Icon Water MEMP

Impact monitoring – autumn 2020, spring 2020, autumn 2021

Icon Water Limited

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→ The Power of Commitment

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Executive summary

To assess the influence of the construction and operation of the Murrumbidgee to Googong transfer pipeline (M2G) and the Murrumbidgee Pump Station (MPS) on ecological conditions in associated waterways, Icon Water developed a detailed Murrumbidgee Ecological Monitoring Program (MEMP) to establish comprehensive baseline data and to satisfy the EIS and compliance commitments for the projects. Currently, the MEMP is aimed at investigating:

– *Potential impacts of water abstraction from the Murrumbidgee River at Angle Crossing and the Murrumbidgee Pump Station (Components 1 & 3)*
– *Subsequent changes that might occur in Burra Creek (Component 2)*

The aim of the 2020-21 impact monitoring presented in this report is to provide baseline data prior to changing to operational phase. This data will be used to compare the ecological conditions of control sites to those of the impacted sites over time to determine if there is any major catchment scale changes to the aquatic ecology in either the Murrumbidgee River or Burra Creek during the project's operational phase. Under the current modes of operation, the major conclusions from the monitoring are:

– *High rainfall in early 2020 ended the 2017-2019 drought and resulted in higher flows in the Murrumbidgee River and Burra Creek. Although there were high and at times low flow periods in 2020 and 2021 comparisons of upstream and downstream locations are still considered valid.*
– *Both the Murrumbidgee River and Burra Creek have high nutrient loads, particularly total phosphorus, total nitrogen and oxidised forms of nitrogen.*
– *There has been no increase in the occurrence of periphyton in the Murrumbidgee River and Burra Creek over time.*
– *There have been no dramatic changes in riparian or instream vegetation in Burra Creek.*
– *There are several areas prone to bank erosion and slumping in Burra Creek that are likely to be at greater risk during high flows.*
– *During low flow periods, edge habitat is reduced in the Murrumbidgee River and riffle habitat is lost in Burra Creek. Despite this, the general health of the two waterways has not dramatically changed over time and variation in these habitats is considered a natural event.*
– *The macroinvertebrate communities in the Murrumbidgee River and Burra Creek are generally reflective of mild to moderate pollution impacts and/or significant impairment with water quality and/or habitat potentially impacted resulting in loss of taxa.*
– *The macroinvertebrate community continues to display a high level of seasonal variation suggesting that that any impairment due to habitat conditions or operation of the M2G and MPS has not been enough to mask natural variability.*
– *Several threatened species are known to occur in the Murrumbidgee River, and it is recommended future fish surveys occur to monitor their condition. Surveys undertaken in 2021 did not detect a negative impact due to operation of the M2G.*
– *Overall, there were little differences waterway health upstream and downstream of the M2G and MPS in the Murrumbidgee River, or the discharge point in Burra Creek. The operation of the M2G and the MPS has not results in significant impairment to the waterways.*
– *Given operation of the M2G and MPS infrastructure has ceased, the MEMP will revert to the sentinel monitoring with the next round planned for 2025. Sentinel monitoring occurs during standby periods when the risk to the ecosystem is deemed to be very low and will continue every three years unless there is a requirement for operation that would trigger additional impact monitoring.*

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GHD would like to acknowledge the Ngunnawal and Ngarigo people who are the Traditional Custodians of the Land on which this project is located. We would also like to pay respect to the Elders both past and present and extend that respect to other Indigenous Australians.

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List of abbreviations

ACT – Australian Capital Territory

ALS – Australian Laboratory Services

ANZECC –Australian and New Zealand Environment and Conservation Council

ANZG – Australian and New Zealand Guidelines

AUSRIVAS – Australian River Assessment System

DO – Dissolved oxygen

D/S – Downstream

EC – Electrical Conductivity

ECD – Enlarged Cotter Dam

EIS – Environmental Impact Statement

EPT – Ephemeroptera, Plecoptera and Trichoptera taxa

GL – Gigalitres

GPS – Global positioning system

M2C – Murrumbidgee to Cotter transfer

M2G – Murrumbidgee to Googong transfer pipeline

MEMP – Murrumbidgee Ecological Monitoring Program

ML – Megalitres

ML/d – Megalitres per day

MPS – Murrumbidgee Pump Station

NATA – National Association of Testing Authorities

NMDS – Non-metric multidimensional scaling

NSW – New South Wales

NTU – Nephelometric Turbidity Units

Q – Rated discharge

QA – Quality Assurance

QC – Quality Control

TN – Total Nitrogen

TP – Total Phosphorus

U/S – Upstream

WL – Water level

1. Introduction

During the 2000-2010 drought in the Australian Capital Territory (ACT) and surrounding regions of New South Wales (NSW), dam storage volumes in the ACT declined to unprecedented levels. Icon Water, the major water utility in the ACT, developed a water security program that involved building additional and upgrading existing infrastructure to improve the future water supply for residents of Canberra and Queanbeyan. The water security projects include:

- Murrumbidgee to Googong transfer pipeline (M2G): from Angle Crossing just within the ACT southern border to Burra Creek in the Googong Reservoir catchment, at a nominal 100 ML/d
- Murrumbidgee Pump Station (MPS): adjacent to the existing Cotter Pump station to increase pump capacity from approximately 50 ML/d to 150 ML/d (nominally 100 ML/d)
- Tantangara Reservoir release: for run of river flow to the M2G abstraction point at Angle Crossing[1]
- Enlarged Cotter Dam (ECD): enlargement to 78 GL just downstream of the existing 4 GL Cotter Dam[1].

The M2G pipeline includes the pump station at Angle Crossing that transfers water from the Murrumbidgee River through a 12 km underground pipeline into Burra Creek. The water is then transported a further 13 km by surface flows through Burra Creek into Googong Reservoir. Water abstraction from the Angle Crossing pump station is dictated by the capacity of Googong Reservoir and the availability of water in the Murrumbidgee River. The system is designed to enable pumping of up to 100 ML/d, and construction was completed in August 2012. Abstraction from the Murrumbidgee River and the subsequent discharges to Burra Creek are directed by the Operational Environmental Management Plan (Icon Water, 2017).

The MPS is located just downstream of the Cotter River confluence with the Murrumbidgee River. It is adjacent to the Cotter Pump Station, which can abstract up to 100 ML/d, contributing to the water supply for the ACT. New infrastructure has increased the abstraction volume from the Murrumbidgee River to approximately 150 ML/d via the MPS. The upgraded pump station was commissioned in 2010 and pumping is dependent on demand, licence requirements, and water quality. The upgraded infrastructure also provides a recirculating flow from the Murrumbidgee River to the base of the ECD, providing environmental flows to the lower Cotter River below the dam which is referred to as the Murrumbidgee to Cotter (M2C) transfer.

There are several potential risks to ecological conditions in the Murrumbidgee River and Burra Creek due to operation of the M2G and MPS. In the Murrumbidgee River, risks are generally related to reduced flow due to water abstraction. For example, during periods of low flow there may be a loss of aquatic habitat and changes to macroinvertebrate communities, excessive periphyton growth, a shift to late successional communities dominated by filamentous algae, and a deterioration in water quality. In Burra Creek, some beneficial ecological effects may be expected due to increased flow including greater connectivity between pools allowing more frequent fish use, increased macroinvertebrate diversity and a reduction in the extent of macrophyte encroachment in the main channel. However, there may also be negative impacts to macroinvertebrate communities, water quality, channel and bank geomorphology, and riparian vegetation.

To assess the influence of the construction and operation of the M2G and MPS on ecological conditions in associated waterways, Icon Water developed the Murrumbidgee Ecological Monitoring Program (MEMP) to establish comprehensive baseline data and satisfy the Environmental Impact Statement (EIS) and compliance commitments for the projects. Comparisons of this baseline data to conditions during and following construction, as well as during operation of M2G and MPS, can be used to determine if there is a detectable change in ecological conditions. This report presents the results of monitoring that occurred in autumn and spring 2020 and autumn 2021 as part of the MEMP.

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[1] Note this report does not consider the Tantangara Reservoir release or the enlarged Cotter Dam.

1.1 Background and adaptive management: changes to the MEMP since 2008

The MEMP has been supported by Icon Water to investigate potential impacts of water abstraction from the Murrumbidgee River and the influence of increased water volumes in Burra Creek on ecological conditions (Figure 1-1). The MEMP was implemented prior to the commencement of the M2G project, allowing Icon Water to collect pre-abstraction baseline data to compare against the post-abstraction data once the M2G project began operation. Seasonal monitoring has occurred in spring and autumn each year between 2008 and 2021.

Over the course of the program, there have been several changes and modifications in line with the adaptive management philosophy of the MEMP. Between spring 2008 and autumn 2013 there were four component areas considered as part of the MEMP:

– Component 1: Angle Crossing (M2G)
– Component 2: Burra Creek (M2G)
– Component 3: Murrumbidgee Pump Station (MPS)
– Component 4: Tantangara to Burrinjuck (Tantangara Transfer).

Following the autumn 2013 monitoring, Icon Water reviewed the MEMP which resulted in the discontinuation of Component 3 and Component 4. The MEMP continued to assess Component 1 and Component 2 from spring 2013 to spring 2014.

The most recent and major change to the MEMP followed a peer review by Jacobs (2014). In this review, Component 3 was recommended to recommence, and three modes of operation were defined for the M2G and MPS to help target the monitoring program. These are defined for the M2G as:

– Standby (maintenance) – Ready to run, all components in place and being operated routinely for maintenance purposes. Peak pump volumes are typically 49 ML/d and transferring approximately 50 ML in total.
– Operating (full pump) – Operating in earnest under normal flow conditions, with continuous transfer of bulk water to Googong Reservoir for a period greater than 30 consecutive days.
– Operating (drought conditions: full pump, drought flows) – Operating in earnest under drought flow conditions with continuous transfer of bulk water to Googong Reservoir for a period greater than 30 consecutive days.

For the MPS, the modes of operation are defined as:

– Standby – Abstraction from the Murrumbidgee River not occurring. Ready to run, all components in place and being operated routinely for maintenance purposes.
– Recirculating Pump Operation – Flow up to 40 ML/d transferred to the base of the Cotter Dam to provide environmental flows to the lower Cotter River. Water to the Cotter River re-enters the Murrumbidgee River just upstream of the MPS.
– Operating (full pump) – Abstraction of up to 150 ML/d of water for raw water supply to Stromlo Water Treatment Plant for greater than 30 consecutive days. While this is the maximum capacity of the MPS, this abstraction volume rarely occurs due to water quality in the Murrumbidgee River. Hence, smaller volumes are likely to be taken (e.g. 80 ML/d) and shandied with cleaner Cotter River water from the Bendora Main.

During periods of standby for M2G and MPS, the risks from these projects to the ecological condition of the Murrumbidgee River and Burra Creek is minimal. Alternatively, it is anticipated that any risks to these waterways are most likely to manifest during periods of full operation. The revised MEMP adopted a two-stage approach which incorporates sentinel monitoring during standby operation modes, and impact monitoring during the various operation modes. These two types of monitoring are described in sections 1.1.1 and 1.1.2 respectively. The monitoring elements for each component of the revised monitoring program are outlined in Table 1-1.

Table 1-1 General suite of monitoring elements and scenarios

Monitoring element	Provider	Sentinel Monitoring		Impact Monitoring	
		M2G	MPS	M2G	MPS
Online Water Quality	Icon Water	✓	✓	✓	✓
Laboratory Water Quality	GHD	✓	✓	✓	✓
Macroinvertebrates	GHD	✓	✓	✓	✓
Periphyton	GHD	Not required	Not required	✓	✓
Geomorphology	GHD	✓	Not required	✓	Not required
Riparian vegetation	GHD	✓	Not required	✓	Not required
Fish	ACT Government	✓	✓	✓	✓

1.1.1 Sentinel monitoring (M2G & MPS)

The purpose of the sentinel monitoring is to understand if major catchment-scale changes to the aquatic ecology are taking place and to establish background conditions. Sentinel monitoring occurs during standby periods when the risk to the ecosystem is deemed to be very low. Sentinel monitoring occurs in autumn and spring every three years which began in autumn 2015. Based on the Jacobs (2014) review, the number of monitoring sites was reduced from six to two for each component resulting in one site upstream and one site downstream of Angle crossing (M2G), the Burra Creek discharge structure (M2G) and the Murrumbidgee Pump Station (MPS). Single macroinvertebrate samples are collected from both edge and riffle habitats when present. Quantitative periphyton monitoring is not required in the sentinel monitoring and qualitative methods, such as photogrammetry and AUSRIVAS habitat assessments, are used to track the conditions of these sites on a broad spatial and temporal scale. Under this scenario testing of hypotheses and targeted monitoring are not required. Sentinel monitoring has been completed in autumn and spring during 2015 and 2018.

1.1.2 Impact monitoring (M2G & MPS)

The trigger for impact monitoring is the decision to operate the M2G or MPS infrastructure. This monitoring scenario requires a before/after and control/impact (BACI) approach and relies on replicated monitoring protocols. Several univariate indicators of river health will be analysed before and after the operation period at upstream and downstream locations. Qualitative periphyton photogrammetry is assessed during both periods and compared between locations. The key difference between impact and sentinel monitoring is the number of sites (two upstream and two downstream), macroinvertebrate replicates (two riffle samples or edge samples if riffles not present), monitoring events (preferably autumn and spring before and after operation) and the level of detail used in the analysis.

Icon Water made the decision to undertake impact monitoring during 2019 due to the planned transition to operation phase during 2020 (see Figure 1-1). Based on this, the first round of impact monitoring was conducted in autumn 2019 for the M2G component, and subsequently in spring 2019 for both the M2G and MPS components. The impact monitoring continued in autumn 2020 during the transfer of 4.51 GL to Googong Reservoir as part of the M2G component. For the MPS component, the autumn 2020 monitoring occurred nine days after water was began to be extracted from the Murrumbidgee River and delivered to the base of the Cotter Dam (Figure 1-2). Post-operation (i.e. after) monitoring was undertaken as part of the impact monitoring in spring 2020 and autumn 2021, following the cessation of operation in August 2020 for the M2G component, and in October 2020 for the MPS component. Monthly totals during operation of the MPS in 2020 are included in Table 1-3.

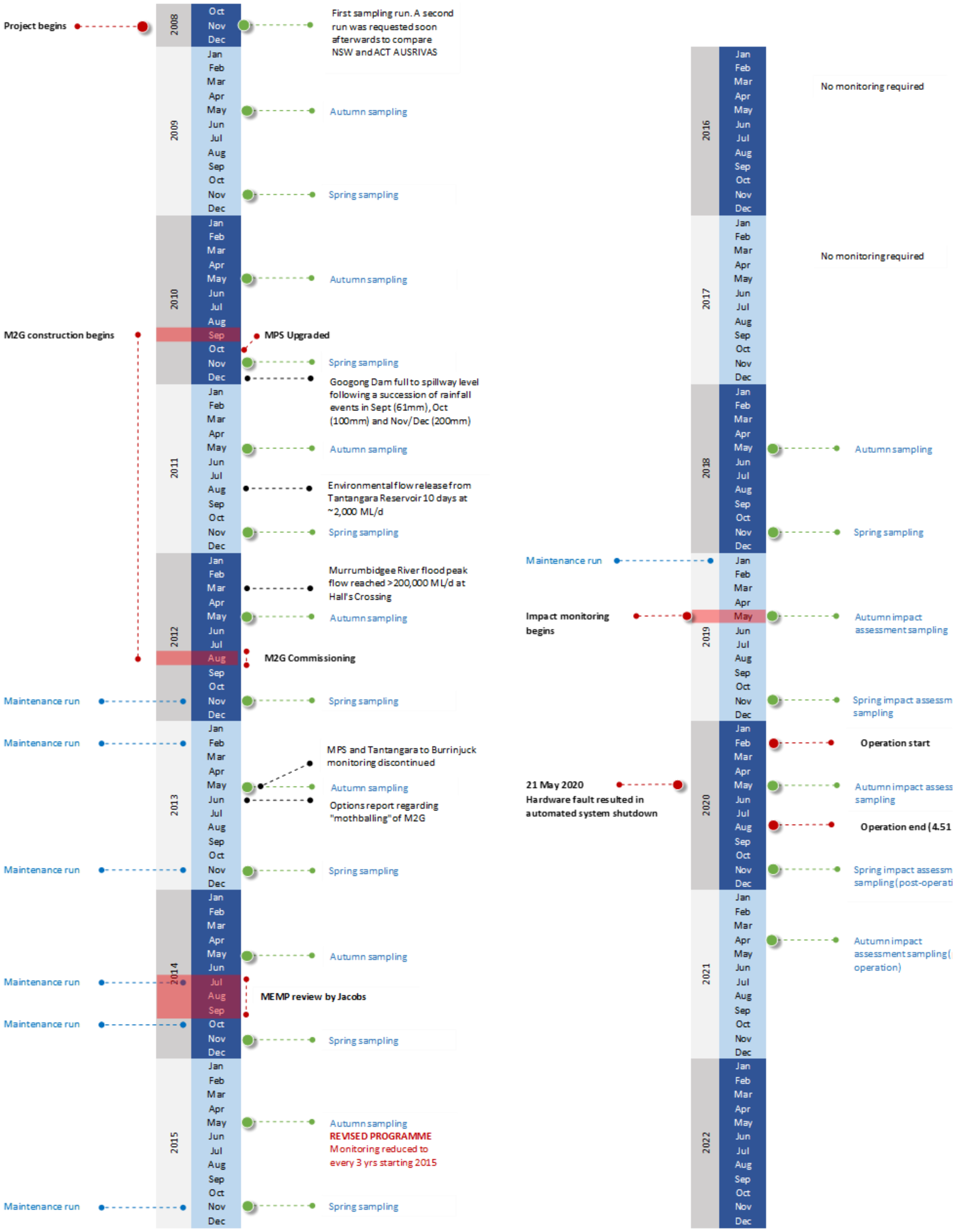

Figure 1-1 *Schematic timeline of the Murrumbidgee Ecological Monitoring Program*

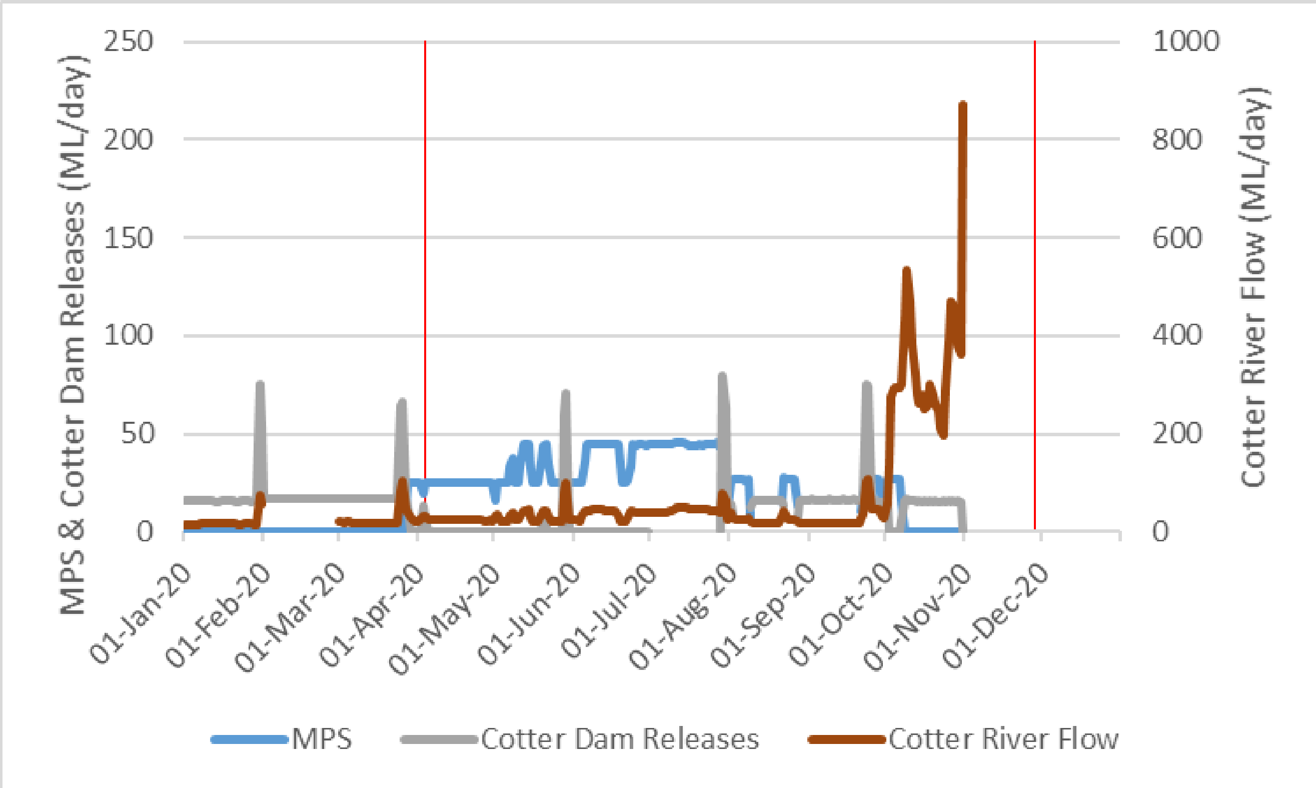

Figure 1-2 Operation of the MPS during 2020 showing water extracted from the Murrumbidgee River (MPS), Cotter River Dam releases and subsequent Cotter River flow; red lines indicate monitoring events; note different scales for MPS and Cotter Dam Releases (left y-axis) and the Cotter River Flow (right y-axis)

Table 1-2 Monthly totals (ML) during operation of the MPS during 2020 showing water extracted from the Murrumbidgee River (MPS), Cotter River Dam releases and subsequent Cotter River flow

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MPS	0.0	0.0	113.3	744.7	919.6	1171.7	1263.3	384.3	214.5	178.2	0.0	0.0
Cotter Dam Releases	588.4	493.0	568.0	19.8	142.4	0.0	158.7	312.1	597.0	381.0	0.0	0.0
Cotter River Flow	602.9	0.0	757.1	736.1	1011.7	1129.7	1391.0	683.3	862.5	10261.5	0.0	0.0

1.1.3 Environmental flow protection rules

The protection of environmental flows in the Murrumbidgee River downstream of the M2G abstraction point is a key governing factor around the operation of the M2G and three gauging stations are used to assess river flow and abstraction volumes (Icon Water, 2018):

- Upstream Angle Crossing Gauging Station (MURW2 / 41000270) - Approximately 1 km upstream of abstraction point in the Murrumbidgee River with flow data used to manage the abstraction regime during operation and maintenance activities.
- Pipeline Flow Meter - Flow meter which measures volume of water being transferred through the pipeline.
- Lobb's Hole Gauging Station (410761) - Approximately 2 km downstream of the abstraction point and serves as a backup to the Upstream Angle Crossing gauge as well as providing supplementary water quality and flow data.

Base flow in the Murrumbidgee River is protected by ensuring the amount of water abstracted does not reduce flow below the specified flows for each month (Table 1-3) and is calculated daily as follows:

- (Flow measured at MURW2) - (Flow measured by the Pipeline Flow Meter) > River flow to be protected specified for that month.

Table 1-3 Baseflow protection rules (ML/d) for M2G pumping operations during standby and operation modes

Conditions	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Normal	33.7	24.1	22.1	37.5	54.1	66.8	89.3	133.6	200.1	145.9	161.6	61.4
Drought	132.2	107.0	118.2	98.5	54.1	66.8	89.3	133.6	200.1	145.9	384.9	207.0

The drought protection rules apply when average flow in at least 15 of the 18 (~80%) past dry season months (November to April inclusive) is below the baseflow protection rules for normal conditions. Furthermore, during operating mode a 250 ML/d flow for riffle maintenance in the Murrumbidgee River is required for a period of 24 hours, once every 30 days, measured at Lobb's Hole (410761).

1.2 Project objectives

The MEMP was established by Icon Water to evaluate:

- Potential impacts of water abstraction from the Murrumbidgee River at Angle Crossing and the MPS (Components 1 & 3)
- Subsequent changes that might occur in Burra Creek due to discharges and increase flows (Component 2).

Since the completion of the M2G infrastructure and MPS upgrade, both have been used infrequently as Icon Water has opted to use available water from other catchments which offer raw water with lower production costs. The breaking of the drought in 2010 also reduced the need to operate the M2G or MPS because of improved water storage levels. However, a decision to transition to operation mode triggered pre-operational impact monitoring in autumn and spring 2019, and has continued into the autumn 2020, spring 2020 and autumn 2021 monitoring periods.

While the data from the 2019 monitoring period was used to gather baseline data prior to the operational phase, the aim of the subsequent impact monitoring presented in this report (autumn 2020, spring 2020 and autumn 2021) is to provide data post changing to the operational phase. This data will be used to compare the ecological conditions of control sites to those of the impacted sites over time to determine if there are any major catchment scale changes to the aquatic ecology in either the Murrumbidgee River or Burra Creek during the projects operational phase. These potential impacts have been assessed by the relevant Government authorities through submission of the EIS or similar assessments. One of the components of the EIS is to undertake an ecological monitoring program, on which this program is based.

Ultimately, the MEMP is aimed at addressing a series of hypotheses developed by Jacobs (2014). The MEMP has been designed to enable information generated to test the hypotheses and whether mitigations rules are effective in protecting river health (Table 1-4).

Table 1-4 Management hypotheses to be tested following impact assessment monitoring for M2G and MPS operations

Hypotheses	Operation(s)
1a: Flow abstraction will not result in the deterioration of the macroinvertebrate community (measured using biological indices) at sites downstream of the abstraction point (Angle Crossing for M2G and downstream of MPS) relative to sites upstream, informed by prevailing conditions in the broader region.	M2G & MPS
1b: Flow discharge to Burra Creek will not result in the deterioration of the macroinvertebrate community (measured using biological indices) at sites downstream of the inflow relative to sites upstream of the abstraction point and informed by prevailing conditions in the broader region.	M2G
2a: Flow abstraction in the Murrumbidgee River will not result in the development of increased periphyton to the extent that it impacts on the quality of the riffle habitat at sites downstream of the abstraction point (Angle Crossing for M2G and downstream of MPS) compared to sites upstream of the abstraction point, and informed by prevailing conditions in the broader region	M2G & MPS
2b: Flow discharge into Burra Creek will not result in the development of increased periphyton to the extent that it impacts on the quality of the riffle habitat at sites downstream of the inflow point compared with sites upstream of the inflow point, and informed by prevailing conditions in the broader region	M2G
3a: Flow transfer to Burra Creek will not result in bank erosion that is beyond that currently occurring in response to natural high flow events.	M2G
3b: Flow discharge to Burra Creek will not result in changes in macrophyte or riparian vegetation that is beyond that currently occurring in response to natural high flow events.	M2G
4a: Flow abstraction from the Murrumbidgee River will not result in an increased threat to threatened cod species due to decreased pool mixing and consequent water quality impacts.	M2G & MPS
4b: Flow discharge to Burra Creek will not result in the introduction of Carp or Oriental Weatherloach populations (via transfer) in Burra Creek or native fish stranding on drawdown.	M2G

1.3 Scope of works

The scope of this report is to convey the results from three rounds of impact monitoring in autumn 2020, spring 2020 and autumn 2021 for Component 1 – Angle Crossing, Component 2 – Burra Creek, and Component 3 – MPS. This work includes:

- Macroinvertebrate samples collected from riffle and edge habitats using AUSRIVAS protocols at the relevant sites
- Macroinvertebrate samples counted and identified to the taxonomic level of genus[2]
- Assessment of macroinvertebrate univariate indices (e.g. AUSRIVAS bands, SIGNAL-2 scores, EPT and total taxa richness) and multivariate community data to assess waterway health
- The use of photogrammetry to monitor periphyton, vegetation and geomorphology
- *In-situ* water quality measurements and water quality grab samples
- A review of fish monitoring results undertaken by the ACT Government

1.4 Licences and permits

All sampling was carried out with current scientific research permits under section 37 of *the Fisheries Management Act 1994 NSW* (permit number P01/0081(C)). All GHD aquatic ecology field staff hold current ACT and NSW AUSRIVAS accreditation.

[2] The reason for the genus resolution stems from the extensive and high-quality data set which precedes the adjusted program. By including genus level identification, the long-term integrity of the data record can be maintained.

2. Study area

2.1 The Upper Murrumbidgee River

The Murrumbidgee River flows for 1,600 km from headwaters in the Snowy Mountains to the Murray River. The catchment area to Angle Crossing is 5,096 km^2. As part of the Snowy Mountains Scheme, headwaters of the Murrumbidgee River are constrained by the 252 GL Tantangara Dam that collects and diverts water outside the Murrumbidgee catchment to Lake Eucumbene. This has reduced base flows and the frequency and duration of floods in the Murrumbidgee River. The Murrumbidgee River is impounded again at Burrinjuck Dam, after flowing through the ACT. Above Burrinjuck Dam is generally referred to as the Upper Murrumbidgee.

Land use varies from National Park in the high country to agricultural use in valley regions. Land use is dominated by urbanisation between Point Hut Crossing and the north-western suburbs of Canberra near the confluence with the Molonglo River. The major urbanised tributary flowing into the Murrumbidgee River is Tuggeranong Creek, which enters the downstream of Point Hut crossing. Average annual rainfall in the Upper Murrumbidgee River catchment ranges from greater than 1400 mm in the mountains, to 675 mm at Lobb's Hole (570985).

2.1.1 Hydrology of the Upper Murrumbidgee River

The upper Murrumbidgee catchment was significantly affected by the Millennium Drought from 2002 to 2010. Impacts include land degradation, increased stress on surface and groundwater resources, increased soil erosion and a shift from mixed farming and cropping, to grazing and reduced stock numbers. In the spring of 2010, the drought broke in the ACT and surrounding NSW regions and frequent high flow events occurred over the next six years, resulting in an upward trend in mean monthly baseflows (Figure 2-1). Particularly high flows occurred in March 2012 and June 2016. Drought returned between 2017 and 2019 and during this period, baseflow decreased in the Murrumbidgee River and there were few high flows (Figure 2-1). Since the drought broke in February 2020, baseflow increased and there have been frequent high flows.

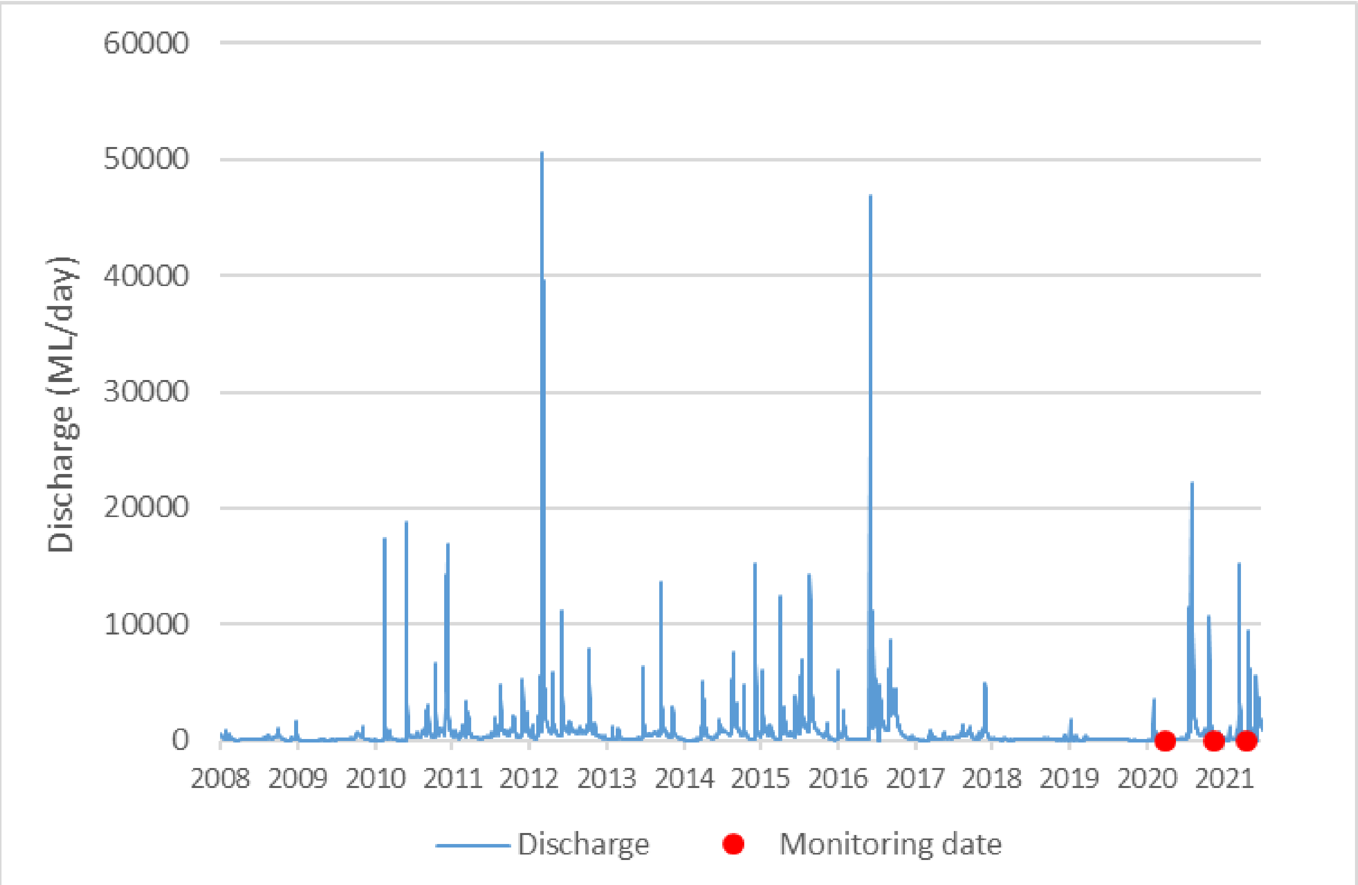

Figure 2-1 Discharge (ML/d) of the Murrumbidgee River at Lobb's Hole (410761) from January 2008 to July 2021

2.2 Burra Creek

Burra Creek is a small ephemeral stream which flows north to north-east along the western edge of the Tinderry Range into Googong Reservoir. Most of the catchment is pastoral and small rural holdings, with the Tinderry Range being natural dry sclerophyll forest. Burra Creek is characterised by emergent and submerged macrophyte beds with limestone bedrock and frequent pool-riffle sequences throughout its length. During low flow periods, the main channel is commonly choked with macrophytes. Burra Creek is within a large macro-channel in the lower reaches, both upstream and downstream of London Bridge (a natural limestone arch). When Googong Reservoir is at >80% capacity, the lower sections of Burra Creek become inundated by the reservoir.

2.2.1 Hydrology of Burra Creek

Burra Creek runs intermittently with occasional high flows. Between January 2008 and July 2021, the discharge was below 2 ML on 58% of days. Although there were seven days when flow was greater than 1,000 ML, there were 455 days of zero flow.

Flow have varied considerably since the inception of the MEMP in late 2008 (Figure 2-2). In 2008, mean daily flow was 0.15 ML/d and this was followed by an equally dry year in 2009 when the mean daily flow was 0.18 ML/d. In early 2010, the Millennium Drought broke and there were several high rainfall events throughout most of the year resulting in an upward trend of daily mean flows, which reached an average of 31.5 ML/d. While discharge was lower in 2011, flows increased in 2012 following high rainfall. Between 2013 and 2017 average annual flows ranged between 6.0 ML/d to 18.3 ML/d. The region was in drought between 2017 and 2019 and flows in Burra Creek reduced. During this period, there were few high flow events and summer in 2019 was the driest since 2009 (Figure 2-2). Drought broke in 2020 and flows increased in Burra Creek. The mean annual discharge for 2020 was 22.01 ML/d, the highest since 2012. Flows have been remained relatively higher in the first half of 2021.

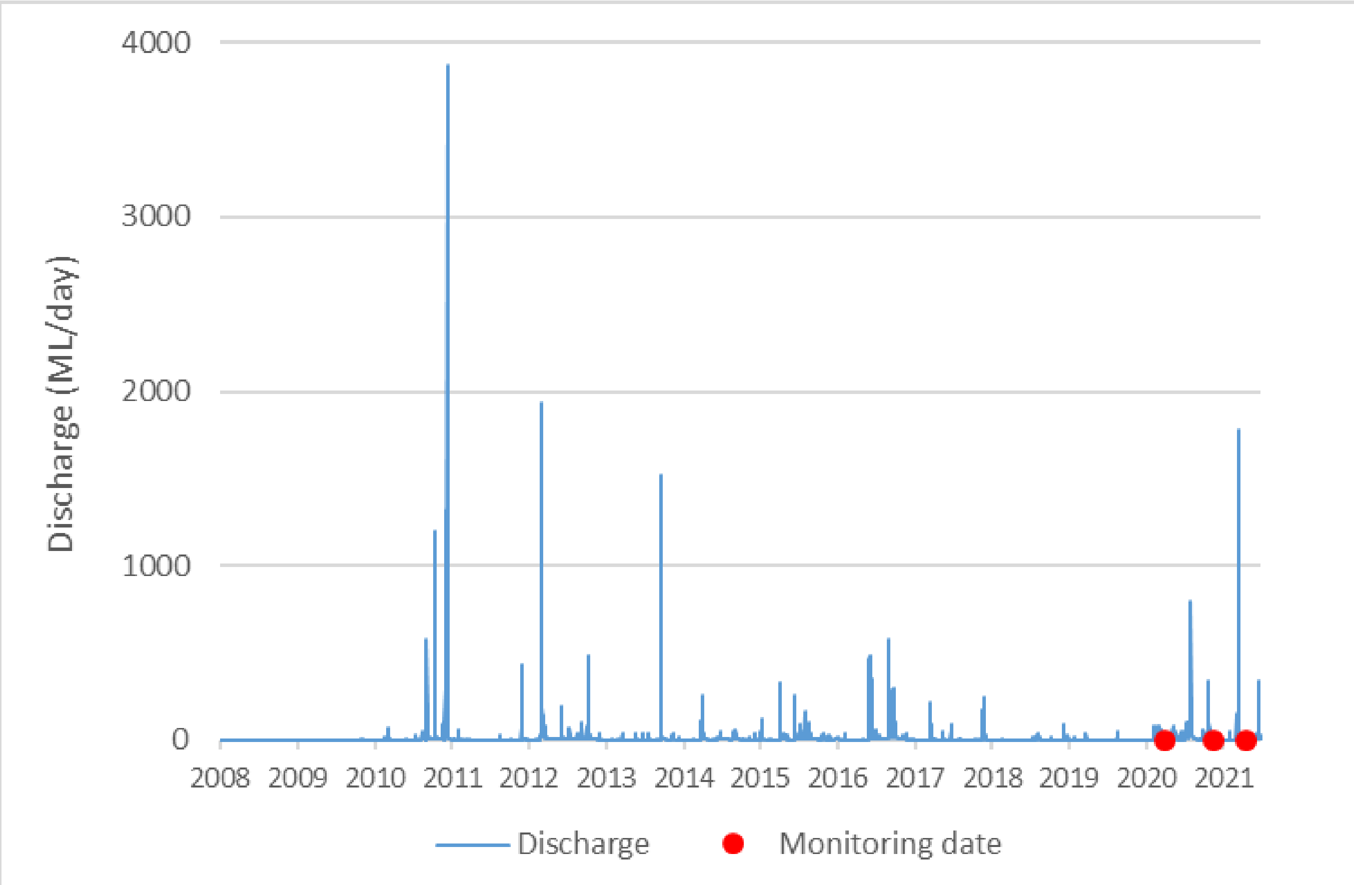

Figure 2-2 Discharge (ML/d) of Burra Creek at the Burra Road weir (410774) from January 2008 to July 2021

3. Methods

3.1 Study sites

Table 3-1 presents the study sites sampled for the autumn 2020, spring 2020 and autumn 2021 monitoring events. The table also identifies the monitoring and investigations that were undertaken at each site which are discussed further below. The locations of the sites are shown in Figure 3-1**,** Figure 3-2 and Figure 3-3.

Upstream (control) and downstream (impact) sites relative to the respective infrastructure formed the basis of the 2020-21 impact monitoring of the MEMP. These sites are a subset of existing sites, which were previously sampled as part of the original MEMP program (2009-2014), as well as the sites modified in response to program review recommendations (Jacobs, 2014). These sites were chosen based on several criteria, which included:

– Safe access and approval from landowners.
– Representative habitats (i.e. riffle / pool sequences). If both habitats were not present, sites with riffle zones took priority as they are the most likely to be affected by abstractions.
– Sites which have historical ecological data sets (e.g. Keen, 2001) took precedence over new sites allowing for comparisons through time to help assess natural variability through the system. This is especially important in this program because there is less emphasis on the reference condition, and more on comparisons between and among sites of similar characteristics in the ACT and surrounds over time.

Table 3-1 Sampling locations, details and investigations undertaken during the autumn 2020, spring 2020 and autumn 2021 impact monitoring

Component		Site	Location	Purpose	Alt. (m)	Land use	Latitude	Longitude	Water quality	Macro-invertebrate	Periphyton	Geo-morphology	Riparian Vegetation	Fish
Component 1 (M2G)	Angle Crossing	MUR17	~950 m upstream Angle Crossing	Control	597	Recreation Grazing	-35.586453	149.112817	✓	✓	✓			
		MUR18	~600 m upstream Angle Crossing	Control	597	Grazing	-35.587542	149.109902	✓	✓	✓			
		MUR19	Immediately downstream Angle Crossing	Impact	596	Recreation Grazing	-35.583027	149.109486	✓	✓	✓	✓		
		MUR20	~400 m downstream Angle Crossing	Impact	595	Recreation Grazing	-35.580979	149.111303	✓	✓	✓			
Component 2 (M2G)	Burra Creek	BUR1a	Upstream Burra Rd	Control	801	Grazing	-35.597819	149.227547				✓		
		BUR1b	Upstream Williamsdale Rd	Control	798	Grazing	-35.597536	149.227023	✓	✓	✓			
		BUR1d	Upstream Williamsdale Rd	Control	748	Grazing	-35.555963	149.222150	✓	✓	✓			
		BUR2	Downstream Williamsdale Rd	Impact	746	Grazing	-35.553320	149.225228	✓	✓	✓	✓	✓	
		BUR2a	Downstream Williamsdale Rd	Impact	748	Grazing	-35.554345	149.224477	✓	✓	✓	✓		
		Pool29	Googong Foreshore upstream London Bridge Homestead	Impact	688	Recreation	-35.531316	149.245800				✓	✓	
		BUR2c	Googong Foreshore upstream London Bridge Arch	Impact	668	Recreation	-35.518833	149.261250				✓	✓	
Component 3 (MPS)	Murrumbidgee Pump Station	MUR28up	Upstream MPS (upstream Cotter River)	Control	462	Grazing	-35.324382	148.950381	✓	✓	✓			
		MUR28down	Upstream MPS (downstream Cotter River)	Control	462	Grazing	-35.324699	148.950417	✓	✓	✓			
		MUR935	Downstream of MPS (Casuarina Sands)	Impact	461	Grazing	-35.319483	148.950211	✓	✓	✓			
		MUR936	Downstream of MPS	Impact	460	Recreation	-35.317535	148.961213	✓	✓	✓			

Paper Size ISO A4

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Kilometers

Map Projection: Mercator Auxiliary Sphere
Horizontal Datum: WGS 1984
Grid: WGS 1984 Web Mercator Auxiliary Sphere

N

GHD

Icon Water
Murrumbidgee Ecological Monitoring Program

Murrumbidgee to Googong
Impact Monitoring Sites

Project No. 2316216
Revision No. 1
Date 15/05/2019

FIGURE **3-1**

G:\23\16216\GIS\Maps\Working\Angle Crossing.mxd
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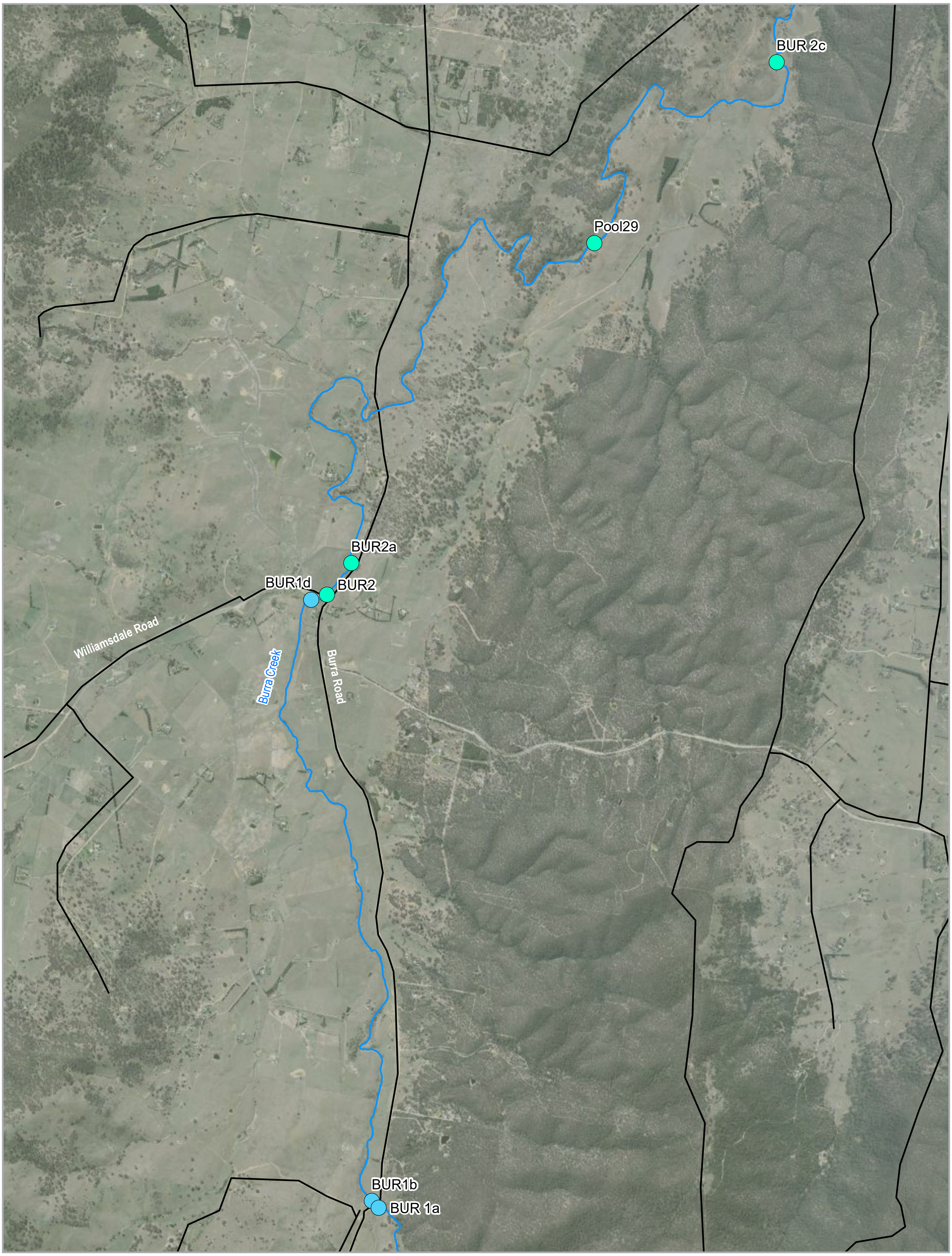
Data source: . Created by: pjtaylor



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Kilometers

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GHD

Icon Water
Murrumbidgee Ecological Monitoring Program

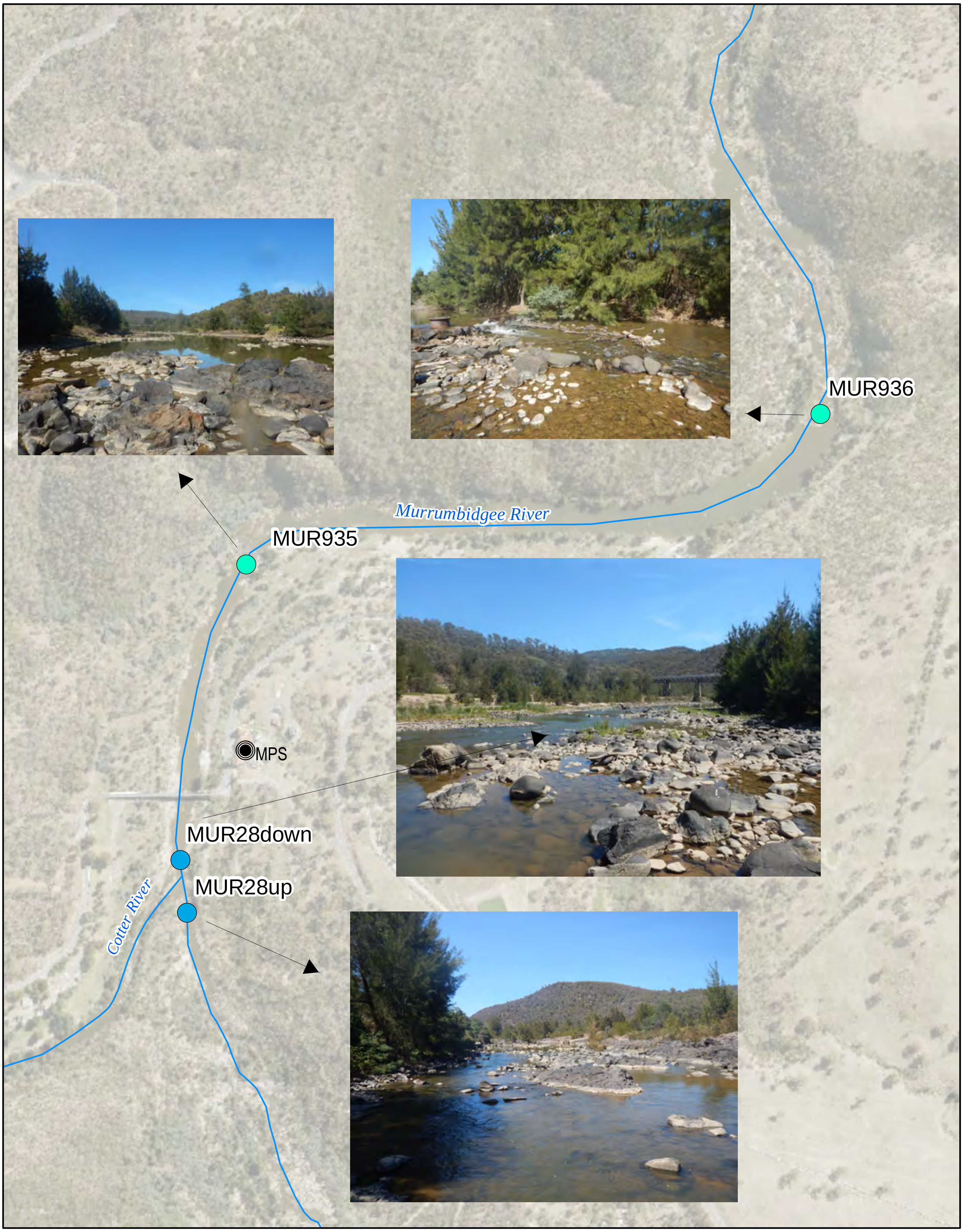
Murrumbidgee to Gogong Impact Monitoring Sites

Project No. 2316216
Revision No. 2
Date 24/07/2020

FIGURE 3-2

N:\AU\Canberra\Projects\23\16216\GIS\Maps\Working\BurraCreek_B.mxd
Print date: 24 Jul 2020 - 10:07

Data source: © Department of Customer Service 2020;Imagery NSW imagery webmap sixmap. Created by: cjauniau



Paper Size ISO A4

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Kilometers

Map Projection: Mercator Auxiliary Sphere
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Grid: WGS 1984 Web Mercator Auxiliary Sphere

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Icon Water
Murrumbidgee Ecological
Monitoring Program

Murrumbidgee Pump Station
Impact Monitoring Sites

Project No. 2316216
Revision No. 1
Date 15/05/2019

FIGURE 3-3

G:\23\16216\GIS\Maps\Working\MPS_updates.mxd
Print date: 21 Nov 2019 - 14:58

Data source: . Created by: pjtaylor

3.2 Hydrology and rainfall

Flow in the Murrumbidgee River reflects rainfall patterns in the region. Prior to spring 2010, drought conditions had a significant impact and more than 80% of catchments in the region had been drought-affected since late 2002. In the spring of 2010, the drought broke in the ACT and surrounding NSW regions and frequent high flows occurred in the Murrumbidgee River in response to high rainfall between 2012 and 2016. Drought returned between 2017 and 2019. However, the most recent drought broke in February 2020. Since then, baseflow has increased and there have been frequent high flows.

River flows and rainfall for the monitoring period were recorded at ALS maintained gauging stations located upstream of Angle Crossing (41001702), at Mt McDonald downstream of the MPS (410738) and Burra Creek at Burra Creek weir (410774). The gauging stations monitor the parameters shown in Table 3-2. Stations were calibrated according to ALS protocols and data were downloaded and verified before quality coding and storage in the ALS database. Water level data were manually verified by comparing data from the gauging station value to the physical staff gauge value and adjusted if required. Rain gauges were also calibrated and adjusted as required. Records were stored using the HYDSTRA© database management system. The ALS gauging station data is presented in this report to indicate trends in water quality.

Table 3-2 River flow monitoring locations and parameters

Site Code	Location/Notes	Parameters*	Latitude	Longitude	Component of the MEMP
41001702	Murrumbidgee River, (U/S of Angle Crossing)	WL, Q, pH, EC, DO, Temperature, Turbidity, Rainfall	-35.5914	149.1204	Angle Crossing (M2G)
410761	Murrumbidgee River @ Lobb's Hole (D/S of Angle Crossing)	WL, Q, pH, EC, DO, Temperature, Turbidity, Rainfall	-35.5398	149.1001	Angle Crossing (M2G) / Murrumbidgee Pump Station (MPS)
410774	Burra Creek D/S road bridge	WL, Q, pH, EC, DO, Temperature, Turbidity, Rainfall	-35.5425	149.2279	Burra Creek (M2G)
410738	Murrumbidgee River at Mt. McDonald	WL, Q	-35.2916	148.9552	Murrumbidgee Pump Station (MPS)

** WL = Water Level; Q = Rated Discharge; EC = Electrical Conductivity; DO = Dissolved Oxygen; Rainfall = Rainfall (mm) D/S = downstream; U/S = upstream.*

3.3 Water quality

Water temperature, turbidity, dissolved oxygen (DO), electrical conductivity (EC) and pH were measured *in-situ* using a laboratory calibrated YSI 556 multi-parameter water quality meter as a part of the ACT AUSRIVAS sampling protocols (Nichols *et al.*, 2000). Bottled water samples (grab samples) were collected at all sites in accordance with AUSRIVAS protocols (Nichols, *et al.* 2000), and submitted to NATA accredited laboratory ALS for analysis. Samples were analysed for ammonia, oxidised nitrogen (nitrate + nitrite), total nitrogen (TN) and total phosphorus (TP). The *in-situ* recordings and grab samples provide a snap-shot of conditions at the time of monitoring only. To compliment this and provide an understanding of water quality dynamics over a longer period, continuous water quality data was also obtained from relevant gauging stations.

In-situ and grab sample results were examined for compliance with the Australian New Zealand Guidelines for Fresh and Marine Water Quality healthy ecosystems in upland streams (ANZG 2018), which supersede the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000). Continuous gauging station data is presented as time series plots.

3.4 Macroinvertebrate monitoring

Where habitat conditions permitted, two replicate samples were collected from both riffle and edge habitats at each site. Both habitats were sampled to provide a more comprehensive assessment of each site (Nichols *et al.*, 2000) and potentially allow the program to isolate flow-related impacts from other disturbances. The reasoning behind this is that each habitat is likely to be affected in different ways by changes in flow conditions. Riffle zones, for example, are likely to be one of the first habitats affected by low flows as water abstraction will result in an immediate reduction in flow velocities and inundation level over riffle zones downstream of the abstraction point. Impacts on edge habitat macroinvertebrate assemblages might be less immediate as it may take some time for the reduced flow conditions to cause loss of macrophyte beds and access to trailing bank vegetation habitat. Therefore, monitoring both habitats will allow the assessment of the short-term and longer-term impacts associated with water abstraction.

Samples were collected using the ACT AUSRIVAS protocols outlined in Nichols *et al*. (2000). Sampling nets and all other associated equipment were washed thoroughly between habitats, sites and sampling events to remove any macroinvertebrates retained on them. The samples were placed in separate containers, preserved with 70% ethanol, and clearly labelled inside and out with project information, site code, date, habitat, and sampler details. ACT AUSRIVAS field sheets were completed at each site.

Processing of samples followed the ACT AUSRIVAS protocols (Nichols *et al*., 2000). In the laboratory, each preserved sample was placed in a sub-sampler, comprising of 100 (10 X 10) cells (Marchant, 1989). The sub-sampler was agitated to evenly distribute the sample, and the contents of randomly selected cells removed and examined under a dissecting microscope until a minimum of 200 animals were counted. All animals within the selected cells were identified. Sample processing was repeated three times for each sample to align with the approach used in previous monitoring events.

Macroinvertebrates were identified to genus level (where possible) using taxonomic keys outlined in Hawking (2000) and later publications. Specimens that could not be identified to the specified taxonomic level (i.e. immature or damaged taxa) were removed from the data set prior to analysis. Genus identification was recommended by Chessman (2008) from his review of the MEMP project design.

3.4.1 Quality control

Several Quality Control procedures were undertaken during the macroinvertebrate identification phase of this program including:

- Individuals heavily damaged were not selected during sorting. To overcome losses associated with damage to intact Individuals during sample handling, attempts were made to obtain significantly more than 200 Individuals.
- Identification was performed by qualified and experienced aquatic ecologists with more than 100 hours of identification experience.
- When required, taxonomic experts confirmed identification. Reference collections were also used when possible.
- ACT AUSRIVAS QA/QC protocols were followed.
- An additional 5% of samples were re-identified by another senior taxonomist.
- Very small, immature, damaged animals or pupae that could not be positively identified were not included in the data set.
- All procedures were performed by AUSRIVAS accredited staff.

3.4.2 Univariate analysis

The macroinvertebrate data has been analysed using a combination of univariate and multivariate techniques. Univariate metrics are often used in a lines-of-evidence approach in river health assessments and have solid foundations in biomonitoring. The univariate techniques include:

- Taxa Richness
- EPT Richness
- SIGNAL-2 Biotic Index
- ACT AUSRIVAS O/E score and Band

Taxa Richness and EPT Richness – The total number of taxa (Taxa Richness) and number of pollution-sensitive taxa of the orders Ephemeroptera, Plecoptera and Trichoptera (EPT Richness) were calculated at family and genus levels. Taxa richness was calculated as a means of assessing macroinvertebrate diversity with high taxa richness scores usually, though not always, indicate better ecological conditions. In certain instances, high taxa richness may indicate a response to the provision of new habitat or food resources that might not naturally occur and are the result of anthropogenic activities. EPT taxa are generally considered more sensitive to pollution.

SIGNAL-2 – Stream Invertebrate Grade Number – Average Level (SIGNAL) is a biotic index based on pollution sensitivity values (grade numbers) assigned to aquatic macroinvertebrate families that have been derived from published and unpublished information on their tolerance to pollutants, such as sewage and nitrification (Chessman, 2003). Each family has been assigned a grade between 1 (most tolerant) and 10 (most sensitive). The SIGNAL index is then calculated as the average grade number for all families present in the sample. The resulting index score can then be interpreted by comparison with other sites, with larger values indicating potential better water quality conditions as the community has higher levels of sensitivity. These grades have been updated and standard errors applied under the SIGNAL-2 model approach developed by Chessman (2003). These changes were introduced to improve the reliability of the SIGNAL index.

AUSRIVAS – AUSRIVAS is a standard approach for assessing the ecological health of freshwaters through biological monitoring and habitat assessment (Nichols et al., 2000). The AUSRIVAS models are a predictive tool that uses site-specific information to predict the macroinvertebrate fauna expected (E) to be present in the absence of environmental stressors. The expected fauna from reference sites with similar sets of predictor variables (physical and chemical characteristics which cannot be influenced by human activities such as altitude) are compared to the observed fauna (O) from monitoring and the ratio derived (O/E) is used to indicate the extent of any impact. The ratio is allocated into Bandwidths (Table 3-3) which are used to gauge the overall health of that site (Coysh *et al*., 2000). AUSRIVAS is based on the results from both the riffle and edge samples, where available. Using a precautionary approach as recommended by Coysh *et al.* (2000), the overall site condition was based on the farthest Band (from the sub-sample) from reference in a particular habitat at a particular site. For example, a site assessed as a Band A in the edge and a Band B in the riffle would be given an overall site assessment of Band B (Coysh *et al*., 2000).

Table 3-3 AUSRIVAS Band widths and interpretations for the ACT 2020-2021 riffle and edge habitats

Band	RIFFLE	EDGE	Explanation
	O/E Band	O/E Band	
X	> 1.12	> 1.17	More diverse than expected. Potential enrichment or naturally biologically rich.
A	0.88 – 1.12	0.83 – 1.17	Similar to reference. Water quality and / or habitat in good condition.
B	0.64 – 0.87	0.49 – 0.82	Significantly impaired. Water quality and/ or habitat potentially impacted resulting in loss of taxa.
C	0.40 – 0.63	0.15 – 0.48	Severely impaired. Water quality and/or habitat compromised significantly, resulting in a loss of biodiversity.
D	< 0.40	< 0.15	Extremely impaired. Highly degraded. Water and /or habitat quality is very low and very few of the expected taxa remain.

3.4.3 Multivariate analyses

Multivariate analyses of macroinvertebrate data were examined separately for riffle and edge habitats. Replicates were examined individually (i.e. not averaged) at all sites as the aim is to examine within-site variation in addition to examining patterns among sites. All multivariate analyses were performed using PRIMER version 7 (Clarke and Gorley, 2015).

Data were square-root transformed to increase the contribution of rare or cryptic taxa in the analyses and a similarity matrix developed based on the Bray-Curtis similarity measure (see Clarke and Warwick, 2001). Non-metric multidimensional scaling (NMDS) ordination plots were produced as a visual representation of similarity amongst samples. The number of dimensions (axes) used in the NMDS procedure was based on the resultant stress levels. The stress level is a measure of the distortion produced by compressing multidimensional data into a reduced set of dimensions and will increase as the number of dimensions is reduced and can be considered a measure of “goodness of fit” to the original data matrix (Kruskal, 1964).

The similarity percentages (SIMPER) routine was carried out on the datasets following a significant PERMANOVA test to examine which taxa contributed to the most variation among statistically significant groupings (Clarke and Warwick, 2001). Factors used in the PERMANOVA where year, season (nested within each year) and location (i.e. upstream or downstream).

3.5 Photogrammetry

Photogrammetry was used to monitor potential changes in response to the operation of M2G and MPS over and above those occurring naturally. Photogrammetry is an inexpensive and robust alternative to quantitative techniques (O’Connor and Bond, 2007). Using this method, photo points were established at each monitoring location using markers and GPS coordinates. Photographs are taken at the same point on a pre-determined temporal scale or at times triggered by natural or other unforeseen events. The aspect of the photograph is determined by either using secondary or tertiary markers or by using landscape features. The resulting photographs provide a robust and valuable resource to help understand the temporal dynamics of the system and provide a visual reference of habitat in relation to the macroinvertebrates results as a measure of river health. This method was applied to monitor periphyton, vegetation and geomorphology at the relevant sites.

3.5.1 Periphyton

Representative photographs were taken at each site of the substrate using a 1 m x 1 m quadrat for scale. These photographs were considered representative of the habitat and site. Semi-quantitative estimates of the proportion of cover were recorded using the ACT AUSRIVAS field sheet methodology (Nichols, *et al.*, 2000). Periphyton has been included in the monitoring program for Angle Crossing (M2G) and the MPS sites as a means of assessing the influence of flow upon the algal communities downstream of the abstraction points compared to upstream. The aim of this monitoring is to determine, during operational pumping, whether algal and periphyton communities downstream of Angle Crossing and the MPS are increasing compared to upstream due to reduced flow. Periphyton has been included in the monitoring program for Burra Creek to monitor the effect flow is having upon algal communities downstream of the M2G discharge weir. The aim of this monitoring is to determine during operational pumping whether algal communities downstream of the discharge are changing compared to upstream sites due to the alteration of the natural flow regime.

3.5.2 Riparian and instream vegetation

Photographs were taken at existing photo points to record the current extent of riparian and instream vegetation at relevant sites. Three photos were taken at each point, one facing upstream, one downstream and another directly across the channel. GPS coordinates have been recorded for all photo points, while some sites also have survey pegs inserted to assist in locating the exact location.

The use of photogrammetry for monitoring the change in the vegetation communities and coverage at Burra Creek is considered an efficient method for assessing whether the maintenance pumping is having a significant impact (Hall, 2001). These photo points will be used for comparison to future photo points, or with photos and observations recorded before and after the use of the M2G pipeline for operational purposes.

3.5.3 Geomorphology

Photographs were taken at each of the geomorphology sites. Geomorphological features of interest have already been recorded (GHD, 2015) and this report represents a continuation of the methods used in monitoring geomorphology in the context of the MEMP.

To capture changes in the morphology as effectively as possible, photos were taken from the existing photo points. Both survey pegs and GPS co-ordinates have been used to accurately record the position of each photo point. Three photos were taken at each point, one facing upstream, one downstream and another directly across the channel, with these photo points chosen to ensure all geomorphological features identified at each site have been adequately recorded.

The use of photogrammetry at previously identified cross-sections along Burra Creek are considered a robust method for monitoring of potential changes in bank erosion and slumping. The photo points collected between autumn 2015 and autumn 2018 will be used for comparison to future photo points, or with photographs and observations recorded before and after the use of the M2G pipeline for operational purposes.

3.6 Fish

The section of the Murrumbidgee River monitored is known to support a number native and alien fish species, including threatened species under the ACT *Nature Conservation Act 2015* (NC Act), NSW *Fisheries Management Act 1991* (FM Act), and *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) identified in Table 3-4.

Fish monitoring in the Murrumbidgee River is carried out every two years and occurred between February and April 2021 at 10 sites between the northern ACT border upstream to Bredbo in NSW (EPSDD 2021; see https://www.environment.act.gov.au/nature-conservation/fish). The sites include popular recreational areas such as Casuarina Sands and Kambah Pool and more isolated locations such as Retallacks Hole, and NSW sites Prutties, Lawler Rd and the Bush Heritage property Scottsdale. Boat electrofishing was the survey technique. Common Carp (*Cyprinus carpio*) surveys using environmental DNA (eDNA) were also carried out in Burra Creek at 10 sites between the M2G discharge and Googong Reservoir in 2019 (UoC 2019).

Table 3-4 Threatened species status of fish known to inhabit the study site

Species	NC Act	FM Act	EBPC Act
Macquarie Perch (*Macquaria australasica*)	E	E	E
Murray Crayfish (*Euastacus armatus*)	V	V	
Murray Cod (*Maccullochella peelii*)	SPS		V

CE- Critically Endangered, E- Endangered, V- Vulnerable, P- Protected and SPS- Special Protection Status

4. Results

4.1 Component 1: Angle Crossing (M2G)

Monitoring of Angle Crossing sites as part of the M2G component was completed on 3 and 4 April 2020 (autumn), 27 November 2020 (spring) and 26 April 2021 (autumn).

4.1.1 Rainfall and hydrology

Overall, in the three seasons that monitoring occurred there was higher rainfall compared to historic averages although this was not consistent in all months (Table 4-1). During autumn 2020, rainfall upstream of Angle Crossing and at Lobb's Hole was above the historical average of 51.2 mm in March and April 2020 but was below the historical average in May 2020. In spring 2020 both October and November were above the historical average of 59.3 mm while September was below. In autumn 2021, only March exceeded the historical average rainfall of 51.2 mm.

Rainfall in the region was generally reflected by corresponding changes in flow in the Murrumbidgee River (Table 4-1). During autumn 2020, there were three high flow events in March following rainfall that peaked at approximately 350 ML/d at Lobb's Hole (Figure 4-1). Flows decreased in April 2020 and ranged from approximately 40 to 100 ML/d. There were no significant high flow events in April 2020 despite heavy rainfall. Flow increased sharply in early May 2020 to around 250 ML/d and over this month, flows decreased to less than 100 ML/d.

Throughout spring 2020, flow was higher than the preceding autumn (Table 4-1). In September 2020 flow steadily decreased from approximately 1,500 to 600 ML/d (Figure 4-1). There was high rainfall throughout October and flow increased to approximately 2,000 ML/d at the end of the month. November 2020 started with a high flow event, with flow exceeding 14,000 ML/d at Angle Crossing. Flows declined during November to less than 400 ML/d at Angle Crossing on the final day of the month.

Overall, flow remained elevated in autumn 2021 (Table 4-1). In March 2021 there was a high flow event towards the end of the month with flow increasing to over 20,000 ML/d at Angle Crossing and 18,000 ML/d at Lobb's Hole (Figure 4-1). Flow decreased throughout April at both sites and with little rainfall there were no high flow events in this month. There were high flow events in May 2021, with peak flows exceeding 10,000 ML/d at both sites. By the end of the May, discharge had decreased to less than 700 ML/d at Angle Crossing and 698 ML/d at Lobb's Hole.

Table 4-1 Autumn 2020, spring 2020 and autumn 2021 rainfall and flow summaries, upstream Angle Crossing (41001702) and Lobb's Hole (410761)

		Upstream Angle Crossing (41001702)		Downstream Angle Crossing @ Lobb's Hole (410761)	
		Rainfall Total (mm)	Mean Flow (ML/d)	Rainfall Total (mm)	Mean Flow (ML/d)
Autumn 2020	March	116.5	119.3	104.8	91.2
	April	64.4	54.4	57.6	54.5
	May	23.3	139.0	22.4	110.5
	Total rainfall	204.1		184.8	
Spring 2020	September	27.4	673.4	30.2	725.5
	October	115.4	690.1	137.6	773.2
	November	65.0	1,924.0	69.0	2,159.0
	Total rainfall	207.8		236.8	
Autumn 2021	March	193.4	2,318.9	257.2	2,484.5
	April	1.0	546.0	1.8	591.0
	May	46.0	1,734.0	40.2	1,854.0
	Total rainfall	240.4		299.2	
Historical autumn monthly average		51.2		49.0	
Historical spring monthly average		59.3		61.2	

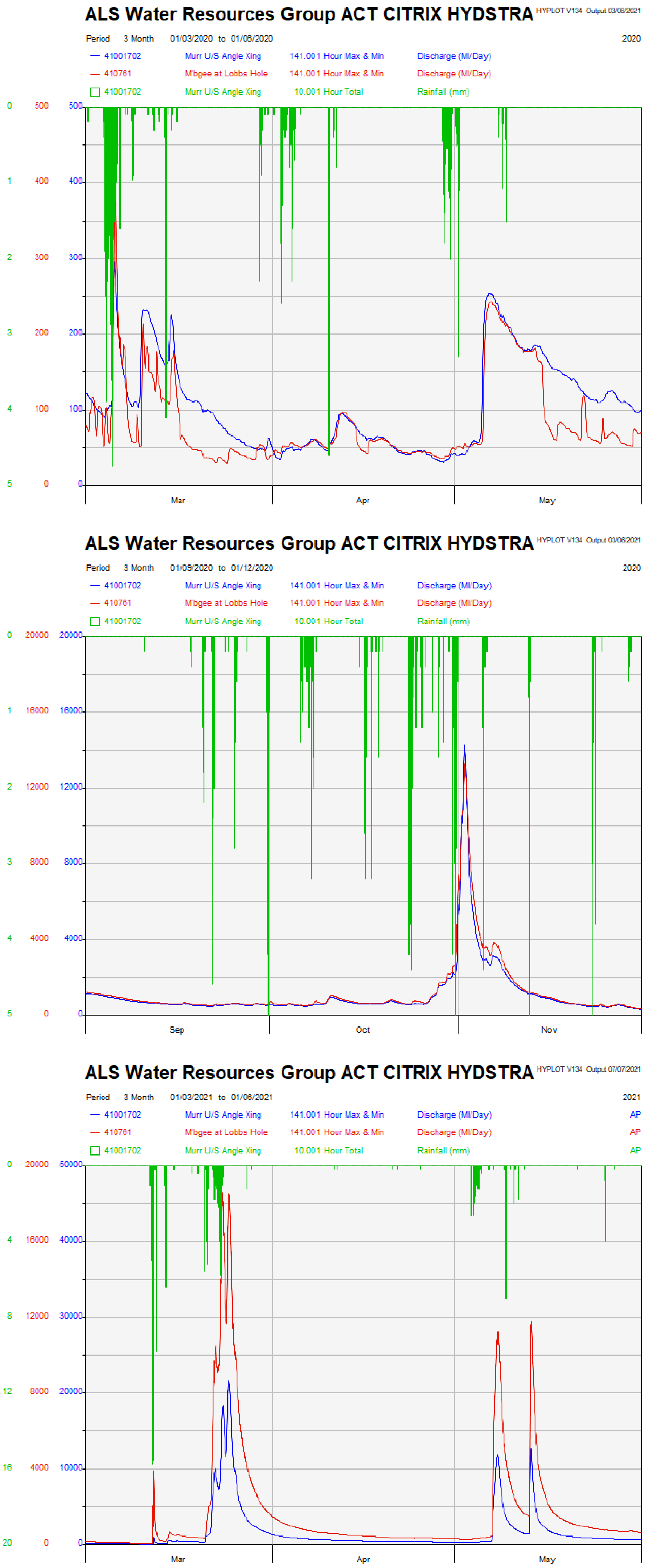


Figure 4-1 *Rainfall and hydrographs of the Murrumbidgee River upstream (41004702) and downstream (410761) of Angle Crossing in autumn 2020 (top), spring 2020 (middle) and autumn 2021 (bottom)*

4.1.2 Water quality

4.1.2.1 *In-situ* monitoring

Water quality results presented in Table 4-2 based on *in-situ* recordings and grab samples provide a snapshot of conditions during the monitoring events. The results indicate the Murrumbidgee River had elevated concentration of nutrients, particularly total nitrogen (TN) and total phosphorus (TP) that exceeded the ANZG (2018) guideline in all seasons both upstream and downstream of the M2G abstraction point. Oxidised forms of nitrogen (NOx) also exceeded the guideline on occasion. In addition, pH usually complied with the guideline range but was elevated at two sites in autumn 2020, while all sites at times had low dissolved oxygen (DO). Electrical conductivity (EC) never exceeded the guideline and turbidity exceeded the guideline at MUR20 during spring 2020 only. Overall, the results indicate there were no consistent patterns suggesting water quality differed between the upstream and downstream locations.

4.1.2.2 Continuous monitoring

Continuous monitoring measured at gauging stations upstream of Angle Crossing is presented in Figure 4-2 and downstream of Angle Crossing at Lobb's Hole in Figure 4-3. Water temperature was similar at the upstream and downstream sites and reflects seasonal changes in climate. Typically, water temperature increased during the warmer months of the year and decreased as winter approaches.

There was some indication pH varied throughout the Murrumbidgee River although it remained above the minimum ANZG (2018) guideline of 6.5 and rarely exceeded the maximum guideline of 8.0. There were some exceptions to this including during autumn 2020 when in April it increased above 8 at Lobb's Hole which was not observed upstream of Angle Crossing. The reasons for differences in pH upstream and downstream of the M2G abstraction point are not known but could be due to differences in site specific conditions such as the abundance of aquatic plants. During daytime hours photosynthesis can lead to increased DO while during the night DO is reduced and the proportion of carbon dioxide increased. Carbon dioxide (CO_2) is acidic and the sequestration of CO_2 during photosynthesis increases the pH of water which can carry over to daytime. There were also some occasions where pH rapidly decreased such as the start of November 2020, late March 2021 and May 2021 both upstream and downstream of the M2G abstraction point. These decreases are likely a dilution effect and correspond with periods of high flow.

The differences in the scale of the y-axis of the turbidity charts in Figure 4-2 and Figure 4-3 make it difficult to compare turbidity across the three seasons. But it does allow for some interpretations of changes in turbidity to be made. Firstly, both upstream of Angle Crossing and at Lobb's Hole (and the M2G abstraction point) turbidity was highly variable and regularly exceeded the ANZG (2018) guideline range of 2 to 25 NTU. Secondly, high flow events associated with rainfall were accompanied by noticeable increases in turbidity (i.e. >200 NTU).

EC complied with the ANZG (2018) guideline range of 30-350 µS/cm upstream of Angle Crossing and downstream of Angle Crossing at Lobb's Hole. As found for other parameters there was an influence of flow, with decreases in EC corresponding to increased flow.

DO regularly complied with the upper ANZG (2018) guideline of 110% although it often decreased below the lower limit of 90% both upstream and downstream of the M2G abstraction point. There was a high degree of diurnal variation in DO with levels increasing during the daytime and decreasing during the night, again suggesting photosynthesis is a driver of DO concentrations and, as discussed above, pH.

Overall, the continuous monitoring of water quality indicates there were no consistent patterns suggesting water quality differed between the upstream and downstream locations. Although there were some occasions when parameters such as pH and DO varied between locations, this is likely due to site-specific conditions rather than any ongoing effect of operation of the M2G.

Table 4-2 In-situ water quality results from M2G sites with red cells outside ANZG (2018) default guideline range

Location	Site	Sampling period	Date	Time	Temp (°C)	EC (µs/cm)	Turbidity (NTU)	pH	D.O. (% Sat.)	D.O. (mg/L)	Alkalinity (mg/L)	NO_x (mg/L)	TP (mg/L)	TN (mg/L)
ANZG (2018) default guideline values						**30-350**	**2-25**	**6.5-8.0**	**90-110**			**0.015**	**0.02**	**0.25**
Upstream	MUR17	Autumn 2020	04/04/20	0930	17.3	249	22	8.3	61	5.8	140	0.03	0.10	1.10
		Spring 2020	27/11/20	1300	24.2	107	18	7.6	95.1	7.4	50	<0.05	0.08	0.59
		Autumn 2021	26/04/21	1300	11.8	107	10	6.9	101.4	10.3	50	0.63	0.03	0.29
Upstream	MUR18	Autumn 2020	03/04/20	1140	18.5	243	25	7.7	70.0	6.7	140	0.03	0.10	1.30
		Spring 2020	27/11/20	1030	22.8	107	12	6.9	92.5	7.4	50	<0.05	0.05	0.43
		Autumn 2021	26/04/21	1030	12.3	110	8	7.2	87.3	8.8	50	0.32	0.03	0.29
Downstream	MUR19	Autumn 2020	03/04/20	1430	18.0	248	22	8.2	72.0	6.8	140	0.01	0.20	1.20
		Spring 2020	27/11/20	1430	27.9	111	24	7.5	98.9	7.2	45	<0.05	0.07	1.11
		Autumn 2021	26/04/21	1430	12.3	107	8	7.0	101.7	10.2	45	0.05	0.03	0.28
Downstream	MUR20	Autumn 2020	03/04/20	1300	18.1	248	25	8.0	69.0	6.7	140	0.02	0.12	1.30
		Spring 2020	27/11/20	1530	26.6	109	29	7.4	99.5	7.4	45	<0.05	0.06	0.58
		Autumn 2021	26/04/21	1530	12.4	108	9	7.2	105.0	10.5	45	<0.05	0.03	0.28

Note: Water Temperature (Temp.), Electrical Conductivity (EC), Dissolved Oxygen (D.O.), percentage saturation (% Sat.), Nitrite + Nitrate as N (NO_x), Total Nitrogen as N (TN), Total Phosphorus as P (TP)

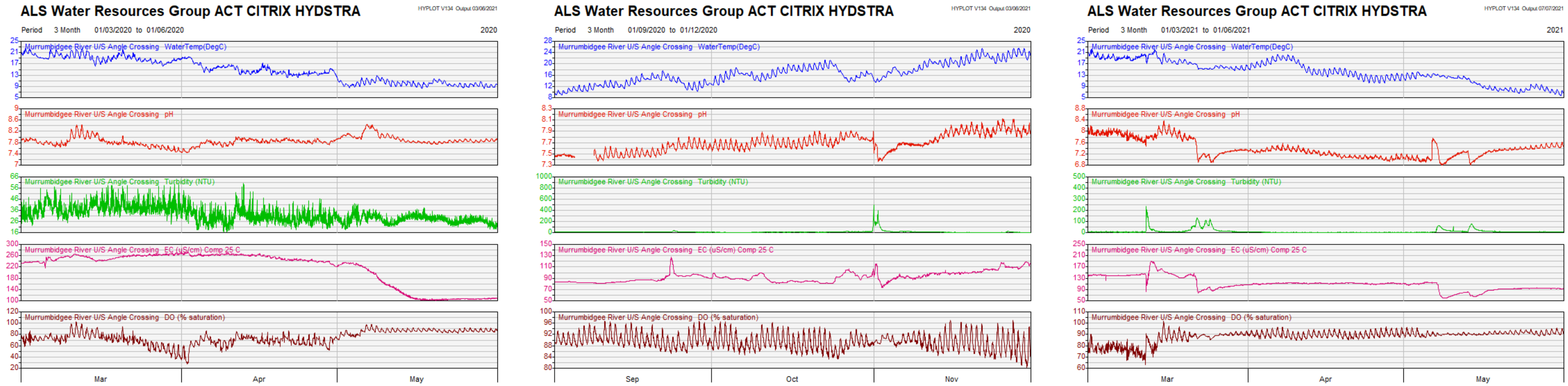


Figure 4-2 Continuous water quality records from upstream Angle Crossing (41001702) for autumn 2020 (left), spring 2020 (middle) and autumn 2021 (right)

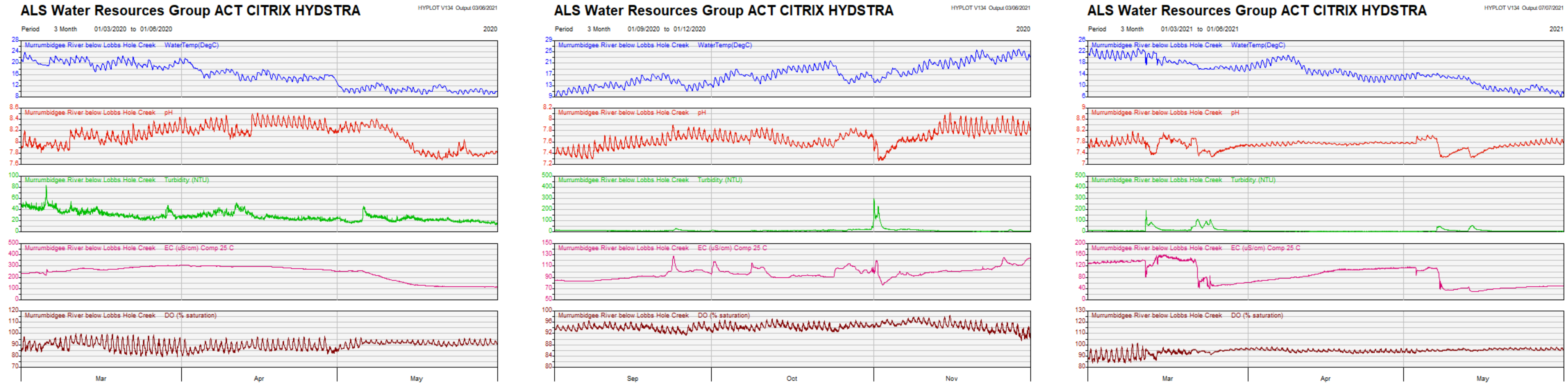


Figure 4-3 Continuous water quality records from Lobb's Hole (410761 - downstream Angle Crossing) for autumn 2020 (left), spring 2020 (middle) and autumn 2021 (right)

4.1.3 Periphyton

Photographs of periphyton at the M2G monitoring sites are presented in Plate 4-1. Across the three seasons, there was no indication of increased periphyton coverage at sites downstream of the M2G abstraction point compared to upstream.

***MUR17* -** Periphyton coverage at MUR17 during autumn 2020 was approximately 35-65% for the reach and 35-65% for the riffle habitat. During spring 2020, periphyton coverage was approximately 65-90% for the reach, 65-90% at the riffle, and >90% in the edge habitat. During autumn 2021, periphyton coverage was approximately 40% for the reach. The most abundant macrophyte in all seasons was *Myriophyllum sp.*

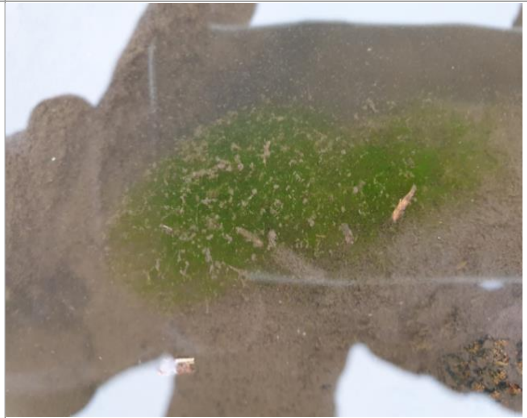
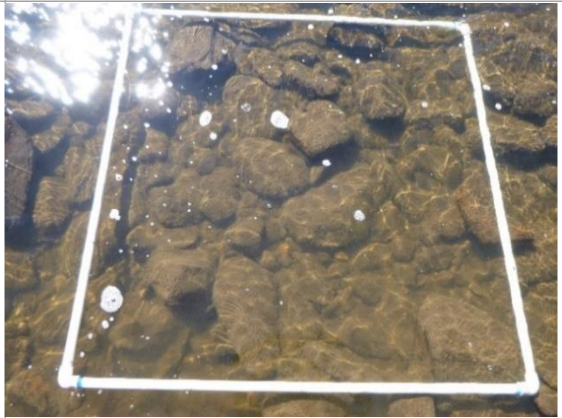
***MUR18* -** The periphyton coverage in autumn 2020 was <10% for the reach and <10% for the riffle habitat. Spring 2020 periphyton coverage was approximately 35-65% for the reach and 65-90% for the edge habitat. During autumn 2021, periphyton coverage was approximately 65% for the reach. The most abundant macrophyte in both seasons was *Myriophyllum sp.*

***MUR19* -** The periphyton coverage in autumn 2020 was approximately 35-65% for the reach and 35-65% for the riffle habitat. The spring 2020 periphyton coverage was approximately 35-65% for the reach, 65-90% for the riffle and 65-90% for the edge habitat. During autumn 2021, periphyton coverage was approximately 5% for the reach. *Myriophyllum sp.* was the most abundant macrophyte in autumn 2021. However, *Triglochin sp*. was most abundant macrophyte during spring 2020.

***MUR20* -** The periphyton coverage in autumn 2020 was approximately 35-65% for the reach and 35-65% for the riffle habitat. Spring 2020 periphyton coverage was approximately 35-65% for the reach, 65-95% for the riffle and >90% for the edge habitat. During autumn 2021, periphyton coverage was approximately 10% for the reach. Higher coverage of filamentous algae (up to 80% in shallow areas) was observed at this site in autumn 2021. *Myriophyllum sp*. was the most abundant macrophyte during both autumn and spring.

4.1.4 Geomorphology

Geomorphological features at Angle Crossing (MUR19) observed in 2020 and 2021 have remained relatively unchanged since 2017. Plate 4-2 to Plate 4-4 show some degree of seasonal variation in water level, which was slightly higher during spring 2020 compared to the two autumn seasons. Changes in bed and bar exposure associated with water levels changes can been seen. Vegetation dieback and recruitment can also be observed to varying degrees. However, the riverbanks have remained stable at each of the photo points and there is no evidence of bank slumping or areas of significant erosion.

Site	Autumn 2020	Spring 2020	Autumn 2021
MUR17			
MUR18			

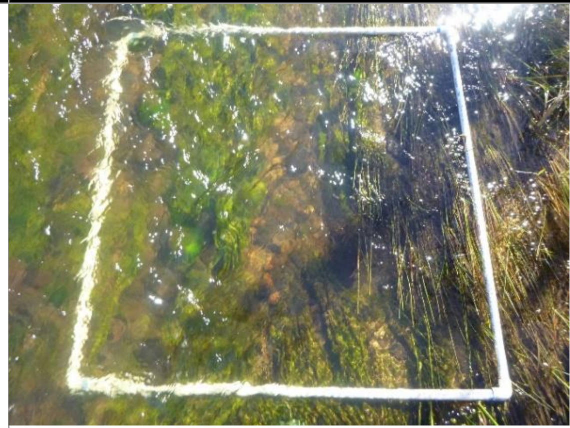
Site	Autumn 2020	Spring 2020	Autumn 2021
MUR19			
MUR20			

Plate 4-1 Photographs showing periphyton coverage in riffles of the Murrumbidgee River at M2G sites

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-2 Geomorphology photo point 1 at Angle Crossing MUR19

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-3 Geomorphology photo point 2 at Angle Crossing MUR19

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-4 Geomorphology photo point 3 at Angle Crossing MUR19

4.1.5 Macroinvertebrates

4.1.5.1 Biological indices

There is minimal edge habitat in this reach of the Murrumbidgee River and therefore no edge samples were collected in the three seasons monitored.

The total taxa richness for M2G sites in the Murrumbidgee River are presented in Table 4-3. Across the three seasons, total taxa richness ranged from 15 to 24 at family level resolution and 24 to 39 at genus level resolution. There were no noticeable differences in taxa richness between the three seasons. There was no consistent pattern in the data indicating sites downstream of the abstraction point on Angle Crossing had lower taxa diversity than upstream.

Table 4-3 Total number of taxa from riffle habitats upstream and downstream of the M2G in the Murrumbidgee River

Location	Site	Sample	Autumn 2020		Spring 2020		Autumn 2021	
			Family	Genus	Family	Genus	Family	Genus
Upstream	MUR17	1	19	35	23	36	18	30
		2	18	32	18	31	18	31
	MUR18	1	20	34	24	37	20	34
		2	18	31	23	39	16	28
Downstream	MUR19	1	18	32	17	28	17	28
		2	22	34	16	26	17	30
	MUR20	1	18	31	18	28	15	25
		2	20	38	22	34	15	24

The EPT richness for M2G sites is presented in Table 4-4. Across the three seasons, EPT richness ranged from 6 to 8 at family level resolution and 5 to 12 at genus level resolution. EPT richness was slightly higher in spring 2020 compared to the two autumn seasons. As was found for total taxa richness, there was no consistent pattern in the data indicating sites downstream of Angle Crossing had lower EPT diversity than upstream.

Table 4-4 Total number of EPT taxa from riffle habitats

Location	Site	Sample	Autumn 2020		Spring 2020		Autumn 2021	
			Family	Genus	Family	Genus	Family	Genus
Upstream	MUR17	1	6	8	7	9	6	6
		2	5	6	7	10	5	9
	MUR18	1	6	8	9	10	7	9
		2	6	9	8	12	6	8
Downstream	MUR19	1	5	8	6	7	5	6
		2	6	8	6	7	7	8
	MUR20	1	6	7	6	7	5	6
		2	6	8	8	9	5	5

The SIGNAL-2 and AUSRIVAS results for the M2G sites are presented in Table 4-5. SIGNAL-2 Scores ranged from 4.6 to 5.1 across the three seasons. Although there were often higher SIGNAL-2 scores in spring 2020 compared to the other two autumn seasons, this was not consistent across all samples. Most sites in all seasons were allocated to AUSRIVAS Band B that possibly suggests significant impairment and fewer families than expected. This could be due to potential impacts on water and/or habitat quality. Some samples were allocated to AUSRIVAS Band A due to most families at reference sites being found, including samples from sites downstream of Angle Crossing. Overall, there was no consistent pattern in the data indicating sites downstream of Angle Crossing had lower SIGNAL-2 scores or AUSRIVAS scores than upstream.

Table 4-5 SIGNAL-2 scores, AUSRIVAS scores and bandings for riffle habitats

	Location	Upstream				Downstream			
	Site	MUR 17		MUR 18		MUR 19		MUR 20	
	Sample	1	2	1	2	1	2	1	2
SIGNAL-2 score	Autumn 2020	5.0	4.7	4.8	4.7	4.9	4.7	4.9	4.8
	Spring 2020	4.9	5.1	5.0	5.0	5.1	4.9	5.1	4.8
	Autumn 2021	4.8	5.0	5.0	4.6	4.8	4.9	4.8	4.7
AUSRIVAS O/E score	Autumn 2020	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.89
	Spring 2020	0.82	0.75	0.85	0.93	0.77	0.62	0.92	0.77
	Autumn 2021	0.78	0.77	0.67	0.78	0.78	0.78	0.78	0.89
AUSRIVAS Band	Autumn 2020	B	B	B	B	B	B	B	A
	Spring 2020	B	B	B	A	B	B	A	B
	Autumn 2021	B	B	B	B	B	B	B	A
Overall habitat assessment	Autumn 2020	B		B		B		B	
	Spring 2020	B		B		B		B	
	Autumn 2021	B		B		B		B	

Table 4-6 presents AUSRIVAS Bands for Angle Crossing since 2012, indicating that these sites were typically placed in Band B, and on occasion Band A. The results of the 2020-21 monitoring are similar to previous years suggesting the three seasons of impact monitoring did not detect any impacts due to operation of the M2G compared to sentinel monitoring prior to operation.

Table 4-6 Overall site assessments for Angle Crossing sites since 2012 (indicates riffle habitats only)*

		Upstream		**Downstream**	
Year	Season	MUR 17	MUR 18	MUR 19	MUR 20
2012	Autumn		B	B	
2012	Spring		B	B	
2013	Autumn		B	B	
2013	Spring		B	B	
2014	Autumn		B	B	
2014	Spring		B	A	
2015	Autumn		B	B	
2015	Spring		A	A	
2018	Autumn		B	B	
2018	Spring		A	B	
2019*	Autumn	B	B	B	B

		Upstream		Downstream	
2019*	Spring	B	B	B	B
2020*	Autumn	B	B	B	B
2020*	Spring	B	B	B	B
2021*	Autumn	B	B	B	B

4.1.5.2 Multivariate analysis – community composition

The NMDS ordination of macroinvertebrate community samples from riffle habitats from the sentinel monitoring (2015 and 2018) and impact monitoring (2019, 2020 and 2021) are presented in Figure 4-4. Note that each point on the NMDS represents a multivariate macroinvertebrate sample (i.e. all taxa collected and their abundances) and those samples close together have a more similar community composition than those further apart. The spread of samples on the ordination highlights that within each year there were clear differences in the community composition between autumn and spring. Furthermore, within each season there was no clear separation between samples collected upstream and downstream of the M2G abstraction.

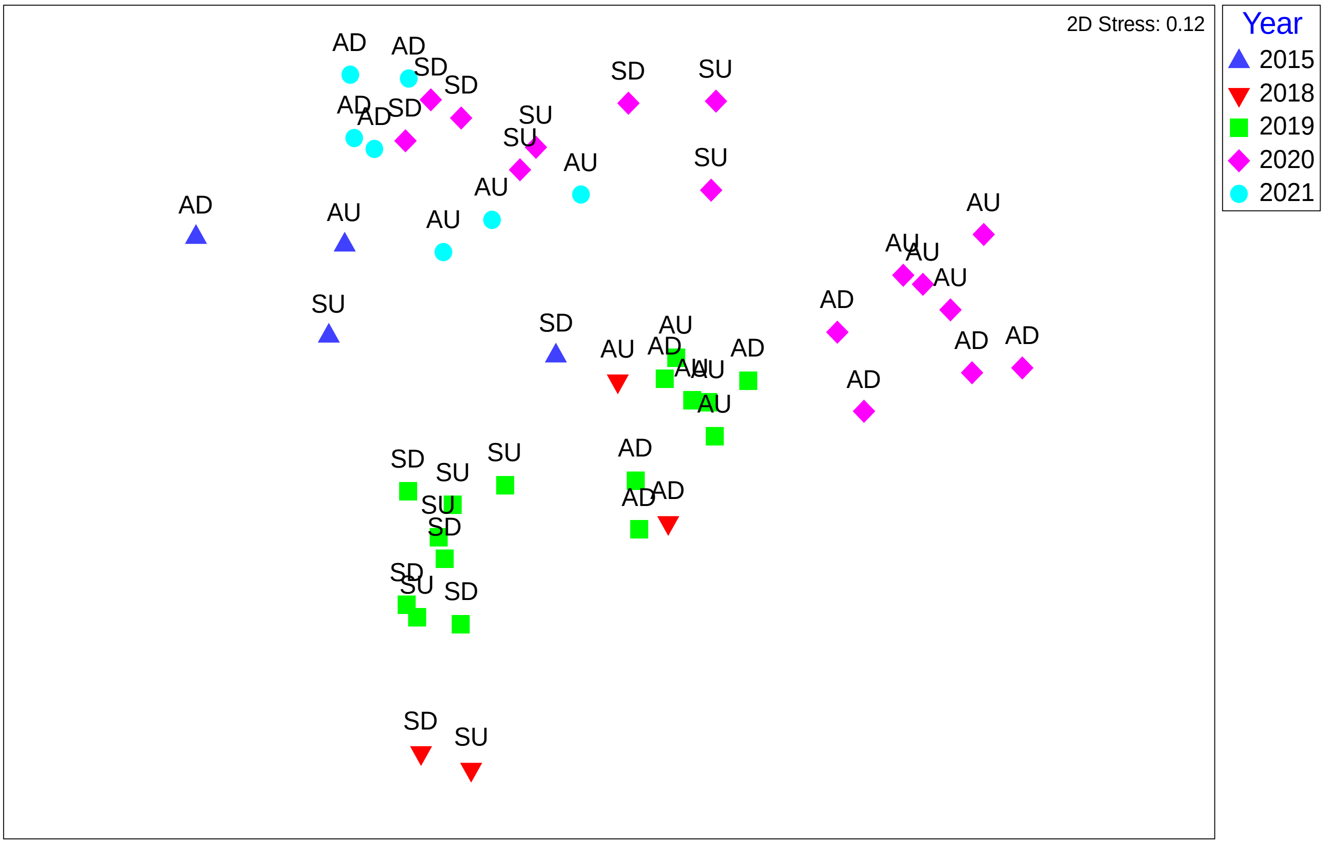


Figure 4-4 MDS ordination of macroinvertebrate communities associated with riffle habitats. A = autumn and S = spring; U = upstream and D = downstream

The patterns on the NMDS were confirmed by the PERMANOVA that detected significant differences between seasons (Pseudo-F 15.2, P = 0.001). However, there was also an interaction between season and locations meaning differences upstream and downstream of the abstraction point where not consistent in each season (Pseudo-F 1.5, P = 0.05). Significant differences in the community composition upstream and downstream of the abstraction point were detected in spring 2019 (t = 0.1.7, P = 0.029) and autumn 2020 (t = 1.9, P = 0.027). In all other seasons, there were no significant differences upstream and downstream of the abstraction. Given there were statistical differences upstream and downstream of the abstraction point for the spring 2019 and the autumn 2020 surveys, SIMPER analyses were only conducted for these seasons.

Overall, in both spring 2019 and autumn 2020 most taxa found upstream of the abstraction were also found downstream. However, there were some differences in abundances of some taxa (see Figure 4-5 and Figure 4-6).

Blackfly larvae (Simuliidae: *Austrosimulium*) had the highest contribution to the differences with higher average abundances upstream compared to downstream. Other taxa generally more abundant upstream included caddisfly larvae (*Cheumatopsyche, Hydropsychidae*) and mayfly larvae (Baetidae). The abundances of midge fly larvae (Chironominae, Orthocladiinae) and worms (Oligochaeta) had no consistent pattern between the upstream and downstream locations.

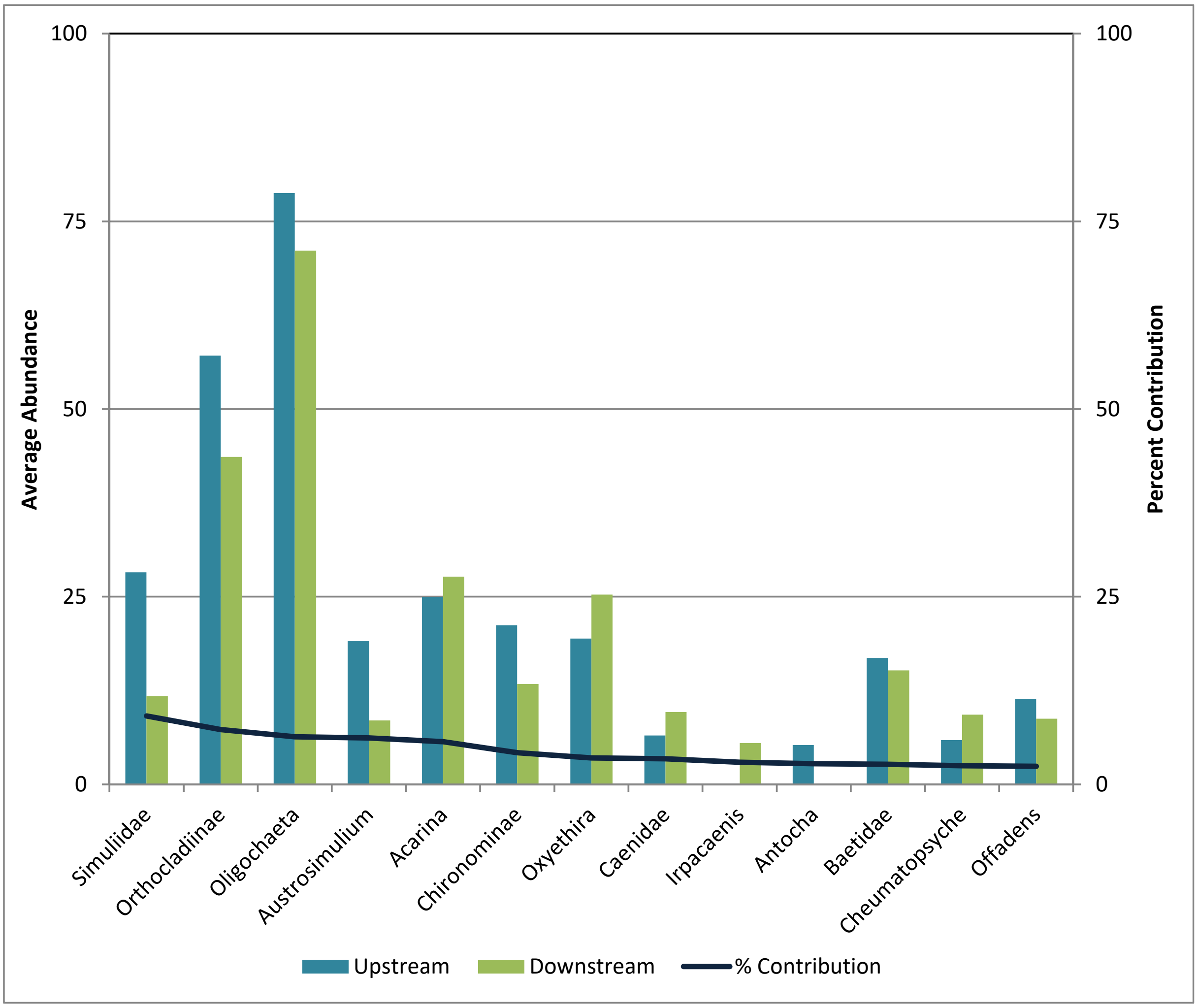


Figure 4-5 ***Spring 2019 riffle habitat SIMPER analyses identifying those taxa that contributed most to the dissimilarity between upstream and downstream locations associated with Angle Crossing. Taxa that contributed to 60% of the dissimilarity are included and the average dissimilarity between samples was 24.61%. Note that abundances are square-root values***

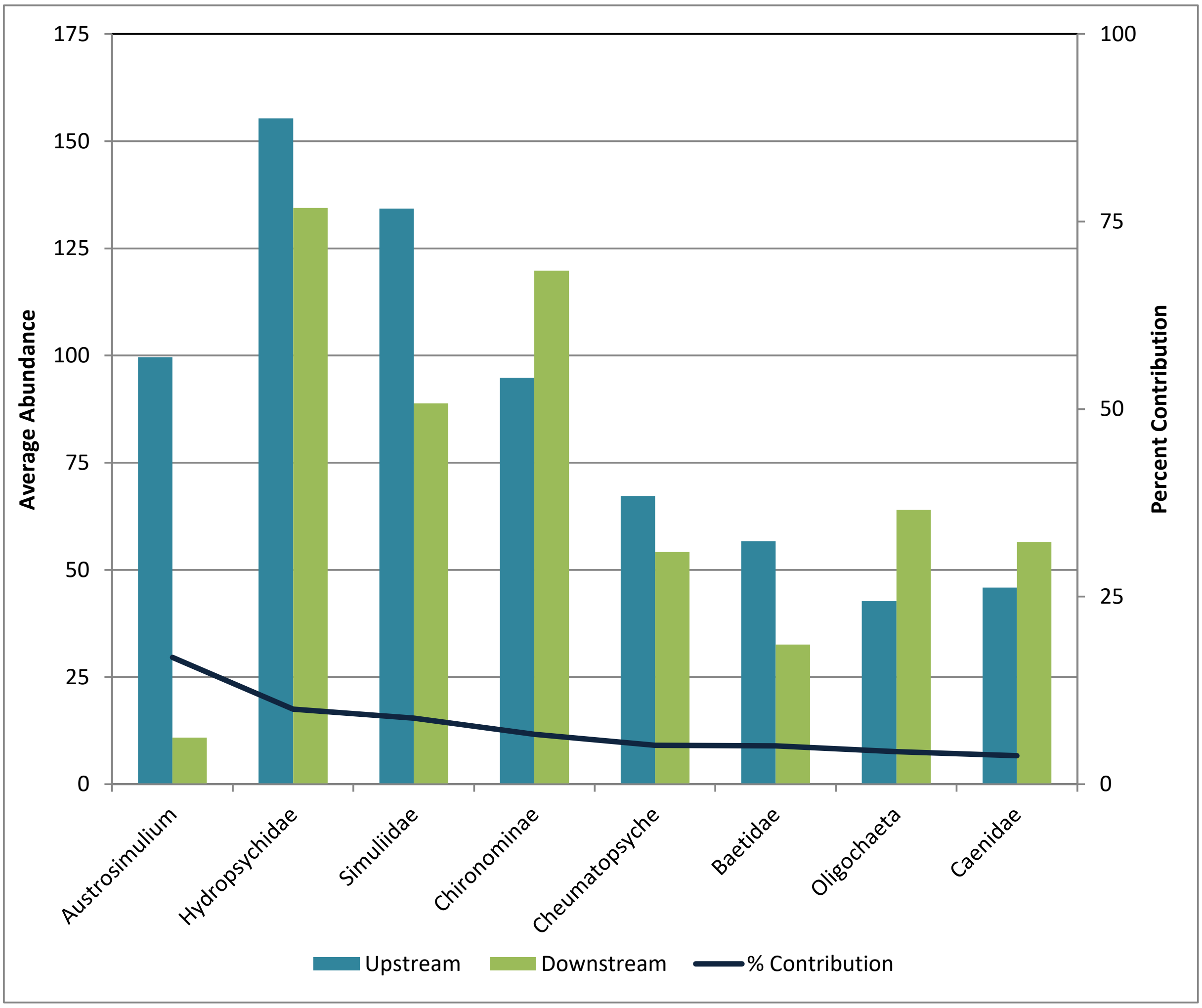


Figure 4-6 ***Autumn 2020 riffle habitat SIMPER analyses identifying those taxa that contributed most to the dissimilarity between upstream and downstream locations associated with Angle Crossing. Taxa that contributed to 60% of the dissimilarity are included and the average dissimilarity between samples was 29.93%. Note that abundances are square-root values***

4.1.6 Fish

The 2021 monitoring of the Murrumbidgee River surveyed fish populations at ten sites on the Murrumbidgee River in the ACT region. Four sites were upstream of the M2G abstraction point (Scottsdale, Lawler Rd, Prutties and Angle Crossing), and six downstream.

The survey detected a total of 216 fish from seven species (see Figure 4-7). Both native and alien species were observed across all sites. Of note, Common Carp dominate most sites with 125 captured. The exceptions to this were Angle Crossing and Tharwa Sandwash, where Murray Cod (mainly juveniles) numbers exceeded Carp. Murray Cod were detected at all sites except for Casuarina Sand. The recruitment of Murray Cod varied across sites, with young of year fish (<1 year old that spawned in spring/summer 2020/21) mainly being detected at upstream sites and only one detected in the five sites downstream of Tharwa. No threatened Macquarie Perch or Trout Cod/Murray Cod hybrids were recorded. Three records of Trout Cod (*Maccullochella macquariensis*) had previously been recorded at Tharwa Sandwash and Lawler Road sites in 2017.

In comparison to the previous survey in 2019, the abundance and biomass of native fish (relative to exotic species) decreased although there has been a general trend of increasing native biomass since 2011 (see Figure 4-8). This trend is common at both upstream and downstream sites and is driven primarily by increases in Murray Cod. Similarly, the decline since 2019, particularly in native fish abundance, is because fewer sites recorded large numbers of juvenile Murray Cod compared to 2019.

The only site where Common Carp were detected in the Burra Creek eDNA surveys was in the Burra Arm of Googong Reservoir.

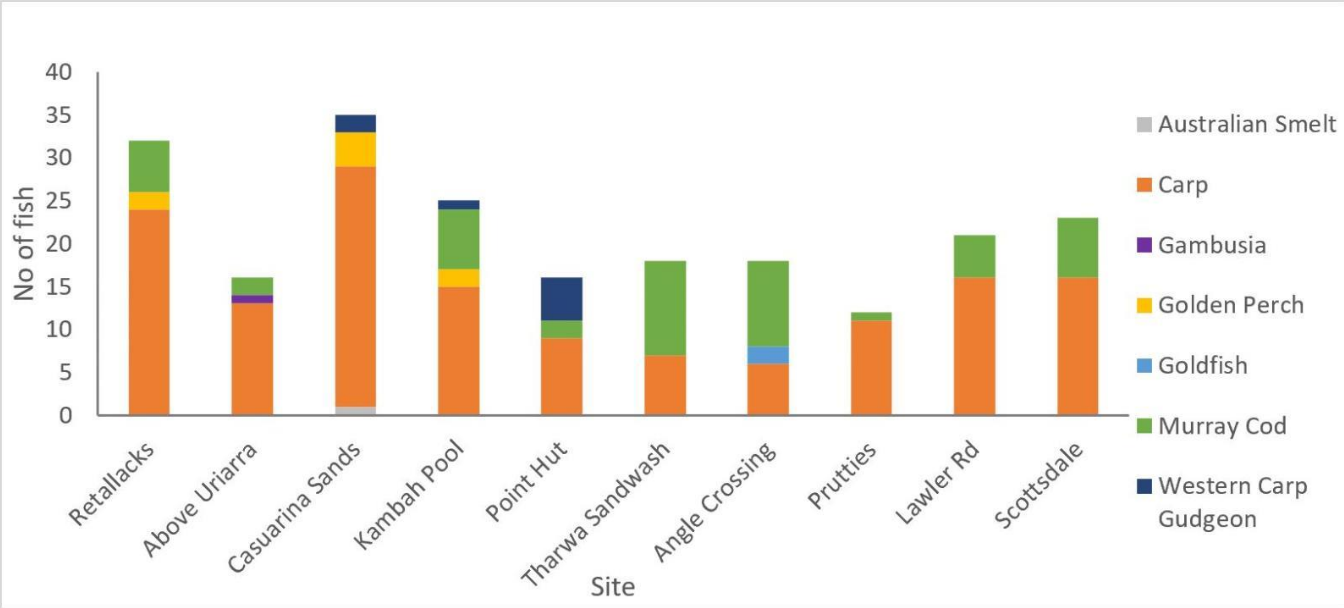


Figure 4-7 ***Number of fish caught in 2021 Murrumbidgee River Monitoring program (Source: EPSDD)***

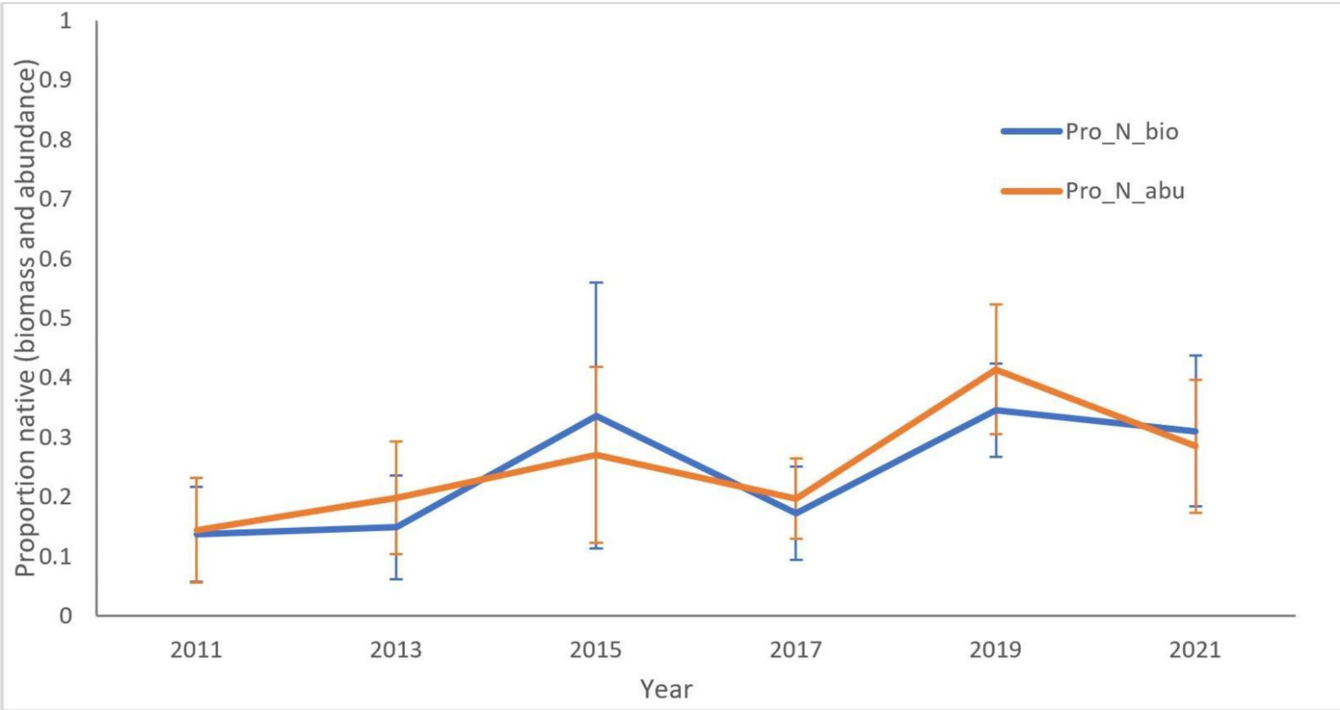


Figure 4-8 ***Proportion of native fish biomass and abundance (Source: EPSDD)***

4.2 Component 2: Burra Creek (M2G)

Monitoring of Burra Creek sites as part of the M2G component was completed on 3 April (autumn 2020), 25 November (spring 2020) and 24 April (autumn 2021).

4.2.1 Rainfall and hydrology

Overall, in the three seasons that monitoring occurred there was higher rainfall compared to historic averages although this was not consistent in all months (Table 4-7). During autumn 2020, rainfall upstream of Burra Creek was above the historical average of 45.3 mm in March and April 2020 but was below the historical average in May 2020. In spring 2020 both October and November were above the historical average of 59.9 mm while September was below. In autumn 2021, only March exceeded the historical average rainfall of 45.3 mm.

In most months, rainfall in the region was generally reflected by corresponding changes in flow in Burra Creek (Table 4-7). During autumn 2020, there was rainfall early in March and flows persisted throughout much of the month and peaked at over 200 ML/d (Figure 4-9). Flow during April was low and below 2 ML/d for most of the month despite some rainfall. There was also little flow in Burra Creek in the first half of May before increasing towards the end of the month.

Spring 2020 was characterised by long periods of low flow and occasional high flows (Figure 4-9). In September, flow remained low for the month; the mean daily discharge was 3.4 ML/d and flow did not exceed 10 ML/d. Flow increased in October in response to rainfall although it remained below 10 ML/d for much of the month. Flow peaked in early November at over 850 ML/d before again decreasing to low flow conditions in the latter part of the month.

Flow in Burra Creek during autumn 2021 was generally low except for two high flow events in March (Figure 4-9). In the first week of March, Burra Creek flow was below 1 ML/d but increased to over 1,000 ML/d around mid-March, and over 3,500 ML/d in the latter part of the month. In April, there was little rainfall and average daily flow was 4.4 ML/d, and flow did not exceed 10 ML/d for the month. May was like April with no flow peaks. The average daily flow in May was 3.3 ML/d and flows did not exceed 8 ML/d.

Table 4-7 Autumn 2020, spring 2020 and autumn 2021 rainfall and flow summaries, upstream Burra Creek (570951)

		Burra Creek (410774)	
		Total Rainfall (mm)	**Mean Flow (ML/d)**
Autumn 2020	March	94.0	45.8
	April	64.8	2.3
	May	33.2	28.6
	Total rainfall	192.0	
Spring 2020	September	39.9	3.4
	October	137.4	30.2
	November	81.2	27.0
	Total rainfall	258.4	
Autumn 2021	March	146.2	91.2
	April	2.6	4.4
	May	40.6	3.3
	Total rainfall	189.4	
Historical autumn monthly average		45.3	
Historical spring monthly average		59.9	

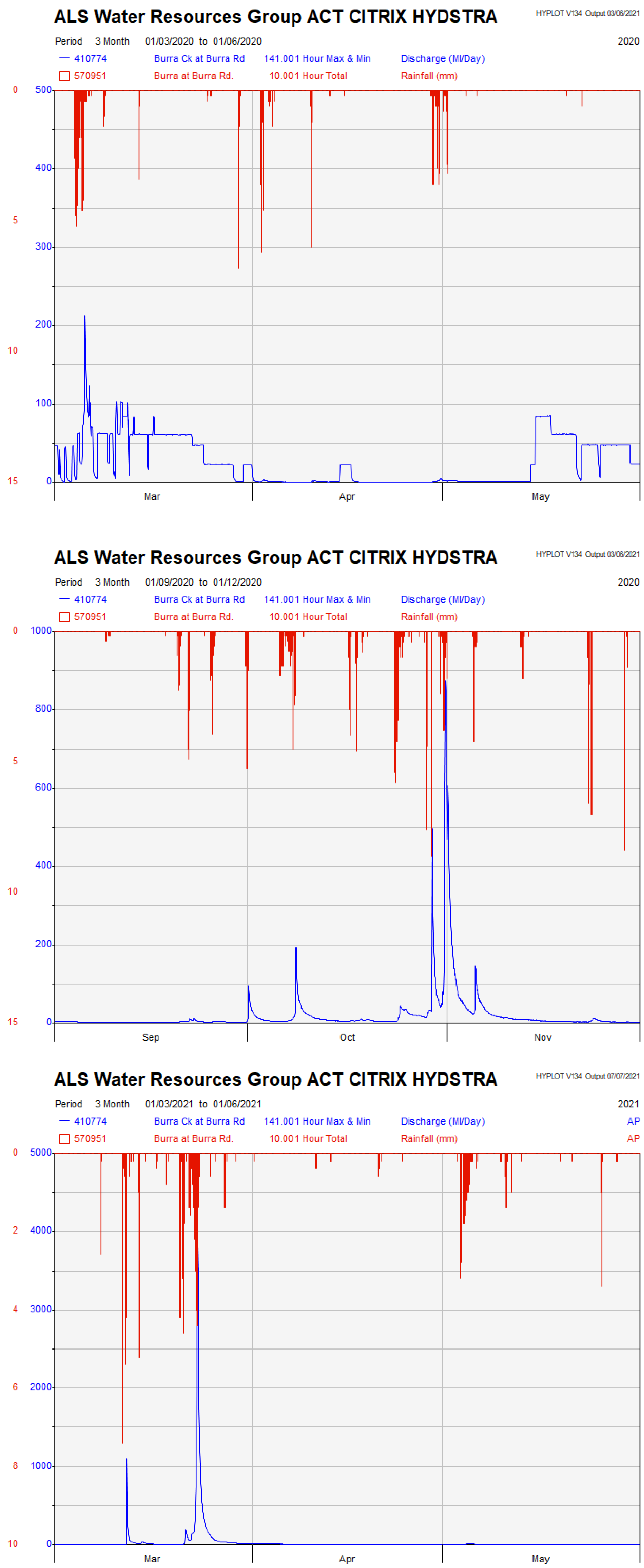


Figure 4-9 *Autumn 2020 rainfall and hydrograph from Burra Creek (410774) during autumn 2020 (top), spring 2020 (middle) and autumn 2021 (bottom)*

4.2.2 Water quality

4.2.2.1 *In-situ* monitoring

Water quality results presented in Table 4-8 based on *in-situ* recordings and grab samples provide a snapshot of conditions during the monitoring events. The results indicate Burra Creek had elevated concentration of nutrients, particularly total nitrogen (TN) that exceeded the ANZG (2018) guideline in all seasons both upstream and downstream of the discharge point. Total phosphorus (TP) and oxidised forms of nitrogen (NOx) also exceeded the guideline on occasion at both locations. In addition, pH and turbidity complied with the guideline range, but all sites had dissolved oxygen (DO) levels below the guideline minimum of 90%. Electrical conductivity (EC) never exceeded the guideline at the most upstream site BUR1b but there was a consistent longitudinal gradient in EC in all seasons with level increasing downstream. Except for downstream increases in EC, which may be due to groundwater inputs, the results indicate there were no consistent patterns suggesting water quality differed between the upstream and downstream locations.

4.2.2.2 Continuous monitoring

Continuous monitoring measured at the gauging station on Burra Creek at Burra Road is presented in Figure 4-10. Water temperature reflects seasonal changes in climate and typically increased during the warmer months of the year and decreased as winter approaches. There was also some diurnal variation in temperature that was higher during daytime periods compared to night.

There was also some indication pH diurnally, with increases during the daytime compared to night. As mentioned in Section 4.1.2.2, this is likely due to the influence of photosynthesis by aquatic plants. Despite this, the continuous monitoring determined pH remained above the minimum ANZG (2018) guideline of 6.5 and but often exceeded the maximum guideline of 8.0. There were also some occasions where pH rapidly decreased such as early November 2020 and late March 2021. These decreases are likely a dilution effect and correspond with periods of high flow.

The differences in the scale of the y-axis of the turbidity charts in Figure 4-10 make it difficult to compare turbidity across the three seasons. But it does allow for some interpretations of changes in turbidity to be made. Firstly, turbidity was highly variable and regularly exceeded the ANZG (2018) guideline range of 2 to 25 NTU. Secondly, high flow events associated with rainfall were often accompanied by noticeable increases in turbidity (i.e. >200 NTU).

EC often exceeded with the ANZG (2018) guideline range of 30-350 µS/cm in Burra Creek. As found for other parameters there was an influence of flow with decreases in EC corresponding to increased flow.

DO regularly complied with the upper ANZG (2018) guideline of 110% although it often decreased below the lower limit of 90%. There was a high degree of diurnal variation in DO with levels increasing during the daytime and decreasing during the night, again suggesting photosynthesis is a driver of DO concentrations and, as discussed above and in Section 4.1.2.2, pH.

Overall, the continuous monitoring of water quality indicates Burra Creek has highly dynamic water quality conditions that are influenced by site-specific factors (e.g. aquatic plants) and flow.

Table 4-8 In-situ water quality results from Burra Creek with red cells outside ANZG (2018) default guideline range

Location	Site	Sampling period	Date	Time	Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	pH	D.O. (% Sat.)	D.O. (mg/L)	Alkalinity (mg/L)	NO_x (mg/L)	TP (mg/L)	TN (mg/L)
ANZG (2018) default guideline values						30-350	2-25	6.5-8	90-110			0.015	0.02	0.25
Upstream	BUR1b	Autumn 2020	3/04/20	1130	13.6	342	8.5	7.3	57	5.8	200	0.01	0.04	1.20
		Spring 2020	25/11/20	1400	28.7	155	7.0	7.7	74.4	5.2	120	<0.05	0.02	0.81
		Autumn 2021	24/04/21	1400	14.0	209	12.0	7.3	85.5	8.0	120	<0.05	0.02	0.30
Upstream	BUR1d	Autumn 2020	3/04/20	0830	14.7	439	9.5	7.6	54	5.3	200	0.01	0.02	0.30
		Spring 2020	25/11/20	1000	24.1	369	9.0	7.3	71.3	5.5	180	<0.05	0.02	0.69
		Autumn 2021	24/04/21	1000	10.1	432	7.0	7.1	87.3	9.1	180	0.23	0.01	0.38
Downstream	BUR2	Autumn 2020	3/04/20	0900	14.8	434	10.0	7.4	54	5.3	200	0.02	0.04	0.40
		Spring 2020	25/11/20	1030	25.2	368	6.0	7.5	82.7	6.2	180	<0.05	0.02	0.71
		Autumn 2021	24/04/21	1030	9.8	428	10.0	7.3	78.9	8.2	180	0.25	0.01	0.38
Downstream	BUR2a	Autumn 2020	3/04/20	1000	15.8	406	13.0	7.4	56	5.5	180	0.03	0.03	0.50
		Spring 2020	25/11/20	1230	24.9	369	11.0	7.6	81.9	6.2	180	<0.05	0.02	0.48
		Autumn 2021	24/04/21	1230	10.1	425	7.0	7.5	78.9	8.2	180	0.21	0.01	0.36

Note: Water Temperature (Temp.), Electrical Conductivity (EC), Dissolved Oxygen (D.O.), percentage saturation (% Sat.), Nitrite + Nitrate as N (NO_x), Total Nitrogen as N (TN), Total Phosphorus as P (TP)

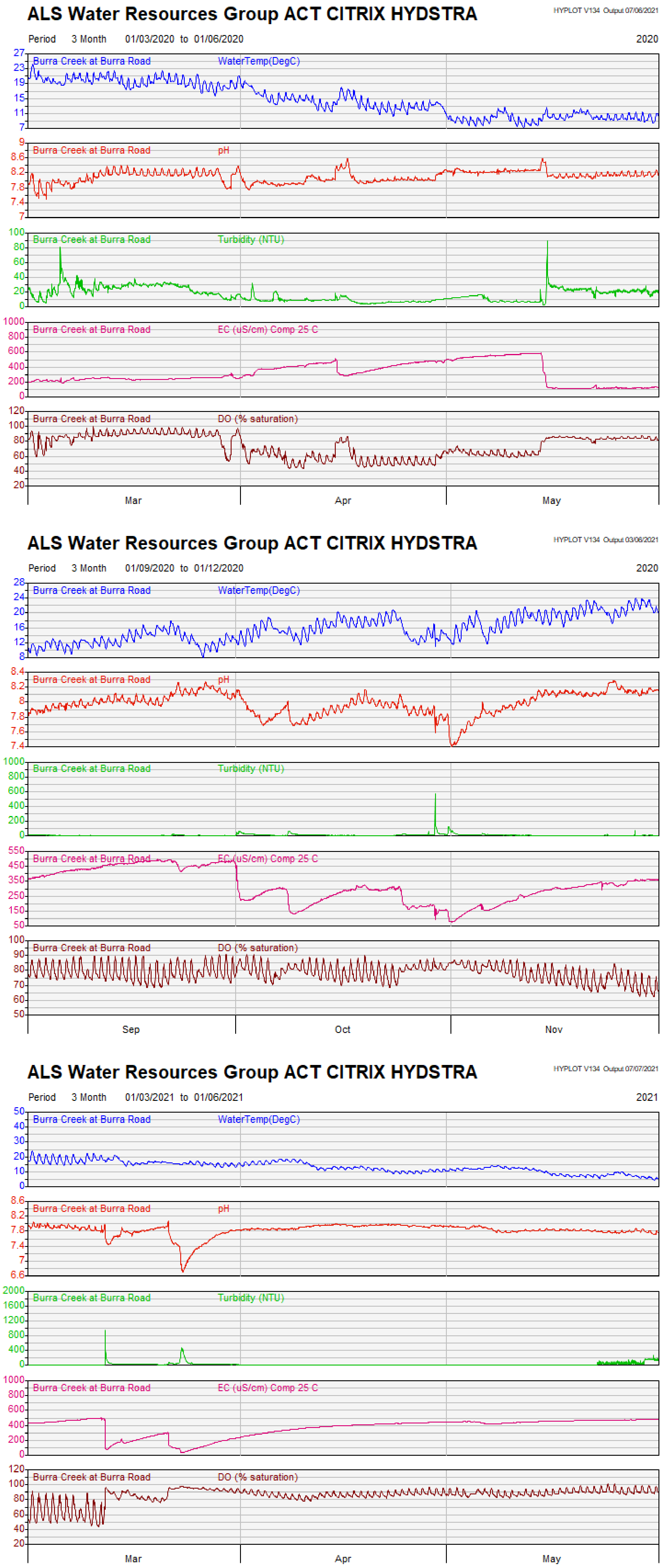


Figure 4-10 Continuous water quality records from upstream Burra Creek at Burra Road (410774) for autumn 2020 (top), spring 2020 (middle) and autumn 2021 (bottom)

4.2.3 Periphyton

Photographs of periphyton in Burra Creek are presented in Plate 4 5. Across the three seasons, there was no indication of increased periphyton coverage at sites downstream of the discharge point into Burra Creek.

BUR 1b - Periphyton coverage in autumn and spring 2020 was both approximately 65-90% in the reach, and 65-90% in the edge habitat. The predominant macrophyte observed was *Typha* sp. Autumn 2021 periphyton coverage was approximately 60% for the reach.

BUR 1d - During autumn and spring 2020 periphyton coverage was approximately 35-65% in the reach, and 65-90% in the edge habitat. There was a high level of filamentous algae and macrophytes present were dominated by *Phragmites* sp. Autumn 2021 periphyton coverage was approximately 70% for the reach.

BUR 2 - The periphyton coverage in autumn 2020 was 65-90% in edge habitat and 35-65% for the study reach. *Myriophyllum* sp. was observed as the dominant submerged macrophyte. The spring 2020 periphyton coverage was approximately 65-90% in the reach and edge habitats. Autumn 2021 periphyton coverage was approximately 30% for the reach. *Myriophyllum* sp. and *Phragmites* sp. were the predominant macrophytes.

BUR 2a - In autumn 2020, the periphyton coverage was estimated to be 65-90% in edge habitat and 65-90% for the study reach. Spring 2020 periphyton coverage was approximately 65-90% at the reach and >90% at the edge habitat. Autumn 2021 periphyton coverage was approximately 60% for the reach. High levels of silt were noted and the predominant macrophyte was *Myriophyllum* sp.

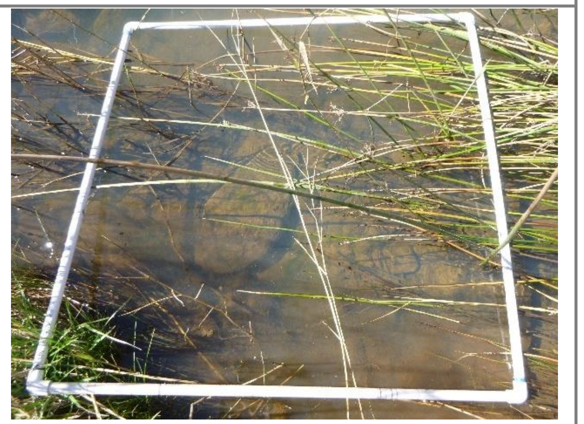
Site	Autumn 2020	Spring 2020	Autumn 2021
BUR1b			
BUR1d			
BUR2			
BUR2a			

Plate 4-5 Photographs showing periphyton coverage at Burra Creek sites

4.2.4 Vegetation

BUR 2 - Minimal change was observed in the vegetation at BUR2 since autumn 2020 (Plate 4-9 through to Plate 4-11). Trees at the site are dominated by exotic species including *Salix* sp. (Willows) and Populus sp. (Poplar) at the discharge point and downstream of the causeway. Photos show the die-back of leaves on these exotics during autumn. Aquatic species include the emergent macrophyte *Phragmites australis* (Common Reed) that is spread throughout the site. Other emergent macrophytes including *Cyperus* sp. (Sedges) and *Juncus* sp. (Rushes) are also present. Low flow periods in Burra Creek facilitates the growth of *Phragmites australis* in shallow areas which provides significant habitat for aquatic species.

Downstream of Pool 29 - There have been minimal changes in the vegetation downstream of Pool 29 since autumn 2020 (Plate 4-14 through to Plate 4-16). Within the channel there are three trees at the site, a native *Acacia dealbata* (Silver Wattle) on the right bank and introduced *Populus* sp. (Poplar) and *Salix* sp. (Willow) on the left bank. The vegetated bars within the channel are dominated by weeds with dense patches of *Rubus fruiticosus* (Blackberry) along the water's edge, and other common weeds across the bar including *Hypericum perforatum* (St. John's Wort), *Conyza* sp. (Fleabane), *Verbascum* sp. (Mullein) and various thistles. There is also considerable coverage by grasses, including native *Poa* spp. and introduced *Phalaris* sp. (Canary Grass) and *Paspalum dilatatum* (Caterpillar Grass). Sections of both banks are bare. The vegetation was denser in spring 2020, than in either autumn 2020 or autumn 2021 which is not surprising given the die-back of introduced species.

BUR 2c - There was evidence of slight growth in the vegetation at site BUR2c between since autumn 2020, particularly in spring 2020 (Plate 4-17 through to Plate 4-20). The site has limited vegetation close to the creek despite the wider surrounds having numerous large *Eucalyptus* spp. The banks are bare in some sections. However, part of the banks and most of the floodplain is covered by grasses, mostly *Poa* spp., and weeds such as *Verbascum* sp. (Mullein), *Hypericum perforatum* (St. John's Wort), *Rubus fruiticosus* (Blackberry) and various thistle species. Several small *Populus* sp. (Poplar) and *Salix* sp. (Willow) are present within the macro-channel. Instream vegetation is dominated by *Typha orientalis* (Broad leaf Cumbungi), while *Schoenoplectus validus* (Great Bulrush) is also present in smaller patches.

4.2.5 Geomorphology

Geomorphological features at in Burra Creek during 2020 and 2021 have undergone further erosion compared to 2017. This has been observed both upstream and downstream of the discharge in Burra Creek and highlights the ongoing erosion issues in the catchment.

BUR1a - Burra Creek at BUR1a is characterised by a large-macro channel with a small inset low-flow channel within the macro-channel (Plate 4-6 through to Plate 4-8). Large sections of the site show evidence of erosion and bank slumping. Of note is the vertical bank in photo point 1b (Plate 4-6) that was observed to have further eroded in autumn 2021 compared to previous seasons. If this increases further, there is a risk of the fence being lost.

BUR2 - No large-scale changes have been observed since 2017 in Burra Creek at BUR2 (Plate 4-9 through to Plate 4-11). Rock works have been installed for erosion protection at the point of discharge and there are no obvious signs of increased erosion (Plate 4-9). Other areas downstream of the discharge are well protected by the large established *Salix* sp. (Willow) and other aquatic macrophytes within the littoral zone of the channel.

BUR2a - This reach is a depositional zone, with silt blanketing all aquatic habitats within the reach and allow for the growth of aquatic macrophytes (Plate 4-12 and Plate 4-13). The steep right bank at BUR2a shows signs of erosion at photo point 2a (Plate 4-13) that would be at risk of increased erosion during high flows. However, this has not noticeably increased since 2017.

Downstream of Pool 29 - There are large eroding sections of bank downstream of Pool 29 (Plate 4-14 through to Plate 4-16). However, there are no signs of significant bank slumps or large-scale bank erosion since spring 2017. There are some signs that sediment is being moved within the channel. For example, during autumn and spring 2020 there was an accumulation of sediment at the base of the bank that is likely due to a previous slumping event (photo point 2c in Plate 4-15). This sediment appears to have been relatively stable given it was covered in grasses and other vegetation. In autumn 2021, this sediment has been removed from the site, possibly during elevated flows. Despite this, bars within the channel appear to have neither increased nor decreased in size and the vegetated island in the riffle habitat also appears stable.

BUR2c - There are large steep banks at this site and it is clear slumping and erosion have occurred overtime (Plate 4-17 through to Plate 4-20). However, there has not been significant increases in erosion since 2017. This area has previously been identified as an area for high erosion potential (GHD, 2015). This expected to occur during future high flow periods.

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-6 Geomorphology photo point 1 at BUR1a

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-7 Geomorphology photo point 2 at BUR1a

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-8. Geomorphology photo point 3 at BUR1a

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-9 Vegetation extent and geomorphology photo point 1 at BUR2

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-10 Vegetation extent and geomorphology photo point 2 at BUR2

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-11 Vegetation extent and geomorphology photo point 3 at BUR2

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-12 Geomorphology photo point 1 at BUR2a

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-13 Geomorphology photo point 2 at BUR2a

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-14 Vegetation extent and geomorphology photo point 1 downstream of Pool 29

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-15 Vegetation extent and geomorphology photo point 2 downstream of Pool 29

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-16 Vegetation extent and geomorphology photo point 3 downstream of Pool 29

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-17 Vegetation extent and geomorphology photo point 1 at BUR2c

	Autumn 2019	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-18 Vegetation extent and geomorphology photo point 2 at BUR2c

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-19 Vegetation extent and geomorphology photo point 3 at BUR2c

	Autumn 2020	Spring 2020	Autumn 2021
a			
b			
c			

Plate 4-20 Vegetation extent and geomorphology photo point 4 at BUR2c

4.2.6 Macroinvertebrates

4.2.6.1 Biological indices

There is minimal riffle habitat in this reach of Burra Creek, particularly during low flow periods. As such, most indices are based on edge samples unless otherwise indicated.

The total taxa richness for M2G sites in Burra Creek are presented in Table 4-9. Across the three seasons, total taxa richness ranged from 20 to 39 at family level resolution and 29 to 59 at genus level resolution. Overall, there some indication of higher diversity during autumn 2020 that gradually decreased over time. There was no consistent pattern in the data indicating sites downstream of the discharge point on Burra Creek had lower taxa diversity than upstream.

Table 4-9 Total number of taxa from edge habitats

Location	Site	Sample	Autumn 2020		Spring 2020		Autumn 2021	
			Family	Genus	Family	Genus	Family	Genus
Upstream	BUR1b	1	33	53	28	43	32	44
		2	35	53	30*	44*	29*	44*
	BUR1d	1	32	52	32	46	22	35
		2	36	53	26	40	20	29
Downstream	BUR2	1	28	44	32	46	23	34
		2	29	48	32*	48*	21*	31*
	BUR2a	1	39	59	26	39	25	37
		2	36	54	26	38	22	32

* Second sample taken from a riffle habitat as flowing water was present

The EPT richness for Burra Creek sites are presented in Table 4-10. Across the three seasons, EPT richness ranged from 5 to 9 at family level resolution and 5 to 10 at genus level resolution. EPT richness was slightly higher in spring 2020 compared to the two autumn seasons. As was found for total taxa richness, there was no consistent pattern in the data indicating sites downstream of the discharge point had lower EPT diversity than upstream.

Table 4-10 Total number of EPT taxa from edge habitats

Location	Site	Sample	Autumn 2020		Spring 2020		Autumn 2021	
			Family	Genus	Family	Genus	Family	Genus
Upstream	BUR1b	1	5	5	7	10	7	9
		2	5	5	5*	5*	7*	9*
	BUR1d	1	5	5	6	8	5	7
		2	5	5	9	10	5	5
Downstream	BUR2	1	5	6	9	10	6	7
		2	5	6	9*	10*	5*	5*
	BUR2a	1	6	7	7	7	7	8
		2	8	8	7	9	6	7

* Second sample taken from a riffle habitat as flowing water was present

The SIGNAL-2 and AUSRIVAS results for the M2G sites are presented in Table 4-11. SIGNAL-2 Scores ranged from 4.1 to 5.1 across the three seasons. Overall, SIGNAL-2 scores showed an inverse pattern overtime to that of total taxa richness discussed above. That is, although total taxa richness decreased overtime, there was an increase in SIGNAL-2 scores. This suggests there was an overall improvement in waterway health and an increased proportion of taxa sensitive to pollution. In autumn and spring 2020 sites were allocated to AUSRIVAS Band A or Band B. Allocation to Band A occurs when most families at reference sites are found at the test site. Band B possibly suggests significant impairment and fewer families than expected due to potential impacts on water and/or habitat quality. There was some indication of lower AUSRIVAS scores in autumn 2021 with all sites allocated to either Band B or Band C. Allocation to Band C suggest sites may be severely impaired with many fewer families than expected due to impacts on water and/or habitat quality. Importantly, although all sites showed some decline in health in autumn 2021, the greatest decline (i.e. Band C) were sites upstream of the Burra Creek discharge point. In all seasons, there was no consistent pattern in the data indicating sites downstream of the discharge point had lower SIGNAL-2 scores or AUSRIVAS scores than upstream.

Table 4-11 SIGNAL-2 scores, AUSRIVAS scores and bandings for edge habitats

	Location	**Upstream**				**Downstream**			
	Site	BUR1b		BUR1d		BUR2		BUR2a	
	Sample	1	2	1	2	1	2	1	2
SIGNAL-2 score	Autumn 2020	4.3	4.3	4.5	4.3	4.5	4.5	4.4	4.5
	Spring 2020	4.4	4.1	4.6	5.0*	4.6	4.9*	4.7	5.0
	Autumn 2021	4.8	4.8	4.6	5.1*	4.8	4.8*	4.9	5.0
AUSRIVAS O/E score	Autumn 2020	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.89
	Spring 2020	0.82	0.75	0.85	0.93*	0.77	0.62*	0.92	0.77
	Autumn 2021	0.78	0.77	0.67	0.78*	0.78	0.78*	0.78	0.89
AUSRIVAS Band	Autumn 2020	B	B	B	A	B	B	A	B
	Spring 2020	A	B	A	A	A	A	B	A
	Autumn 2021	C	B	C	C	B	B	B	B
Overall habitat assessment	Autumn 2020	B		B		B		B	
	Spring 2020	B		A		A		B	
	Autumn 2021	C		C		B		B	

* Second sample taken from a riffle habitat as flowing water was present

Table 4-12 presents AUSRIVAS Bands for Burra Creek since 2012 and show that spring scores and bandings are typically higher than autumn. Historically, all sites generally have been allocated to Band A or Band B, with one exception in spring 2015, when BUR1d was in Band X (above reference condition). The AUSRIVAS results for autumn 2020 and spring 2020 were typical of previous years. However, AUSRIVAS scores at BUR1b and BUR1d in autumn 2021 were lower than previous years with sites allocated to Band C for the first time. Given these sites are upstream of the discharge, the three seasons of impact monitoring did not detect any impacts due to operation of the M2G compared to sentinel monitoring prior to operation.

Table 4-12 Overall site assessments for Burra Creek sites since 2012

	Location	Upstream		Downstream	
		BUR 1b	BUR1d	BUR2	BUR2a
Autumn	2012		B	B	
Spring	2012		B	A	
Autumn	2013		B	B	
Spring	2013		B	A	
Autumn	2014		B	B	
Spring	2014		A	A	
Autumn	2015		B	B	
Spring	2015		X	A	
Autumn	2018		B	B	
Autumn	2019*	B	B	B	C
Spring	2019*	B	B	B	B
Autumn	2020*	B	B	B	B
Spring	2020	B	A	A	B
Autumn	2021	C	C	B	B

4.2.6.2 Multivariate analysis – community composition

The NMDS ordination of macroinvertebrate community samples from edge habitats from the sentinel monitoring (2015 and 2018) and impact monitoring (2019, 2020, 2021) are presented in Figure 4-11. Note that each point on the NMDS represents a multivariate macroinvertebrate sample (i.e. all taxa collected and their abundances) and those samples close together have a more similar community composition than those further apart.

The spread of samples on the ordination highlights the following patterns:

- The community composition in 2020 and 2021 differed to 2015, 2018 and 2019
- Within 2018 and 2019, and to a lesser extent 2020, there were clear differences in the community composition between autumn and spring
- Within 2015 there was some suggestion that upstream sites differ to downstream sites
- Within 2018, 2019, 2020 and 2021 there was no clear separation between samples collected upstream and downstream of the MPS abstraction.

The patterns of the NMDS were confirmed by the PERMANOVA that detected no significant differences in community composition upstream and downstream of the abstraction (Psuedo-F = 2.1, P = 0.128). Given there were no obvious or statistical differences upstream and downstream of the abstraction point, no SIMPER analyses have been undertaken.

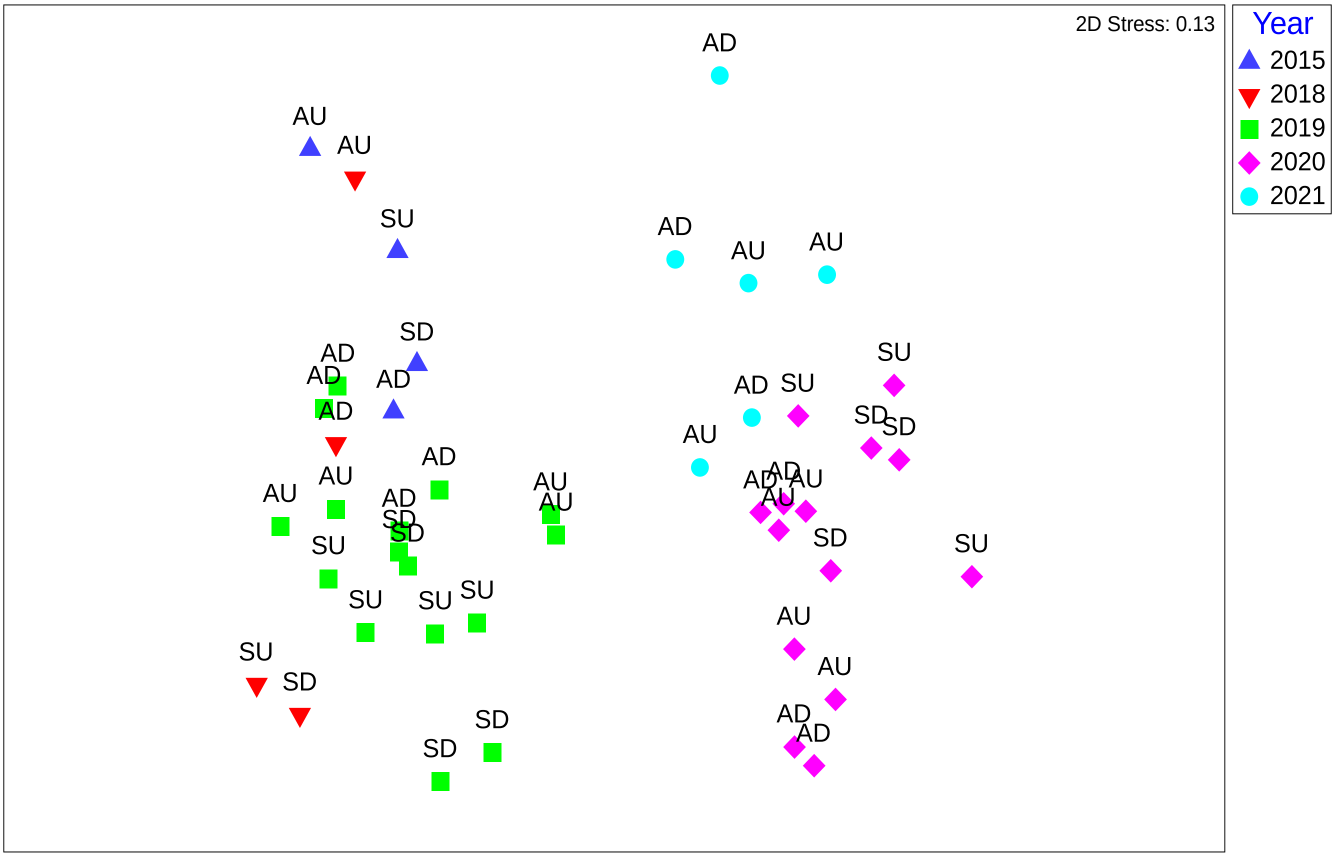


Figure 4-11 *NMDS ordination of macroinvertebrate communities associated with edge habitats associated with Burra Creek. A = autumn and S = spring; U = upstream and D = downstream*

4.3 Component 3: Murrumbidgee Pump Station (MPS)

Monitoring of sites related to the MPS component were carried out on 4 April (autumn 2020), 28-29 November (spring 2020) and 25 April (autumn 2021).

4.3.1 Rainfall and hydrology

The closest rain gauge for Component 3 is Lobb's Hole weather station (410761). Overall, in the three seasons that monitoring occurred there was higher rainfall compared to historic averages although this was not consistent in all months (Table 4-13). During autumn 2020, rainfall was above the historical average of 51.4 mm in March and April 2020 but was below the historical average in May 2020. In spring 2020 both October and November were above the historical average of 58.0 mm while September was below. In autumn 2021, only March exceeded the historical average rainfall of 51.4 mm.

Rainfall in the region was generally reflected by corresponding changes in flow in the Murrumbidgee River (Table 4-13). During autumn 2020, there were several high flow events in March following rainfall with a peak of over 8,000 ML/day at Mt. McDonald (Figure 4-12). Flow in the Murrumbidgee River decreased towards the end of March and remained relatively low throughout April. At Lobb's Hole there was a noticeable increase in flow during May that peaked at almost 250 ML/d at Lobb's Hole.

Throughout spring 2020, flow was higher than the preceding autumn (Table 4-13). Flow was relatively steady in September 2020, despite some high rainfall late in the month (Figure 4-12). Rainfall throughout October 2020 led to an increase in flow reaching a peak in early November, when flow exceeded 13,000 ML/d at Lobb's Hole and 17,000 ML/d at Mt. McDonald. After the peak in early November 2020, flows steadily decreased to 392 ML/d at Lobb's Hole and 728 ML/d at Mt. McDonald.

Overall, flow remained elevated in autumn 2021 (Table 4-13) with floods in March and May (Figure 4-12). Flow was low at the beginning of March but peaked at over 18,000 ML/d at Lobb's Hole and over 90,000 ML/d at Mt. McDonald. There was little rainfall in April 2020 and flows in the Murrumbidgee decreased throughout the month. In April 2021, flows continued to decrease before increasing two flow peaks which peaked at over 9,000 ML/d at Lobb's Hole and approximately 10,000 ML/d at Mt. McDonald.

Table 4-13 Autumn 2020, spring 2020 and autumn 2021 rainfall and flow summaries upstream of the MPS at Lobb's Hole and downstream at Mount McDonald

		Lobb's Hole (410761)		Mt. McDonald (410738)	Cotter River at Kiosk (410700)
		Rainfall Total (mm)	Mean Flow (ML/d)	Mean Flow (ML/d)	Mean Flow (ML/d)
Autumn 2020	March	104.8	91.2	490.0	24.4
	April	57.6	54.5	135.4	24.6
	May	22.4	110.5	241.8	32.6
	Total rainfall	184.8			
Spring 2020	September	30.2	725.5	981.9	28.7
	October	137.6	773.2	1,905.7	331.0
	November	69.0	2,159.0	3,205.9	403.6
	Total rainfall	236.8			
Autumn 2021	March	257.2	2,484.5	5,893.2	1,139.8
	April	1.8	591.0	1,362.7	207.4
	May	40.2	1,854.0	2,299.8	102.9
	Total rainfall	299.2			
Historical autumn monthly average		51.4			
Historical spring monthly average		58.0			

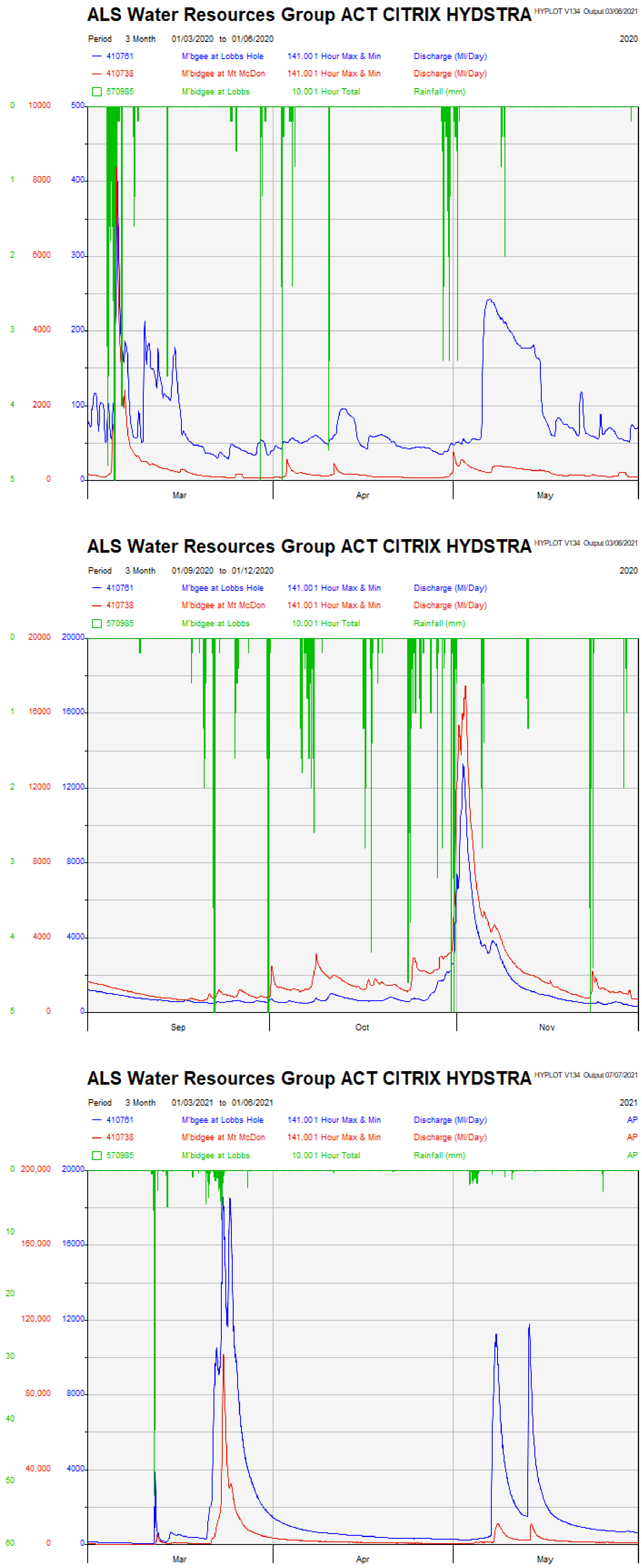


Figure 4-12 Autumn 2020 rainfall and hydrograph of the Murrumbidgee River at Lobb's Hole (410761) and Mt. McDonald (410738) for autumn 2020 (top), spring 2020 (middle) and autumn 2021 (bottom); Note different scales are displayed on the y-axis

4.3.2 Water quality

4.3.2.1 *In-situ* monitoring

Water quality results presented in Table 4-14 based on *in-situ* recordings and grab samples provide a snapshot of conditions during the monitoring events. The results indicate the Murrumbidgee River had elevated concentration of nutrients (total nitrogen, total phosphorus and oxidised forms of nitrogen) that often exceeded the ANZG (2018) guideline both upstream and downstream of the MPS. There is evidence that nutrients are often decreased downstream of the confluence between the Murrumbidgee River and Cotter River. This is indicated by reduced nutrient concentrations at MUR28down during spring 2020 and autumn 2021 that may have carried through to sites further downstream due to a dilution effect.

In addition, pH usually complied with the guideline range but was elevated at all sites in autumn 2020. Dissolved oxygen (DO) varied amongst sites and exceeded the upper guideline range of 100% upstream of the MPS in autumn 2021 but was below the lower guideline range of 90% both upstream and downstream of the MPS at other times. Electrical conductivity (EC) never exceeded the guideline and turbidity exceeded the guideline at MUR28up during autumn 2020 only. Overall, the results indicate there were no consistent patterns suggesting water quality differed between the upstream and downstream locations.

4.3.2.2 Continuous monitoring

Continuous monitoring data for the MPS is obtained from the gauging station on the Murrumbidgee River at Lobb's Hole (downstream of Angle Crossing). This station is also used for continuous monitoring data for Component 1 and therefore, for a description of continuous water quality for Component 3 refer to section 4.1.2.2 and Figure 4-3.

Table 4-14 In-situ water quality results from MPS sites with red cells outside ANZG (2018) default guideline range

Location	Site	Sampling period	Date	Time	Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	pH	D.O. (% Sat.)	D.O (mg/L)	Alkalinity (mg/L)	NO_x (mg/L)	TP (mg/L)	TN (mg/L)
ANZG (2018) default guideline values						30-350	2-25	6.5-8	90-110			0.015	0.02	0.25
Upstream	MUR28up	Autumn 2020	04/04/20	1430	18.9	303	25.2	8.7	88.0	8.2	120	0.08	0.29	1.40
		Spring 2020	28/11/20	1030	25.5	125	7.0	7.2	94.7	7.3	55	<0.05	0.04	0.42
		Autumn 2021	25/04/21	1030	12.2	112	9.0	7.1	124.6	11.1	55	<0.05	0.02	0.26
	MUR28down	Autumn 2020	04/04/20	1330	18.4	187	25.0	8.5	87.0	8.2	120	0.17	0.09	1.30
		Spring 2020	28/11/20	1230	24.7	57	3.0	7.2	93.5	7.3	30	<0.05	0.02	0.24
		Autumn 2021	25/04/21	1230	12.9	114	7.0	7.2	100.1	10.1	30	<0.05	0.02	0.21
Downstream	MUR935	Autumn 2020	04/04/20	1615	19.7	271	23.2	8.8	89.0	8.1	140	0.12	0.10	1.20
		Spring 2020	29/11/20	1030	25.3	125	5.0	7.4	89.0	6.8	50	<0.05	0.04	0.46
		Autumn 2021	25/04/21	1100	13.7	112	8.0	7.3	101.4	10.1	50	<0.05	0.02	0.25
	MUR936	Autumn 2020	04/04/20	1700	19.2	254	18.9	8.8	90.0	8.3	140	0.14	0.09	1.30
		Spring 2020	29/11/20	1300	25.1	94	8.0	7.6	97.1	7.5	45	<0.05	0.02	0.31
		Autumn 2021	25/04/21	1300	12.8	101	10.0	6.9	101.4	10.3	45	<0.05	0.02	0.25

Note: Water Temperature (Temp.), Electrical Conductivity (EC), Dissolved Oxygen (D.O.), percentage saturation (% Sat.), Alkalinity (Alk.), Nitrite + Nitrate as N (NO_x), Total Nitrogen as N (TN), Total Phosphorus as P (TP)

4.3.3 Periphyton

Photographs of periphyton in the Murrumbidgee River are presented in Plate 4-21. Across the two seasons, there was no indication of increased periphyton coverage at sites downstream of the discharge point into Burra Creek.

MUR28up / down - In all seasons, periphyton coverage in at both MUR28up and MUR28down was approximately 35-65%. There was no indication to suggest periphyton coverage varied upstream and downstream of the Cotter River confluence with the Murrumbidgee River.

MUR935 and MUR936 - Periphyton cover at MUR935 and MUR936 was similar at both sites in all seasons with a coverage of approximately 35-65%. Persicaria sp. was the dominant macrophyte species and there was no evidence to suggest an increase in periphyton downstream of the MPS.

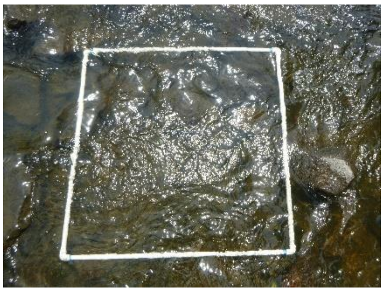
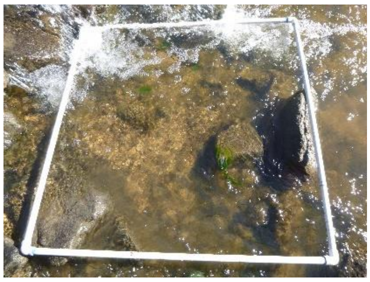
Site	Spring 2020	Autumn 2021
MUR28up		
MUR28down		
MUR935		
MUR936		

Plate 4-21 Photographs showing periphyton coverage in riffles of the Murrumbidgee River at MPS sites

4.3.4 Macroinvertebrates

4.3.4.1 Biological indices

There is minimal edge habitat in this reach of the Murrumbidgee River and therefore no edge samples were collected in the three seasons monitored.

The total taxa richness for M2G sites in the Murrumbidgee River are presented in Table 4-15. Across the three seasons, total taxa richness ranged from 16 to 22 at family level resolution and 25 to 38 at genus level resolution. Overall, there some indication of higher diversity during autumn 2020 that gradually decreased overtime. There was no consistent pattern in the data indicating sites downstream of the MPS on the Murrumbidgee River had lower taxa diversity than upstream. There was also no difference in total taxa richness upstream and downstream of the confluence with the Cotter River.

Table 4-15 Total number of taxa from riffle habitats

Location	Site	Sample	Autumn 2020		Spring 2020		Autumn 2021	
			Family	Genus	Family	Genus	Family	Genus
Upstream	MUR28up	1	18	31	19	30	16	27
		2	19	31	18	27	18	30
	MUR28down	1	20	33	20	32	16	25
		2	17	29	18	27	16	27
Downstream	MUR935	1	24	38	18	30	16	28
		2	20	34	18	30	16	25
	MUR936	1	24	35	19	28	13	25
		2	20	38	21	31	18	27

The EPT richness for Murrumbidgee River sites is presented in

Table 4-16. Across the three seasons, EPT richness ranged from 4 to 9 at family level resolution and 5 to 10 at genus level resolution. EPT richness was slightly higher in spring 2020 compared to the two autumn seasons. As was found for total taxa richness, there was no consistent pattern in the data indicating sites downstream of the discharge point or the Cotter River confluence had lower EPT diversity than upstream.

Table 4-16 Total number of EPT taxa from riffle habitats

Location	Site	Sample	Autumn 2020		Spring 2020		Autumn 2021	
			Family	Genus	Family	Genus	Family	Genus
Upstream	MUR28up	1	6	7	6	7	7	7
		2	6	6	6	7	6	6
	MUR28down	1	8	9	7	9	5	6
		2	5	5	6	6	5	7
Downstream	MUR935	1	6	6	7	9	6	7
		2	7	10	6	7	4	5
	MUR936	1	6	7	6	7	5	6
		2	6	9	9	10	5	6

The SIGNAL-2 and AUSRIVAS results for the MPS sites are presented in Table 4-17. SIGNAL-2 Scores ranged from 4.4 to 5.2 across the three seasons, but there were no noticeable differences between the seasons. Most sites in all seasons were allocated to AUSRIVAS Band B that possibly suggests significant impairment and fewer families than expected. This could be due to potential impacts on water and/or habitat quality. Some samples were allocated to AUSRIVAS Band A due to most families at reference sites being found, including samples from sites downstream of the MPS. Overall, there was no consistent pattern in the data indicating sites downstream of the MPS or Cotter River confluence had lower SIGNAL-2 scores or AUSRIVAS scores than upstream.

Table 4-17 SIGNAL-2 scores, AUSRIVAS scores and bandings from riffle habitats

	Location	Upstream				Downstream			
	Site	BUR1b		BUR1d		BUR2		BUR2a	
	Sample	1	2	1	2	1	2	1	2
SIGNAL-2 score	Autumn 2020	4.9	5.1	4.8	4.8	4.6	5.1	4.8	4.8
	Spring 2020	4.9	5.1	4.8	4.8	4.7	4.9	4.8	5.2
	Autumn 2021	4.9	5.0	4.4	4.7	4.5	4.5	4.8	4.8
AUSRIVAS O/E score	Autumn 2020	0.89	0.78	0.78	0.78	0.89	0.78	0.78	0.89
	Spring 2020	0.67	0.75	0.75	0.75	0.7	0.78	0.78	0.85
	Autumn 2021	0.78	0.78	0.78	0.78	0.78	0.78	0.89	0.78
AUSRIVAS Band	Autumn 2020	A	B	B	B	A	B	B	A
	Spring 2020	B	B	B	B	B	B	B	B
	Autumn 2021	B	B	B	B	B	B	A	B
Overall habitat assessment	Autumn 2020	B		B		B		B	
	Spring 2020	B		B		B		B	
	Autumn 2021	B		B		B		B	

Table 4-18 presents AUSRIVAS Bands for the Murrumbidgee River since 2012. Historically, all sites generally have been allocated to Band A or Band B. The results of the 2020-21 monitoring are similar to previous years suggesting the three seasons of impact monitoring did not detect any impacts due to operation of the MPS compared to sentinel monitoring prior to operation. Although there were site allocated to Band A in autumn 2015 and spring 2019, all sites included those upstream of the MPS and Cotter River confluence were allocated to Band B during the impact monitoring.

Table 4-18 Overall AUSRIVAS assessments for MPS sites since 2011

	Location	**Upstream**		**Downstream**	
		MUR28up	MUR 28down	MUR935	MUR936
Autumn	2011		B	B	
Spring	2011		B	B	
Autumn	2012		B	NRA	
Spring	2012		B	B	
Autumn	2013		B	B	
Autumn	2015		A	A	
Spring	2015		B	B	
Spring	2019*		A	A	
Autumn	2020*	B	B	B	B
Spring	2020*	B	B	B	B
Autumn	2021*	B	B	B	B

NRA = no reliable assessment, Bands were significantly different between habitats.
* Overall assessment based on riffle habitat only

4.3.4.2 Multivariate analysis – community composition

The NMDS ordination of macroinvertebrate community samples from riffle habitats from the sentinel monitoring (2015 and 2018) and impact monitoring (2019, 2020 and 2021) are presented in Figure 4-13. Note that each point on the NMDS represents a multivariate macroinvertebrate sample (i.e. all taxa collected and their abundances) and those samples close together have a more similar community composition than those further apart. The spread of samples on the ordination highlights two obvious patterns; 1) the community composition in 2018 and 2019 differs to 2020 and 2021, and 2) within 2015, 2018 and 2019 there are clear differences in the community composition between autumn and spring, 3) there is a large overlap between samples collected in spring 2020 and autumn 2021 indicating the similarities of the macroinvertebrate communities between these surveys, and 5) within each season there was no clear separation between samples collected upstream and downstream of the MPS abstraction.

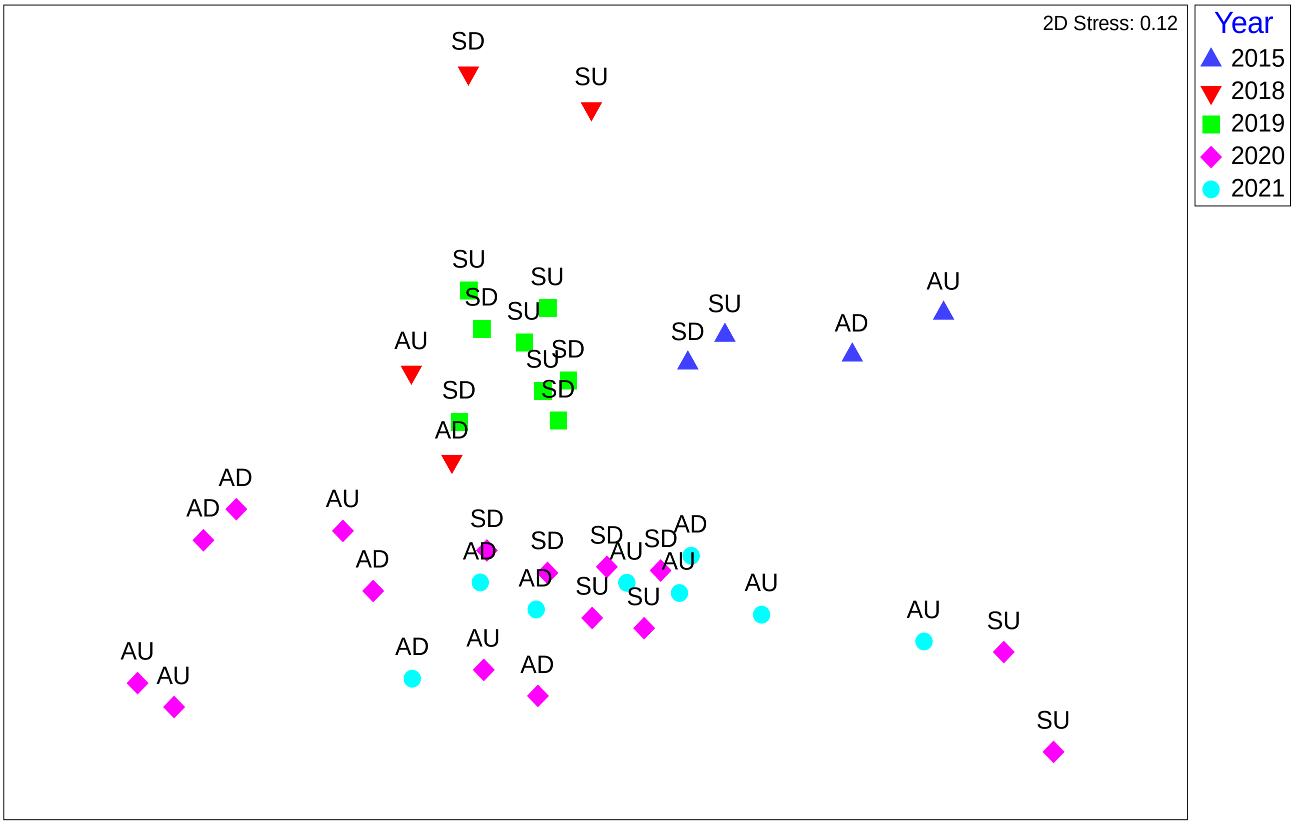


Figure 4-13 MDS ordination of macroinvertebrate communities associated with riffle habitats. A = autumn and S = spring; U = upstream and D = downstream

The patterns on the NMDS were confirmed by the PERMANOVA that detected no significant differences in community composition upstream and downstream of the abstraction (Pseudo-F = 2.2, P = 0.156). Given there were no obvious or statistical differences upstream and downstream of the abstraction point, no SIMPER analyses have been undertaken.

5. Discussion

5.1 Component 1: Angle Crossing (M2G)

5.1.1 Rainfall and hydrology

Overall, in the three seasons that monitoring occurred there was generally higher rainfall compared to historic averages and this was reflected by flow in the Murrumbidgee River. There were several high flow events during autumn 2020 in response to rainfall which peaked at 350 ML/d at Lobb's Hole. Throughout spring 2020, flow was higher than the preceding autumn including a high flow event exceeding 14,000 ML/d at Angle Crossing. Flow remained elevated in autumn 2021 and high flow events included over 20,000 ML/d at Angle Crossing and 18,000 ML/d at Lobb's Hole.

There was no abstraction associated with the M2G during any of the three seasons that monitoring occurred. Differences in flow upstream and downstream of the abstraction point are therefore related to other components of the system such as natural inputs. Despite this, the magnitude of differences in flow are not considered large enough to lead to flow induced differences between the upstream and downstream sites. As such, valid comparisons of river health can be made between the two locations.

5.1.2 Water quality

At sites associated with the M2G, the Murrumbidgee River has high nutrient loads with total nitrogen and total phosphorous exceeding the ANZG (2018) guidelines at all sites in all seasons. Oxidised forms of nitrogen also often exceeded the guideline while low dissolved oxygen and high pH are also characteristics of the Murrumbidgee River. Continuous monitoring indicates that turbidity increases in response to rainfall and increased flow. Alternatively, during these periods, pH and electrical conductivity decreases. There was little difference in water quality upstream and downstream of the abstraction point. The results indicate there has been no residual influence on water quality due to operation of the M2G.

5.1.3 Periphyton

Periphyton coverage in the Murrumbidgee River was reasonably consistent upstream and downstream of the M2G abstraction point. The results align with previous findings and are more likely relate to flow, nutrients and site-specific habitat conditions than an influence of the current level of operation of the M2G. Nutrient enrichment can lead to excessive growth of periphyton, algae and other aquatic macrophytes but this was not observed during the three seasons of monitoring.

5.1.4 Geomorphology

Minimal change in geomorphology has been observed in the Murrumbidgee River downstream of Angle Crossing (MUR19) since 2015. Increased flow and water levels were observed in spring 2020 compared to the two autumn seasons monitored during 2020 and 2021. Although individual high flow events can result in significant changes (GHD, 2014; GHD, 2015), there was no evidence of increased bank erosion, incising or scouring that were exacerbated by the current level of operation of the M2G.

The Murrumbidgee River downstream of Angle Crossing has a relatively intact riparian zone with little evidence of current erosion risks. Future operation of the M2G is likely to reduce risks further as flow and associated shear forces would be reduced. The main risks to geomorphic features downstream of Angle Crossing is considered natural flow variation rather than any changes due to future operation of the M2G.

5.1.5 Macroinvertebrate communities and river health assessment

Due to the habitat conditions in the Murrumbidgee River, there was limited edge habitat available to sample and the assessment of river health is based primarily on riffle habitat. The univariate indices found there was no consistent pattern indicating sites downstream of Angle Crossing had lower river health than upstream. Most sites in all seasons were allocated to AUSRIVAS Band B that suggests significant impairment and fewer families than expected. This could be due to potential impacts on water and/or habitat quality. The univariate indices during the 2020-21 monitoring are similar to previous years suggesting the three seasons of impact monitoring did not detect any impacts due to operation of the M2G compared to sentinel monitoring prior to operation.

The multivariate community analyses found there were little differences upstream and downstream of the M2G. While there were some significant differences during spring 2019 and autumn 2020, an examination of the macroinvertebrate composition determined there were similar communities upstream and downstream and that only the abundance of certain taxa varied. This suggests site-specific habitat conditions contributed to differences in the composition rather than any influence due to variation in flow and current operation of the M2G.

Overall, the results suggest that the macroinvertebrate community in the Murrumbidgee River are subjected to some level of disturbance due to water quality, and the composition is influenced by habitat conditions. However, given that there is a general increase in river health during the more productive spring period, any impacts are not limiting the seasonal dynamics of the community. Importantly, this is the case both upstream and downstream of the abstraction point and any differences observed during operation mode must consider this natural and broad-scale variation.

5.1.6 Fish

The 2021 fish monitoring the Murrumbidgee River represents the first period in which the M2G pipeline was used for water supply since its construction in 2012. The surveys determined that drought and bushfire runoff had an overwhelming influence on all the sites with, for example, lower recruitment of Murray Cod during the drought period. Overall, the surveys determined there was no negative effect due to operation of the M2G, even at the nearest downstream site (Tharwa Sandwash), in comparison to the upstream sites.

Although Common Carp were only detected in the Burra Arm of Burra Creek system, the Murrumbidgee fish population is in a degraded condition with native fish outnumbered by carp. Despite this, native species (Murray Cod and Golden Perch), are present and Murray Cod are naturally breeding in the Murrumbidgee River. There is also some evidence that populations of Murray Cod may be increasing in the region.

5.2 Component 2: Burra Creek (M2G)

5.2.1 Rainfall and hydrology

Overall, in the three seasons that monitoring occurred there was generally higher rainfall compared to historic averages and this was reflected by flow in Burra Creek. Flow was relatively low in autumn 2020 compared to the other seasons and flow peaked at over 200 ML/d following rainfall. Throughout spring 2020, flow was higher than the preceding autumn including a high flow event exceeding 850 ML/d. Flow remained elevated in autumn 2021 and high flow events included over 1,000 ML/d around mid-March, and over 3,500 ML/d in the latter part of the month.

Burra Creek is an intermittent stream with variable flows. This was observed during the monitoring with, for example, flow in March 2020 being 45.8 ML/d and in March 2021 almost double that at 91.2 ML/d. Consequently, changes in river health may be expected to vary across the same season in different years.

There was no discharge into Burra Creek associated with the M2G during any of the three seasons that monitoring occurred. Differences in flow upstream and downstream of the abstraction point are therefore related to other components of the system such as natural inputs. Despite this, the magnitude of differences in flow are not considered large enough to lead to flow induced differences between the upstream and downstream sites. As such, valid comparisons of river health can be made between the two locations.

5.2.2 Water quality

Burra Creek has high nutrient loads with total nitrogen exceeding the ANZG (2018) guidelines at all sites in all seasons. Total phosphorus and oxidised forms of nitrogen also often exceeded the guideline while low dissolved oxygen and high electrical conductivity are also characteristics of Burra Creek. Nutrients have historically been shown to increase with decreasing flow and following runoff events. Continuous monitoring indicates that turbidity increases in response to rainfall and increased flow. Alternatively, during these periods, dissolved oxygen increases and electrical conductivity decreases. There was little difference in water quality upstream and downstream of the discharge point. The results indicate there has been no residual influence on water quality due to operation of the M2G.

5.2.3 Periphyton

Periphyton coverage in Burra Creek was reasonably consistent upstream and downstream of the M2G abstraction point. The results align with previous findings and are more likely relate to flow, nutrients and site-specific habitat conditions than an influence of the current level of operation of the M2G. Nutrient enrichment can lead to excessive growth of periphyton, algae and other aquatic macrophytes but this was not observed during the three seasons of monitoring.

5.2.4 Vegetation

There has been minimal change to riparian vegetation surrounding Burra Creek or instream aquatic macrophytes since 2015. Burra Creek in the vicinity of the discharge is largely cleared of riparian vegetation with dominant forms current present consisting of exotic species including Salix sp. (Willows) and Populus sp. (Poplars). While these species were observed to go through natural seasonal changes, there were noticeable flow induced changes. Further downstream in the Googong Foreshore (Pool 29 and BUR2c), there is also limited riparian vegetation that has or could be impact by changes in flow.

In channel aquatic macrophytes include the emergent macrophyte Phragmites australis (Common Reed), Cyperus sp. (Sedges) and Juncus sp. (Rushes). Low flow periods in Burra Creek facilitates the growth of aquatic macrophytes in shallow areas can provide significant habitat for aquatic species. While there has been some changed overtime, macrophytes remain within the channel and have not been removed due to either natural high flows, or the operation of the M2G.

5.2.5 Geomorphology

There are several reaches in Burra Creek where bank erosion is considered severe. This includes upstream of the discharge point (BUR1a), downstream of the discharge and Williamsdale Road (BUR2a) and further downstream in the Googong Foreshore (Pool 29 and BUR2c). At the discharge point into Burra Creek (BUR2) the placement of rocks as part of the infrastructure works has been used to stabilised banks and prevent erosion.

No significant increase in the rate of bank erosion has been observed since 2017. While some changes have been noted, this considered to be predominantly due to land use and the condition of riparian vegetation in many areas that is contributing to bank instability and an increased risk of erosion. Increases in flow would have contributed to bank erosion. However, at the current level of M2G operation, natural flow increases are expected to be a greater influence than operation of the M2G. Should operation of the M2G become more common in the future, increased discharge of water into Burra Creek may exacerbate current erosion issues in the waterway. The contribution of discharges will need to be considered in the context of natural flow changes and current land use and riparian vegetation issues.

5.2.6 Macroinvertebrates and river health assessment

Due to the habitat conditions in Burra Creek, there was limited riffle habitat available to sample and the assessment of river health is based primarily on edge habitat. The univariate indices found there was no consistent pattern indicating sites downstream of the discharge point into Burra Creek had lower river health than upstream, particularly during low flow periods. Most sites in all seasons were allocated to AUSRIVAS Band B that suggests significant impairment and fewer families than expected. This could be due to potential impacts on water and/or habitat quality. There were some sites allocated to Band C suggesting these sites were severely impaired with water quality and/or habitat compromised significantly, resulting in a loss of biodiversity. However, these sites were upstream of the discharge point. Overall, the univariate indices during the 2020-21 monitoring are similar to previous years suggesting the three seasons of impact monitoring did not detect any impacts due to operation of the M2G compared to sentinel monitoring prior to operation. This was also confirmed by the multivariate community analyses that found there were no differences upstream and downstream of the discharge.

Overall, the results suggest that the macroinvertebrate community in Burra Creek are subjected to some level of disturbance due to water quality, and the composition is influenced by habitat conditions. Given that there is a general increase in river health during the more productive spring period, any impacts are not limiting the seasonal dynamics of the community. Importantly, this is the case both upstream and downstream of the discharge point and any differences observed during operation mode must consider this natural and broad-scale variation. Furthermore, future discharges into Burra Creek may increase the overall health of the waterways and provide additional riffle habitat.

5.3 Component 3: Murrumbidgee Pump Station (MPS)

5.3.1 Rainfall and hydrology

Overall, in the three seasons that monitoring occurred there was generally higher rainfall compared to historic averages and this was reflected by flow in the Murrumbidgee River. There were several high flow events during autumn 2020 in response to rainfall which peaked at over 8,000 ML/day at Mt. McDonald. During spring 2020, flow was higher than the preceding autumn including a high flow event exceeding 13,000 ML/d at Lobb’s Hole and 17,000 ML/d at Mt. McDonald. Flow remained elevated in autumn 2021 and high flow events included over 18,000 ML/d at Lobb’s Hole and over 90,000 ML/d at Mt. McDonald.

There was no abstraction associated with the MPS during any of the three seasons that monitoring occurred. Differences in flow upstream and downstream of the abstraction point are therefore related to other components of the system such as natural inputs. Despite this, the magnitude of differences in flow are not considered large enough to lead to flow induced differences between the upstream and downstream sites. As such, valid comparisons of river health can be made between the two locations.

5.3.2 Water quality

At sites associated with the MPS, the Murrumbidgee River has high nutrient loads with total nitrogen, oxidised forms of nitrogen and total phosphorous often exceeding the ANZG (2018) guidelines at all sites in all seasons. Low dissolved oxygen and high pH are also characteristics of the Murrumbidgee River in this reach. On occasions, flow from the Cotter River has a dilution effect and reduces nutrient concentrations in the Murrumbidgee River. Continuous monitoring indicates that turbidity increases in response to rainfall and increased flow. Alternatively, during these periods, pH and electrical conductivity decreases. There was little difference in water quality upstream and downstream of the MPS and the results indicate there has been no residual influence on water quality due to operation. Furthermore, there were no noteworthy differences in water quality downstream of the Cotter River at MUR28down compared to MUR28up. This suggests these two sites are suitable as replicate upstream control sites to assess potential changes due to abstraction of water by the MPS.

5.3.3 Periphyton

Periphyton coverage in the Murrumbidgee River was reasonably consistent upstream and downstream of the MPS. The results align with previous findings and are more likely relate to flow, nutrients and site-specific habitat conditions than an influence of the current level of operation of the MPS. Nutrient enrichment can lead to excessive growth of periphyton, algae and other aquatic macrophytes but this was not observed during the three seasons of monitoring.

5.3.4 Macroinvertebrates and river health assessment

Due to the habitat conditions in the Murrumbidgee River, there was very little edge habitat available to sample and the assessment of river health is based primarily on riffle habitat. The univariate indices found there was no consistent pattern indicating sites downstream of the MPS had lower river health than upstream. Most sites in all seasons were allocated to AUSRIVAS Band B that suggests significant impairment and fewer families than expected. This could be due to potential impacts on water and/or habitat quality. The univariate indices during the 2020-21 monitoring are similar to previous years suggesting the three seasons of impact monitoring did not detect any impacts due to operation of the MPS compared to sentinel monitoring prior to operation. This was also confirmed by the multivariate community analyses that found there were no differences upstream and downstream of the discharge.

Overall, the results suggest that the macroinvertebrate community in the Murrumbidgee River are subjected to some level of disturbance due to water quality, and the composition is influenced by habitat conditions. Given that there is a general increase in river health during the more productive spring period, any impacts are not limiting the seasonal dynamics of the community. Importantly, this is the case both upstream and downstream of the MPS and any differences observed during operation mode must consider this natural and broad-scale variation.

6. Conclusion

The MEMP has been carried out by Icon Water to investigate potential impacts of water abstraction from the Murrumbidgee River and the influence of increased water volumes in Burra Creek on ecological conditions. The MEMP was implemented prior to the commencement of the M2G project, allowing Icon Water to collect pre-abstraction baseline data to compare against the post-abstraction data once the M2G project began operation. Seasonal monitoring has occurred in spring and autumn each year between 2008 and 2021.

The purpose of sentinel monitoring in 2015 and 2018 was to provide a broad-scale assessment of control and impact sites related to the Angle Crossing abstraction point (M2G), the Burra Creek discharge and the MPS. Specifically, the monitoring prior to operation was to "*provide confidence that the condition of the potential impact sites is broadly similar to non-impact sites across time*". The sentinel monitoring confirmed the study design is suitable and provides baseline data that can be compared to conditions during operation (GHD 2018).

Icon Water made the decision to undertake impact monitoring during 2019 due to the planned transition to operation phase during 2020. Based on this, the first round of impact monitoring was conducted in autumn 2019 for the M2G component, and subsequently in spring 2019 for both the M2G and MPS components. There were no major differences upstream and downstream of the M2G or MPS in the Murrumbidgee River, or the discharge point in Burra Creek during the initial round of impact monitoring (GHD 2020). This confirmed the findings of the sentinel monitoring and highlighted that upstream and downstream comparisons should enable detection of any potential impacts from the discharge.

This report includes results from impact monitoring that continued in autumn 2020 during the transfer of 4.51 GL to Googong Reservoir. It also includes post-operation monitoring undertaken in spring 2020 and autumn 2021, following the cessation of operation in August 2020. Under this operational scenario, the key conclusions from the monitoring are:

– High rainfall in early 2020 ended the 2017-2019 drought and resulted in higher flows in the Murrumbidgee River and Burra Creek. Although there were high and at times low flow periods in 2020 and 2021 comparisons of upstream and downstream locations are still considered valid.
– Both the Murrumbidgee River and Burra Creek have high nutrient loads, particularly total phosphorus, total nitrogen and oxidised forms of nitrogen.
– There has been no increase in the occurrence of periphyton in the Murrumbidgee River and Burra Creek over time.
– There have been no dramatic changes in riparian or instream vegetation in Burra Creek.
– There are several areas prone to bank erosion and slumping in Burra Creek that are likely to be at greater risk during high flows.
– During low flow periods, edge habitat is reduced in the Murrumbidgee River and riffle habitat is lost in Burra Creek. Despite this, the general health of the two waterways has not dramatically changed over time and variation in these habitats is considered to be due to natural events.
– The macroinvertebrate communities in the Murrumbidgee River and Burra Creek are generally reflective of mild to moderate pollution impacts and/or significant impairment with water quality and/or habitat potentially impacted resulting in loss of taxa.
– The macroinvertebrate community continues to display a high level of seasonal variation suggesting that that any impairment due to habitat conditions or operation of the M2G and MPS has not been enough to mask natural variability.
– Several threatened species are known to occur in the Murrumbidgee River, and it is recommended future fish surveys occur to monitor their condition. Surveys undertaken in 2021 did not detect a negative impact due to operation of the M2G.
– Overall, there were little differences waterway health upstream and downstream of the M2G and MPS in the Murrumbidgee River, or the discharge point in Burra Creek. The operation of the M2G and the MPS has not results in significant impairment to the waterways.

The conclusions from the sentinel and impact monitoring are considered in relation to the management hypotheses in Table 6-1.

Table 6-1 Management hypotheses to be tested following impact assessment monitoring for M2G and MPS operations

Hypotheses	Operation	Conclusions
1a: Flow abstraction will not result in the deterioration of the macroinvertebrate community (measured using biological indices) at sites downstream of the abstraction point (Angle Crossing for M2G and downstream of MPS) relative to sites upstream, informed by prevailing conditions in the broader region.	M2G MPS	Historical monitoring, including sentinel monitoring, provided evidence of background conditions and confirmed upstream and downstream comparisons (control / impact) were valid. No deterioration in the macroinvertebrate community has been detected at downstream sites has been detected due to flow abstraction under the current level of operation.
1b: Flow discharge to Burra Creek will not result in the deterioration of the macroinvertebrate community (measured using biological indices) at sites downstream of the inflow relative to sites upstream of the abstraction point and informed by prevailing conditions in the broader region.	M2G	Historical monitoring, including sentinel monitoring, provided evidence of background conditions and confirmed upstream and downstream comparisons (control / impact) were valid. No deterioration in the macroinvertebrate community has been detected at downstream sites has been detected due to increases in abstraction under the current level of operation.
2a: Flow abstraction in the Murrumbidgee River will not result in the development of increased periphyton to the extent that it impacts on the quality of the riffle habitat at sites downstream of the abstraction point (Angle Crossing for M2G and downstream of MPS) compared to sites upstream of the abstraction point, and informed by prevailing conditions in the broader region.	M2G MPS	Historical monitoring, including sentinel monitoring, provided evidence of background conditions and confirmed upstream and downstream comparisons (control / impact) were valid. No increase in periphyton downstream of the M2G or MPS abstraction has been detected due to flow abstraction under the current level of operation. The quality of riffle habitats has been maintained.
2b: Flow discharge into Burra Creek will not result in the development of increased periphyton to the extent that it impacts on the quality of the riffle habitat at sites downstream of the inflow point compared with sites upstream of the inflow point, and informed by prevailing conditions in the broader region.	M2G	Historical monitoring, including sentinel monitoring, provided evidence of background conditions and confirmed upstream and downstream comparisons (control / impact) were valid. There is little riffle habitat in Burra Creek, especially under low flow conditions. The quality of riffle habitats, when present, has been maintained under the current level of operation.
3a: Flow transfer to Burra Creek will not result in bank erosion that is beyond that currently occurring in response to natural high flow events.	M2G	In some areas, Burra Creek is prone to severe bank erosion due to land use and riparian vegetation conditions. While there has been some further erosion in some areas, this is more attributable to natural flow events rather than operation of the M2G. Prolonged operation of the M2G in the future is likely to contribute to increased erosion although this may not be significant in the context of natural events.
3b: Flow discharge to Burra Creek will not result in changes in macrophyte or riparian vegetation that is beyond that currently occurring in response to natural high flow events.	M2G	Under the current level of operation, there has been no significant changes to aquatic macrophytes than would be expected under natural high flow events. There has also been no change in riparian vegetation although this is of low quality and dominated by exotic species.
4a: Flow abstraction from the Murrumbidgee River will not result in an increased threat to threatened cod species due to decreased pool mixing and consequent water quality impacts.	M2G MPS	The 2021 fish monitoring the Murrumbidgee River represents the first period in which the M2G pipeline was used for water supply since its construction in 2012. Overall, the surveys determined there was no negative effect due to operation of the M2G, even at the nearest downstream site (Tharwa Sandwash), in comparison to the upstream sites. Although Common Carp were only detected in the Burra Arm of Burra Creek system, the Murrumbidgee fish population is in a degraded condition with native fish outnumbered by carp. Despite this, native species (Murray Cod and Golden Perch), are present and Murray Cod are naturally breeding in the Murrumbidgee River and there is evidence populations of Murray Cod may be increasing in the region.
4b: Flow discharge to Burra Creek will not result in the introduction of Carp or Oriental Weatherloach populations (via transfer) in Burra Creek or native fish stranding on drawdown.	M2G	Fish surveys of Burra Creek required to address this hypothesis.

7. Future monitoring

As described in Section 1.1, the trigger for impact monitoring is the decision to operate the M2G or MPS infrastructure. This monitoring scenario requires a before/after and control/impact (BACI) approach and relies on replicated monitoring protocols.

Icon Water made the decision to undertake impact monitoring during 2019 due to the planned transition to operation phase during 2020. Based on this, the first round of impact monitoring was conducted in autumn 2019 for the M2G component, and subsequently in spring 2019 for both the M2G and MPS components. The impact monitoring continued in autumn 2020 during the transfer of 4.51 GL to Googong Reservoir as part of the M2G component. For the MPS component, the autumn 2020 monitoring occurred nine days after water was began to be extracted from the Murrumbidgee River and delivered to the base of the Cotter Dam. Post-operation (i.e. after) monitoring was undertaken as part of the impact monitoring in spring 2020 and autumn 2021, following the cessation of operation in August 2020 for the M2G component, and in October 2020 for the MPS component.

Given operation of the M2G and MPS infrastructure has ceased, the MEMP will revert to the sentinel monitoring with the next round planned for 2025. The sentinel monitoring will inform if major catchment-scale changes to the aquatic ecology are taking place. This will confirm what the background conditions are and confirm that the BACI approach remains valid should impact monitoring be again triggered. Sentinel monitoring occurs during standby periods when the risk to the ecosystem is deemed to be very low and will continue every three years unless there is a requirement for operation that would trigger additional impact monitoring.

8. References

ANZECC (2000) National water quality management strategy: Paper No. 4. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1. The Guidelines. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand

ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Available online: https://www.waterquality.gov.au/anz-guidelines

Chessman, B. C. (2003) New sensitivity grades for Australian river macroinvertebrates. Marine and Freshwater Research, 54: 95-103

Chessman, B. (2008) Review of the Murrumbidgee Ecological Monitoring Program study design. Report to Ecowise Australia Pty Ltd

Clarke, K.N. and Gorley, R.N. (2015) Getting started with PRIMER v7. Primer-E Ltd. Plymouth Marine Laboratory, Plymouth UK

Clarke, K. N. and Warwick, R. M. (2001) Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Primer-E Ltd. Plymouth Marine Laboratory, Plymouth UK

Coysh, J., Nichols, S., Ransom, G., Simpson, J., Norris, R. H., Barmuta, L. A. and Chessman, B. (2000) AUSRIVAS Macroinvertebrate bioassessment: Predictive modelling manual. Canberra

GHD (2014) Murrumbidgee Ecological Monitoring Program: Burra Creek geomorphology and vegetation assessment. GHD, Canberra

GHD (2015b) Murrumbidgee Ecological Monitoring Program: Burra Creek Geomorphology Update. GHD, Canberra

GHD (2018) Murrumbidgee Ecological Monitoring Program 2015-21 Sentinel Monitoring - Autumn 2018. Report for Icon Water. GHD, Canberra

GHD (2020) Murrumbidgee Ecological Monitoring Program Impact Monitoring - Autumn 2019 and Spring 2019. Report for Icon Water. GHD, Canberra

Hall, F. C. (2001) Ground-based photographic monitoring. Gen. Tech. Rep. PNW-GTR-503. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 340 p.

Hawking, J. H. (2000) Key to Keys: A guide to keys and zoological information to identify invertebrates from Australian inland waters. Cooperative Research Centre for Freshwater Ecology, Albury

Icon Water (2017) Murrumbidgee to Googong Operational Environmental Management Plan. EN03.03.10

Icon Water (2018) Murrumbidgee to Googong Streamflow and Water Quality Management Plan. EN03.01.12

Jacobs (2014) Review of the Murrumbidgee Environmental Monitoring Program. Report to ACTEW Water. VW07641

Keen, G. (2001) Australia-Wide Assessment of River Health: Australian Capital Territory Bioassessment Report. Department of Urban Services, Canberra

Kruskal, J. B. (1964) Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika, 29(1), 1-27

Marchant, R. (1989) A subsampler for samples of benthic invertebrates. Bulletin of the Australian Society of Limnology, 12, 49-52

Nichols, S., Sloane, P., Coysh, J., Williams, C. and Norris, R. H. (2000) AUStralian RIVer Assessment System - Australian Capital Territory: Sampling and Processing Manual. Cooperative Research Centre for Freshwater Ecology, Canberra

O'Connor, P. and Bond, A. J. (2007) Maximizing the effectiveness of photopoint monitoring for ecological management and restoration Ecological Management & Restoration, 8, 228-233

UoC (2019). Environmental DNA Detection of Carp in the Burra Creek and Burra Arm of the Googong Reservoir. Report to Icon Water by Institute of Applied Ecology, University of Canberra ACT

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