2018–19 Basin-scale evaluation of Commonwealth environmental water – Stream Metabolism and Water Quality

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This report was prepared for the Commonwealth Environmental Water Office by Monash University in collaboration with The Centre for Freshwater Ecosystems, La Trobe University.

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

Contents

List of tables

List of figures

Summary of Key Findings

Evaluation Questions:

This component of the Commonwealth Environmental Water Office's Long-Term Intervention Monitoring (LTIM) project's Basin-scale evaluation of Commonwealth environmental water will address the following short-term (1-year) and longer term questions:

- What did Commonwealth environmental water contribute to patterns and rates of decomposition?
- What did Commonwealth environmental water contribute to patterns and rates of primary production
- What did Commonwealth environmental water contribute to pH and dissolved oxygen levels and to salinity and turbidity regimes?

For the longer term, the relevant objective is that 'water-dependent ecosystems are able to support episodically high ecological productivity and its ecological dispersal' (CEWO 2013). The above questions will seek to identify the contribution of Commonwealth environmental water to long-term patterns of productivity and the frequency, intensity and duration of adverse water quality events where allocation of Commonwealth environmental water can influence the occurrence or severity of these events.

This Report:

This Basin scale Evaluation examines patterns in stream metabolism *across* the six Selected Areas where stream metabolism is a Category 1 indicator and relationships with discharge (including Commonwealth environmental water) over the five years of the LTIM project. *Note that stream metabolism in the Gwydir Selected Area was not a Category 1 indicator hence is not included in this report.* This evaluation includes analysing seasonal effects as well as inter-annual variability. The grouping of discharge into flow stages according to the companion hydrology report by Stewardson and Guarino (2018), first examined in last year's Basin Evaluation Report (Grace 2019a) has been significantly expanded. This has enabled new insights into the benefits of environmental water for stream metabolism – which measures the 'food resource' in the river supporting, for example, native fish populations. The evaluation of the impacts of Commonwealth environmental water in this report are based on the measured effects of discharge on metabolic rates, the stratification of flows into the categories defined by thresholds, the influence of the proportion of discharge comprising CEW on rates of gross primary production (GPP) and ecosystem respiration (ER) and the conceptual models presented in Annex A.

While the majority of this report focusses on the full data set (Years 1-5 corresponding to July 2014 to June 2019), attention is also directed to the specific results of Year 5 alone (July 2018–June 2019) and placing them into the context of the full five years.

Key Findings:

- Using flow categories based on discharge thresholds and expressing metabolism as organic carbon ('food' source) produced and consumed per day has enabled new and exciting insights into the effects of flow (and Commonwealth environmental water) on stream metabolism. This methodology, first employed in the Year 3 report (Grace 2018), has been significantly expanded and extended this year. *This methodology has not been used before anywhere in the world.*
- At the start of the LTIM program, it was thought that flows that remain in channel are unlikely to boost rates of GPP and ER. The larger data set now available, accompanied by some preliminary modelling, shows that this assumption is NOT correct. ***When considering the amount of organic carbon being produced and consumed in the river, even small increases in flow which remain in the stream channel e.g. from*** **very low (nominally base) flow to moderately low flow** ***can see a substantial positive benefit.***
- In general, the source of the water used to increase flows, resulting in enhanced daily loads of organic carbon production (more "fish food") does not appear to matter. There *are* site specific instances throughout the Murray–Darling Basin where source water identity may have an effect e.g. return water from Chowilla (and see next dot point). Notwithstanding that, it is the *quantity* of water that is most important. Hence CEW is well-suited for achieving the objective of generating more food resources for aquatic food webs.
- Inundation of wetlands may entrain nutrients and organic matter which have the potential to enhance metabolism within the river channel, but this requires water to return from the backwaters and wetlands to the river. Such return water may also constrain primary production within the river channel due to high turbidities. It is likely that such effects may be more pronounced in the northern half of the Basin, due to the very fine colloidal soil particles. With high river turbidity, introduction of clearer water from dams higher in the catchment may promote primary production despite a decrease in bioavailable nutrient concentrations.
- Another initial assumption is that sustainability of native fish populations may (in part) be compromised by lack of food supply, hence increasing rates of both GPP and ER to provide a greater food supply will be beneficial. The link between food supply and fish population dynamics has yet to be addressed. Nevertheless, higher metabolic rates (more food) than currently measured are seen as a target, provided rates are not so high as to indicate algal blooms (from excess GPP) or anoxic conditions (excess ER).
- The first fresh following winter to inundate dry sediment has the greatest potential to enhance metabolic rates, but this is also dependent upon timing as freshes in winter – early spring will result in lower primary production due to colder temperatures and shorter hours of lower intensity sunlight than freshes that are delayed until late spring – summer.
- ***It is still expected that watering actions that reconnect backwaters, flood runners and the floodplain should see a major increase in both primary production and ER (beyond in-channel increases)*** but the types of watering actions delivered over the five years did not provide the opportunity to confirm this expectation. The flood in the southern Murray–Darling Basin during October-December 2016 instigated anoxic conditions due to the very long period of inundation and perhaps the long period between inundation. Watering actions should not mimic this large flood event for that reason even if such a water volume became available. If extended dry periods exacerbate this anoxia problem upon eventual rewetting, then more frequent inundation is required.
- It is also expected that the monitored waterways in the Selected Areas will broadly represent stream metabolism across the Basin, with a nominal north-south division. Thus, it is believed likely (again without sufficient evidence yet 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.

- When planning environmental flows, consideration of the trade-off between magnitude and duration may be influenced by consideration of metabolism outcomes. Two options may be worth considering:

  - If shortening the duration of the flow would significantly increase the extent of lateral connection, then it may be worth increasing magnitude and reducing duration.
  - If, however, there is limited scope to achieve significant lateral connectivity, then a longer smaller flow is likely to have a greater influence on metabolism as it will enable colonisation and accumulation of primary producers and decomposers. There will obviously be a balance here between promoting such biota and leaving the system too stable which may lead to declines due to senescence.

- Using watering actions to maintain a base flow in a reach can also be important in avoiding adverse water quality outcomes. This is exemplified by Zone 2 in the Edward–Wakool River Selected Area where very low flow resulted in dissolved oxygen concentrations below the threshold at which fish health is compromised.
- The watering actions undertaken in the Lower Murray River were effective in exporting salt and nutrients from the Murray Mouth which would be expected to contribute to 1–5-year improvements in water quality in the Basin (Ye et al. 2019).

1 Introduction

1.1 Context

This report seeks to evaluate the influence of environmental water on stream metabolism, which 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. Gross Primary Productivity (GPP) is the rate of biomass creation through photosynthesis and estimated by oxygen production, and is usually simplified to 'Gross Primary Production' throughout this report.[1] The abbreviation 'GPP' is retained. Ecosystem Respiration (ER), formerly called Community Respiration, is the amount of organic matter decomposed, estimated by oxygen consumption, under aerobic conditions.

In seeking to achieve healthy and resilient ecosystems with rivers and creeks regularly connected to their floodplains and, ultimately, the ocean (Basin Plan section 5.02.2), the Murray–Darling Basin Plan (referred to hereafter as the Basin Plan) recognises the importance of these processes and has included objectives concerning ecological productivity (section 8.05.2(c)) and the protection and restoration of the ecosystem functions of water-dependent ecosystems.

These objectives reflect best available science, including major river conceptual models that state that patterns of production are a major influence on ecosystem character and condition. These models describe the critical role that flow plays in determining patterns of productivity.

Stream metabolism has been included as an ecological indicator to be evaluated at the whole-of-Basin scale (i.e. a 'Basin Matter') within the Commonwealth Environmental Water Office (CEWO) Long Term Intervention Monitoring (LTIM) Project because of its inclusion as an environmental objective in the Murray–Darling Basin Plan, but also for the following reasons:

- Australian aquatic ecosystems are characterised by their cycles of 'boom and bust'. These cycles are built on changes in productivity associated with flood and drought. This is also recognised in the Basin Plan objectives that state that the Basin's rivers should support episodic periods of very high production.
- Stream metabolism is sensitive to changes in flow, particularly changes in hydrological connectivity between the river and floodplain.
- Monitoring ecosystem processes provides insight into the mechanisms driving patterns of change in biota. Included within this is our current belief that food abundance is critically important in the recruitment of both young native fish and waterbirds which are often targets of environmental watering.

These characteristics mean that understanding river metabolic responses to environmental flows both enables feedback on how environmental flows are influencing a critical environmental function (in line with the Basin Plan objectives) and, in conjunction with an evaluation of habitat availability, contributes to understanding fish and waterbird population responses.

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[1] Strictly speaking, Gross Primary Productivity is the *rate* of biomass accrual through photosynthesis while Gross Primary Production is the amount of biomass created. They are numerically equivalent. The Whole Stream Metabolism method estimates GPP from the diel oxygen curve, hence results and plots are presented as GPP not Primary Production.

1.2 Objectives of the Stream Metabolism and Water Quality Basin Matter

This component of the LTIM project's Basin-scale evaluation of Commonwealth environmental water will address the following short-term (1-year) 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 rates of ecosystem respiration will increase in response to the delivery of environmental water. Increased rates of decomposition that do not contribute to hypoxia facilitate energy movement through ecosystems and have the potential to increase energy and nutrient supply to riverine food webs.
- What did Commonwealth environmental water contribute to patterns and rates of (gross) primary production
    - The hypothesis is that rates of (gross) primary production will increase in response to the delivery of environmental water. Increased rates of primary production that do not contribute to blooms of cyanobacteria will increase the energy and nutrient supply to river food webs.
- What did Commonwealth environmental water contribute to pH and dissolved oxygen levels and to salinity and turbidity regimes?

The long-term questions are essentially the same as the short term questions for metabolism and water quality, except that the focus is on long-term patterns. In the case of metabolism, the relevant objective is that 'water-dependent ecosystems are able to support episodically high ecological productivity and its ecological dispersal' (CEWO 2013) and so the above questions will seek to identify the contribution of Commonwealth environmental water to long-term patterns of productivity. For water quality, the long-term questions will focus on the frequency, intensity and duration of adverse water quality events; that is, events where the allocation of Commonwealth environmental water can influence the occurrence or severity of these events.

These questions stem from the relevant Basin-scale objectives set out in the Basin Plan and 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'.

Estimates of river metabolism are derived from daily measurements of changes in dissolved oxygen, temperature and light in open water (Figure 1). The open water measurements (Figure 1.a) average out all metabolic activity occurring in the channel and these data are then used to generate estimates of gross primary production, ecosystem respiration and the re-aeration coefficient per litre of water (Figure 1.b). The estimates of gross primary production and ecosystem respiration can then be scaled up to provide an estimate of reach scale metabolism using an estimate of the volume of water in the monitored reach (Figure 1.c). See the *Stream Metabolism and Water Quality foundation report* (Grace 2019b) for more detail on the method.

The previous Basin Level Evaluation Reports contained a significant amount of background description aimed at conceptual understanding of the possible influences of flow on stream metabolism and how we believe the major flow types included in the Basin Plan can affect metabolism in multiple ways. This information is now found in Annex A.

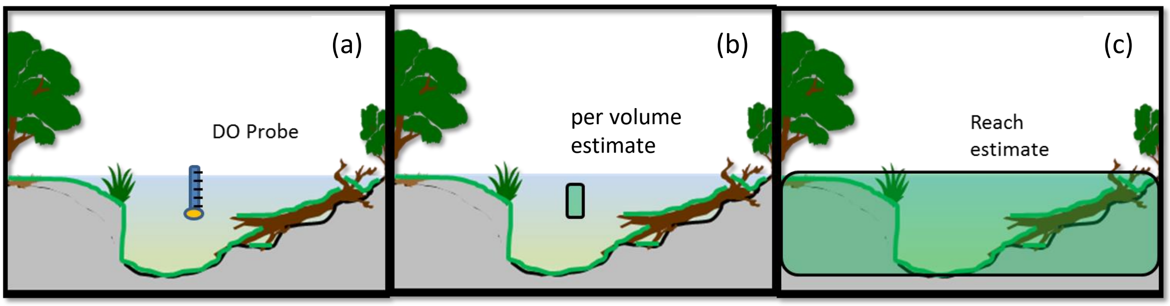

Figure 1. Illustration of the three steps in generating a reach-scale estimate of stream metabolism: (a) monitoring open water dissolved oxygen (DO); (b) using data to develop a 'per unit volume' measure; and (c) scaling up to the reach.

1.3 Evaluating the contribution of environmental water to stream metabolism at the Basin-scale

This evaluation seeks to identify the influence of Commonwealth environmental water on rates of stream metabolism using the rates per unit volume and three derived units: rates per unit area, the mass of organic carbon created or consumed per day in the passing flow (i.e. the load) and per stream kilometre (i.e. reach scale).

A recent review of the international state of research on metabolism in flowing waters (Bernhardt *et al.* 2018) identified the need for long term data sets to help distinguish between short-term and local drivers of metabolism (e.g. weather, topographic shading, recent scouring flow) and large scale, long term impacts including land-use alteration and climate change. Flow manipulation, as investigated in this LTIM project, falls between these two scales. The review focusses mainly on North American and European systems where leaf-fall and leaf-out (the growth of new leaves in spring) are key factors contributing to rates of metabolism in smaller streams, but then links expected metabolic behaviour to the River Continuum Concept (RCC, Vannote *et al.* 1980). Briefly, this concept suggests that streams will become net autotrophic (creating more energy than is used) when they become wide enough to overcome shading effects by riparian vegetation and with more catchment supply of nutrients. Even further downstream, conditions become more turbid and light limitation controls rates of Gross Primary Production. The Australian streams, including many in the LTIM project, do not adhere to the RCC due to naturally high turbidity from highly weathered, fine soils and the absence of significant riparian shading. The review concludes that "By examining the patterns of metabolism over entire years, we can observe how the extrinsic controls of light, heat, allochthonous inputs, and disturbance together shape metabolism, and we can begin to understand and predict how these drivers have changed and are likely to change because of widespread flow regulation, climate change, land use, and eutrophication". This recommendation for long term studies ('over entire years') is at the core of the LTIM program.

Bernhardt *et al.* (2018) also stress "One clear need is the further development of integrative, ecosystem-level models that link metabolic, biogeochemical, and hydrologic processes within rivers". ***The LTIM project through this Stream Metabolism Basin Matter is developing this capability***.

Evaluation of the impacts of Commonwealth environmental water is based around the use of the conceptual models presented in Annex A and comparisons of stream metabolic rates from before, during and after the watering action. The data generated by the LTIM project over its five year duration has helped enable prediction and/or estimation of:

- the capacity to generate reach estimates of metabolism

- the reference against which observed outcomes are measured. This overcomes the issues associated with comparing rates before, during and after a watering action
- an evaluation of extended watering actions (e.g. base flows, wetland inundations) for which there is currently no suitable reference
- expanded capacity to enable evaluation of the outcomes of water regimes rather than individual actions which for improved alignment with Basin Plan objectives, the hydrology evaluation and Category 1 fish evaluation.

These data and the associated models will enable the evaluation of a greater range of watering actions. The development of a quantitative model will improve the rigour of all evaluations by providing a robust counterfactual prediction (i.e. determining the marginal benefit of environmental water). The three data requirements are: hydrology – the contribution of Commonwealth environmental water to flows in the channel; hydraulic – the influence of Commonwealth environmental water on key hydraulic outcomes, including average depth and channel width; and metabolism – the metabolism estimates derived from records of dissolved oxygen. The situation is summarised in Table 1.

This evaluation will, as in the previous two reports, focus on the outcomes of freshes and water returned from wetland or floodplain inundation and whether they were associated with entrainment or resuspension (see Annex A for further explanation of these terms).

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.

Table 1. Summary of the relevant conceptual models and their proposed inclusion in this evaluation.

Flow	Relevant models	Data requirements	Included in evaluation	Comment
Cease to flow	Habitat, Mixing Model	Hydrology, hydraulic, metabolism	-	Not included in the evaluation.
Base flow	Habitat	Hydrology, hydraulic, metabolism	Years 3-5	Evaluation of base flows' influence on metabolism is reliant on hydraulic information not available to the first 2 years' evaluations.
Fresh	Habitat, Entrainment, Disturbance, Mixing Model	Hydrology, hydraulic, metabolism	Year 1 & later	Fresh flows can be evaluated on a per unit volume without hydraulic information; hydraulic information will enable reach estimates to be generated.
Bankfull	Habitat, Entrainment, Disturbance	Hydrology, hydraulic, metabolism	Year 3	Short bankfull flows can be evaluated on a per unit volume without hydraulic information; hydraulic information will enable reach estimates to be generated.
Overbank	Habitat, Entrainment,	Hydrology, hydraulic, metabolism	Year 1	Overbank flows can be evaluated on a per unit volume without hydraulic information; hydraulic information will enable reach estimates to be generated.

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 2019b). The key points are summarised here.

All Monitoring and Evaluation (M&E) Providers deploy loggers at their Selected Areas to record changes in dissolved oxygen, light and temperature over the course of 24 hours (Figure 2). Details about the locations and methods for each site are included in the Selected Area evaluation reports. To ensure a consistent approach to estimating rates of primary production and ecosystem respiration, the field data are then analysed using the same statistical model ('BASEv2' – BAyesian Single-station Estimation). The model (Grace *et al*. 2015) was updated during 2016 in accordance with methodological recommendations contained within Song *et al.* (2016). These volumetric estimates have also been converted into reach-scale estimates with the appropriate hydraulic information (cross-sectional area) as foreshadowed in the 2015–16 report. The reach scale estimates are the amount of organic carbon being created by photosynthesis or consumed by ecosystem respiration in a nominal 1 kilometre (km) stream reach at the gauging site.

Quantification of the effects of environmental flows on metabolism requires a prediction of rates in the absence of the environmental water. This capability is being developed through the LTIM project as the data set grows and covers a larger temporal scale (now five years) with the inherent variability in weather and annual climate over this time. Worldwide, there are still no quantitative models that enable prediction of the metabolic rates expected at a specified flow, either with, or in the absence of, environmental watering. This leaves two potential approaches in addition to the data base interrogation used in this current report:

1. The use of monitoring at times or places where there is no environmental flow. The Edward–Wakool river system is fortunate in having several rivers that provide opportunities for comparisons between similar systems with and without environmental flows. In other systems, comparisons are made through time. There are limitations associated with these comparisons because many factors vary through time (e.g. daylight, temperature, nutrients) that confound our ability to identify the influence of flow.
2. Conceptual models describing the relationship between flow and metabolism (Annex A) provide a starting point for making predictions to support evaluation.

This approach has enabled the:

- estimation of the rate of stream metabolism in the absence of environmental watering at the reach scale for reaches that are monitored,
- prediction of both environmental flow and non-flow rates of stream metabolism at the reach scale for reaches that are not monitored,
- support of estimation of Basin-scale changes to stream metabolism in response to environmental watering and,
- provision of critical information to support the development of any future statistical metabolism models.

Work undertaken over the five years of the LTIM project has also identified many of the drivers of metabolism. It will also inform key decisions about whether one model will be able to be used across the Basin or whether different models may be needed for northern and southern systems.

The evaluation described in this report is based on pooled results from multiple sites in each Selected Area, then considered across Selected Areas at a Basin scale. Generic findings across Selected Areas, often stratified at a seasonal time scale can then be applied to unmonitored sites. The Selected Areas used in this report and the LTIM project in general are shown in Figure 2.

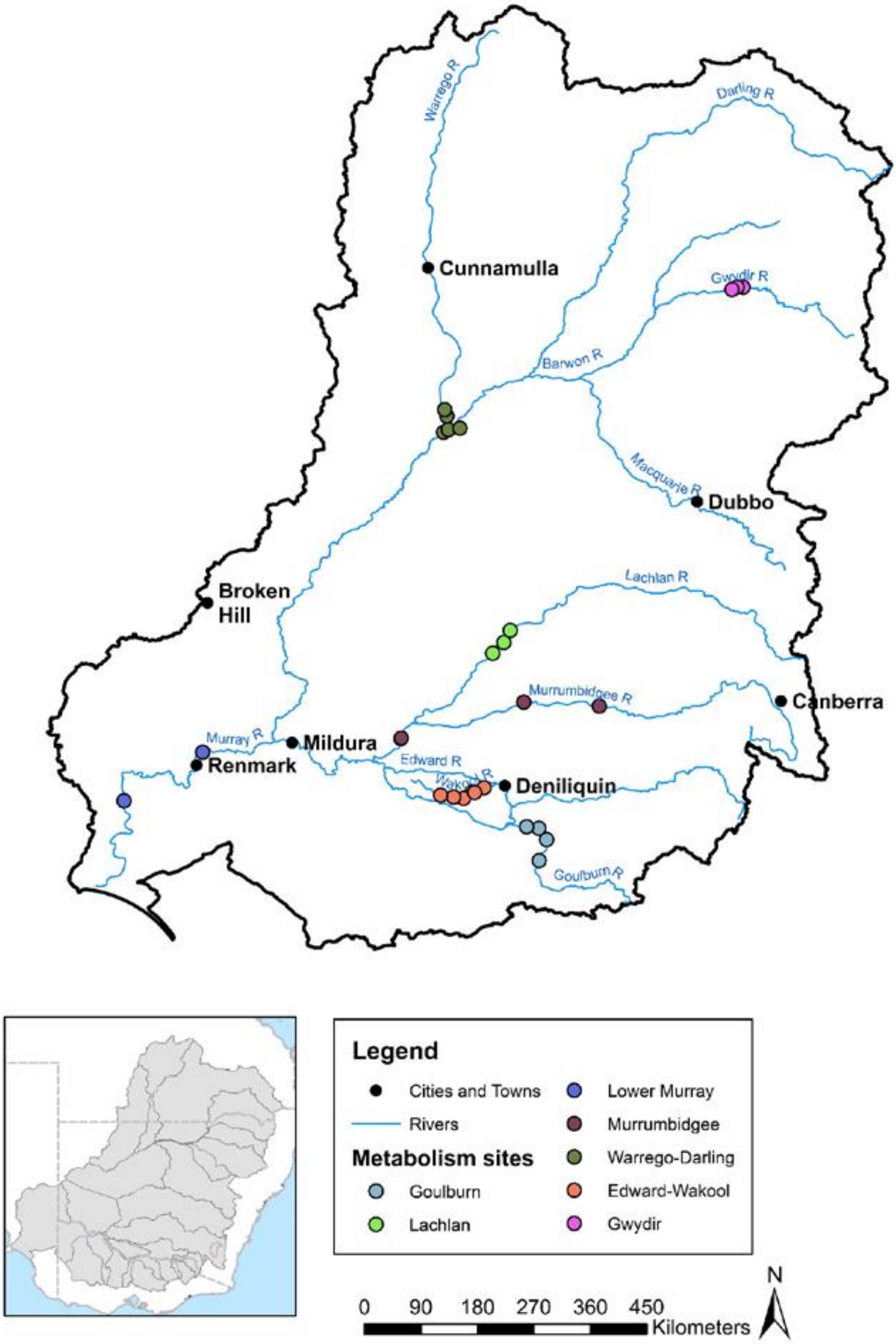

Figure 2. Location of LTIM Stream Metabolism monitoring sites. Note, there was no Category 1 stream metabolism data collected from the Gwydir system.

2.2 The Water Quality Basin Matter approach

Water quality data to address both the short- and long-term questions was typically collected 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 temperature collected using the loggers acquiring metabolism data) is a constraint imposed by the overall project budget. Hence, it is extremely difficult to attribute the effects of watering actions on any parameter other than DO. However, aggregated water quality data *are* useful to help explain patterns of metabolism at catchment and Basin scales.

2.3 Hydrology Data used in this report

Collection of the stream metabolism data set discussed in this report is underpinned by daily flow data from the nearest gauging stations to where the DO loggers were deployed. Later in the report, the effect of Commonwealth Environmental Water (CEW) on stream metabolism and organic carbon production is assessed. This analysis necessitates usage of the proportion of daily flow at each site contributed by CEW. For most sites this information is available for the full period of this study (July 2014 – June 2019), for other sites, the CEW contribution is unavailable for 2014–15 and for a few sites, there is no CEW contribution information. The flow information available for each site is summarised in Table 2, the CEW-related data was kindly provided by Enzo Guarino and Nick Bond (Years 1-4, pers. comm. July 2019; Year 5, pers. comm., December 2019).

Table 2. Flow data availability, CEW contribution and source for stream metabolism monitoring sites within the six Selected Areas.

Valley	River Name	Metabolism Site Name	Hydrology Site	Years with CEW Contribution Data	Years without CEW Contribution Data
BDL	Darling River	Akuna	425004 - Darling River@Louth	2014–19	-
BDL	Darling River	Yanda	425003 - Darling River@Bourke	2017–19	2014–17
EWK	Yallakool Creek	Yallakool Creek	409020 – Yallakool@Offtake	2014–19	-
EWK	Wakool River	Wakool River (Zone 2)	409019 – Wakool@Offtake	2015–19	2014–15
EWK	Wakool River	Wakool River (Zone 3)	Calculated – Note 2	-	2014–19
EWK	Wakool River	Wakool River (Zone 4)	409045 – Barham-Moulamien	2015–19	2014–15
GLB	Goulburn River	Moss Rd / Day Rd	409200 – Murchison	2014–19	-
GLB	Goulburn River	Darcy's Track	409200 – Murchison (1 day offset)	2014–19	-
GLB	Goulburn River	Loch Garry	Calculated – Note 3	-	2014–19
GLB	Goulburn River	McCoy's Bridge	409232 – McCoy's Bridge	2014–19	-

Valley	River Name	Metabolism Site Name	Hydrology Site	Years with CEW Contribution Data	Years without CEW Contribution Data
LCH	Lachlan River	Lane's Bridge, Cowl Cowl	412039 – Lachlan @Hillston Weir	2015–19	2014–15
LCH	Lachlan River	Whealbah	412078 – Lachlan @Whealbah	2015–19	2014–15
LWM	Lower Murray River	Lock 6	SAWater – Murray @D/S Lock 6	2014–19	-
LWM	Lower Murray River	Lock 1	SAWater – Murray @D/S Lock 1	2014–19	-
MBG	Murrumbidgee River	Narrandera	410005 – Murrumbidgee @Narrandera	2014–19	-
MBG	Murrumbidgee River	McKenna’s	410078 – Murrumbidgee @Carrathool	2014–19	-

Notes:

1/ All hydrology data, including CEW contributions, provided by Nick Bond, Latrobe University, 20 December, 2019.

2/ Calculated as 85 per cent of the sum of Yallakool Offtake and Wakool Offtake, offset by 4 days water travel.

3/ Calculated as 92.97 x McCoy’s Bridge Flow + 91.781 (based on a long term regression)

3 Basin-scale Evaluation of Stream Metabolism

3.1 Approach

This year's report examines the stream metabolism and associated data collected over the entire five years of the LTIM project. Further information about specific sites are contained within the relevant Selected Area reports and are not discussed further here. This report will focus on patterns in metabolism *across* the Selected Areas and examine relationships with discharge. In particular, discharge will be grouped according to the flow stages developed by Stewardson and Guarino (2018).

According to Stewardson and Guarino (2018), the various flow levels are established as (Figure 3):

- Very low flows: flows less than the lowest flow in the unimpacted monthly flow series or 2 per cent of mean unimpacted flow, whichever is greater.
- Moderate low flows: flows that fall below the 95th percentile exceedance flow in the unimpacted monthly flow series or 10 per cent of the mean unimpacted flow, whichever is greater.
- Low freshes: flow spells that raise water levels at least 1/8 of the height of the bank above the medium low flow level.
- Medium freshes: flow spells that raise water levels at least 1/4 of the height of the bank above the medium low flow level
- High freshes flow spells that raise water levels at least 1/2 of the height of the bank above the medium low flow level.

The flow thresholds associated with these stages was provided by Guarino (pers. comm. 24/12/19) – the data relevant to the metabolism sites in the six Selected Areas are presented in Table 3. The number of days with metabolism data meeting acceptance criteria in each of these nominal flow categories plus the mean and median flows in each case are presented in Annex B for the sites in all six Selected Areas for which the flow categories are shown in Table 3.

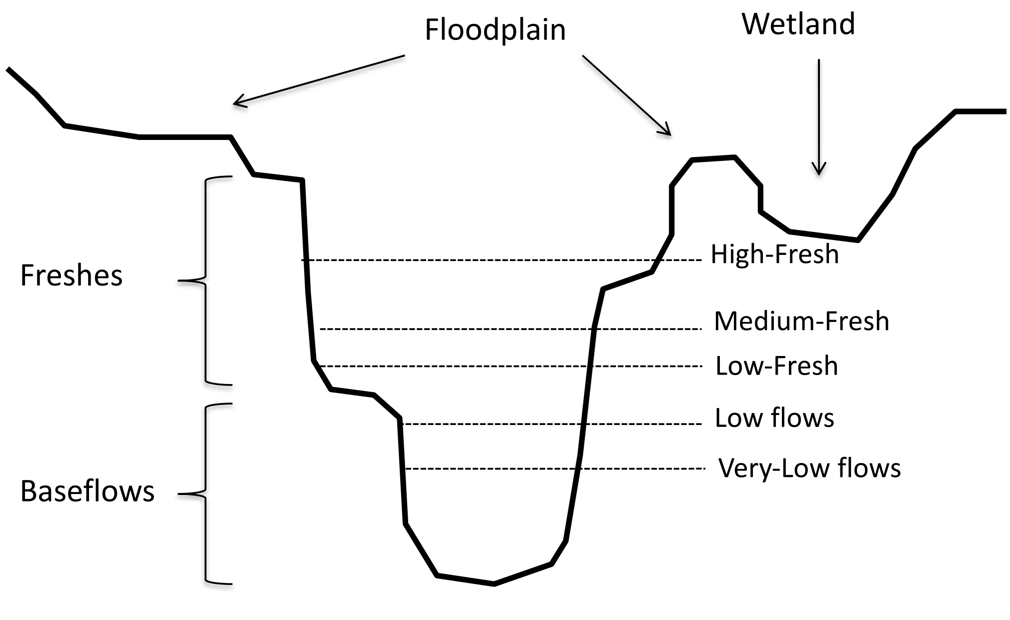

Figure 3. Flow stages according to Stewardson and Guarino (2018).

Table 3. Flow Thresholds (ML/Day) for stream metabolism monitoring sites within the six Selected Areas.

Valley	River Name	Site Name	LTIM Site	Modelled Natural Flow Site Name	Very Low	Moderate Low	Low Fresh	Medium Fresh	High Fresh	Finalised Bankfull
BDL	Darling River	Louth	Akuna	425004 - Darling River@Louth	220	1098	2047	3479	8308	30000
BDL	Darling River	Bourke	Yanda	425003 - Darling River@Bourke	223	1117	2073	3511	8349	30000
EWK	Yallakool Creek	Yallakool Offtake	Yallakool	409020 – Yallakool Creek @Yallakool Offtake	13	66	119	198	458	1600
EWK	Wakool River	Wakool Offtake	Hopwood, Windra Vale	409019 – Wakool River @Wakool Offtake	13	66	167	349	1082	5100
EWK	Wakool River	Barham-Moulamien	Barham Bridge, Noorong	409045 – Wakool River @Barham-Moulamien	59	294	427	598	1081	2800
GLB	Goulburn River	Murchison	Moss/Day Rd	405200 – Goulburn @Murchison	252	868	1772	3211	8347	33000
GLB	Goulburn River	Murchison	Darcy's Track	405200 – Goulburn @Murchison	252	868	1772	3211	8347	33000
GLB	Goulburn River	McCoy’s	McCoy's Bridge	405232 – Goulburn @D/S McCoy's Bridge	312	960	1822	3135	7613	28000
LCH	Lachlan River	Hillston	Lane's Bridge, Cowl Cowl	412039 – Lachlan @Hillston Weir	23	117	223	386	945	3500
LCH	Lachlan River	Whealbah	Whealbah	412078 – Lachlan @Whealbah	23	117	223	386	945	3500
LWM	Murray River	Lock 6	Lock 6 (Lower Murray)	Murray d/s Lock 6 A4260511	430	2493	4293	6881	15158	50000
LWM	Murray River	Lock 1	Lock 1 (Lower Murray)	Murray d/s Lock 1 A4260903	689	3744	5854	8707	17223	50000

Valley	River Name	Site Name	LTIM Site	Modelled Natural Flow Site Name	Very Low	Moderate Low	Low Fresh	Medium Fresh	High Fresh	Finalised Bankfull
MBG	Murrumbidgee River	Narrandera	Narrandera	410005 – Murrumbidgee @Narrandera	205	1026	1857	3087	7156	25000
MBG	Murrumbidgee River	Carrathool	McKenna's	410078 – Murrumbidgee @Carrathool	185	927	1527	2367	4969	15500

It is important to note that these nominal flow categories delineated in Table 3 based on hydrological stages provide a convenient and useful method for dividing the hydrograph at each site into a fixed number of flow ranges. This allows exploration of the effects of increasing flow (for example by addition of Commonwealth environmental water) on rates of GPP and ER. Commonalities between sites and Selected Areas can then be investigated with the purpose of then applying these findings to unmonitored stream reaches and catchments. However, this analysis does not intend to imply that a change from low flow to moderately low flow in a smaller stream system will have the same effects on metabolism as the same change in flow category in the Lower Murray River for example. Stream geomorphology and extent of interaction with the riparian zone will be extremely different in these two cases and this in turn will affect the metabolic outcomes. For streams of similar size and geomorphology, predictions for unmonitored reaches will likely be far more robust.

This five-year evaluation has required all of the data used in the past for stream metabolism (stored on the CEWO Monitoring Data Management System (MDMS) as dissolved oxygen, light and temperature data at 10-minute intervals) to be rerun on the BASEv2 program to ensure a common methodology across both Selected Areas and time (years) as the BASE model has evolved during the four years of LTIM. Changes to the optimization routine during 2017 has meant that there are now many more days that meet the acceptance criteria for inclusion in the meta-analysis presented here. This is especially evident in the dramatically larger data set for 2017–18 and 2018–19 from the two sites in the Darling River. It is important to note however, that there has been no change in the fundamental model explaining how dissolved oxygen changes as a function of time due to primary production, respiration and reaeration (see the Stream Metabolism Foundation Report, Grace (2019b) for further details).

There are gaps in the data records for some individual sites at various times throughout these four years. For example, in the Lachlan Selected Area (Dyer *et al.* 2017), very high flows occurred during 2016–17 resulting in loggers being lost (Wallanthery) or inaccessible (e.g. Whealbah from January 2017 onwards). As noted later, another major factor affecting data availability in many Selected Areas in 2016–17 was a major springtime flood which continued into December in some sites. Not only did the extended duration mean logger battery failure but, in many cases, (e.g. Goulburn, Edward-Wakool) the dissolved oxygen concentration fell to 0 mg/L and remained at that anoxic level for days to weeks (Webb *et al.* 2017, Watts *et al.* 2017). The BASEv2 model (and all other metabolism models) cannot model GPP and ER for any days when there is no oxygen present. The use of multiple sites within a Selected Area and multiple data years mean that data losses from a few sites are far less problematic. Extended periods of high water levels for many months is an ongoing challenge as most logger battery systems will run for around 8-10 weeks. Once the battery fails, no further data is recorded, although data already present is not lost. Consultation with the water managers can help manipulate water levels to some extent but when the high water is due to natural flooding then such capacity is greatly diminished.

Examination of the resultant large data set revealed a small number of instances (data days) where there were abnormally high or low daily estimates for GPP or ER (or occasionally both). Some of these were attributable for example to the algal bloom in the Edward-Wakool. Others were associated with unlikely values of the reaeration coefficient, K. Consequently, an additional acceptance criterion was added for year 3 data and kept from that point onwards, namely that K had to be in the range 0.1–15 /Day. The lower bounds (0.1 /Day) is below that normally ascribed to oxygen exchange across a completely still air-water interface (no water movement, no wind). K values in excess of 15 /Day are found in smaller, turbulent streams where reaeration is enhanced by the physical entrainment of air into the water column. This extra acceptance criterion resulted in the removal of < 1 per cent of the total data days, but did remove a number of anomalously high values for GPP and ER. *All year 1 and 2 data were then re-evaluated and any data days with reaeration coefficients outside this range were subsequently removed prior to all statistical compilation and data meta-analysis.* Only a small number of data days (< 2% of the data set) were removed following this application of the normal bound range for K.

In several places throughout this report, the flow categorisation described in this section is applied to the individual sites, shown in Table 3, within each of the six Selected Areas. It is important to note that these hydrological thresholds are entirely arbitrary. A similar analysis could be undertaken using other means for assigning flow categories. The numerical outcomes would be slightly different but the qualitative patterns, and the findings derived from these, would be the same. *For example, the approach developed by Bond for the Edward-Wakool and evaluated in that Selected Area's Year 4 report (Watts et al. 2018) could be applied across all sites for all Selected Areas. Briefly, this method involves using the data set itself to generate flow bands, where all data days meeting acceptance criteria at a site are partitioned into proportions of the maximum flow value which yielded an acceptable data day. This can be stratified across seasons.*

3.1.1 Derived Metabolic Parameters

In the 2016–17 Basin Level Evaluation (Grace 2018), three derived metabolism units were explored:

1. Areal metabolism units (g O_2/m^2/Day). This unit expresses GPP and ER as oxygen produced/consumed per m^2 of stream (or sediment) surface per day.
2. The amount (mass) of organic carbon created/consumed each day in a one km stream reach (kg org C/km/Day). This unit is intended to relate to the amount of organic carbon required by the food web in that stream reach each day and eventually to the sustainable stocking capacity for native fish in that reach on the assumption that this capacity is resource (food) limited.
3. The mass of oxygen (or organic carbon, see above) produced per day in the passing flow. This is calculated by multiplying the GPP or ER in mg O_2/L/Day by the number of Litres discharged that day.[2]

In this report, the focus is on the organic carbon produced (or consumed) per day in the river flowing past the monitoring point as this metric showed a promising capacity to assess the effects of discharge, including Commonwealth Environment Water on stream metabolism (Grace 2018). Further examination of the carbon production per stream km will be undertaken following completion of the LTIM project, as this method may enable estimation of carbon production per stream drainage network (entire Selected Area).

It is extremely important to distinguish the volumetric rates, which are obtained directly from the BASE model, and refer to the amount of organic carbon produced (GPP) or consumed (ER) per litre of water per day, and the 'load' of organic carbon which is the bulk measurement obtained for all the water flowing past the monitoring point in that day. The relevance of the volumetric and load units to the aquatic ecosystem depends on the perspective of the organism involved. For an organism that is stationary and needs organic carbon, it is the concentration of organic carbon (or dissolved oxygen) in the immediate vicinity that is important, not the total amount in the river. On

[2] The calculation given here produces a measure of organic carbon "load". This measure is typically used if a river is flowing into a lake in order to estimate the input load; this concept is used extensively for salt loads and nutrient loads, including for setting management targets. In a flowing river it estimates the amount of carbon passing a point on the bank per day. It is designed to look at organic carbon production (i.e. GPP) within a particular system and how this changes with discharge (including added CEW). It is *not* conducive to cross-system comparison.

the other hand, mobile organisms such as fish, are able to move freely to find their food, hence a more 'dilute' food supply per litre of water is not such a problem given that there are many more accessible litres of water available. This complex argument is further complicated by the duration of time that this food is available. Higher flows generally mean a shorter residence time for each litre of water in a river reach, as water velocities have typically increased. The extent of increase will depend on the channel geomorphology. Hence there may be 'more food' but it is available for a shorter period of time before it moves downstream. These matters are beyond the scope of this report and the LTIM project but are going to be vital when quantitatively integrating the production of 'fish food' via stream metabolism and the energetic requirements of the fish populations.

3.1.2 Data collection

The stream metabolism data set used for this five-year analysis is summarised in Table 4. The data were downloaded from the Monitoring Data Management System (MDMS). As there was no data uploaded for the Gwydir Selected Area (Stream Metabolism is not a Category 1 indicator in this one Selected Area), all following analysis is restricted to the remaining six Selected Areas (Edward-Wakool, Lachlan, Goulburn, Murrumbidgee, Warrego-Darling and Lower Murray). For each stream metabolism monitoring site in the six 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 BASEv2 model met or failed the criteria for subsequent analysis. These criteria – $R^2 \geq 0.90$ and coefficients of variation for GPP, ER and K < 50% – were established during the LTIM project meeting of Selected Area (Stream Metabolism Matter) leaders in Sydney, 21–22 July 2015 and in subsequent Annual LTIM fora. These criteria also stipulate that the model must have converged and that the fit parameter PP_{fit} must be in the range 0.1 to 0.9. Values of PP_{fit} outside this range indicate that the 'best fit' to the data is still an implausible model. Finally, as noted above, the reaeration coefficient needs to be in the range 0.1 to 15 /Day. This final criterion has been applied at the Basin level to the full data set.

Data collection specifically for Year 5 (2018–19) is summarized in Annex C.

It is emphasised that this method of data collection and analysis using the BASEv2 model is *only* appropriate for flowing waters, not wetlands, lagoons, lakes or other standing water bodies. Analysis of lentic (standing water) metabolism is much more difficult as water column stratification and resulting heterogeneity means that multiple (as many as 6–10) loggers need to be deployed in a single wetland. Water column stratification is far more common in lentic systems as these lack the energy of the flowing water to break down the temperature layering. In large lakes and reservoirs, stratification patterns can be relatively uniform but in smaller systems including wetlands, where wind fetch, topographic and vegetation derived shading and differing water depths affect water column hydrodynamics at a very small scale, stratification is usually extremely heterogeneous. Consequently, single measurements of metabolism in wetlands are considered as assays of the immediate vicinity of the dissolved oxygen probe rather than being indicative of whole wetland metabolism. As such, they are not discussed in this report.

Table 4. Summary of stream metabolism data records - Years 1-5.

Catchment	Logger site	Period of record		Days with metabolism data (no.)			
		First date	Last date	Pass	Fail	Total	% Accept
Edward–Wakool	Barham Bridge	11/8/14	15/4/19	586	421	1007	58
Edward–Wakool	Hopwood	11/8/14	15/4/19	589	437	1026	57
Edward–Wakool	Llanos Park2	11/8/14	15/4/19	628	596	1224	51
Edward–Wakool	Noorong2	11/8/14	17/3/19	594	415	1009	59
Edward-Wakool	Tralee / Cummins	15/8/15	15/4/19	414	557	971	43
Edward–Wakool	Widgee	11/8/14	15/4/19	761	367	1128	67
Edward–Wakool	Windra Vale	11/8/14	15/4/19	705	278	983	72
Goulburn	Darcy's Track	12/12/14	20/4/19	422	389	811	52
Goulburn	Loch Garry Gauge	29/11/14	12/6/19	353	635	988	36
Goulburn	McCoy's Bridge	11/10/14	12/6/19	1027	462	1489	69
Goulburn	Moss Rd / Day Road	11/10/14	20/2/19	437	551	988	44
Lachlan	Cowl Cowl	28/8/14	31/3/19	481	627	1108	43
Lachlan	Lane's Bridge	27/8/14	30/6/19	904	555	1459	63
Lachlan	Whealbah	28/8/14	30/6/19	752	594	1346	56
Lower Murray	LK1DS_265km	5/11/14	5/3/19	413	304	717	58
Lower Murray	LK6DS_616km	5/11/14	4/3/19	342	339	681	50
Murrumbidgee	McKenna's	21/10/14	16/4/19	713	180	993	82
Murrumbidgee	Narrandera	23/10/14	16/4/19	449	62	511	88
Warrego–Darling	Akuna	28/8/15	21/4/19	213	715	928	23#
Warrego–Darling	Yanda	28/8/15	14/12/18	282	315	597	47#

Acceptance criteria lowered to $r^2 > 0.75$ to ensure sufficient data to analyse. Note that almost all of the data meeting this reduced criterion came from 2017–18 and 2018–19.

3.2 Year 5 Highlights from the Selected Areas (2018–19)

The following highlights are taken from the Year 5 reports from each of the Selected Areas with Stream Metabolism as a Category 1 indicator. Many of the insights are related to the full five-year LTIM project rather than specifically to solely Year 5. Full details reside in each of these Selected Area Reports.

From the Goulburn Selected Area (Webb *et al.* 2020):

- Even small increases in discharge that remain within channel can still have positive benefits for the energy ('food') underpinning aquatic foodwebs. (*This is a common finding across Several Selected Areas*)
- Non-equivalence of sites: There appeared to be a 'Goulburn Weir' effect as the Day Road site (close downstream from the weir) consistently had higher rates of GPP and ER than the three sites further downstream, probably due to the export of nutrients and organic carbon from the Nagambie Lakes forming the weir.
- All rates found in the Goulburn Selected Area were typical of those in the southern Murray-Darling Basin, where usually low bioavailable nutrient concentrations constrained GPP.
- Categorization of flows into 'bands' (flow categories) allowed pooling of metabolism data, thereby averaging out variation due to season and daily weather conditions and hence provided an excellent way of comparing metabolism in different flow regimes (but see the important caveat about effects of the river size in the paragraph below Table 3) :
    - e.g. it was clearly demonstrated that increases from the very low to moderately low categories resulted in greater daily loads of organic carbon produced through GPP and consumed through ER in the water flowing past the monitoring point. The changes from moderately low flow to freshes were more equivocal, but did not significantly decline. For the McCoy's Bridge site where there is sufficient data across all seasons, it was found that there were comparable increases in load of organic carbon produced with flow category increases across spring, summer and autumn but increasing flow in winter had almost no effect as well as the lowest organic carbon load produced.
- Using the complete set of data from McCoy's Bridge, it was estimated that Commonwealth environmental water produced about a quarter of the organic carbon created by GPP over the five-year period. From an ecological perspective, CEW-enhanced GPP was perhaps most important in spring-time when 35 – 73% of all GPP was associated with the extra CEW (with the exception of 2016 when there was large flooding and CEW was only 2% of all flow). CEW also contributed around 60-65% of winter-time organic carbon load in the final three years of the LTIM project.
- It is still suggested that larger flow increases that do move the water out of channel and then back again will provide even greater benefit due to the introduction of higher organic carbon and bioavailable nutrient concentrations.
- DO concentrations in some years dropped to very low levels that raise concerns about the immediate effects on aquatic biota, but anoxia only occurred in 2016–17. The origin of the low DO regime is water entering the Goulburn River from the tributaries downstream from Goulburn Weir as the Day Road site was unaffected. These poor water quality events were of moderate duration (typically 1-2 weeks before DO levels reverted to 'normal') and appeared to be stochastic, arising from intense summer storms in the northern half of the Goulburn Catchment.

From the Edward-Wakool Selected Area (Watts *et al.* 2020):

- Commonwealth environmental watering decreased the rates of gross primary production and ecosystem respiration when expressed as mg O_2/L/Day, through dilution[3]. However, when GPP was calculated as the amount of organic carbon ('fish food') produced per day, all watering actions had an increased load of organic carbon. Again, when ER was calculated as the amount of organic carbon consumed per day (kg org C/Day), watering actions had a beneficial effect, with significant differences between sites. A higher amount of organic carbon consumed means more nutrient recycling and hence greater nutrient supply to fuel GPP. At no stage did the environmental watering actions create so much respiration that dissolved oxygen dropped below 'safe' values for aquatic biota.

- CEW from the 800 ML/Day watering action increased organic carbon production in zones 1 to 4 by 36%, 134%, 71% and 38% compared to operational flows. CEW added an additional 7.27 tonnes of organic carbon to the 13.9 tonnes generated by GPP without the CEW; an overall increase of 52%.

- Across all watering actions from 2014 to 2019, the size of the beneficial impact was largely related to the proportion of total flow that came from the watering action rather than the source of water. Carbon production was enhanced by between 0% and 330% over the ten watering actions assessed between 2014 and 2019, with a sum over all zones and watering actions of 52% more carbon produced compared to no Commonwealth environmental water. Results from the five years of the LTIM project confirm that GPP is almost always constrained within the range 1-3 mg O_2/L/Day, with ER typically between 3 and 5 mg O_2/L/Day. The lower flows typically found in zone 2 led to higher volumetric rates of GPP and especially ER over the five years, but the organic carbon load from this zone was often relatively low due to the much smaller discharge volumes.

- With small freshes (operational flows plus Commonwealth environmental water), rates of GPP and ER will increase slightly to 3-5 mg O_2/L/Day. Much larger increases are expected if significant backwater areas are reconnected to the main channel due to enhanced nutrient delivery (these 'larger flows' either did not occur in 2014–19, or the data at these times did not meet the acceptance criteria from the BASEv2 model).

- Primary production in the Edward-Wakool system is limited by low phosphorus concentrations. It is highly probable that the median rates of GPP and ER observed in the Edward-Wakool (and in all five of the southern Murray-Darling Basin Selected Areas) are at the lower end of the normal range by world standards due to a combination of very low bioavailable nutrient concentrations and a water column that inhibits photosynthesis by limiting light penetration. Apart from the

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[3] The common and general finding in Selected Areas and basin-wide that volumetric rates of metabolism i.e. amount of organic carbon created by GPP or consumed by ER per litre of water per day, typically *decrease* when discharge increases is attributed to a 'dilution effect'. It is the number of organisms (e.g. bacteria, algae) per litre of water that has decreased, simply because there are now more litres of water. It may be the case that each organism is still performing photosynthesis and/or respiration at the same rate as before extra water enters that river reach, but that is difficult to ascertain without enumeration of the organisms. It is certainly conceivable that additional water entering the river may *increase* the volumetric rates of GPP and/or ER if that additional water is much higher in nutrients and organic carbon than the water already in the river. This increase would also require sufficient time for the populations of these organisms to substantially increase in response to the added nutrients and organic carbon. Such times range from hours for bacteria to days and even weeks for algae. Such increases in volumetric GPP and ER have been observed in the Lachlan Selected Area with small flow increases.

greatly elevated nutrient concentrations in the September-November 2016 period associated with unregulated flooding, all bioavailable nutrient concentrations in the Edward-Wakool sites are low

- During 2018–19, turbidity levels at all seven sites were in the range 40-200 NTU (Figure 5.4). This means that light penetration into the water column will be inhibited by the fine suspended particulate matter, which in turn will decrease the photosynthetically active radiation (PAR) available for photosynthesis by benthic algae (and to a lesser extent, phytoplankton).

From the Murrumbidgee Selected Area (Wassens *et al.* 2020):

- During 2018–19, median rates of stream metabolism were within the range observed for the previous water years (2014–15 to 2017–18) and relatively low, corresponding with apparently low nutrient availability. Riverine nutrient concentrations were lower during 2018–19 compared to previous watering years. In a study of the drivers of metabolism in the Murrumbidgee River, Vink (2005) found evidence that algal production was phosphate limited. Biofilms, which are a key site of production in rivers, respond slowly to changes in flow height and variability. Rates of ecosystem metabolism increase with temperature, hence rates of production, biofilm growth and nutrient uptake are slower during colder months. This means floodplain-derived nutrients move downstream before being taken up, with a more diffuse, de-localised response in production during winter than during warmer months.
- There was a negative correlation between the annual median daily flow rate and the annual median GPP/ER ratio at the both Narrandera and Carrathool sites. The GPP/ER ratio differed between the two sites and for Narrandera (but not Carathool) across years as well. Narrandera site was net heterotrophic for 2014–15 and 2016–17 but strongly autotrophic (GPP/ER > 1) for 2015–16, 2017–18 and 2018–19 and tended to decrease with increasing flow rate. At the Carrathool site, the GPP/ER ratio remained slightly less than 1 (range: 0.81-0.92), irrespective of flow. The GPP/ER ratio differed markedly between the two sites even within the similar flow range indicating the GPP/ER ratio may be largely regulated by site-specific factors.
- The low GPP/EP ratio alone is unlikely to indicate the likelihood of hypoxic conditions. For example, hypoxic conditions in lowland river systems are often associated with high levels of dissolved organic carbon (DOC) in the water column; in the studied area of the Murrumbidgee River system, the DOC concentration remained relatively low throughout the monitoring period (mostly <5 mg C/L).

From the Lachlan Selected Area (Dyer *et al.* 2020):

- There was a strong, water-temperature related seasonality in GPP and ER. Despite high natural variability, there are marked effects of environmental flow delivery on GPP and ER. This high variability appears to result from variability in the physical process of reaeration and biological responses. There were large intervals where estimates for GPP and ER could not be calculated, corresponding to times of higher flows, including the large natural flood in 2016–17 and environmental flow events. This complicates determining the magnitude of metabolism responses to changing discharge.
- Increased GPP and ER correlated with higher nutrient and algal concentrations and higher DOC during environmental flow delivery, particularly if this was associated with warm water

conditions. In cooler conditions, the GPP response was considerably subdued, whereas the ER response appeared to be maintained.

- Delivery of small autumn flows have been achieved several times in the Lachlan. Despite lower water temperatures, this produces increases in volumetric ER rates, and smaller but detectable increases in algal production (GPP), although these increases are not as large as in warmer months. It is still unclear what role these autumn flows may play in determining the magnitude of spring responses in the following year. These may also be important ecologically in providing resources at a relatively resource-poor period, supporting maintenance of fish condition into the winter period.
- There is evidence for productivity responses to environmental flow delivery in the lower Lachlan River, particularly when water temperatures are warmer. While the river was generally heterotrophic (dominated by external carbon rather than in situ photosynthesis), it tended to be more autotrophic during environmental flows. This may be suggestive of generating higher quality local production. This suggests that flows targeting productivity responses and/or supporting fish larvae should occur during warmer conditions.

From the Lower Murray Selected Area (Ye *et al.* 2020):

- Patterns of daily GPP (photosynthesis) and ER (respiration) varied markedly within and between years, and across sites, with particularly high respiration rates evident in the 2016–17 flood year. Generally, GPP and ER were of similar magnitude and daily NEP values varied between negative and positive values but were often close to zero, with integrals over time close to zero.

- In general, Commonwealth environmental water deliveries increased the average water depth and reduced volumetric GPP, but increased cross-sectional areas which increased the cross-sectional GPP. These opposite shifts in local food production versus total river food production are likely to have fundamental effects on the composition and functioning of food webs, but the significance is currently not understood.

- Effects of environmental flows on volumetric and cross-sectional GPP were small across all years due to the relatively constant water levels. The potential effects of flow interactions with channel morphology were modelled for a less regulated channel reach at Hattah. Modelled GPP underwent large changes with up to 17% reductions in volumetric rates and 24% increases in cross-sectional rates, demonstrating that the interaction of flows and channel morphometry can have a major influence.

- CEW decreased the likelihood of low dissolved oxygen levels in the LMR (Lower Murray River) during spring–summer by increasing water mixing and oxygen exchange at the surface. For example, in 2014–15, it was estimated that environmental water contributed to reducing the risk of low oxygen levels by 31 extra days, when environmental water contributed to increasing water velocities a threshold of 0.18 m/s. During the flood in 2016–17, dissolved oxygen levels fell to zero in the LMR for a short period resulting in extensive kills of Murray cod.

- Increased flow from environmental water deliveries widened the river, increasing the volume of water available for aquatic plant and animals. As a result, the rates of food production (measured as cross-sectional gross primary production) increased slightly (by ~2% each year). The influence of environmental water on riverine food production in the LMR was only minor due to the largely 'fixed' water levels set by regulation (weirs).

- A significant correlation was obtained between ER and the variables GPP and DOC. In most monitoring periods the bacterial contribution to ER (BCR) was equivalent to, or less than the phytoplankton contribution, except early in the 2016–17 flood year when BCR made up almost all the respiratory activity.

- Bacterial respiration is a function of the DOC concentration and leads to bacterial production which enhances carbon supplies to the food web. However, high DOC concentrations can cause enhanced bacterial respiration rates leading to oxygen depletion. Environmental flows need to be managed to achieve beneficial DOC concentrations either by selecting appropriate sources of water supply from the catchment, or by managing flows to achieve suitable interactions with terrestrial supplies of organic carbon as flows progress downstream. The latter approach will need to consider the accumulation of terrestrial carbon on the floodplain and the area that might be inundated to provide a beneficial supply of DOC, without leading to concentrations that have detrimental effects, especially on DO concentrations.
- Estimates of ER for the modelled flow conditions without Commonwealth environmental water or environmental water need to include the contributions from both phytoplankton and heterotrophs.
- GPP relies directly on the mean light within the water column, which in turn depends on the average depth, and light attenuation which is related to turbidity and DOC concentrations. Environmental flows which alter the attenuation of light through increased turbidity and DOC, can greatly influence GPP. However, DOC concentrations are important to heterotrophic metabolism, with increased concentrations enhancing heterotrophic net production. These opposite influences of DOC on phytoplankton and heterotrophic net production is one example of a number of trade-offs that need to be considered regarding the water quality of flows.

Note: Unlike the other Selected Areas (with the partial exception of the Murrumbidgee River), due to its size and depth, metabolism in the Lower Murray River is almost totally in the water column in contrast to the other rivers where benthic and littoral zone contributions may dominate. Hence many of the findings above cannot be extrapolated to these other systems without the need for estimating separate water column and benthic contributions (which would be extremely useful information but is not part of the LTIM project).

From the Warrego-Darling Selected Area (Southwell *et al.* 2020):

- Generally, the Darling River zone was a carbon sink during the project period (2014–2019), with more carbon consumed than produced, reflected as negative NPP. The major reason for heterotrophy in this system was consistently low rates of GPP, linked to low chlorophyll a concentrations, and high rates of ER, fueled by dissolved organic matter and respiring algae. Energy flow and organic matter cycling through these systems appears to be dominated by a heterotrophic (detritus-decomposer-consumer) pathway, in which organic matter is colonised by microbes and fungi or consumed by detritivores that then fuel the invertebrate, fish and water bird food webs.
- GPP rates typically increased with increasing in-stream total nitrogen and chlorophyll *a* concentrations, although this behaviour differed between sites. GPP rates also increased with increasing temperature but were highly variable during base flow conditions and constrained to below 5 mg/O_2/L/Day when discharge was above 150 ML/Day. Thus flow events generally led to lower net carbon production. GPP rates also fell in higher turbidity from decreased light penetration e.g. above 100 NTU, GPP rates generally dropped to below 5 mg/O_2/L/Day, indicating that primary production rates were predominantly affected by available light, nutrient availability and in-stream temperature.
- Metabolic indicators appear to respond to change in specific thresholds in discharge, rather than following a linear trend. The relationship between discharge and turbidity, the effect of

flocculation, and the complex interactions between conductivity, turbidity and chlorophyll *a* concentrations need further investigation.

- The downstream station generally had lower metabolism rates than the upstream. Additional water quality sampling in the 2016–17 peak flow event showed a dilution effect in pH, conductivity, chlorophyll *a* and total nitrogen concentrations that was caused by Warrego River inflow and this needs further investigation.
- Estimated carbon production ranged from 3.2 to 1,000 kg org C/km/Day with strong seasonal effects; temperature exerts a strong influence on carbon production with generally lower carbon production in winter. In 2018–19, carbon production per unit area was higher than other years. The Darling downstream station generally had the higher carbon production due to larger channel volume. In 2015–17, there was less carbon produced from the environmental water contribution because the proportion of environmental water in those flow events was smaller. In 2017–19, more carbon production was supported by environmental water.

3.3 Overview of stream metabolism at monitored sites within Selected Areas

As an initial overview, the metabolic parameters GPP and ER for the six Selected Areas during 2014–19 are presented in Figure 4 and Figure 5, respectively. The data are then stratified into season (spring, summer, autumn and winter) (Figure 6 and Figure 7) to evaluate any seasonal patterns. The statistical information describing this data is also summarized in Annex D. After four years of data compilation, the most striking feature of both Figure 4 and Figure 5 is the similarity in median rates across most Selected Areas with the exception of the still relatively small data set from the Warrego-Darling, where the median GPP was 3.1 mg O_2/L/Day. At other sites GPP medians ranged from 1.2 to 2.1 mg O_2/L/Day. ER medians spanned a slightly larger range from 1.2 to 3.7 mg O_2/L/Day, again with a much higher median of 7.5 mg O_2/L/Day from the two sites on the Darling River at Akuna and Yanda.. Especially for the Lower Murray and Murrumbidgee Selected Areas, the annual median rates would be slightly lower due to the absence of winter-time data where rates are reduced due to short daylight hours and much colder water temperatures (thus suppressing physiological rates). Collection of winter-time data during Year 4 has helped quantify this effect.

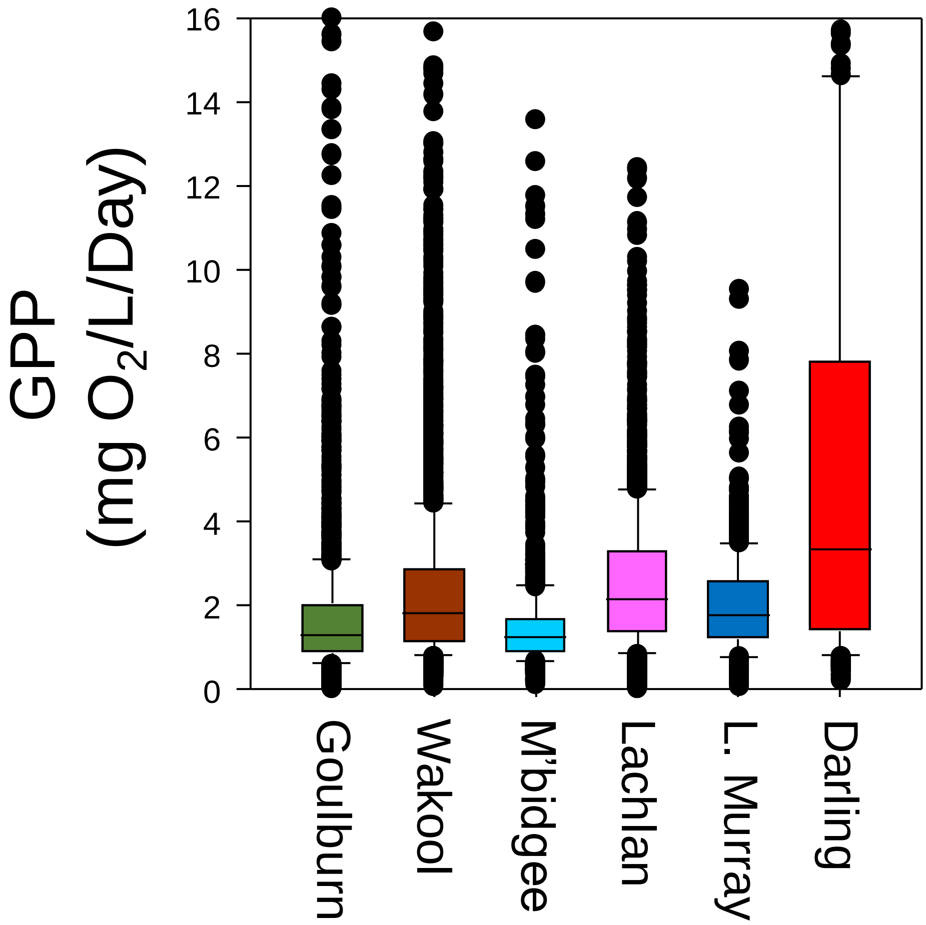


Figure 4. Box plot representing gross primary productivity (GPP) in the six Selected Areas for which data are available. Within each area, results from individual loggers (sites) have been composited. Data cover the five years of the LTIM Project, nominally July 2014 to June 2019.

For all boxplots presented in this report, 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. When there are fewer than 6 points in a particular data category, no box is drawn.

It is pertinent to note that these generic diagrams can 'mask' variation in metabolism at the site level within a Selected Area. For example, the median GPP and ER rates from five years data (2014–2019) at the Widgee site (Zone 2) in the Edward-Wakool Selected Area were 2.60 and 8.07 mg O_2/L/Day (n = 774) whereas for the other six sites, the median GPP was constrained in the range 1.31 – 2.02 mg O_2/L/Day and the median ER was even more tightly bound in the range 3.45 – 3.74 mg O_2/L/Day (n = 3517). The origins of this difference at Widgee is largely attributed to the much lower flows throughout the year, thus enabling benthic processes to control oxygen concentrations in the very shallow water column. Detailing and discussing site specific differences is the purview of the individual Selected Area reports, but it would be misleading to over-generalize and state that all southern MDB streams will fit into the remarkably constrained 'boxes' portrayed in Figure 4 and Figure 5.

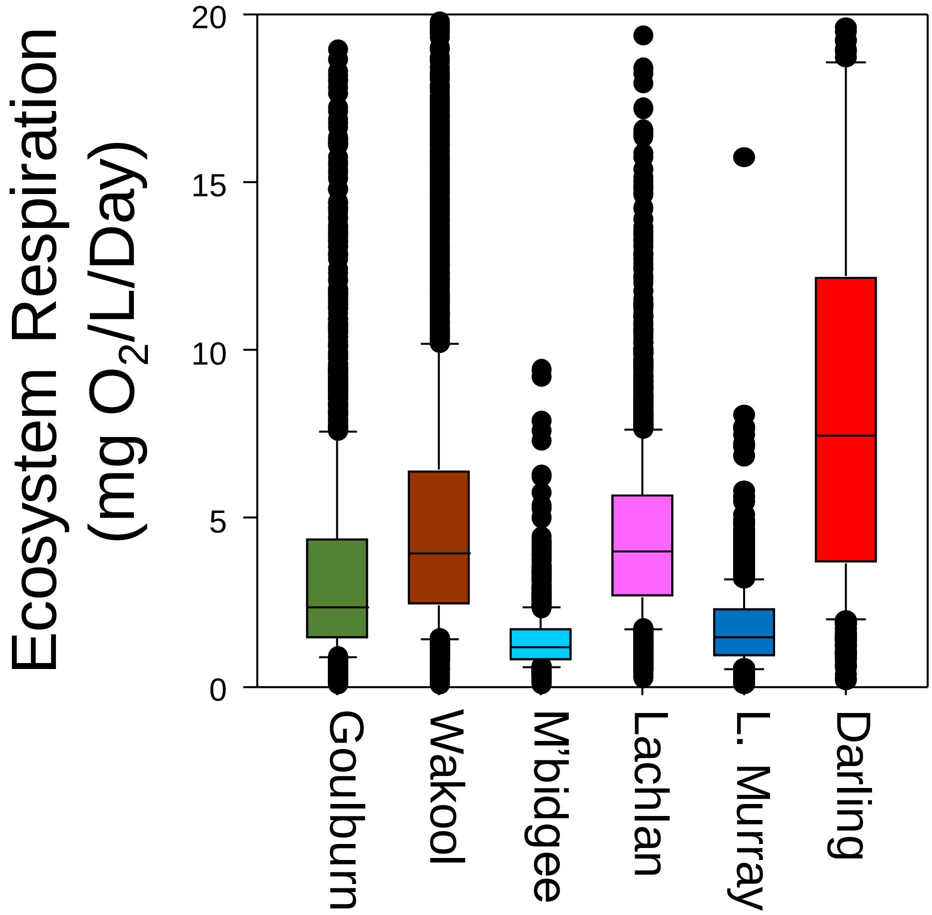


Figure 5. Box plot representing Ecosystem Representation (ER) in the six Selected Areas for which data are available. Within each area, results from individual loggers (sites) have been composited. Data cover the five years of the LTIM Project, nominally July 2014 to June 2019.

Although there is a reasonably constrained range for both GPP and ER for all Selected Areas (the range spanned between the 25th and 75th percentile rates is typically only 3-4 mg O_2/L/Day and much less for the Murrumbidgee and Lower Murray Selected Areas), rates can increase by factors of three to 10 or more above this when growth conditions are highly conducive. For example, during the algal bloom in the Edward-Wakool in late summer to early autumn 2016, GPP rates at several sites were consistently above 10 mg O_2/L/Day and for a few days even exceeded 20 mg O_2/L/Day. To put these values into context, Table D1 (Annex D) summarizes all the metabolism results over the five years of the LTIM project. All the 75th percentile GPP values, irrespective of Selected Area and season are below 5 mg O_2/L/Day. Ecosystem Respiration rates during the time of the bloom were also correspondingly much higher than typical. Such high rates are not problematic unless they are arising from algal blooms or, in the case of the hetrotrophic component of Ecosystem Respiration, could lead to anoxia.

GPP and ER are integral components of aquatic ecosystems everywhere. It may therefore be valuable to compare rates found in the Murray-Darling Basin with those measured elsewhere to gain further insights into the constraints on these rates and possible implications of such constraints. There are no other Australian data sets of sufficient duration and spatial coverage to enable comparison with these LTIM results. Consequently, for comparison on a global scale, a compendia of stream metabolism data collected worldwide (but mostly featuring the United States of America; USA) indicate that primary production and ER values are typically in the range 2–20 mg O_2/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. Many of the US studies have been on smaller streams or larger, but still realtively shallow, rivers such that a nominal average depth of 1 m is reasonable. More detailed comparisons would involve using the average reach depth estimated each stream (but not routinely available for the LTIM study reaches, as the multiple cross-section depth transects required to estimate mean reach depth are beyond the scope of LTIM). Hence, the LTIM project data fall towards the bottom end of this range. Anecdotal descriptions of as yet unreleased United States Geological Survey data from a large number of sites across the USA over many years suggest that the LTIM data are not unusually low after all, but confirmation of this finding awaits official release of these data which may still be a year or two away. 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 2014–18 was an unusually low (or high) period for the Basin. A study by Hall *et al.* (2016) of 14 larger rivers in the western USA revealed a wide range of primary production rates (0.2–26.2 mg O_2/L/Day). However, for 10 of these 14 rivers, rates were < 5 mg O_2/L/Day, putting them in the same range as the rates typically found (Figure 4) from this LTIM project. It was suggested that the rates at the lower end of this range were constrained mainly by low bioavailable[4] nutrient concentrations or, in the cases of the Colorado River and the Green River at Gray Canyon, by very high turbidities (turbidity > 100 NTU) limiting the euphotic depth and inhibiting photosynthesis. Further comparison of LTIM results with this data set is tempered by the fact that in the US study, typically only a few days of metabolism data were collected from each of the rivers – in stark contrast to the extensive LTIM data set which covers several seasons across multiple years.

Consequently, questions relating to whether these rates are low on a global basis and mean that food webs (and hence native fish populations) are resource/energy limited will remain a key focus of annual reports at the end of the LTIM project. This will also require access to appropriate international data sets.

[4] 'Bioavailable' refers to those forms of nitrogen (N), carbon and phosphorus (P) most readily taken up by organisms. This typically equates to 'dissolved' or 'filterable' phosphate for P and the combination of ammonia, nitrate and nitrite for N.

3.3.1 Seasonal variation in stream metabolism

When considering seasonal effects on metabolism, the typical trend was that both volumetric GPP (Figure 6) and ecosystem respiration (Figure 7) rates increased in all six Selected Areas when moving from spring into summer. This is consistent with longer days (more hours of sunlight), more intense sunlight, and warmer days leading to higher cellular metabolic rates during summer. As algae can double in number every 1–2 days when the environmental conditions such as light and nutrients are conducive to growth, the highest algal populations are often found in late summer rather than earlier in the season. One graphic example of this was the formation of the cyanobacterial *Chrysosporum ovalisporum* bloom in the Murray–Edward–Wakool system in late summer through early autumn, 2016.

Moving from summer into autumn, there was no common pattern between the Selected Areas for primary production or ER. The Edward–Wakool results showed higher rates in autumn due to the algal bloom in 2016. In the Lower Murray, there was also a slight increase in GPP from summer to autumn; however in this case, the small number of data points in autumn (23) were all recorded in the first half of March when growth conditions for algae are still highly conducive. In most other areas, metabolic rates decreased as light intensity and average water temperature dropped and daylight hours diminished. There relatively limited amount of data from the Warrego–Darling Selected Area conformed to this pattern of seasonal change, although the summertime GPP (Figure 6) was much higher than either spring or autumn.

Wintertime GPP rates for the four selected areas for which there was data at this time of year (Goulburn, Edward-Wakool, Lachlan, Warrego-Darling) showed the expected much lower rates for GPP compared to the other seasons. There was a corresponding decrease in ER rates from autumn to winter and an increase moving into spring for the Lachlan and Edward-Wakool Selected Areas, but winter-time ER in the Goulburn was similar to both autumn and spring rates. Most of the Goulburn Selected Area data is from the one logger at McCoy's Bridge that is now deployed for 12 months a year. Unlike the other three seasons, wintertime data was only from 2016–17 hence seasonal differences may also be associated with annual differences. This discussion is continued in section 3.3.2 where inter-annual variability in GPP and ER is examined on a seasonal basis.

As stressed in the Year 1 (2014–15) Basin Matter report (Grace 2016), 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. Other approaches for assessing effects of Commonwealth environmental water are discussed later in this report.

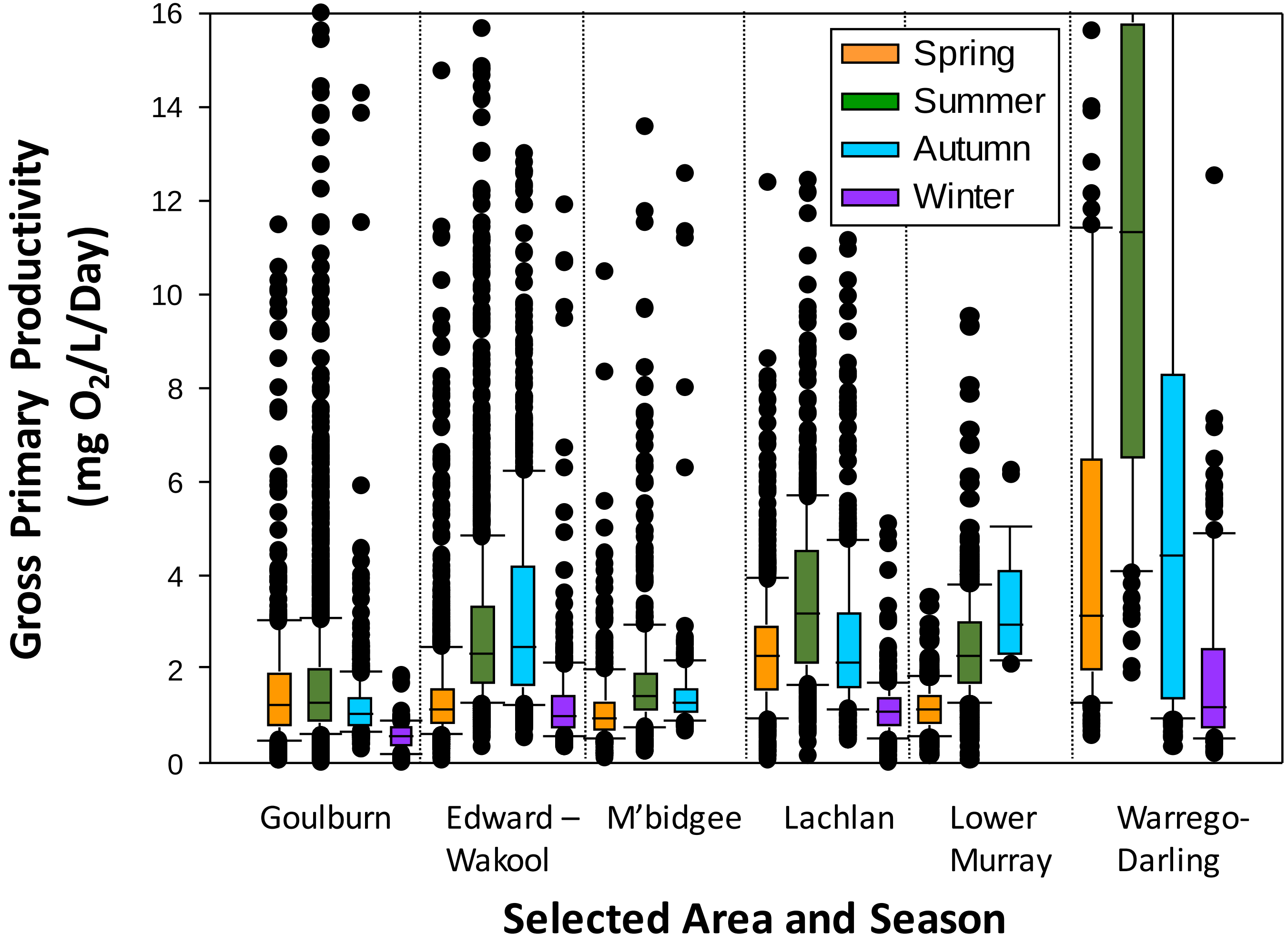


Figure 6. Box plot representing the seasonal dependence of gross primary productivity (GPP) in the six Selected Areas for which data are available over the five years of the LTIM project. Within each area, results from individual loggers (sites) have been composited. The boundary of the box closest to 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.

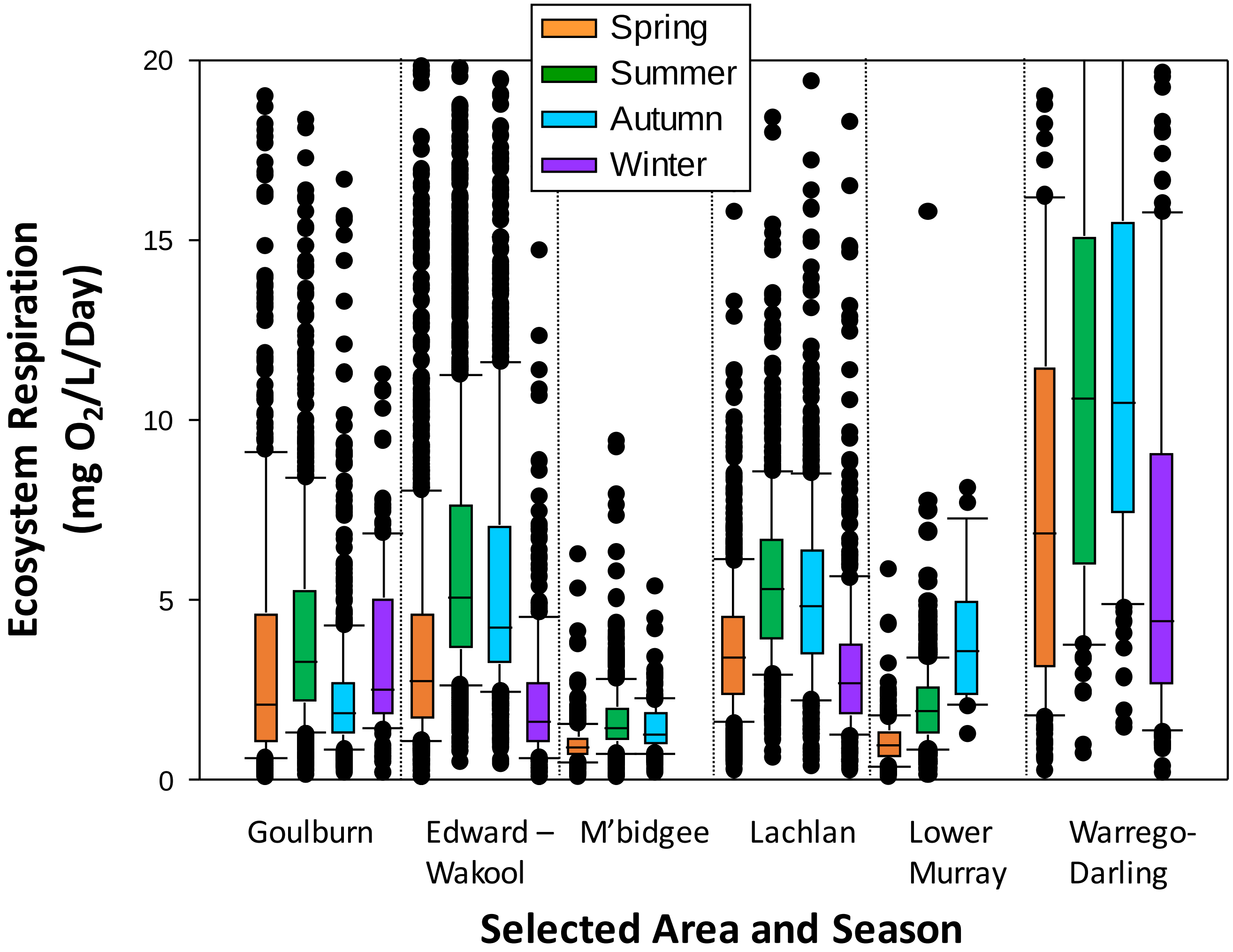


Figure 7. Box plot representing the seasonal dependence of ecosystem respiration (ER) in the five Selected Areas for which data are available over the five years of the LTIM project. Within each area, results from individual loggers (sites) have been composited. The boundary of the box closest to zero 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.

3.3.2 Annual variation in seasonal stream metabolism

Annual variability, stratified by season, for GPP and ER are presented in the following figures for the six Selected Areas:

- GPP for the Goulburn and Edward-Wakool Selected Areas (Figure 8)
- GPP for the Lachlan and Warrego-Darling Selected Areas (Figure 9)
- GPP for the Murrumbidgee and Lower Murray Selected Areas (Figure 10)
- ER for the Goulburn and Edward-Wakool Selected Areas (Figure 11)
- ER for the Lachlan and Warrego-Darling Selected Areas (Figure 12)
- ER for the Murrumbidgee and Lower Murray Selected Areas (Figure 13).

As a convenient guide to relative flows in each of the five years, stratified by season, and pooled for all metabolism-based stream gauging sites in each Selected Area, Table 5 presents the ratios of Years 2, 3, 4 and 5 mean discharge in that season to the corresponding mean seasonal discharge in Year 1. A value of 1 in this table means the same mean seasonal discharge as in 2014–15. A value less than 1 indicates drier conditions in that season for that year compared to 2014–15; conversely a value greater than 1, indicates a higher mean discharge.

The discharge ratios presented in Table 5 clearly show that the spring of 2016–17 was much wetter than the same period for 2014–15, with mean flows increasing by a factor between three times (Goulburn) and 556 times (Darling River); the latter is potentially misleading as there was almost no springtime flow in the Darling River in 2014–15. Other key features include 2015–16 being much drier across the whole year in the Goulburn compared to Year 1, whereas Year 2 mean seasonal flows in the Murrumbidgee were similar to Year 1. Apart from Year 3 spring, autumn and winter there were no other time period that was uniformly wetter or drier across all six Selected Areas compared to the nominal 2014–15 baseline. This reflects regional rainfall patterns within the Basin i.e. the Basin is so large that even major rain events may only impact on some but not all Selected Areas.

The key features of the Year 5 discharges compared to the Year 1 comparison point include:

- The Darling River was extremely low (ceased to flow) for almost all of spring and summer, with low flows (comparatively) also in autumn and winter.
- With the exception of lower winter-time flows in 2018–19, in the Edward-Wakool, the other three seasons were similar to the 2014–15 benchmark. The Goulburn Broken also had similar discharges to Year 1 during autumn and winter, whereas spring flows were down by 23% and summer flows up by 43%.
- Year 5 seasonal flows in the Lachlan were similar to Year 1 in spring and summer and elevated by around 50% in autumn and winter.
- In the Murrumbidgee, flows were generally much lower in 2018–19 compared to 2014–15, with all but spring being at least 50% lower if not more. The opposite trend was seen in the Lower Murray, where spring, summer and autumn flows in 2018–19 were substantially higher than 2014–15.

This pronounced variability of flow patterns between the selected areas in most years confounds simply basin-wide trends across the five years; *a simple 'this is a wet year across the basin, hence all rivers had higher flows than the reference year' does not hold true.*

Table 5. Ratios of mean seasonal flows in 2015–16, 2016–17, 2017–18 and 2018–19 compared to 2014–15 Flows.

	Edward-Wakool	Murrumbidgee	Lower Murray	Goulburn	Warrego-Darling	Lachlan
Spring						
Year 2/Year 1	0.95	1.02	1.61	0.61	10.7	4.20
Year 3/Year 1	16.7	7.13	12.7	2.96	556	26.1
Year 4/Year 1	1.04	0.88	2.02	0.65	4.54	1.79
Year 5/Year 1	1.00	0.74	1.61	0.77	0.01	1.05
Summer						
Year 2/Year 1	1.07	0.87	0.90	0.44	0.44	1.23
Year 3/Year 1	1.96	1.21	6.65	0.87	2.24	5.90
Year 4/Year 1	1.07	0.90	1.86	1.44	0.44	1.70
Year 5/Year 1	1.25	0.50	1.49	1.43	0.00	1.09
Autumn						
Year 2/Year 1	0.99	1.03	0.75	0.90	0.34	1.43
Year 3/Year 1	1.12	1.63	1.70	1.32	1.79	1.28
Year 4/Year 1	1.02	0.93	1.25	1.52	0.52	1.79
Year 5/Year 1	0.84	0.46	1.51	1.07	0.23	1.56
Winter						
Year 2/Year 1	0.36	1.26	0.63	0.28	2.37	2.81
Year 3/Year 1	1.95	2.37	2.03	1.10	14.0	17.0
Year 4/Year 1	0.58	0.92	0.91	0.90	1.62	1.34
Year 5/Year 1	0.53	0.44	0.82	0.81	0.38	1.56

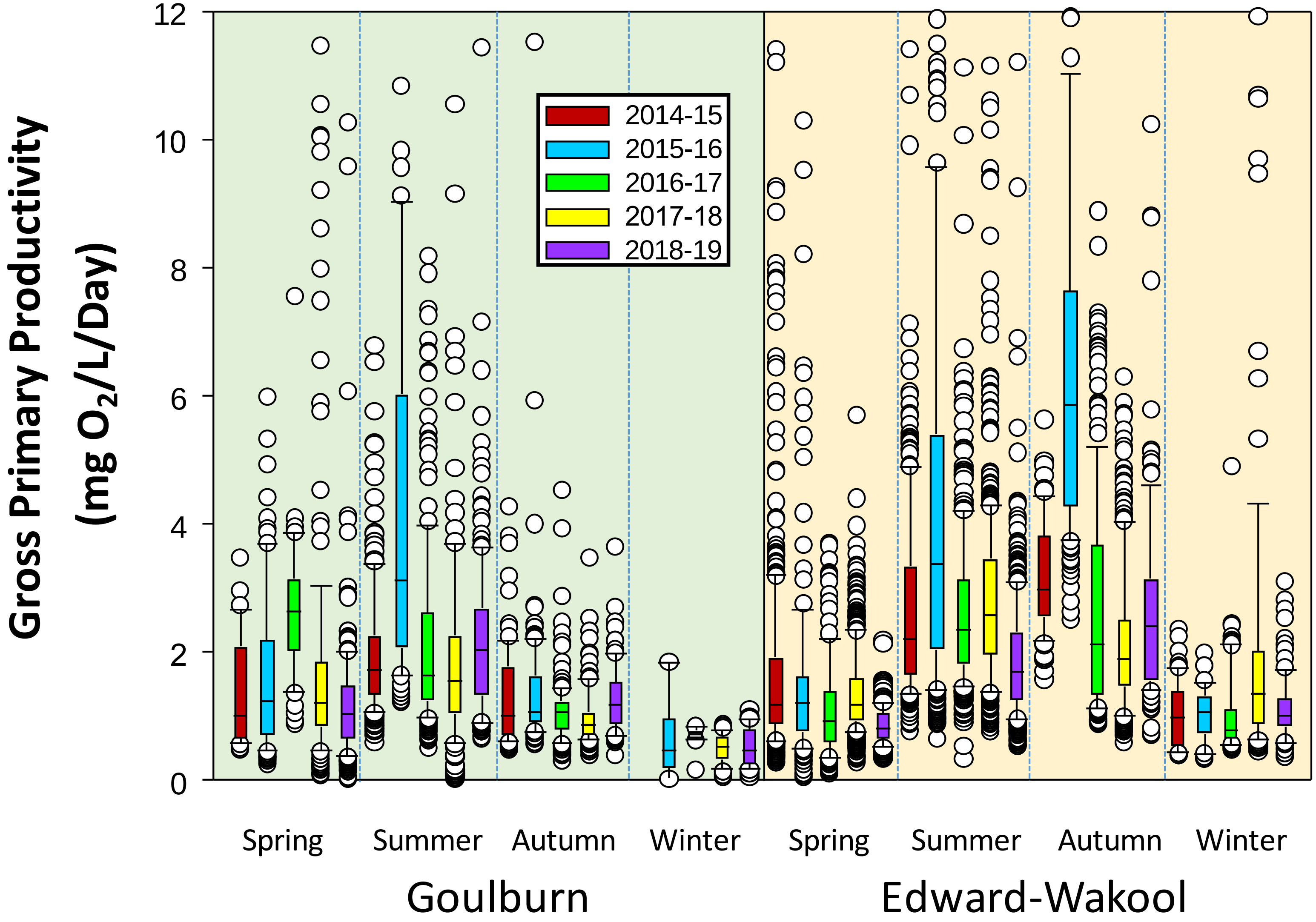


Figure 8. Gross Primary Production in the Goulburn and Edward-Wakool Selected Areas. Data are stratified into season and year to facilitate inter-annual comparisons.

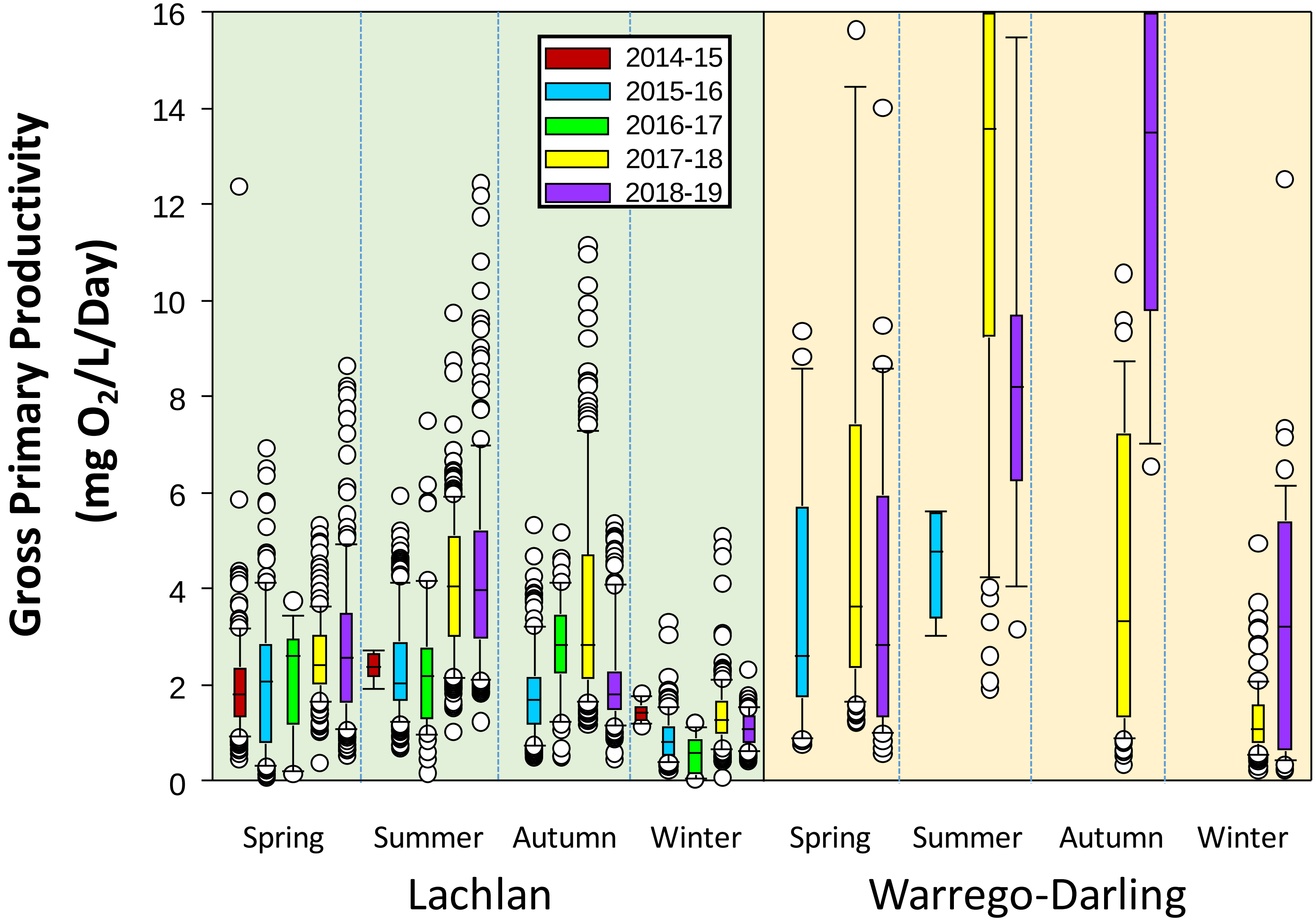


Figure 9. Gross Primary Production in the Lachlan and Warrego-Darling Selected Areas. Data are stratified into season and year to facilitate inter-annual comparisons.

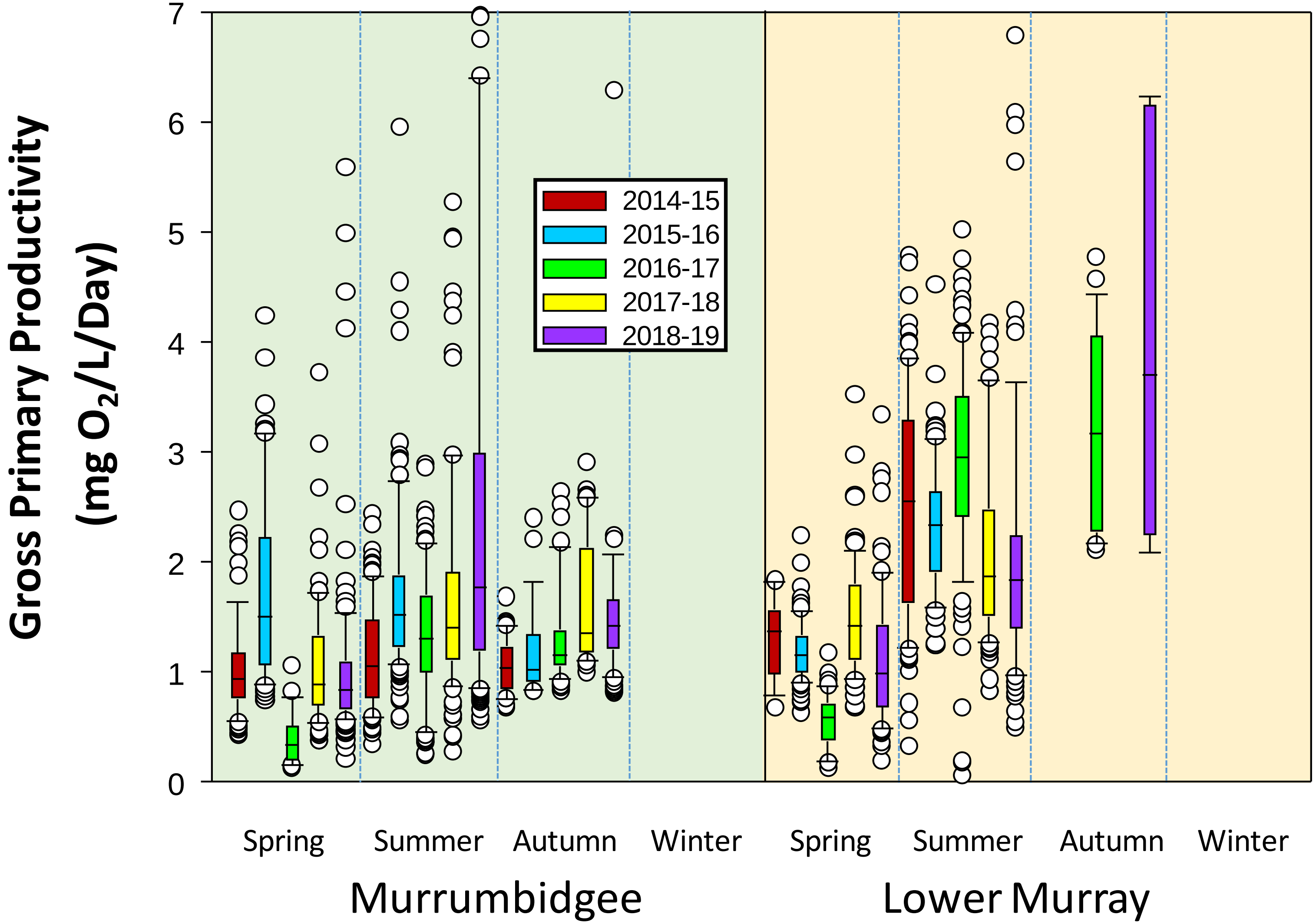


Figure 10. Gross Primary Production in the Murrumbidgee and Lower Murray Selected Areas. Data are stratified into season and year to facilitate inter-annual comparisons. There was no Winter data to plot from either Selected Area.

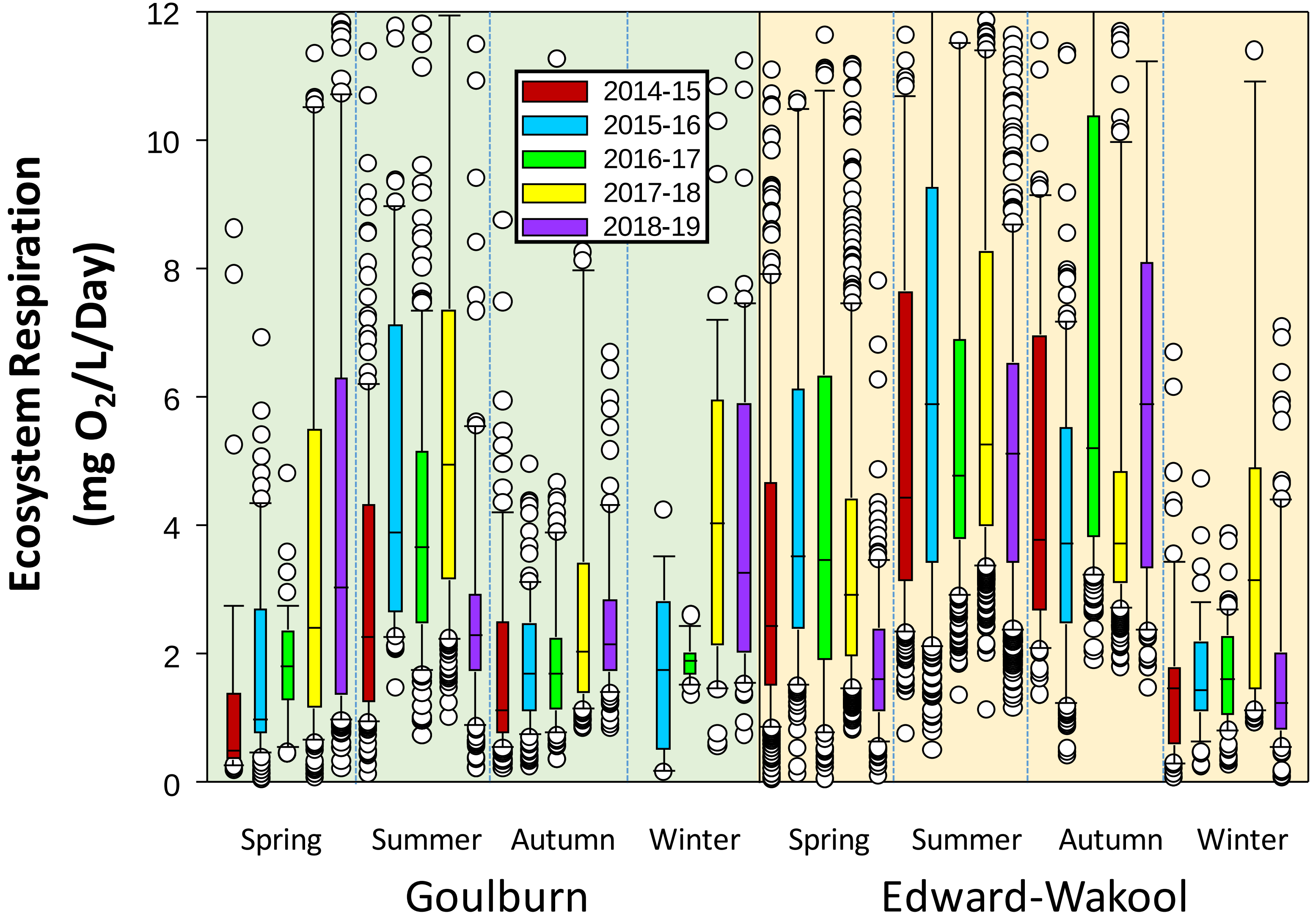


Figure 11. Ecosystem Respiration in the Goulburn and Edward-Wakool Selected Areas. Data are stratified into season and year to facilitate inter-annual comparisons.

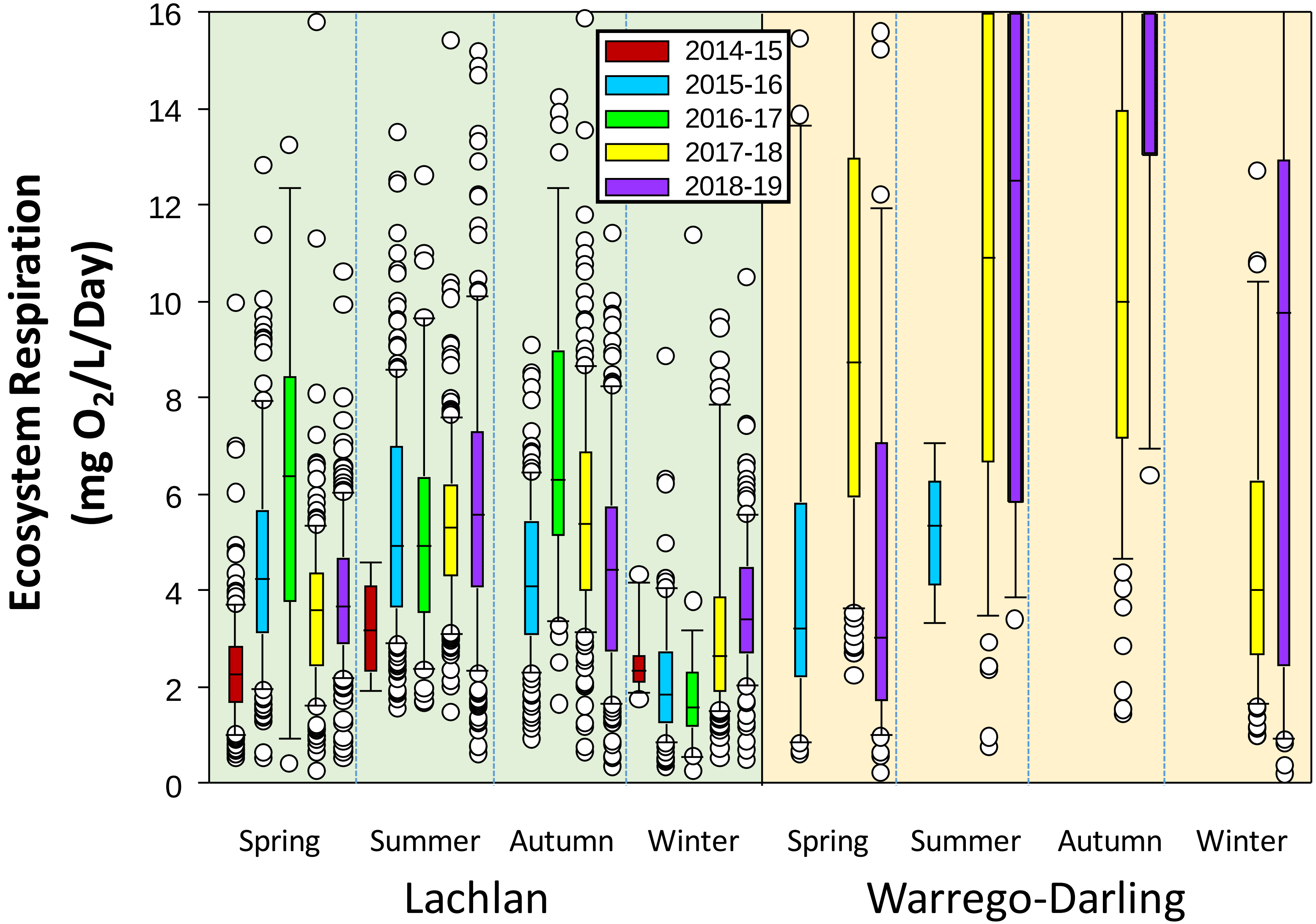


Figure 12. Ecosystem Respiration in the Lachlan and Warrego-Darling Selected Areas. Data are stratified into season and year to facilitate inter-annual comparisons

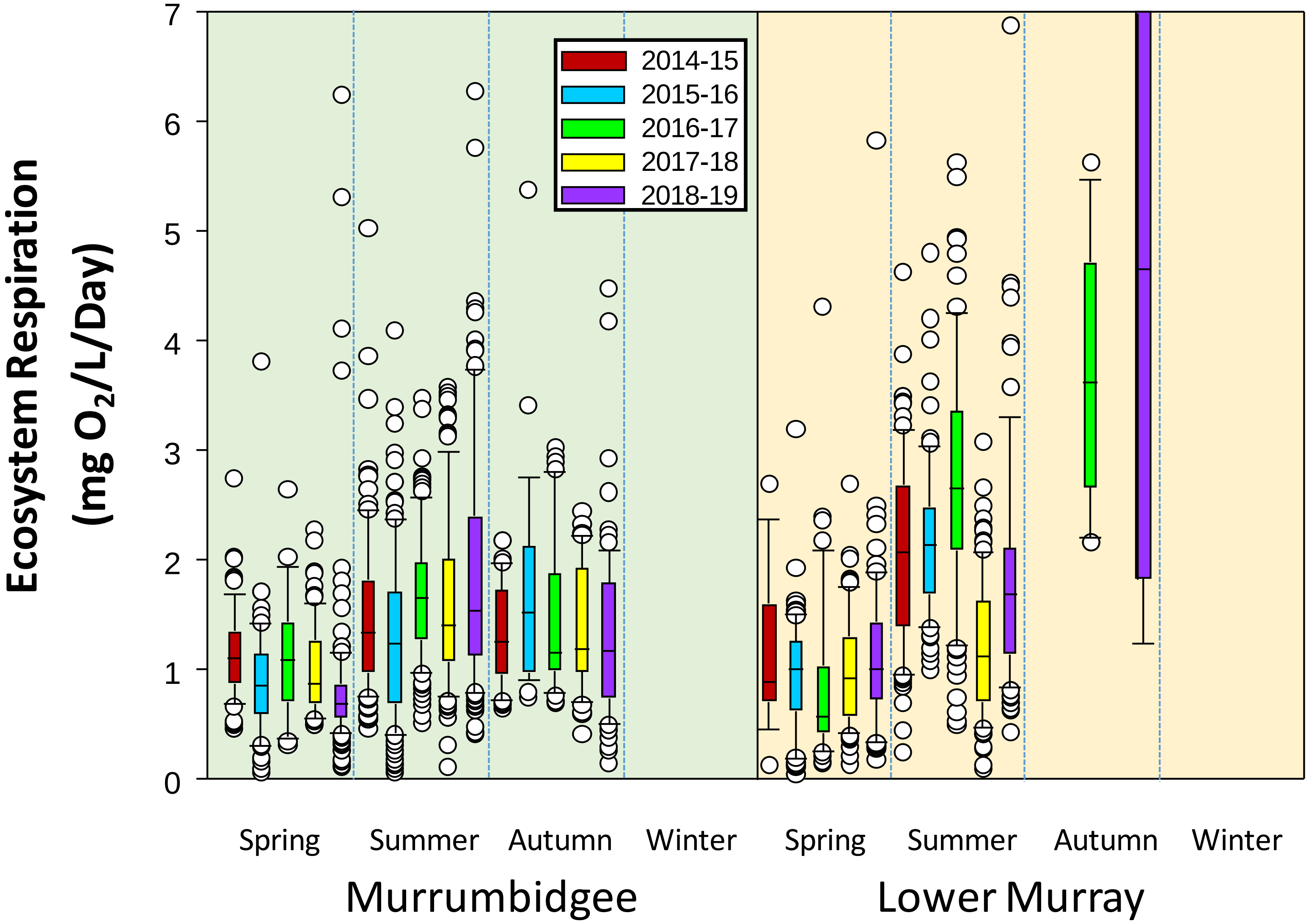


Figure 13. Ecosystem Respiration in the Murrumbidgee and Lower Murray Selected Areas. Data are stratified into season and year to facilitate inter-annual comparisons.

The data displayed in the four figures above highlight two separate points:

1. As noted above with Figure 4 and Figure 5, even when stratified by season GPP and ER rates fall in a relatively narrow window (one order of magnitude): GPP from 0.5 to 4 mg O_2/L/Day (ignoring the extant algal bloom in the Edward-Wakool system that contributed heavily to a much higher GPP in Autumn 2015–16), with median ER spread from around 1 – 6 mg O_2/L/Day.
2. Within these ranges, there is a lot of idiosyncratic behaviour across Selected Areas, Seasons and Years.

The summer GPP for the Goulburn, Edward-Wakool and Lachlan Selected Areas all have one higher year than the other three in the period 2014–18 (Figure 8, Figure 9); this 'high year' was 2015–16 for the first two areas and 2017–18 (and 2018–19) in the Lachlan. For ER there was no strong annual summertime difference. The most notable feature in summer GPP for the Lower Murray and Murrumbidgee Selected Areas (Figure 10) is the much lower rates in spring of 2016–17.

Seasonal patterns are also dependent upon the individual selected area. For the Lower Murray Selected Area, summer GPP is double that of spring, whereas in the Murrumbidgee, there is only a small rate enhancement moving from spring to summer. A strong seasonal increase in GPP is found for the Edward-Wakool Selected Area from spring to summer and then higher summer rates are maintained into autumn. Part of this is an artefact of the sampling program where monitoring was concluded in April therefore missing the colder month of May when rates would be expected to decline due to the cooler temperatures slowing metabolic responses and shorter days with less intense sunlight. There was no strong seasonal trend in the Lachlan Selected Area whereas in the Goulburn, GPP peaked in the summer and then declined in the autumn.

Summer ER in the Goulburn Selected Area was much higher than in spring and autumn (Figure 11), and this pattern is also seen with the Edward-Wakool, albeit with large variation between individual years. For the Lachlan Selected Area there was much more variation between years within a season than between seasons. The Murrumbidgee Selected Area ER (Figure 13) was marginally lower in spring than in summer and autumn which were comparable to each other but again with an autumn data set that was restricted to March and April. Summer ER in the Lower Murray Selected Area generally showed a much higher rate than spring, although summer 2017–18 was much lower than the preceding three years.

These preceding six figures also enable visual comparison of metabolism in Year 5 (the purple boxes in the boxplots) with the four previous years. The summary statistics, stratified by season for the six Selected Areas, including mean and median GPP and ER rates for 2018–19 and the earlier years along with the usual indicators of spread (standard deviation, standard error, minimum, maximum, 25th percentile and 75th percentile) are presented in Tables D6 and D7 in Annex D. This visual comparison and examination of the data in Annex D reveal the following information about the stream metabolism behaviour in 2018–19 when contrasted to the average of the preceding four years:

- Goulburn: Year 5 was very similar to previous years for rates of both GPP and ER;
- Edward-Wakool: Spring and summer rates of GPP were the lowest during the LTIM project for GPP as was spring ER. GPP and ER rates for the other seasons were typical;
- Lachlan: There was no difference in GPP rates in 2018–19, although winter ER rates were the highest of any year;
- Murrumbidgee: GPP in the summer was the highest in 2018–19, whilst ER was lowest in Spring 2018–19. Other seasonal GPP and ER data for Year 5 were commensurate with the four previous years. Despite these changes in 2018–19, all

are still occurring within a narrow band and the rates are usually the lowest of any of the Selected Areas;

- Lower Murray: Year 5 seasonal rates were similar to previous years. As noted earlier, the higher rates for both GPP and ER in autumn compared to summer are a manifestation of the short autumn data collection period focussing on early to mid-March. Along with late summer, this is typically the time of the year when rates are highest due to the standing biomass of primary producers and continuing warm temperatures and relatively intense sunlight over a large proportion of the daylight hours. The algal detritus also fuels higher rates of ER;
- Warrego-Darling: The paucity of data, especially from Years 1-3 makes any multi-year comparison impossible at this stage.

To investigate whether there is a link between seasonal discharge and volumetric rates of metabolism (GPP, ER) at the same temporal scale, Figure 14 shows the median seasonal metabolic rates for the six Selected Areas against the corresponding seasonal discharge. Values for the independent (X) axis are taken from Table 5; dependent (Y) axis values are calculated from the data presented in Annex D, Tables D3 and D4. A value > 1 indicates a seasonal parameter greater than the corresponding value in 2014–15.

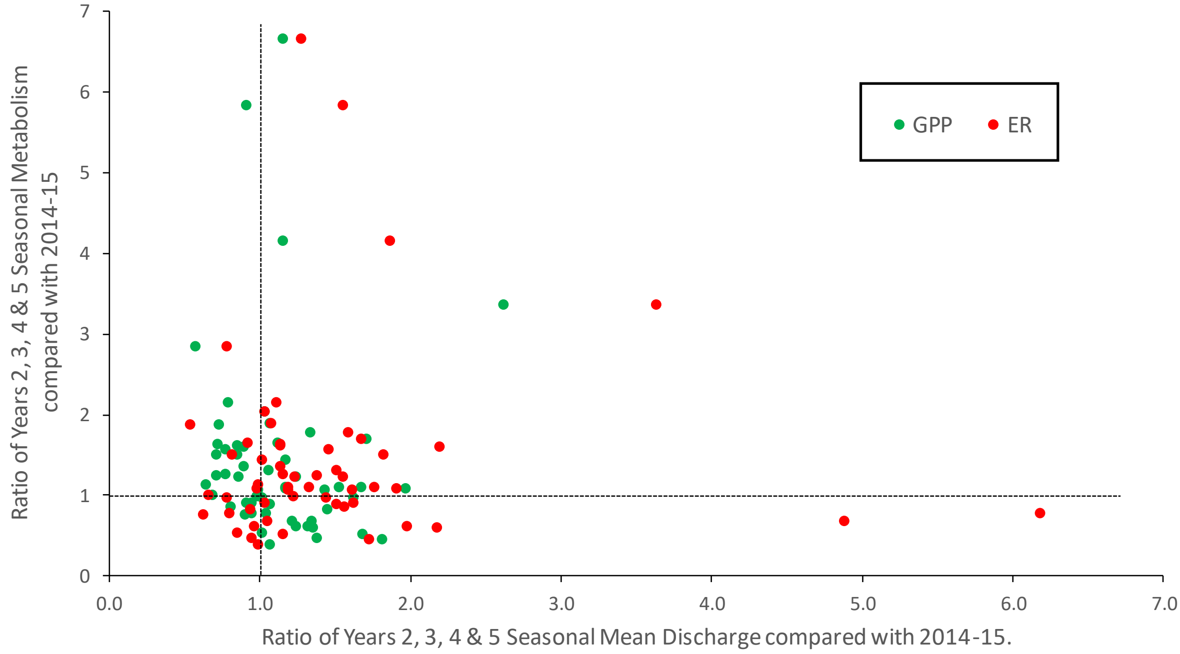


Figure 14. Relationships between mean seasonal discharge and median volumetric metabolic rates (GPP, ER) both referenced to 2014–15 values. Results are pooled across the five Selected Areas which have multiple years of data (including 2014–15). *There are not sufficient data from the Warrego-Darling Selected Area to include in this plot*.

This figure shows that there is no systematic relationship between increased mean seasonal discharge and increased rates of GPP or ER. Increased discharge in 2015–16 or 2016–17 did result in suppression of GPP in 3 instances and on one occasion for ER, but most increased seasonal mean flows yielded higher median seasonal rates of GPP and ER. Similarly, drier conditions than 2014–15 (x values < 1) also predominantly resulted in increases in GPP and ER. Although the data shown here are pooled over the five selected areas, there was no individual season or Selected Area that consistently showed enhancement of the volumetric metabolic rate with increased seasonal discharge.

3.3.3 Investigating derived metabolism parameters

The information in Figure 6 and Figure 7 can be combined to estimate the daily Net Primary Productivity (NPP, mg O_2/L/Day). The NPP reflects the balance of daily GPP and ER and indicates whether more (or less for negative values) dissolved oxygen, hence organic carbon, is being produced by photosynthesis than is being consumed by ecosystem respiration. Values for NPP are termed net autotrophic if greater than 0 and net heterotrophic if less than 0. Values around 0 indicate a likely strong link ('coupling') between the oxygen (and organic carbon) produced via primary production and consumed via ecosystem respiration. Such coupling is relatively common in pelagic systems where the contribution of the littoral and benthic zones to primary production are less important than from phytoplankton. Figure 15 shows NPP for the six Selected Areas on a seasonal basis.

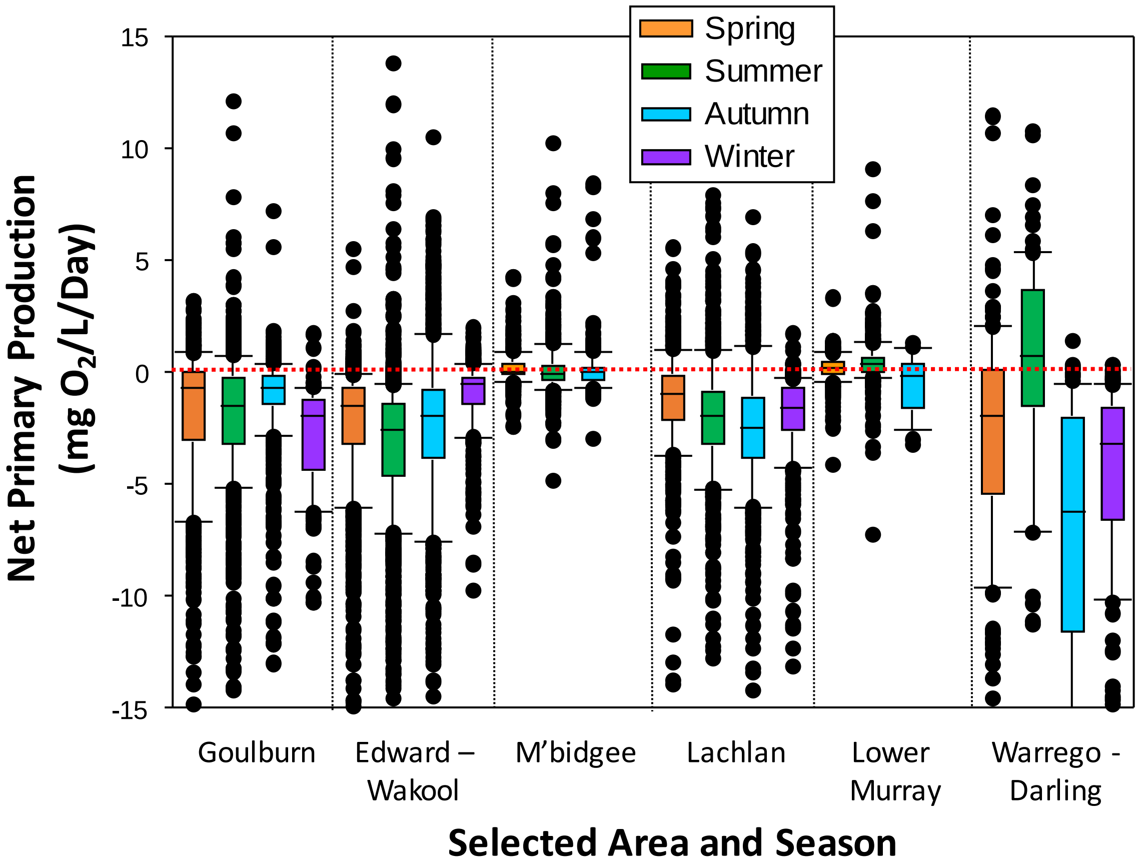


Figure 15. Seasonal Net Primary Production (mg O_2/L/Day) for each of the six Selected Areas, for all Year 1-5 metabolism data. The dotted red horizontal line marks an NPP of zero.

Figure 15 indicates that GPP and ER are closely coupled in two of the Selected Areas (Lower Murray – with the slight exception of autumn - and the Murrumbidgee), while the three smaller rivers (Goulburn, Edward-Wakool and Lachlan) and the Darling are mostly net heterotrophic, meaning ER rates are typically higher than GPP rates. One exception to this general finding of heterotrophy is the Darling River during summer. With the caveat that this finding is driven almost exclusively by data from the 2017–18 and 2018–19 years, rates of gross primary production exceeded ecosystem respiration. It is likely that warm water temperatures and high nutrient concentrations (Annex E), coupled with the very low flows in 2018–19 (Table 5) contributed to this outcome. It is likely that in the bigger south Basin rivers with typical NPP around 0, there is a tight coupling between water column primary production through phytoplankton and ecosystem respiration. In the smaller rivers, benthic respiration may be more important hence leading to net heterotrophy. As a brief example, if the respiration rate in the surface sediment layer is the same, the impact on ER in a river 2 metres deep will be only half that for a river 1 metre deep.

It is also pertinent to note that there are a large number of outliers in Figure 15 for all Selected Areas, indicating that when conditions are highly conducive for primary production, then elevated rates of GPP can arise (positive NPP rates of 5 mg O_2/L/Day and higher). Conversely, ER can also dominate at times especially in the Goulburn, Edward-Wakool, Lachlan and Warrego-Darling, with NPP rates lower than -10 mg O_2/L/Day on multiple days over the five years of record. ***Hence the perception that GPP and ER (and by extension, NPP) are constrained within fairly narrow bands is true for the majority, but definitely not all, of the time***.

3.3.4 Responses in stream metabolism to flow events

Given both the size of the growing metabolism data set (now five years) and within that set, the substantially higher number of data days that meet the acceptance criteria, responses of GPP and ER to stream discharge can now be evaluated (also see Section 3.3.5 below). In addition, the specific impacts of water introduced as CEW can also be assessed (see Section 3.3.6).

As a starting point, the relationship between the stage heights as defined in Figure 3 (plus accompanying text) and the pooled GPP, ER and NPP from all sites, again stratified by season, are displayed in Figure 16, Figure 17 and Figure 18 respectively. By necessity the data used to create these figures and all figures and tables looking at effects of flow delineated into these arbitrary flow bands are restricted to those fourteen sites where the thresholds are available (Table 3).

The summary statistics of the data used to develop these three figures are found in Annex F. While such pooling of data across Selected Areas will mostly reflect the Areas with the greatest amount of data, it is still illustrative to view the data in its entirety, especially given that patterns are evident, as described below the figures).

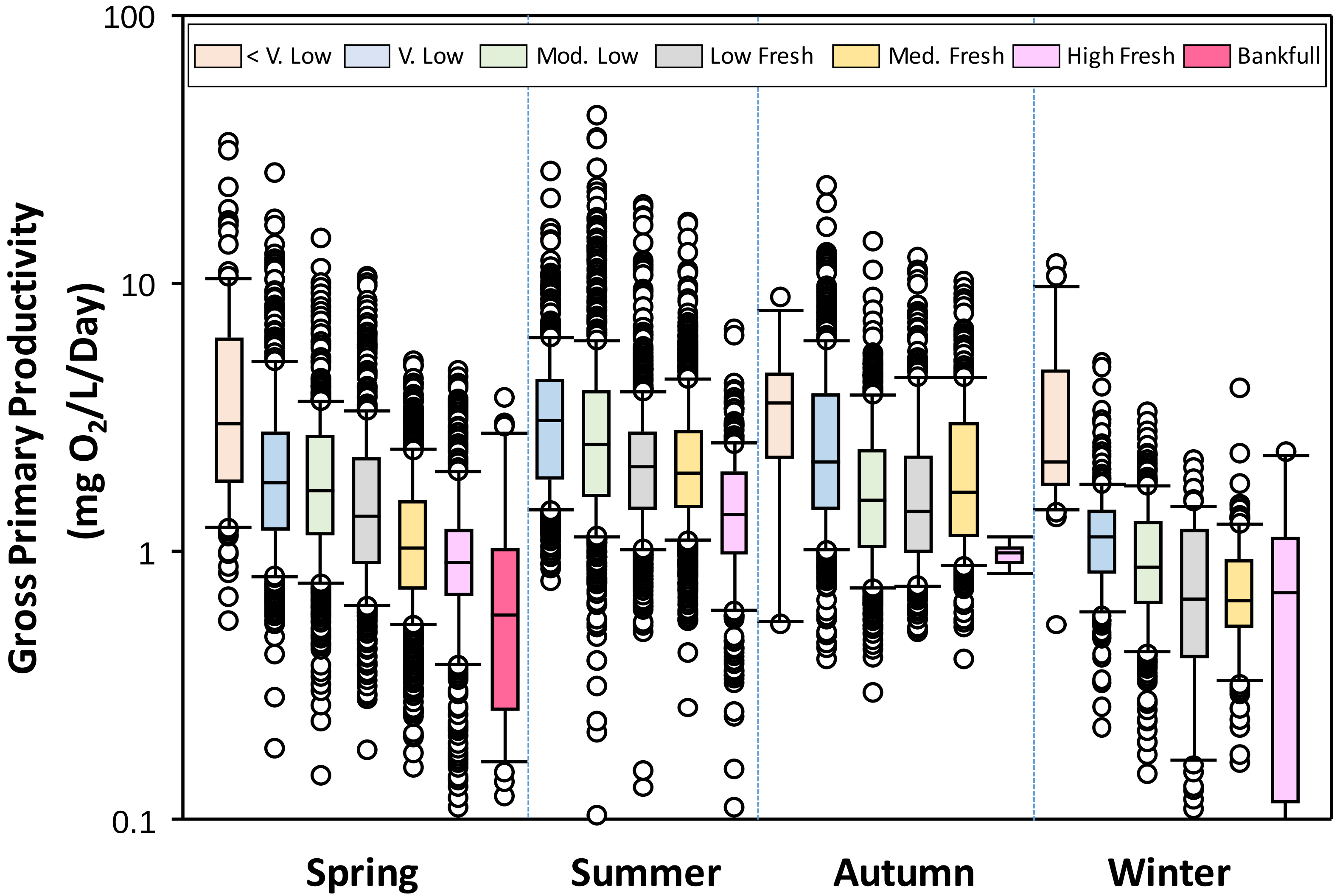


Figure 16. Relationship between flow category according to hydrographic stage height and Gross Primary Production (mg O_2/L/Day). All sites are pooled but the data is stratified by season. Categories are defined as per Figure 3 and accompanying text. Note the exponential Y-axis scale.

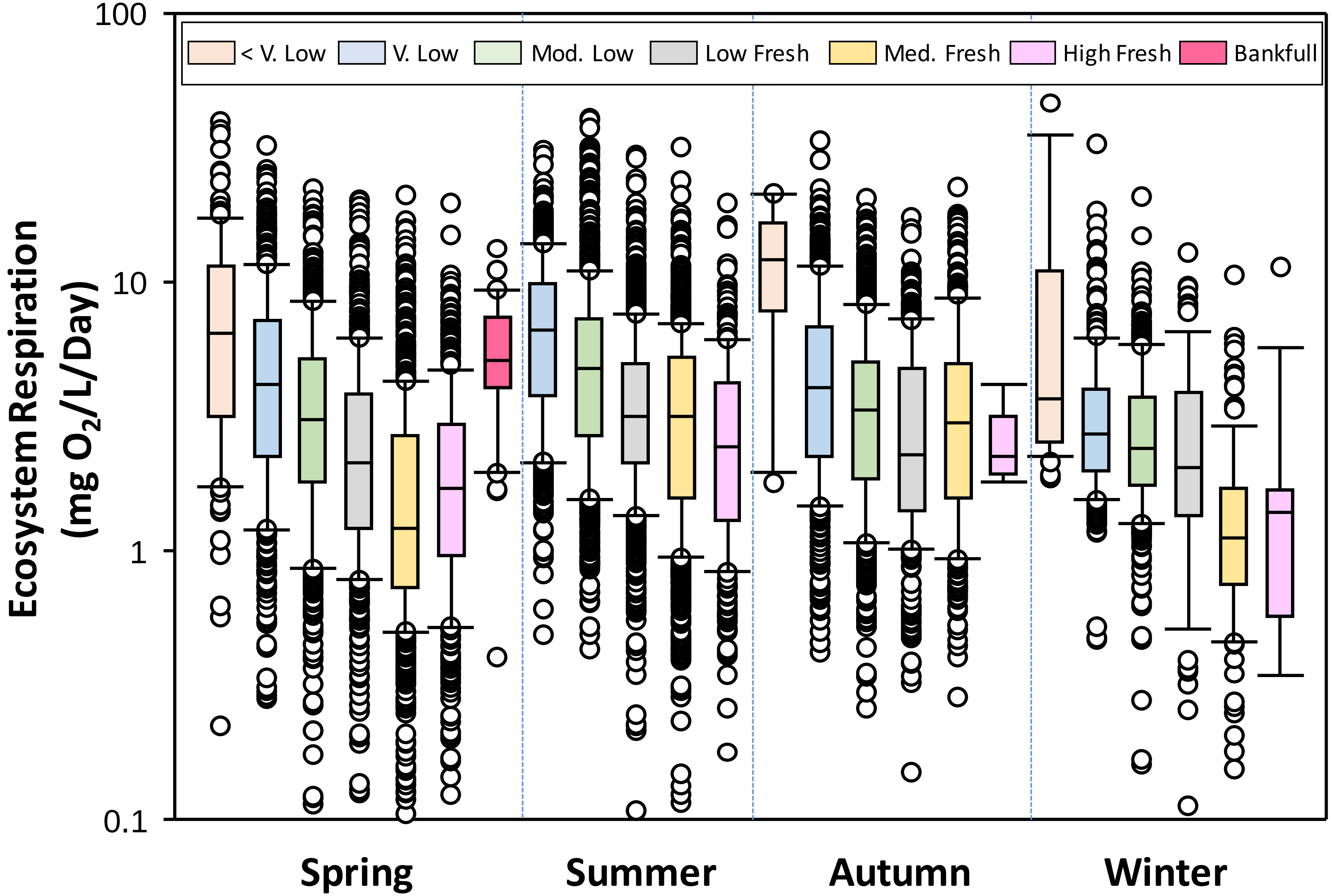


Figure 17. Relationship between flow category according to hydrographic stage height and Ecosystem Respiration (mg O_2/L/Day). All sites are pooled but the data is stratified by season. Categories are defined as per Figure 3 and accompanying text. Note the exponential Y-axis scale.

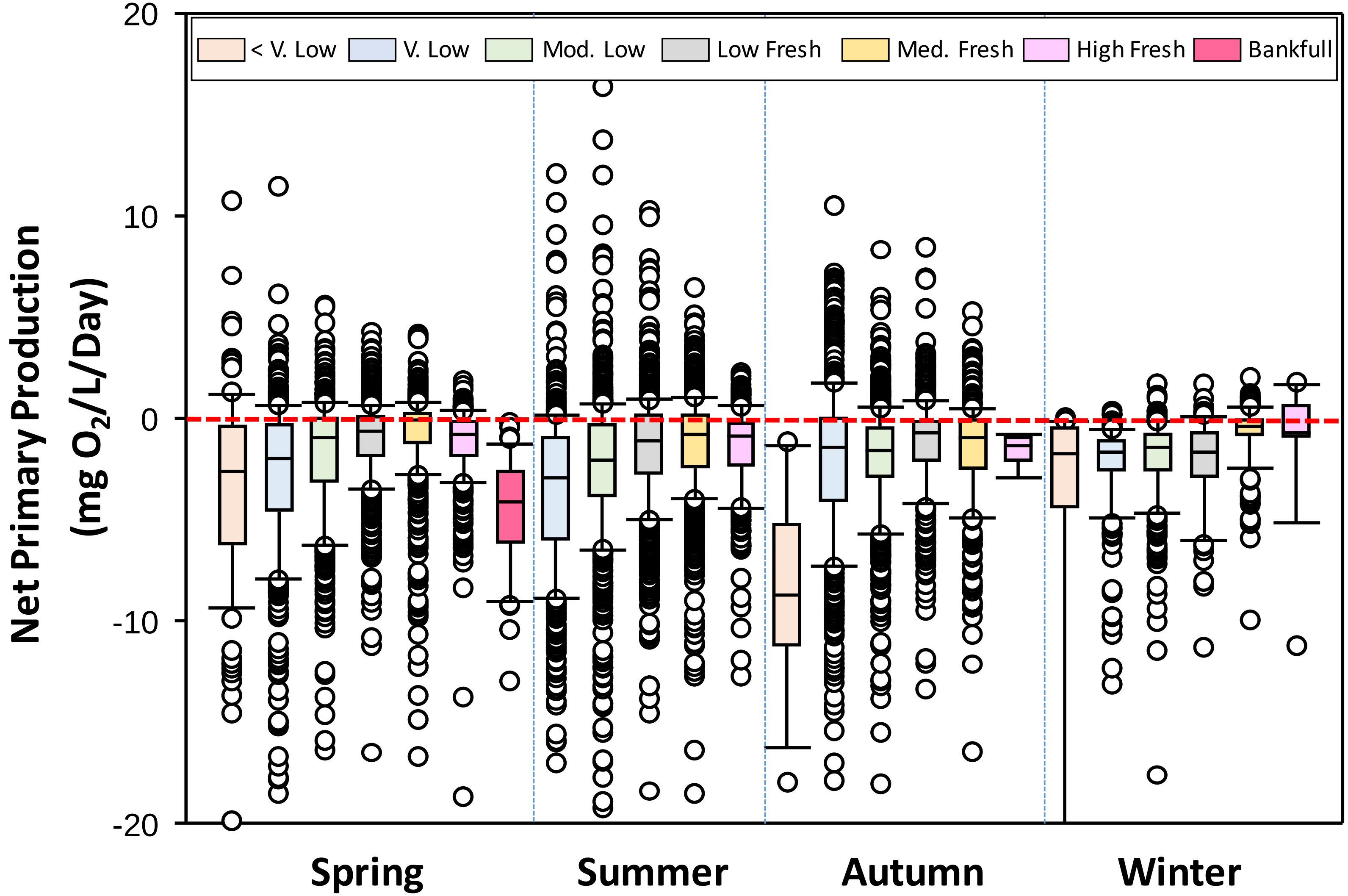


Figure 18. Relationship between flow category according to hydrographic stage height and Net Primary Production (mg O_2/L/Day). All sites are pooled but the data is stratified by season. Categories are defined as per Figure 3 and accompanying text. The dotted red horizontal line marks an NPP of zero.

Figure 16 shows that compared to the very low flow ('baseflow') category, the rates of GPP pooled across all six selected Areas are diminishing with increasing discharge. Similarly, Figure 17 shows that compared to the very low flow category, and with the exception of springtime bankfull flows, ER rates, again pooled across all six selected Areas also diminished with increasing discharge. Due to the Y-axis being on an exponential rather than linear scale, some of these differences are much more subtle than they may appear, primarily when the median data centres around 1 mg O_2/L/Day. The most prominent example is GPP rates in winter time, where the decrease with flow is clearly evident in Figure 16 yet this represents a drop from a median rate of 1.21 mg O_2/L/Day under Very Low Flow to 0.81 mg O_2/L/Day under High Fresh discharges.

Apart from a zero NPP wintertime rate for high fresh events, all other median NPP rates were negative (Figure 18), indicating that ER is the dominant process, which is extremely common in most Australian (and international) streams most of the time. Comparison with the NPP plot (Figure 15) which showed some positive NPP for some seasons in some of the Selected Areas, the cause of the uniform negative NPP here is the dominant effect that Selected Areas with the most data (Goulburn, Edward-Wakool, Lachlan; Table 4) have on the combined data set. All three of these Selected Areas have negative median GPPs across all seasons (Figure 15 and Table D5, Annex D).

It is stressed that these changes in metabolic rates are relatively small and are typically due to the initial depression of metabolic rates expressed as mg O_2/L/Day by dilution on the rising hydrograph. As noted earlier, the volumetric metabolic rates in the LTIM project almost universally show declines with increasing flow, with the exception being some very small flow increases in the Lachlan River, when volumetric rates increased. As metabolic rates are generally higher in spring and summer, then dilution by a flow event results in a larger decline in volumetric rates.

3.3.5 Responses in daily organic carbon loads to increases in flow

In the Year 3 Basin Level Evaluation Report (Grace 2018), several new, 'derived' metabolism metrics were investigated. In the Year 4 report (Grace 2019a), one of these parameters, the daily organic carbon load produced (by GPP) or consumed (by ER), was further scrutinized and these findings are updated here using the full five-year data set. The daily organic carbon loads are calculated from the analogous oxygen load data, by multiplying by 12/32, the molar ratio of carbon to oxygen gas (O_2). In particular, this section of the report will determine how stream flow affects the organic carbon load. As noted above, flow is divided into arbitrary categories as shown in Figure 3 and the accompanying text with threshold values taken from Table 3. One important note is that this analysis only uses a subset of the full metabolism data set; the restriction is that only 14 sites have defined thresholds, but all Selected Areas are covered by at least two sites.

The flow category dependence of the daily organic carbon load produced by GPP is illustrated in Figure 19 (Goulburn and Edward-Wakool Selected Areas), Figure 20 (Lachlan and Murrumbidgee Selected Areas) and Figure 21 (Lower Murray and Warrego-Darling Selected Areas). In several cases there was insufficient data to reliably characterize "Bankfull" flows, so these few data are excluded from each plot. Similarly, apart from the two sites on the Darling River (Akuna and Yanda) there was almost no other data from the "< Very Low Flow" category from the other 5 Selected Areas so this category was also omitted from these plots. Figure 22, Figure 23 and Figure 24 are the analogous plots showing the daily organic carbon load consumed by ER across the six Selected Areas.

The effect of flow category on metabolism on the daily loads of organic carbon produced and consumed is very clearly illustrated in all of these six figures.

As first noted in the Year 3 Basin Evaluation (Grace 2018), and now much more clearly shown with the addition of two extra year's data, the dilution effect of increased water (causing the apparent suppression of GPP and ER on a per litre basis, shown above in Figure 16 and Figure 17) is smaller than the overall increase in organic carbon being produced or consumed that day. i.e. even though there is less metabolism per litre, there are many more litres of water, so the overall effect is much more organic carbon produced or consumed. This effect is clearly observed for GPP in four of the six Selected Areas across all three (Murrumbidgee, Lower Murray) or four seasons (Lachlan, Edward-Wakool) and flow categories. Summer GPP organic carbon loads in the Goulburn are a little more equivocal with very similar median rates for the very low and moderately low flow categories although there is then an increase in organic carbon load created when discharge increases to the low fresh category. Unlike the other four southern Basin Selected Areas, there was no additional organic carbon created by flow increases in the Goulburn River during winter.

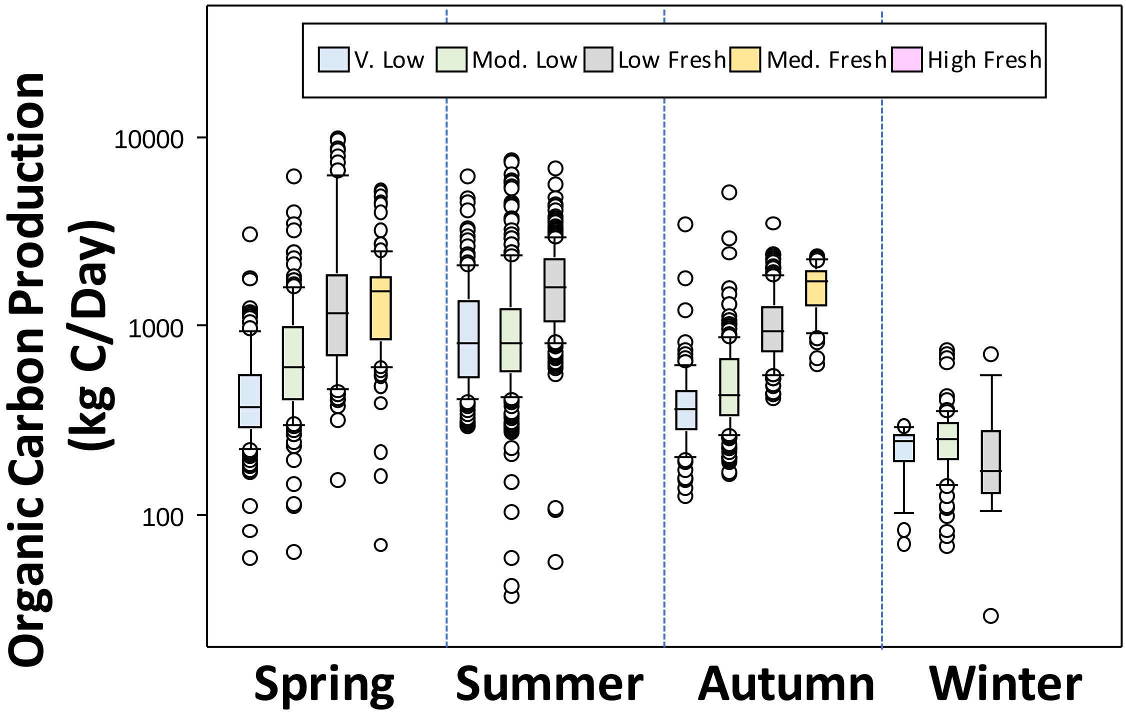
Similar trends are observed with the organic carbon loads being consumed by ER, although the patterns are not as strong in some cases. For example, the Lachlan River (Figure 23) showed strong increases with increasing discharge (with the exception of Medium Fresh in winter), but in the Edward-Wakool (Figure 22) once discharge reached Low Fresh, then further increases did not result in higher organic carbon load and in winter there was no effect of discharge on median load at all.

There is still insufficient data at this stage to make any compelling conclusion about organic carbon loads in the Darling River (Figure 21 and Figure 24), as almost all data meeting the acceptance criteria from the two sites at Yanda and Akuna are under the < Very Low and Very Low flow categories. The distribution of metabolic rates within the < Very Low flow category in particular is extremely wide, largely due to extant no flow conditions prevailing for much of 2018–19. It is expected that the Darling River will behave similarly to the five southern Basin Selected Areas described here in that organic carbon loads will increase with increasing discharge. A major caveat here is that the source of the extra flow will likely have a major impact on the extent of increase in organic carbon loads: if most of the additional water is flowing down the Culgoa River from southern Queensland, then GPP is likely to be significantly suppressed by the extremely high turbidity associated with this river; conversely, if the majority of the new inflow is from the Bogan system flowing northwards into the Darling, then this will bring much (relatively) clearer water and the potential for higher primary production; finally if the increased flows are coming down the main channel of the Barwon River and all its tributaries, then turbidity and nutrient levels in the Darling should remain relatively constant and result in the expected organic carbon load increases (Oliver et al., 1999). The Culgoa and Bogan Rivers join the Barwon to form the Darling just upstream of Bourke and the Yanda sampling site a little way downstream.

It is a very reasonable question to ask whether there is any ecological benefit to a higher GPP when the system is net heterotrophic (more breakdown of organic matter by ER than new organic matter being created by GPP, as shown above in Figure 18). So 'Isn't all the new organic carbon created simply being respired?'. The answer to that is an emphatic 'no'. In a study examining this specific question, Hall and Beaulieu (2013), estimated that on average about 44% of new organic carbon created by GPP is then rapidly respired by microbial communities in close proximity to, or in the case of biofilms within the matrix of, the primary producers. Hence over half of this new organic carbon is used for cellular growth and thus a food resource for higher consumers. The rest of the organic carbon being consumed by ER is coming from carbon already present in the waterway at that time – from upstream transport, from wash-in of benches and banks, from litter fall from riparian vegetation, from plant and animal detritus and from organic matter stores in the surface sediments (e.g. Robertson *et al*., 2016).

Overall, this study is ***very*** **strong and** ***compelling*** **evidence that increases in discharge (via natural flows or watering events) which remain in the river channel can still have major benefits for organic carbon (hence energy supply) at the base of the food web. CEW that enhances discharge will therefore provide environmental benefit.**

a) Goulburn



b) Edward-Wakool

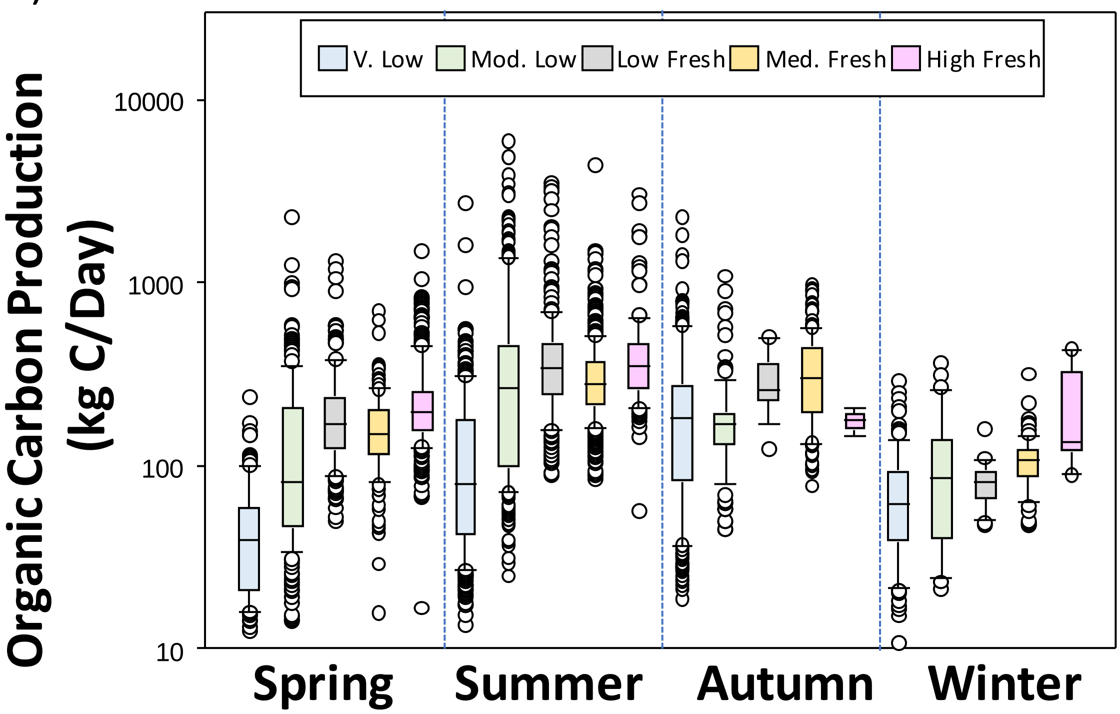


Figure 19. Relationship between flow category according to hydrographic stage height and organic carbon production, stratified by season, for a) Goulburn and b) Edward-Wakool Selected Areas, for pooled Year 1-5 metabolism data. Flow categories are defined as per Figure 3 and accompanying text. Note the exponential Y-axis scale.

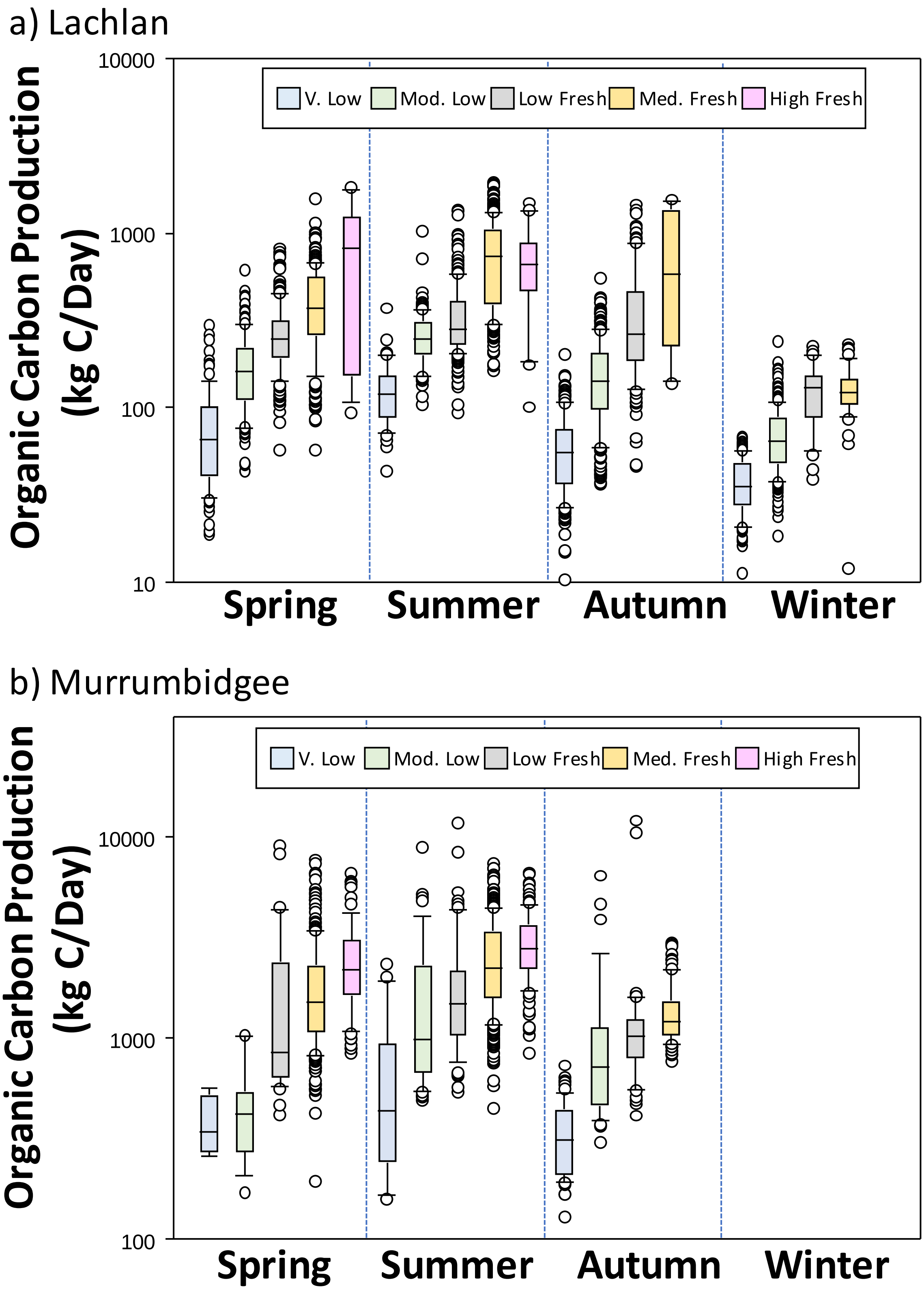


Figure 20. Relationship between flow category according to hydrographic stage height and organic carbon production, stratified by season, for a) Lachlan and b) Murrumbidgee Selected Areas, for pooled Year 1-5 metabolism data. Flow categories are defined as per Figure 3 and accompanying text. There was no winter-time data collected for the Murrumbidgee Selected Area. Note the exponential Y-axis scale.

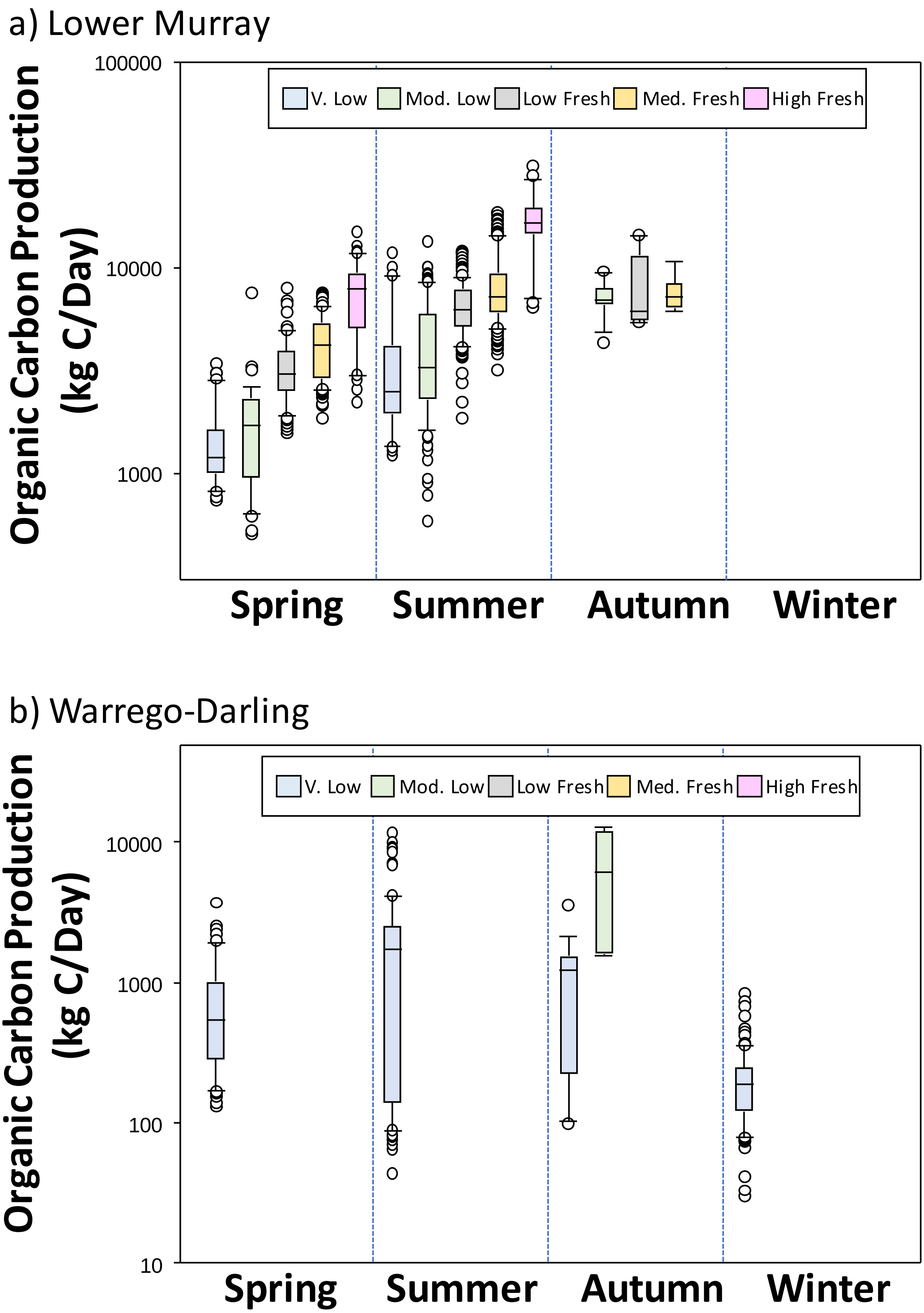
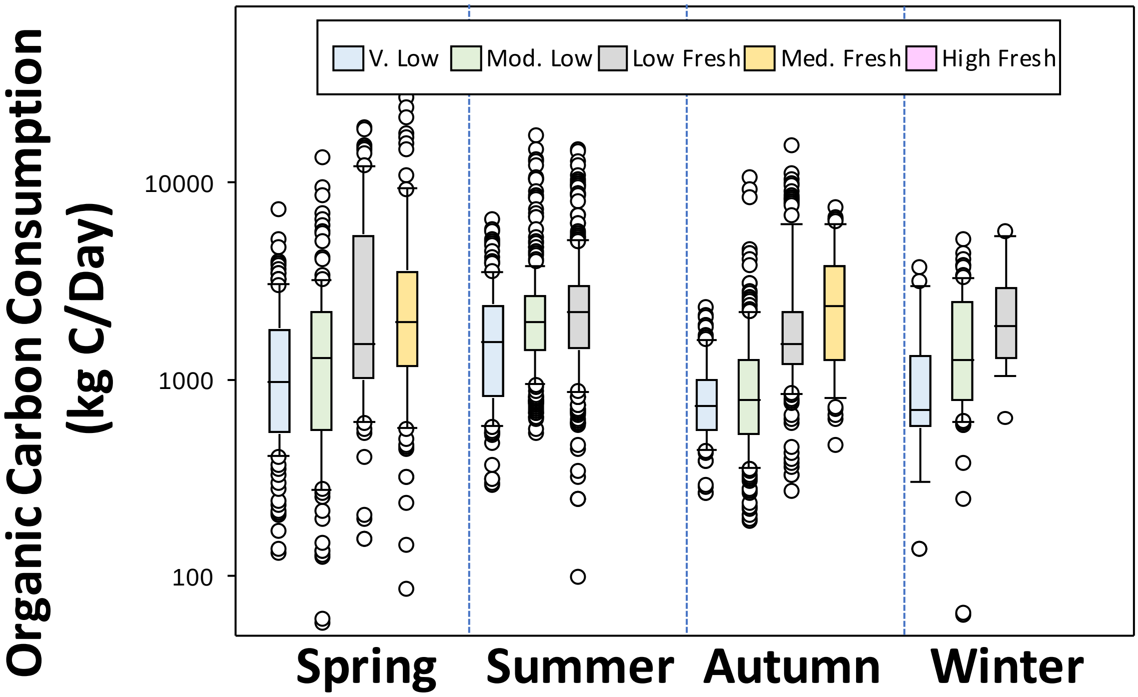


Figure 21. Relationship between flow category according to hydrographic stage height and organic carbon production, stratified by season, for a) Lower Murray and b) Warrego-Darling Selected Areas, for pooled Year 1-5 metabolism data. Flow categories are defined as per Figure 3 and accompanying text. There was no winter-time data collected for the Lower Murray Selected Area. Note the exponential Y-axis scale.

a) Goulburn



b) Edward-Wakool

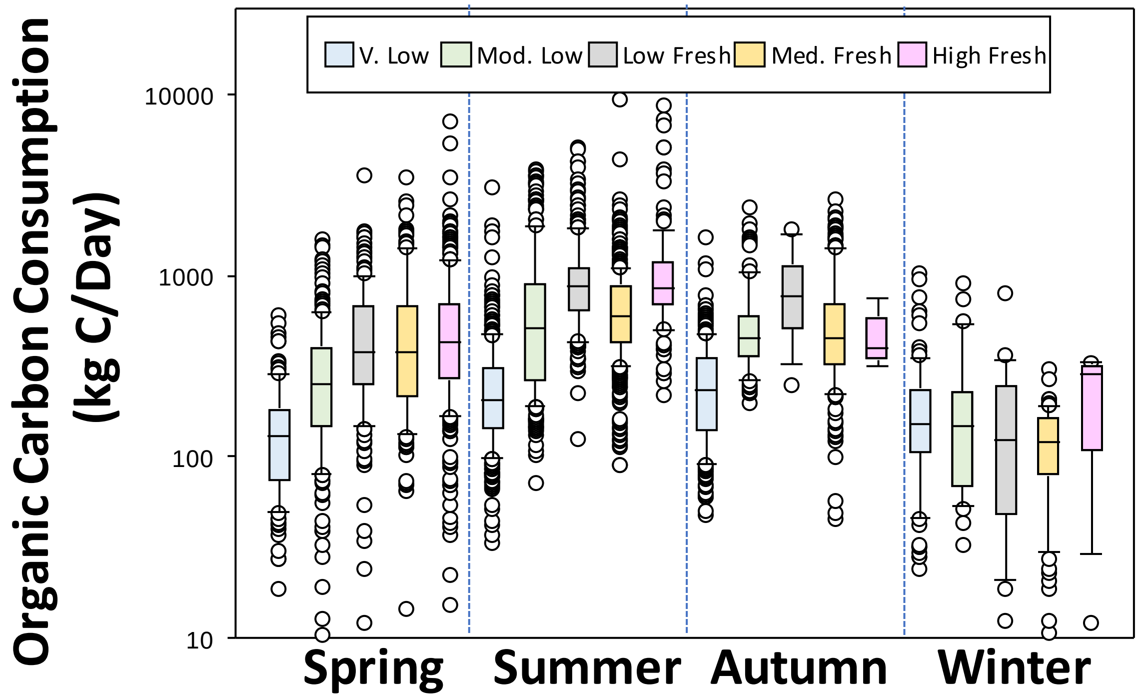
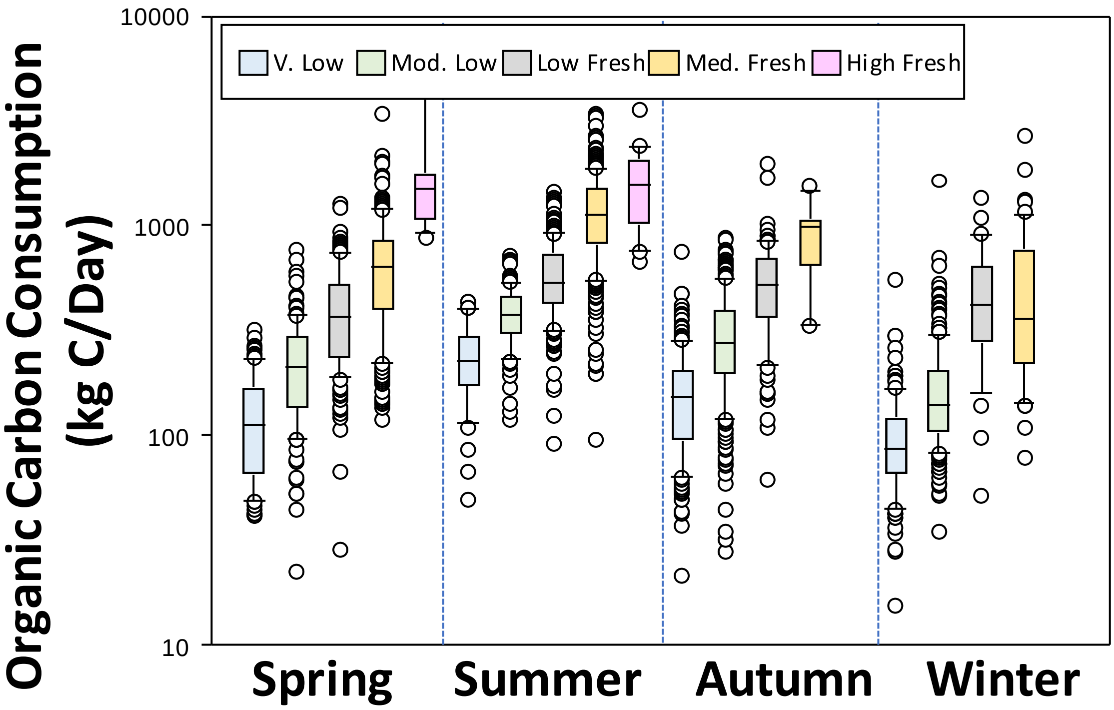


Figure 22. Relationship between flow category according to hydrographic stage height and organic carbon consumption, stratified by season, for a) Goulburn and b) Edward-Wakool Selected Areas, for pooled Year 1-5 metabolism data. Flow categories are defined as per Figure 3 and accompanying text. Note the exponential Y-axis scale.

a) Lachlan



b) Murrumbidgee

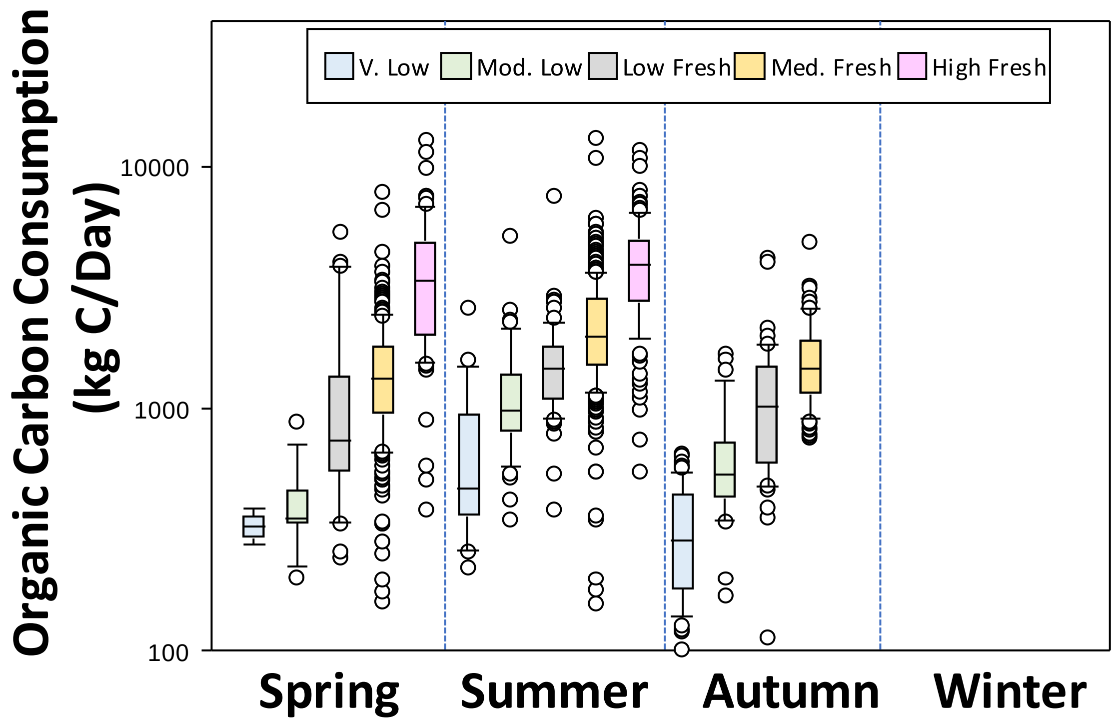
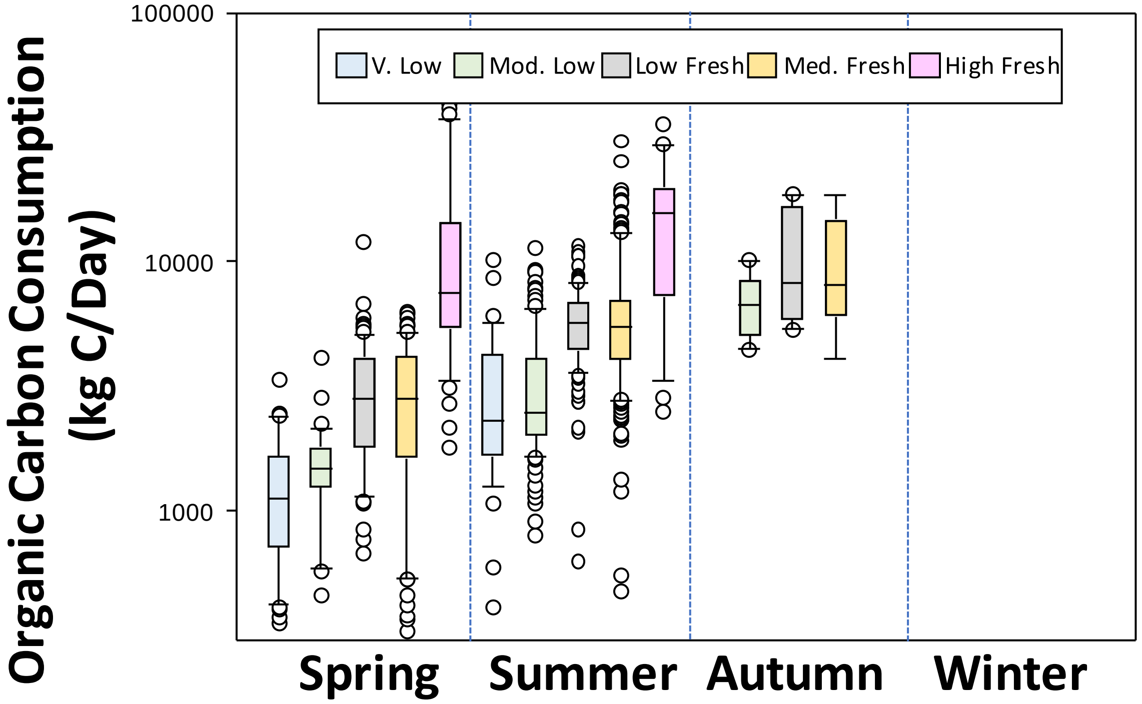


Figure 23. Relationship between flow category according to hydrographic stage height and organic carbon consumption, stratified by season, for a) Lachlan and b) Murrumbidgee Selected Areas, for pooled Year 1-5 metabolism data. Flow categories are defined as per Figure 3 and accompanying text. There was no winter-time data collected for the Murrumbidgee Selected Area. Note the exponential Y-axis scale.

a) Lower Murray



b) Warrego-Darling

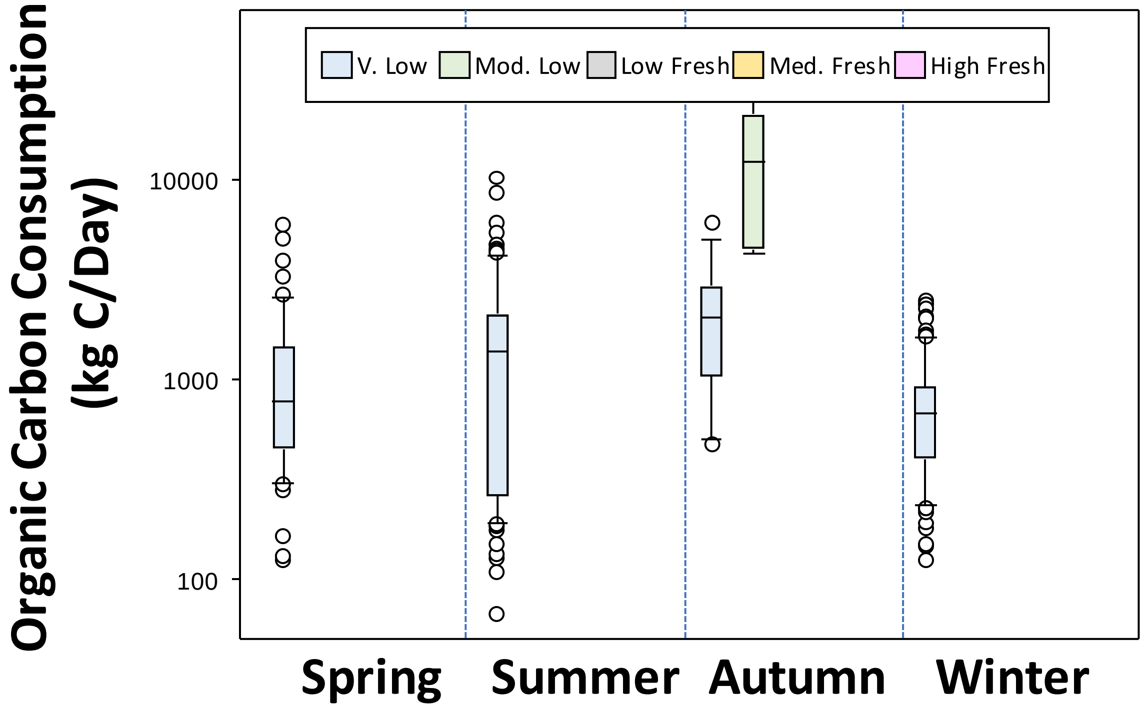


Figure 24. Relationship between flow category according to hydrographic stage height and organic carbon production, stratified by season, for a) Lower Murray and b) Warrego-Darling Selected Areas, for pooled Year 1-5 metabolism data. Flow categories are defined as per Figure 3 and accompanying text. There was no winter-time data collected for the Lower Murray Selected Area. Note the exponential Y-axis scale.

The previous six figures clearly showed that, in general, higher flows induced greater production (and consumption) of organic carbon in the water flowing past the monitoring point each day, irrespective of location and season. Even when a proportion of the organic carbon produced is nearly immediately lost again through respiration, this finding demonstrates that increase discharge will lead to a higher food resource availability for consumers further up the food web. It may be the case that the limited recruitment of golden perch during the LTIM project may be due to a lack of sufficient 'food'. It is pertinent to note though, that this 'more food production', a very beneficial outcome if say fish growth is limited by food resources as hypothesized above, does not take into account any changed degree of food uptake induced by such flow changes. One example of this would be that higher flows are generally associated with faster water velocities, hence at any one physical point in the stream, the 'food' suspended in the water column will be flowing past much more quickly. In addition, there will be less organic carbon food per litre of water, hence supply is more dilute. These matters are well beyond the scope of this report but are important considerations when tailoring flow patterns to obtain optimal outcomes in terms of this 'food' production.

Results of modelling of the relationship between stream flow category and the additional amount of organic carbon produced are presented in Table 6 and organic carbon consumed in Table 7, which both use the full five-year data set from the Goulburn River Selected Area as an exemplar. Results for the other Selected Areas are presented in Annex G. The final column in the table shows the percentage of extra organic carbon load created (or consumed), based on the median values, as the river moves from one flow category to the next higher category e.g. through introduction of CEW. A value of 100 indicates no change whereas a value of 200 indicates a doubling of the amount of organic carbon. Values less than 100 (highlighted in red) show a decrease in the amount of organic carbon load.

Table 6. Organic Carbon Loads (kg org C/Day) Produced in the combined Goulburn River Selected Area sites by GPP, stratified by season and nominal flow category.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low									
	Very Low	143	491	31	59	3090	368	285	548	
	Moderately Low	131	863	70	64	6232	611	400	1003	166
	Low Fresh	83	2036	255	152	9925	1166	694	1886	191
	Medium Fresh	103	1544	97	69	5257	1528	835	1828	131
	High Fresh	2	1549							
	Bankfull									
Summer	< Very Low									
	Very Low	138	1121	79	293	6163	811	535	1372	
	Moderately Low	289	1210	74	37	7528	811	563	1240	100
	Low Fresh	282	1756	54	56	6920	1593	1062	2312	196
	Medium Fresh	3	1031							
	High Fresh	1	353							
	Bankfull									
Autumn	< Very Low									
	Very Low	93	430	40	125	3478	360	280	453	
	Moderately Low	211	555	32	165	5070	427	329	667	119
	Low Fresh	162	1070	40	412	3508	932	735	1286	218
	Medium Fresh	55	1634	63	634	2346	1742	1261	1989	187
	High Fresh									
	Bankfull									
Winter	< Very Low									
	Very Low	29	220	13	70	295	245	191	268	
	Moderately Low	91	264	12	68	735	251	196	306	102
	Low Fresh	18	226	39	29	707	171	130	278	68
	Medium Fresh	5	199							
	High Fresh	2	136							
	Bankfull									

Table 7. Organic Carbon Loads (kg org C/Day) Consumed in the Goulburn River Selected Area sites by ER, stratified by season and nominal flow category.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low									
	Very Low	143	1380	98	132	7300	979	533	1819	
	Moderately Low	131	1756	170	31	13449	1290	549	2204	132
	Low Fresh	83	4007	530	154	19332	1510	1000	5452	117
	Medium Fresh	103	3918	581	86	36069	1978	1167	3588	131
	High Fresh	2	1155							
	Bankfull									
Summer	< Very Low									
	Very Low	138	1801	108	291	6553	1537	814	2401	
	Moderately Low	289	2520	134	534	17574	1962	1405	2669	128
	Low Fresh	282	2728	138	99	14873	2204	1427	3013	112
	Medium Fresh	3	2886							
	High Fresh	1	16658							
	Bankfull									
Autumn	< Very Low									
	Very Low	93	847	46	262	2325	736	549	994	
	Moderately Low	211	1138	88	192	10672	791	524	1256	107
	Low Fresh	162	2324	194	270	15741	1499	1197	2218	190
	Medium Fresh	55	2781	248	469	7454	2361	1248	3826	157
	High Fresh									
	Bankfull									
Winter	< Very Low									
	Very Low	29	1108	172	138	3727	696	570	1321	
	Moderately Low	91	1691	116	63	5148	1266	791	2479	182
	Low Fresh	18	2328	335	637	5680	1858	1282	2936	147
	Medium Fresh	5	4160							
	High Fresh	2	2070							
	Bankfull									

Examination of Table 6 shows that throughout the year, all increases in discharge lead to higher amounts of organic carbon being created in the water flowing past the monitoring point each day (as previously illustrated in Figure 19a), with the exception of a 32% decline when moving up to low freshes in winter, when the dilution effect of extra water is the major impact on load. Actual loads changes are calculated in these tables, for example, in spring, increasing the flow from the very low flow category to the moderately low category increases the median amount of organic carbon produced by GPP by a factor of 1.66, an extra 243 kg of Organic Carbon per day (from 368 kg org C/Day to 611 kg/ Day). In terms of the highest spring time increase in organic carbon production, raising the Goulburn River from moderately low flow to low fresh gives the best numerical outcome (an increase of 555 kg org C/Day), even higher than the low fresh to medium fresh transition (555 kg org C/Day). *The ecological importance of the timing of increased carbon production also must be* *considered. When is the optimal time to create 'more food' at the base of the food web?* This will clearly require integration with other aspects of the LTIM project, most notably the fish component.

The amount of water available to the CEWO for release, and the ability to do so with other operational and availability constraints is also clearly of great importance.

The percentage increase in median daily organic carbon load when discharge moves from one flow category up to the next was presented in the final column of each of.Table 6 and Table 7 using the Goulburn River as the exemplar for the full data set. Table 8 presents this final organic carbon load increase for all six of the Selected Areas with respect to GPP and organic carbon production, based again on median rates of GPP in each flow category. Similarly, Table 9 displays the comparable data from organic carbon load consumption by ER. As noted above, the data for these two tables from the other five Selected Areas are drawn from the tables shown in Annex G.

There are 66 individual data entries in each of Table 8 and Table 9, representing changes to organic carbon loads upon increase in flow from one nominal category to the next higher level as defined in Table 3. Of these 66 GPP load changes, only 9 are decreases, of which only 5 have loads less than 90% of the preceding category (three of which are in the Edward-Wakool Selected Area). Six of the 66 values fall in the range 90-110% which can be considered unchanged within the uncertainties of each constituent number making up the ratio. Thus 55 (or 83%) of cases demonstrate a greater than 10% increase in organic carbon load created by GPP from increasing the discharge to the next higher nominal category.

From Table 9, there are 8 instances of values for organic carbon consumption change on increasing discharge category of less than 100%, and as above, five of these are below 90%. All but one of these five are within the Edward-Wakool Selected Area but not dominated by any specific transition (e.g. low fresh to medium fresh). Ten values could be considered 'no significant change' (90-110%) and 51 of the 66 (77%) indicate a strong increase in organic carbon loading with increasing flow category.

There are several important points that can be drawn from these details:

i) Most of the time (around 80% on average), a flow increase from one nominal category to the next higher level will result in a significant increase in daily organic carbon loading from either production (GPP) or consumption (ER).

ii) There is no consistent trend across Selected Areas within each season. For example, the low fresh to medium fresh transition results in a load suppression (down to 82%) for the Edward-Wakool Selected Area in summer, yet this same transition yields the highest summertime increase of all transitions in the Lachlan (260%). Thus using this information for flow delivery (e.g. from CEW) will definitely require local information, rather than using a 'non-existent' Basin-wide set of figures.

iii) Despite the previous point, during **spring and summer** (arguably the most important times for extra food resources to become available), in all five Selected Areas with the appropriate data (so excluding the Warrego-Darling), **increasing discharge from very low to moderately low, or moderately low to low fresh always resulted in an increase in organic carbon loads.** Results for higher discharge levels and in autumn and winter were more idiosyncratic.

iv) The extremely high apparent increases from < very low to very low flow categories in the two Darling River sites are an artefact of the extremely low (sometime no) flow for extended periods, especially in Year 5. Hence no particular significance is drawn from these very large ratios.

Table 8. Summary of Percentage Increases in Organic Carbon Loads (kg org C/Day) Produced in all Selected Area sites by GPP, as flow increases by category, stratified by season. Basin names are from Table 2. Red numbers highlight when decreases in organic carbon load have occurred.

Season	Flow Category	GLB	EWK	LCH	MBG	LWM	BDL
Spring	< Very Low						
	Very Low						905
	Moderately Low	166	203	244	123	142	
	Low Fresh	191	209	154	201	177	
	Medium Fresh	131	88	152	177	139	
	High Fresh		134	221	146	188	
	Bankfull		514	371			
Summer	< Very Low						
	Very Low						
	Moderately Low	100	329	210	228	131	
	Low Fresh	196	128	114	149	194	
	Medium Fresh		82	260	152	114	
	High Fresh		125	91	124	228	
	Bankfull						
Autumn	< Very Low						
	Very Low						
	Moderately Low	119	93	255	230		509
	Low Fresh	218	155	184	143	88	
	Medium Fresh	187	116	224	116	118	
	High Fresh		58				
	Bankfull						
Winter	< Very Low						
	Very Low						543
	Moderately Low	102	137	184			
	Low Fresh	68	95	202			
	Medium Fresh		131	93			
	High Fresh		127				
	Bankfull						

Table 9. Summary of Percentage Increases in Organic Carbon Loads (kg org C/Day) Consumed in all Selected Area sites by ER, as flow increases by category, stratified by season. Basin names are from Table 2. Red numbers highlight when decreases in organic carbon load have occurred.

Season	Flow Category	GLB	EWK	LCH	MBG	LWM	BDL
Spring	< Very Low						
	Very Low						587
	Moderately Low	132	194	192	109	133	
	Low Fresh	117	151	172	208	188	
	Medium Fresh	131	101	173	182	101	
	High Fresh		113	234	254	266	
	Bankfull		2134	713			
Summer	< Very Low						
	Very Low						
	Moderately Low	128	246	166	211	108	
	Low Fresh	112	172	142	149	227	
	Medium Fresh		69	212	136	97	
	High Fresh		144	140	197	285	
	Bankfull						
Autumn	< Very Low						
	Very Low						
	Moderately Low	107	191	183	188		591
	Low Fresh	190	173	189	192	122	
	Medium Fresh	157	59	188	141	98	
	High Fresh		86				
	Bankfull						
Winter	< Very Low						
	Very Low						501
	Moderately Low	182	96	164			
	Low Fresh	147	84	298			
	Medium Fresh		97	86			
	High Fresh		238				
	Bankfull						

3.3.6 Responses in stream metabolism to the proportion of flow from Commonwealth environmental water

The Year 4 Basin Level Evaluation report (Grace 2019a) clearly demonstrated that **there is no consistent detriment (or advantage) to the amount of organic carbon produced by GPP each day by increasing the proportion of discharge coming from CEW rather than any other water source** (or rainfall) i.e. the source of this water generally does not matter. In general, the supply of CEW from different sources at different times, seems not to have a systematic effect on metabolism and contributes to metabolic changes in the same way as other typical flow sources. Hence this analysis will not be repeated here, although the bottom panels of Figure 25 (GPP) and Figure 26 (ER) for the Lachlan River Selected Area are reproduced here to emphasize this finding. These two figures plot the seasonally-stratified GPP rates as a proportion of the discharge originating from CEW. Hence the pink boxes mean that between 75 and 100% of the discharge was made up of CEW.

In essence it is the **increase in the total volume of discharge that is highly beneficial for creating organic carbon biomass as a food resource for the aquatic ecosystem** rather than from where this additional water came. This very important but general finding can be varied at specific sites and river reaches in the Basin. The example given in previous years that release of clear water from Copeton Dam may have additional effects due to changing the physicochemical nature of the water downstream (in this case reducing the turbidity) is still valid.

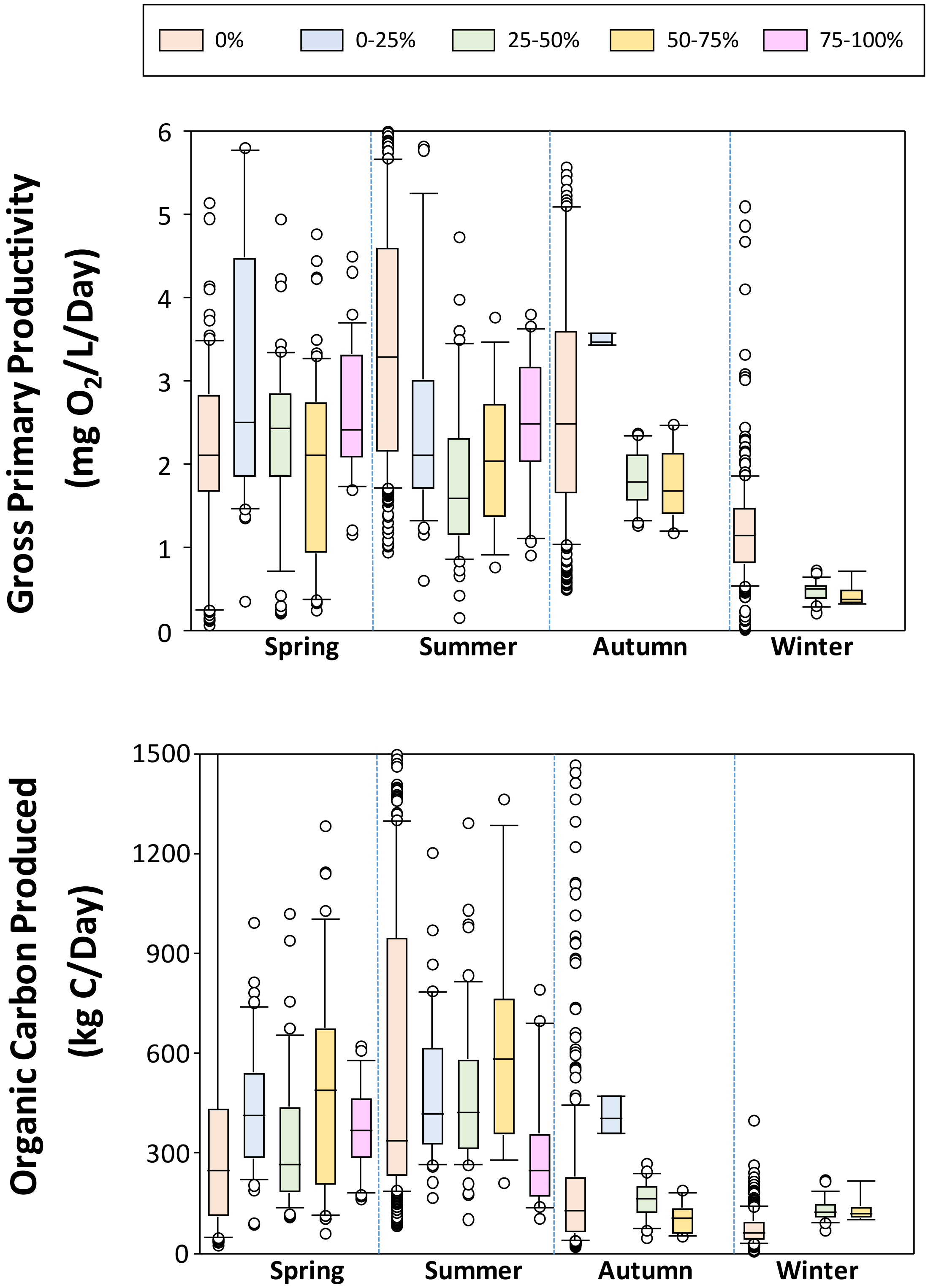


Figure 25. Box plots of GPP (top) and the Organic Carbon Load Produced (bottom) from the Lachlan Selected Area vs the percentage of discharge made up by CEW, stratified by season, for all Year 1-4 metabolism data.

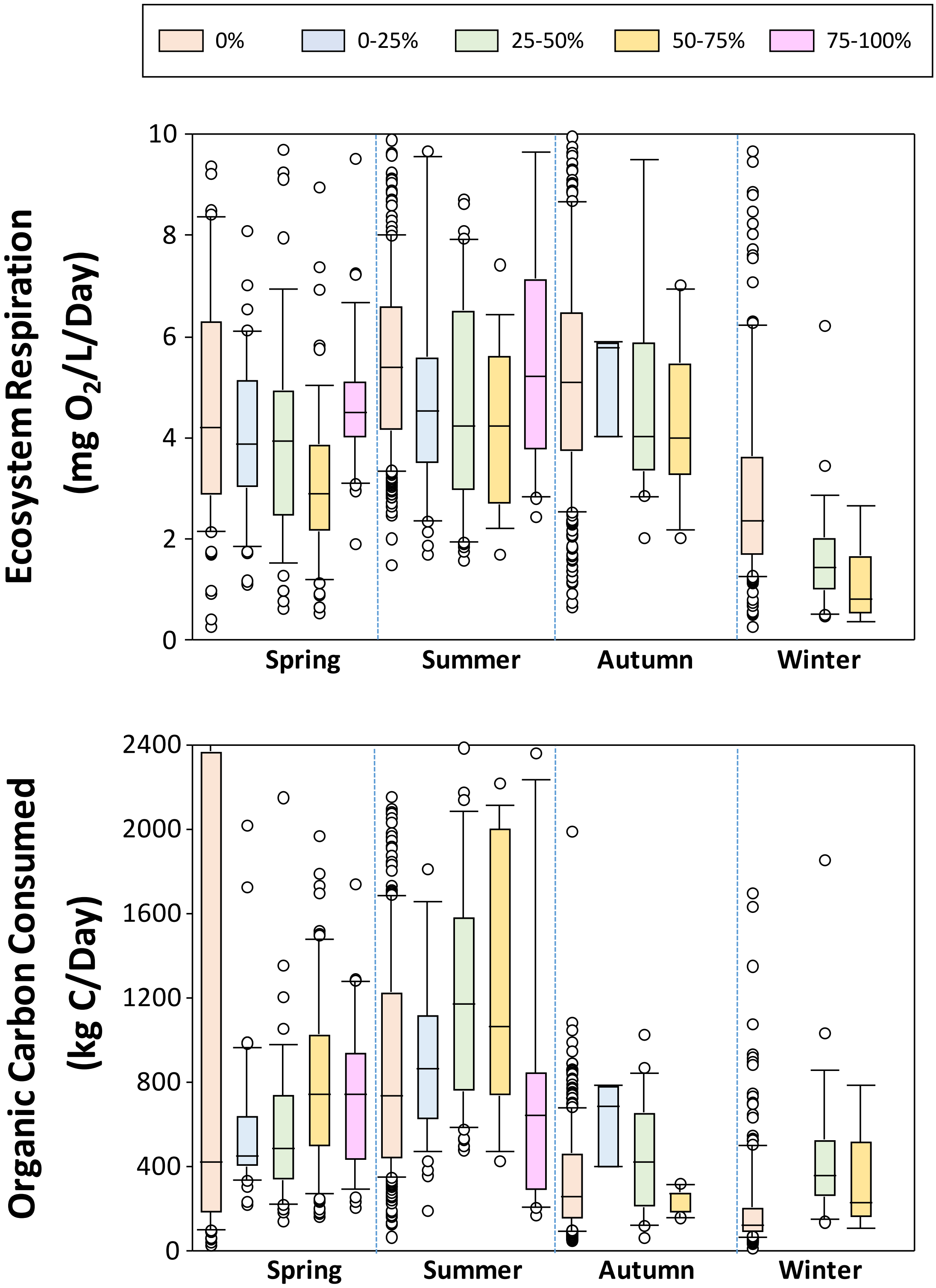


Figure 26. Box plots of ER (top) and the Organic Carbon Load Consumed (bottom) from the Lachlan Selected Area vs the percentage of discharge made up by CEW, stratified by season, for all Year 1-4 metabolism data.

3.3.7 *The Contribution of CEW to the Organic Carbon Load Produced by GPP*

Despite CEW generally having no specific effect on rates and loads of organic carbon production and consumption (Section 3.3.6), the earlier section (3.3.5) demonstrates that provision of this extra water clearly increases discharge and therefore in at least 80% of cases increases the daily loads. This section of the report will quantify how much addition organic carbon is being produced in the water flowing past the monitoring point each day by GPP or consumed by ER from the addition of CEW over the five-year duration of the LTIM Project.

The methodology underlying these calculations is as follows:

1) For each day with the metabolic fit meeting the usual acceptance criteria (Section 3.1.2) from each individual stream metabolism site within the LTIM project, calculate the percentage of that day's discharge arising from CEW. This necessitates the analysis being restricted to those sites where CEW contributions are available (14 of the 16 sites, Table 2; there are no CEW contribution data for Loch Garry (Goulburn) and Zone 3 (Edward-Wakool). Several sites only have data commencing in Year 2).
2) Making the assumption, already justified above, that in general CEW water does not induce a differential metabolic response than other water in the river at that time, simply proportion that day's GPP (or ER) load according to the proportion of each water source (CEW and non-CEW)
3) Collate all the data for each site and then pool for season and Selected Area and stratify for nominal flow category (Table 3).
4) Mean daily loads from CEW and non CEW sources are calculated (provided there are at least 6 data points)
5) The % of total daily organic carbon load is then determined.

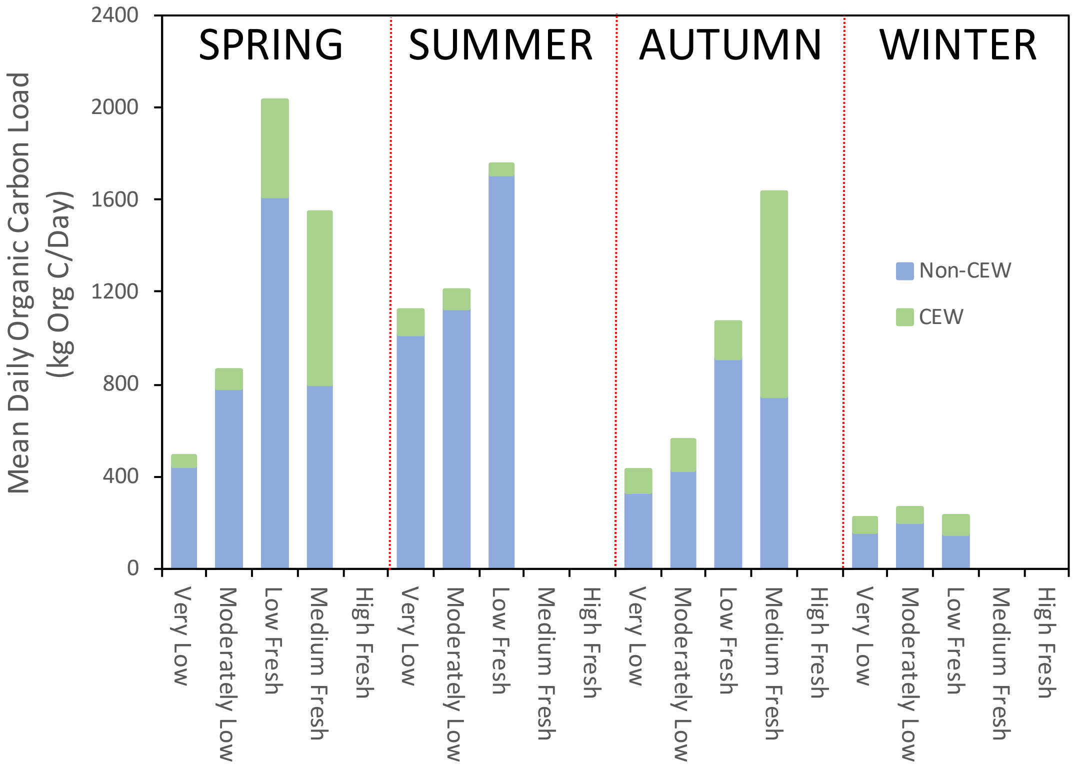
Figure 27 is a stacked bar chart showing the contribution of CEW (green) and non-CEW water (blue) to the average daily organic carbon load, stratified by season within a) the Goulburn Selected Area, and b) the Edward-Wakool Selected Area. Figure 28 is an analogous plot for a) the Lachlan Selected Area, and b) the Murrumbidgee Selected Area, while Figure 29 represents a) the Lower Murray Selected Area and b) the Warrego-Darling Selected Area. The combined height of both bars represents the total average organic carbon produced by GPP in the water flowing past the monitoring point each day.

Table 10 shows all the summary data associated with each bar of each plot plus the percentage contribution of CEW to the overall organic carbon loading in each case.

It can be clearly seen from these figures that CEW usually makes a relatively small contribution to the average amount of organic carbon produced each day within the six Selected Areas. However, during some seasons and in some Selected Areas, this contribution can be large and in fact be the major contributor. Examples of this are spring for the Lachlan sites (Figure 28), where CEW provided between 5 and 68% of the organic carbon load depending on the flow category, spring also in the Goulburn with a CEW contribution of 10 to 48% of the organic carbon created (Figure 27) and summer in the Lower Murray (Figure 29) with a CEW contribution ranging between 19% (very low flow) up to 54% (high freshes). There is also considerable inter-annual variability (data not shown) associated with the different CEWO watering actions each year, as delineated in Annex H.

CEW contributions will also vary according to competing water requirements across the Basin and weather conditions, particularly extended dry or wet periods.

a) Goulburn



b) Edward-Wakool

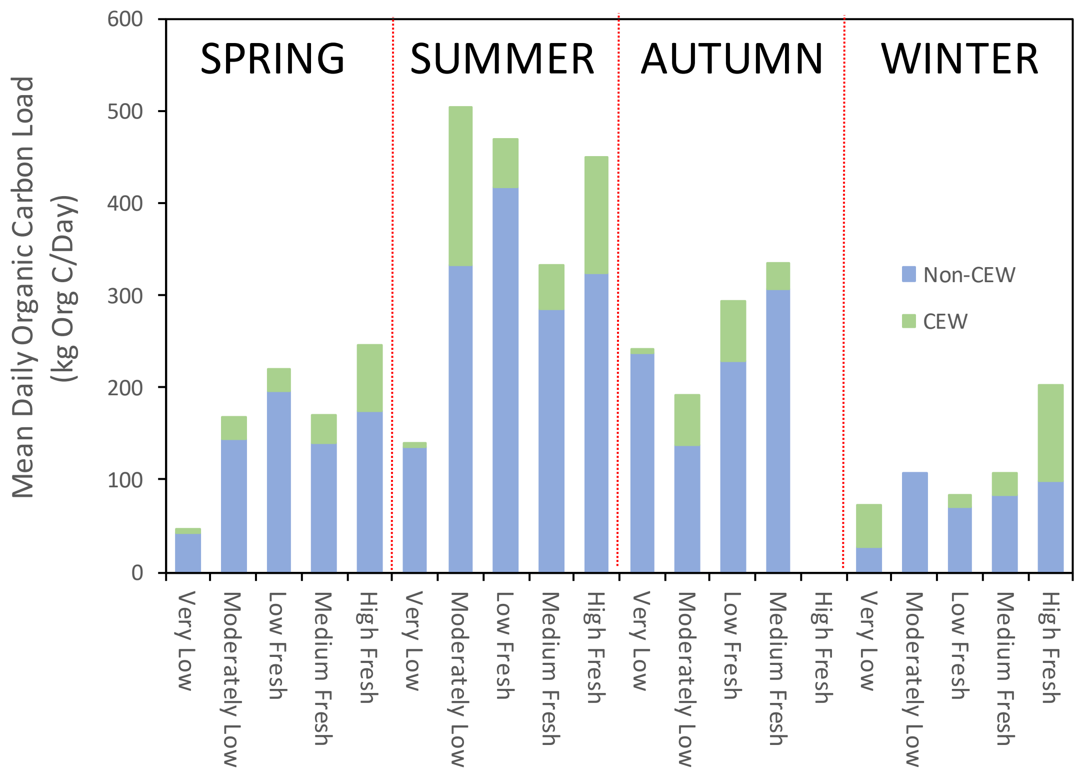
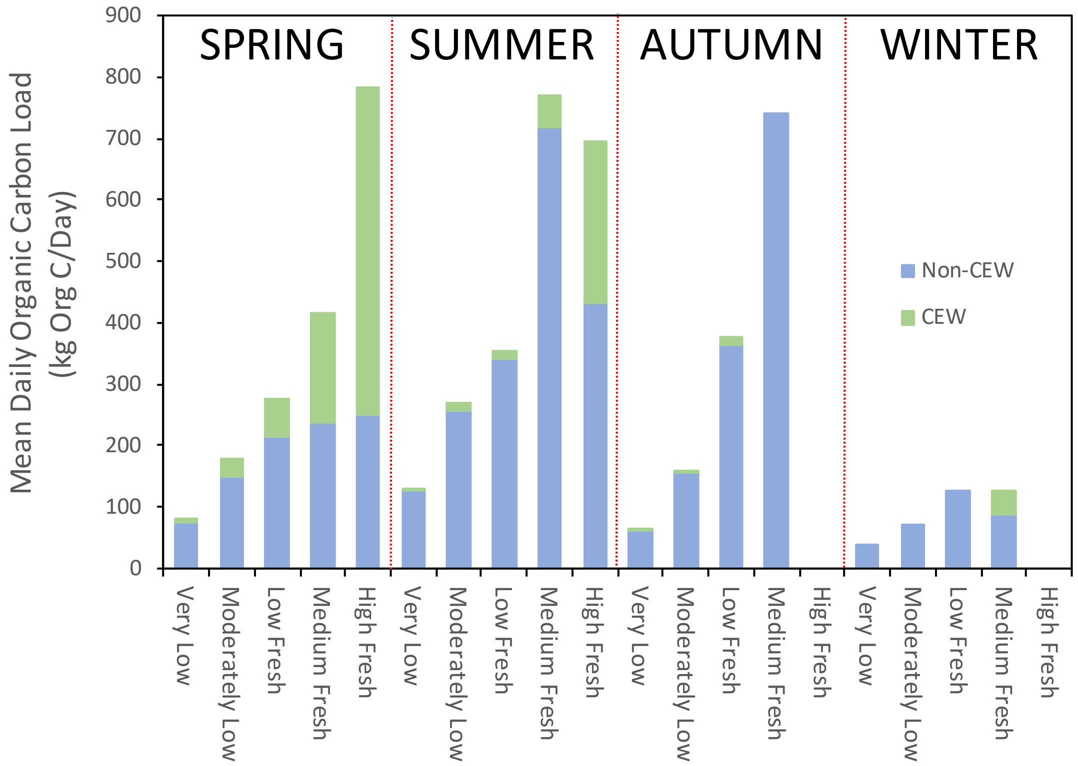


Figure 27. Contribution of Commonwealth Environmental Water to the Mean Daily Organic Carbon Load produced by GPP (kg Org C/Day), stratified into seasons, using the full five-year data set. Plots are for a) the Goulburn River Selected Area, and b) the Edward-Wakool Selected Area.

a) Lachlan



b) Murrumbidgee

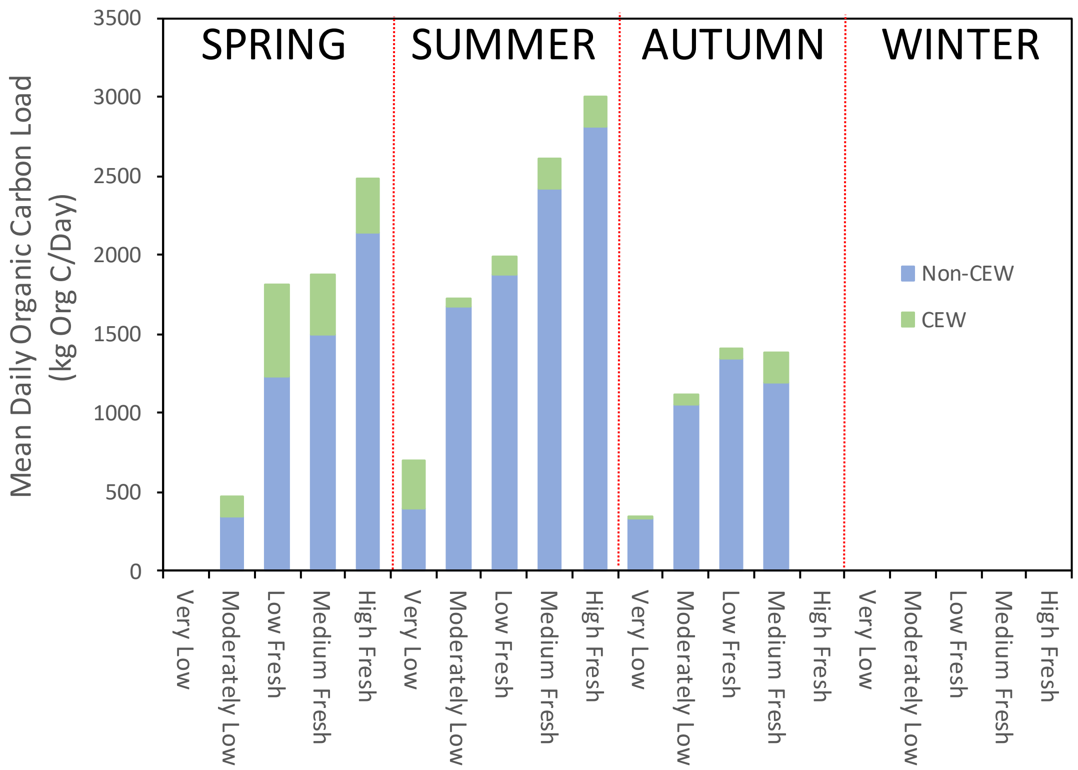


Figure 28. Contribution of Commonwealth Environmental Water to the Mean Daily Organic Carbon Load produced by GPP (kg Org C/Day), stratified into seasons, using the full five-year data set. Plots are for a) the Lachlan Selected Area, and b) the Murrumbidgee Selected Area. There was no wintertime data from the Murrumbidgee.

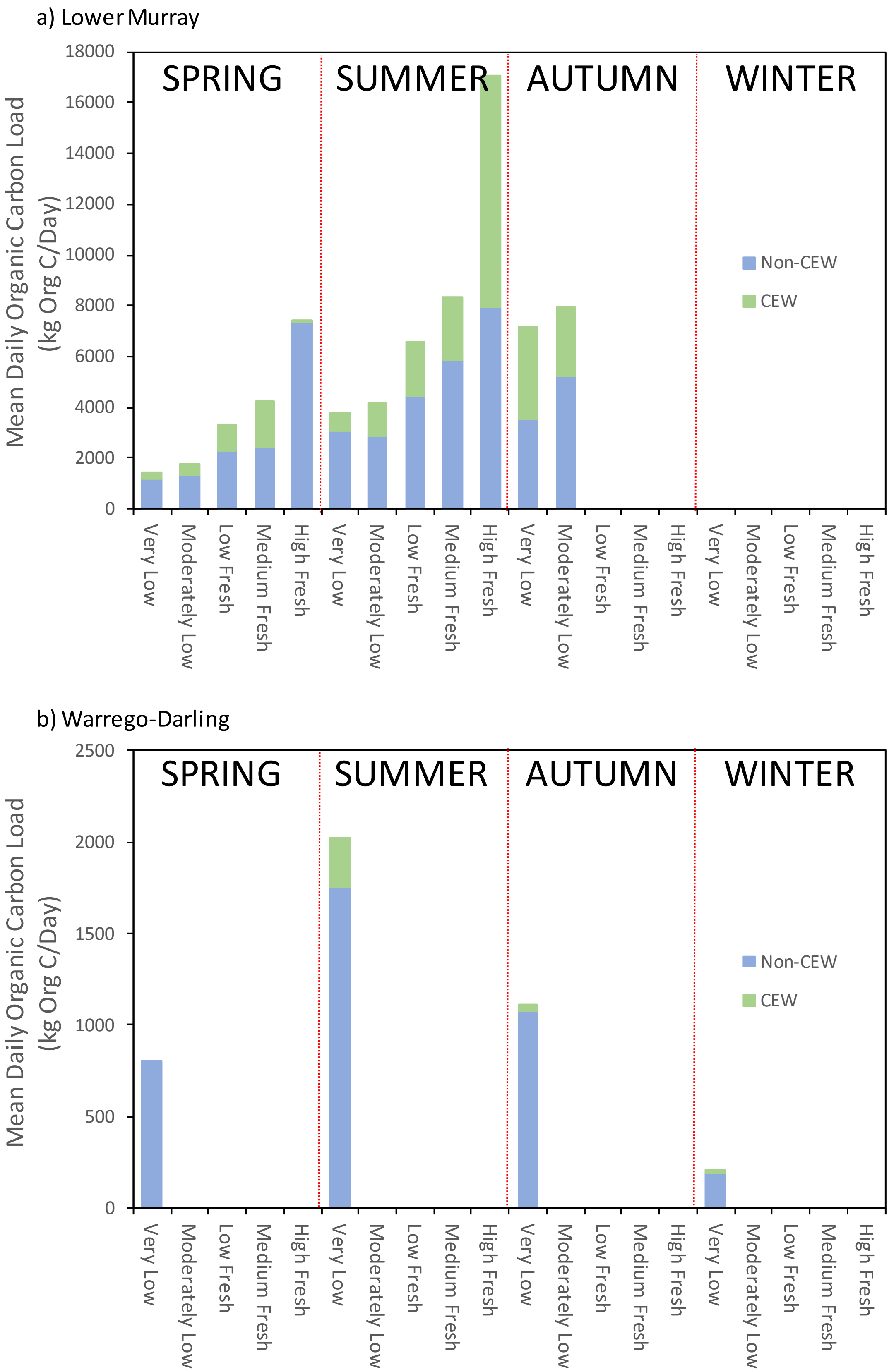


Figure 29. Contribution of Commonwealth Environmental Water to the Mean Daily Organic Carbon Load produced by GPP (kg Org C/Day), stratified into seasons, using the full five-year data set. Plots are for a) the Lower Murray Selected Area, and b) the Warrego-Darling Selected Area. There was no wintertime data from the Lower Murray.

Table 10. Percentage Contribution of Commonwealth Environmental Water to Mean Daily Organic Carbon Produced by GPP (kg Org C/Day) stratified into flow categories and seasons. The flow categories for each Selected Area are taken from Table 3.

a) Goulburn and Edward-Wakool Selected Areas

		Goulburn				Edward-Wakool			
Season	Flow Category	n	Mean Daily GPP Load from CEW (kg Org C/Day)	Mean Daily GPP Load from non-CEW (kg Org C/Day)	% Contribution to Total Organic Carbon Load from CEW	n	Mean Daily GPP Load from CEW (kg Org C/Day)	Mean Daily GPP Load from non-CEW (kg Org C/Day)	% Contribution to Total Organic Carbon Load from CEW
Spring	Very Low	143	47	445	10	114	6	42	13
	Moderately Low	131	83	780	10	188	23	144	14
	Low Fresh	83	421	1615	21	172	24	197	11
	Medium Fresh	103	743	801	48	139	29	140	17
	High Fresh	2				310	72	175	29
Summer	Very Low	138	102	1020	9	333	6	135	4
	Moderately Low	289	77	1134	6	244	170	333	34
	Low Fresh	282	48	1708	3	231	52	417	11
	Medium Fresh	3				449	48	285	14
	High Fresh	1				126	126	325	28
Autumn	Very Low	93	102	329	24	294	3	238	1
	Moderately Low	211	130	425	23	118	54	138	28
	Low Fresh	162	153	916	14	18	65	230	22
	Medium Fresh	55	882	752	54	181	28	307	8
	High Fresh	0				6			
Winter	Very Low	29	63	157	29	97	45	28	62
	Moderately Low	91	62	203	23	38	0	108	0
	Low Fresh	18	74	152	33	24	13	70	15
	Medium Fresh	5				76	24	84	22
	High Fresh	2				11	103	99	51

Table 10 continued….

b) Lachlan and Murrumbidgee Selected Areas

		Lachlan				Murrumbidgee			
Season	Flow Category	n	Mean Daily GPP Load from CEW (kg Org C/Day)	Mean Daily GPP Load from non-CEW (kg Org C/Day)	% Contribution to Total Organic Carbon Load from CEW	n	Mean Daily GPP Load from CEW (kg Org C/Day)	Mean Daily GPP Load from non-CEW (kg Org C/Day)	% Contribution to Total Organic Carbon Load from CEW
Spring	Very Low	87	4	75	5	6	110	271	29
	Moderately Low	130	29	149	16	13	125	348	27
	Low Fresh	156	64	213	23	32	581	1231	32
	Medium Fresh	196	179	237	43	242	380	1492	20
	High Fresh	16	535	249	68	79	349	2141	14
Summer	Very Low	43	3	127	2	23	308	390	44
	Moderately Low	97	12	256	5	47	55	1670	3
	Low Fresh	182	15	340	4	64	115	1875	6
	Medium Fresh	283	53	718	7	309	186	2420	7
	High Fresh	20	261	433	38	117	184	2817	6
Autumn	Very Low	152	1	60	2	67	8	329	2
	Moderately Low	222	3	156	2	34	58	1058	5
	Low Fresh	114	11	365	3	51	58	1345	4
	Medium Fresh	12	0	741	0	84	184	1198	13
	High Fresh	0				0			
Winter	Very Low	113	0	37	0	0			
	Moderately Low	199	0	71	0	0			
	Low Fresh	37	0	125	0	0			
	Medium Fresh	55	38	88	30	0			
	High Fresh	2				0			

Table 10 continued….

c) Lower Murray and Warrego-Darling Selected Areas

		Lower Murray				Warrego-Darling			
Season	Flow Category	n	Mean Daily GPP Load from CEW (kg Org C/Day)	Mean Daily GPP Load from non-CEW (kg Org C/Day)	% Contribution to Total Organic Carbon Load from CEW	n	Mean Daily GPP Load from CEW (kg Org C/Day)	Mean Daily GPP Load from non-CEW (kg Org C/Day)	% Contribution to Total Organic Carbon Load from CEW
Spring	Very Low	41	253	1178	18	59	0	801	0
	Moderately Low	38	459	1344	25	0			
	Low Fresh	77	1015	2320	30	0			
	Medium Fresh	82	1847	2404	43	1			
	High Fresh	42	24	7376	0	0			
Summer	Very Low	35	706	3064	19	90	275	1754	14
	Moderately Low	105	1318	2873	31	1			
	Low Fresh	117	2141	4430	33	0			
	Medium Fresh	161	2478	5856	30	0			
	High Fresh	27	9139	7939	54	0			
Autumn	Very Low	12	3626	3516	51	17	33	1074	3
	Moderately Low	11	2755	5195	35	6			
	Low Fresh	6				0			
	Medium Fresh	0				0			
	High Fresh	0				0			
Winter	Very Low	0				93	24	186	11
	Moderately Low	0				0			
	Low Fresh	0				0			
	Medium Fresh	0				0			
	High Fresh	0				0			

4 Watering actions and stream discharge – Summary of expected outcomes

4.1 Overview of watering actions with expected outcomes for stream metabolism and water quality

4.1.1 2018–2019

In 2018–19, the CEWO contributed water to 131 watering actions targeting lotic (flowing) systems and wetlands; of these, fifteen were to specifically achieve expected outcomes associated with ecosystem processes including stream metabolism[5] (including actions with expected outcomes for nutrient cycling and/or ecosystem function) (Table 11), with only one of these actions being in a Selected Area (Basin-scale Evaluation Water Action Reference = 1819-LCH-01). The extended duration actions targeting the Lower Murray would include effects on the LTIM sites downstream of Lock 1 and Lock 6, although these aren't explicitly mentioned.

These fifteen watering actions had expected outcomes for other indicators too, notably water quality but also in many cases including fish and vegetation. Four of the metabolism actions used CEW, which constituted 100 per cent of the baseflow at that time (two in the Lachlan, one in the Gwydir and one in the Warrego, Table 11). A further 21 watering actions using CEW focused on water quality as a key outcome (Annex I; watering actions already included in Table 11 were not repeated in this annex).

The effects of the individual watering actions and comparisons of metabolism between individual sites are discussed in the respective Selected Area reports.

4.1.2 2014–2019

Over the full five years of the LTIM Program, the CEWO contributed water to 541 watering actions targeting lotic (flowing) systems and wetlands; of these, 144 watering actions included an objective related to ecosystem processes. The 129 of these actions occurring in Years 1 to 4 are listed in Annex H (the fifteen 2018–19 actions are listed in Table 11, as noted above). Of these 129 actions, 47 were within the Selected Area rivers[6] to specifically achieve expected outcomes associated with stream metabolism (including actions with expected outcomes for nutrient cycling and/or ecosystem function).

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[5] This information was collated from the 2018–19 CEWO Water Use Summary. There were several watering actions in the Lower Murray that targeted salt and nutrient movement (i.e. to facilitate meeting Water Quality objectives) and these are included in Annex I.

[6] This information was collated from the combined 2014–19 CEWO Water Use Summary. There were several watering actions in the Lower Murray that targeted salt and nutrient movement (i.e. to facilitate meeting Water Quality objectives) and these are included in Annex H.

Table 11. Summary of 2018–19 watering actions targeting stream metabolism and generic ecosystem functioning.

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1819-LCH-01	10081-01	Lachlan: Lachlan River	10391	10391	24/8/18 - 10/11/18	Fresh	Stream productivity	
1819-CNM-02	10078-01	Central Murray: River Murray Channel	24975	24996	6/7/18 - 31/7/18	Fresh, overbank	Contribute to riverine functioning by supporting primary and secondary production along River Murray.	Supporting the managed export of salt and nutrients from the River Murray system.
1819-GWY-04	10085-05	Gwydir: Gywdir River, Mehi River and Carole Creek	4000	4000	6/4/19 - 6/5/19	Baseflow	Support instream habitat (including refugial habitat), ecological function and nutrient cycling.	Maintain water quality.
1819-LCH-04	10081-03	Lachlan: Great Cumbung Swamp	5338	5338	9/6/19 - 28/6/19	Wetland	Provide longitudinal connectivity and variability to flows to encourage productivity.	
1819-LOD-01	10001-05	Loddon: Loddon River	2636	7952	8/10/18 - 31/10/18	Fresh	Flush accumulated organic matter from in-channel benches to aid carbon and nutrient cycle and flush fine sediment and scour biofilms to replenish food supply	
1819-LWM-55	10078-02; 10078-08	Lower Murray: Lock 2	0	0	15/8/18 - 5/11/18	Fresh	Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	Supporting the managed export of salt and nutrients from the River Murray system.
1819-LWM-56	10078-02; 10078-08	Lower Murray: Lock 5	0	0	15/8/18 - 5/11/18	Fresh	Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	Supporting the managed export of salt and nutrients from the River Murray system.
1819-LWM-57	10078-02; 10078-08	Lower Murray: Lock 7	0	0	1/9/18 - 31/12/18	Fresh	Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	Supporting the managed export of salt and nutrients from the River Murray system.

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1819-LWM-58	10078-02; 10078-08	Lower Murray: Lock 7	0	0	1/1/19 - 31/5/19	Fresh	Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	Supporting the managed export of salt and nutrients from the River Murray system.
1819-LWM-59	10078-02; 10078-08	Lower Murray: Lock 8	0	0	1/7/18 - 30/6/19	Fresh	Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	Supporting the managed export of salt and nutrients from the River Murray system.
1819-LWM-61	10078-02; 10078-08	Lower Murray: Lock 9	0	0	1/7/18 - 30/6/19	Fresh	Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	Supporting the managed export of salt and nutrients from the River Murray system.
1819-LWM-63	10078-02; 10078-08	Lower Murray: Lock 15	0	0	1/7/18 - 1/9/18	Fresh	Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	Supporting the managed export of salt and nutrients from the River Murray system.
1819-LWM-64	10078-02; 10078-08	Lower Murray: Lock 15	0	0	25/12/18 - 3/3/19	Fresh	Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	Supporting the managed export of salt and nutrients from the River Murray system.
1819-LWM-65	10078-02; 10078-08	Lower Murray: Lock 15	0	0	1/5/2019 - 30/5/19	Fresh	Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	Supporting the managed export of salt and nutrients from the River Murray system.
1819-WAR-05	00152-11	Warrego: Toorale Western Floodplain	8106	8106	7/5/19 - 20/5/19	Baseflow	Nutrient and sediment cycling from inundation of lower level benches (Darling River).	

[1] As reported by the Commonwealth Environmental Water Office (CEWO).

4.1.3 Base flows

Environmental flows that increase base flows are likely to influence the amount and diversity of habitat available for primary producers (Section 1.3.1). Any increase in available habitat is likely to increase the supply of organic carbon, the energy source driving and sustaining aquatic food webs and essential nutrient recycling via ecosystem respiration. In flowing systems in which environmental flows have had a significant influence on base flows, it is likely that there will have been an associated effect on metabolism. These watering actions are likely to have provided base levels of organic carbon and nutrients – the quantities of these essential components are determined by primary producer biomass and the amount of organic carbon available. As noted in the previous sections, even small increases in water level from very low (base flow) to moderately low flow (Figure 3, Table 3) can introduce more organic carbon into the food web.

The situation in impounded rivers is likely to be different, as changes to base flows may not affect the amount of habitat, but may influence habitat type (still water versus flowing water). The effect of this change on metabolism is not clear. The effects of water level manipulations in the Lower Murray on (a) stream metabolism and (b) biofilm community composition and succession were examined in two papers prepared for the South Australian Department of Environment, Water and Natural Resources by Wallace and Cummings (2016 a, b). Murray River weir pools were raised by 0.45 m and 0.50 m, while the Chowilla Environmental Regulator was used to increase the water height in the anabranch system by 1.5 m. As a result of these watering actions, primary production (GPP) and ecosystem respiration (ER) increased by a factor of up to 2–3 above baseline values, while there was an even larger (5-fold) increase in ER, but not GPP, in the Chowilla Creek anabranch (Punkah Creek) and associated wetlands. These increases were attributed to changed resource (organic carbon, nutrients) availability associated with the water level rise and then fall. Water level manipulations in the weir pools also induced longer term changes in biofilm community composition. It might be expected that enhanced biofilm community turnover and succession would result in enhanced GPP, but this was not observed here. Watering actions in this region, including spring flooding, have previously been shown to introduce a large amount of organic carbon from the floodplains of the Lower Murray into the main river channel (e.g. Wallace & Furst 2016). The impacts of such organic carbon delivery on metabolism in the river channel will also depend on the relative volumes of water.

Using watering actions to maintain a base flow in a reach can also be important in avoiding adverse water quality outcomes. This is exemplified by Zone 2 in the Edward–Wakool river system Selected Area where very low flow resulted in dissolved oxygen concentrations below that at which fish health is compromised.

4.1.4 Freshes

The addition of fresh flows typically has the effect of initially reducing rates of metabolism (expressed as mg O_2/L/Day) through simple dilution by the incoming water. However, as noted above, these flows enhance the amount of organic carbon produced and consumed in terms of daily load. Allocation of environmental water to provide freshes may have significant environmental benefits from a variety of mechanisms (see Section 1.2.3). It was originally anticipated that analysis would allow quantitative exploration of the idea that the amount of carbon produced can be determined by nutrient availability, temperature and the light climate during and immediately after the fresh. However, such assessment was severely constrained by the availability of sufficient nutrient data across seasons and especially stages of the hydrograph. Regression of nutrient and chlorophyll-a concentrations against median GPP rates and of dissolved organic carbon concentrations against ER did indicate that the expected relationships were occurring, as discussed later in Section 4.3 on water quality.

4.2 Unmonitored area outcomes

Over the 2018–19 watering period, Commonwealth environmental water contributed to fourteen 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 11.

Based on results for the monitored Selected Areas presented in Section 3, it is anticipated that environmental watering actions confined within the defined river channels will result in initial decreases in volumetric rates, but enhanced rates of organic carbon production and consumption on a daily load basis. Furthermore, base metabolic rates for unmonitored sites in the southern Basin are expected to be in the range 1-3 mg O_2/L/Day for GPP and 1-5 mg O_2/L/Day for ER as found for the monitored sites. 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' phosphorus for GPP and labile organic carbon for ER).

Based on the relatively small amount of data now available from the two Darling river sites, it is anticipated that primary production rates, in particular, will be constrained in the unmonitored sites due to high turbidities. There is not yet sufficient information on flow–metabolism relationships in the northern Basin to determine whether Commonwealth environmental water will attenuate the high turbidity and therefore facilitate primary production or suppress photosynthesis further. Hopefully, more extensive data sets from the Warrego–Darling system and introduction of extended monitoring in the Gwydir sites as part of the MER Program will enable further insights into relationships between discharge, light availability and ensuing primary production. It is highly likely that nutrient concentrations will be sufficient to initiate significant primary production should the light climate be conducive to such growth.

For watering actions targeting stream metabolism and water quality in unmonitored sites, it is expected that water returning to the main river channel after inundating wetlands and floodplains (e.g. Macquarie River) is likely to affect water quality and rates of primary production and ecosystem respiration. On this basis, it appears likely that the watering actions taken in previous years in the Macquarie River 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.

There is no *a priori* reason why the commonality of metabolism behaviour observed for the five 'southern' Selected Areas would not be observed in other streams of similar size in this region. It would be very informative to construct carbon metabolism budgets for the southern basin (and eventually all the basin) so that metabolism can be mapped and modelled at a catchment scale. However, it is expected that the myriad small, shallow streams and creeks (permanent and intermittent) may behave quite differently due to the greatly increased importance of the benthos (including biofilms) in controlling photosynthesis and ecosystem respiration. Very high rates on a volumetric basis may be expected although these may then be scaled down on an areal basis when incorporating mean reach depth.

4.3 Water Quality

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 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 cyanobacterial 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.

While individual water quality issues and any management actions taken to attenuate these are described in the relevant Selected Area reports, it is worth highlighting here the impact of the major flooding that occurred during October-December 2016. One outcome from the extended duration of water on the floodplain and slowly returning to the main channel was the development of very low dissolved oxygen and even anoxic conditions within the river channel for periods of days to several weeks. The larger rivers exhibited suppressed dissolved oxygen: down to 3 mg O_2/L in the Murrumbidgee at Carathool (Wassens *et al.* 2017) and to below 50% saturation (ca. 4.5 mg O_2/L) in the Lower Murray (Ye *et al.* 2018). These concentrations are considered potentially lethal to fish populations. In the smaller rivers (Goulburn, Edward-Wakool, Lachlan) extended periods of anoxia were measured. Removal of oxygen from the water column was driven by respiration of the elevated dissolved organic carbon (and presumably particulate organic carbon – but this was not monitored) concentrations originating from the flooding. For example, in the Edward-Wakool during the flooding event, DOC increased from the typical value of 5 mg/L to 12-15 mg/L (Watts *et al.* 2017) and similarly to 14 mg/L in the Murrumbidgee at Carathool (Wassens *et al.* 2017). Ye *et al.* (2018) note that the reduced frequency of floodplain inundation due to river regulation has led to the accumulation of large organic carbon standing stocks which then induce low dissolved oxygen/anoxia when floodwaters eventually return to the river channel. This low dissolved oxygen/anoxia in the water column necessitated Commonwealth watering actions (listed in Annex A) specifically targeting introduction of more oxygenated water (e.g. via the Wakool offtake in the Edward –Wakool system). Such actions were necessitated in the Goulburn, Edward-Wakool, Murrumbidgee and Lachlan Selected Areas. ***These hypoxic/anoxic events and the subsequent delivery of ameliorating flows (including through CEW) have demonstrated the effectivess of the targeted management acitons and given the ongoing likelihood of recurrence of anoxia, the importance of retaining water in storages upstream from likely problematic river reaches.***

The watering actions undertaken in the Lower Murray River were effective in exporting salt and nutrients from the Murray Mouth which would be expected to contribute to 1–5 year improvements in water quality in the Basin (Ye *et al.* 2019). Extensive overbank flooding thwarted attempts to assess the effects of weir pool raising and lowering on stream metabolism.

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 monitoring and evaluation projects. Annex C of this report lists the nutrient data from samples collected from the Selected Areas during the 5 years (2014–19). Of particular importance to stream metabolism are the concentrations of the bioavailable forms of nitrogen (N) (nitrate+nitrite = 'NOx' and ammonia/ammonium) [7] and phosphorus (P) (filterable reactive P (FRP) which is usually equated to phosphate). The Edward–Wakool, Murrumbidgee, Goulburn and Lower Murray sites in particular had very low median FRP concentrations (around 2–4 µg P/L; Table E5) which almost certainly constrained primary production. FRP was also relatively low in the Lachlan. Median FRP was much higher in samples from the Gwydir and especially the Warrego–Darling samples (primarily due to much higher phosphorus content naturally in the catchment soils), 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 E3 and E4, 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 southern Basin.

Dissolved organic carbon (DOC) concentrations (Table E6) 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 ('quality' – related to chemical composition) 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*. 2018), is essential to tease these factors apart.

4.4 Adaptive management

Based on the information from the five years of the LTIM project, it appears that, in line with the entrainment model, rates of GPP and ER are unlikely to increase in response to base flows or freshes on a per unit volume basis when constrained within the river channel. It does appear likely that stream metabolism did respond to those watering actions that achieved significant floodplain or wetland inundation; for example, in the Lower Murray (Section 7.3.2, Annex G). However, when coupling the slightly decreased rates of GPP and ER per litre of water (from dilution) with the increased number of litres due to the enhanced flow*, it is becoming very clear that these relatively small flow increases can introduce more organic carbon into the river* as measured as organic carbon load (mass per day). This is a new insight that has arisen from this LTIM program as the expectation at the start of this program was that unless flows were large enough to reconnect floodplains, backwaters, billabongs and flood runners, then there would be little ecological benefit in terms of metabolism and the energy base of aquatic food webs.

Results suggest that in some cases, but *not* as a generalization, delivery of water from alternative sources (e.g. Chowilla into the Lower Murray, flows from Copeton Dam rather than other sources into the Gwydir, attenuating high turbidity) can induce higher metabolic rates. In general, timing of the water delivery has a much greater effect on metabolic rates than water origin. Nutrient increases may also be mediated through rewetting dried areas, as seen in the Murrumbidgee. In addition, there is a limited amount of evidence to indicate that higher nutrient concentrations do stimulate GPP 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 GPP and ER on a world scale, although what now constitutes 'average' ranges for metabolic

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[7] Reported concentrations that were lower than the detection limit for the analytical method were ascribed a value equal to half the detection limit. This avoids overestimating summary statistics (which would occur if all the very low concentrations were removed)

parameters across the globe is an open question as more data sets slowly emerge with rates similar to those found during this LTIM project.

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. When planning environmental flows, consideration of the trade-off between magnitude and duration may be influenced by consideration of metabolism outcomes. Two options may be worth considering:
   - If shortening the duration of the flow would significantly increase the extent of lateral connection, then it may be worth increasing magnitude and reducing duration.
   - If, however, there is limited scope to achieve significant lateral connectivity, then a longer smaller flow is likely to have a greater influence on metabolism as it will enable colonisation and accumulation of primary producers and decomposers. There will obviously be a balance here between promoting such biota and leaving the system too stable which may lead to declines due to senescence.
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. Timing of the water delivery is an extremely important consideration to maximize benefit for multiple objectives. For example, providing flows that stimulate organic carbon production at times when food resources threaten viability of native fish populations.

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 to help sustain fish populations for example. This recognizes that stream metabolism is a vital enabling function intimately linked to support of aquatic ecosystems rather than being two ‘stand-alone’ processes to be protected to the exclusion of the higher level organisms.

4. From a water quality perspective, Commonwealth environmental water has the capacity to benefit water quality as evidenced by the outcomes in the Gwydir and Edward–Wakool systems. In the Edward–Wakool system, dissolved oxygen levels were maintained in rivers where Commonwealth environmental water was delivered; this had beneficial effects by preventing the development of the low dissolved oxygen conditions found in a nearby site river which did not receive environmental water. For example, in late 2016 during an extensive unregulated flood and widespread hypoxic blackwater conditions, Commonwealth environmental water had a positive impact on water quality by delivering oxygenated water from irrigation canal escapes to create local refuges for fish and other aquatic biota.

5 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 (s5.03 of the Basin Plan; currently undergoing review, MDBA (2019)). 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 to 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.

A potential exception to the above is suggested by the Basin Plan objective; specifically, that the capacity of water-dependent ecosystems 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 which would help guide future water management toward short-term improvements in condition that would underpin longer term outcomes during episodes of high ecological productivity.

Monitoring outcomes of freshes and base flows during the LTIM project (2014–19) generally did not detect any significant increases in rates of gross primary productivity or ER with the addition of environmental water using the traditional volumetric parameters (in mg O_2/L/Day), instead there was typically a decrease associated with dilution by more water. However, as noted in sections 3 and 4, ***these relatively small increases of flow, which remained within the confines of the main channel, did introduce more organic carbon production and consumption each day in the river flowing past the monitoring point, thereby boosting the energy (food) base of aquatic food webs***. It is also likely that these smaller environmental watering actions created additional habitat for primary producers and decomposers. The challenge now is to link these important findings to the support and sustainability of native fish populations, assuming that, at least in part, these populations are constrained by resource (food) availability. There may also be important food resource effects for other biota including waterbirds.

Even with the positive outcomes (higher production and consumption of organic carbon) now detected from relatively small within-channel flow increases, it is extremely important not to ignore the potential for much larger gains with the occasional higher flow which reconnects backwaters and perhaps even the floodplain to the river. These larger flows will entrain more organic carbon and nutrients than frequently wetted, in-channel banks.

6 Expected Basin-scale outcomes

6.1 Stream metabolism

As identified in previous Basin-scale Evaluation Reports, with the notable exception of an extensive study of metabolism at three sites in the Murray River in 1998–99 by Oliver and Merrick (2006), there were essentially no long-term data on stream metabolism across the Basin prior to the short-term monitoring projects in 2011 and onwards into the five years of the LTIM project. As this data set has expanded further, it is much more likely that it represents typical rates of GPP and ER in these waterways. The obvious caveat is that although there have been some large flow events, the data may well not be representative of either a prolonged wet period or even more importantly, extended drought conditions. The rates found in the combined five-year data set were lower in the Murrumbidgee than recorded a decade ago, but it now appears these differences may be attributed to differences in sites, methodology and/or analysis methods, rather than a real decline.

Across the data set, there was significant variability in rates, even in the absence of major flow changes, and a general seasonal trend towards higher values for GPP and ER moving from spring into summer. High daily variability in GPP especially is unsurprising given the importance of daily weather (cloud cover, temperature) on photosynthetic rates. Behaviour of GPP and ER into autumn was more idiosyncratic, but several Selected Areas had higher rates in early-mid autumn compared to summer. Light and temperature conditions are still highly conducive to primary production in March especially and many autumn data sets contain mostly data from this month. Some selected areas have more April, May and even June data now being incorporated which in turn drives down the autumn median and average GPP and ER values due to shorter days and cooler temperatures. The latest year's data has seen an increase in winter results for some Selected Areas. More wintertime data (e.g. through the three years of the MER Project) will provide greater confidence in the assessment of CEW delivery during this period (e.g. for the Goulburn River).

One advantage in using areal units i.e. g O_2/m^2/Day for GPP and ER is that it facilitates comparison with metabolic rates from elsewhere in the world. There are reasons to expect similar rates (driven by physiological constraints of organisms) and differences. Certainly, higher rates are found in streams with very low turbidity and moderate levels of nutrients (higher than typically found in the southern Basin Selected Areas in this LTIM Program, Annex C). More international data is slowly becoming available, including a very large, as yet unpublished, data set from the USGS. Nevertheless, there is still a dearth of studies both in Australia and globally that have looked at lowland rivers. One important feature that is emerging from the LTIM data set and is highlighted in Figure 4 (GPP) and Figure 5 (ER), is that there is a fairly narrow range for these metabolic parameters under normal conditions. In the southern Basin for example, median GPPs for the Selected Areas vary in the range 1-3 mg O_2/L/Day and ER from 1-5 mg O_2/L/Day, with seasonal variability within these relatively constrained ranges. As the data set grows, and encompasses a broad range of interannual differences in climatic conditions, it will become apparent whether these parameter ranges really are representative of the 'normal' functioning of these southern Basin catchments. One important difference when comparing systems between Australia and many aquatic systems 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 'bathtub 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). Longer term metabolism data is also starting to emerge from locations with a Mediterranean climate (e.g. Spain), much more similar to that in the Murray-Darling Basin than most locations in North America, which will provide useful comparison.

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, both from algal detritus and photosynthetically derived algal exudates. Conversely, if an external source of organic matter is the dominant carbon supply mechanism, then the link between GPP and ER will be relatively weak and mediated through the flow events introducing both nutrients and organic carbon into the river channel. As noted by Fuß *et al.* (2017), as well as several others, the lability (palatability) of the organic carbon to microbial communities is also very important, as the same concentration of dissolved organic carbon can have very different effects on respiration rates depending on whether it is labile or refractory. Insights into this point are being obtained through the Edward–Wakool Selected Area, using fluorescence excitation–emission matrices (FEEM, Watts *et al.* 2018). Even the use of this technique cannot provide all information required about lability of the organic matter driving ecosystem respiration (and related nutrient recycling) as FEEM measures the type of carbon remaining in the sample, rather than the potentially more labile carbon that has already been consumed. Studies of organic carbon upon rewetting and through the early stages of the rising hydrograph will be very helpful here, but are outside the scope of the LTIM project.

Hence, it is still *expected* that watering actions that reconnect backwaters, flood runners and the floodplain should increase both GPP and ER but the types of watering actions delivered over the five years did not provide the opportunity to confirm this expectation. The very large, extended flood in the southern Basin during October-December 2016 instigated anoxic conditions in the main river channel due to the very long period of inundation. Clearly, watering actions should not mimic this large flood event for that reason (anoxia) even if such a water volume became available. It is also expected that the monitored waterways in the Selected Areas will broadly represent stream metabolism across the Basin, with a nominal north-south division. However, as noted above, if the extended dry period between inundations contributes to enhanced anoxia, then more, rather than less frequent inundation would be beneficial. 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.

It is hoped that stream metabolism data from both the Gwydir river system and many more data days meeting acceptance criteria from the Junction of the Warrego and Darling rivers will enable disentanglement of 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 Selected Areas (Annex E, Table E5). These much higher bioavailable phosphorus levels decrease the likelihood of nutrient limitation, hence provide a counterpoint to the five more southern selected areas. As data from the northern Basin becomes available to support this contention, it will perhaps require different management strategies to boost productivity in these northern catchments, which may focus on attenuation of the very high turbidities. However, given the much higher bioavailable nutrient concentrations, care will be required not to generate conditions amenable to algal bloom formation.

Consequently, despite the uncertainty described above, the following key points can be made regarding managing future watering actions and continuing to achieve improvements in stream metabolism to boost food resources for the aquatic food webs in the Basin:

1. At the commencement of the LTIM program, it was initially thought that freshes that remain in channel and do not rewet significant areas of dry sediment are unlikely to boost rates of primary production and ecosystem respiration due to nutrient limitation. The larger data set now available show that this assumption is clearly NOT correct. ***When considering the amount of oxygen (hence organic carbon) being produced and consumed in the river, even small increases in flow (e.g. to Moderate Low Flows according to Table 3) can see a substantial positive***

benefit. The systemic effects of larger flows that do connect backwaters, flood runners and fringing wetlands have still not yet been assessed due to the lack of such flows.

2. The first fresh following winter to inundate dry sediment has the greatest potential to enhance metabolic rates, but this is also dependent upon timing as findings in this report have demonstrated that freshes in winter – early spring result in lower primary production due to colder temperatures and shorter hours of lower intensity sunlight than freshes that are delayed until late spring – summer. Subsequent freshes may have a much lower effect as standing stocks of organic carbon and nutrients on elevated river channel benches, in wetlands and on the floodplain have been depleted by the earlier flow event and have had insufficient time to rebuild. It should be noted, however, that some sediments may not have the opportunity to accumulate much organic matter due to the channel shape or associated riparian vegetation.
3. Inundation of wetlands may entrain nutrients and organic matter which have the potential to enhance metabolism within the river channel, but this requires water to return from the backwaters and wetlands to the river. As local hydrology associated with the connection of wetlands and the stream channel is of critical importance, it is recommended that Selected Areas look specifically for these events and the ensuing metabolic data when waters return to the stream channel.
4. Returned water from wetlands and the floodplain may also constrain primary production within the river channel due to high turbidities. It is likely that such effects may be more pronounced in the northern half of the Basin, due to the very fine colloidal soil particles.
5. In regions of the Basin where light limitation (rather than nutrient limitation) is constraining primary production (such as the northern Basin), then the introduction of clearer water from dams higher in the catchment may promote primary production even though there may be an actual decrease in bioavailable nutrient concentrations.
6. In catchments where a mix of water sources is available, metabolic responses to flow may change significantly depending on the source of that flow. The example of the effect of Chowilla on the metabolism in the Lower Murray is a case in point here. Another example may prove to be the proportion of flows coming from the Border Rivers, the Condamine–Balonne and the Bogan River for metabolism in the Darling River below Bourke.
7. Preliminary modelling has enabled estimation of the amount (biomass) of organic carbon that can be created via primary production (or consumed via respiration) by increasing the flow in channel. This then enables estimation of food resource provision at the base of the aquatic food web, which then needs to be integrated with the needs of consumers including fish.
8. This was covered in last year’s report (Grace (2019a) but is sufficiently important to repeat here: the analysis undertaken at this Basin level has demonstrated that in general there is no deleterious effect (or benefit) on metabolic rates from increasing discharge using CEW compared to other water sources, hence CEW, when available, is an excellent method for increasing the organic carbon loads being created.

6.2 Water quality

Water quality data are generally still too sparse to provide detailed insights into the effects of individual watering actions on pH, turbidity and salinity (electrical conductivity). As described in section 4.3, the extended duration flood event in spring-early summer 2016 resulted in low dissolved oxygen concentrations and in some sites, lengthy periods of anoxia. Without the availability of local scale refugia, this anoxia can be highly damaging to the endemic biota, including native fish populations. Watering action plans were altered to focus on alleviating this very poor water quality (see 2016–17 Selected Area and Basin Evaluation Reports for details). 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 dissolved oxygen). 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.

Using all data pooled from Years 1 to 5, Figure 30 illustrates relationships between median GPP and median nutrient concentrations (Filterable Reactive Phosphorus and Dissolved Inorganic Nitrogen (D.I.N. = ammonium plus nitrate)) and between median ER and median Dissolved Organic Carbon for the six Selected Areas.

All three plots in Figure 30 demonstrate a reasonable to very good linear relationship between nutrients and the median rates of metabolism (GPP and ER) on a volumetric basis (GPP vs FRP: r^2 = 0.94; GPP vs D.I.N.: r^2 = 0.75; ER vs DOC: r^2 = 0.59). Volumetric units for metabolism are the most appropriate since nutrient concentrations are also expressed on this basis. For the two GPP plots in particular, this apparent linearity is driven by the data set from the two Darling River sites (Yanda and Akuna) which mainly emanated from the two most recent year's data set (2017–18 and 2018–19).

Such relationships are expected due to the substrate (nutrient) needs of the GPP and ER processes. It does indicate that although light availability may be also important, especially in the northern Basin, nutrient concentrations can still strongly influence metabolic rates when other growth factors are favourable i.e. PAR, hydrodynamics, extent and duration of bench and bank inundation for biofilm growth.

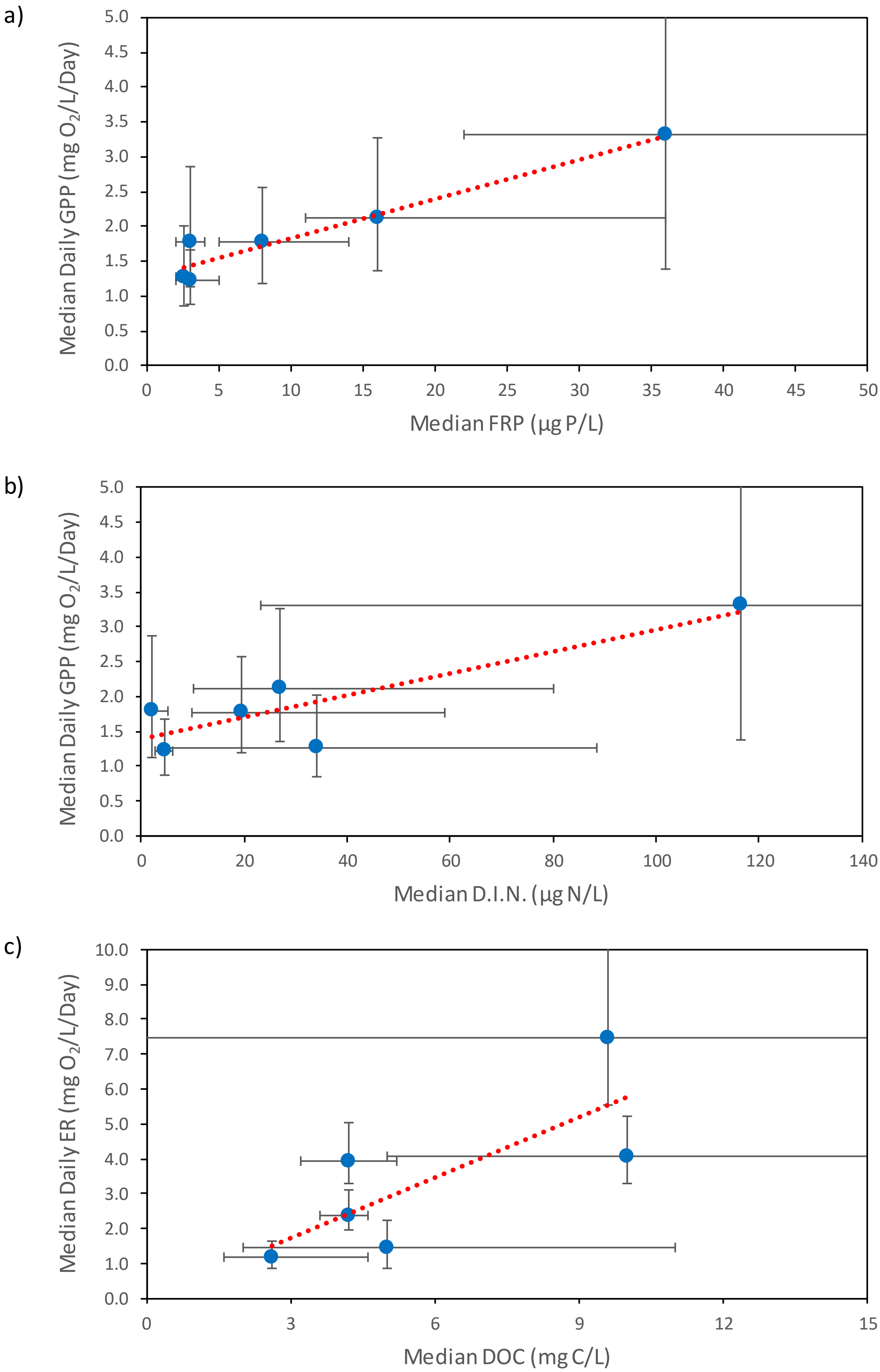

Figure 30. Relationships between median GPP and median nutrient concentrations (Filterable Reactive Phosphorus (FRP) and Dissolved Inorganic Nitrogen (D.I.N. = ammonium plus nitrate)) and between median ER and median Dissolved Organic Carbon (DOC) for the six Selected Areas; pooled data from Years 1-5. Error bars represent the interquartile ranges (25th percentile to median, median to 75th percentile).

In addition to nutrients and sunlight, GPP is also dependent upon the biomass of photosynthesizing primary producers. As shown in Figure 31, there was a very weak positive relationship ($r^2 = 0.12$) between GPP and water column chlorophyll-a concentrations which are a surrogate for phytoplankton biomass.

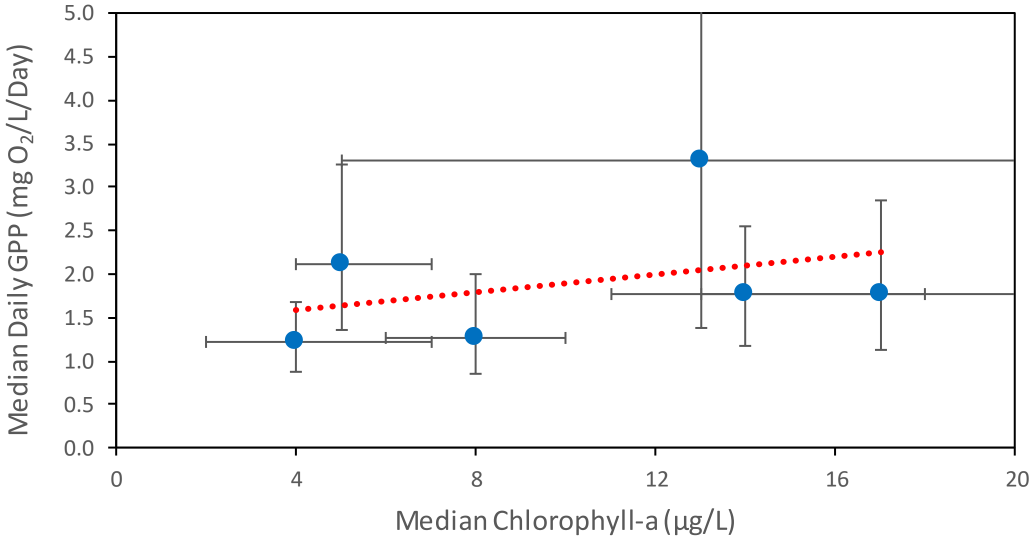

Figure 31. Relationship between median GPP and water-column Chlorophyll-a concentration for the six Selected Areas; pooled data from Years 1-4. Error bars represent the interquartile ranges (25th percentile to median, median to 75th percentile).

The absence of a strong positive relationship between GPP and Chlorophyll-a is unsurprising, as in turbid systems, much of the primary production occurs in shallow littoral zones where sufficient sunlight can penetrate to the surface sediments to stimulate benthic biofilms. In such cases, GPP is dominated by primary production by benthic algae (e.g. in biofilm matrices) rather than by primary production in the water column.

The benefit of establishing these relationships is that it also allows better prediction of metabolic rates in unmonitored sites where some nutrient data is available.

7 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 the ability of water-dependent ecosystems to support episodically high ecological productivity and its ecological dispersal. As noted earlier, the data from the Selected Areas showed significant, positive changes in stream metabolism in response to watering actions that provided base flows and freshes within river channels, when metabolism was expressed as the total mass (load) of organic carbon per day. ***This is a major finding supporting the ecological benefits of these smaller watering actions***. Although there are as yet no firm data, it is likely that watering actions that have 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, especially using the derived metabolism metrics (organic carbon produced/consumed). It is anticipated that increasing the number of days over which metabolic data are collected in the Gwydir will enable future investigation of the role of wetland return water.

It is strongly anticipated that increases in rates of GPP and ER, measured using these derived metrics, will result when the added water also brings in higher concentrations of nutrients and organic carbon (Entrainment Model; see Annex G, 1. 2,**Error! Reference source not found.**). It is expected 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 associated with major wetting events, but not extended duration flooding, initially through the CEWO Monitoring Evaluation and Research Program from 2019-2020 onwards.

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 GPP and ER rates (due to dilution), the effects appeared to be relatively temporary. Using the full five-year LTIM data set and the methodology described in this report has enabled disentangling of normal seasonal effects on metabolic rates (e.g. the determination of seasonal 'counterfactual' flows and the associated metabolic rates and ensuing loads of organic carbon produced and consumed) and changes induced by Commonwealth environmental water. Further insights are anticipated as the MER Program builds on this new understanding. The best way to 'flesh out' these insights is to vary the amount and timing of CEW delivery within each Selected Area from year to year (within operational constraints). *For this reason,* ***it is vital that, if possible, 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 has only considered the stream channel data from all of the metabolism sites in each Selected Area, but 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 dissolved oxygen conditions found in a nearby site that did not receive this water and that watering actions successfully mitigated the extent and duration of low oxygen/anoxia arising from the major flooding in the southern Basin in spring-early summer of 2016 (Watts et al. 2017, Wassens et al. 2017).

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Annex A. Conceptual understanding of flow-metabolism relationships

A.1. Conceptual understanding – influence of flow

There are four ways by which flow may influence river metabolism. These influences are not mutually exclusive and metabolic responses to changes in flow may involve interactions among the various responses. The next four subsections provide a brief summary of these influences.

A.1.1. Available habitat

Flow interacts with channel morphology to create habitat for algae and macrophytes, with the habitat characteristics influencing the species present, their abundance and distribution. As an example, in a clear water system where light penetrates to the streambed, the area of illuminated streambed represents the available habitat for attached algae (**Error! Reference source not found.**). An increase in flow increases the amount of habitat available for these algae. The increase in flow may also mean that other components, such as plant stems and wood, may also become available as habitat. Even in turbid systems in which planktonic algae dominate, an increase in flow may be associated with an increase in channel width which also represents an increase in the amount of habitat available for floating algae.

The relationship between flow and algal habitat can be quite complex as increases in flow are not always associated with predictable changes in habitat availability; for example:

- The relationship between the area of inundated streambed and discharge is not linear, and small changes in discharge may be associated with large increases in the area inundated.
- Increases in discharge may reduce the amount of illuminated streambed due to depth or changes in turbidity.
- Changes in discharge may create or destroy slack water habitats that are important for planktonic algae.

When new habitat is created or existing habitat is changed, the algal community takes time to respond because the response may include colonisation or growth from very small numbers. The time taken to respond will depend on other conditions including temperature, light and nutrients, but usually occurs with 2-4 weeks.

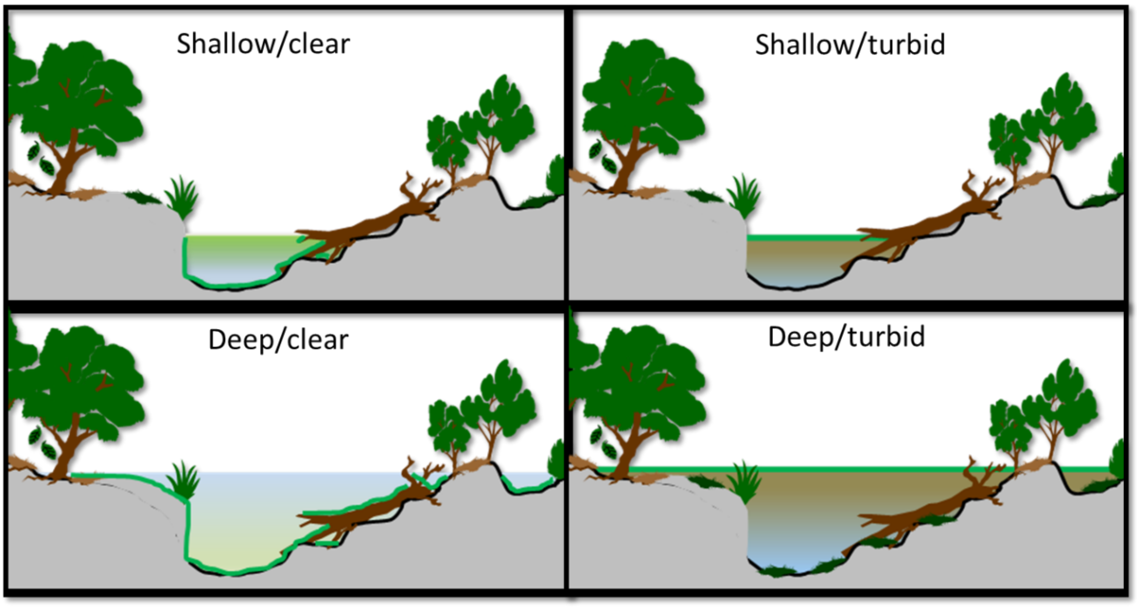

Figure 32. Conceptual model of increased flow and turbidity effects on stream metabolism through their influence on habitat (Habitat Model). In shallow/clear systems, light penetrates to the riverbed, but there is less habitat than when flows increase (deep/clear). In turbid systems, light may not penetrate to the riverbed, meaning that primary production is confined to the 'bathtub ring' and floating algae. In these systems, increases in flow may lead to an increase in the size of both the illuminated water column and inundated sediment (deep/turbid)

A.1.2 Entrainment

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. **Error! Reference source not found.** shows that when discharge levels increase, more nutrients and organic matter can be transported into the stream, potentially alleviating nutrient and organic matter limitation. Fuß *et al.* (2017) recently demonstrated that both the quantity and quality (chemical composition) of the dissolved organic matter in flowing waters had major impacts on ecosystem respiration in 33 streams in Austria; the nature and amount of this organic matter was, in part, determined by land use. In addition, land use, and specifically agricultural activities, were closely linked to effects on primary production, mediated by nutrient delivery. It concluded that organic carbon was the link between catchment activities and stream metabolism.

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).

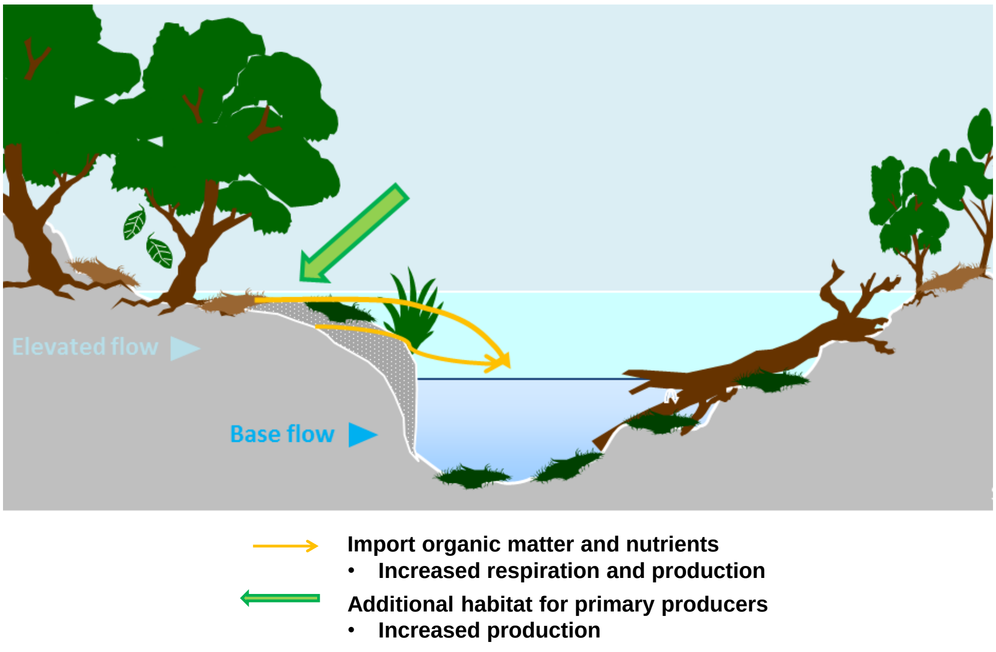

Figure 33. Conceptual model of increased flow effects on stream metabolism through increased nutrient and organic matter delivery from riparian and floodplain habitats (Entrainment Model).

A.1.3 Mixing or resuspending material

There are several situations in which changes in flow can entrain material that has accumulated within sinks found in river channels. Examples of these sinks include:

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

Within the channel, organic matter may accumulate in areas of low flow, such as slack waters or the bottom of deep pools (**Error! Reference source not found.**). 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).

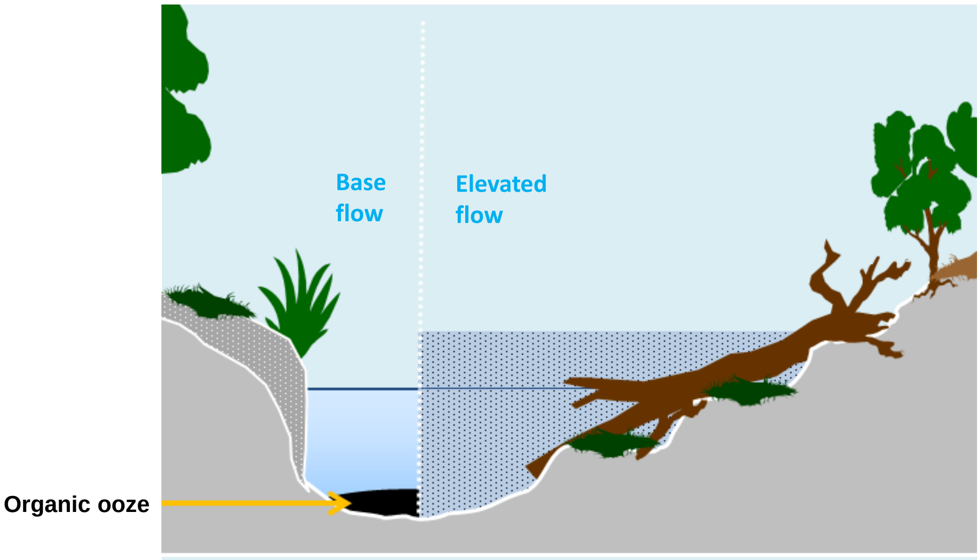

Figure 34. Conceptual model of increased flow effects on stream metabolism through resuspension of soft bottom sediments (Mixing Model).

A.1.4 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 and respiration in a stream. Flow events with sufficient stream power (resulting from higher water velocities) cause scouring of these biofilms (Ryder *et al*. 2006) and can 'reset' primary production to very low rates which are then maintained until the 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) (**Error! Reference source not found.**).

Reductions in flow may also disturb biofilms through desiccation. The drying of the biofilms kills much of the microbial community and the slime in which the algae and bacteria are imbedded dries, shrinks and cracks. When the surface is then inundated, the dried biofilm often sloughs off, leaving an altered community.

Planktonic communities of algae and bacteria are also subject to disturbance by changes in flow (Reynolds *et al.* 1991; Reynolds 1992; Reynolds & Descy 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 slack waters within the reach. As discharge increases, existing slack waters may be flushed out and the overall area of slack waters may change, either increasing or decreasing. The flushing of slack waters will lead to reductions in floating algae. The longer-term effects will depend on populations building up in newly created slack waters

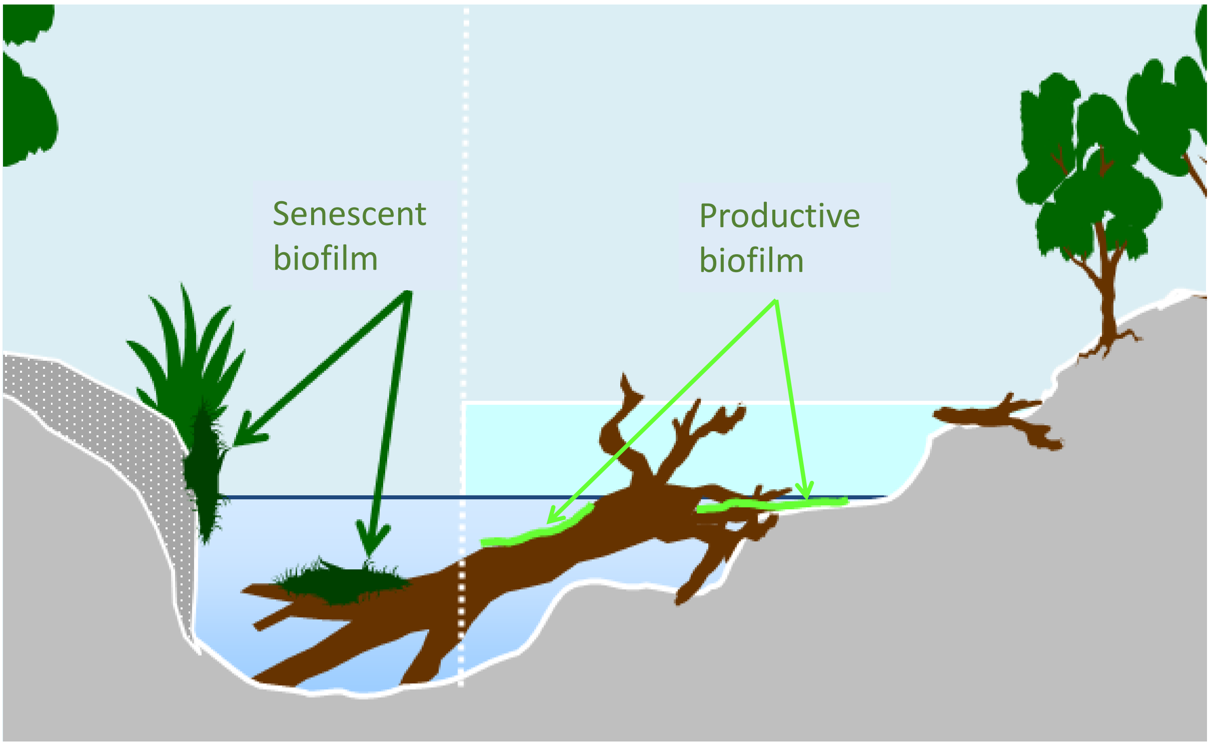

Figure 35. Conceptual model of increased flow effects on stream metabolism through scouring of biofilms (Disturbance Model).

A.2 Conceptual understanding – flow types

The discussion in section 1.3 describes how flow changes may influence stream metabolism. This information can be used to make predictions of how the allocation of environmental flows to different flow types is likely to influence stream metabolism. The response to a given environmental flow is complicated by the fact that several of the processes described in the sections above may occur during the same flow. Our understanding of how these processes interact is currently limited; however, it will improve as the LTIM monitors more environmental flows and builds the capacity to evaluate both flow responses per unit volume and at the reach scale. The following sections describe the influence of the major flow types included in the Basin Plan to illustrate how we believe flow can affect metabolism in multiple ways.

A.2.1 Cease to flow

The effects of cease-to-flow events on metabolism may be complex due to interactions between changes in habitat availability, accumulation of material and food-web changes. Toward the later stages of drying, metabolism is likely to increase as consumers are lost and material accumulates in still water. Cease-to-flow events are often associated with declines in water quality (**Error! Reference source not found.**). Ultimately, flow cessation may lead to drying, which is a disturbance that will ultimately lead to major reductions or cessation of metabolism. While the cease to flow and subsequent drying will affect metabolism, subsequent inundation may be associated with an increase in metabolism in response to release of nutrients from dried sediments and dead or accumulated organic matter.

Figure 36. An algal bloom within a still pool of the drying Ovens River during the millennium drought.

A.2.2 Base flows

Base flows are often dominated by algal production as inputs of terrestrial organic matter are reduced due to the limited lateral connectivity and the increased distance between the water and riparian vegetation. Flow influences the amount of available habitat and also interacts with factors including substrate availability (sediment type, wood, macrophytes), nutrient availability and light availability (season, weather and turbidity) to determine productivity. Allocating environmental water to enhance base flows can influence the amount of available habitat, but also prevent cease-to-flow conditions associated with declines in water quality.

A.2.3 Freshes

Metabolic responses to freshes are complicated because they integrate three different processes:

1. Entrainment (Section 1.3.2) of organic material and nutrients from adjacent habitats has the capacity to influence metabolism, increasing the use of entrained organic matter. This model was proposed by Tockner *et al.* (1999) in a modification of the flood pulse concept (Junk *et al.* 1989).
2. Disturbance (Section 1.3.4) – the increase in discharge may both flush out slack water areas where floating algae accumulate and also scour attached biofilms. Both of these influences may reduce metabolism in the short term, but may end up leading to higher rates if the disturbed biofilms had become senescent prior to the fresh.
3. Available habitat – increasing discharge may create additional habitat for primary producers; however, utilisation of this new habitat takes time as the algae or plants need to colonise and then grow. This response is also likely to be variable depending on the time of year (influence of light and temperature) and the influence of the change in flow on turbidity (source of water, disturbed sediments) and the amount and type of habitat inundated.

If the fresh entrains significant amounts of organic matter, one would expect a fresh to be associated with an increase in decomposition per unit volume. The amount of organic matter entrained will depend on antecedent flow conditions, condition of stream-side vegetation and the area of bank/riparian habitat inundated. The algal response will depend on the change in current velocity, slack water habitat and factors that influence algal growth (e.g. nutrients, light and temperature). As noted above, the complexity of these interactions means we expect responses to freshes to be variable.

A.2.4 Bankfull

Metabolic responses to bankfull may be similar to those described for freshes if they are of short duration. The effects of longer periods of bankfull discharge will depend on river morphology and riparian vegetation. In general, deeper water limits light penetration and this reduces habitat for attached biofilms and tends to favour floating algae. Floating algae can accumulate if algae are retained in the reach and this is influenced by the interaction between flow and channel morphology. Slack water areas , for example bank indentations, reduce the average water velocity and may enhance light penetration and nutrient supply, thereby resulting in enhanced growth of floating algae. Many rivers have low retention when running at bankfull with limited slack water or backwater habitats to retain algae. Retention also influences the fate of external organic matter that may enter the river, increasingly the likelihood that it will be transported downstream.

A.2.5. Overbank flows

Overbank flows are associated with large increases in metabolism for a number of reasons, including:

- inundation of accumulated organic matter and associated nutrients
- increases in the amount of available habitat – large areas of shallow water, macrophytes and plant material
- changes in water quality as a result of subsidies coming from the floodwater and their settlement on the floodplain in slow-flowing water.

While all these factors may contribute to an increase in metabolism, every overbank flow is different and the type of metabolic increase, magnitude and fate of the organic matter will all vary in response to a number of factors, including land use, sediment loads, flow paths and hydraulics, antecedent flow conditions, duration and timing of the overbank flow.

Annex B. Summary Characteristics of Stream Discharge stratified into Flow Categories

The following table categorizes daily flow in terms of the flow categories delineated in Table 3.

		LTIM Site Name	Hopwood, Windra Vale	Widgee	Barham Bridge, Noorong	Narrandera	McKenna's	Murray Lock 6	Murray Lock 1	Moss Rd & Day Rd	Darcy's Track	McCoys	Akuna	Yanda	Whealbah	Lane's Bridge, Cowl Cowl
Season	**Flow Cat**	**Stream Gauge Site**	**Yallakool Offtake**	**Wakool Offtake**	**Barham-Moulamien**	**Narrandera**	**Carrathool**	**Lock 6**	**Lock 1**	**Murchison**	**Murchison**	**McCoys**	**Louth**	**Bourke**	**Whealbah**	**Hillston Weir**
Spring	<V Low	n	0	0	0	0	0	0	0	0	0	0	264	260	4	1
		Mean											44	59	17	13
		Median											0	24	17	13
	V Low	n	0	207	14	2	10	79	61	183	183	118	100	104	114	21
		Mean		56	259	897	776	1403	3260	690	693	736	418	397	71	86
		Median		59	254	897	805	1276	3500	724	750	750	414	391	70	86
	Mod Low	n	0	163	86	5	18	24	128	84	82	128	0	0	112	49
		Mean		89	405	1521	1183	3665	4613	1064	1067	1341			157	165
		Median		79	411	1493	1172	3967	4485	968	970	1386			152	167
	Low Fresh	n	0	7	257	40	67	157	136	52	53	52	0	0	41	142
		Mean		259	486	2541	2006	5576	7378	2581	2574	2468			293	296
		Median		279	487	2624	2012	5619	7483	2676	2656	2481			288	291
	Med Fresh	n	176	21	25	238	237	104	39	112	113	105	23	23	72	123
		Mean	418	548	756	5107	3457	8602	9280	5734	5717	5405	6056	6249	585	634
		Median	431	427	719	5101	3424	8221	9044	5818	5817	5621	6184	6522	547	614
	High Fresh	n	225	45	15	117	68	64	83	24	24	44	47	37	15	20
		Mean	533	2950	2024	11069	9019	39839	37903	16760	16760	14397	20276	19652	2278	1874
		Median	496	3098	2003	8963	9471	37796	35551	17167	17167	12502	20884	20738	2375	1486
	Overbank	n	53	9	58	53	55	27	8	0	0	7	21	31	97	99
		Mean	4637	6289	11628	52554	40675	66517	52606			39340	32554	36402	5046	6213
		Median	4804	6400	10845	54826	46285	63512	52775			40392	32791	37371	5133	6480

		LTIM Site Name	Hopwood, Windra Vale	Widgee	Barham Bridge, Noorong	Narrandera	McKenna's	Murray Lock 6	Murray Lock 1	Moss Rd & Day Rd	Darcy's Track	McCoys	Akuna	Yanda	Whealbah	Lane's Bridge, Cowl Cowl
Season	**Flow Cat**	**Stream Gauge Site**	**Yallakool Offtake**	**Wakool Offtake**	**Barham-Moulamien**	**Narrandera**	**Carrathool**	**Lock 6**	**Lock 1**	**Murchison**	**Murchison**	**McCoys**	**Louth**	**Bourke**	**Whealbah**	**Hillston Weir**
Summer	<V Low	n	0	1	0	0	0	0	0	0	0	0	330	313	10	0
		Mean		12.8									20	30	17	
		Median											0	0	14	
	V Low	n	0	298	90	0	31	13	80	122	124	137	98	112	109	4
		Mean		49	247		636	2377	3125	759	756	733	427	440	75	69
		Median		51	243		724	2434	3206	783	782	692	354	399	82	66
	Mod Low	n	0	125	149	10	47	94	147	168	168	147	11	13	165	21
		Mean		85	358	1669	1301	3075	4904	1151	1148	1251	1553	1585	166	183
		Median		74	358	1678	1331	2982	4999	1093	1091	1213	1486	1511	164	184
	Low Fresh	n	3	19	173	28	62	113	133	156	155	154	10	12	78	122
		Mean	181	210	482	2517	1984	5698	6731	2597	2600	2559	2545	2727	286	317
		Median	182	202	483	2609	1990	5854	6634	2698	2700	2679	2380	2720	271	320
	Med Fresh	n	366	0	6	253	254	177	49	1	1	7	2	1	52	257
		Mean	358		829	5417	3737	9151	12382	6829	6829	4275	3801	3699	627	585
		Median	372		831	5415	3899	8469	11989	6829	6829	4051	3801	3699	645	577
	High Fresh	n	82	0	31	160	57	32	9	3	3	6	0	0	24	37
		Mean	560		1442	9268	6232	19477	20894	11126	11126	12827			1768	1730
		Median	523		1460	8950	5900	16857	19011	12351	12351	13272			1792	1801
	Overbank	n	0	0	0	0	0	20	33	0	0	0	0	0	13	10
		Mean						87548	70609						4823	5344
		Median						90277	71900						4994	5576

		LTIM Site Name	Hopwood, Windra Vale	Widgee	Barham Bridge, Noorong	Narrandera	McKenna's	Murray Lock 6	Murray Lock 1	Moss Rd & Day Rd	Darcy's Track	McCoys	Akuna	Yanda	Whealbah	Lane's Bridge, Cowl Cowl
Season	**Flow Cat**	**Stream Gauge Site**	**Yallakool Offtake**	**Wakool Offtake**	**Barham-Moulamien**	**Narrandera**	**Carrathool**	**Lock 6**	**Lock 1**	**Murchison**	**Murchison**	**McCoys**	**Louth**	**Bourke**	**Whealbah**	**Hillston Weir**
Autumn	<V Low	n	27	86	3	0	0	0	0	0	0	0	257	293	6	4
		Mean	1	1	50								24	25	20	20
		Median	0	0	50								0	0	20	20
	V Low	n	5	340	263	30	214	93	136	126	124	117	162	127	234	202
		Mean	42	43	248	801	572	1283	2779	781	782	860	619	588	71	71
		Median	42	44	254	847	554	1306	2631	821	820	897	593	530	70	69
	Mod Low	n	3	34	161	158	53	148	226	191	191	193	26	31	193	148
		Mean	94	71	346	1503	1203	3248	4588	1115	1115	1196	1309	1464	155	171
		Median	96	69	340	1549	1169	3101	4408	966	968	1074	1256	1393	148	173
	Low Fresh	n	47	0	33	106	59	130	93	115	116	121	7	3	23	97
		Mean	176		460	2274	2015	5497	6676	2439	2436	2446	2566	2904	254	288
		Median	179	0	462	2217	2063	5383	6454	2452	2449	2470	2597	2971	244	287
	Med Fresh	n	367	0	0	159	134	89	5	28	28	29	0	5	4	9
		Mean	276			4723	3034	7964	10280	4108	4108	3857		4290	412	436
		Median	265			4658	2997	7701	10548	4169	4169	3891		4348	412	453
	High Fresh	n	10	0	0	7	0	0	0	0	0	0	0	0	0	0
		Mean	483			8450										
		Median	486			8427										
	Overbank	n	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Mean														
		Median														

		LTIM Site Name	Hopwood, Windra Vale	Widgee	Barham Bridge, Noorong	Narrandera	McKenna's	Murray Lock 6	Murray Lock 1	Moss Rd & Day Rd	Darcy's Track	McCoys	Akuna	Yanda	Whealbah	Lane's Bridge, Cowl Cowl
Season	**Flow Cat**	**Stream Gauge Site**	**Yallakool Offtake**	**Wakool Offtake**	**Barham-Moulamien**	**Narrandera**	**Carrathool**	**Lock 6**	**Lock 1**	**Murchison**	**Murchison**	**McCoys**	**Louth**	**Bourke**	**Whealbah**	**Hillston Weir**
Winter	<V Low	n	172	280	194	0	0	0	0	0	0	0	155	177	9	0
		Mean	0	1	8								59	50	20	
		Median	0	0	3								39	39	22	
	V Low	n	3	97	178	3	48	77	126	243	243	73	238	212	178	121
		Mean	32	43	211	977	646	1174	3083	697	696	817	533	544	66	73
		Median	38	45	220	976	635	1183	3119	802	802	816	493	504	60	75
	Mod Low	n	4	46	37	95	83	97	137	74	75	161	11	9	170	191
		Mean	93	102	336	1595	1277	3538	4666	1164	1168	1191	1504	1546	154	167
		Median	92	98	330	1623	1299	3690	4642	1052	1054	1081	1403	1655	152	167
	Low Fresh	n	69	5	30	109	84	150	84	50	49	67	19	8	16	50
		Mean	177	249	473	2314	1884	5449	7011	2490	2495	2449	2740	2701	292	278
		Median	177	256	470	2284	1822	5404	6967	2437	2443	2405	2842	2662	288	272
	Med Fresh	n	162	15	8	137	116	97	77	77	76	118	34	51	43	50
		Mean	293	688	879	4957	3398	10190	11941	5565	5589	5270	5480	5936	681	701
		Median	257	678	915	4958	3248	10023	11279	5103	5140	5228	5665	6285	731	772
	High Fresh	n	50	0	13	113	120	39	35	16	16	41	0	3	7	7
		Mean	625		1318	13430	9092	24682	24460	9102	9102	9419		8470	2058	2023
		Median	509		1315	12419	8805	25811	25317	8795	8795	8359		8457	1988	1860
	Overbank	n	0	0	0	3	9	0	0	0	0	0	0	0	37	40
		Mean				27686	16279								4228	4406
		Median				27410	16340								4218	4434

Annex C. Summaries of 2018–19 Results

Table C1 lists the data collection duration and number of days that the metabolism modelling results met acceptance criteria for all 20 sites in the six Selected Areas over the period 2018–19.

Table C1. Summary of stream metabolism data collection and rates of acceptance - Year 5.

Catchment	Logger site	Period of record		Days with metabolism data (no.)			
		First date	Last date	Pass	Fail	Total	% Accept
Edward–Wakool	Barham Bridge	29/5/18	15/4/19	128	111	239	54
Edward–Wakool	Hopwood	3/8/18	15/4/19	111	129	240	46
Edward–Wakool	Llanos Park2	29/5/18	15/4/19	128	176	304	42
Edward–Wakool	Noorong2	29/5/18	7/3/19	71	135	206	34
Edward-Wakool	Cummins	29/5/18	15/4/19	86	218	304	28
Edward–Wakool	Widgee	22/8/18	15/4/19	132	78	210	63
Edward–Wakool	Windra Vale	4/8/18	15/4/19	152	87	239	64
Goulburn	Darcy's Track	1/7/18	20/4/19	88	103	191	46
Goulburn	Loch Garry Gauge	1/7/18	12/6/19	52	254	306	17
Goulburn	McCoy's Bridge	1/5/18	12/6/19	1027	462	1489	69
Goulburn	Moss Rd / Day Road	1/7/18	20/2/19	98	127	225	44
Lachlan	Cowl Cowl	1/7/18	31/3/19	100	174	274	36
Lachlan	Lane's Bridge	1/7/18	30/6/19	254	79	333	76
Lachlan	Whealbah	1/7/18	30/6/19	260	105	365	71
Lower Murray	LK1DS_265km	13/9/18	5/3/19	89	58	147	61
Lower Murray	LK6DS_616km	12/9/19	4/3/19	85	70	155	55
Murrumbidgee	McKenna's	25/9/18	16/4/19	186	13	199	93
Murrumbidgee	Narrandera	26/9/18	16/4/19	147	23	170	86
Warrego–Darling	Akuna	1/7/18	21/4/19	74	220	294	25#
Warrego–Darling	Yanda	1/7/18	14/12/18	49	80	129	38#

Acceptance criteria lowered to $r^2 > 0.75$ to ensure sufficient data to analyse.

Annex D. Summary statistics for all stream metabolism data.

Data in the Tables D1 (GPP) and D2 (ER) are summarised for each of the six Selected Areas with Stream Metabolism data in MDMS, i.e. Junction of the Warrego and Darling rivers, Lachlan river system, Murrumbidgee river system, Edward–Wakool river system, Goulburn River and Lower Murray River. These data are presented firstly grouped by Selected Area and then stratified into seasons (Tables D3 and D4) pooled across the five years of sampling (2014–15, 2015–16, 2016–17, 2017–18 and 2018–19) Table D5 presents Net Primary Production (NPP). Tables D6 (GPP) and D7 (ER) further stratify this data set into season x year to facilitate inter-annual comparisons across the four years. Only data that met the daily acceptance criteria are included in this table.

Table D1. Gross primary productivity (mg O_2/L/Day) in each Selected Area (2014–2019).

Selected Area	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Goulburn	4	2213	1.76	1.94	0.04	0.01	25.7	1.27	0.85	2.01
Edward-Wakool	7	4291	2.41	2.39	0.04	0.04	42.3	1.78	1.13	2.86
Murrumbidgee	2	1168	1.52	1.34	0.04	0.11	13.6	1.22	0.88	1.67
Lachlan	3	2148	2.53	1.71	0.04	0.02	12.4	2.12	1.36	3.27
Lower Murray	2	757	1.99	1.19	0.04	0.05	9.53	1.77	1.18	2.56
Warrego-Darling	2	495	5.67	6.05	0.27	0.20	33.5	3.31	1.38	7.80

Table D2. Ecosystem Respiration (mg O_2/L/Day) in each Selected Area (2014–2019).

Selected Area	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Goulburn	4	2213	3.61	3.86	0.08	0.03	48.1	2.37	1.45	4.39
Edward-Wakool	7	4291	5.14	4.37	0.07	0.03	62.5	3.95	2.43	6.43
Murrumbidgee	2	1168	1.38	0.92	0.03	0.06	9.42	1.17	0.80	1.71
Lachlan	3	2148	4.52	2.79	0.06	0.26	32.7	4.05	2.67	5.70
Lower Murray	2	757	1.74	1.28	0.05	0.04	15.8	1.44	0.90	2.29
Warrego-Darling	2	495	9.70	9.63	0.43	0.19	79.7	7.48	3.68	12.2

Table D3. Gross primary productivity (mg O_2/L/Day) in each Selected Area (2014–19) stratified by season.

Selected Area and season	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Goulburn – spring	4	567	1.62	1.55	0.06	0.03	11.5	1.21	0.74	1.91
Goulburn – summer	4	894	1.76	1.94	0.04	0.01	25.7	1.27	0.85	2.01
Goulburn – autumn	4	606	1.27	1.44	0.06	0.30	25.7	1.04	0.77	1.38
Goulburn – winter	4	146	0.55	0.31	0.03	0.01	1.85	0.55	0.33	0.75
Edward–Wakool – spring	7	1299	1.42	1.25	0.03	0.04	14.8	1.11	0.81	1.56
Edward–Wakool – summer	7	1791	2.98	2.81	0.07	0.32	42.3	2.29	1.67	3.33
Edward–Wakool – autumn	7	827	3.24	2.42	0.08	0.54	23.2	2.46	1.62	4.17
Edward–Wakool – winter	7	374	1.30	1.31	0.07	0.33	11.9	1.00	0.72	1.42
Murrumbidgee – spring	2	372	1.14	0.96	0.05	0.11	10.5	0.91	0.68	1.30
Murrumbidgee – summer	2	560	1.77	1.48	0.06	0.24	13.6	1.41	1.07	1.90
Murrumbidgee – autumn	2	236	1.52	1.35	0.09	0.66	12.6	1.25	1.04	1.56
Murrumbidgee – winter		0								
Lachlan – spring	3	605	2.40	1.37	0.06	0.07	12.4	2.25	1.51	2.93
Lachlan – summer	3	630	3.50	1.83	0.07	0.16	12.4	3.17	2.07	4.50
Lachlan – autumn	3	501	2.62	1.69	0.08	0.46	11.1	2.14	1.59	3.17
Lachlan – winter	3	412	1.12	0.62	0.03	0.02	5.09	1.07	0.74	1.40

Table D3 cont...

Selected Area and season	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Lower Murray – spring	2	280	1.16	0.54	0.03	0.12	3.52	1.10	0.80	1.44
Lower Murray – summer	2	448	2.42	1.17	0.06	0.05	9.53	2.26	1.66	2.98
Lower Murray – autumn	2	29	3.38	1.21	0.23	2.08	6.22	2.91	2.28	4.08
Lower Murray – winter		0								
Warrego–Darling – spring	2	171	5.23	5.35	0.41	0.55	33.5	3.12	1.94	6.46
Warrego–Darling – summer	2	90	11.4	5.64	0.59	1.91	22.6	11.3	6.50	15.8
Warrego–Darling – autumn	2	93	6.62	7.23	0.75	0.31	32.4	4.40	1.34	8.27
Warrego–Darling – winter	2	141	1.93	1.89	0.16	0.20	12.5	1.16	0.72	2.42

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 winter in the Murrumbidgee and Lower Murray River. Autumn data was collected from only one (McKenna's) of the two Murrumbidgee River sites until 2018–19.

Table D4. Ecosystem respiration (mg O_2/L/Day) in each Selected Area (2014–19) stratified by season.

Selected Area and season	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Goulburn – spring	4	567	3.57	3.98	0.17	0.03	24.3	2.04	1.03	4.59
Goulburn – summer	4	894	4.44	4.29	0.14	0.11	40.7	3.26	2.12	5.26
Goulburn – autumn	4	606	2.48	2.97	0.12	0.20	48.1	1.80	1.22	2.66
Goulburn – winter	4	146	3.44	2.38	0.20	0.16	11.2	2.46	1.81	5.01
Edward–Wakool – spring	7	1299	3.84	3.56	0.10	0.03	27.7	2.72	1.68	4.56
Edward–Wakool – summer	7	1791	6.29	4.25	0.10	0.49	40.1	5.04	3.63	7.61
Edward–Wakool – autumn	7	827	5.75	4.07	0.14	0.40	33.3	4.21	3.18	7.04
Edward–Wakool – winter	7	374	2.77	5.81	0.30	0.06	62.5	1.57	1.03	2.66
Murrumbidgee – spring	2	372	0.97	0.61	0.03	0.06	6.24	0.85	0.65	1.15
Murrumbidgee – summer	2	560	1.65	1.06	0.04	0.06	9.42	1.41	1.05	1.97
Murrumbidgee – autumn	2	236	1.41	0.71	0.05	0.15	5.38	1.24	0.93	1.83
Murrumbidgee – winter		0								
Lachlan – spring	3	605	3.67	2.07	0.08	0.26	16.6	3.36	2.33	4.51
Lachlan – summer	3	630	5.62	2.82	0.11	0.61	27.3	5.28	3.89	6.65
Lachlan – autumn	3	501	5.18	2.69	0.12	0.34	19.4	4.82	3.45	6.35
Lachlan – winter	3	412	3.27	2.89	0.14	0.26	32.7	2.65	1.78	3.74

Table D4 cont...

Selected Area and season	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Lower Murray – spring	2	280	1.02	0.65	0.04	0.04	5.83	0.94	0.57	1.32
Lower Murray – summer	2	448	2.04	1.26	0.06	0.10	15.8	1.88	1.22	2.56
Lower Murray – autumn	2	29	3.93	1.83	0.34	1.24	8.09	3.54	2.35	4.91
Lower Murray – winter		0								
Warrego–Darling – spring	2	171	8.31	7.18	0.55	0.22	39.2	6.81	3.12	11.4
Warrego–Darling – summer	2	90	12.6	12.2	1.28	0.73	79.7	10.5	5.94	15.1
Warrego–Darling – autumn	2	93	14.4	12.9	1.33	1.44	77.6	10.4	7.39	15.5
Warrego–Darling – winter	2	141	6.43	5.33	0.45	0.19	23.4	4.38	2.63	9.04

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 winter in the Murrumbidgee and Lower Murray River. Autumn data was collected from only one (McKenna's) of the two Murrumbidgee River sites until 2018–19.

Table D5. Net Primary Production (NPP, mg O_2/L/Day) in each Selected Area (2014–19) stratified by season.

Selected Area and season	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Goulburn – spring	4	567	-1.95	3.39	0.14	-21.58	3.17	-0.69	-3.12	0.03
Goulburn – summer	4	894	-2.05	3.12	0.10	-21.75	12.09	-1.55	-3.23	-0.22
Goulburn – autumn	4	606	-1.21	2.19	0.09	-22.38	7.15	-0.71	-1.48	-0.15
Goulburn – winter	4	146	-2.89	2.37	0.20	-10.34	1.69	-2.00	-4.44	-1.20
Edward–Wakool – spring	7	1299	-2.42	2.94	0.08	-20.85	5.48	-1.51	-3.24	-0.66
Edward–Wakool – summer	7	1791	-3.31	3.36	0.08	-38.35	18.34	-2.57	-4.68	-1.39
Edward–Wakool – autumn	7	827	-2.52	3.97	0.14	-29.07	10.50	-1.98	-3.89	-0.75
Edward–Wakool – winter	7	374	-1.47	4.73	0.25	-52.79	1.96	-0.57	-1.44	-0.17
Murrumbidgee – spring	2	372	0.17	0.75	0.04	-2.43	4.25	0.05	-0.17	0.41
Murrumbidgee – summer	2	560	0.13	1.18	0.05	-4.88	10.23	-0.06	-0.40	0.35
Murrumbidgee – autumn	2	236	0.11	1.19	0.08	-2.99	8.39	-0.02	-0.38	0.22
Murrumbidgee – winter		0								
Lachlan – spring	3	605	-1.27	2.23	0.09	-13.95	5.53	-1.01	-2.18	-0.12
Lachlan – summer	3	630	-2.12	2.93	0.12	-20.37	7.86	-1.95	-3.30	-0.84
Lachlan – autumn	3	501	-2.57	2.86	0.13	-14.21	6.92	-2.47	-3.85	-1.07
Lachlan – winter	3	412	-2.15	2.60	0.13	-29.61	1.70	-1.58	-2.64	-0.70

Table D5 cont...

Selected Area and season	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Lower Murray – spring	2	280	0.15	0.66	0.04	-4.15	3.30	0.16	-0.09	0.48
Lower Murray – summer	2	448	0.38	1.29	0.06	-15.73	9.04	0.34	-0.01	0.72
Lower Murray – autumn	2	29	-0.55	1.32	0.24	-3.29	1.30	-0.18	-1.66	0.40
Lower Murray – winter		0								
Warrego–Darling – spring	2	171	-3.09	5.15	0.39	-29.43	11.43	-1.94	-5.49	0.10
Warrego–Darling – summer	2	90	-1.18	11.56	1.22	-74.38	10.73	0.74	-1.57	3.69
Warrego–Darling – autumn	2	93	-7.80	7.78	0.81	-48.08	1.38	-6.21	-11.62	-2.01
Warrego–Darling – winter	2	141	-4.51	4.04	0.34	-18.48	0.30	-3.23	-6.61	-1.54

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 winter in the Murrumbidgee and Lower Murray River. Autumn data was collected from only one (McKenna's) of the two Murrumbidgee River sites until 2018–19.

Table D6. Gross primary productivity (mg O_2/L/Day), stratified by season and year.

Data Set	n	Mean	Std Dev	Max	Min	Median	25%	75%
Goulburn-Spring 2014–15	37	1.34	0.85	3.48	0.48	1.00	0.65	2.08
Goulburn-Spring 2015–16	85	1.64	1.25	5.98	0.26	1.24	0.71	2.19
Goulburn-Spring 2016–17	57	2.65	1.04	7.57	0.89	2.62	2.02	3.15
Goulburn-Spring 2017–18	177	1.79	2.07	11.47	0.08	1.21	0.85	1.84
Goulburn-Spring 2018–19	210	1.24	1.15	10.28	0.03	1.04	0.66	1.47
Goulburn-Summer 2014–15	183	1.98	1.05	6.78	0.60	1.73	1.34	2.25
Goulburn-Summer 2015–16	81	4.43	3.64	20.75	1.23	3.13	2.07	6.03
Goulburn-Summer 2016–17	233	2.16	1.58	12.22	0.50	1.63	1.24	2.61
Goulburn-Summer 2017–18	215	2.38	3.34	22.90	0.03	1.54	1.04	2.25
Goulburn-Summer 2018–19	182	2.21	1.33	11.44	0.64	2.03	1.33	2.68
Goulburn-Autumn 2014–15	94	1.45	1.55	14.30	0.47	1.00	0.71	1.78
Goulburn-Autumn 2015–16	113	1.40	1.19	11.52	0.55	1.07	0.91	1.62
Goulburn-Autumn 2016–17	165	1.09	0.52	4.54	0.30	1.06	0.80	1.23
Goulburn-Autumn 2017–18	125	0.98	0.46	3.48	0.40	0.85	0.71	1.06
Goulburn-Autumn 2018–19	108	1.38	1.32	13.84	0.39	1.17	0.88	1.53
Goulburn-Winter 2014–15	0							
Goulburn-Winter 2015–16	16	0.66	0.62	1.85	0.01	0.47	0.20	0.95
Goulburn-Winter 2016–17	26	0.70	0.13	0.83	0.15	0.72	0.66	0.77
Goulburn-Winter 2017–18	48	0.48	0.22	0.86	0.05	0.51	0.32	0.68
Goulburn-Winter 2018–19	56	0.51	0.28	1.11	0.04	0.46	0.25	0.79
Edward-Wakool-Spring 2014–15	390	1.76	1.78	14.78	0.27	1.19	0.88	1.92
Edward-Wakool-Spring 2015–16	142	1.56	1.62	10.29	0.04	1.21	0.75	1.61
Edward-Wakool-Spring 2016–17	153	1.12	0.80	3.70	0.09	0.92	0.59	1.38
Edward-Wakool-Spring 2017–18	470	1.35	0.66	5.71	0.29	1.18	0.93	1.58
Edward-Wakool-Spring 2018–19	144	0.87	0.31	2.19	0.35	0.82	0.65	1.04
Edward-Wakool-Summer 2014–15	297	2.85	2.21	19.28	0.77	2.21	1.65	3.35
Edward-Wakool-Summer 2015–16	297	4.83	5.15	42.31	0.65	3.37	2.04	5.40
Edward-Wakool-Summer 2016–17	305	2.76	1.77	16.31	0.32	2.35	1.81	3.13
Edward-Wakool-Summer 2017–18	467	2.91	1.67	14.80	0.76	2.58	1.97	3.45
Edward-Wakool-Summer 2018–19	425	2.01	1.67	19.79	0.53	1.70	1.25	2.31
Edward-Wakool-Autumn 2014–15	78	3.16	0.87	5.63	1.57	2.97	2.56	3.81
Edward-Wakool-Autumn 2015–16	145	6.55	3.18	23.19	2.50	5.85	4.28	7.64
Edward-Wakool-Autumn 2016–17	227	2.67	1.73	8.91	0.87	2.12	1.34	3.67
Edward-Wakool-Autumn 2017–18	255	2.16	1.10	6.29	0.58	1.90	1.47	2.50
Edward-Wakool-Autumn 2018–19	118	2.71	1.60	10.24	0.70	2.39	1.55	3.14
Edward-Wakool-Winter 2014–15	60	1.03	0.51	2.35	0.38	0.99	0.54	1.39
Edward-Wakool-Winter 2015–16	48	1.05	0.39	1.99	0.33	1.06	0.73	1.32
Edward-Wakool-Winter 2016–17	85	1.06	0.69	4.91	0.48	0.78	0.65	1.10
Edward-Wakool-Winter 2017–18	87	2.07	2.38	11.92	0.46	1.34	0.89	2.02
Edward-Wakool-Winter 2018–19	94	1.11	0.51	3.11	0.37	1.00	0.84	1.27

Table D6 continued…

Data Set	n	Mean	Std Dev	Max	Min	Median	25%	75%
Lachlan-Spring 2014–15	142	2.00	1.25	12.37	0.44	1.79	1.33	2.37
Lachlan-Spring 2015–16	120	2.11	1.50	6.92	0.07	2.07	0.79	2.85
Lachlan-Spring 2016–17	13	2.08	1.13	3.73	0.15	2.60	1.15	2.96
Lachlan-Spring 2017–18	164	2.55	0.88	5.32	0.36	2.39	2.00	3.01
Lachlan-Spring 2018–19	166	2.81	1.64	8.62	0.51	2.56	1.61	3.49
Lachlan-Summer 2014–15	7	2.36	0.27	2.70	1.93	2.37	2.16	2.64
Lachlan-Summer 2015–16	189	2.34	1.05	5.93	0.66	2.04	1.67	2.88
Lachlan-Summer 2016–17	50	2.39	1.50	7.48	0.16	2.16	1.30	2.78
Lachlan-Summer 2017–18	198	4.10	1.46	9.73	1.01	4.05	3.00	5.09
Lachlan-Summer 2018–19	186	4.39	2.11	12.42	1.22	3.97	2.95	5.22
Lachlan-Autumn 2014–15	0							
Lachlan-Autumn 2015–16	140	1.84	0.97	5.31	0.49	1.67	1.19	2.18
Lachlan-Autumn 2016–17	56	2.77	1.01	5.18	0.50	2.81	2.22	3.45
Lachlan-Autumn 2017–18	164	3.66	2.18	11.12	1.17	2.81	2.11	4.70
Lachlan-Autumn 2018–19	141	2.11	1.09	5.37	0.46	1.78	1.46	2.29
Lachlan-Winter 2014–15	15	1.42	0.20	1.82	1.12	1.42	1.25	1.56
Lachlan-Winter 2015–16	105	0.90	0.52	3.31	0.22	0.81	0.54	1.15
Lachlan-Winter 2016–17	26	0.55	0.41	1.20	0.02	0.58	0.13	0.87
Lachlan-Winter 2017–18	145	1.40	0.76	5.09	0.06	1.27	0.98	1.68
Lachlan-Winter 2018–19	121	1.07	0.35	2.30	0.39	1.09	0.80	1.35
Murrumbidgee-Spring 2014–15	69	1.01	0.44	2.46	0.42	0.92	0.74	1.16
Murrumbidgee-Spring 2015–16	60	1.73	0.84	4.24	0.73	1.49	1.05	2.21
Murrumbidgee-Spring 2016–17	27	0.38	0.24	1.05	0.11	0.33	0.19	0.49
Murrumbidgee-Spring 2017–18	89	1.07	0.58	3.71	0.37	0.87	0.69	1.32
Murrumbidgee-Spring 2018–19	127	1.14	1.31	10.49	0.20	0.83	0.65	1.09
Murrumbidgee-Summer 2014–15	95	1.13	0.48	2.43	0.33	1.04	0.76	1.46
Murrumbidgee-Summer 2015–16	126	1.69	0.78	5.95	0.55	1.51	1.21	1.88
Murrumbidgee-Summer 2016–17	99	1.33	0.59	2.88	0.24	1.29	0.98	1.69
Murrumbidgee-Summer 2017–18	109	1.72	1.13	7.46	0.26	1.40	1.10	1.89
Murrumbidgee-Summer 2018–19	131	2.70	2.46	13.56	0.55	1.75	1.18	2.98
Murrumbidgee-Autumn 2014–15	41	1.04	0.24	1.67	0.66	1.02	0.83	1.23
Murrumbidgee-Autumn 2015–16	28	1.19	0.42	2.39	0.82	1.00	0.90	1.33
Murrumbidgee-Autumn 2016–17	44	1.29	0.43	2.63	0.82	1.14	1.05	1.37
Murrumbidgee-Autumn 2017–18	48	1.64	0.56	2.90	0.99	1.34	1.17	2.12
Murrumbidgee-Autumn 2018–19	75	1.96	2.24	12.58	0.81	1.41	1.20	1.65
Murrumbidgee-Winter 2014–15	0							
Murrumbidgee-Winter 2015–16	0							
Murrumbidgee-Winter 2016–17	0							
Murrumbidgee-Winter 2017–18	0							
Murrumbidgee-Winter 2018–19	0							

Table D6 continued…

Data Set	n	Mean	Std Dev	Max	Min	Median	25%	75%
Lower Murray-Spring 2014–15	17	1.30	0.36	1.82	0.66	1.36	0.98	1.56
Lower Murray-Spring 2015–16	75	1.18	0.28	2.23	0.62	1.15	0.99	1.32
Lower Murray-Spring 2016–17	42	0.55	0.25	1.17	0.12	0.58	0.37	0.71
Lower Murray-Spring 2017–18	75	1.48	0.52	3.52	0.67	1.40	1.10	1.79
Lower Murray-Spring 2018–19	71	1.15	0.63	3.33	0.19	0.98	0.67	1.42
Lower Murray-Summer 2014–15	82	2.48	1.02	4.79	0.31	2.55	1.62	3.28
Lower Murray-Summer 2015–16	74	2.33	0.61	4.52	1.23	2.33	1.90	2.63
Lower Murray-Summer 2016–17	99	2.91	0.95	5.01	0.05	2.95	2.40	3.50
Lower Murray-Summer 2017–18	96	2.26	1.42	9.53	0.81	1.86	1.49	2.47
Lower Murray-Summer 2018–19	97	2.11	1.37	8.03	0.48	1.82	1.39	2.23
Lower Murray-Autumn 2014–15	0							
Lower Murray-Autumn 2015–16	0							
Lower Murray-Autumn 2016–17	22	3.23	0.93	4.77	2.10	3.16	2.27	4.05
Lower Murray-Autumn 2017–18	0							
Lower Murray-Autumn 2018–19	6	4.02	1.99	6.22	2.08	3.69	2.24	6.15
Lower Murray-Winter 2014–15	0							
Lower Murray-Winter 2015–16	0							
Lower Murray-Winter 2016–17	0							
Lower Murray-Winter 2017–18	0							
Lower Murray-Winter 2018–19	0							
Warrego-Darling-Spring 2014–15	0							
Warrego-Darling-Spring 2015–16	31	3.87	3.50	17.50	0.75	2.60	1.72	5.70
Warrego-Darling-Spring 2016–17	0							
Warrego-Darling-Spring 2017–18	96	6.23	6.25	33.50	1.20	3.63	2.33	7.43
Warrego-Darling-Spring 2018–19	43	4.01	3.67	17.22	0.55	2.81	1.32	5.95
Warrego-Darling-Summer 2014–15	0							
Warrego-Darling-Summer 2015–16	6	4.54	1.08	5.60	3.03	4.77	3.38	5.58
Warrego-Darling-Summer 2016–17	0							
Warrego-Darling-Summer 2017–18	66	12.87	5.56	22.59	1.91	13.57	9.24	17.16
Warrego-Darling-Summer 2018–19	17	8.46	3.68	17.80	3.14	8.20	6.24	9.68
Warrego-Darling-Autumn 2014–15	0							
Warrego-Darling-Autumn 2015–16	0							
Warrego-Darling-Autumn 2016–17	0							
Warrego-Darling-Autumn 2017–18	79	4.72	4.78	24.55	0.31	3.32	1.32	7.24
Warrego-Darling-Autumn 2018–19	14	17.35	9.29	32.43	6.54	13.49	9.80	27.03
Warrego-Darling-Winter 2014–15	0							
Warrego-Darling-Winter 2015–16	0							
Warrego-Darling-Winter 2016–17	0							
Warrego-Darling-Winter 2017–18	92	1.30	0.80	4.93	0.20	1.08	0.77	1.57
Warrego-Darling-Winter 2018–19	49	3.10	2.66	12.53	0.21	3.22	0.63	5.40

Table D7. Ecosystem Respiration (mg O_2/L/Day), stratified by season and year.

Data Set	n	Mean	Std Dev	Max	Min	Median	25%	75%
Goulburn-Spring 2014–15	37	1.25	1.93	8.62	0.19	0.49	0.35	1.38
Goulburn-Spring 2015–16	85	1.89	2.30	17.68	0.03	0.97	0.77	2.69
Goulburn-Spring 2016–17	57	1.83	0.85	4.82	0.43	1.78	1.27	2.37
Goulburn-Spring 2017–18	177	4.08	4.38	20.21	0.06	2.39	1.14	5.49
Goulburn-Spring 2018–19	210	4.69	4.39	24.27	0.21	3.03	1.34	6.29
Goulburn-Summer 2014–15	183	3.04	2.27	11.39	0.11	2.25	1.25	4.31
Goulburn-Summer 2015–16	81	5.07	2.90	15.37	1.46	3.88	2.65	7.12
Goulburn-Summer 2016–17	233	4.26	2.87	23.74	0.72	3.64	2.46	5.15
Goulburn-Summer 2017–18	215	6.68	6.56	40.70	1.01	4.93	3.14	7.36
Goulburn-Summer 2018–19	182	3.14	3.24	18.09	0.21	2.29	1.72	2.92
Goulburn-Autumn 2014–15	94	1.85	1.78	8.75	0.20	1.12	0.75	2.48
Goulburn-Autumn 2015–16	113	1.86	0.98	4.95	0.25	1.69	1.10	2.48
Goulburn-Autumn 2016–17	165	2.30	2.42	16.67	0.34	1.69	1.12	2.25
Goulburn-Autumn 2017–18	125	3.17	2.90	15.62	0.83	2.04	1.38	3.43
Goulburn-Autumn 2018–19	108	2.75	2.55	22.40	0.85	2.14	1.72	2.84
Goulburn-Winter 2014–15	0							
Goulburn-Winter 2015–16	16	1.74	1.25	4.24	0.16	1.75	0.51	2.82
Goulburn-Winter 2016–17	26	1.88	0.30	2.60	1.36	1.87	1.67	2.01
Goulburn-Winter 2017–18	48	4.18	2.52	10.83	0.57	4.01	2.12	5.94
Goulburn-Winter 2018–19	56	4.02	2.50	11.24	0.74	3.24	2.01	5.91
Edward-Wakool-Spring 2014–15	390	3.65	3.47	20.35	0.03	2.44	1.51	4.66
Edward-Wakool-Spring 2015–16	142	5.32	5.20	27.74	0.12	3.51	2.38	6.11
Edward-Wakool-Spring 2016–17	153	4.64	3.86	19.67	0.03	3.45	1.91	6.33
Edward-Wakool-Spring 2017–18	470	3.88	3.09	23.29	0.81	2.90	1.97	4.42
Edward-Wakool-Spring 2018–19	144	1.88	1.25	7.82	0.09	1.60	1.08	2.39
Edward-Wakool-Summer 2014–15	297	5.93	4.40	40.15	0.76	4.43	3.14	7.65
Edward-Wakool-Summer 2015–16	297	7.22	5.15	29.56	0.49	5.89	3.42	9.26
Edward-Wakool-Summer 2016–17	305	6.34	4.63	31.73	1.35	4.76	3.78	6.89
Edward-Wakool-Summer 2017–18	467	6.58	3.81	27.66	1.13	5.27	3.98	8.27
Edward-Wakool-Summer 2018–19	425	5.53	3.38	29.66	1.14	5.10	3.43	6.53
Edward-Wakool-Autumn 2014–15	78	4.90	2.77	12.54	1.35	3.77	2.67	6.96
Edward-Wakool-Autumn 2015–16	145	4.19	2.60	16.44	0.40	3.70	2.47	5.52
Edward-Wakool-Autumn 2016–17	227	7.59	5.25	33.26	1.90	5.20	3.81	10.38
Edward-Wakool-Autumn 2017–18	255	4.95	3.27	19.05	1.79	3.71	3.09	4.83
Edward-Wakool-Autumn 2018–19	118	6.51	3.82	17.89	1.46	5.88	3.34	8.09
Edward-Wakool-Winter 2014–15	60	1.55	1.36	6.70	0.06	1.45	0.58	1.80
Edward-Wakool-Winter 2015–16	48	1.64	0.92	4.73	0.25	1.43	1.09	2.19
Edward-Wakool-Winter 2016–17	85	1.85	1.61	14.68	0.27	1.61	1.04	2.27
Edward-Wakool-Winter 2017–18	87	6.19	11.13	62.49	0.92	3.15	1.44	4.90
Edward-Wakool-Winter 2018–19	94	1.81	1.60	7.09	0.06	1.23	0.81	2.01

Table D7 continued…

Data Set	n	Mean	Std Dev	Max	Min	Median	25%	75%
Lachlan-Spring 2014–15	142	2.41	1.29	9.96	0.51	2.27	1.68	2.84
Lachlan-Spring 2015–16	120	4.61	2.32	12.83	0.52	4.24	3.10	5.68
Lachlan-Spring 2016–17	13	6.23	3.59	13.25	0.40	6.36	3.76	8.44
Lachlan-Spring 2017–18	164	3.57	1.85	15.79	0.26	3.60	2.42	4.37
Lachlan-Spring 2018–19	166	3.96	1.86	16.56	0.51	3.66	2.88	4.68
Lachlan-Summer 2014–15	7	3.27	0.95	4.56	1.91	3.16	2.29	4.08
Lachlan-Summer 2015–16	189	5.43	2.34	13.52	1.56	4.90	3.64	6.99
Lachlan-Summer 2016–17	50	5.51	3.31	21.00	1.68	4.91	3.53	6.35
Lachlan-Summer 2017–18	198	5.38	1.75	15.40	1.47	5.29	4.31	6.21
Lachlan-Summer 2018–19	186	6.19	3.81	27.32	0.61	5.56	4.06	7.28
Lachlan-Autumn 2014–15	0							
Lachlan-Autumn 2015–16	140	4.30	1.99	17.23	0.91	4.07	3.06	5.45
Lachlan-Autumn 2016–17	56	7.25	3.43	19.39	1.64	6.31	5.14	8.99
Lachlan-Autumn 2017–18	164	5.67	2.50	16.39	0.65	5.39	4.00	6.87
Lachlan-Autumn 2018–19	141	4.67	2.63	15.05	0.34	4.41	2.71	5.76
Lachlan-Winter 2014–15	15	2.55	0.73	4.32	1.75	2.33	2.09	2.64
Lachlan-Winter 2015–16	105	2.46	2.56	20.70	0.35	1.82	1.24	2.75
Lachlan-Winter 2016–17	26	2.03	2.08	11.38	0.26	1.57	1.16	2.30
Lachlan-Winter 2017–18	145	3.85	3.90	32.70	0.51	2.65	1.90	3.87
Lachlan-Winter 2018–19	121	3.63	1.52	10.51	0.48	3.40	2.69	4.49
Murrumbidgee-Spring 2014–15	69	1.14	0.41	2.74	0.47	1.10	0.88	1.35
Murrumbidgee-Spring 2015–16	60	0.91	0.55	3.80	0.06	0.86	0.60	1.14
Murrumbidgee-Spring 2016–17	27	1.11	0.55	2.65	0.32	1.09	0.71	1.44
Murrumbidgee-Spring 2017–18	89	0.98	0.40	2.28	0.50	0.88	0.69	1.27
Murrumbidgee-Spring 2018–19	127	0.86	0.80	6.24	0.12	0.69	0.57	0.87
Murrumbidgee-Summer 2014–15	95	1.49	0.75	5.03	0.47	1.34	0.98	1.81
Murrumbidgee-Summer 2015–16	126	1.37	1.05	9.42	0.06	1.25	0.69	1.71
Murrumbidgee-Summer 2016–17	99	1.68	0.58	3.49	0.51	1.65	1.27	1.97
Murrumbidgee-Summer 2017–18	109	1.62	0.82	3.58	0.12	1.41	1.07	2.01
Murrumbidgee-Summer 2018–19	131	2.02	1.52	9.24	0.41	1.54	1.13	2.40
Murrumbidgee-Autumn 2014–15	41	1.34	0.47	2.18	0.65	1.25	0.96	1.73
Murrumbidgee-Autumn 2015–16	28	1.70	0.98	5.38	0.75	1.53	0.98	2.13
Murrumbidgee-Autumn 2016–17	44	1.47	0.67	3.02	0.70	1.15	0.99	1.87
Murrumbidgee-Autumn 2017–18	48	1.40	0.56	2.45	0.42	1.20	0.98	1.93
Murrumbidgee-Autumn 2018–19	75	1.32	0.78	4.48	0.15	1.18	0.75	1.79
Murrumbidgee-Winter 2014–15	0							
Murrumbidgee-Winter 2015–16	0							
Murrumbidgee-Winter 2016–17	0							
Murrumbidgee-Winter 2017–18	0							
Murrumbidgee-Winter 2018–19	0							

Table D7 continued…

Data Set	n	Mean	Std Dev	Max	Min	Median	25%	75%
Lower Murray-Spring 2014–15	17	1.18	0.67	2.70	0.13	0.89	0.71	1.60
Lower Murray-Spring 2015–16	75	0.96	0.51	3.20	0.04	1.01	0.63	1.26
Lower Murray-Spring 2016–17	42	0.86	0.80	4.31	0.14	0.58	0.43	1.03
Lower Murray-Spring 2017–18	75	0.99	0.50	2.69	0.14	0.92	0.57	1.30
Lower Murray-Spring 2018–19	71	1.16	0.78	5.83	0.17	1.01	0.74	1.44
Lower Murray-Summer 2014–15	82	2.08	0.86	4.63	0.24	2.08	1.40	2.68
Lower Murray-Summer 2015–16	74	2.20	0.71	4.80	1.00	2.14	1.69	2.48
Lower Murray-Summer 2016–17	99	2.88	1.76	15.78	0.49	2.66	2.09	3.36
Lower Murray-Summer 2017–18	96	1.20	0.61	3.07	0.10	1.12	0.71	1.63
Lower Murray-Summer 2018–19	97	1.87	1.17	7.71	0.43	1.69	1.14	2.11
Lower Murray-Autumn 2014–15	0							
Lower Murray-Autumn 2015–16	0							
Lower Murray-Autumn 2016–17	22	3.74	1.30	7.15	2.17	3.62	2.67	4.72
Lower Murray-Autumn 2017–18	0							
Lower Murray-Autumn 2018–19	6	4.72	3.25	8.09	1.24	4.65	1.83	7.78
Lower Murray-Winter 2014–15	0							
Lower Murray-Winter 2015–16	0							
Lower Murray-Winter 2016–17	0							
Lower Murray-Winter 2017–18	0							
Lower Murray-Winter 2018–19	0							
Warrego-Darling-Spring 2014–15	0							
Warrego-Darling-Spring 2015–16	31	5.04	4.68	18.75	0.61	3.21	2.19	5.82
Warrego-Darling-Spring 2016–17	0							
Warrego-Darling-Spring 2017–18	96	10.97	7.77	39.16	2.23	8.72	5.92	12.97
Warrego-Darling-Spring 2018–19	43	4.90	4.36	16.22	0.22	3.00	1.70	7.06
Warrego-Darling-Summer 2014–15	0							
Warrego-Darling-Summer 2015–16	6	5.24	1.32	7.06	3.32	5.34	4.12	6.27
Warrego-Darling-Summer 2016–17	0							
Warrego-Darling-Summer 2017–18	66	11.67	7.15	35.96	0.73	10.92	6.67	16.04
Warrego-Darling-Summer 2018–19	17	19.22	23.28	79.66	3.39	12.51	5.82	17.92
Warrego-Darling-Autumn 2014–15	0							
Warrego-Darling-Autumn 2015–16	0							
Warrego-Darling-Autumn 2016–17	0							
Warrego-Darling-Autumn 2017–18	79	11.49	7.90	48.92	1.44	9.98	7.15	13.96
Warrego-Darling-Autumn 2018–19	14	30.99	21.13	77.60	6.38	23.56	13.04	46.95
Warrego-Darling-Winter 2014–15	0							
Warrego-Darling-Winter 2015–16	0							
Warrego-Darling-Winter 2016–17	0							
Warrego-Darling-Winter 2017–18	92	5.30	4.35	23.41	0.97	3.99	2.67	6.28
Warrego-Darling-Winter 2018–19	49	8.55	6.33	21.15	0.19	9.76	2.43	12.92

Annex E. Summary statistics for nutrient data collected July 2014 to June 2019

Data in the tables are summarised for all LTIM riverine sites in each of the Selected Areas, i.e. Junction of the Warrego and Darling rivers, Gwydir river system, Lachlan river system, Murrumbidgee river system, Edward–Wakool river system, Goulburn River and Lower Murray River.

Table E1. Total nitrogen concentration (µg N/L).

Selected Area	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Warrego–Darling	5	86	683	285	31	0	1600	601	500	892
Gwydir	13	220	766	453	31	30	2375	615	468	1012
Lachlan	8	186	1030	494	36	320	2870	880	693	1173
Murrumbidgee	11	182	333	203	15	130	1600	277	220	366
Edward–Wakool	9	290	623	345	20	290	3200	540	463	670
Goulburn	4	123	366	181	16	180	1600	330	285	390
Lower Murray	2	68	776	360	44	340	1929	668	549	881

Table E2. Total phosphorus concentration (µg P/L).

Selected Area	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Warrego–Darling	5	80	198	161	18	0	950	200	100	300
Gwydir	13	220	161	135	9	30	1042	120	90	200
Lachlan	8	186	123	107	8	25	479	84	61	118
Murrumbidgee	11	182	48	37	3	0	285	40	30	50
Edward–Wakool	9	290	66	32	2	30	330	60	50	70
Goulburn	4	123	35	19	2	10	140	30	20	40
Lower Murray	2	68	125	235	28	36	1970	83	62	109

Table E3. Ammonia concentration (µg N/L). Reported concentrations that were lower than the detection limit for the analytical method were ascribed a value equal to half the detection limit.

Selected Area	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Warrego–Darling	5	38	19	36	6	0	172	8	3	20
Gwydir	13	53	16	37	5	0	171	1.1	0.2	8.2
Lachlan	8	186	65	142	10	2	761	8	2	47
Murrumbidgee	11	182	11	29	2	0	220	5	3	6
Edward–Wakool	9	286	3	7	0	1	92	1	1	3
Goulburn	4	112	7	9	1	1	70	5	2	7
Lower Murray	2	68	16	35	4	3	291	8	4	16

Table E4. Nitrate concentration (µg N/L). Reported concentrations that were lower than the detection limit for the analytical method were ascribed a value equal to half the detection limit.

Selected Area	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Warrego–Darling	5	86	137	137	15	0	481	109	5	200
Gwydir	13	220	168	152	10	0	872	120	71	213
Lachlan	8	186	65	142	10	2	761	8	2	47
Murrumbidgee	11	182	44	93	7	0	780	3	1	48
Edward–Wakool	9	286	4	16	1	1	180	1	1	2
Goulburn	4	108	63	71	7	0.5	360	43	2	90
Lower Murray	2	68	33	62	8	2	343	6	2	41

Table E5. Filterable reactive phosphorus concentration (µg P/L). Reported concentrations that were lower than the detection limit for the analytical method were ascribed a value equal to half the detection limit.

Selected Area	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Warrego–Darling	5	80	53	54	6	0	273	36	22	65
Gwydir	13	220	40	44	3	0	525	32	15	50
Lachlan	8	186	37	50	4	2	257	16	11	36
Murrumbidgee	11	182	8	17	1.2	1	110	3	2	5
Edward–Wakool	9	286	4	8	0.4	1	85	3	2	4
Goulburn	4	123	4	4	0.4	1	27	3	2	3
Lower Murray	2	68	16	29	4	2	182	8	5	14

Table E6. Dissolved organic carbon concentration (mg org C/L).

Selected Area	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Warrego–Darling	5	54	12	10	1.3	5.6	80	9.6	8.4	12
Gwydir	13	184	12	7	0.5	4.5	76	11	9.5	12
Lachlan	8	186	12	5	0.3	6.0	33	10	9.0	14
Murrumbidgee	11	182	2.9	2	0.1	0.5	14	2.6	1.8	3.4
Edward–Wakool	9	316	4.8	2	0.1	2.3	28	4.2	3.5	5.3
Goulburn	4	123	5.5	4	0.4	1.9	29	4.2	3.1	5.8
Lower Murray	2	68	6	4	0.5	3	22	5	4	6

Table E7. Chlorophyll-a concentration (µg/L). Reported concentrations that were lower than the detection limit for the analytical method were ascribed a value equal to half the detection limit.

Selected Area	No. sites	n	Mean	Standard deviation	Standard error	Min	Max	Median	25%	75%
Warrego–Darling	5	86	18	19	2.0	0	113	13	5	24
Gwydir	13	220	14	20	1.4	0	159	8.6	4	15
Lachlan	8	186	6.7	6	0.4	1	45	5.0	4	7
Murrumbidgee	11	182	5.7	6	0.5	0	32	4.0	2	7
Edward–Wakool	9	269	19	9	0.6	1	59	17	13	23
Goulburn	4	96	8.6	4	0.4	4	27	8.0	6	10
Lower Murray	2	68	17	10	1.3	0	67	14	11	18

Annex F. Summary statistics for Metabolism Parameters pooled by Selected Area, Season and Flow Category, 2014–2019.

This table summarizes all the GPP, ER and NPP data from all sites in the six Selected Areas where flow categories have been designated (see Figure 3 and Table 3 for details).

Season	Parameter	Flow Cat	n	Mean	Std. Dev.	Std. Err.	Min	Max	Median	25%	75%
Spring	GPP	< Very Low	113	5.10	5.58	0.53	0.55	33.50	2.99	1.81	6.28
Spring	GPP	Very Low	450	2.60	2.65	0.13	0.19	26.07	1.81	1.20	2.78
Spring	GPP	Moderate Low	500	2.08	1.56	0.07	0.15	14.78	1.69	1.15	2.70
Spring	GPP	Low Fresh	520	1.84	1.55	0.07	0.18	10.57	1.36	0.90	2.25
Spring	GPP	Medium Fresh	763	1.26	0.80	0.03	0.03	5.14	1.03	0.73	1.54
Spring	GPP	High Fresh	449	1.08	0.75	0.04	0.04	4.76	0.92	0.69	1.21
Spring	GPP	Bankfull	49	0.93	0.94	0.13	0.10	3.73	0.58	0.26	1.03
Summer	GPP	Very Low	575	3.59	2.52	0.11	0.77	26.14	3.06	1.86	4.35
Summer	GPP	Moderate Low	782	3.50	3.75	0.13	0.06	42.31	2.49	1.60	3.98
Summer	GPP	Low Fresh	876	2.48	2.00	0.07	0.06	19.79	2.07	1.44	2.79
Summer	GPP	Medium Fresh	1205	2.42	1.64	0.05	0.03	16.99	1.96	1.45	2.82
Summer	GPP	High Fresh	291	1.55	0.88	0.05	0.11	6.74	1.37	0.98	1.98
Autumn	GPP	< Very Low	12	3.66	2.28	0.66	0.54	8.91	3.57	2.23	4.65
Autumn	GPP	Very Low	606	3.04	2.61	0.11	0.40	23.19	2.14	1.44	3.86
Autumn	GPP	Moderate Low	597	1.92	1.38	0.06	0.30	14.30	1.55	1.03	2.40
Autumn	GPP	Low Fresh	356	2.06	1.92	0.10	0.50	12.58	1.40	0.99	2.25
Autumn	GPP	Medium Fresh	338	2.34	1.72	0.09	0.40	10.24	1.67	1.13	3.03
Autumn	GPP	High Fresh	6	0.98	0.10	0.04	0.82	1.13	0.98	0.90	1.04

Season	Parameter	Flow Cat	n	Mean	Std. Dev.	Std. Err.	Min	Max	Median	25%	75%
Winter	GPP	< Very Low	38	3.57	3.06	0.50	0.53	11.92	2.14	1.77	4.73
Winter	GPP	Very Low	239	1.21	0.64	0.04	0.22	5.09	1.14	0.83	1.42
Winter	GPP	Moderate Low	328	1.01	0.53	0.03	0.06	3.31	0.87	0.64	1.29
Winter	GPP	Low Fresh	79	0.80	0.51	0.06	0.04	2.21	0.66	0.40	1.21
Winter	GPP	Medium Fresh	136	0.75	0.46	0.04	0.01	4.09	0.65	0.52	0.93
Winter	GPP	High Fresh	15	0.81	0.75	0.19	0.03	2.35	0.70	0.12	1.12
Spring	ER	< Very Low	113	8.49	7.58	0.71	0.22	39.16	6.40	3.10	11.51
Spring	ER	Very Low	450	5.54	4.74	0.22	0.28	31.90	4.14	2.22	7.19
Spring	ER	Moderate Low	500	3.98	3.35	0.15	0.06	22.19	3.06	1.78	5.22
Spring	ER	Low Fresh	520	2.98	2.85	0.13	0.03	20.13	2.10	1.20	3.83
Spring	ER	Medium Fresh	763	2.05	2.31	0.08	0.03	20.90	1.21	0.72	2.69
Spring	ER	High Fresh	449	2.31	2.09	0.10	0.09	19.67	1.71	0.95	2.96
Spring	ER	Bankfull	49	5.61	2.77	0.40	0.40	13.25	5.12	4.00	7.45
Summer	ER	Very Low	575	7.27	4.72	0.20	0.48	30.97	6.58	3.71	9.88
Summer	ER	Moderate Low	782	5.99	5.31	0.19	0.43	40.70	4.76	2.65	7.32
Summer	ER	Low Fresh	876	4.03	3.23	0.11	0.11	29.66	3.15	2.10	4.97
Summer	ER	Medium Fresh	1205	3.75	2.89	0.08	0.06	31.73	3.13	1.56	5.23
Summer	ER	High Fresh	291	3.12	2.59	0.15	0.18	19.50	2.43	1.27	4.24
Autumn	ER	< Very Low	12	12.12	6.23	1.80	1.78	21.27	12.05	7.71	16.63
Autumn	ER	Very Low	606	5.25	4.23	0.17	0.42	33.26	4.06	2.20	6.82
Autumn	ER	Moderate Low	597	3.99	3.07	0.13	0.26	20.43	3.33	1.83	5.03
Autumn	ER	Low Fresh	356	3.37	2.70	0.14	0.15	17.23	2.27	1.39	4.81
Autumn	ER	Medium Fresh	338	3.90	3.54	0.19	0.28	22.40	2.96	1.55	5.01

Season	Parameter	Flow Cat	n	Mean	Std. Dev.	Std. Err.	Min	Max	Median	25%	75%
Autumn	ER	High Fresh	6	2.54	0.86	0.35	1.79	4.12	2.25	1.89	3.19
Winter	ER	< Very Low	38	10.45	15.83	2.57	1.87	62.49	3.65	2.50	11.07
Winter	ER	Very Low	239	3.61	3.18	0.21	0.47	32.70	2.70	1.95	3.98
Winter	ER	Moderate Low	328	3.03	2.12	0.12	0.16	20.70	2.40	1.73	3.74
Winter	ER	Low Fresh	79	2.98	2.51	0.28	0.07	12.73	2.03	1.33	3.88
Winter	ER	Medium Fresh	136	1.53	1.44	0.12	0.06	10.51	1.12	0.74	1.73
Spring	NPP	< Very Low	113	-3.39	4.72	0.44	-19.92	10.68	-2.67	-6.27	-0.36
Spring	NPP	Very Low	450	-2.93	4.10	0.19	-29.43	11.43	-2.01	-4.62	-0.26
Spring	NPP	Moderate Low	500	-1.90	3.12	0.14	-21.58	5.53	-0.96	-3.16	0.05
Spring	NPP	Low Fresh	520	-1.14	2.17	0.10	-16.54	4.25	-0.64	-1.93	0.10
Spring	NPP	Medium Fresh	763	-0.79	2.21	0.08	-16.73	4.14	-0.14	-1.28	0.29
Spring	NPP	High Fresh	449	-1.22	1.83	0.09	-18.75	1.84	-0.81	-1.88	-0.13
Spring	NPP	Bankfull	49	-4.68	2.79	0.40	-13.01	-0.25	-4.12	-6.16	-2.59
Summer	NPP	Very Low	575	-3.68	4.03	0.17	-21.06	12.09	-2.94	-6.02	-0.90
Summer	NPP	Moderate Low	782	-2.50	3.96	0.14	-38.35	18.34	-2.09	-3.87	-0.28
Summer	NPP	Low Fresh	876	-1.55	2.79	0.09	-18.45	10.23	-1.11	-2.75	0.14
Summer	NPP	Medium Fresh	1205	-1.32	2.46	0.07	-26.88	6.43	-0.85	-2.47	0.15
Summer	NPP	High Fresh	291	-1.58	2.21	0.13	-12.76	2.19	-0.91	-2.35	-0.20
Autumn	NPP	< Very Low	12	-8.46	4.66	1.35	-18.00	-1.21	-8.76	-11.31	-5.21
Autumn	NPP	Very Low	606	-2.21	4.14	0.17	-29.07	10.50	-1.47	-4.12	-0.01
Autumn	NPP	Moderate Low	597	-2.07	2.84	0.12	-18.06	8.29	-1.62	-2.95	-0.42
Autumn	NPP	Low Fresh	356	-1.31	2.50	0.13	-13.44	8.39	-0.77	-2.18	-0.11
Autumn	NPP	Medium Fresh	338	-1.56	2.67	0.15	-16.53	5.26	-0.97	-2.55	-0.06

Season	Parameter	Flow Cat	n	Mean	Std. Dev.	Std. Err.	Min	Max	Median	25%	75%
Autumn	NPP	High Fresh	6	-1.56	0.79	0.32	-2.98	-0.82	-1.38	-2.15	-0.91
Winter	NPP	< Very Low	38	-6.89	13.22	2.15	-52.79	-0.03	-1.80	-4.48	-0.49
Winter	NPP	Very Low	239	-2.40	2.79	0.18	-29.61	0.35	-1.69	-2.63	-1.06
Winter	NPP	Moderate Low	328	-2.02	2.10	0.12	-17.65	1.69	-1.46	-2.66	-0.73
Winter	NPP	Low Fresh	79	-2.19	2.31	0.26	-11.38	1.70	-1.69	-2.93	-0.68
Winter	NPP	Medium Fresh	136	-0.78	1.55	0.13	-9.97	1.96	-0.44	-0.91	-0.06
Winter	NPP	High Fresh	15	-0.98	3.01	0.78	-11.26	1.72	-0.76	-0.99	0.64

Annex G. Seasonal Organic Carbon Loads for all Selected Areas by Flow Category

Results of modelling of the relationship between stream flow category and the additional amount of organic carbon produced and consumed for the five Selected Areas not shown in Table 6 and Table 7. The final column in the table shows the percentage of extra organic carbon load created (consumed), based on the median values, as the river moves from one flow category to the next higher category e.g. through introduction of CEW. A value of 100 indicates no change whereas a value of 200 indicates a doubling of the amount of organic carbon. Values less than 100 (highlighted in red) show a decrease in the amount of organic carbon load.

Table G1 a) Organic Carbon Loads (kg org C/Day) Production in the combined Edward-Wakool Selected Area sites by GPP, stratified by season and nominal flow category.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low	0								
	Very Low	114	48	3	12	234	40	21	59	
	Moderately Low	188	167	17	14	2266	80	46	208	203
	Low Fresh	172	221	14	50	1290	168	122	237	209
	Medium Fresh	139	169	8	16	695	148	114	201	88
	High Fresh	310	247	10	6	1483	198	154	254	134
	Bankfull	31	1003	123	119	3622	1019	648	1229	514
Summer	< Very Low	1								
	Very Low	333	140	11	13	2734	80	42	178	
	Moderately Low	244	504	51	25	5870	263	98	456	329
	Low Fresh	231	469	34	88	3508	338	245	470	128
	Medium Fresh	449	333	13	84	4380	277	212	367	82
	High Fresh	126	451	38	56	3029	346	259	459	125
	Bankfull	0								
Autumn	< Very Low	11	7	3	0	34	1	0	10	
	Very Low	294	241	15	19	2279	181	82	276	
	Moderately Low	118	192	14	44	1077	168	130	194	93
	Low Fresh	18	295	27	121	505	261	225	366	155
	Medium Fresh	181	335	13	77	970	301	193	445	116
	High Fresh	6	175	9	143	205	176	158	193	58
	Bankfull	0								
Winter	< Very Low	37	9	3	0	63	0	0	11	
	Very Low	97	73	5	11	287	62	38	94	
	Moderately Low	38	108	14	21	364	85	40	138	137
	Low Fresh	24	83	5	47	158	81	66	94	95
	Medium Fresh	76	108	5	47	316	106	87	122	131
	High Fresh	11	202	38	88	433	135	120	325	127
	Bankfull	0								

Table G1 b) Organic Carbon Loads (kg org C/Day) Consumption in the combined Edward-Wakool Selected Area sites by ER, stratified by season and nominal flow category.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low									
	Very Low	114	150	10	18	598	129	74	184	
	Moderately Low	188	323	20	10	1589	251	147	405	194
	Low Fresh	172	507	33	6	3534	379	250	680	151
	Medium Fresh	139	575	47	9	3480	382	216	677	101
	High Fresh	310	606	37	15	7102	430	267	700	113
	Bankfull	31	9126	984	1581	22462	9167	4857	12807	2134
Summer	< Very Low	1								
	Very Low	333	270	15	33	3093	205	142	308	
	Moderately Low	244	781	51	71	3856	505	265	906	246
	Low Fresh	231	1038	49	125	5133	867	637	1099	172
	Medium Fresh	449	709	27	90	9304	594	425	891	69
	High Fresh	126	1205	113	219	8758	857	686	1193	144
	Bankfull									
Autumn	< Very Low	11	23	10	0	110	2	0	41	
	Very Low	294	268	10	47	1615	233	140	348	
	Moderately Low	118	569	36	199	2372	445	358	594	191
	Low Fresh	18	843	106	245	1788	770	505	1139	173
	Medium Fresh	181	619	35	45	2630	456	320	696	59
	High Fresh	6	456	66	315	745	394	342	589	86
	Bankfull									
Winter	< Very Low	37	38	13	0	327	0	0	25	
	Very Low	97	197	18	24	1034	151	106	237	
	Moderately Low	38	205	32	32	913	146	68	226	96
	Low Fresh	24	168	35	12	792	123	48	247	84
	Medium Fresh	76	117	7	10	303	119	79	164	97
	High Fresh	11	228	35	12	331	283	108	321	238
	Bankfull									

Table G2 a) Organic Carbon Loads (kg org C/Day) Production in the combined Lachlan Selected Area sites by GPP, stratified by season and nominal flow category.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low	2	24							
	Very Low	87	79	6	19	300	66	41	101	
	Moderately Low	130	178	8	44	612	161	110	222	244
	Low Fresh	156	277	11	57	821	247	192	317	154
	Medium Fresh	196	416	16	57	1570	375	261	561	152
	High Fresh	16	784	159	93	1830	829	152	1247	221
	Bankfull	18	3279	666	164	8180	3072	334	5885	371
Summer	< Very Low	1	52							
	Very Low	43	131	9	43	372	118	88	152	
	Moderately Low	97	268	12	103	1036	249	201	313	210
	Low Fresh	182	355	15	93	1370	283	231	406	114
	Medium Fresh	283	770	24	164	1941	737	393	1052	260
	High Fresh	20	694	84	101	1494	670	470	886	91
	Bankfull	1	5460							
Autumn	< Very Low	1	36							
	Very Low	152	61	3	10	202	56	37	75	
	Moderately Low	222	159	6	36	555	142	98	205	255
	Low Fresh	114	375	27	46	1465	262	187	465	184
	Medium Fresh	12	741	169	137	1562	587	227	1361	224
	High Fresh	0								
	Bankfull	0								
Winter	< Very Low	1	39							
	Very Low	113	37	1	7	68	35	27	49	
	Moderately Low	199	71	2	5	240	64	48	88	184
	Low Fresh	37	125	8	39	226	130	89	152	202
	Medium Fresh	55	126	6	6	232	121	105	147	93
	High Fresh	2	84							
	Bankfull	5	202							

Table G2 b) Organic Carbon Loads (kg org C/Day) Consumption in the combined Lachlan Selected Area sites by ER, stratified by season and nominal flow category.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low	2	23							
	Very Low	87	124	7	41	319	112	66	170	
	Moderately Low	130	233	11	23	771	215	136	297	192
	Low Fresh	156	407	17	29	1282	369	237	523	172
	Medium Fresh	196	688	30	119	3430	638	399	856	173
	High Fresh	16	2075	473	869	8124	1489	1082	1780	234
	Bankfull	18	11892	1583	649	25163	10613	6920	16205	713
Summer	< Very Low	1								
	Very Low	43	239	15	50	438	226	175	299	
	Moderately Low	97	384	12	119	723	375	308	458	166
	Low Fresh	182	593	18	91	1462	533	430	738	142
	Medium Fresh	283	1202	36	95	5302	1127	815	1500	212
	High Fresh	20	1594	161	671	3544	1575	1019	2064	140
	Bankfull	1	9864							
Autumn	< Very Low	1	89							
	Very Low	152	167	8	21	757	152	95	206	
	Moderately Low	222	311	11	28	873	278	198	393	183
	Low Fresh	114	545	26	62	1989	525	365	700	189
	Medium Fresh	12	894	102	331	1540	985	646	1074	188
	High Fresh	0								
	Bankfull	0								
Winter	< Very Low	1	104							
	Very Low	113	104	6	16	549	87	66	122	
	Moderately Low	199	179	10	35	1635	142	104	205	164
	Low Fresh	37	474	48	52	1353	422	278	642	298
	Medium Fresh	55	526	64	78	2695	361	220	770	86
	High Fresh	2	7232							
	Bankfull	5	3416							

Table G3 a) Organic Carbon Loads (kg org C/Day) Production in the combined Murrumbidgee Selected Area sites by GPP, stratified by season and nominal flow category. No winter-time data was collected in this Selected Area.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low									
	Very Low	6	381	52	257	569	341	271	521	
	Moderately Low	13	473	75	171	1023	420	272	544	123
	Low Fresh	32	1812	371	413	9022	844	637	2399	201
	Medium Fresh	242	1872	81	194	7726	1498	1078	2312	177
	High Fresh	79	2489	144	843	6608	2193	1626	3066	146
	Bankfull									
Summer	< Very Low									
	Very Low	23	698	131	157	2345	434	241	940	
	Moderately Low	47	1725	247	488	8872	990	678	2302	228
	Low Fresh	64	1990	229	536	11811	1474	1032	2166	149
	Medium Fresh	309	2606	75	447	7438	2246	1591	3406	152
	High Fresh	117	3001	109	839	6671	2790	2215	3661	124
	Bankfull									
Autumn	< Very Low									
	Very Low	67	337	17	128	730	314	210	442	
	Moderately Low	34	1115	223	303	6438	722	461	1128	230
	Low Fresh	51	1403	288	411	12106	1029	798	1240	143
	Medium Fresh	84	1382	55	768	2992	1198	1041	1538	116
	High Fresh									
	Bankfull									

Table G3 b) Organic Carbon Loads (kg org C/Day) Consumption in the combined Murrumbidgee Selected Area sites by ER, stratified by season and nominal flow category. No winter-time data was collected in this Selected Area.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low									
	Very Low	6	325	16	275	383	323	291	357	
	Moderately Low	13	403	45	198	871	351	333	457	109
	Low Fresh	32	1199	221	240	5368	730	546	1358	208
	Medium Fresh	242	1478	57	94	7805	1331	944	1808	182
	High Fresh	79	3778	264	383	12840	3375	1995	4873	254
	Bankfull									
Summer	< Very Low									
	Very Low	23	686	115	219	2573	466	358	936	
	Moderately Low	47	1209	115	344	5182	984	794	1369	211
	Low Fresh	64	1583	114	382	7487	1464	1090	1801	149
	Medium Fresh	309	2285	74	157	13168	1986	1506	2832	136
	High Fresh	117	4052	177	542	11575	3907	2743	4973	197
	Bankfull									
Autumn	< Very Low									
	Very Low	67	311	19	67	651	284	178	443	
	Moderately Low	34	648	63	168	1678	533	426	718	188
	Low Fresh	51	1166	109	113	4193	1022	590	1483	192
	Medium Fresh	84	1609	75	757	4894	1445	1142	1898	141
	High Fresh									
	Bankfull									

Table G4 a) Organic Carbon Loads (kg org C/Day) Production in the combined Lower Murray Selected Area sites by GPP, stratified by season and nominal flow category. No winter-time data was collected in this Selected Area.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low									
	Very Low	41	1431	111	245	3430	1199	998	1620	
	Moderately Low	38	1803	196	506	7537	1698	951	2294	142
	Low Fresh	77	3335	141	1554	7896	3004	2530	3905	177
	Medium Fresh	82	4251	166	1851	7543	4169	2875	5361	139
	High Fresh	42	7400	473	2221	14879	7853	5084	9410	188
	Bankfull									
Summer	< Very Low									
	Very Low	35	3770	489	1216	11761	2469	1933	4164	
	Moderately Low	105	4191	260	582	13316	3233	2281	5948	131
	Low Fresh	117	6570	188	1834	11910	6284	5163	7853	194
	Medium Fresh	161	8334	273	3169	18584	7168	6060	9371	114
	High Fresh	27	17078	1194	6385	30972	16329	14620	19464	228
	Bankfull	3	3335							
Autumn	< Very Low									
	Very Low									
	Moderately Low	12	7142	390	4285	9594	6966	6620	7902	
	Low Fresh	11	7950	1057	5389	14312	6142	5584	11481	88
	Medium Fresh	6	7553	669	6116	10671	7228	6384	8369	118
	High Fresh									
	Bankfull									

Table G4 b) Organic Carbon Loads (kg org C/Day) Consumption in the combined Lower Murray Selected Area sites by ER, stratified by season and nominal flow category. No winter-time data was collected in this Selected Area.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low									
	Very Low	41	1263	109	355	3329	1116	715	1658	
	Moderately Low	38	1528	109	285	4081	1489	1244	1800	133
	Low Fresh	77	3087	200	264	12000	2795	1813	4136	188
	Medium Fresh	82	2897	181	115	6254	2818	1636	4159	101
	High Fresh	42	13103	2256	1801	75667	7502	5390	14325	266
	Bankfull									
Summer	< Very Low									
	Very Low	35	2979	354	410	10137	2296	1662	4248	
	Moderately Low	105	3315	203	800	11277	2483	2006	4089	108
	Low Fresh	117	5700	183	630	11525	5627	4426	6873	227
	Medium Fresh	161	6549	352	479	30400	5476	4082	7021	97
	High Fresh	27	14890	1770	2488	35581	15634	7282	19732	285
	Bankfull	3	230896							
Autumn	< Very Low									
	Very Low									
	Moderately Low	12	6867	570	4452	10075	6704	5045	8337	
	Low Fresh	11	10772	1583	5307	18611	8199	5891	16513	122
	Medium Fresh	6	9814	2177	4104	18531	8033	6022	14772	98
	High Fresh									
	Bankfull									

Table G5 a) Organic Carbon Loads (kg org C/Day) Production in the combined Warrego-Darling Selected Area sites by GPP, stratified by season and nominal flow category.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low	111	186	35	0	2749	59	0	214	
	Very Low	59	801	95	130	3715	533	283	1008	905
	Moderately Low									
	Low Fresh									
	Medium Fresh	1	7302							
	High Fresh									
	Bankfull									
Summer	< Very Low	67	145	42	0	1703	0	0	164	
	Very Low	90	2029	255	43	11761	1709	140	2526	-
	Moderately Low	1	2481							
	Low Fresh									
	Medium Fresh									
	High Fresh									
	Bankfull									
Autumn	< Very Low	70	21	5	0	212	0	0	16	
	Very Low	17	1107	217	98	3544	1213	225	1550	-
	Moderately Low	6	6644	2246	1567	12820	6172	1603	11842	509
	Low Fresh									
	Medium Fresh									
	High Fresh									
	Bankfull									
Winter	< Very Low	48	71	12	0	305	34	1	102	
	Very Low	93	209	14	30	833	186	121	248	543
	Moderately Low									
	Low Fresh									
	Medium Fresh									
	High Fresh									
	Bankfull									

Table G5 b) Organic Carbon Loads (kg org C/Day) Consumption in the combined Warrego-Darling Selected Area sites by ER, stratified by season and nominal flow category.

Season	Flow Category	n	Mean	Std. Error	Min	Max	Median	25%	75%	% of Lower Flow Cat
Spring	< Very Low	111	341	48	0	3001	132	0	536	
	Very Low	59	1162	146	125	5852	776	449	1448	587
	Moderately Low									
	Low Fresh									
	Medium Fresh	1	2859							
	High Fresh									
	Bankfull									
Summer	< Very Low	67	148	49	0	2238	0	0	97	
	Very Low	90	1647	188	50	10137	1388	262	2114	-
	Moderately Low	1	2875							
	Low Fresh									
	Medium Fresh									
	High Fresh									
	Bankfull									
Autumn	< Very Low	70	136	32	0	1236	0	0	136	
	Very Low	17	2194	360	466	6020	2045	1033	2917	-
	Moderately Low	6	13000	3835	4278	25552	12088	4468	20985	591
	Low Fresh									
	Medium Fresh									
	High Fresh									
	Bankfull									
Winter	< Very Low	48	259	41	0	930	136	3	486	
	Very Low	93	789	57	123	2448	679	399	911	501
	Moderately Low									
	Low Fresh									
	Medium Fresh									
	High Fresh									
	Bankfull									

Annex H. Commonwealth Watering Actions targeting Ecosystem Processes and Water Quality, Years 1-4.

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1415–BDL-01	00111-24	Barwon Darling: Barwon-Darling River and fringing wetlands	1256		11/01/15 - 17/01/15	Fresh	Nutrient and sediment cycling from inundation of lower level benches	Water quality improvement including salinity and potential for algal blooms
1415-BDL-02	00111-25	Barwon Darling: Barwon-Darling River and fringing wetlands	108		30/05/15 - 31/05/15	Fresh	Nutrient and sediment cycling from inundation of lower level benches	Water quality improvement including salinity and potential for algal blooms
1415-BDL-03	00111-26	Barwon Darling: Barwon-Darling River and fringing wetlands	396		Late Feb & May 2015	Fresh	Nutrient and sediment cycling from inundation of lower level benches	Water quality improvement including salinity and potential for algal blooms
1415-BRD-03	00111-18	Border Rivers: Dumaresq–Macintyre River and fringing wetlands	332		29/01/15 – 05/02/15	Fresh	Nutrient and sediment cycling (from inundation of upper channel areas, some anabranch channel and near stream wetlands)	
1415-BRD-04	00111-19	Border Rivers: Dumaresq–Macintyre River and fringing wetlands	231		6/04/2015	Fresh	Nutrient and sediment cycling (from inundation of upper channel areas, some anabranch channel and near stream wetlands)	
1415-CMP-01	10003-01	Campaspe: Campaspe River	5791		09/10/14 – 22/10/14	Fresh	flush organics from bank and benches to reduce the risk of blackwater events in summer	flush and mix river pools for improved water quality
1415-CNM-03	NA	Central Murray: Hattah Lakes	34239		26/05/14 – 17/01/15	Wetland	Nutrient and carbon cycling; primary productivity; decomposition	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1415-GLB-01	10002-01	Goulburn: Lower Goulburn River	12986		25/08/14 – 25/09/14	Baseflow	Disrupt biofilms, move fine sediment, entrain organic matter in stream to support ecosystem function	maintain water quality
1415-GLB-02	10002-01	Goulburn: Lower Goulburn River	1315		10/11/14 – 17/11/14	Baseflow	Disrupt biofilms, move fine sediment, entrain organic matter in stream to support ecosystem function	maintain water quality
1415-GLB-03	10002-01	Goulburn: Lower Goulburn River	67460		14/10/14 – 11/11/14	Fresh	Disrupt biofilms, move fine sediment, entrain organic matter in stream to support ecosystem function	
1415-GLB-04	10002-01	Goulburn: Lower Goulburn River	14472		20/11/14 – 30/11/14	Fresh	Disrupt biofilms, move fine sediment, entrain organic matter in stream to support ecosystem function	
1415-GLB-05	10002-01	Goulburn: Lower Goulburn River	18291		01/12/14 – 28/02/15	Baseflow	Disrupt biofilms, move fine sediment, entrain organic matter in stream to support ecosystem function	maintain water quality
1415-GLB-06	10002-01	Goulburn: Lower Goulburn River	21103		01/03/15 – 15/03/15 13/04/15 – 12/06/15	Baseflow	Disrupt biofilms, move fine sediment, entrain organic matter in stream to support ecosystem function	maintain water quality
1415-GLB-07	10002-01	Goulburn: Lower Goulburn River	13321		16/03/15 – 12/04/15	Fresh	Disrupt biofilms, move fine sediment, entrain organic matter in stream to support ecosystem function	
1415-GLB-08	10002-01	Goulburn: Lower Goulburn River	65444		13/06/15 – 30/06/15	Fresh	Disrupt biofilms, move fine sediment, entrain organic matter in stream to support ecosystem function	
1415-GWY-01	00016-01	Gwydir: Gwydir wetlands	30000		17/09/14 – 07/03/15	Wetland	Allow for sediment transport, nutrient and carbon cycling	Maintain water quality

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1415-GWY-03	00016-03	Gwydir: Carole Creek	3656		03/10/14 – 29/10/15	Fresh	Support in-stream ecological function and nutrient cycling contributing to the health of in stream habitat and maintaining water quality	Support in-stream ecological function and nutrient cycling contributing to the health of in stream habitat and maintaining water quality
1415-GWY-04	00016-04	Gwydir: Mehi River	13316		02/10/14 – 27/10/14	Fresh	Support in-stream ecological function and nutrient cycling contributing to the health of in stream habitat and maintaining water quality	Support in-stream ecological function and nutrient cycling contributing to the health of in stream habitat and maintaining water quality
1415-MBG-01	10023-01	Murrumbidgee: Mid North Redbank	40000		12/08/14 – 20/01/15	Wetland	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	
1415-MBG-02	10023-02	Murrumbidgee: Yanga National Park	74512		23/10/14 – 10/04/15	Wetland	support ecosystem functions	
1415-MBG-03	10023-03	Murrumbidgee: Upper North Redbank	20000		01/10/14 – 25/03/15	Wetland	support ecosystem functions	
1415-OVN-01	10004-01	Ovens: Ovens River	50		04/04/15 – 05/04/15	Baseflow	Improve primary production through the disruption of biofilms	
1415-OVN-02	10004-02	Ovens: Ovens River	20		30/04/15 – 30/04/15	Baseflow	Improve primary production through the disruption of biofilms	
1415/MCQ-01	10015-01	Macquarie: Macquarie Marshes	10000		13/10/14 – 12/12/14	Baseflow, Fresh	sediment transport, nutrient and carbon cycling	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1516-BDL-01	111-32	Barwon-Darling: Barwon-Darling River and fringing wetlands (Mungindi to Menindee)	2702	2702	01/07/15 - 30/09/15	Fresh	Nutrient and sediment cycling from inundation of lower level benches (Darling River at Toorale Selected Area and downstream)	Water quality improvement including salinity and potential for algal blooms
1516-BDL-02	111-32	Barwon-Darling: Barwon-Darling River and fringing wetlands (Mungindi to Menindee)	3481	3481	28/01/16 - 01/03/16	Fresh	Nutrient and sediment cycling from inundation of lower level benches (Darling River at Toorale Selected Area and downstream)	Water quality improvement including salinity and potential for algal blooms
1516-BDL-03	111-32	Barwon-Darling: Barwon-Darling River and fringing wetlands (Mungindi to Menindee)	1457	1457	1/06/2016 - 30/06/16	Fresh	Nutrient and sediment cycling from inundation of lower level benches (Darling River at Toorale Selected Area and downstream)	Water quality improvement including salinity and potential for algal blooms
1516-BRD-02	111-26	Border Rivers: Dumaresq-Macintyre River and Fringing Wetlands	409	409	26/07/15 - 07/08/15	Fresh	Nutrient and sediment cycling (from inundation of upper channel areas, some anabranch channel and near stream wetlands)	
1516-BRD-03	111-26	Border Rivers: Dumaresq-Macintyre River and Fringing Wetlands	235	235	26/08/15	Fresh	Nutrient and sediment cycling (from inundation of upper channel areas, some anabranch channel and near stream wetlands)	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1516-BRD-04	111-26	Border Rivers: Dumaresq-Macintyre River and Fringing Wetlands	137	137	1/02/2016	Fresh	Nutrient and sediment cycling (from inundation of upper channel areas, some anabranch channel and near stream wetlands)	
1516-BRD-05	111-26	Border Rivers: Dumaresq-Macintyre River and Fringing Wetlands	244	244	7/11/2015	Fresh	Nutrient and sediment cycling (from inundation of upper channel areas, some anabranch channel and near stream wetlands)	
1516-BRD-06	111-27	Border Rivers: Lower Moonie River and Fringing Wetlands	201	201	28/08/15 - 02/09/15	Fresh	Contributing to natural flow events to support key ecosystems functions and aquatic habitats.	
1516-CNM-01	10031-07	Central Murray: Hattah Lakes	5348	6619	12/10/2015 - 23/10/2015	Wetland	Exchange and cycling of nutrients and carbon between the River and the Lakes	
1516-CNM-04	10031_01, 10031_02	NSW and Vic Murray - River Murray to SA and Floodplain - River Murray Channel	99400	99400	22/06/15 - 24/07/15	Baseflow, Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-CON-01	111-28	Condamine-Balonne: Nebine Creek	998	998	23/06/15 - 27/06/15	Fresh	Contributing to natural flow events to support key ecosystems functions and aquatic habitats.	
1516-GLB-01	10037-01	Goulburn: Lower Goulburn River	10661	10661	01/07/15 - 08/07/15	Fresh	Support ecosystem function	
1516-GLB-02	10037-01	Goulburn: Lower Goulburn River	10549	33229	09/07/15 - 02/10/15	Baseflow	Support ecosystem function	Maintain water quality
1516-GLB-03	10037-01	Goulburn: Lower Goulburn River	99139	104034	03/10/15 - 29/10/15	Fresh	Support ecosystem function	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1516-GLB-04	10037-01	Goulburn: Lower Goulburn River	915	39083	30/10/15 - 12/03/16	Baseflow	Support ecosystem function	Maintain water quality
1516-GLB-05	10037-01	Goulburn: Lower Goulburn River	26961	47621	15/03/16 - 05/04/16	Baseflow	Support ecosystem function	
1516-GLB-06	10037-01	Goulburn: Lower Goulburn River	33356	33356	06/04/16 - 30/06/16	Baseflow	Support ecosystem function	Maintain water quality
1516-GWY-01	10037-01	Gwydir: Gwydir Wetlands	1350	2700	09/01/16 - 11/02/16	Overbank	Allow for sediment transport, nutrient and carbon cycling	
1516-GWY-03	10037-01	Gwydir: Mehi River	964	964	09/11/15 - 11/11/15	Fresh	To support in-stream ecological function and nutrient cycling, contributing to the health of in-stream habitat and maintaining water quality	
1516-GWY-04	10037-01	Gwydir: Gwydir River System	2600	6000	10/04/16 - 30/05/16	Baseflow	Support fundamental ecosystem function processes of nutrient and carbon cycling and primary production	
1516-LCH-01	10039	Lachlan: Great Cumbung Swamp	24059	32078	9/08/2015 - 15/10/15	Fresh	Contribute to ecosystem function	
1516-LWM-40	10031-06, 10031-09	Lower Murray: Lock 15	5249	5249	01/07/15 - 30/12/15	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-LWM-41	10031-06, 10031-09	Lower Murray: Lock 15	0	0	01/04/16 - 30/06/16	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-LWM-42	10031-06, 10031-09	Lower Murray: Lock 9	0	0	01/07/15 - 30/09/15	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-LWM-43	10031-06, 10031-09	Lower Murray: Lock 9	0	0	01/10/15 - 30/02/16	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-LWM-44	10031-06, 10031-09	Lower Murray: Lock 8	0	0	01/08/15 - 30/12/15	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1516-LWM-45	10031-06, 10031-09	Lower Murray: Lock 8	0	0	01/12/15 - 30/05/16	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-LWM-46	10031-06, 10031-09	Lower Murray: Lock 7	2739	2739	01/08/15 - 30/01/16	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-LWM-47	10031-06, 10031-09	Lower Murray: Lock 7	0	0	01/01/16 - 30/05/16	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-LWM-48	10031-06, 10031-09	Lower Murray: Lock 5	4346	4346	01/08/15 - 30/11/15	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-LWM-49	10031-06, 10031-09	Lower Murray: Lock 2	738	738	01/09/15 - 30/11/15	Fresh	Supporting the managed transport and export of salt and nutrients from the River Murray system.	
1516-MBG-01	10035-15	Murrumbidgee: Hobblers Lake – Penarie Creek	5000	5910	08/03/16 - 29/3/16	Fresh	Provide winter refuge habitat and drying habitat into spring-summer 2016-17	
1516-MBG-05	10035-09	Murrumbidgee: Yanga National Park waterbird support	10000	11605	17/11/15 - 11/01/16	Wetland	Support ecosystem functions	
1516-MBG-10	10035-17	Murrumbidgee: Sandy Creek	105	270	01/04/16 - 30/06/16	Wetland	No stated ecological objective	No stated ecological objective
1516-MBG-13	10034-03	Murrumbidgee: Yanco Creek Wetland inundation	18263	22829	21/07/15 - 13/08/15	Wetland	Support ecosystem functions, such as dispersal of biota and transfer of nutrients, that relate to longitudinal and lateral connectivity.	
1516-MCQ-01	10036-02	Macquarie: Macquarie Marshes	12114	52554	6/08/15 - 17/10/15	Fresh	Allow for sediment transport, nutrient and carbon cycling	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1516-MCQ-02	10032-01	Macquarie River: Mid-Macquarie River	2125	2500	25/06/16 - 30/06/16	Fresh	Allow for sediment transport, nutrient and carbon cycling	
1516-OVN-01	10004-02	Ovens River - with benefit to King River en route from Lake William Hovell	50	50	05/04/16 - 07/05/16	Baseflow	Improved primary production through the disruption of biofilms	
1516-OVN-02	10004-02	Ovens River - with benefit to Buffalo River en route from Lake Buffalo	20	20	25/04/16 - 26/04/16	Baseflow	Improved primary production through the disruption of biofilms	
1617-BDL-01	111-40	Barwon Darling: Barwon-Darling River and fringing wetlands	9446	9446	01/07/16 - 15/08/16	Fresh	Nutrient and sediment cycling from inundation of lower level benches (Darling River at Toorale Selected Area and downstream).	Water quality improvement including salinity and potential for algal blooms (flow pulse from the regulated action in the Gwydir, Darling at Toorale).
1617-BDL-02	111-40	Barwon Darling: Barwon-Darling River and fringing wetlands	3631	3631	20/08/16 - 31/08/16	Fresh	Nutrient and sediment cycling from inundation of lower level benches (Darling River at Toorale Selected Area and downstream).	Water quality improvement including salinity and potential for algal blooms (flow pulse from the regulated action in the Gwydir, Darling at Toorale).
1617-BDL-03	111-40	Barwon Darling: Barwon-Darling River and fringing wetlands	13719	13719	13/09/16 - 01/10/16	Fresh	Nutrient and sediment cycling from inundation of lower level benches (Darling River at Toorale Selected Area and downstream).	Water quality improvement including salinity and potential for algal blooms (flow pulse from the regulated action in the Gwydir, Darling at Toorale).
1617-BRD-03	111-34	Border Rivers - Dumaresq-Macintyre River and Fringing Wetlands	14377	14377	25/08/16 - 25/10/16	Bankfull	Nutrient and sediment cycling (from inundation of anabranch channels, near stream wetlands and some areas of the lower Macintyre River floodplain)	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1617-CLM-01	10050-02	Lower Murray: Coorong, Lower Lakes and Murray Mouth	618476	995776	01/06/16 - 30/06/17	Baseflow, Fresh	Export nutrients to support estuarine productivity in the mouth estuary and Coorong Northern Lagoon.	Export salt to maintain water quality in the lower lakes (minimum annual barrage discharge of 650 GL - regardless of the source of water). Protect water quality in the Northern Lagoon for benthic invertebrates, a key food source for migratory birds.
1617-CNM-01	10050-01	Central Murray: Barmah-Millewa Forest	39170	245273	22/06/16 - 31/12/16	Overbank	4. Contribute to riverine functioning by: a) Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. b) Supporting the managed export of salt and nutrients from the River Murray system.	
1617-CNM-02	10050-01	Central Murray: Murray River	124754	144752	01/01/17 - 30/06/17	Fresh	4. Contribute to riverine functioning by: a) Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. b) Supporting the managed export of salt and nutrients from the River Murray system.	
1617-CNM-03	10030-02	Central Murray - Gunbower Creek	23563	23563	01/07/16 - 30/06/17	Baseflow	Improve water quality and hydrological connectivity between Gunbower Forest and Gunbower Creek to support native fish, aquatic invertebrates and, nutrient and carbon movement.	Improve water quality and hydrological connectivity between Gunbower Forest and Gunbower Creek to support native fish, aquatic invertebrates and, nutrient and carbon movement.
1617-GLB-03	10051-01	Goulburn - Lower Goulburn River	64290	92558	01/03/17 - 03/04/17	Fresh	Disrupt biofilms, move fine sediment and entrain organic matter in-stream to support ecosystem function.	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1617-GLB-04	10051-01	Goulburn - Lower Goulburn River	39585	55965	04/04/17 - 25/06/17	Baseflow	Disrupt biofilms, move fine sediment and entrain organic matter in-stream to support ecosystem function.	
1617-GLB-05	10051-01	Goulburn - Lower Goulburn River	21119	21119	26/06/17 - 26/06/17	Fresh	Disrupt biofilms, move fine sediment and entrain organic matter in-stream to support ecosystem function.	
1617-GWY-01	100057-01	Gwydir - Gwydir Wetlands	9000	30000	27/12/16 - 28/02/17	Wetland	Support fundamental ecosystem function processes of nutrient and carbon cycling, and primary production.	
1617-GWY-03	100057-03	Gwydir - Carole Creek	1351	1351	15/09/2016 - 21/09/16	Baseflow	Support in-stream ecological function and nutrient cycling, contributing to the health of in-stream habitat and maintaining water quality	Maintain in-stream water quality
1617-GWY-04	100057-04	Gwydir - Mehi River	5000	5000	17/09/2016 - 21/09/16	Fresh	Support in-stream ecological function and nutrient cycling, contributing to the health of in-stream habitat and maintaining water quality	Maintain in-stream water quality
1617-LWM-12	10050-06	Lower Murray - Rufus River	29570	59140	17/12/16 - 01/01/17	Fresh	Contributing to riverine function by - Supporting the managed transport and export of salt and nutrients from the River Murray system - Maintaining the diversity, condition and extent of aquatic and littoral vegetation in the Lower Lakes.	
1617-LWM-13	10050-01	Lower Murray: Lock 15	0	0	04/07/16 - 28/07/16	Fresh	Contributing to riverine functioning by: - Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal - Supporting the managed export of salt and nutrients from the River Murray system	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1617-LWM-14	10050-01	Lower Murray: Lock 15	0	0	19/03/17 - 09/05/17	Fresh	Contributing to riverine functioning by: - Supporting the managed export of salt and nutrients from the River Murray system	
1617-LWM-15	10050-01	Lower Murray: Lock 9	0	0	15/07/16 - 30/12/16	Fresh	Contributing to riverine functioning by: - Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal - Supporting the managed export of salt and nutrients from the River Murray system	
1617-LWM-16	10050-01	Lower Murray: Lock 9	0	0	30/04/17 - 30/06/17	Fresh	Contributing to riverine functioning by: - Supporting the managed export of salt and nutrients from the River Murray system	
1617-LWM-17	10050-01	Lower Murray: Lock 8	0	0	20/7/16 - 14/10/16	Fresh	Contributing to riverine functioning by: - Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. - Supporting the managed export of salt and nutrients from the River Murray system.	
1617-LWM-18	10050-01	Lower Murray: Lock 8	0	0	26/01/17 - 23/05/17 12/06/17 - 30/06/17	Fresh	Contributing to riverine functioning by: - Supporting the managed export of salt and nutrients from the River Murray system.	
1617-LWM-19	10050-01	Lower Murray: Lock 7	0	0	01/08/16 - 01/01/17	Fresh	Contributing to riverine functioning by: - Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. - Supporting the managed export of salt and nutrients from the River Murray system.	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1617-LWM-20	10050-01	Lower Murray: Lock 7	0	0	01/02/17 01/03/17 01/05/17 - 01/06/17	Fresh	Contributing to riverine functioning by: - Supporting the managed export of salt and nutrients from the River Murray system.	
1617-LWM-21	10050-02	Lower Murray: Lock 5	0	0	01/07/16 - 01/10/16	Fresh	Contributing to riverine functioning by: - Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. - Supporting the managed export of salt and nutrients from the River Murray system.	
1617-LWM-22	10050-02	Lower Murray: Lock 2	0	0	01/07/16 - 01/10/16	Fresh	Contributing to riverine functioning by: - Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. - Supporting the managed export of salt and nutrients from the River Murray system.	
1617-MBG-01	10052-02	Murrumbidgee - Murrumbidgee River	150978	370839	28/10/16 - 05/01/17	Fresh, Bankfull	To reduce slumping of saturated banks	To slow wetland discharge of low dissolved oxygen (DO) water back into the river channel, and to maintain a steady in-channel dilution flow until dissolved oxygen levels had risen to safe levels for native fish and other aquatic animals
1617-MBG-10	10052-13	Murrumbidgee - Lower Murrumbidgee River	47548	48587	01/04/17 - 20/04/17	Fresh	Support biotic and nutrient dispersal	Improving water quality
1617-MCQ-01	10055-01	Macquarie: Macquarie Marshes	17039	46413	24/01/17 - 18/02/17	Wetland	Support in-channel processes	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1617-NAM-02	10063-01	Namoi - Peel River	1257	6190	04/06/17 - 30/06/17	Fresh	Restore flow variability and to increase the food supply for native fish by "flushing" nutrients off the low in-channel bars.	
1617-WAR-06	152-07	Warrego: Lower Warrego River and fringing wetlands.	7763	7763	08/10/16 - 28/10/16	Fresh	Nutrient and sediment cycling from inundation of lower level benches (Darling River).	
1718-BRD-08	10046-04	Border Rivers: Dumaresq-Macintyre River and Fringing Wetlands	684	8684	21/08/17 - 08/10/17	Baseflow, Fresh	Contributing to carbon/nutrient cycling processes.	Improving water quality.
1718-CLM-01	10065-04	Lower Murray: Coorong, Lower Lakes and Murray Mouth	326320	326320	01/07/17 - 30/09/17	Fresh	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	Deliver Commonwealth environmental water into the Coorong via a hydrological regime that: in dry conditions, aims to maximise estuarine habitat by prolonging barrage releases to support water levels and improve water quality in the north lagoon in order to: potentially reduce peak salinity in the Coorong in summer-autumn to reduce the risk of irreversible damage to *Ruppia tuberosa*.

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1718-CLM-02	10065-04	Lower Murray: Coorong, Lower Lakes and Murray Mouth	354807	354807	01/10/17 - 31/01/18	Fresh	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	Deliver Commonwealth environmental water into the Coorong via a hydrological regime that: in dry conditions, aims to maximise estuarine habitat by prolonging barrage releases to support water levels and improve water quality in the north lagoon in order to: potentially reduce peak salinity in the Coorong in summer-autumn to reduce the risk of irreversible damage to *Ruppia tuberosa*.

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1718-CLM-03	10065-04	Lower Murray: Coorong, Lower Lakes and Murray Mouth	203279	203279	01/02/18 - 31/05/18	Baseflow	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	Deliver Commonwealth environmental water into the Coorong via a hydrological regime that: in dry conditions, aims to maximise estuarine habitat by prolonging barrage releases to support water levels and improve water quality in the north lagoon in order to: potentially reduce peak salinity in the Coorong in summer-autumn to reduce the risk of irreversible damage to *Ruppia tuberosa*. Environmental water delivered to the Lower Lakes is expected to also support the following outcomes: Export of salt from the Lower Lakes. Maintenance of water quality for consumptive water users in the Lower Lakes.

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1718-CLM-04	10065-04	Lower Murray: Coorong, Lower Lakes and Murray Mouth	9331	9331	01/06/18 - 30/06/18	Baseflow	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	Deliver Commonwealth environmental water into the Coorong via a hydrological regime that: in dry conditions, aims to maximise estuarine habitat by prolonging barrage releases to support water levels and improve water quality in the north lagoon in order to: potentially reduce peak salinity in the Coorong in summer-autumn to reduce the risk of irreversible damage to *Ruppia tuberosa*.
1718-CNM-01	10065-02	Central Murray: Barmah-Millewa Forest	3344	11012	01/07/17 - 23/03/18	Wetland	Support primary and secondary production through the creeks/anabranches through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal.	-
1718-CNM-04	10065-01	Central Murray: River Murray	289606	289606	01/07/17 - 31/12/17	Fresh, Overbank	Contributing to riverine functioning by: a) Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. b) Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-EWK-01	10070-01	Edward Wakool: Yallakool Wakool System	16452	16452	01/09/17 - 01/05/18	Fresh	Support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organise matter) through longitudinal and lateral hydrological connectivity. Provide connectivity between existing remnant pools and the Edward River.	Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH.

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1718-EWK-02	10070-01	Edward Wakool: Tuppal Creek	1641	3282	21/08/17 - 10/11/17	Baseflow	Support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity. Provide connectivity between existing remnant pools and the Edward River.	Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH. Improve water quality in the Tuppal Creek particularly EC.
1718-EWK-03	10070-03	Edward Wakool: Colligen-Neimur	13832	13832	01/09/17 - 01/05/18	Fresh	Support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity.	Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH.
1718-EWK-04	10070-04	Edward Wakool: Tuppal Creek	933	3712	29/03/18 - 05/05/18	Baseflow	Support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity. Provide connectivity between existing remnant pools and the Edward River.	Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH. Improve water quality in the Tuppal Creek particularly EC.
1718-EWK-05	10054-11	Edward Wakool: Yallakool Wakool System	7915	7915	01/07/17 - 30/08/17	Baseflow	Support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity.	Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH.
1718-EWK-06	10054-12	Edward Wakool: Colligen-Neimur	6370	6370	01/07/17 - 30/08/17	Baseflow	Support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity.	Maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH.
1718-GWY-01	10069-01	Gwydir: Gwydir Wetlands	4000	8000	19/12/17 - 17/01/18	Wetland	Allow for sediment transport, nutrient and carbon cycling.	-

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1718-GWY-02	10069-04	Gwydir: Mehi River	7000	10000	26/08/17 - 04/09/17	Fresh	Support in-stream ecological function and nutrient cycling.	Maintain in-stream water quality.
1718-GWY-03	10069-04	Gwydir: Mehi River	5000	10040	30/10/17 - 20/11/17	Baseflow	Support in-stream ecological function and nutrient cycling.	Maintain in-stream water quality.
1718-LCH-01	10053	Lachlan: Lachlan River	32572	32572	27/09/17 - 19/11/17	Baseflow	Additional productivity boost and hence replenish food sources for larvae as they begin to feed on their own.	-
1718-LCH-02	10053	Lachlan: Lachlan River	951	951	27/09/17 - 16/10/17	Baseflow	Additional productivity boost and hence replenish food sources for larvae as they begin to feed on their own.	-
1718-LDL-01	10072-01	Lower Darling: Lower Darling River	2738	25810	21/11/17 - 28/11/17	Fresh	Transport propagules and nutrients to the Lower River Murray.	Improve water quality (particularly salinity and pH).
1718-LWM-03	10065-01	Lower Murray: Lock 7	409	1569	08/09/17 - 10/12/17	Overbank	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-LWM-04	10065-01	Lower Murray: Lock 7	409	-27	22/02/18 - 31/05/18	Baseflow	Contributing to riverine functioning by: Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-LWM-05	10065-01	Lower Murray: Lock 8	409	1315	10/09/17 - 06/12/17	Overbank	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-LWM-06	10065-01	Lower Murray: Lock 8	409	-220	22/02/18 - 31/05/18	Baseflow	Contributing to riverine functioning by: Supporting the managed export of salt and nutrients from the River Murray system.	-

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1718-LWM-07	10065-01	Lower Murray: Lock 9	409	483	30/08/17 - 09/10/17	Overbank	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-LWM-08	10065-01	Lower Murray: Lock 9	409	-1419	22/02/18 - 30/05/18	Baseflow	Contributing to riverine functioning by: Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-LWM-09	10065-01	Lower Murray: Lock 15	409	1815	05/09/17 - 26/11/17	Overbank	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-LWM-10	10065-01	Lower Murray: Lock 15	409	-242	23/03/18 - 31/05/18	Baseflow	Contributing to riverine functioning by: Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-LWM-11	10065-06	Lower Murray: Lock 2	335	335	Mid Jul - Early Aug 17	Baseflow	Contributing to riverine functioning by: Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-LWM-12	10065-06	Lower Murray: Lock 2	335		Aug – Oct 17	Overbank	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Process	Water quality
1718-LWM-13	10065-06	Lower Murray: Lock 5	1266	1266	Mid Jul - Early Aug 17	Baseflow	Contributing to riverine functioning by: Supporting the managed export of salt and nutrients from the River Murray system.	-
1718-LWM-14	10065-06	Lower Murray: Lock 5	1266	1266	Aug - Mid Nov 17	Overbank	Contributing to riverine functioning by: Supporting primary and secondary production along the River Murray through the mobilisation and transport of nutrients, carbon cycling and biotic dispersal. Supporting the managed export of salt and nutrients from the River Murray system.	
1718-MBG-02	10062-01	Murrumbidgee: Mid-Murrumbidgee wetlands	159283	236205	24/07/17 - 01/09/17	Fresh, Wetland	Support hydrological connectivity and biotic and nutrient dispersal.	-
1718-MCQ-02	10067-01	Macquarie River: Mid-Macquarie River and Macquarie Marshes	48421	128438	15/08/17 - 12/11/17	Fresh, Wetland	Contribute to sediment transport, nutrient and carbon cycling.	-
1718-NAM-01	10066-01	Namoi: Lower Namoi River	4100	4100	12/03/18 - 15/05/18	Baseflow	Maintain water quality, carbon and nutrient cycling processes and improve productivity.	Maintain water quality, carbon and nutrient cycling processes and improve productivity.
1718-NAM-02	10063-02	Namoi: Peel River	1257	3892	05/06/18 - 18/06/18	Fresh	Increase instream productivity.	-
1718-WAR-02	152-10	Warrego: Lower Warrego River and fringing wetlands	0	0	1/04/2018	Fresh	Nutrient and sediment cycling from inundation of lower level benches (Darling River)	

Annex I. Other watering actions in 2018-19 associated with water quality.

Table I1 lists those watering actions in 2018-19 that explicitly targeted water quality outcomes (as distinct from stream metabolism) or for which water quality was a target of monitoring.

Table I1. Watering actions explicitly targeting water quality outcomes (as distinct from stream metabolism) or for which water quality was the target of monitoring.

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Water quality
1819-BRK-04	10077-01	Broken: Lower Broken Creek	19079	47307	1/1/19 - 31/5/19	Baseflow	Maintain DO levels above 5 mg/L
1819-CLM-01	10078-02	Lower Murray: Coorong, Lower Lakes and Murray Mouth	174491	174491	1/7/18 - 31/8/18	Baseflow	Coorong water quality/habitat suitability.
1819-CLM-02	10078-02	Lower Murray: Coorong, Lower Lakes and Murray Mouth	133167	133167	1/9/18 - 31/12/18	Baseflow	Coorong water quality/habitat suitability.
1819-CLM-03	10078-02	Lower Murray: Coorong, Lower Lakes and Murray Mouth	241762	241762	1/1/19 - 30/6/19	Baseflow, fresh	Coorong water quality/habitat suitability.
1819-CMP-01	10003-05	Campaspe: Campaspe River	1189	18260	12/9/18 - 28/9/18	Fresh	Flush river benches of organic matter to mitigate potential water quality issues during summer.
1819-CMP-03	10003-05	Campaspe: Campaspe River	1670	21955	1/12/18 - 30/4/19	Baseflow	Contribute to baseflows in summer to maintain: connectivity for protecting instream and fringing vegetation; and pool habitat for native fish populations, especially with respect to dissolved oxygen and salinity levels.
1819-EWK-01	10083-01	Edward Wakool: Colligen-Neimur	13943	13943	21/8/18 - 30/6/19	Baseflow, fresh	Improve water quality

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Water quality
1819-EWK-02	10083-01	Edward Wakool: Yallakool Wakool System	19365	19365	21/8/18 - 30/6/19	Baseflow, fresh	Improve water quality
1819-EWK-03	10083-03	Edward Wakool: Tuppal Creek	2870	2870	17/9/18 - 30/6/19	Baseflow, fresh	Improve water quality in the Tuppal Creek, particularly to help reduce salt levels.
1819-LWM-32	10078-06	Lower Murray: Gurra Gurra Lyrup Lagoon	67	67	6/5/19 - 31/5/19	Wetland	Freshen sallow permanent saline lagoon.
1819-LWM-35	10078-06	Lower Murray: Pike Lagoon Flood-runner	31	31	10/5/19 - 15/5/19	Wetland	Freshen ground water lens.
1819-MBG-01	10082-02	Murrumbidgee: Yanga National Park	10500	79794	20/8/18 - 31/1/19	Wetland	Improve water quality.
1819-MBG-02	10082-03	Murrumbidgee: Yanga National Park	30000	30000	17/9/18 - 25/1/19	Wetland	Improve water quality.
1819-MBG-15	10082-16	Murrumbidgee: Lower Murrumbidgee River	3300	27600	30/1/19 - 9/4/19	Fresh	Contribute to improving water quality, with the aim of increasing dissolve oxygen to safe levels for native fish and other aquatic fauna and/or preventing dissolved oxygen levels dropping below critical thresholds.
1819-MCQ-03	10084-02	Macquarie River: Lower Nyngan Weir Pool (Bogan River)	150	300	19/3/19 - 30/6/19	Baseflow	Increase and maintain water levels and water quality in the weir pool to reduce the risk of a potential fish kill.
1819-MCQ-04	10084-03	Macquarie River: Methalibah Reserve - Ewenmar Creek	520	800	30/4/19 - 1/6/19	Baseflow	Increase and maintain water levels and water quality in the Bundemar weir pool at Methalibah Reserve, to reduce the risk of a potential fish kill.
1819-NAM-01	10087	Namoi: Lower Namoi River	5500	5500	9/11/18 - 15/12/18	Fresh	Improve water quality in refuge habitats.
1819-WIM-01	10007-02	Wimmera: Wimmera River	186	434	7/11/18 - 12/11/18	Fresh	Manage water quality (salinity).
1819-WIM-02	10007-02	Wimmera: Wimmera River	778	778	25/9/18 - 2/11/18	Baseflow, fresh	Manage water quality (salinity).

Basin-scale Evaluation Water Action Reference	WAR	Surface water region/asset	CEW (ML)	Total (ML)	Dates	Flow component	Water quality
1819-WIM-03	10007-02	Wimmera: Wimmera River	748	2274	13/11/18 - 21/12/18	Baseflow, fresh	Manage water quality (salinity).
1819-WIM-04	10007-02	Wimmera: Wimmera River	4126	8252	8/1/19 - 28/6/19	Baseflow, fresh	Manage water quality (salinity).