in the shallow, littoral regions where light inhibition is minimised (the 'bath tub ring effect'; Bunn *et al.* 2006). This is in distinct contrast to many international clear-water rivers and streams where there can be prolific benthic plant growth (macrophytes and benthic algae).

It is the interplay of increasing nutrient concentrations and increasing light penetration into the water column (through lower turbidities) that should give rise to higher rates of primary production.

If ER is driven largely by autochthonous production, then increased primary production should also result in increased ER. Conversely, if an external source of organic matter is the dominant carbon supply mechanism, then the link between primary production and ER will be relatively weak and mediated through the flow events introducing both nutrients and organic carbon into the river channel.

Hence it is *expected* that watering actions that reconnect backwaters, flood runners and the floodplain should increase both primary production and ER but there is little evidence from 2014–15 to strongly support this assertion. It is also expected that the monitored waterways in the Selected Areas will broadly represent stream metabolism across the Basin. Thus, it is believed likely (again without evidence to support or refute the statement) that higher trophic levels across the Basin, including native fish populations, may be constrained by the availability of food supplies.

Stream metabolism data from both the Gwydir and Warrego–Darling Selected Areas in 2015–16 and beyond may help disentangle the effects of nutrient concentrations on metabolism in these Australian lowland rivers, as phosphorus concentrations are much higher in these two waterways than in the other five (Appendix C, Table C5), thereby decreasing the likelihood of nutrient limitation.

5.2 Water Quality

Although the data were too sparse to provide any detailed insights into the effects of watering actions on pH, turbidity and salinity (electrical conductivity), it is worth noting that there were no generalised water quality problems associated with these parameters in 2014–15. It is likely that these findings are also representative across the Basin. Localised conditions (e.g. drying down of streams into isolated pools) may result in development of poor water quality through concentration of salts but this phenomenon was not observed at the larger scale. Depending on the size of the event, subsequent rewetting may lead to a first flush with very poor water quality (high salt content, low dissolved oxygen).

Commonwealth environmental water may provide benefits for dilution of poor-quality water (the counterfactual was observed in the Edward–Wakool where the one site that did not receive Commonwealth environmental water developed low DO). In terms of the benefits of increasing loads of nutrients and phytoplankton to receiving waters low in these commodities, the modelling from the Lower Murray suggests that export increases are primarily through increases in discharge rather than increases in concentration.

6 Contribution to achievement of Basin Plan objectives

This section provides a brief overview of the extent to which the management of Commonwealth environmental water contributed to water-dependent ecosystems' ability to support episodically high ecological productivity and its ecological dispersal. The data from the Selected Areas did not detect any change in stream metabolism in response to watering actions that provided base flows and freshes within river channels. Although there are no firm data, it is likely that watering actions that achieved significant wetland or floodplain inundation and then returned water to the main channel (Gwydir, Warrego–Darling and Macquarie) would have been associated with increases in metabolism. Although no metabolic response was evident following the return of water from the wetlands to the Murrumbidgee — which was associated with increased nutrients and organic matter — this was likely due to the small volumes returned.

As emphasised earlier in this report, no significant 'improvements' in primary production and ER rates as a result of environmental watering actions were detected. It is likely that increases from the

'low' rates of primary production and ER — based on comparison with international values — will only result when the added water also brings in higher concentrations of nutrients and organic carbon (Entrainment Model). It is suggested that the greatest benefit will occur when added water enables reconnection with backwaters and flood runners (and perhaps the floodplain itself). It is hoped and recommended that this contention be tested with real data in 2015–16 and beyond.

As Commonwealth environmental water was intended 'to protect and restore the ecosystem functions of water-dependent ecosystems', it is worth highlighting that although increased discharges frequently resulted in a small decline in primary production and ER rates (due to dilution), the effects appeared to be relatively temporary. Collecting data over years 2–5 will allow the disentangling of normal seasonal effects on metabolic rates (thus enabling future modelling of the 'counterfactual') and changes induced by Commonwealth environmental water. *For this reason, it is vital that watering actions not occur with the same magnitude and at exactly the same time each year.*

In addition, from a water quality perspective, Commonwealth environmental water was intended 'to ensure water quality is sufficient to achieve the above objectives for water-dependent ecosystems, and for Ramsar wetlands, sufficient to maintain ecological character'. This report only considered the stream data, not the wetlands. However, it was argued that Commonwealth environmental water had a beneficial effect in the Edward–Wakool by preventing the development of the low DO conditions found in a nearby site which did not receive this water.

References

- Aristi I, Arroita M, Larrañaga A, Ponsatí L, Sabater S, von Schiller D, Elosegi A, Acuña V (2014) Flow regulation by dams affects ecosystem metabolism in Mediterranean rivers. *Freshwater Biology* **59(9)**, 1816–1829.
- Baldwin DS, Rees GN, Wilson JS, Colloff MJ, Whitworth KL, Pitman TL, Wallace TA (2013) Provisioning of bioavailable carbon between the wet and dry phases in a semi-arid floodplain. *Oecologia* **172(2)**, 539–550.
- Baldwin DS, Wallace T (2009) Biogeochemistry. In: Overton IC, Colloff MJ, Doody TM, Henderson B, Cuddy SM (eds) *Ecological outcomes of flow regimes in the Murray–Darling Basin*. Report prepared for the National Water Commission by CSIRO Water for a Healthy Country Flagship. CSIRO, Canberra, pp 47–57.
- Bernot MJ, Sobota DJ, Hall RO Jr, Mulholland PJ, Dodds WK, Webster JR, Tank JL, Ashkenas LR, Cooper LW, Dahm CN, Gregory SV, Grimm NB, Hamilton SK, Johnson SL, McDowell WH, Meyer JL, Peterson B, Poole GC, Valett HM, Arango C, Beaulieu JJ, Burgin AJ, Crenshaw C, Helton AM, Johnson L, Merriam J, Niederlehner BR, O’Brien JM, Potter JD, Sheibley RW, Thomas SM, Wilson K (2010) Inter-regional comparison of land-use effects on stream metabolism. *Freshwater Biology* **55(9)**, 1874–1890.
- Borchardt MA (1996) Nutrients. In: Stevenson RJ, Bothwell ML, Lowe RL (eds) *Algal ecology: freshwater benthic ecosystems*. Academic Press, San Diego, pp 184–227.
- Boulton AJ, Brock MA (1999) *Australian freshwater ecology: processes and management* Gleneagles Publishing, Glen Osmond.
- Bunn SE, Balcombe SR, Davies P, Fellows CS, McKenzie-Smith FJ (2006) Aquatic productivity and food webs of desert river ecosystems. In: Kingsford RT (ed) *Ecology of Desert Rivers*. Cambridge University Press, Cambridge, pp 76–99.
- Dyer F, Broadhurst B, Thiem J, Thompson R, Driver P, Bowen S, Asmus M, Lenehan J (2015) *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Lower Lachlan river system Selected Area 2014–15 annual monitoring and evaluation report* Commonwealth of Australia, Canberra.
- Ellis I, Meredith S (2004) *An independent review of the February 2004 Lower Darling River fish deaths: guidelines for future release effects on Lower Darling River fish populations*. A report to the NSW Department of Infrastructure Planning and Natural Resources. MDFRC Technical Report 7/2004. Murray–Darling Freshwater Research Centre, Wodonga, 46 pp.
- Gawne B, Roots J, Hale J, Stewardson M (2014) *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Basin Evaluation Plan*. Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre (MDFRC). MDFRC Publication 42/2014. MDFRC, Wodonga, 55 pp.
- Grace M (2015) *Long Term Intervention Monitoring Basin Matter — Stream Metabolism and Water Quality foundation report*. Final Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre (MDFRC). MDFRC Publication 69/2015. MDFRC, Wodonga, 9 pp.
- Junk WB, Bayley PB, Sparks RE (1989) The flood pulse concept in river–floodplain systems. In: Dodge DP (ed) *Proceedings of the International Large River Symposium*. Canadian Special Publication of Fisheries and Aquatic Sciences **106**, 110–127.
- McGinness HM, Arthur AD (2011) Carbon dynamics

- during flood events in a lowland river: the importance of anabranches. *Freshwater Biology* **56(8)**, 1593–1605.
- Marcarelli AM, Baxter CV, Mineau MM, Hall RO Jr (2011) Quantity and quality: unifying food web and ecosystem perspectives on the role of resource subsidies in freshwaters. *Ecology* **92(6)**, 1215–1225.
- Odum HT (1956) Primary production in flowing waters. *Limnology & Oceanography* **1(2)**, 102–117.
- Oliver RL, Hart BT, Olley J, Grace MR, Rees CM, Caitcheon CG (1999) *The Darling River: algal growth and the cycling and sources of nutrients*. Murray–Darling Basin Commission Report M386: CRC for Freshwater Ecology & CSIRO Land and Water, Canberra, 200 pp.
- Reynolds CS (1992) Algae. In: Calow P, Petts GE (eds) *The rivers handbook*, volume 1. Blackwell Scientific Publishers, Boston, pp 195–215.
- Reynolds CS, Carling PA, Beven KJ (1991) Flow in river channels: new insights into hydraulic retention. *Archiv für Hydrobiologie* **121**, 171–179.
- Reynolds CS, Descy J-P (1996) The production, biomass and structure of phytoplankton in large rivers. *Archiv für Hydrobiologia (Supplement)* **113**, 161–187.
- Roberts BJ, Mulholland PJ (2007) In-stream biotic control on nutrient biogeochemistry in a forested stream, West Fork of Walker Branch. *Journal of Geophysical Research* **112**, G04002, doi:10.1029/2007JG000422.
- Ryder DS, Watts RJ, Nye E, Burns A (2006) Can flow velocity regulate epixylic biofilm structure in a regulated floodplain river? *Marine and Freshwater Research* **57(1)**, 29–36.
- Southwell M, Frazier P, McCue R, Burch L, van der Veer N, Southwell E, Ryder D, Butler G, Spence J, Bowen S, Humphries J (2015a) *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Gwydir river system Selected Area: annual evaluation report — year 1* Commonwealth of Australia, Canberra.
- Southwell M, Ryder D, Frazier P, Southwell E, Linden Burch L, Martin B (2015b) *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project junction of the Warrego and Darling rivers Selected Area: annual evaluation report — year 1* Commonwealth of Australia, Canberra.
- Southwell M Thoms M (2011) Patterns of nutrient concentrations across multiple floodplain surfaces in a large dryland river system. *Geographical Research* **49(4)**, 431–443.
- Thoms MC, Southwell M, McGuinness H (2005) Floodplain–river ecosystems: fragmentation and water resources development. *Geomorphology* **71(1–2)**, 126–138.
- Tockner K, Pennetzdorfer D, Reiner N, Schiemer F, Ward JV (1999) Hydrological connectivity, and the exchange of organic matter and nutrients in a dynamic river–floodplain system (Danube, Austria). *Freshwater Biology* **41(3)**, 521–536.
- Uehlinger U (2000) Resistance and resilience of ecosystem metabolism in a flood-prone river system. *Freshwater Biology* **45**, 319–332.
- Vink S, Bormans M, Ford PW, Grigg NJ (2005) Quantifying ecosystem metabolism in the middle reaches of Murrumbidgee River during irrigation flow releases. *Marine and Freshwater Research* **56(2)**, 227–241.
- Wassens S, Bino G, Spencer J, Thiem J, Wolfenden B, Jenkins K, Thomas R, Hall A, Ocock J, Lenon E, Kobayashi T, Heath J, Cory F (2016a) *Commonwealth Environmental Water Office Long Term*

Intervention Monitoring Project: Murrumbidgee river system Selected Area 2014–15, synthesis report Commonwealth of Australia, Canberra.

Wassens S, Thiem J, Spencer J, Bino G, Hall A, Thomas R, Wolfenden B, Jenkins K, Ocock J, Lenon E, Kobayashi T, Heath J, Cory F (2016b) *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Murrumbidgee river system Selected Area 2014,15, technical report* Commonwealth of Australia, Canberra.

Watts RJ, McCasker N, Thiem J, Howitt JA, Grace M, Kopf RK, Healy S, Bond N (2015a) *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward–Wakool Selected Area synthesis report, 2014–15*. Institute for Land, Water and Society, Charles Sturt University, prepared for Commonwealth Environmental Water Office. Commonwealth of Australia, Canberra.

Watts RJ, McCasker N, Thiem J, Howitt JA, Grace M, Kopf RK, Healy S, Bond N. (2015b). *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward-Wakool Selected Area Technical Report, 2014-15*. Institute for Land, Water and Society, Charles Sturt University, prepared for Commonwealth Environmental Water. Commonwealth of Australia, Canberra.

Webb A, Casanelia S, Earl G, Grace M, King E, Koster W, Morris K, Pettigrove V, Sharpe A, Townsend K, Vietz G, Woodman A, Ziebell A (2015) *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project — Goulburn River Selected Area evaluation report 2014–15*. Report prepared for the Commonwealth Environmental Water Office. Commonwealth of Australia: Canberra.

Ye Q, Giatas G, Aldridge K, Busch B, Gibbs M, Hipsey M, Lorenz Z, Oliver R, Shiel R, Zampatti B (2016) *Long Term Intervention Monitoring for the ecological responses to Commonwealth environmental water delivered to the Lower Murray River Selected Area in 2014/15*. A report prepared for the Commonwealth Environmental Water Office. South Australian Research and Development Institute, Aquatic Sciences, Adelaide.

Appendix A. Other watering actions associated with water quality

The following table lists those watering actions that explicitly targeted water quality outcomes (as distinct from stream metabolism) or for which water quality was a target of monitoring.

Selected Area (Watering Action Reference) ¹	Water delivery dates (start – end) ¹	Flow component type ¹	Commonwealth environmental water volume delivered (GL) ¹	Expected ecological outcome ¹	Monitored site(s) ²	Observed ecological outcomes ²	Influences ²
Campaspe – Reaches 2 and 4 (10003-01)	09/10/14 – 22/10/14	Fresh flow	5.7914	Flush and mix river pools for improved water quality		Not monitored	Not monitored
Edward–Wakool (10008-01)	12/08/14 – 09/01/15	Base flow	34.563	No water quality expected outcome defined.	Yallakool Creek	Assisted in the maintenance of dissolved oxygen concentrations Other water quality parameters not affected	
Edward–Wakool (10008-03)	15/09/15 – 23/11/15	Fresh flow; base flow	2.000	Improve water quality	Tuppall Creek	Not monitored	Not monitored
Edward–Wakool (10008-05)	15/03/15 – 27/04/15	Fresh flow; base flow	0.05	Improve water quality	Tuppall Creek	Not monitored	Not monitored
Goulburn (10002-01)	20/11/14 – 30/11/14	Fresh flow	14.472	Maintain water quality	Moss Rd, Darcy’s Creek, Loch Garry, McCoys Bridge		
	01/12/14 – 28/02/15	Base flow	18.291	Maintain water quality			
Gwydir (00016-01)	17/09/14 – 07/03/15	Fresh flow	30.000	Maintain water quality	Pallamalla on Gwydir River	Water quality parameters within normal ranges Reduced average pH, conductivity and dissolved oxygen (DO). DO linked with low chlorophyll-a (algae) concentrations	Due primarily to dilution effects

Selected Area (Watering Action Reference)¹	Water delivery dates (start – end)¹	Flow component type¹	Commonwealth environmental water volume delivered (GL)¹	Expected ecological outcome¹	Monitored site(s)²	Observed ecological outcomes²	Influences²
Lachlan (10013-01)	Oct–Nov 2014, Dec–Mar 2015, Apr–May 2015	Base flow (water not specifically delivered, rather held as unregulated entitlement and reliant on upstream catchment availabilities)	None accounted	Assess the response of temperature, pH, turbidity, salinity and dissolved organic carbon	Wallanthery, Lanes Bridge, Cowl Cowl, Whealbah	No observable effect on temperature, pH, DO, turbidity, conductivity, nitrogen or phosphorus within the target reach	
Murrumbidgee (00023-01)	12/08/14 – 20/01/15	Wetland	40.000	No specific water quality related expected outcome	Upper North Redbank	Dissolved organic carbon concentrations decreased between October (first return flow) and February (second return flow)	Combination of flushing flows in October removing carbon from the floodplain, extended inundation period and relatively small volumes of water released during the second return flow contributed to a reduction in hypoxic blackwater risk

Selected Area (Watering Action Reference)¹	Water delivery dates (start – end)¹	Flow component type¹	Commonwealth environmental water volume delivered (GL)¹	Expected ecological outcome¹	Monitored site(s)²	Observed ecological outcomes²	Influences²
SA River Murray (10009-01)	04/09/14 – 31/12/14	Base flow	191.833	Maintain water quality within the River Murray by contributing to the transport and export of salt and nutrients through the Murray Mouth and mitigating environmental risks associated with hypoxic dissolved oxygen levels and algal blooms	Murray River Channel, Lower Lakes, Murray Mouth	Reduced salinity concentrations in the Murray Mouth Increased export of salt from the Murray River Channel and Lower Lakes, and decreased net import of salt to the Coorong Increased transport of nutrients and phytoplankton	
Warrego–Darling (Information from Appendix C, Selected Area Technical Report)	Oct–Nov 2014, Dec–Mar 2015, Apr–May 2015	Base flow (water not specifically delivered, rather held as unregulated entitlement and reliant on upstream catchment availabilities)	None accounted	Assess the response of temperature, pH, turbidity, salinity and dissolved organic carbon	Yanda and Akuna (above Warrego–Darling rivers junction)	Insufficient data from the Darling River water quality loggers No water quality–related stress was observed and parameters within normal expected ranges	
Loddon – Reaches 3 and 4 and fringing wetlands (10001-01)	21/09/14 – 07/10/15	Fresh flow	2.8695	Hydrological connectivity and water quality		Not monitored	Not monitored

Selected Area (Watering Action Reference)¹	Water delivery dates (start – end)¹	Flow component type¹	Commonwealth environmental water volume delivered (GL)¹	Expected ecological outcome¹	Monitored site(s)²	Observed ecological outcomes²	Influences²
SA Murray – Calperum Station (10024-01)	05/11/14 – 15/06/15	Wetland inundation	0.276	Improve water quality in wetlands		Not monitored	Not monitored
Wimmera–Mallee – Brickworks Billabong (10011-02)	x	Wetland	0.0999	Suitable water quality to support Murray Hardyhead		Not monitored	Not monitored
Wimmera–Mallee – Cardross Lakes (10011-02)	x	Wetland inundation	0.2883	Provide freshwater inflows to reduce salinity levels and improve the condition and diversity of wetland vegetation, improving ecological function		Not monitored	Not monitored
Wimmera–Mallee – Psyche Bend (10011-02)	x	Wetland inundation	0.4176	Provide freshwater inflows to reduce salinity levels and improve the condition and diversity of wetland vegetation, improving ecological function		Not monitored	Not monitored

Selected Area (Watering Action Reference)¹	Water delivery dates (start – end)¹	Flow component type¹	Commonwealth environmental water volume delivered (GL)¹	Expected ecological outcome¹	Monitored site(s)²	Observed ecological outcomes²	Influences²
Wimmera–Mallee – Woorlong Wetlands (10011-02)	x	Wetland inundation	0.3341	Provide freshwater inflows to reduce salinity levels and improve the condition and diversity of wetland vegetation, improving ecological function		Not monitored	Not monitored
NSW Barwon– Darling (00111-24)	11/01/15 – 17/01/15 30/05/15 – 31/05/15 Late Feb – May 2015	Fresh	1.2564 0.108 0.39636	Water quality improvement including salinity and potential for algal blooms			

Appendix B. Summary statistics for all Stream Metabolism data stratified into the three seasons — spring, summer and autumn

Table B1. Gross primary productivity (mg O₂/L/day).

Selected Area and season	Sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Edward–Wakool — spring	6	366	1.51	1.37	0.07	0.35	9.88	1.10	0.86	1.55
Edward–Wakool — summer	6	281	2.65	1.94	0.12	0.67	16.1	2.08	1.60	3.28
Edward–Wakool — autumn	6	66	2.97	0.92	0.11	1.38	5.55	2.78	2.25	3.53
Goulburn — spring	3	39	1.30	0.80	0.13	0.38	3.09	0.93	0.65	2.12
Goulburn — summer	3	159	1.56	0.60	0.05	0.44	3.43	1.45	1.16	1.82
Goulburn — autumn	3	82	1.05	0.47	0.05	0.45	2.06	0.80	0.67	1.47
Murrumbidgee — spring	4	105	0.82	0.37	0.04	0.34	2.31	0.75	0.60	0.91
Murrumbidgee — summer	4	147	1.28	0.54	0.04	0.36	2.72	1.27	0.77	1.66
Murrumbidgee — autumn	4	50	0.95	0.25	0.04	0.49	1.45	0.93	0.78	1.16
Lachlan — spring	3	164	1.78	0.72	0.06	0.52	4.05	1.66	1.28	2.22
Lachlan — summer	3	8	2.27	0.33	0.12	1.73	2.69	2.26	2.00	2.55
Lower Murray — spring	2	33	1.30	0.42	0.07	0.53	2.41	1.26	0.98	1.59
Lower Murray — summer	2	105	2.61	1.15	0.11	0.35	5.40	2.60	1.56	3.52

Note: n = number of sample days that met the acceptance criteria pooled over the number of sites in that Selected Area. No data were collected in autumn in either the Lachlan or Lower Murray Selected Areas and no data were available at all from the Gwydir and Warrego–Darling Selected Areas.

Table B2. Ecosystem respiration (mg O₂/L/day).

Selected Area and season	Sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Edward–Wakool — Spring	6	366	2.93	2.71	0.14	0.34	16.6	1.94	1.35	3.22
Edward–Wakool — Summer	6	281	4.94	3.32	0.20	1.48	26.5	3.61	2.79	6.49
Edward–Wakool — Autumn	6	66	4.38	2.63	0.32	1.40	12.3	3.21	2.53	6.21
Goulburn — Spring	3	39	0.70	0.53	0.08	0.25	2.60	0.44	0.34	1.07
Goulburn — Summer	3	159	2.07	1.23	0.10	0.16	5.71	1.74	1.14	2.78
Goulburn — Autumn	3	82	1.36	1.06	0.12	0.19	5.50	1.03	0.67	1.56
Murrumbidgee — Spring	4	105	1.23	0.51	0.05	0.56	3.60	1.11	0.89	1.39
Murrumbidgee — Summer	4	147	1.76	0.91	0.08	0.51	4.33	1.53	1.05	2.16
Murrumbidgee — Autumn	4	50	1.19	0.33	0.05	0.72	1.84	1.09	0.94	1.49
Lachlan — Spring	3	164	2.97	1.70	0.13	0.73	12.7	2.70	1.77	3.79
Lachlan — Summer	3	8	3.25	0.63	0.22	2.42	4.41	3.25	2.68	3.54
Lower Murray — Spring	2	33	1.34	0.56	0.10	0.30	2.62	1.36	0.95	1.58
Lower Murray — Summer	2	105	2.28	1.00	0.10	0.31	4.65	2.32	1.37	3.04

Note: n = number of sample days that met the acceptance criteria pooled over the number of sites in that Selected Area. No data were collected in autumn in either the Lachlan or Lower Murray Selected Areas and no data were available at all from the Gwydir and Warrego–Darling Selected Areas.

Appendix C. Summary statistics for selected nutrient data collected during 2014–15

Table C1. Total nitrogen concentration ($\mu\text{g N/L}$).

Selected Area	No. of sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Edward–Wakool	8	53	528	95	13	370	810	530	460	585
Goulburn	4	24	335	39	8	280	440	330	303	358
Gwydir	18	71	855	749	89	114	3690	572	315	1166
Warrego–Darling	7	28	1042	345	65	386	1817	977	778	1353
Lachlan	4	32	709	209	37	320	1470	700	585	788
Lower Murray	2	14	647	134	36	450	1030	629	573	698
Murrumbidgee	8	58	373	247	32	160	1290	288	254	341

Note: n = number of sample days that met the acceptance criteria pooled over the number of sites in that Selected Area.

Table C2. Total phosphorus concentration ($\mu\text{g P/L}$).

Selected Area	No. of sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Edward–Wakool	8	53	56	13	2	40	100	50	50	65
Goulburn	4	24	35	9	2	20	50	35	30	40
Gwydir	18	71	139	103	12	32	608	115	68	161
Warrego–Darling	7	28	491	374	71	76	1201	412	165	818
Lachlan	4	32	67	24	4	25	125	61	48	86
Lower Murray	2	14	76	15	4	57	102	75	65	85
Murrumbidgee	8	58	40	24	3	10	145	36	28	45

Note: n = number of sample days that met the acceptance criteria pooled over the number of sites in that Selected Area.

Table C3. Ammonia concentration ($\mu\text{g N/L}$).

Selected Area	No. of sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Edward–Wakool	8	50	4.1	6.9	1.0	1.0	41.0	2.0	1.0	4.3
Goulburn	4	24	3.0	2.8	0.6	0.5	11.0	2.0	0.5	4.8
Gwydir	18	71	18.1	44.2	5.2	0.0	204.7	0.9	0.2	7.9
Warrego–Darling	7	28	113.5	103.7	19.6	0.2	299.7	101.6	16.3	180.1
Lachlan	4	32	11.7	18.7	3.3	2.0	99.0	6.5	4.0	10.5
Lower Murray	2	14	12.4	6.5	1.7	5.0	25.0	10.0	7.0	18.5
Murrumbidgee	8	58	3.8	4.1	0.5	0.4	24.3	2.5	1.9	4.6

Note: n = number of sample days that met the acceptance criteria pooled over the number of sites in that Selected Area.

Table C4. Nitrate concentration ($\mu\text{g N/L}$).

Selected Area	No. of sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Edward–Wakool	8	50	4.8	10.7	1.5	1.0	72.0	2.0	1.0	3.3
Goulburn	4	24	44.4	37.1	7.6	0.5	97.0	47.5	1.3	76.8
Gwydir	18	71	141.8	182.7	21.7	1.0	872.2	93.7	51.8	139.2
Warrego–Darling	7	28	325.6	284.2	53.7	44.6	1133.1	270.8	83.7	403.3
Lachlan	4	32	38.0	134.7	23.8	1.0	599.0	2.0	1.0	4.0
Lower Murray	2	14	5.6	9.0	2.4	1.5	34.0	1.5	1.5	8.0
Murrumbidgee	8	58	5.4	14.3	1.9	0.3	66.7	0.6	0.6	2.2

Note: n = number of sample days that met the acceptance criteria pooled over the number of sites in that Selected Area.

Table C5. Filterable reactive phosphate concentration ($\mu\text{g P/L}$).

Selected Area	No. of sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Edward–Wakool	8	53	2.6	1.1	0.2	0.0	5.0	2.0	2.0	3.0
Goulburn	4	24	2.5	1.6	0.3	1.0	8.0	2.0	2.0	2.0
Gwydir	18	71	60.6	62.2	7.4	15.1	493.7	45.1	34.0	63.2
Warrego–Darling	7	28	145.8	160.6	30.4	23.1	471.8	82.6	43.4	131.6
Lachlan	4	32	15.3	10.7	1.9	5.0	70.0	14.0	11.0	16.8
Lower Murray	2	14	10.3	3.8	1.0	4.0	16.0	10.5	7.8	13.3
Murrumbidgee	8	58	5.3	12.3	1.6	0.7	75.2	2.1	1.4	3.4

Note: n = number of sample days that met the acceptance criteria pooled over the number of sites in that Selected Area.

Table C6. Dissolved organic carbon concentration (mg C/L).

Selected Area	No. of sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Edward–Wakool	8	69	4.6	3.3	0.4	2.6	28.0	3.9	3.4	4.9
Goulburn	4	24	4.7	2.7	0.5	1.9	14.0	3.7	3.1	6.0
Gwydir	18	71	12.6	5.9	0.7	6.0	37.5	10.8	9.0	13.6
Warrego–Darling	7	28	14.6	5.4	1.0	8.0	34.9	14.0	10.9	16.7
Lachlan	4	32	9.0	1.4	0.2	7.0	15.0	9.0	8.0	9.8
Lower Murray	2	14	5.1	0.9	0.2	3.9	6.7	5.0	4.4	6.0
Murrumbidgee	8	58	4.6	4.1	0.5	1.8	19.0	3.3	2.8	3.6

Note: n = number of sample days that met the acceptance criteria pooled over the number of sites in that Selected Area.