Icon Water

Murrumbidgee Ecological Monitoring Program 2015-21
Sentinel Monitoring - Autumn 2018

September 2018

Executive summary

The Murrumbidgee Ecological Monitoring Program commenced in 2008. The project is being undertaken by the GHD Water Science Group for Icon Water, to meet regulatory requirements and to add to an already substantial and important database in relation to the Murrumbidgee to Googong (M2G) water transfer project and Murrumbidgee Pump Station (MPS).

Over the course of this monitoring program, there have been a number of changes and modifications, which have been in line with the adaptive management philosophy adopted in the design phase of the MEMP. The most recent and major change to the MEMP followed the recent peer review by Jacobs Group (Australia) (Jacobs, 2014). The review resulted in a number of recommendations so that Icon Water can continue to have a robust monitoring program, capable of detecting potential ecological impacts, while at the same time accounting for the lowered ecological risk during periods of standby and maintenance modes of operation.

*Three modes of operation are defined for the M2G and MPS to help target the monitoring program during these different modes of operation. The modes of operation for the **M2G** are:*

- ***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 of 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 of greater than 30 consecutive days.*

*The modes of operation for the **MPS** are:*

- ***Standby** – abstraction from the Murrumbidgee River is 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 Murrumbidgee Pump Station, this extraction volume rarely occurs due to water quality in the Murrumbidgee River. Hence, smaller volumes are likely to be taken and shandied with cleaner Cotter River water from the Bendora Main.*

*With this in mind, the revised MEMP has adopted a two-stage approach, which incorporates sentinel monitoring during **standby** operation modes and **impact** monitoring assessment during the various operation modes.*

The purpose of the sentinel monitoring is to detect if major catchment-scale changes to the aquatic ecology occur during the standby mode. Sentinel monitoring will therefore occur during standby periods when the risk to the ecosystem is deemed to be very low. Monitoring will occur in autumn and spring every three years beginning in autumn 2015 with a reduced number of monitoring sites (1 upstream and 1 downstream of Angle Crossing (M2G), Burra Creek discharge structure (M2G) and the Murrumbidgee Pump Station (MPS)). Periphyton sampling 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.*

The trigger for impact monitoring to go ahead is the decision to operate the M2G or MPS infrastructure. This monitoring scenario requires a before and after approach, and relies on replicated sampling protocols. Under this monitoring protocol several univariate indicators of river health and condition with be analysed before and after the operation period at both upstream and downstream locations. Periphyton photogrammetry will be assessed at both time periods and compared between monitoring locations. The key difference between this, and the sentinel monitoring is the number of sites, replicates and sampling events (impact monitoring requires at least one before and one after sampling event) and the level of detail used in the analysis.

Following the operation period, a consecutive spring and autumn monitoring schedule must also be carried out; and should pumping occur across a spring and/ or autumn period, sampling will be carried out during those times.

Component 1 – Angle Crossing Overview

Icon Water constructed an intake structure and pipeline to abstract water from the Murrumbidgee River at Angle Crossing (southern border of the ACT). The system is designed to pump up to a nominal 100 ML/d and was completed in August 2012. There are operating rules in place that limit when and how much water can be extracted to ensure that environmental harm is minimised. The Angle Crossing component of the MEMP has focused on the assessment of potential impacts associated with flow reductions in the Murrumbidgee River downstream of Angle Crossing as a result of water abstraction. However, during the current reporting period the only pumping which was undertaken by Icon Water was that of maintenance flows. These flows only have a minimal impact upon flow in the Murrumbidgee River.

Component 1 – Angle Crossing autumn 2018

***Water quality** at Angle Crossing had the same characteristics, both upstream and downstream of the M2G intake and most of the physico-chemical parameters were within the ANZECC and ARMCANZ guidelines (2000). Total phosphorus and total nitrogen were the only parameters which were above the guideline values. Nitrogen, upstream of Angle Crossing was below the limits of detection (<0.05), while downstream at MUR19, the concentration was 0.30 mg/L which exceeds the current guideline value. Previous nitrogen samples collected at MUR18 have shown nitrogen concentrations to be almost identical to those at MUR19, which suggests that the reading at MUR18 is erroneous and should be rechecked.*

The coverage of periphyton in the riffle habitat during autumn 2018 was higher than that recorded during spring 2015, changing from 35-65% to 65-90%, which is a function of the prolonged low flows experienced in the Murrumbidgee River over this time.

*While the **geomorphology** at Angle Crossing has shown that over recent years, it is a dynamic reach, which can have significant changes from individual high flow events, during the period since spring 2015 there has been very little change within this reach.*

The current photographs show areas of exposed river margins from the declining water level and some newly exposed sand bars and bedrock. These features are linked to the ongoing low rainfall period throughout much of the upper Murrumbidgee River Catchment at present and is not considered to be related to M2G. There is no photographic evidence of bank erosion, incising or scouring that may be considered to be caused by the M2G project.

There has been no change in the ecological condition since the preceding autumn sentinel sampling run in 2015. Both MUR18 and MUR19 had an overall assessment rating of Band B, which is based on the overall condition of the edge and riffle habitats, combined, and is unchanged in the current period.

The impacts of the prolonged low flow period were not evident from the macroinvertebrate assessment, as both sites had significant numbers of highly sensitive taxa. The AUSRIVAS Bands were similar to previous autumn sampling runs, when Murrumbidgee Flows have been considerably higher.

Component 2–Burra Creek Overview

The operational phase of the M2G will involve the transfer of water from Angle Crossing to Burra Creek, where it will be released as a run of river flow into Googong reservoir for storage. Up to 100 ML/d will be pumped to Burra Creek, with the natural flow regime characterised by low base flows and peak flow events that only exceed 100 ML/d for short periods of time. Consequently, this could potentially result in changes to the hydrological regime of this system and subsequent changes to its ecology (both detrimental and beneficial). The Burra Creek component of the MEMP has focused on assessing the potential impacts of changes in hydrology on aquatic biota.

Monitoring for the Angle Crossing and Burra Creek components of the MEMP has been carried out in autumn and spring for ten years. This includes a baseline monitoring phase between 2009 and 2018 followed by monitoring of an operation phase from August 2012 to present. However, since the completion of the M2G in August 2012, the system has only been operating in standby mode. Only limited trial and maintenance abstractions and releases have occurred. Hence the monitoring to date, including the last two years, largely represents an extended baseline survey. However, it has encompassed a range of natural flow conditions and, consequently, has been useful in terms of collecting data that allows a better understanding of the relationships between biota and flow with better predictive capacity in respect to the likely nature of changes that will occur once the M2G goes into full operation.

Monitoring to date has covered ACT AUSRIVAS macroinvertebrate sampling, periphyton sampling, water quality monitoring (via in situ testing, laboratory analysis and continuous data loggers) and an assessment of hydrology at locations upstream and downstream of Angle Crossing and the nominated release point in Burra Creek.

Component 2– Burra Creek autumn 2018

Overall, the Burra Creek sites were the most affected by the low flows, which was evidenced by the absence of riffle habitat and degrading water quality in the edge habitat, leading to some stress on the macroinvertebrate communities in terms of low numbers of EPT taxa and taxa with SIGNAL scores greater than 7. As well as declining water quality, the quality of the habitat was also in decline due to severe encroachment of the main channel by macrophytes. The overall site assessment for the Burra Creek sites was Band B at both sites, which is equivalent to the assessment in the previous autumn sampling (in 2015). However, there was a decline in the condition in the edge habitat at BUR1c from and A to Band B, which agrees with the observations relating to declining water and habitat quality.

Periphyton coverage was high at both sites, with >90% coverage across the reach approximately 100% in the drying riffle habitat at both sites, and the edge habitat, which is an increase since both monitoring periods in 2015.

In the MEMP ***geomorphology*** *report it was pointed out that the area of greatest concern along Burra Creek is the downstream reach at BUR2c. There were no signs of any significant geomorphological changes at the photo monitoring locations in Burra Creek between spring 2015 and the current monitoring period. The creek channel appeared to be stable as did the creek banks, with no obvious slumping or collapse observed from the photographs – even at the most vulnerable sites (i.e. Pool 29 and BUR2c).*

Component 3- Murrumbidgee Pump Station Overview

The Murrumbidgee Pump Station (MPS) is located just downstream of the Cotter River confluence with the Murrumbidgee River. The MPS underwent a significant upgrade which increased its pumping capacity to the Mount Stromlo Water Treatment Plant from 50ML/d to approximately 150ML/d. The *framework for this program responds primarily to the Icon Water abstraction licence reporting requirements. Water abstraction at the MPS, requires an assessment of the response of the river through monitoring methods that can quantify subtle impacts.*

Component 3- Murrumbidgee Pump Station autumn 2018

Water quality at the Murrumbidgee Pump Station sites showed an exceedance of pH at MUR28; however it should be noted that this value is not considered high in relation to the historical records from this site. There is no indication of any lasting impacts related to the MPS or the releases from the Cotter Dam in April as the water quality parameters at both locations are highly comparable; although there is some dilution effect on EC evident at MUR935, but this effect is minimal as there is on a 20 us/cm difference between the two sites.

Overall there were some minor differences in the total number and in the number of sensitive macroinvertebrates between locations. There were some sensitive taxa collected at MUR935, which were not collected at MUR28. Two potential explanations for this is that the habitat quality at MUR935 was more compatible with the requirements of these taxa. The other potential explanation is that the environmental releases from the Cotter Reservoir either relocated some individuals from the Cotter River, or the additional flow over this site facilitated their local colonisation.

The variation in taxa richness and EPT richness did not change the AUSRIVAS result from the previous autumn monitoring period as both sites and habitats are still assessed as Band A.

There are no new recommendations to be put forward for the MEMP at this stage.

Table of contents

Table index

Figure index

Plate index

Appendices

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List of abbreviations

ACT – Australian Capital Territory

ACTEW – ACTEW Corporation Limited

ALS – Australian Laboratory Services

ANZECC –Australian and New Zealand Environment and Conservation Council

APHA – American Public Health Association

APPLE – Angle Crossing Planned Pumped Lubrication Exercise (Icon Water acronym)

ARMCANZ – Agriculture and Resource management Council of Australia and New Zealand

AUSRIVAS – Australian River Assessment System

EC – Electrical Conductivity

ECD – Enlarged Cotter Dam

EIS – Environmental Impact Statement

EPA – Environmental Protection Authority

EPT – Ephemeroptera, Plecoptera and Trichoptera taxa

GL/a – Gigalitres per annum

GPS – Global positioning system

M2G – Murrumbidgee to Googong

MEMP – Murrumbidgee Ecological Monitoring Program

ML/d – Megalitres per day

MPS – Murrumbidgee Pump Station

NATA – National Association of Testing Authorities

NSW – New South Wales

NTU – Nephlelometric Turbidity Units

QA – Quality Assurance

QC – Quality Control

TN – Total Nitrogen

TP – Total Phosphorus

1. Introduction

During the 2000-2010 drought in the Australian Capital Territory (ACT) and surrounding regions of New South Wales (NSW), the ACT's dam storage volumes declined to unprecedented levels. Icon Water (formally ACTEW Corporation), 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 security for the residents of Canberra and Queanbeyan.

The water security projects include:

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

To assess the influence of the construction and operations of these major projects Icon Water developed a detailed monitoring program to establish a comprehensive baseline data set which could then be compared to the conditions during and following construction and also during the operation of M2G and MPS.Since the completion of the MPS upgrade and the M2G infrastructure, both have been used infrequently because Icon Water has opted to use available water from other catchments which offer raw water with lower production costs. Furthermore, given the breaking of the drought in 2010 there has been no operational need to operate M2G or MPS because of improved water storage levels. Modelling by Icon Water has shown that it may be several years before full scale operation of either infrastructure is required which means that the MPS and M2G are both essentially on standby mode; implying that ecological impacts relating to these projects may be minimal.

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

The Murrumbidgee Ecological Monitoring Program (MEMP) has been supported by Icon Water to evaluate the potential impacts of water abstraction from the Murrumbidgee River and the influence of increased water volumes in Burra Creek on ecological communities. 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. To date, sampling has been conducted in spring and autumn each year between spring 2008 and autumn 2018.

Over the course of this monitoring program, there have been a number of changes and modifications which have been in line with the adaptive management philosophy of the MEMP. The history of the MEMP is shown schematically in Figure 1-1.

Between spring 2008 and autumn 2013 there were four component areas being 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).

1 Note that the MEMP does not include monitoring related to the Cotter Dam

However, following the autumn 2013 monitoring period Icon Water reviewed the MEMP which resulted in the discontinuation of Component 3 (the Murrumbidgee Pump Station component) and Component 4 (the Tantangara to Burrinjuck component).

Following this review the MEMP continued to assess Component 1 and Component 2 from spring 2013 to spring 2014. During 2014 Icon Water commissioned a full independent review of the MEMP project. This review was completed by Jacobs (2014) and resulted in a number of recommendations, which are outlined below.

Commencing in autumn 2015, these changes are:

- Sentinel monitoring – completion of autumn and spring seasonal analysis every 3 years;
- The re-establishment of Component 3: Murrumbidgee Pump Station;
- Reduction of the number of sites assessed for macroinvertebrates for each Component from 6 sites to 2 sites;
- Reduction from 2 riffle and 2 edge habitat samples to 1 riffle and 1 edge habitat sample;
- Removal of quantitative periphyton assessment;
- Introduction of photogrammetry monitoring for periphyton, vegetation and geomorphology at relevant locations.

1.2 Project review and requirements

The peer review of the program by Jacobs Group (Australia) (Jacobs, 2014) resulted in a number of recommendations to adapt the program so that Icon Water may continue to have a robust monitoring program, capable of detecting potential ecological impacts, while at the same time accounting for the lowered ecological risk during periods of standby and maintenance modes of operation.

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 of 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 of greater than 30 consecutive days.

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

- **Standby –** abstraction from the Murrumbidgee River is 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 Murrumbidgee Pump Station, this extraction volume rarely occurs due to water quality in the Murrumbidgee River. Hence smaller volumes are likely to be taken 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 the Murrumbidgee River and Burra Creek are most likely to manifest during periods of full operation.

With this in mind, the revised MEMP will adopt a two-stage approach which incorporates sentinel monitoring during **standby** operation modes and **impact** monitoring assessment during the various operation modes. These two types of monitoring are described in sections 1.2.1 and 1.2.2 respectively.

1.2.1 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. Sentinel monitoring will occur during standby periods when the risk to the ecosystem is deemed to be very low. Sentinel monitoring will occur in autumn and spring every three years which begun in autumn 2015 with a reduced number of monitoring sites (1 upstream and 1 downstream of Angle crossing (M2G); Burra Creek discharge structure (M2G) and at the Murrumbidgee Pump Station (MPS)). Periphyton sampling 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.

1.2.2 Impact monitoring (M2G & MPS)

The trigger for impact monitoring to go ahead is the decision to operate the M2G or MPS infrastructure. This monitoring scenario requires a before and after approach, and relies on replicated sampling protocols. Under this monitoring protocol several univariate indicators of river health and condition will be analysed before and after the operation period at both upstream and downstream locations. Periphyton photogrammetry will be assessed at both time periods and compared between monitoring locations. The key difference between this, and the sentinel monitoring is the number of sites, replicates and sampling events (impact monitoring requires at least one before and one after sampling event) and the level of detail used in the analysis.

Following the operation period, a consecutive spring and autumn monitoring schedule must also be carried out; and should pumping occur across a spring and/or autumn period, sampling will be carried out during those times.

1.2.3 Environmental flows and the 80:90 percentile rule

The environmental flow rules for the Murrumbidgee to Googong (M2G) component have been adopted from the framework outlined in the Environmental Flow Guidelines (ACT Government, 2013). Under the current Licence agreement (Icon Water's Licence to take water, 2018 under the Water Resources ACT 2007), flows in the Murrumbidgee River at the Murrumbidgee Pump Station must be maintained at 20 ML/d during any stage of water restrictions. When these restrictions do not apply, flows must be maintained using the 80:90 rule.

The 80:90 rule has been applied to hydrological modelling of the Murrumbidgee River at Angle Crossing for the M2G environmental operational plan (Icon Water, 2017) and was based on data collected from the Lobb's Hole gauging station. Specifically the 80th percentile flow applies from November to May and the 90th percentile from June through to October (Figure 1-2).

As can be seen from Figure 1-2, the lowest flows in the Murrumbidgee River occur in summer and autumn. The 80th percentile flows from November to May are less than the 90th percentile flows except for November. It is during these low flow months that abstraction from the Murrumbidgee River is likely to have the most significant impact, as the proportion of the abstraction rate to the base flow is the greatest.

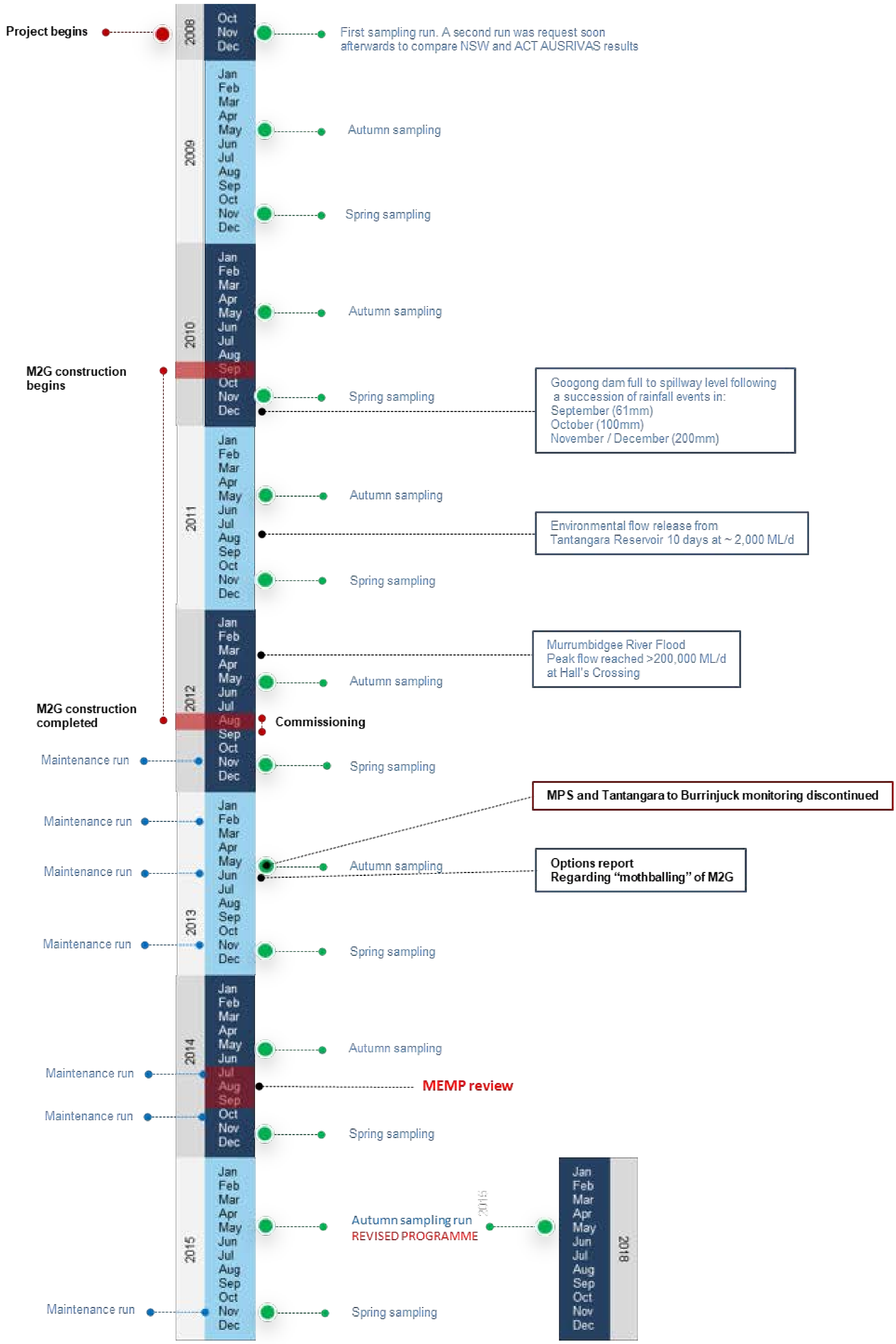


Figure 1-1. Schematic time line of the Murrumbidgee Ecological Monitoring Program

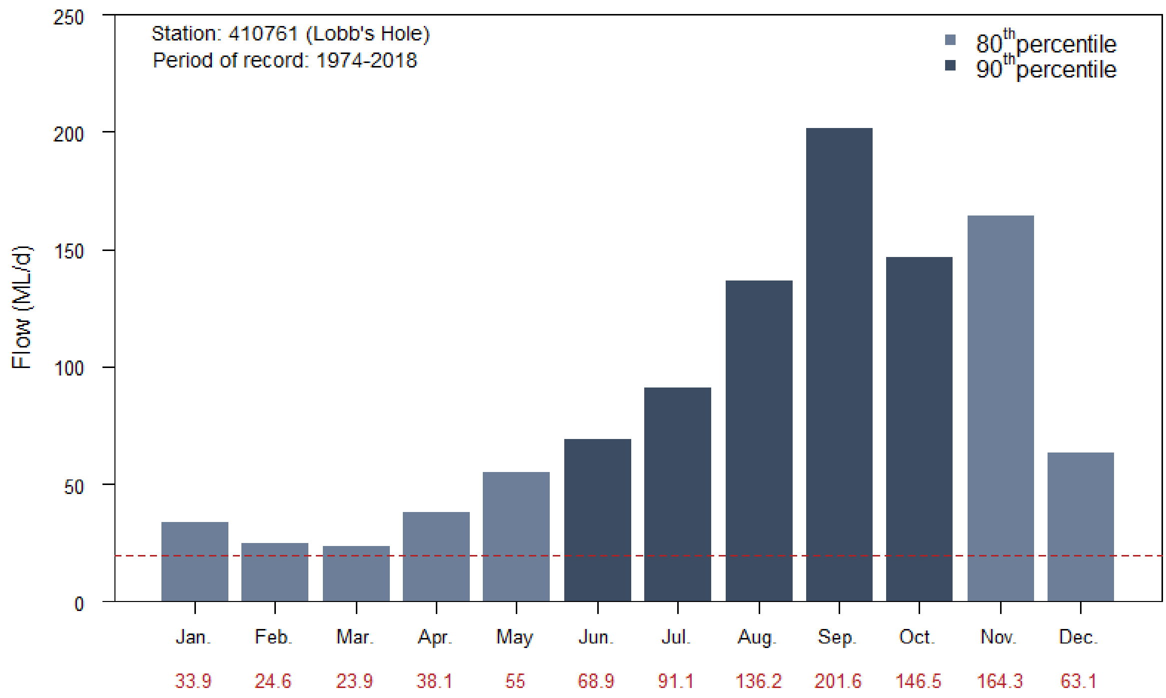


Figure 1-2. Environmental flow values for the operation of the M2G pipeline

Note: Flow data values to 31/05/2018. Monthly values in red are mega litres per day (ML/d) and are based on continuous daily flow data from the Lobb's Hole gauging station (410761) since its commencement of operation in 1974. Dashed line shows 20 ML/d.

1.2.4 Parts 1 & 2 – Murrumbidgee to Googong transfer pipeline (M2G)

The pumping system at Angle Crossing transfers water from the Murrumbidgee River through a 12 km underground pipeline into Burra Creek. The water is then to be transported a further 13 km by run-of-river flows into Googong Reservoir. Water abstraction from the Angle Crossing pump station will be dictated by Googong Reservoir's capacity and by 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 will be directed by the Operational Environmental Management Plan (Icon Water, 2017).

Murrumbidgee River

During periods of low flow (whether climate related or artificially induced), impacts upon aquatic environments can be measured using surrogate indices based on changes to macroinvertebrate communities such as changes in species richness, abundances and community structure. Such changes can result either directly through invertebrate drift, or indirectly through reductions in habitat diversity or flow conditions, which do not suit certain taxa.

Dewson *et al.*, (2007) reported that certain macroinvertebrate taxa are especially sensitive to reductions in flow and can be useful indicators in flow restoration assessments and assist in longer term management of flows in regulated river systems. It is possible that there will be changes to the aquatic ecosystem within the Murrumbidgee River as a result of M2G. Some of these effects include, but are not limited to:

- changes to water chemistry;
- changes to channel morphology;
- changes to velocity;
- changes to water depth.

All of these changes have potential knock-on effects to the biota within the river's ecosystem. The current monitoring program forms the basis of an Ecological Monitoring Program to satisfy the EIS and compliance commitments for the M2G Project.

Burra Creek

In light of the natural low flow conditions in Burra Creek compared to the nominal pumping rate of 100 ML/d, it is expected that the increased flow due to the discharge from the M2G pipeline may have several impacts on water quality, channel and bank geomorphology and the ecology of the system. Some beneficial ecological effects might occur in the reaches of Burra Creek between the discharge point (just upstream of Williamsdale Road) to the confluence of the Queanbeyan River.
These may include, but are not limited to:

- The main channel being more frequently used by fish species due to increased flow permanence and longitudinal connectivity between pools;
- Increased biodiversity in macroinvertebrate communities;
- A reduction in the extent of macrophyte encroachment in the Burra Creek main channel.

On the other hand, there is potential for the transfer of Murrumbidgee River water into Burra Creek to adversely affect the natural biodiversity within Burra Creek due to the different physico-chemical characteristics of water in each system (particularly with regards to EC). Potential impacts are highlighted in Table 1-1.

1.2.5 Part 3 – Murrumbidgee Pump Station (MPS)

The Murrumbidgee Pump Station (MPS) is located on the eastern side of the Murrumbidgee River, approximately 200m downstream of the confluence with the Cotter River. It is adjacent to the Cotter Pump Station, which can abstract up to 150 ML/d, contributing to the water supply for the ACT. New infrastructure has increased the abstraction amount from the Murrumbidgee River to 150 ML/d via the MPS. The upgraded infrastructure also provides a recirculating flow from the Murrumbidgee River to the base of the Enlarged Cotter Dam (ECD), providing environmental flows to the lower Cotter River below the dam. This project is referred to as the Murrumbidgee to Cotter (M2C) transfer. The MEMP project does not include monitoring related to the M2C transfer, but rather provides a characterisation of the Murrumbidgee River condition upstream and downstream of the MPS.

The upgraded pump station was commissioned in 2010. Pumping is dependent on demand, Licence requirements, and water quality. The framework for this program responds primarily to requirements of Icon Water's abstraction Licence.

The increase in abstraction at the MPS may place additional stress on the downstream river ecosystem. Originally part of the MEMP, the MPS component was removed following a review by Icon Water after the autumn 2013 reporting period. However, following the Jacobs (2014) review Component 3 has been re-established with sentinel monitoring of the Murrumbidgee River at the key upstream and downstream sites.

Table 1-1. Potential impacts to Burra Creek following Murrumbidgee River discharges

Property	Possible impact	Source	Comments based on data collected to date (2009-2018)
Water Quality	The inter-basin transfers (IBT) can bring adverse water quality conditions from the donor systems such as contaminants or micropollutants. The IBT of soft Murrumbidgee water into the harder water of Burra Creek may change the natural biodiversity within Burra Creek.	Davies *et al.* (1992); Martin and Rutlidge (2009); Zhuang (2016)	Based on the data collected following the short-term maintenance runs, there have been changes to several physico-chemical water quality parameters. The changes to these parameters are short lived and there has been no evidence of alterations to the indices of macroinvertebrate community composition and quality as a result. It is still unknown if this will be the case for prolonged periods of M2G operation or if there are likely to be cumulative impacts to these periodic changes in water quality. Turbidity increases with the first initial pulse following flow release. These are short-term changes only and there is no evidence to date to support the possible impacts.
	Changes in water temperature could result from the IBT and increased turbidity. This may affect plant growth, nutrient uptake and dissolved oxygen levels; and ultimately compromise the quality of fish habitat.	Martin and Rutlidge (2009)	The observed changes to the water temperature, turbidity and dissolved oxygen are only short term during the pumping schedule. Compromising fish habitat is not a concern in Burra Creek as the fish community is comprised of wholly introduced species (GHD, 2014a).
Ecology	Changes in macroinvertebrate communities and diversity through habitat alteration from sedimentation, changes to riparian vegetation, scouring of macrophytes and changes in biofilm production. Changes in macroinvertebrates are also expected with an increase of flow (e.g. increased abundances of flow dependant taxa).	Bunn and Arthington (2002); Ryder *et al.,* (2006)	The current M2G pumping regime has not continued for durations long enough to, nor at volumes large enough to result in significant macrophyte scouring, sediment movement or alter the community composition over and above what occurs naturally within the system.
	The rewetting of an intermittent stream channel is the trigger for a number of biochemical processes such as inundation of habitat, leaching of organic matter and bacterial respiration that, under certain conditions (e.g. timing, frequency, duration, organic material build up) can lead to hypoxia blackwater events and subsequent fish kills.	(Bond and Cottingham 2008).	To date we have no evidence of this occurring in the monitored reaches in Burra Creek.
	Potential risk of exotic species recruitment from IBT. This could displace native species in the catchment and pose a risk of the spread of disease.	Martin and Rutledge (2009); Davies *et al.* (1992); Zhuang (2016)	There has been no evidence of any new introduced species since the commencement of M2G operations, including fish species (GHD, 2015a). This is potentially due to the use of fish egg filters, which were installed during the construction phase of M2G.
	Exchange of water and dissolved material with the hyporheic zone and ground water influence the biota and chemistry of these layers, with near bed organisms shown to be sensitive to flow regime alteration. High flow can limit exchange and starve streambed of sediment. Infilling from fine sediment transport could threaten the quality of the hyporheic zone, which provides important habitat for macroinvertebrates in temporary streams.	Brunke and Gonser (1997); Hancock (2002); Jones *et al*., (2015)	The transport of fine sediment within the creek by the operation of M2G is minor compared to the sediment transport capabilities of the natural high flow events that occur in Burra Creek.
	Increased flow with improved longitudinal connectivity which will potentially provide fish with more breeding opportunities and range expansion, although this will be dependent on the flow regime.	Martin and Rutlidge (2009)	Water transfer has increased the longitudinal connectivity between the pools in Burra Creek. However, the short duration of the releases would be unlikely to facilitate breeding opportunities or range expansion by native fish species.
Bank Geomorphology	Bank failure from the initial construction phase and first releases. This could result in increased sedimentation, loss of riparian vegetation and increased erosion rates from bank instability. Increased sedimentation may also reduce benthic habitat complexity, which may result in a loss of benthic macroinvertebrate diversity and a potential loss of sensitive taxa.	GHD, 2015c	Natural events have a much larger impact potential upon the geomorphology than the pump maintenance releases from M2G. However, if the pumps are run for a prolonged period (greater than 1 week), this may have additional impact due to saturation of the creek embankment from continued elevated water levels.
Channel Geomorphology	Scouring of the river bed may result in a loss of emergent and submerged macrophyte species. This would result in a reduction of river bed stability and a change in macroinvertebrate diversity and dynamics.	Harrod (1964)	There has been no evidence of scouring directly related to commissioning flows over and above the scouring, which has been recorded following natural high flow events (GHD, 2015c). Ongoing vegetation monitoring is coinciding with seasonal biological sampling.
Riparian vegetation	Changes in the natural flow regime could potentially lead to change riparian ecosystem function, such as changes community structure, species composition and dominance of select species leading to a reduction in diversity. An increase in bare ground due to more frequent high flow events could also lead to an increase in opportunistic species and weed coverage and diversity, or encroachment of terrestrial species. Increases in flow level could result in changes to instream macrophyte cover and diversity.	Stromberg *et al.,* (2007); ALS, 2010; Tonkin *et al.,* (2018)	Current flows from the M2G pipeline are restricted to maintenance flows which are short in duration and infrequent. The current M2G flow regime does not pose a threat to fringing riparian vegetation or instream macrophytes due to short duration that the flow level is increased (GHD, 2014b).

1.3 Project Objectives

The Murrumbidgee Ecological Monitoring Program (MEMP) was set up by Icon Water to evaluate the potential impacts of water abstraction from the Murrumbidgee River at Angle Crossing and the Murrumbidgee Pump Station (Components 1 & 3) and the subsequent changes that might occur in Burra Creek (Component 2).

Increasing water abstractions from the Murrumbidgee River could have several impacts on water quality, riparian vegetation, riverine geomorphology and the aquatic ecology of the system. Some beneficial ecological effects could be expected in the reaches downstream of the discharge point in Burra Creek under the proposed flow release regime, including increased habitat availability for native fish species. The increased flow in those locations is also likely to favour flow-dependent macroinvertebrates and improve surface water quality.

The aim of the sentinel monitoring presented in this report is 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 projects standby phase.

These potential impacts have been assessed by the relevant Government authorities through submission of Environmental Impact Statements (EIS) or similar assessments. One of the components of the EIS is to undertake an ecological monitoring program, on which this program is based.

This monitoring program is designed to be adaptive. This has been demonstrated through the adjustments to the program following the autumn 2013 reporting period and also the project review completed by Jacobs (2014). The information derived from this program will also support Icon Waters' adaptive management approach to water abstraction and environmental flow provision in the ACT.

1.4 The Upper Murrumbidgee River

The Murrumbidgee River flows for 1,600 km from its headwaters in the Snowy Mountains to its junction with the Murray River. The catchment area to Angle Crossing is 5,096 km^2. As part of the Snowy Mountains Scheme, the headwaters of the Murrumbidgee River are constrained by the 252 GL Tantangara Dam, which was completed in 1961. The reservoir collects water and diverts it outside the Murrumbidgee catchment to Lake Eucumbene. This has reduced base flows and the frequency and duration of floods in the Murrumbidgee River downstream. The Murrumbidgee River is impounded again at Burrinjuck Dam, after the river passes through the ACT. This region 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 the 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 contributing urbanised tributary flowing into the Murrumbidgee River is Tuggeranong Creek, which enters the Murrumbidgee River downstream of Point Hut crossing. Annual rainfall in the Upper Murrumbidgee River catchment ranges from greater than 1400 mm in the mountains, to an average annual rainfall of 675 mm at Lobb's Hole (570985).

Prior to spring 2010, drought was the most significant impact on catchment quality within the upper Murrumbidgee catchments. During this period, more than 80% of catchments had been drought-affected since late 2002. Some of the effects of this were drought-induced 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 throughout the following twelve months, resulting in an upward trend in the mean monthly base flows (Figure 1-3). More recently, during the period between November 2012 and May 2013, there was a decline in base flows in the Murrumbidgee River following a particularly dry summer and autumn. The smoother line indicates that while flows remained stable during 2014-15, since 2016 base flows in the Murrumbidgee River have generally declined and continue to decline as of 31st May 2018 (Figure 1-3).

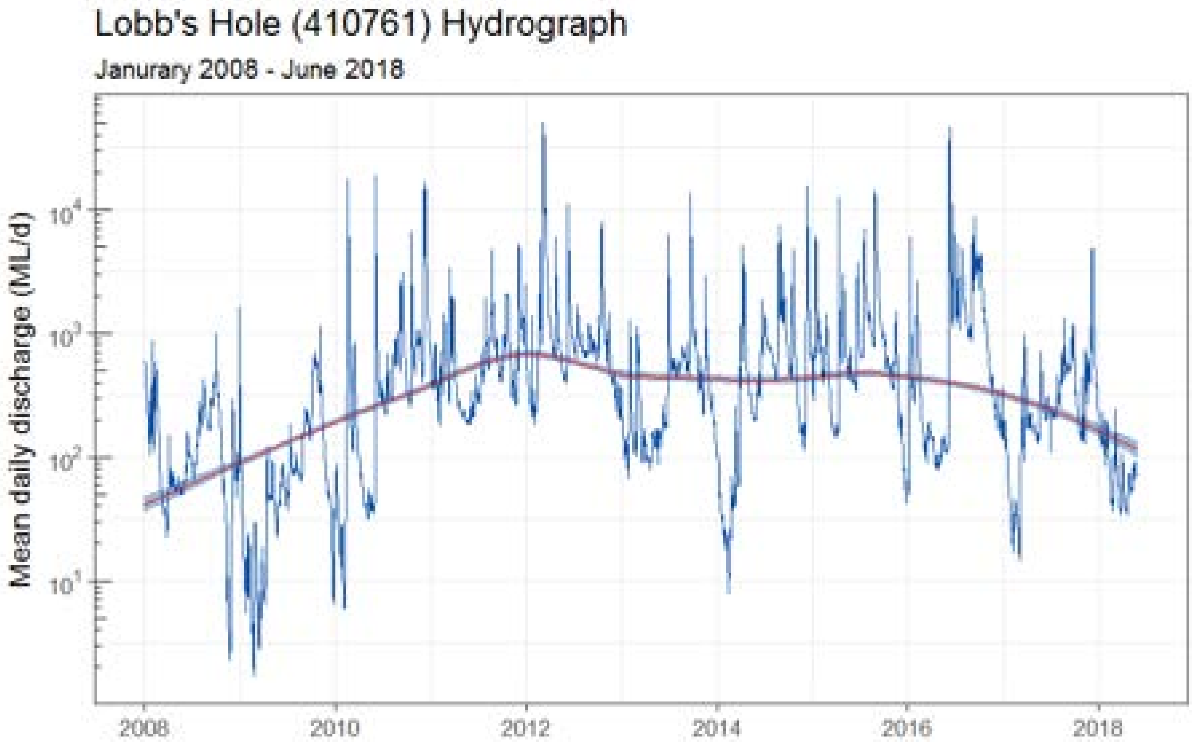


Figure 1-3. Hydrograph of the Murrumbidgee River at Lobb's Hole (410761) from 2008 to May 2018

Note: The red line is a locally weighted smoother (LOESS) trend line with a smoothing coefficient of 0.6.

1.5 Burra Creek

Burra Creek is a small intermittent stream, which flows north to north-east along the western edge of the Tinderry Range into Googong Reservoir. The majority of its 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.

Flow conditions have varied considerably since the inception of the MEMP in late 2008 (Figure 1-4). 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 there were a few rainfall events and this pattern continued throughout most of the year resulting in an upward trend of daily mean flows, which reached 23.4 ML/d. 2011 was a moderately dry year and mean flows fell back to less than 5 ML/d until March 2012, which saw another period of large rainfall events. These rainfall events resulted in another upward trend in average flows until early spring 2012 (Figure 1-4). Summer in 2018 was the driest since 2010 (Figure 1-4). Summer flows are an ecologically important consideration because summer is potentially a particularly stressful period for macroinvertebrates, especially in intermittent streams and these flows have the potential to strongly influence the dynamics and structure of macroinvertebrate communities.

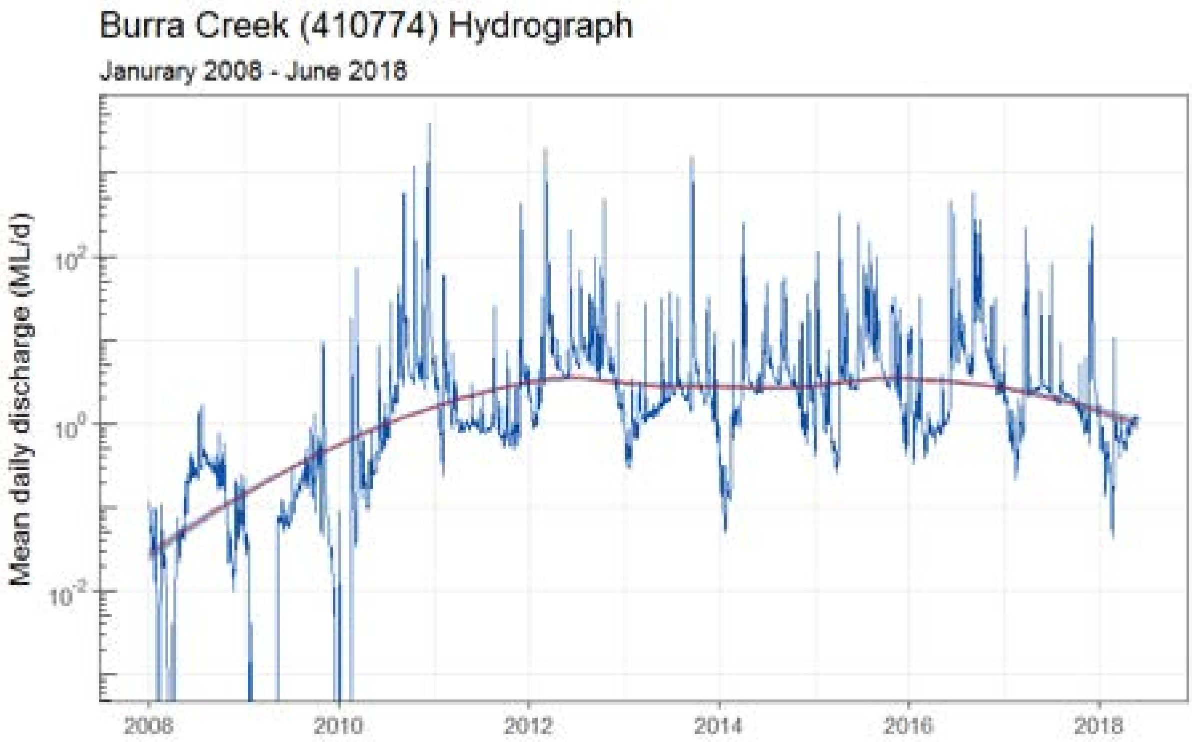


Figure 1-4. Hydrograph of Burra Creek at the Burra Road weir (410774) from 2009 to May 2018

Note: The red line is locally weighted smoother (LOESS) trend line with a smoothing function coefficient of 0.6.

1.6 Scope of works

Part 1 – 3: Angle Crossing, Burra Creek & Murrumbidgee Pump Station

The current ecological health of the monitoring locations was estimated using AUSRIVAS protocols for macroinvertebrate community data, combined with a suite of commonly used biological metrics and descriptors of community composition. The scope of this report is to convey the results from the autumn 2018 sentinel monitoring. Specifically, as outlined in the MEMP proposal to Icon Water (GHD, 2015b) 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];
- Riffle and edge samples assessed through the appropriate AUSRIVAS model;
- The use of photogrammetry to monitor periphyton[3], vegetation and geomorphology at the relevant sites;
- *In-situ* water quality measurements; and
- Water quality grab samples analysed for nutrients in the Australian Laboratory Services (ALS) Canberra NATA accredited laboratory.

The monitoring elements for each component of the revised monitoring program are outlined in Table 1-2.

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.

3 Not required for sentinel monitoring but it was felt that given the extra effort was negligible in the field, that it would be a useful inclusion to assist in the interpretation of macroinvertebrate data and to continue the data record.

Table 1-2. General suite of monitoring elements and monitoring scenario to which they will be undertaken

Monitoring element	Provider	M2G sentinel	M2G impact	MPS sentinel	MPS impact
Water Quality (online)	Icon Water	✓	✓	✓	✓
Water Quality (grab samples)	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	✓	✓	✓	✓

2. Methodology

2.1 Study sites

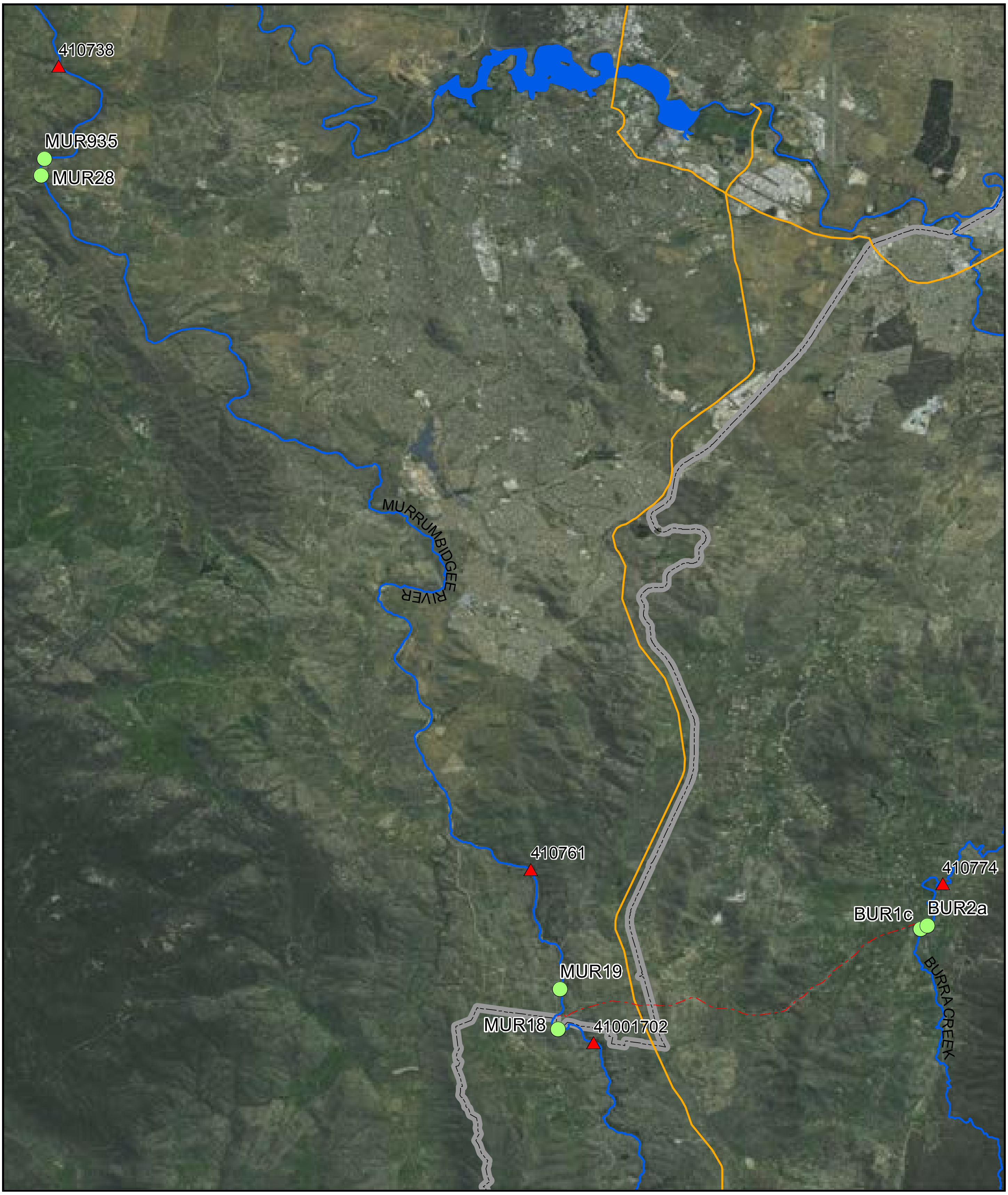
One site upstream and one site downstream of the respective infrastructure formed the basis of the sentinel monitoring of the MEMP. These sites are a subset of existing sites, which were previously sampled as part of the original MEMP program (2009-2014). These sites were initially chosen based on several criteria, which included:

- Safe access and approval from land owners;
- Sites have representative habitats (i.e. riffle / pool sequences). If both habitats were not present then 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.

The number of sites to be sampled during sentinel monitoring was specified in the MEMP project review (Jacobs, 2014). The sentinel monitoring component therefore consists of six sites (details of these sites are given in Table 2-1) and locations are shown in Figure 2-1. Macroinvertebrate and water quality sampling, and photogrammetry for periphyton, vegetation and geomorphology were conducted at the relevant sites on the Murrumbidgee River and Burra Creek. Aquatic macroinvertebrates were sampled from two habitats (riffle and pool edges) and organisms identified to genus level (where practical) to characterise each site in terms of river health and community composition.

Table 2-1. Sampling locations and details

Component of the MEMP		Site Code	Location	Alt. (m)	Landuse	Latitude	Longitude
PART 1	Angle Crossing	MUR18	U/S Angle Crossing	608	Grazing	**-35.587542**	**149.109902**
		MUR19	D/S Angle Crossing	608	Grazing / Recreation	**-35.583027**	**149.109486**
PART 2	Burra Creek	BUR1c	Upstream Williamsdale Road	762	Grazing / residential	**-35.556511**	**149.221238**
		BUR2a	Downstream Williamsdale Road	760	Grazing	**-35.554345**	**149.224477**
PART 3	Murrumbidgee Pump Station	MUR28	Upstream Cotter River Confluence	468	Grazing	**-35.324382**	**148.950381**
		MUR935	Casuarina Sands	471	Grazing	**-35.319483**	**184.951667**



LEGEND

- Sentinel Monitoring Sites
- Gauging Stations
- M2G Pipeline
- Waterway
- Major Road
- Lake Burley Griffin
- ACT Border

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

1:180,000 @ A4

0 0.75 1.5 3 4.5 6

Kilometres

Horizontal Datum: WGS 1984
Grid: GCS WGS 1984

N

Icon Water
Murrumbidgee Ecological Monitoring Program

Sentinel Monitoring Locations

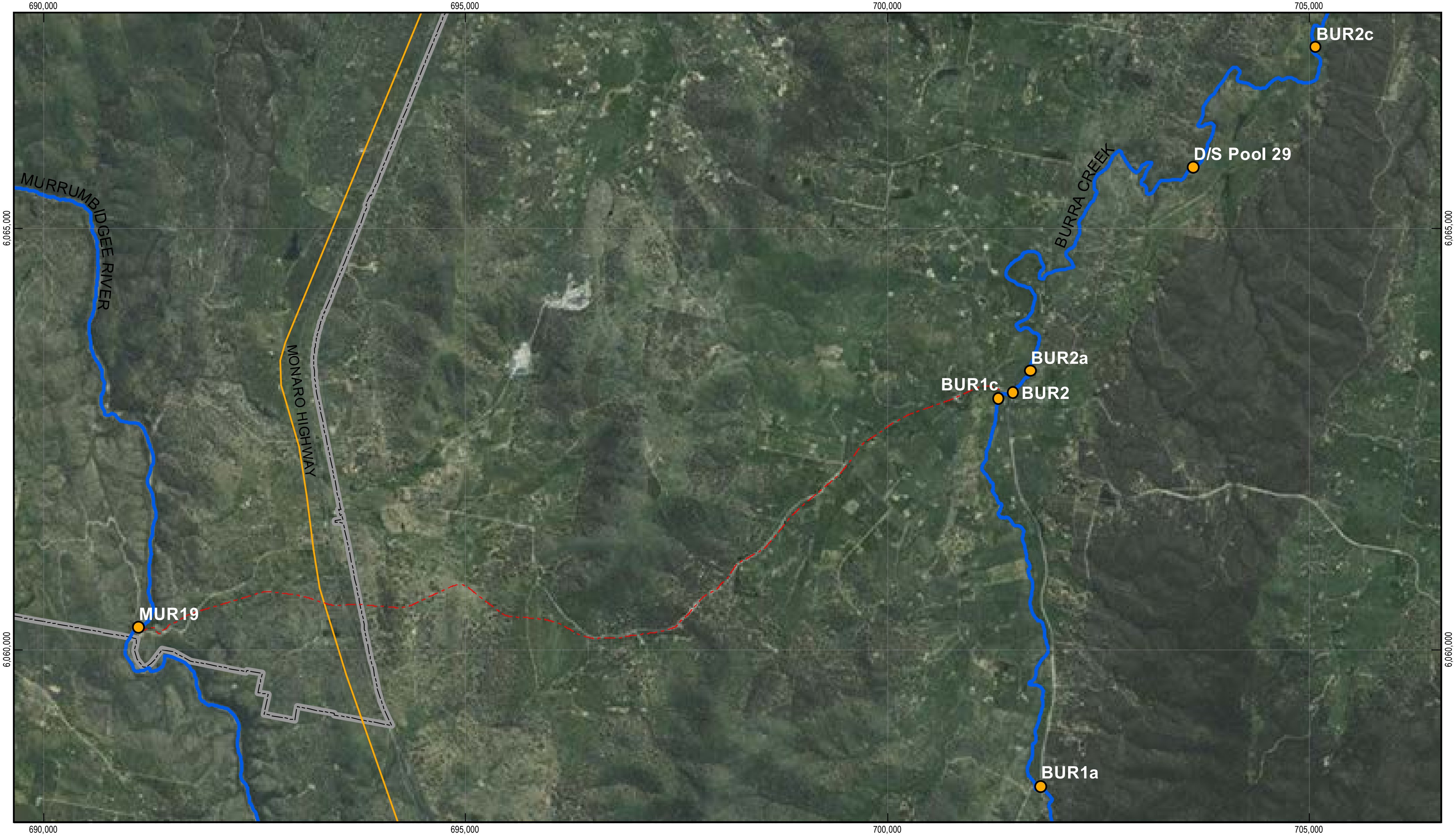
Job Number	23-15531
Revision	A
Date	03 Aug 2015

Figure 2-1

G:\23\15531\GIS\Maps\Working\MEMP Sentinel Sites.mxd

Level 7, 16 Marcus Clarke Street Canberra ACT 2601 Australia T 61 2 6113 3200 F 61 2 6113 3299 E cbrmail@ghd.com W www.ghd.com

Data source: GHD, MEMP, Version A, 28/05/2015. Created by:jpcox



1:60,000 @ A4

0 0.25 0.5 1 1.5 2

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- Site
- Waterway
- M2G Pipeline
- Major Road
- ACT Border

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and

Icon Water
Murrumbidgee Ecological Monitoring Program

Job Number 23-15531
Revision A
Date 22 Dec 2015

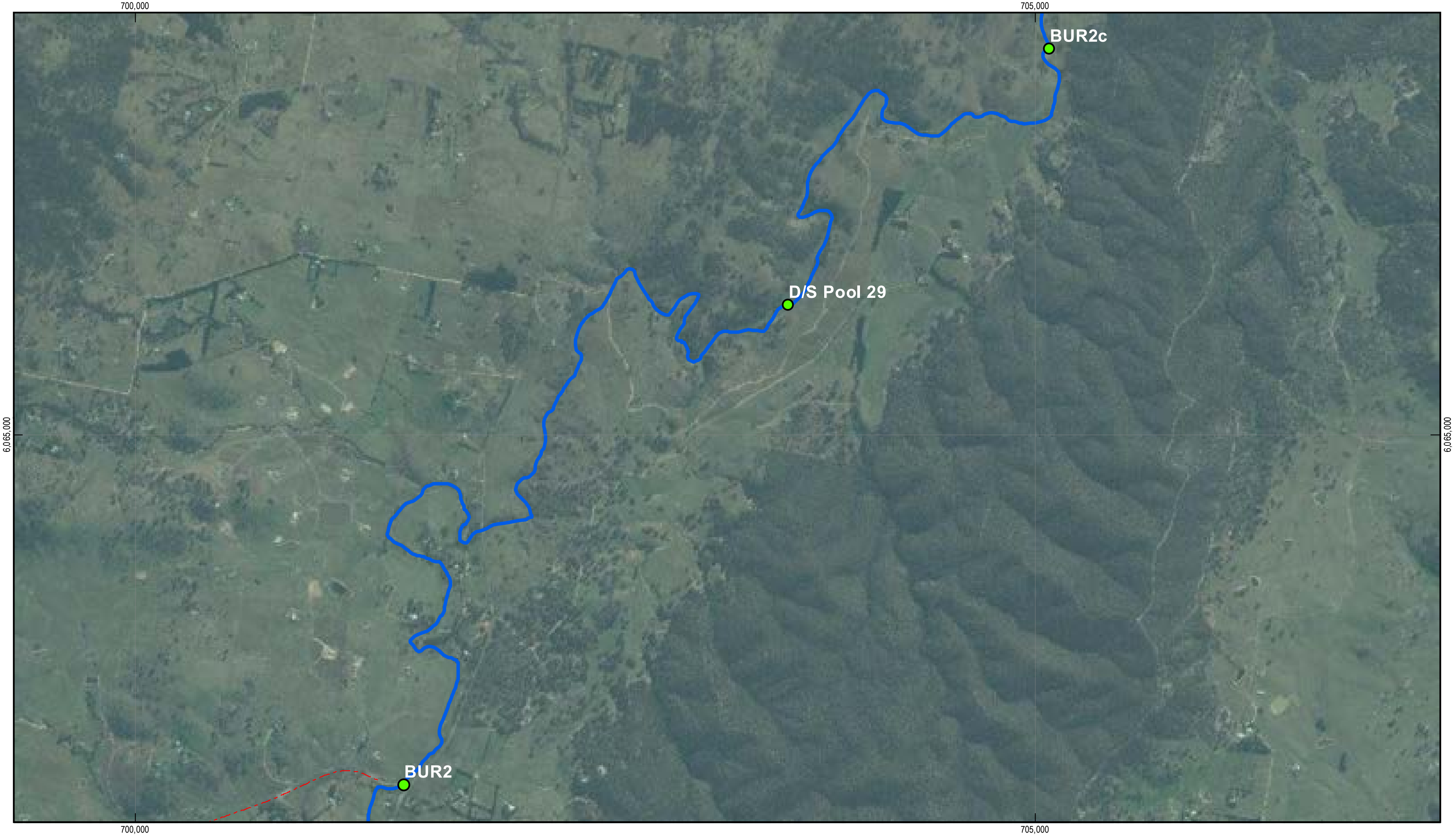
Sentinel Monitoring
Geomorphology Sites

Figure 2-2

G:\23\15531\GIS\Maps\Working\Geomorphology Sites.mxd

Level 7, 16 Marcus Clarke Street Canberra ACT 2601 Australia T 61 2 6113 3200 F 61 2 6113 3299 E cbrmail@ghd.com W www.ghd.com

Data source: GHD, MEMP. Created by:jpcox



1:60,000 @ A4

0 0.1 0.2 0.4 0.6 0.8

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

Site

Burra Creek

M2G Pipeline

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and

Icon Water
Murrumbidgee Ecological Monitoring Program

Job Number | 23-15531
Revision | A
Date | 22 Dec 2015

Sentinel Monitoring
Riparian Vegetation Sites

Figure 2-3

G:\23\15531\GIS\Maps\Working\Vegetation Sites.mxd

Level 7, 16 Marcus Clarke Street Canberra ACT 2601 Australia T 61 2 6113 3200 F 61 2 6113 3299 E cbrmail@ghd.com W www.ghd.com

Data source: GHD, MEMP. Created by:jpcox

2.2 Hydrology and rainfall

River flows and rainfall for the sampling period were recorded at ALS maintained gauging stations located: upstream of Angle Crossing (41001702); at Lobb's Hole (downstream of Angle Crossing: 410761); Mt. MacDonald (downstream of the MPS; 410738) and Burra Creek (at Burra Creek weir: 410774). A list of parameters measured at each station is given in Table 2-2. 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.

Table 2-2. 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, Temp, Turb, Rainfall	-35.5914	149.1204	Angle Crossing
410761	Murrumbidgee River @ Lobb's Hole (D/S of Angle Crossing)	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	-35.5398	149.1001	Angle Crossing / Murrumbidgee Pump Station
410738	Murrumbidgee River @ Mt. MacDonald	WL, Q	-35.2916	148.9552	Murrumbidgee Pump Station
410774	Burra Creek D/S road bridge	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	-35.5425	149.2279	Burra Creek

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

2.3 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).

Grab samples were collected at all sites in accordance with AUSRIVAS protocols (Nichols, *et al.* 2000), and submitted to ALS for analysis. Samples were analysed for alkalinity, total NO_x, TP, TN, total iron and total manganese.

2.3.1 Data analysis

Water quality parameters were examined for compliance with ANZECC water guidelines for healthy ecosystems in upland streams (ANZECC and ARMCANZ, 2000). Summary statistics were calculated for the parameters collected at the gauging stations and time series plots were created to assist with the interpretation.

2.4 Macroinvertebrate monitoring

Rapid bio-assessment (RBA) methods (i.e. AUSRIVAS) will occupy the main component of the sentinel monitoring program. The Australian Rivers Assessment System (AUSRIVAS) is a rapid, standard method for assessing the ecological health of freshwaters through biological monitoring and habitat assessment (Nichols *et al.*, 2000). This assessment will provide an overview of the system that will indicate on a broad scale whether there are notable changes based on the ratio of the number of observed to expected taxa which are recorded at each site. The observed / expected ratio is an indication of the current ecological condition at a given site. The data will be used for comparison with data collected during operational periods (i.e. during impact monitoring) in the Murrumbidgee River and Burra Creek, so relative seasonal and annual changes over time can be monitored against any potential changes directly resulting from the Icon Water projects.

At each site, macroinvertebrates were sampled in the riffle and edge habitats where available. 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.

Riffle and edge habitats were sampled for macroinvertebrates using the ACT AUSRIVAS protocols outlined in Nichols *et al*. (2000). The sampling nets and all other associated equipment were washed thoroughly between habitats, sites and sampling events to remove any macroinvertebrates retained on them. A single sample was collected from each of the two habitats (edge and riffle - where available) at all sites. The bulk 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. The ACT AUSRIVAS field sheets were also completed at each site.

Processing of the aquatic macroinvertebrate bulk samples followed the ACT AUSRIVAS protocols (Nichols *et al*., 2000). In the laboratory, each preserved macroinvertebrate sample was placed in a sub-sampler, comprising of 100 (10 X 10) cells (Marchant, 1989). The sub-sampler was then agitated to evenly distribute the sample, and the contents of randomly selected cells were removed and examined under a dissecting microscope until a minimum of 200 animals were counted. All animals within the selected cells were identified.

In order to preserve the long term integrity of the data record within the experimental design, laboratory processing of each sample was repeated 3 times to align with the data collected between 2009-2014 which will allow the data and the historical data to be amalgamated with limited disruption to the project methodology.

For similar reasons, 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. To enable comparison with previous sample seasons where genus level data was utilised, Icon Water has continued the use of this method, based on recommendations from GHD.

2.4.1 Data analysis

The broader, less intensive nature of the sentinel monitoring component (Jacobs, 2014) means that all formal hypothesis testing, is either not required or has limited power due to the low sample sizes. In light of this, the statistical component of this report is presented in the form of descriptive methods including univariate indices and metrics.

The univariate techniques performed on the macroinvertebrate data include:

- Taxa Richness and EPT taxa index (richness);
- SIGNAL-2 Biotic Index;
- ACT AUSRIVAS O/E scores and Bandings.

These metrics are often used in a lines-of-evidence approach to river assessments and have solid foundations in biomonitoring. Each index is used to assess slightly different aspects of river health. SIGNAL-2 for example usually relates to changes in water quality while AUSRIVAS is mainly an indicator of habitat changes. Taxa richness is an indicator of changes in composition and needs to be assessed carefully because it does not indicate where in the community changes such as increases or losses of sensitive taxa occur. EPT is used to do just this, which is why it is used together with taxa richness since both provide complimentary information.

Taxa Richness

The number of taxa (taxa richness) was counted for each site and richness of pollution-sensitive taxa (Ephemeroptera, Plecoptera and Trichoptera - EPT) were examined at family and genus levels. Taxa richness was calculated as a means of assessing macroinvertebrate diversity. In assessing the taxonomic richness of a site, it is important to keep in mind that high taxa richness scores may, though not always, indicate better ecological condition at a given location. 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.

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 higher values indicating higher community sensitivity. These grades have been improved 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

In addition to assessing the composition and calculating biometrics based on the macroinvertebrate data, river health assessments based on the ACT AUSRIVAS autumn riffle and edge models were conducted. AUSRIVAS is a prediction system that uses macroinvertebrate communities to assess the biological health of rivers and streams. Specifically, the model uses site-specific information to predict the macroinvertebrate fauna expected (E) to be present in the absence of environmental stressors. The expected fauna from sites with similar sets of predictor variables (physical and chemical characteristics which cannot be influenced by human activities, e.g. altitude) are then compared to the observed fauna (O) and the ratio derived (O/E) is used to indicate the extent of any impact. The ratio derived from this analysis is compiled into Band-widths (i.e. X, A-D; Table 2-3) which are used to gauge the overall health of that particular site (Coysh *et al*., 2000). Data are presented using the AUSRIVAS O/E 50 ratio (Observed/Expected score for taxa with a >50% probability of occurrence) and the previously mentioned rating Band-widths or Bands (Table 2-3).

The site assessments are based on the results from both the riffle and edge samples. Using a precautionary approach as recommended by Coysh *et al.* (2000), the overall site condition was based on the farthest Band 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). In cases where the Bands deviate significantly between habitat (e.g. D – A) then an overall site-level assessment was avoided due to the unreliability of the results, leading to no reliable assessment.

The use of the O/E 50 scores is standard in AUSRIVAS. Taxa that are not predicted to occur more than 50% of the time are not included in the O/E scores produced by the model. This could potentially limit the inclusion of rare and sensitive taxa and might also reduce the ability of the model to detect any changes in macroinvertebrate community composition over time (Cao*, et al*., 2001).

Table 2-3. AUSRIVAS Band widths and interpretations for the ACT autumn riffle and edge habitats

Band	RIFFLE O/E Band width	EDGE O/E Band width	Explanation
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.

2.4.2 Quality control

A number of Quality Control procedures were undertaken during the identification phase of this program including:

- Organisms that were heavily damaged were not selected during sorting. To overcome losses associated with damage to intact organisms during sample handling, attempts were made to obtain significantly more than 200 organisms;
- Identification was performed by qualified and experienced aquatic biologists 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 and these QA/QC results are found in Appendix A;
- Very small, immature, damaged animals or pupae that could not be positively identified were not included in the dataset.

All procedures were performed by AUSRIVAS accredited staff.

2.5 Photogrammetry (periphyton, geomorphology and vegetation)

Photogrammetry is introduced in this component of the MEMP as a means to monitor potential changes in response to the full pumping operation of M2G and MPS over and above those occurring naturally.

Photogrammetry is a cheap and robust alternative to quantitative techniques (O'Connor and Bond, 2007). Using this method, photo points are 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. Photo points have been established at all of the existing MEMP sites.

The resulting photographs provide a robust and valuable resource to help understand the temporal dynamics of the system; and provide a good visual reference of habitat in relation to the qualitative macroinvertebrates results as a measure of river health. This method will be used to monitor periphyton, vegetation and geomorphology at the relevant sites as listed in Table 2-4.

Table 2-4. Locations of photogrammetry for each assessment type and number of photo points

Site	Periphyton	Vegetation	Geomorphology
Burra Creek			
BUR1c	✓		2 Photo Points
BUR2a	✓		4 Photo Points
BUR1a			3 Photo Points
BUR2		4 Photo Points	4 Photo Points
BUR2c		4 Photo Points	4 Photo Points
D/S Pool 29		3 Photo Points	3 Photo Points
Murrumbidgee River			
MUR18	✓		
MUR19	✓		5 Photo Points
MUR28	✓		
MUR935	✓		

Note: Ticks indicate sites at which periphyton monitoring occurs.

2.5.1 Periphyton

Representative photographs were taken at each macroinvertebrate site of the substrate using a 1m x 1m quadrat for scale (Table 2-4). These photographs were considered to be representative of the habitat and site. Quantitative assessments of the proportion of cover were recorded using the ACT AUSRIVAS field sheet methodology (Nichols, *et al.*, 2000).

2.5.2 Vegetation

Photographs were taken at a number (site dependent) of existing photo points to record the current extent of riparian and instream vegetation at relevant sites (Table 2-4). Three photos were taken at each point, one facing upstream, one facing downstream and another directly across the channel. GPS co-ordinates have been recorded for all photo points, while some sites also have survey pegs inserted to assist in locating the exact location. Sites were visited in 2017, as vegetation photo points are to be visited every 2 years, as per the long-term review by Jacobs (2014). These will be revisited in 2019, when photographs will be taken again and field notes recorded.

2.5.3 Geomorphology

Photographs were taken at each of the geomorphology sites (Table 2-4). Geomorphological features of interest have already been recorded (GHD, 2015c) and this report, represents a continuation of the methods that have already been used in monitoring geomorphology in the context of the MEMP.

To capture changes in the morphology as effectively as possible, the 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 facing 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. Sites were visited in 2017, as vegetation photo points are to be visited every 2 years, as per the long-term review by Jacobs (2014). These will be revisited in 2019, when photographs will be taken again and field notes recorded.

2.5.4 Photogrammetry reporting

The monitoring and reporting schedules of the photogrammetry and macroinvertebrate sentinel monitoring are not synchronised. Photogrammetry is conducted every two years, whereas the macroinvertebrate sentinel monitoring is scheduled for every three years, shown in Table 2-5, meaning that the reporting schedules are also not synchronised. To that end, this report presents the photograph chronology from autumn 2015 to spring 2017 and discusses any findings from these records.

Table 2-5 Monitoring schedule of the photogrammetry and sentinel, macroinvertebrate monitoring

Component	A15	S15	A16	S16	A17	S17	A18	S18
Vegetation and geomorphology	✓	✓			✓	✓		
Macroinvertebrates	✓	✓					✓	Scheduled

2.6 Licences and permits

All sampling was carried out with current scientific research permits under section 37 of the Fisheries Management Act 1994 (permit number P01/0081(C)).

All GHD aquatic ecology field staff hold current ACT and NSW AUSRIVAS accreditation.

3. Angle Crossing

3.1 Summary of sampling and river conditions

Sampling of the Angle Crossing sites was conducted on the 3rd May 2018. The weather on the day was fine and the maximum temperature reached over 24°C (Canberra Airport (BoM, 2018)). River flow in the Murrumbidgee River was low and the mean daily flow on the day was approximately 55 ML/d at the Lobb's Hole gauging station (410761). A single riffle and a single edge sample were collected at both the upstream and downstream sites (MUR18 and MUR19 respectively). Site photographs are presented in Plate 3-1. Submerged macrophyte cover was high at both sites, but particularly at MUR19, where the dominant macrophyte species was *Myriophyllum* sp. (watermilfoil); small patches of filamentous algae were also present at MUR19. Site summaries are presented in Appendix B and general habitat data is provided in Appendix C.

MUR18: Looking upstream (left) and downstream (right)

MUR19: Looking upstream (left) and downstream (right)

Plate 3-1. Photographs of the Angle Crossing monitoring sites at the time of sampling – autumn 2018

3.2 Hydrology and rainfall

Total rainfall in autumn was 102.4 mm, which was less than half of that which fell in autumn 2015 (231.9mm). April was a particularly dry month, when only 8.2mm was recorded, making it the driest April since 2004 (2.6mm).

Full Rainfall and flow summaries for upstream and downstream of Angle Crossing in autumn 2018 are presented in Figure 3-1 and Table 3-1.

River flow during autumn was characterised by long periods of low base flows (typically below 50ML/d), and two small rainfall events in March; the largest of these peaked at just 258 ML/d (Figure 3-2). During the same period in 2015, the autumn mean flow at Lobb's Hole was 850 ML/d compared to 67.8 ML/d for the 2018 period.

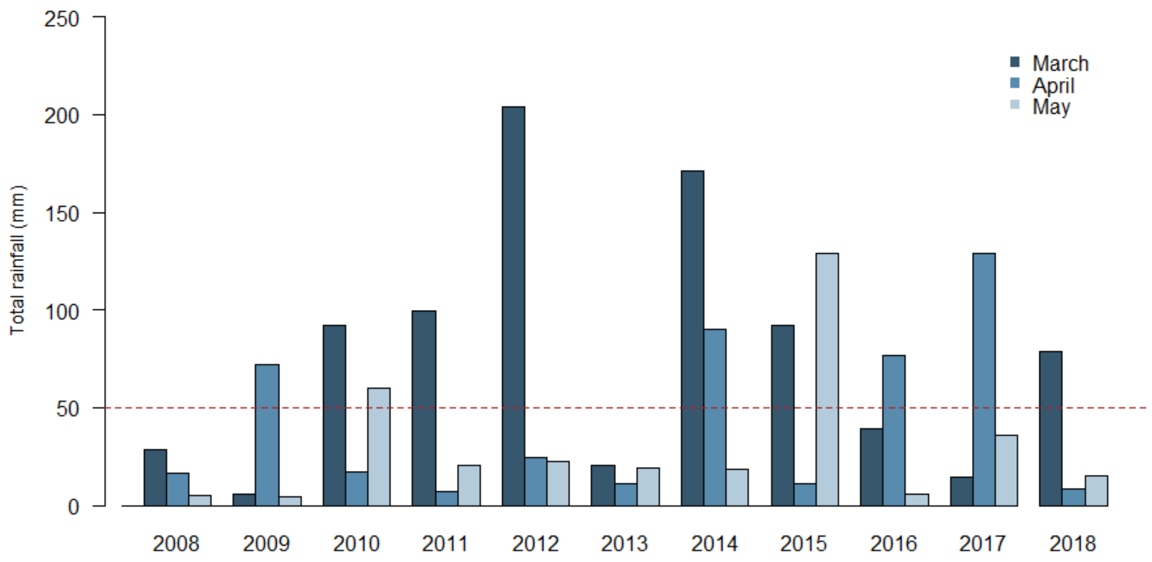


Figure 3-1. Annual comparison of autumn rainfall (mm) recorded at Lobb's Hole (570985)

Note: Red dotted line and text shows the mean autumn rainfall for (2008-2018) (49.8mm)

Table 3-1. Autumn rainfall and flow summaries, upstream and downstream of Angle Crossing

	Upstream Angle Crossing (41001702)		Lobb's Hole (410761)	
	Rainfall Total (mm)	Mean Flow (ML/d)	Rainfall Total (mm)	Mean Flow (ML/d)
March	55.8	81.5	79.0	81.3
April	12.2	47.3	8.2	53.5
May	12.6	66.3	15.2	67.6
Autumn (mean)	80.6 (26.8)	65.0	102.4 (34.1)	67.8

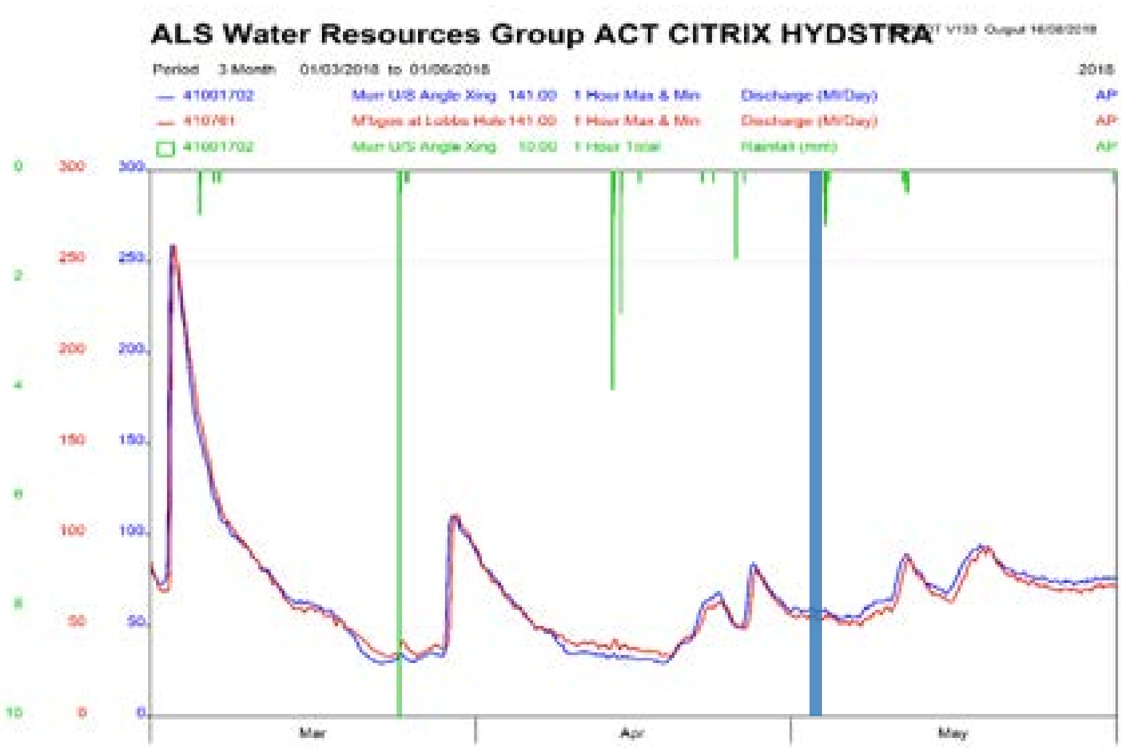


Figure 3-2. Autumn 2018 hydrograph of the Murrumbidgee River upstream (41004102) and downstream (410761) of Angle Crossing

Note: Sampling day highlighted by light blue shading.

3.3 Water quality

3.3.1 Grab samples and *in-situ* parameters

In-situ water quality parameters and grab sample results are presented in Table 3-2. Total nitrogen at MUR19 and Total Phosphorus at MUR18 and MUR19 was the only parameters to exceed the ANZECC & ARMCANZ (2000) guidelines, however these values are typical of these section of the Murrumbidgee River.

3.3.2 Continuous water quality monitoring

The continuous water quality monitoring from Lobb's Hole (410761) and upstream Angle Crossing (41001702) are presented in Figure 3-3 and Figure 3-4 respectively. Turbidity at Lobb's Hole and upstream of Angle Crossing were relatively consistent during autumn. There was a spike in early March at Lobb's Hole, which was in response to the small rainfall event. There were no exceedances in turbidity at either location during autumn. pH was typically above the upper ANZECC value of 8.0 during autumn, with 62% of the daily mean values in exceedance of pH 8.0. There were no exceedances in electrical conductivity at either location. Dissolved oxygen was below the 90% saturation 50% of the time at the upstream site (based on daily means) and only 9% of the time at Lobb's Hole, which may be due to the location of the probes at either site because there was nothing observed on site which may have caused these differences.

Table 3-2. *In-situ* water quality results from Angle Crossing during autumn 2018

	Site	Date	Time	Temp. (°C)	EC (µs/cm) (30-350)	Turbidity (NTU) (2-25)	pH (6.5-8)	D.O.(% Sat.) (90-110)	D.O. (mg/L)	Alkalinity (mg/L)	NO_x (mg/L) (0.015)	TP (mg/L) (0.02)	TN (mg/L) (0.25)	Total Iron (mg/L)	Total Manganese (mg/L) (1.9)
Upstream	MUR18	3/5/18	9:50	13.0	130.5	6.38	7.84	96.2	9.52	74	<0.05	0.06	0.05	0.19	0.055
Downstream	MUR19	3/5/18	10:45	12.5	128.9	4.45	7.76	98.0	9.77	79	<0.05	0.03	0.30	0.50	0.100

Note: ANZECC and ARMCANZ (2000) guidelines are in yellow parentheses, yellow cells indicate values outside of the guidelines; guideline value for Total Manganese is the 95% species level protection for slightly-moderately disturbed systems.

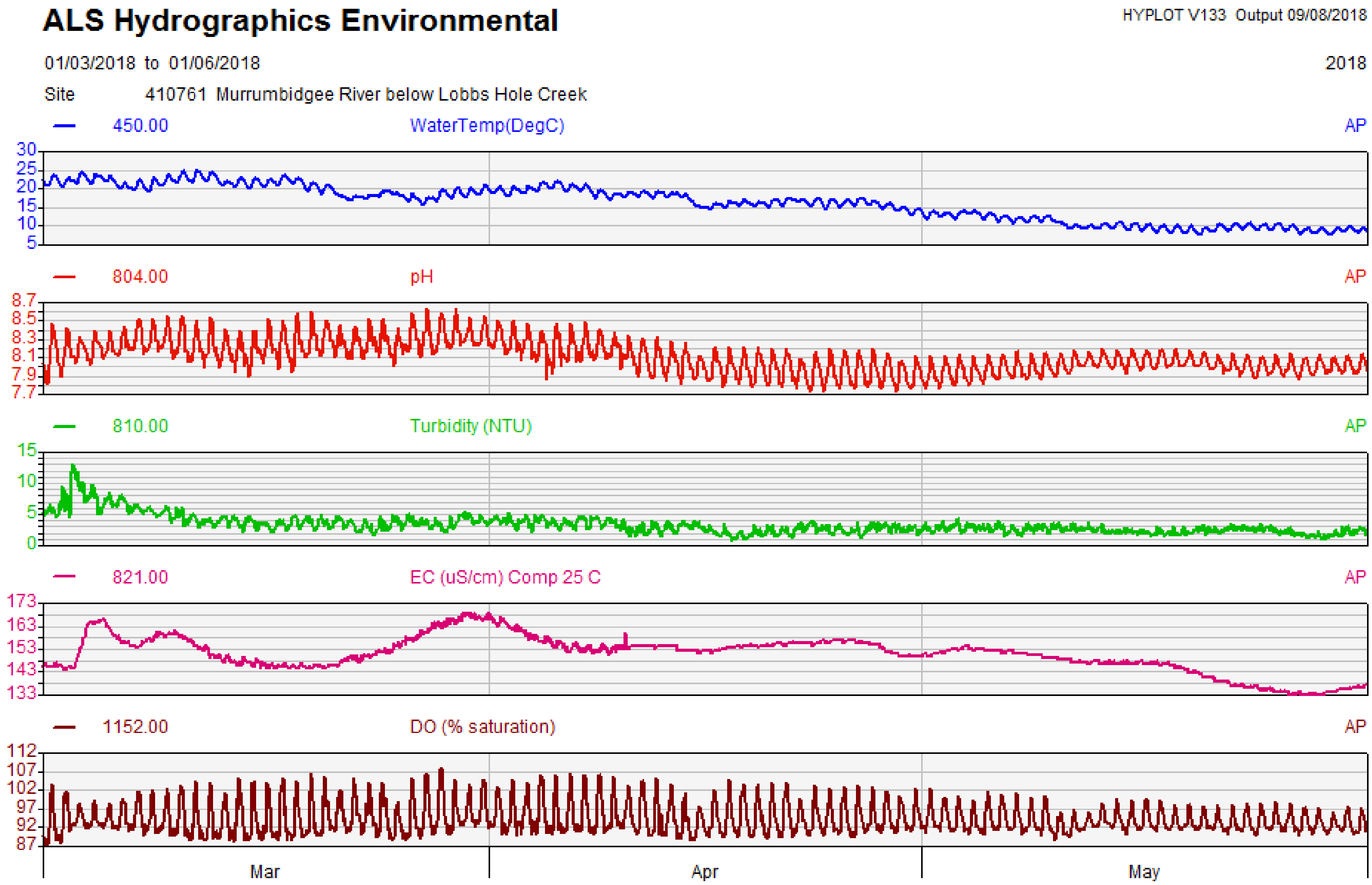


Figure 3-3. Continuous water quality records from Lobb's Hole (410761) for autumn 2018

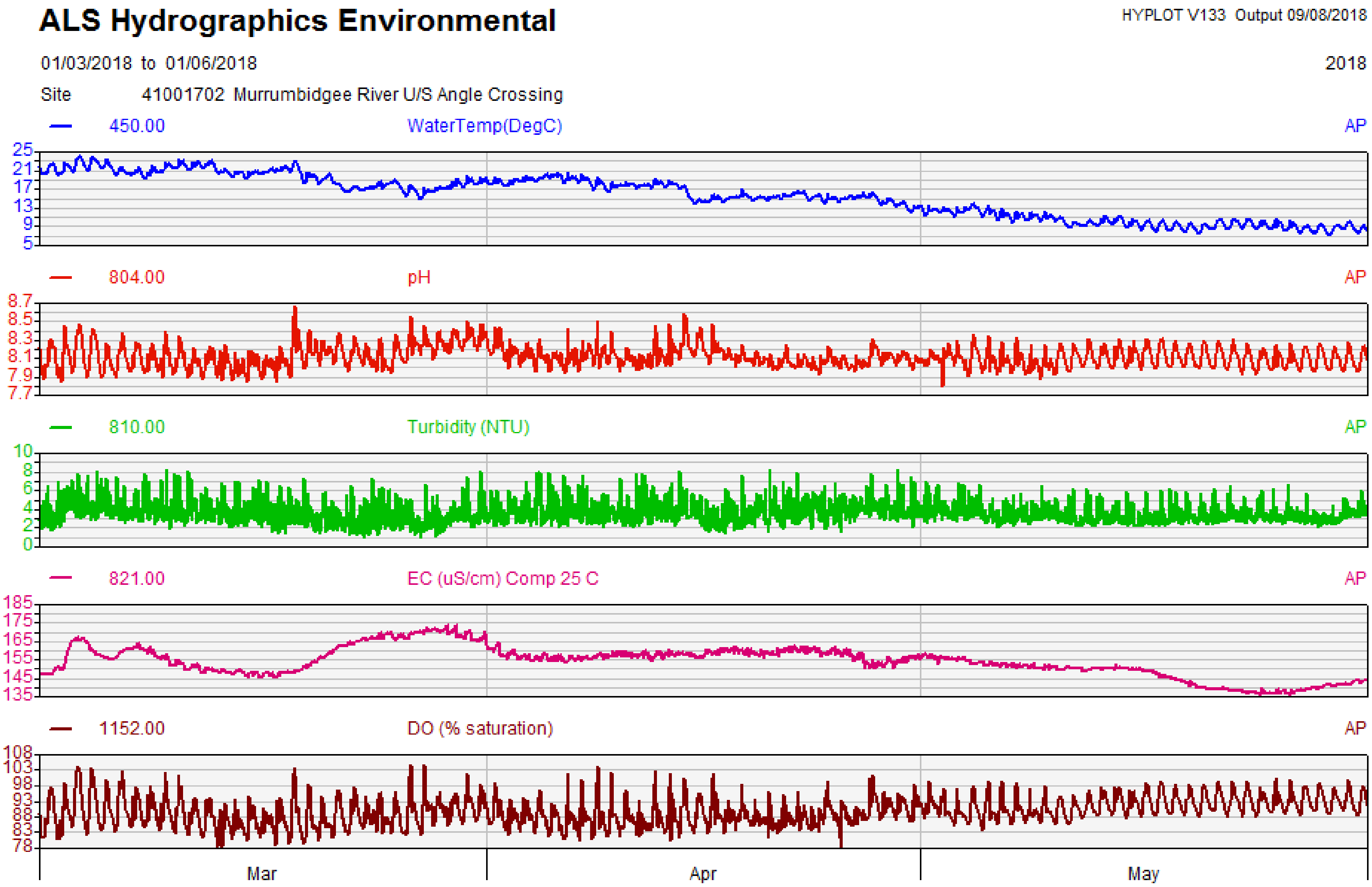


Figure 3-4. Continuous water quality records from upstream Angle Crossing (41001702) for autumn 2018

3.4 Photogrammetry

3.4.1 Periphyton

MUR18

The periphyton coverage at MUR18 was approximately 35-65% for the reach and 65-90% for the riffle habitat based on the AUSRIVAS assessment method (Appendix C). There were large stands of the submerged macrophyte *Myriophyllum* sp. growing throughout the reach, particularly at the tail of the riffle habitat and along the river margins. The dominant substrate in the riffle habitat was cobble.

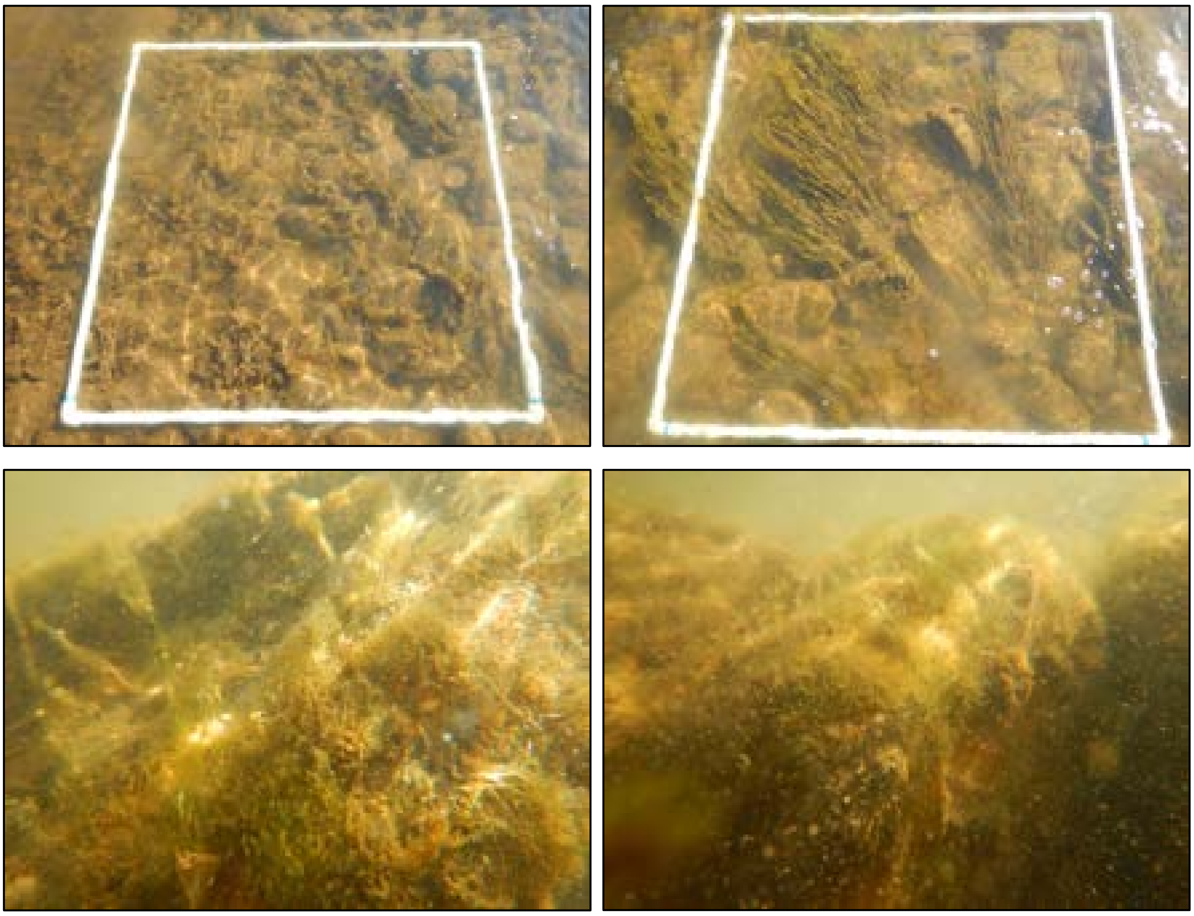


Plate 3-2. Photos showing the periphyton and macrophyte coverage in the reach and riffle at MUR18

Note: Quadrat area is 1m^2.

MUR19

The periphyton coverage was approximately 35-65% at MUR19 for the riffle habitat (Plate 3-3). The cleanest substrate was located in the middle of the river. *Myriophyllum* sp. was dominant throughout the riffle habitat, particularly near the margins, and the dominant substrate types were cobble and pebble.

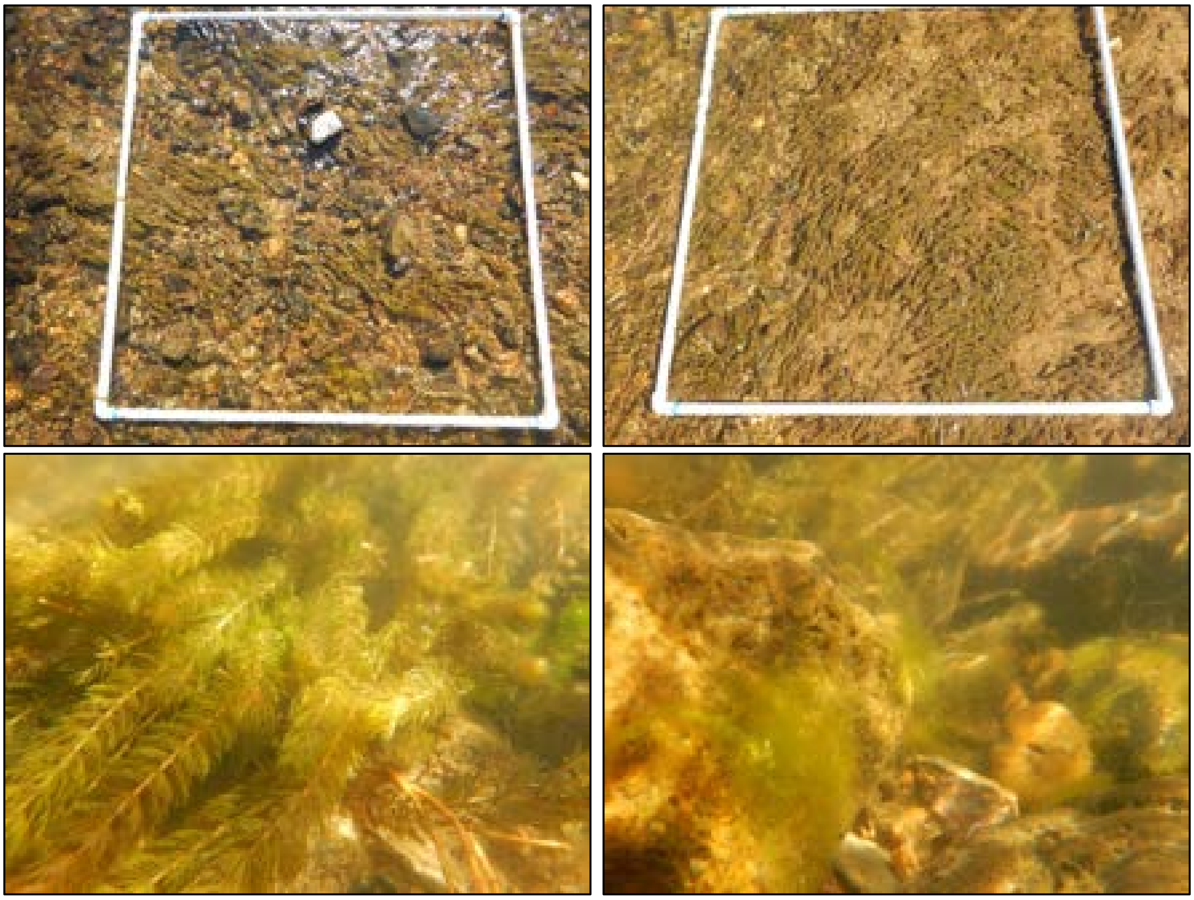


Plate 3-3. Photos showing the periphyton coverage in the riffle at MUR19

Note: Quadrat area is 1m^2.

3.4.2 Geomorphology

Angle Crossing

Geomorphological features at Angle Crossing have remained relatively unchanged compared to spring 2015 (GHD, 2015), which is the last point of reference.

Between spring 2015 and autumn 2017 there was a deposit of sand on the eastern bank of the Murrumbidgee River, just upstream of the off-take (Plate 3-4), which has smothered some of the existing coarse material and potentially limited some vegetation growth.

Overall, the key differences in geomorphological features in Plate 3-4 through to Plate 3-8 appear to be changes in bed and bar exposure due to changes in the water level since the last monitoring period; and various degrees of vegetation die back and recruitment due to the seasonal comparisons being made. The river banks appear stable at each of the photo points.

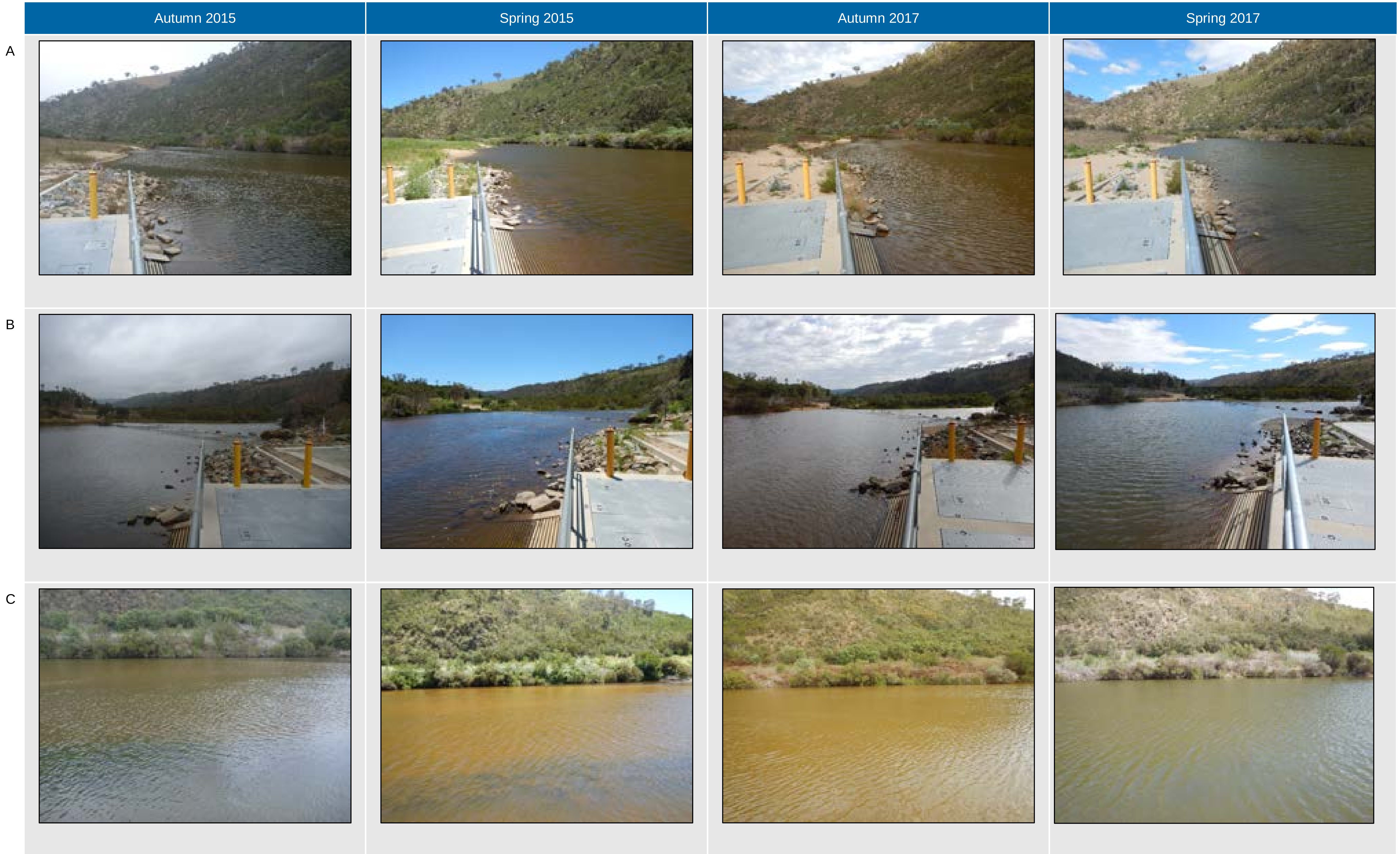


Plate 3-4 Geomorphology photo point 1 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 to spring 2017

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 3-5 Geomorphology photo point 2 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 to spring 2017

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C	NA			

Plate 3-6 Geomorphology photo point 3 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 to spring 2017

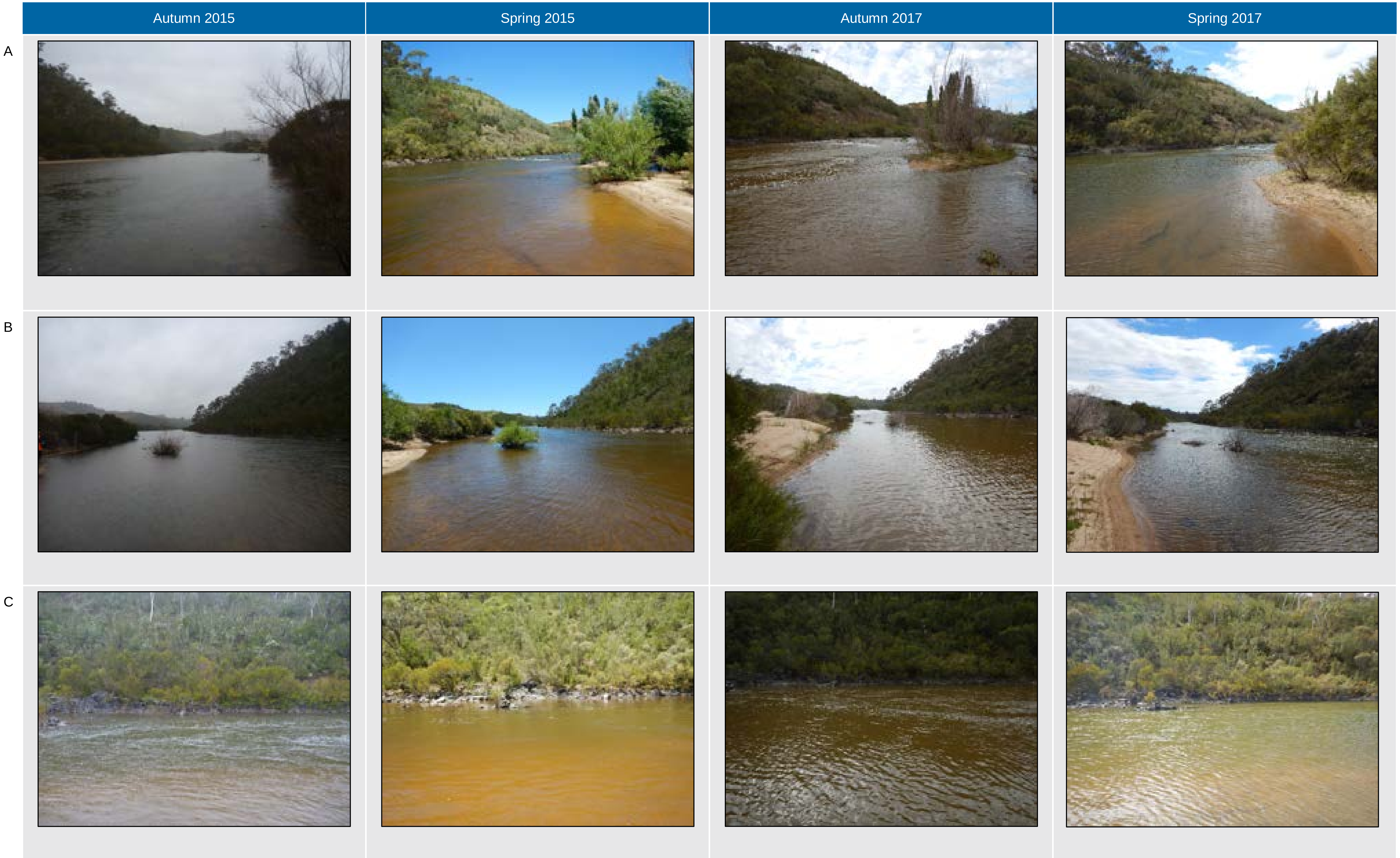


Plate 3-7 Geomorphology photo point 4 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 to spring 2017

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 3-8 Geomorphology photo point 5 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 to spring 2017

3.5 Macroinvertebrates

Biological indices based on the macroinvertebrate riffle and edge samples collected in autumn 2018 are presented in Table 3-3, Table 3-4 and Table 3-5 for both family and genus level taxonomic resolution.

In the riffle habitat, the total taxa richness (diversity) was inconsistent across upstream and downstream sites for taxa richness. There was slightly higher diversity found in family level resolution at MUR18 compared to MUR19 (Table 3-3), but more genera were found at MUR 19. This contrasts with the 2015 results (GHD, 2015e), in which diversity was found to be the identical for both family and genus resolutions at both locations (Table 3-3). In the edge habitat, we found higher family and genus diversity at the upstream site, MUR18.

There were eight EPT (Ephemeroptera, Plecoptera and Trichoptera) families collected at MUR18 compared to seven at MUR19 (Table 3-4). Similarly, EPT mean richness scores follow the same pattern in the edge habitat, with only minor differences in diversity. As with the total taxa richness scores, EPT taxa richness was typically greater in the edge habitat than the riffle habitat, with this pattern most strongly observed at site MUR19 (Table 3-4). The EPT scores are consistent with those observed in 2015 across habitat and location, except that there were noticeably more genera collected in the edge habitat in 2015 compared to the results from autumn 2018

Table 3-3. Number of taxa at family and genus level from riffle and edge habitats

Total Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
MUR18	20 (13)*	21 (16)	22 (19)	30 (27)
MUR19	18 (13)	24 (16)	19 (16)	26 (22)

Table 3-4. Number of EPT taxa at family and genus level from riffle and edge habitats

EPT Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
MUR18	8 (7)	9 (10)	7 (8)	13 (16)
MUR19	7 (6)	10 (9)	8 (8)	10 (14)

*number in parentheses are values from autumn 2015

SIGNAL-2 scores presented in Table 3-5, range from 3.89 to 5.10 in autumn 2018. In the riffle habitat SIGNAL-2 scores were consistent across all replicates at both MUR18 and MUR19, with a slightly higher mean score of 4.81 calculated for upstream compared to a mean of 4.51 at the downstream site. Average SIGNAL-2 scores in the riffle habitat were lower in autumn 2018 than 2015 (5.11 and 5.15 respectively). There was greater variability in the SIGNAL-2 scores for the edge habitat sample replicates (Table 3-5). The mean scores for SIGNAL-2 in the edge upstream site was similar to that of the riffle habitat at 4.80.

The AUSRIVAS results for autumn 2018 are presented in Table 3-5. Ecological condition was similar between MUR18 and MUR19 in the riffle habitat with nearly all sample replicates placed in Band A with scores ranging from 0.78 to 1.11. The overall AUSRIVAS assessment indicates that the upstream riffle site is of slightly better ecological condition than downstream and placed in Band A, and is considered to be close to reference condition. The downstream site was placed in Band B for the overall riffle assessment and is considered to be poorer than reference condition, with few families found than expected (Table 3-5). In the edge habitat, there was greater variability of O/E scores across replicates for both sites. AUSRIVAS O/E scores for edge habitat replicates ranged from 0.70 to 0.93.

The overall site assessments for MUR18 and MUR19 in autumn 2018 indicate that these sites are poorer than reference condition with fewer families collected than expected (Table 3-5), but these results are typical of the historical results observed since autumn 2012 Table 3-6.

Table 3-5. AUSRIVAS and SIGNAL 2 scores for autumn 2018

Site	Rep.	SIGNAL-2		AUSRIVAS O/E score		AUSRIVAS Band		Overall habitat assessment		Overall site assessment
		Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
MUR18	1	4.90	4.75	1.11	0.93	A	A	**A**	**B**	**B**
	2	4.89	5.10	1.00	0.78	A	B			
	3	4.63	4.55	0.89	0.85	A	A			
MUR19	1	4.89	3.89	1.00	0.70	A	B	**B**	**B**	**B**
	2	4.50	4.73	0.89	0.85	A	A			
	3	4.14	4.36	0.78	0.85	B	A			

Table 3-6. Overall site assessments for Angle Crossing sites since 2012

	Autumn 2012	Spring 2012	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014	Autumn 2015	Spring 2015	Autumn 2018	Change since spring 2015
MUR18	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**A**	B	↓
MUR19	**B**	**B**	**B**	**B**	**B**	**A**	**B**	**A**	B	↓

3.6 Discussion

3.6.1 Water quality

Total phosphorus and total nitrogen were the only parameters which were above the ANZECC & ARMCANZ (2000) guideline values (Table 3-2). Elevated phosphorus concentrations have been shown to originate upstream of the ACT (GHD, 2013). Nitrogen, upstream of Angle Crossing was below the limits of detection (<0.05), while downstream at MUR19, the concentration was 0.30 mg/L which exceeds the current guideline value (0.25 mg/L). Previous nitrogen samples collected at MUR18 (eg. Spring 2015) have shown nitrogen concentrations to be almost identical to those at MUR19, which suggests that the reading at MUR18 is erroneous and will be rechecked.

3.6.2 Photogrammetry

Periphyton

Periphyton has been included in the monitoring program for Angle Crossing sites as a means of assessing the influence of flow upon the algal communities downstream of the abstraction point compared to upstream. The aim of this monitoring is to determine, during operational pumping, whether algal and periphyton communities downstream of Angle Crossing are increasing compared to upstream sites due to the reduction in flow through abstraction. While not required for the sentinel monitoring component, the inclusion of these images will increase the baseline information for the impact monitoring which will occur if the pumping conditions are satisfied.

The photos of the substrate presented in section 3, using both the quadrat and underwater aspects, provides a good overview of the periphyton coverage at both upstream and downstream sites. The coverage of periphyton in the riffle habitat during autumn 2018 was lower than that recorded during spring 2015, changing from 35-65% to 65-90%, which is a function of the prolonged low flows experienced in the Murrumbidgee River over this time.

Geomorphology

While the geomorphology at Angle Crossing has shown that over recent years it is a dynamic reach which can have significant changes from individual high flow events (GHD, 2014c; GHD, 2015c), during the period since spring 2015 there has been very little change within this reach.

The current photographs show areas of exposed river margins from the declining water level and some newly exposed sand bars and bedrock. These features are linked to the ongoing low rainfall period throughout much of the upper Murrumbidgee River Catchment at present and is not considered to be related to M2G. There is no photographic evidence of bank erosion, incising or scouring that may be considered to be in relation to M2G.

3.6.3 Macroinvertebrate communities and river health assessment

There has been no change in the ecological condition since the preceding autumn sentinel sampling run in 2015. Both MUR18 and MUR19 had an overall assessment rating of Band B, which is based on the overall condition of the edge and riffle habitats, combined, and is unchanged in the current period.

Taxa missing from the edge samples, but predicted by the AUSRIVAS model (Appendix E) include two taxa which are consistently not collected at either of these sites which are: Synlestidae (SIGNAL = 7) and Conoesucidae (Signal = 7). Both taxa are considered to be sensitive to poor water quality. However, Elmidae (Signal = 7) and Gripopterygidae (Signal = 8) were present at these sites and have equally or slightly higher sensitivities to water quality, suggesting that the quality of habitat may be a contributing factor. However, based on the described habitat and ecological features of these taxa (Gooderham and Tsyrlin, 2005) it appears that habitat requirements for both taxa are met at both monitoring locations.

It should be pointed out, that there are known, ongoing issues with the autumn AUSRIVAS model. The output from the monitoring period were noted as being "*nearly outside the experience of the model",* which should be considered when interpreting these outputs and this could be a reason for these taxa being expected but not collected.

Looking at the long term trends, (Appendix D), the O/E50 scores decreased significantly since the spring 2015 monitoring period but are still comparable to the historical values for autumn. A key point to note is that this decline was seen at both locations, suggesting a broad change in conditions as opposed to M2G related activities driving these changes.

SIGNAL scores in the edge habitat differed between locations with MUR18 having a higher weighted score than downstream. Elmidae (Signal = 7) were not collected at MUR19 but were common at MUR18 which is probably related to the absence of coarse woody debris (Elmidae habitat) at MUR19.

Other observations from the long term macroinvertebrate metrics in relation the current conditions show a similar temporal trend at both locations in the riffle habitat, although there was some divergence in the O/E50 scores in the current period, with MUR19 having low scores than MUR18 (Appendix E), but both resulting scores were both within the long term range of scores for each site. The results from the current round of monitoring are actually the second highest AUSRIVAS score for MUR18 (the highest was seen in spring 2014).

The similar temporal trajectories for the biological metrics between locations indicates a natural, environmentally driven variation, influencing both monitoring sites, as opposed to activities related to M2G driving this variability. There are differences between locations in some cases, but looking at the confidence intervals for these metrics, these are considered to be not-significant in a statistical sense.

4. Burra Creek

4.1 Summary of sampling conditions

Sampling of Burra Creek sites was completed on the 3 May 2018. The weather on the day was fine with a maximum temperature of 24.5°C recorded at the Canberra Airport (BoM, 2018). The mean daily flow in Burra Creek on the 3rd May was 0.98 ML/d recorded at the Burra Weir (410774).

Macroinvertebrate samples were collected at both BUR1c and BUR2a. Riffle samples could not be collected at either site due to the low flow conditions and the absence of that habitat type at both locations. Photographs showing BUR1c and BUR2a are presented in Plate 4-1.

Great Bullrush (*Schoenoplectus validus*) was severely encroaching the channel at BUR1c (Plate 4-1); and at BUR2a, the Common Reed (*Phragmites australis*) encroached the upstream sections of the channel - but the macrophyte stands thinned out as the shape of the channel and the channel substrate changed (from silt and sand to the larger substrate types).

The riffle habitats at both sites were almost dry, highly silted and overgrown with macrophytes which equated to very poor habitat quality and ultimately meant that samples could not be collected. Site summaries can be found in Appendix B, while site habitat data is given in Appendix C.


BUR1c: Looking upstream (left) and looking downstream (right)


BUR2a: Looking upstream (left) and looking downstream (right)

Plate 4-1. Photographs of the Burra Creek sites during autumn 2018 sampling

4.2 Hydrology and rainfall

Surface flow in Burra Creek during autumn was low, typically ranging between 0.3 – 1.5 ML/d (Figure 4-1). For the majority of autumn (71%), the mean daily flow was below 1 ML/d. Most of the readings above 1 ML/d (92%) occurred in May following an upward trend beginning in the middle of April (Figure 4-1). Rainfall during autumn was the lowest total recorded since 2008 (Figure 4-2) and for the first time since the beginning of this project fell below the autumn average of 43.4 mm (Figure 4-3).

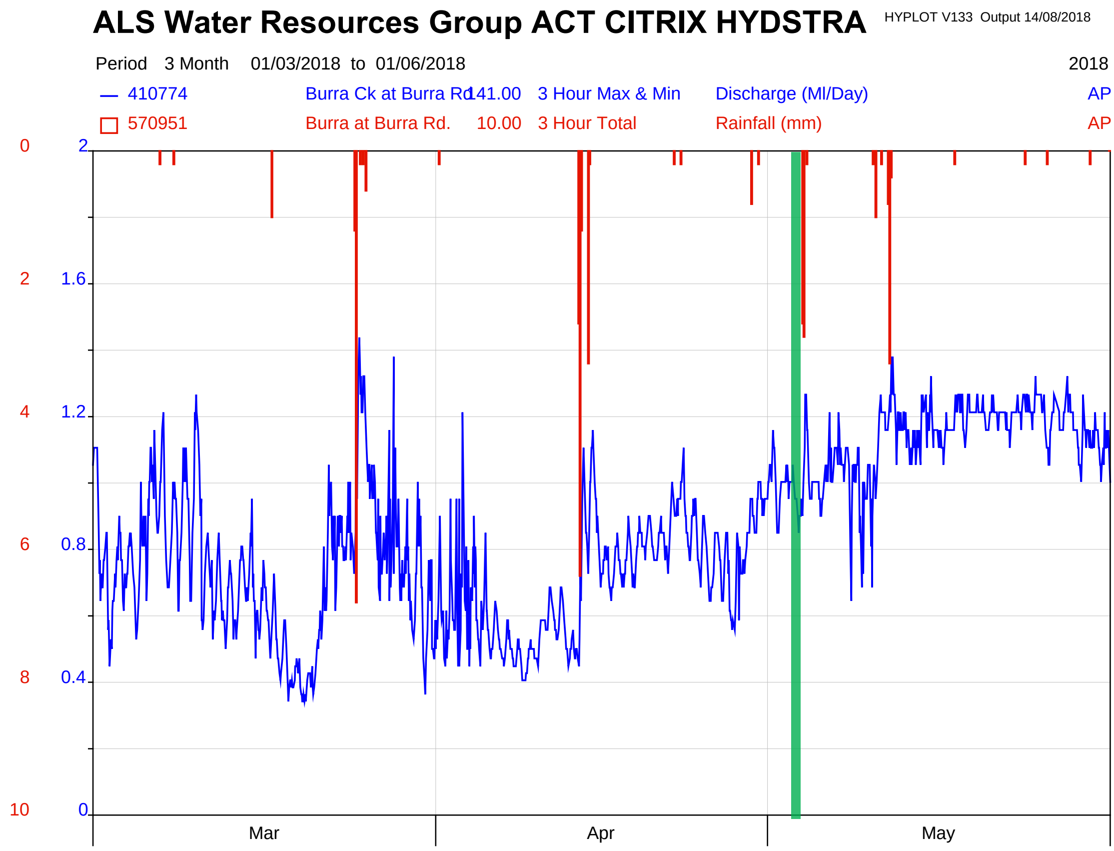


Figure 4-1. Hydrograph and rainfall from Burra Creek (410774) during autumn 2018

Note: The green shading indicates time of sampling.

Table 4-1. Rainfall and flow summaries for Burra Creek in autumn 2018

	Burra Creek (410774)	
	Total Rainfall (mm)	Mean Flow (ML/d)
March	10.4	0.77
April	15.0	0.69
May	12.4	1.12
Autumn (mean)	12.6	0.86

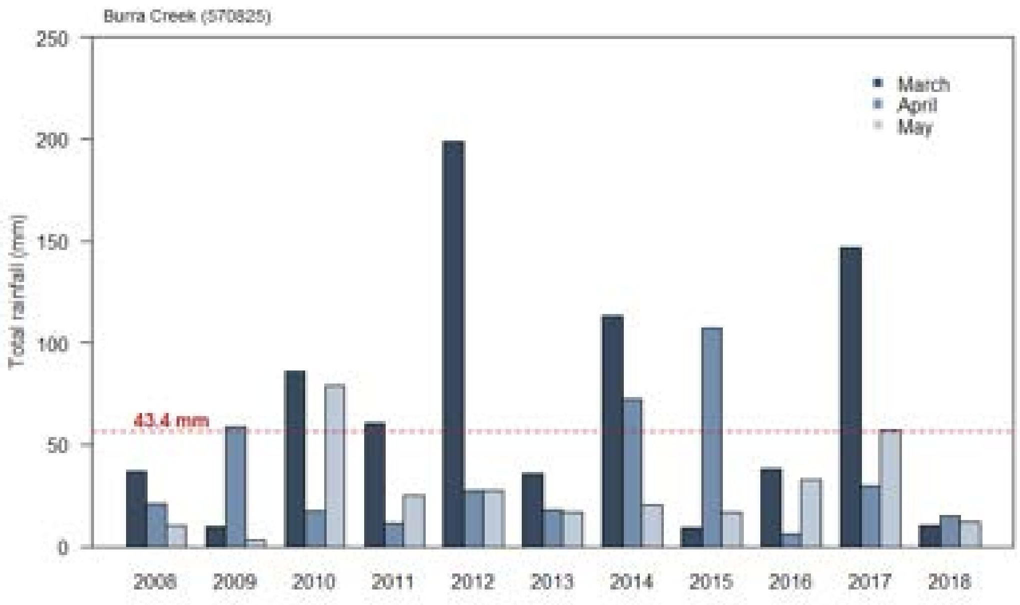


Figure 4-2. Annual comparisons of autumn rainfall (mm) recorded at Burra Creek (570951)

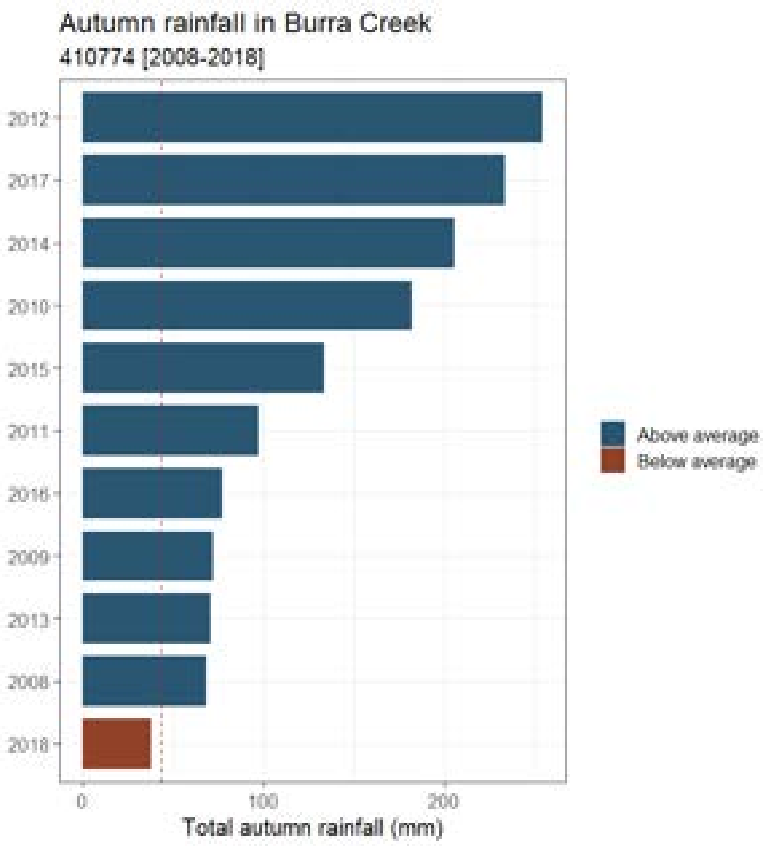


Figure 4-3 Ranked total autumn rainfall at station 410774 for the period 2008-2018

*Note that the vertical red line indicates the average total autumn rainfall for the period of record

4.3 Water Quality

4.3.1 Grab samples and *in-situ* parameters

Both sites exceeded the upper range for electrical conductivity (EC) and dissolved oxygen at both sites were below the lower limit for dissolved oxygen (Table 4-3); although there were significant differences between sites. Dissolved oxygen at BUR1c was all but depleted, but was only just under the ANZECC & ARMCANZ guideline value of 90% at BUR2a. These differences reflected the differences in surface water depth and velocity between the sites.

Nutrient values were only exceeded at BUR1c, which is probably a function of the creek being almost dry coupled with high decomposition of plant matter compared to BUR2a. pH was within the guideline range (6.5-8.0) at both sites.

4.3.2 Continuous water quality monitoring

The continuous water quality data recorded at the Burra Weir (410774) is presented in Figure 4-4. Mean pH increased over the autumn period, though the daily variation decreased throughout most of May as the average daily discharge increased (Table 4-2).

Turbidity was relatively stable throughout autumn. There were some spikes in turbidity levels in response to small rainfall events; however the spikes were short-lived and none of them exceeded the guideline values. Electrical conductivity (EC) increased over the autumn period, but on average remained over 500 µS/cm for all of autumn. While in exceedance of the ANZECC & ARMCANZ (2000) upper limit, these values are all within the natural range of values experienced in Burra Creek.

Daily mean dissolved oxygen was below the guideline values for the entire autumn period. The maximum daily mean reached 71.3, while the minimum value of 48% occurred in early April, when the creek was almost dry at the weir. These values are related to low flows throughout autumn and are considered to be natural given that there were no releases from M2G for the autumn period.

Table 4-2 Summary of the continuous water quality parameters recorded at 410774 in autumn 2018

	D.O.(% sat.)	EC (us/cm)	Turbidity (NTU)	Temp. (ºC)	pH
March	54.3	521.8	5.7	18.4	7.93
April	59.6	579.7	4.7	15.7	8.05
May	68.8	577.7	3.4	8.9	8.11

Table 4-3. *In-situ* water quality results from Burra Creek during autumn 2018 sampling

	Site	Date	Time	Temp. (°C)	EC (µs/cm) (30-350)	Turbidity (NTU) (2-25)	pH (6.5-8)	D.O.(% Sat.) (90-110)	D.O. (mg/L)	Alkalinity (mg/L)	NO_x (mg/L) (0.015)	TKN (mg/L)	TP (mg/L) (0.02)	TN (mg/L) (0.25)	Total Iron (mg/L)	Total Manganese (mg/L) (1.9)
Upstream	BUR1c	3/5/2018	12.30	13.0	472.9	21	7.4	5.3	0.44	236	<0.05	1.04	0.12	1.04	32.4	0.97
Downstream	BUR2a	3/5/2018	1345	11.4	397	8	7.6	89.3	8.9	270	<0.05	0.22	0.01	0.22	1.87	0.09

Note: ANZECC and ARMCANZ (2000) guidelines are in yellow parentheses; yellow cells indicate values outside of the guidelines; guideline value for Total Manganese is the 95% species level protection for slightly-moderately disturbed systems.

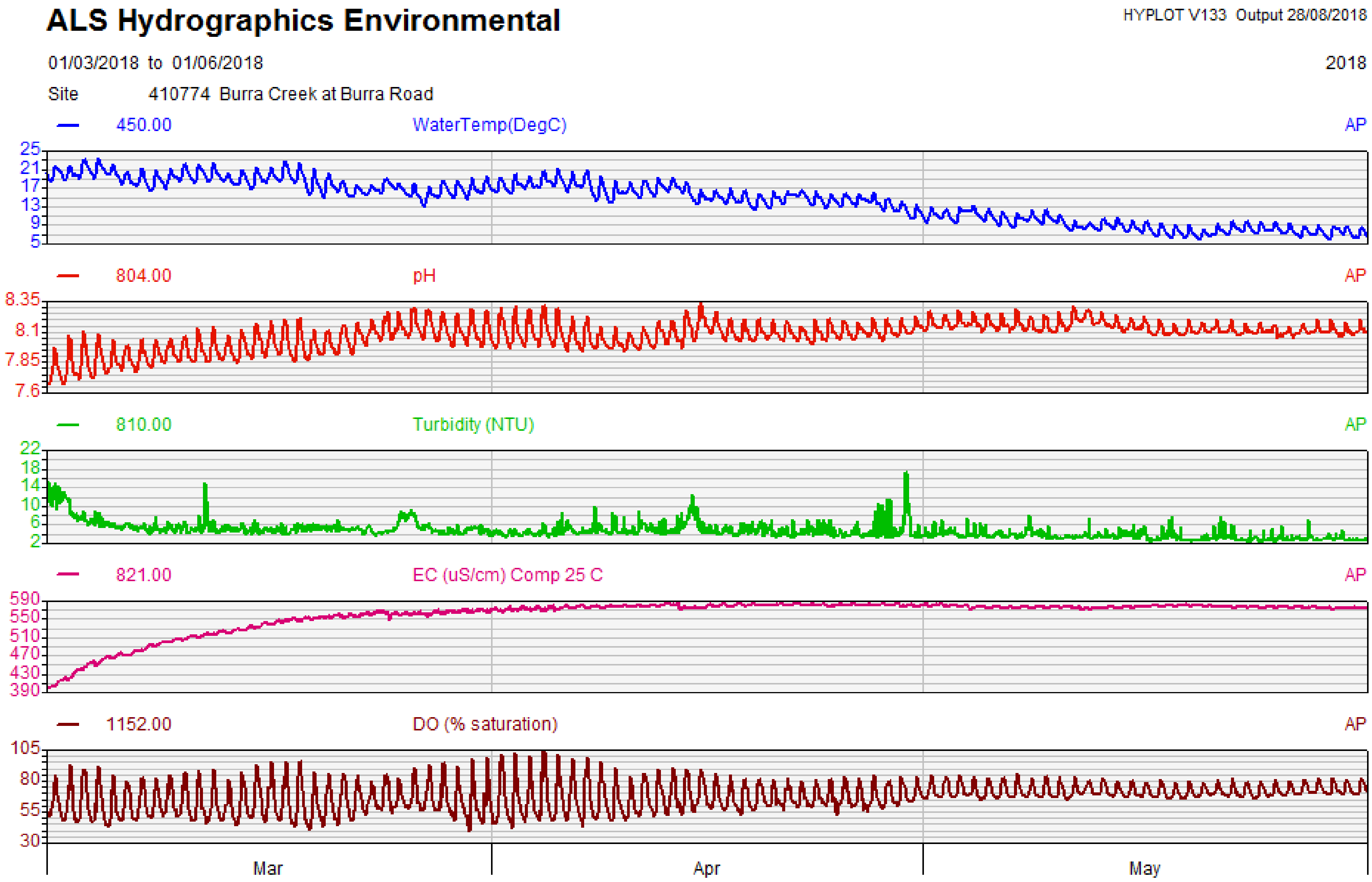


Figure 4-4. Continuous water quality recorded at Burra Creek (410774) during autumn 2018

4.4 Photogrammetry

4.4.1 Periphyton

BUR1c

The periphyton coverage at BUR1c was estimated at 85% for the reach scale and 100% for the riffle habitat using the AUSRIVAS assessment. There significant amount of iron-oxidising bacteria within the reach (Plate 4-2) resulting in a red tinge to the surface periphyton and algae and an oily sheen on the surface of the temporary pools.

Large areas of *Myriophyllum sp.* (watermilfoil) were evident throughout the reach, where there was surface water and there were isolated patches of *Isolepis habra* (wispy clubsedge) growing along the edge of the dry riffle habitat. The main channel, was almost entirely inundated and choked by significant stands of *Schoenoplectus validus,* which impaired our ability to capture quality periphyton photographs.

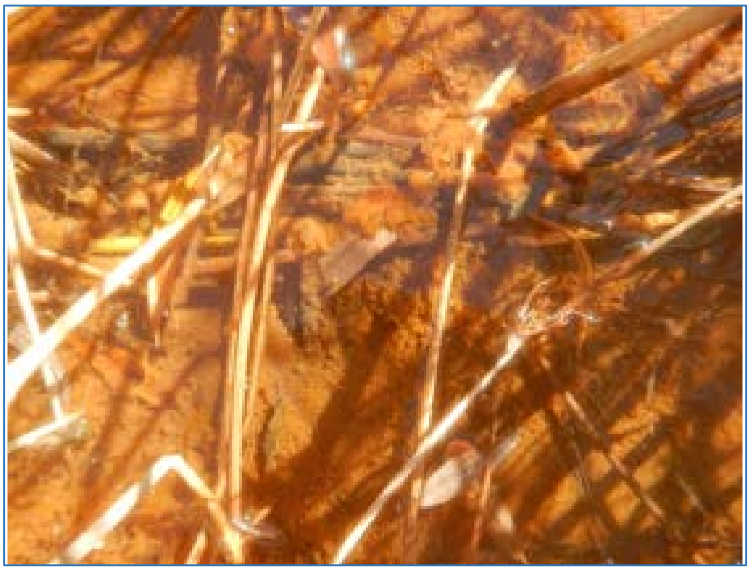


Plate 4-2. Periphyton coverage at BUR1c

BUR2a

Periphyton coverage at BUR2a was approximately 90% at the reach scale and 100% in the riffle habitat using the AUSRIVAS assessment (Plate 4-3). There were *Schoenoplectus validus* stands encroaching the main channel, which was otherwise dominated by tall thickets of *Phragmites australis* and smaller patches of *Typha orientalis.* Through the lower sections of the reach, the dominant substrate was cobbles, and silt which was largely blanketed with periphyton and algae (Plate 4-3).

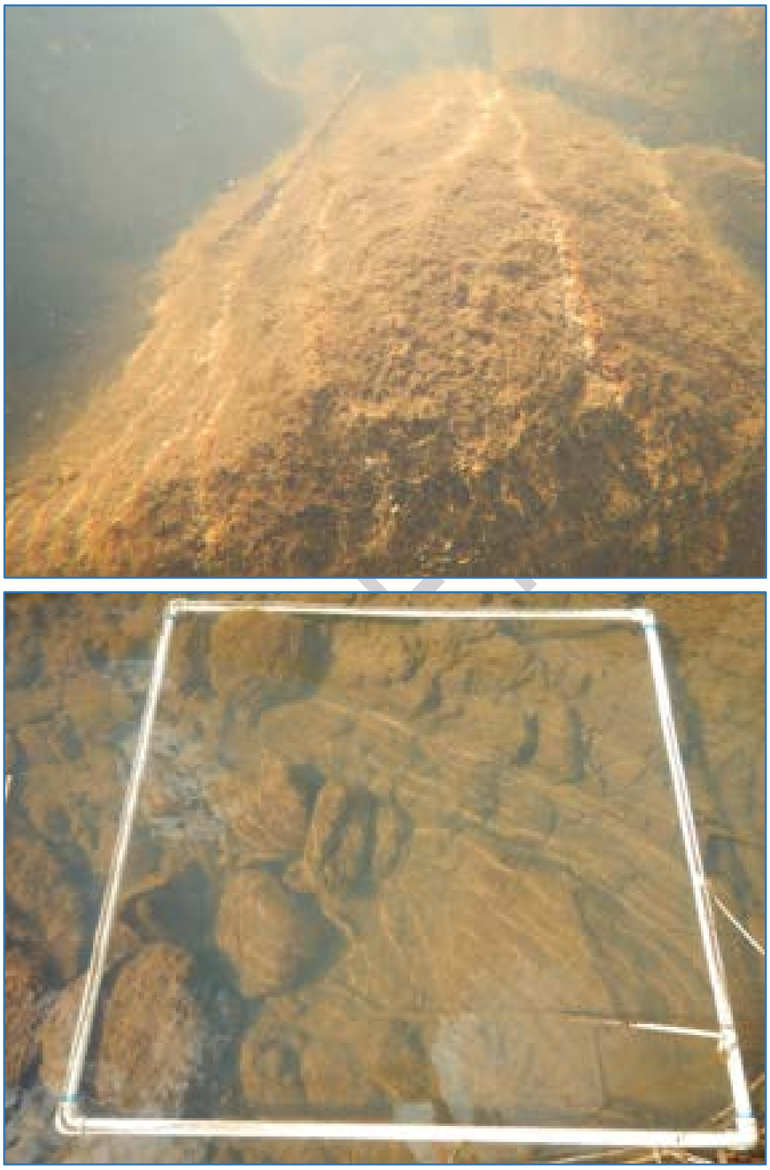


Plate 4-3. Periphyton coverage at BUR2a

4.4.2 Vegetation

BUR2

There are a number of trees present at BUR2. The large *Populus* sp. (Poplar) located immediately downstream of the causeway and a couple of young *Populus* sp. (approx. 3m tall) across the site were all displaying new growth from the spring period. There were high levels of macrophyte growth across the site, where *Phragmites australis* (Common Reed) was dominant throughout. There were large stands both upstream and downstream of the Williamsdale Road causeway, as can be seen in all of the photo points Plate 4-4 to Plate 4-6. Crack willow (*Salix fragilis*) has established itself on the western side of the creek, upstream of the weir (Plate 4-4) since spring 2015. New growth is visible in the foreground of the photographs.

Downstream of Pool 29

The site downstream of Pool 29 has few large vegetated areas to which provide shade. Three trees were present 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.(Plate 4-7 and Plate 4-8).

There are a considerable number of juvenile *Populus* sp. on the vegetated laterally attached bar on the left bank, approximately 60-80 cm high (Plate 4-9). The large vegetated bank-attached point bar on the right bank is 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), throughout the macro channel. Aquatic macrophytes showed significant growth within the reach with *Mentha* x *piperita* **var.** *'piperita'* (Peppermint) common throughout the shallow riffle zone and small infrequent stands of *Typha orientalis* (Broad leaf Cumbungi) across the reach. *Schoenoplectus validus* (Great Bulrush) was common along the edges of the channel lining most of the creek.

Other than seasonal growth of the vegetation describe above, there were no other notable changes in species composition or recruitment observed at this site during autumn and spring 2017.

BUR2c

While BUR2c is surrounded by numerous large *Eucalyptus* spp. on the floodplain, there is minimal vegetation close to the creek to provide any shading (Plate 4-10). Within the macro channel there are large sections covered by grasses, mostly *Poa* spp., while weeds such as *Verbascum* sp. (Mullein), *Hypericum perforatum* (St. John's Wort), *Rubus fruiticosus* (Blackberry) and various thistle species are also frequent. Several small *Populus* sp. (Poplar) and *Salix* sp. (Willow) are present within the macro channel as well as two larger *Populus* sp. (approximately 3-4 m tall), which are the tallest individuals within the channel. Instream vegetation is dominated by *Typha orientalis* (Broad leaf Cumbungi) with numerous large stands visible from all photo points (i.e. Plate 4-10 to Plate 4-13), while *Schoenoplectus validus* (Great Bulrush) is also present in smaller patches.

As with the previous locations on Burra Creek, there were no obvious compositional changes, or changes to the distribution of the surveyed vegetation since spring 2015.

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 4-4 Vegetation extent photo at BUR2 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 to spring 2017

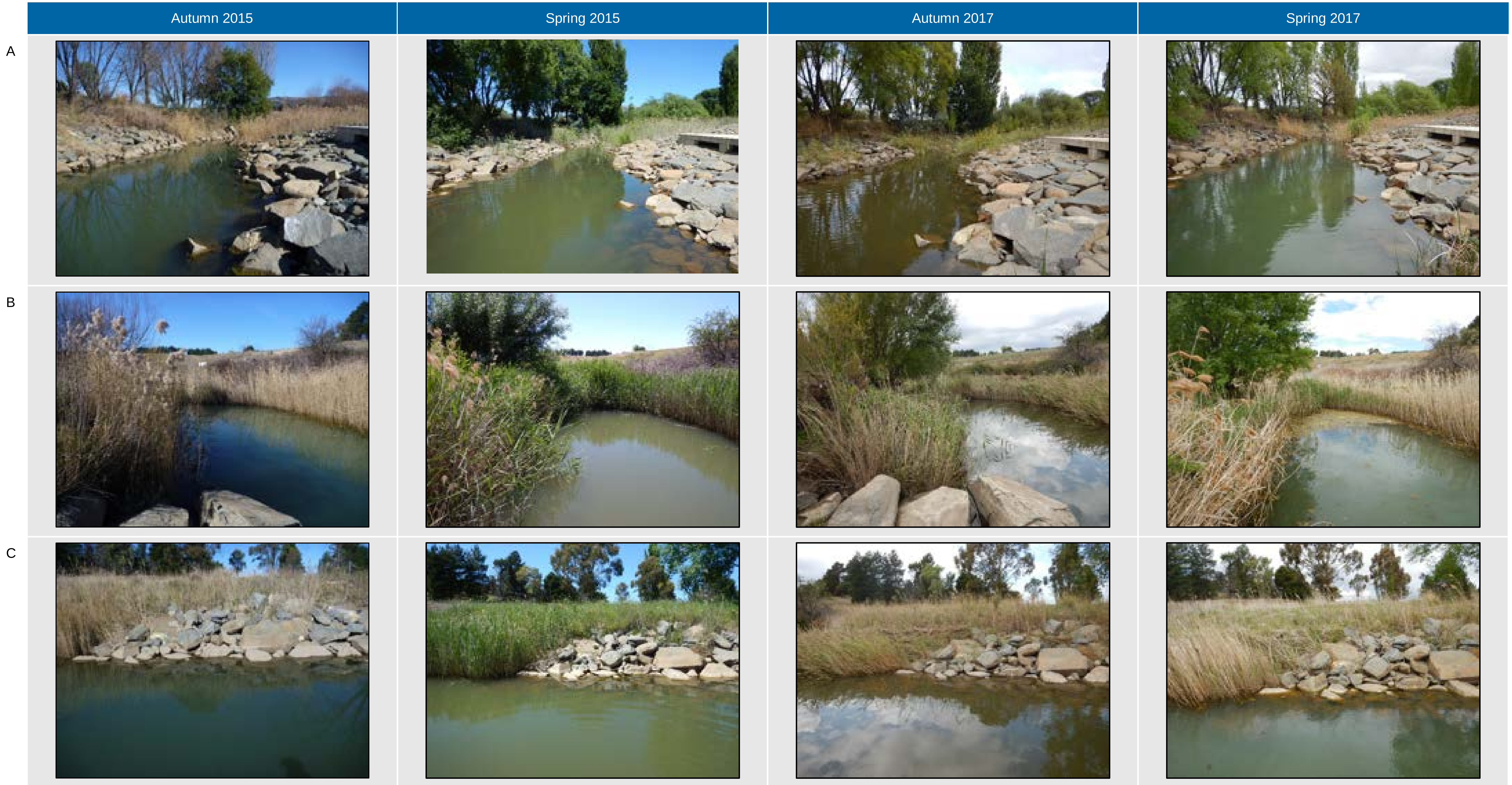


Plate 4-5 Vegetation extent photo point 2 at BUR2 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 4-6 Vegetation extent photo point 3 at BUR2 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

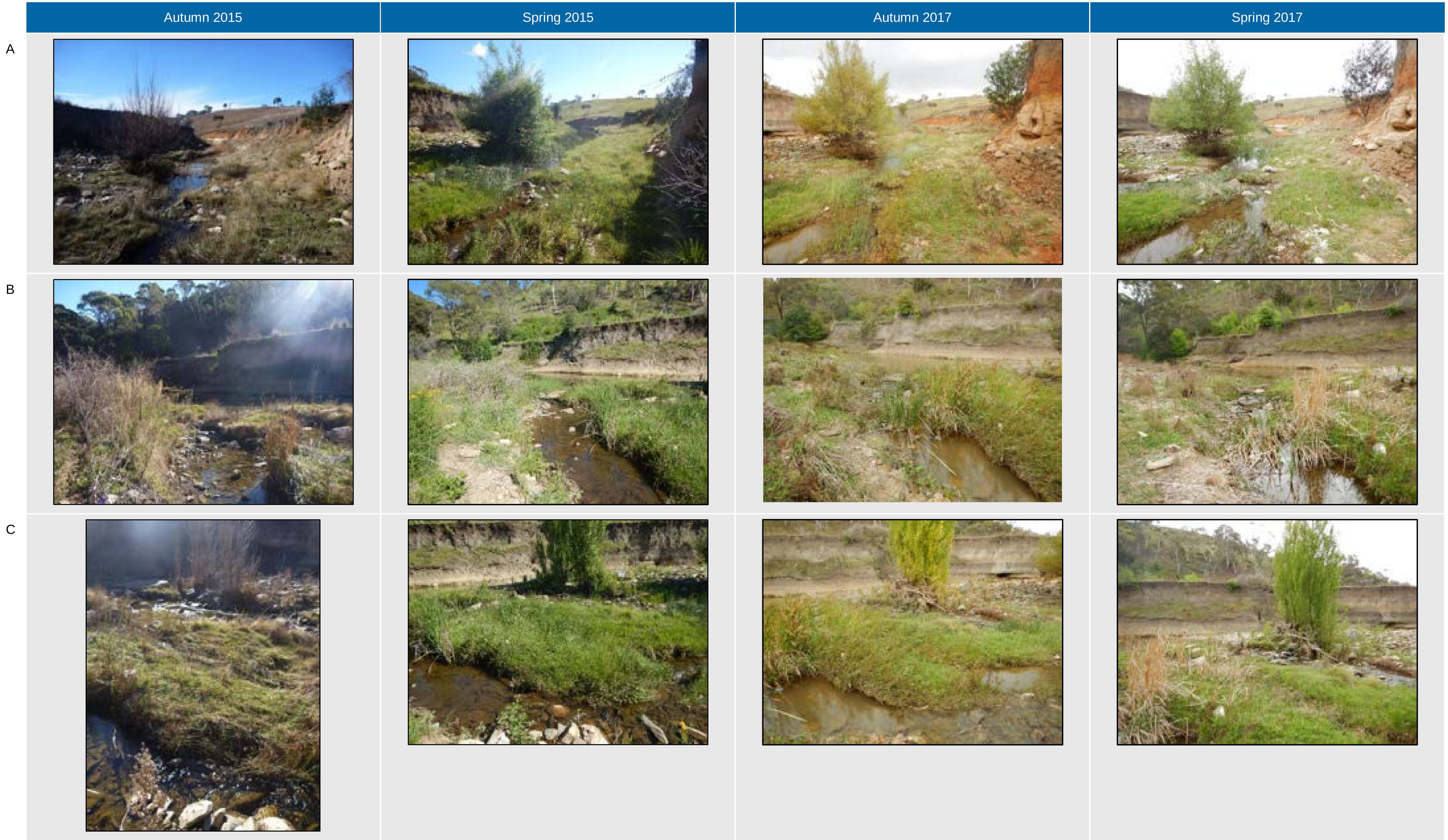


Plate 4-7 Vegetation extent photo point 1 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 4-8 Vegetation extent photo point 2 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 4-9 Vegetation extent photo point 3 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

Plate 4-10 Vegetation extent photo point 1 at BUR2c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017

A

B

C

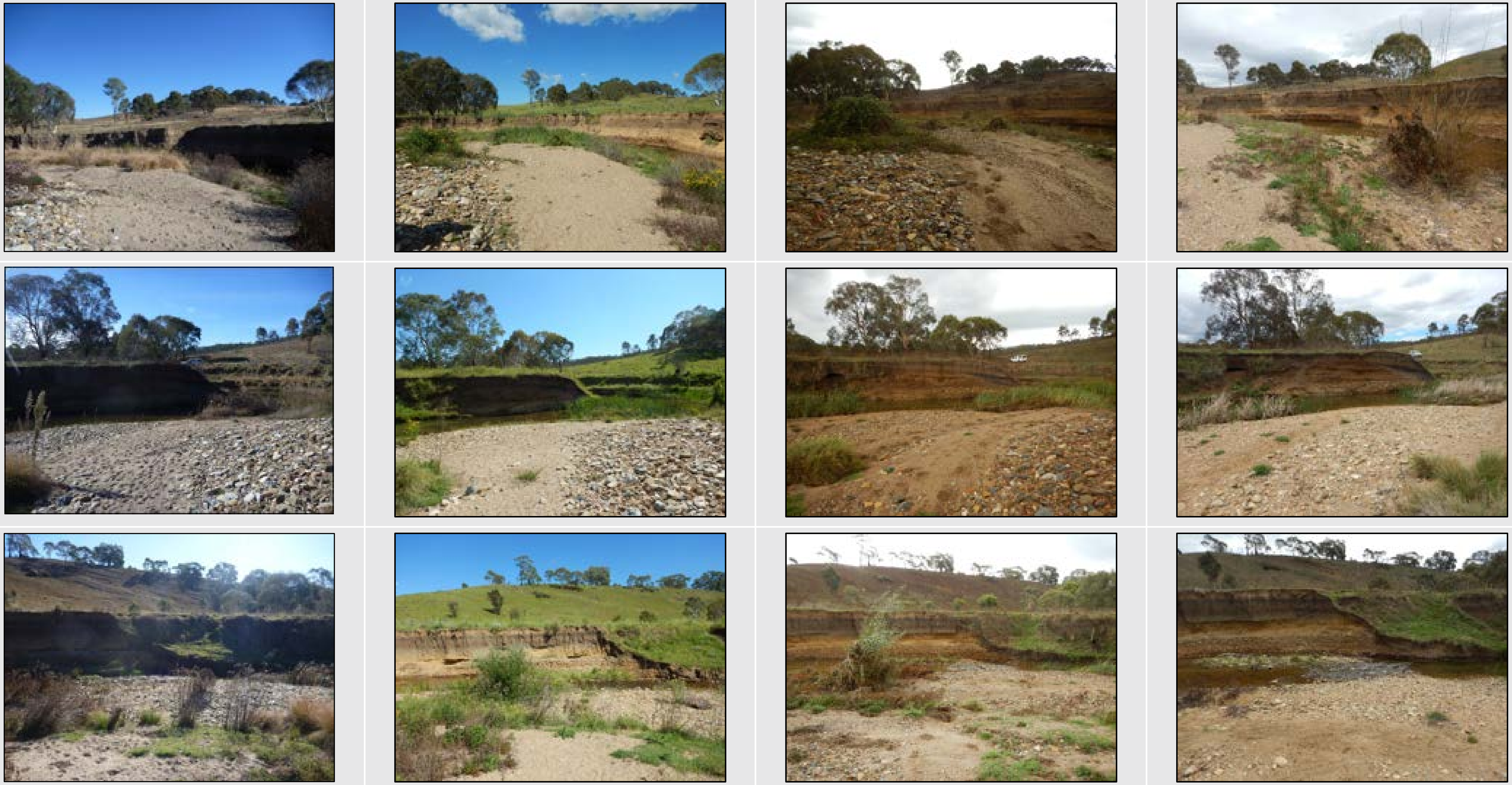


Plate 4-11 Vegetation extent photo point 2 at BUR2c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

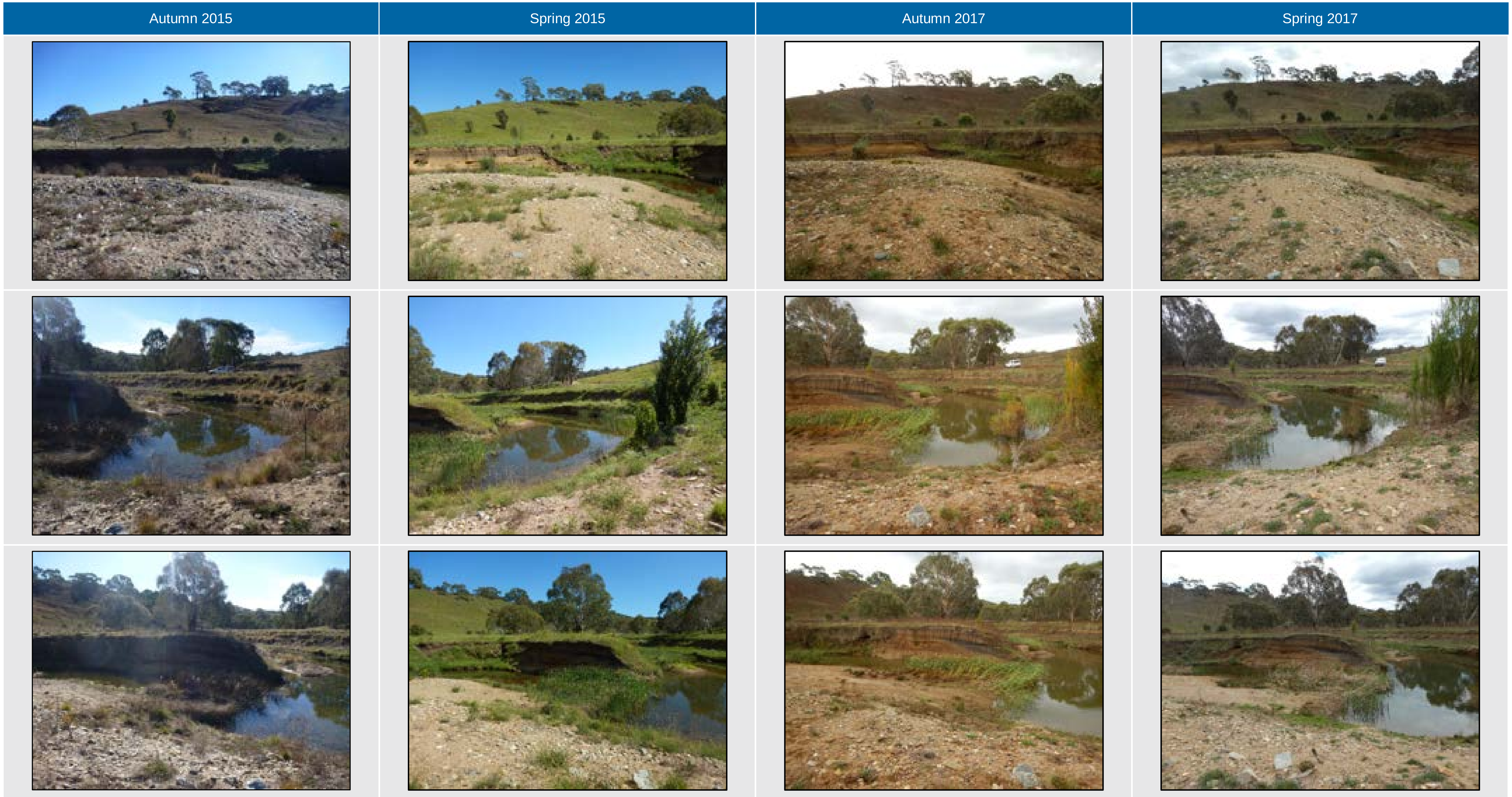


Plate 4-12 Vegetation extent photo point 3 at BUR2c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

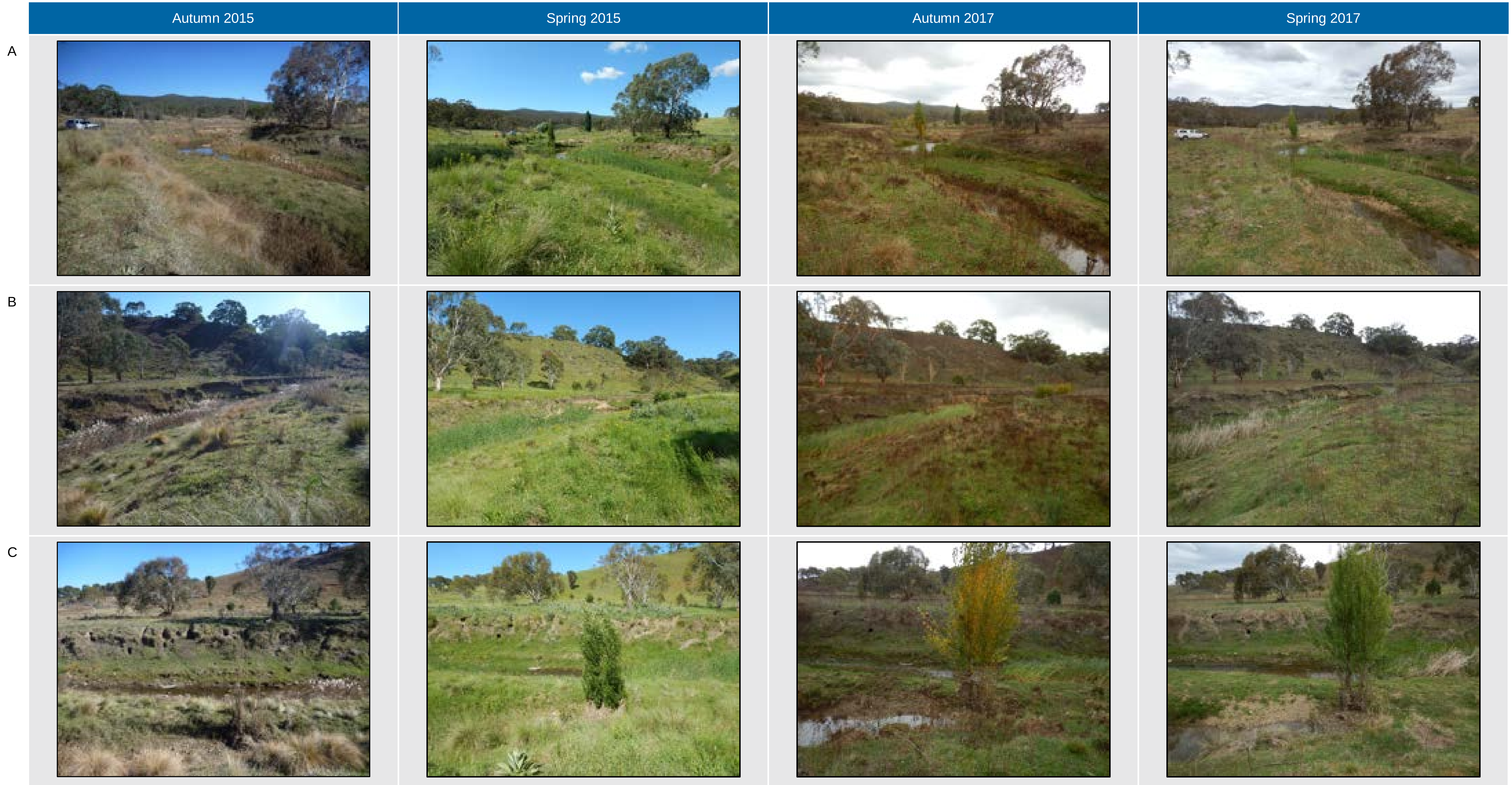


Plate 4-13 Vegetation extent photo point 4 at BUR2c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

4.4.3 Geomorphology

BUR 1a

The conditions at BUR 1a have remained relatively unchanged since spring 2015.

This site is characterised by a large macro channel with a small inset low flow channel set along the right side of the main channel.

Vast sections of the site are subject to significant erosion and bank slumping (Plate 4-14); however since spring 2015, there has been no significant changes, based on the photo records Plate 4-14 to Plate 4-16.

BUR1c

The banks at BUR1c are highly vegetated; however this vegetation is almost exclusively restricted to grasses, with very few trees and no shrubs along the reach. The creek has a very low sinuosity throughout this reach, while a small laterally attached sand bar is located immediately downstream of the riffle habitat. This reach is a depositional zone with high macrophyte coverage restricting flows and causing blanketing of silt across all habitats (Plate 4-17 and Plate 4-18). There has been very little water in this section of Burra Creek over the past few years and the in-channel encroachment by macrophytes has notably increased into most sections of the previously existing riffle habitat - since 2015.

BUR2

Downstream of the causeway the creek banks are well protected by the large established *Salix* sp. (Willow) (Plate 4-19). The discharge pool has shown no geomorphological changes since spring 2015. Four photo points were collected at BUR2 during spring 2015 and are presented in Plate 4-19 through to Plate 4-22

BUR2a

Like BUR1c, this reach is a depositional zone and there is blanketing silt across all habitats. Since the 2015 monitoring period, there have been no observable geomorphological changes at this site (Plate 4-23 and Plate 4-24).

Downstream of Pool 29

Despite the moderate to heavy erosion potential in this reach, there has been little photographic evidence of slumping or movement from autumn 2015 to spring 2017 (Plate 4-25, Plate 4-26 and Plate 4-27. Both of the banks and the channel through this reach have not shown any major changes to their morphology. There were no major changes to the large macro channel morphology observed during the most recent visit in spring 2017. The formed vegetated island in the riffle habitat also appears stable.

BUR2c

There was some slumping of the steep bank adjacent to the riffle habitat between the autumn 2015 and spring 2015 sampling periods. In the subsequent monitoring rounds (autumn 2017 and spring 2017) there has been little or no further slumping in this section of the bank (Plate 4-28; Plate 4-29), which may be related to the low rainfall and low flows over this period. Downstream of the main pool, the banks appear to be relatively stable due to the large areas of the face of the bank being vegetated by various grass species. There have been no obvious changes to the channel morphology since the last monitoring period.

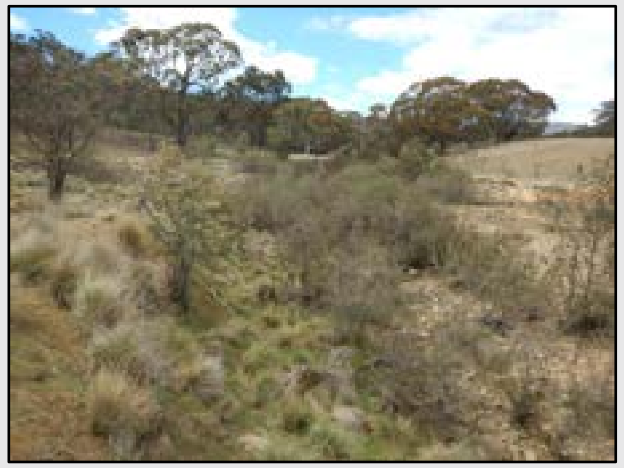
	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 4-14 Geomorphology photo point 1 at BUR 1a showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 4-15 Geomorphology photo point 2 at BUR 1a showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

Plate 4-16 Geomorphology photo point 3 at BUR 1a showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C	N/A			

Plate 4-17 Geomorphology photo point 1 at BUR1c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C	N/A			

Plate 4-18 Geomorphology photo point 2 at BUR1c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

Plate 4-19 Geomorphology photo point 1 at BUR2 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

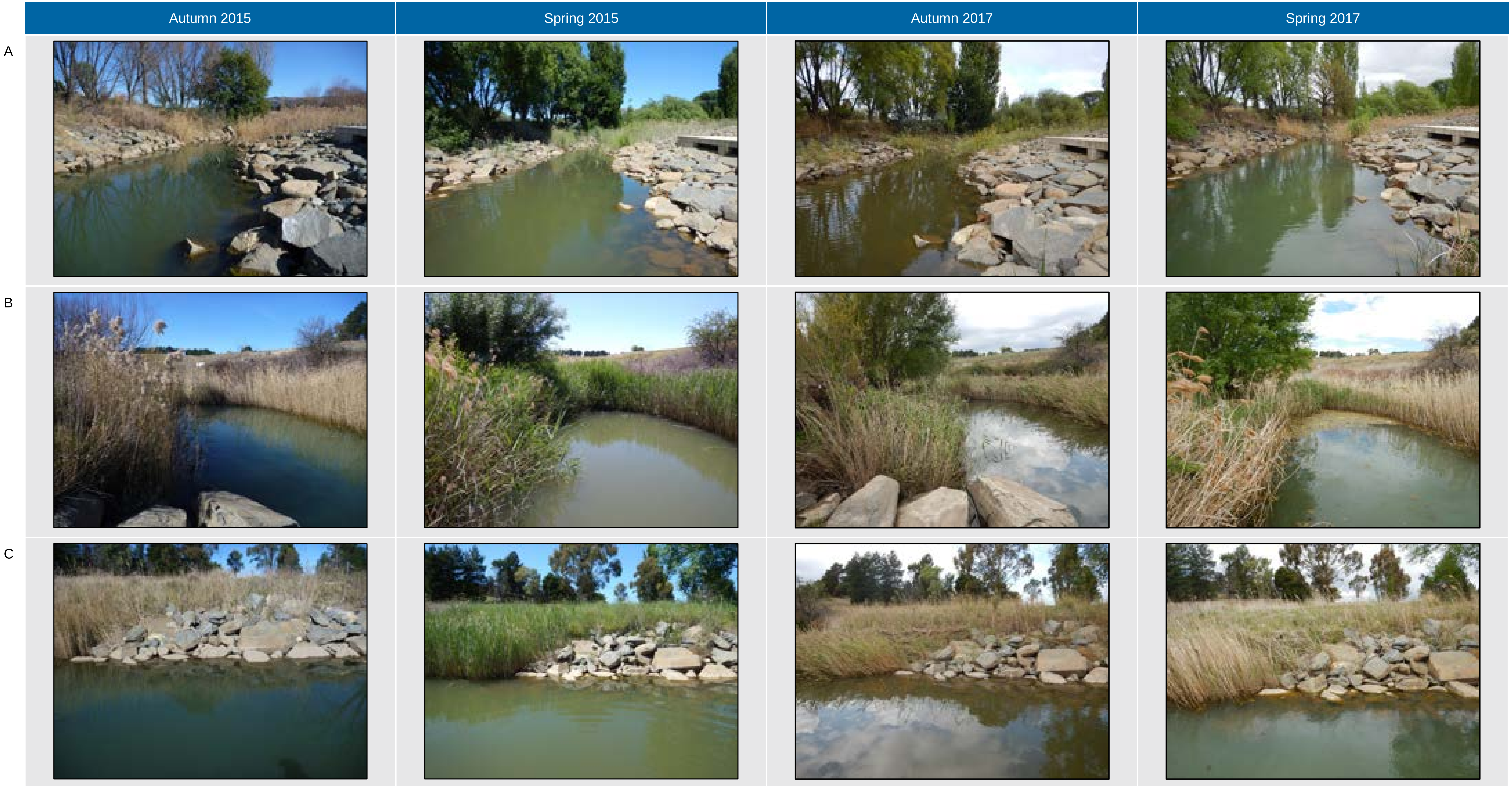


Plate 4-20 Geomorphology photo point 2 at BUR2 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 4-21 Geomorphology photo point 3 at BUR2 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

Plate 4-22 Geomorphology photo point 4 at BUR2 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

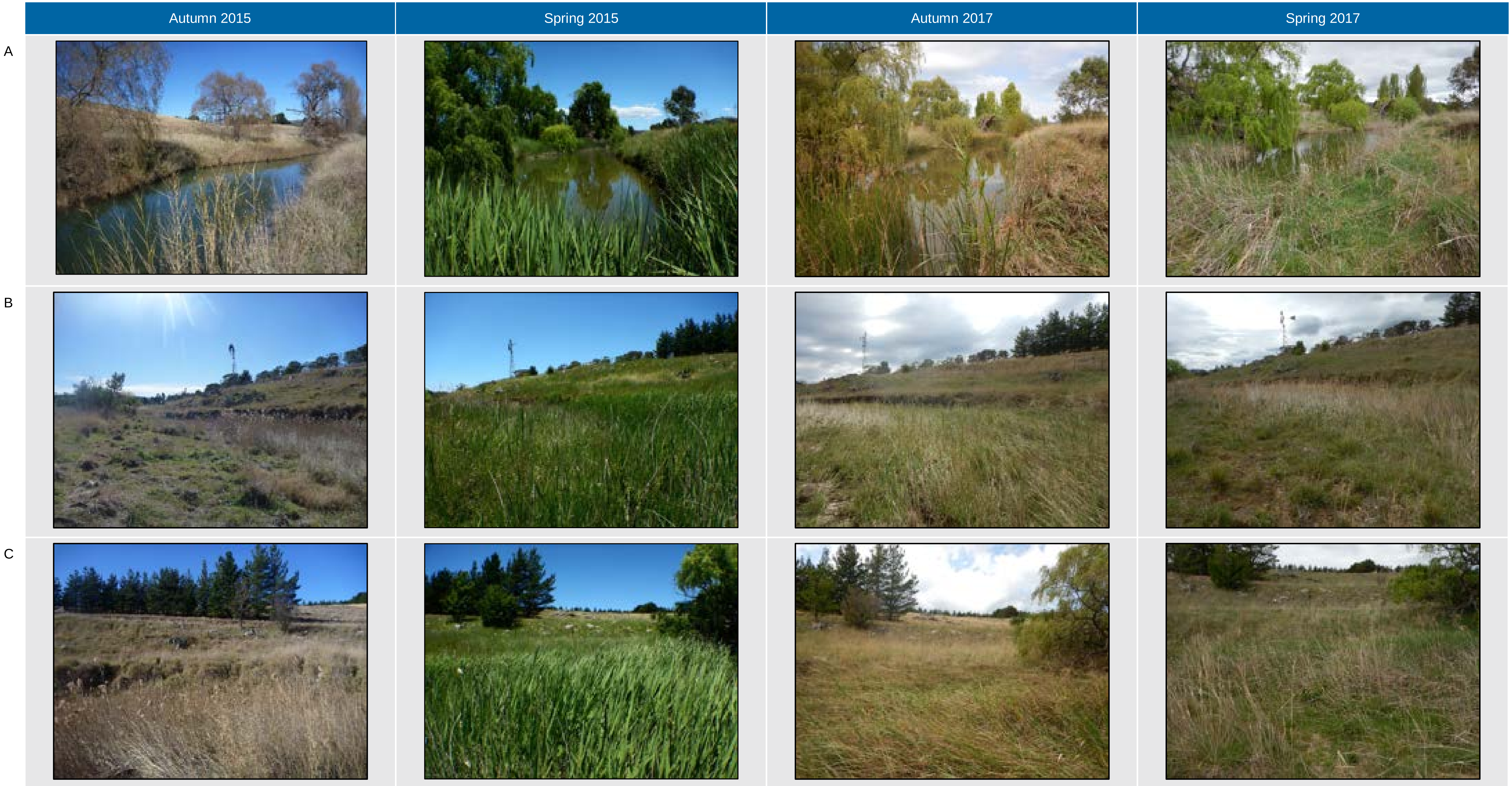


Plate 4-23 Geomorphology photo point 1 at BUR2a showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

Plate 4-24 Geomorphology photo point 2 at BUR2a showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

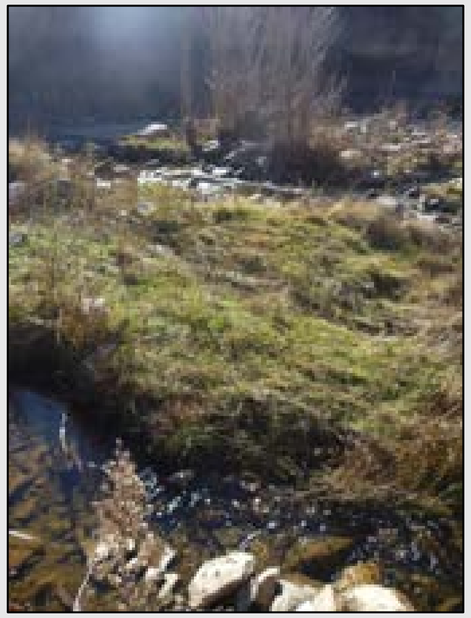
	Autumn 2015	Spring 2015	Autumn 2017	Spring 2017
A				
B				
C				

Plate 4-25 Geomorphology photo point 1 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

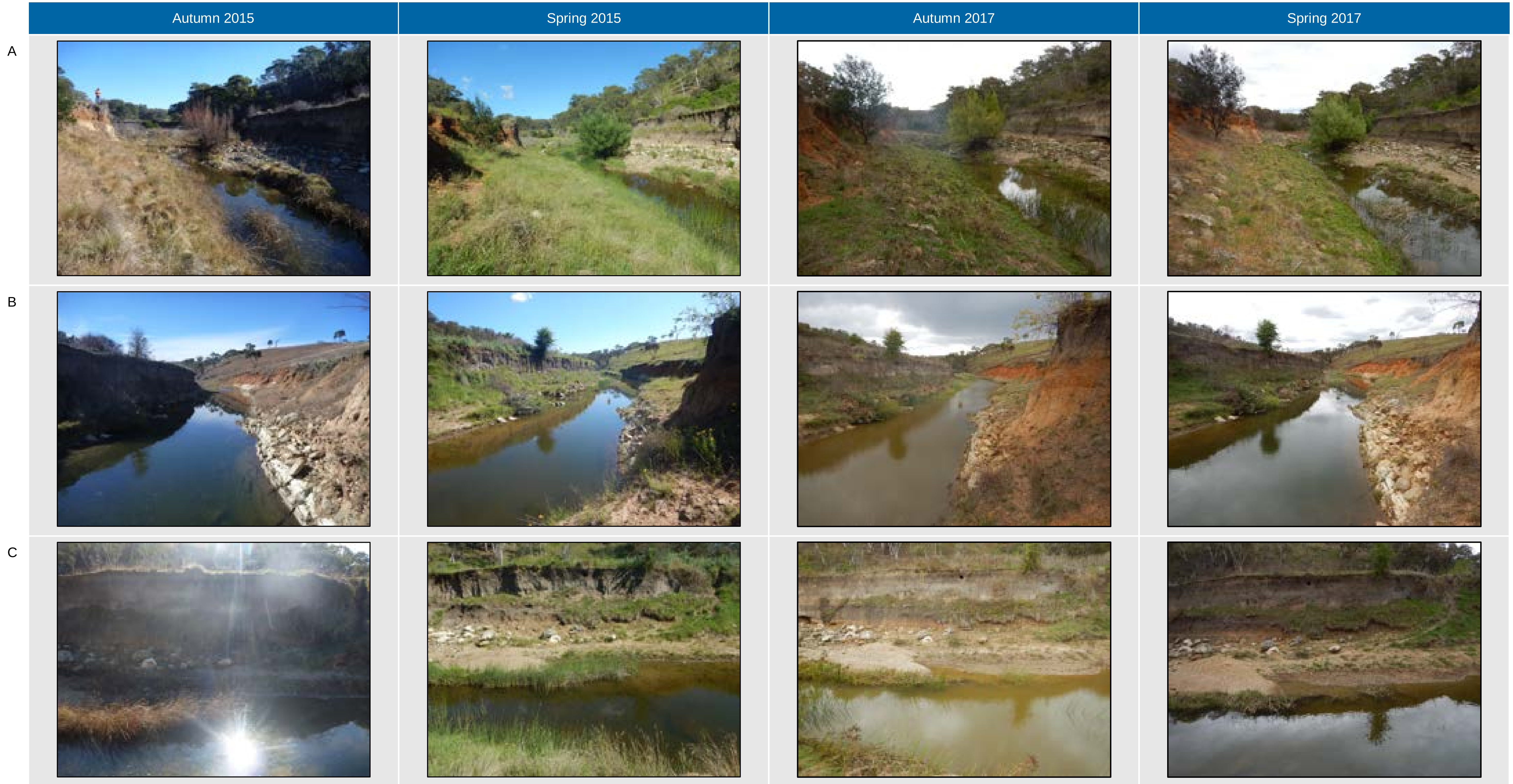


Plate 4-26 Geomorphology photo point 2 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

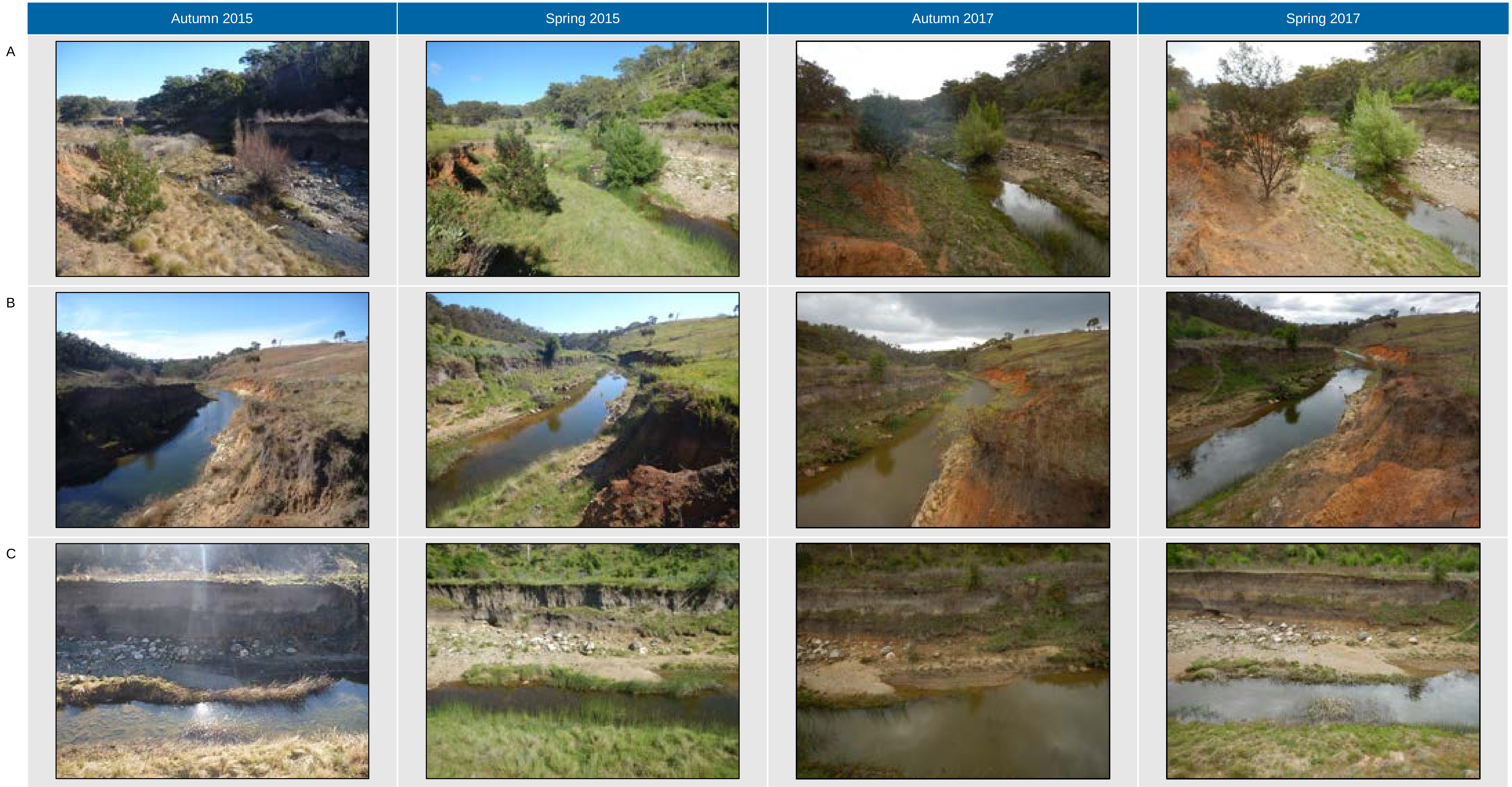


Plate 4-27 Geomorphology photo point 3 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

Plate 4-28 Geomorphology photo point 1 at BUR2c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

Plate 4-29 Geomorphology photo point 2 at BUR2c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

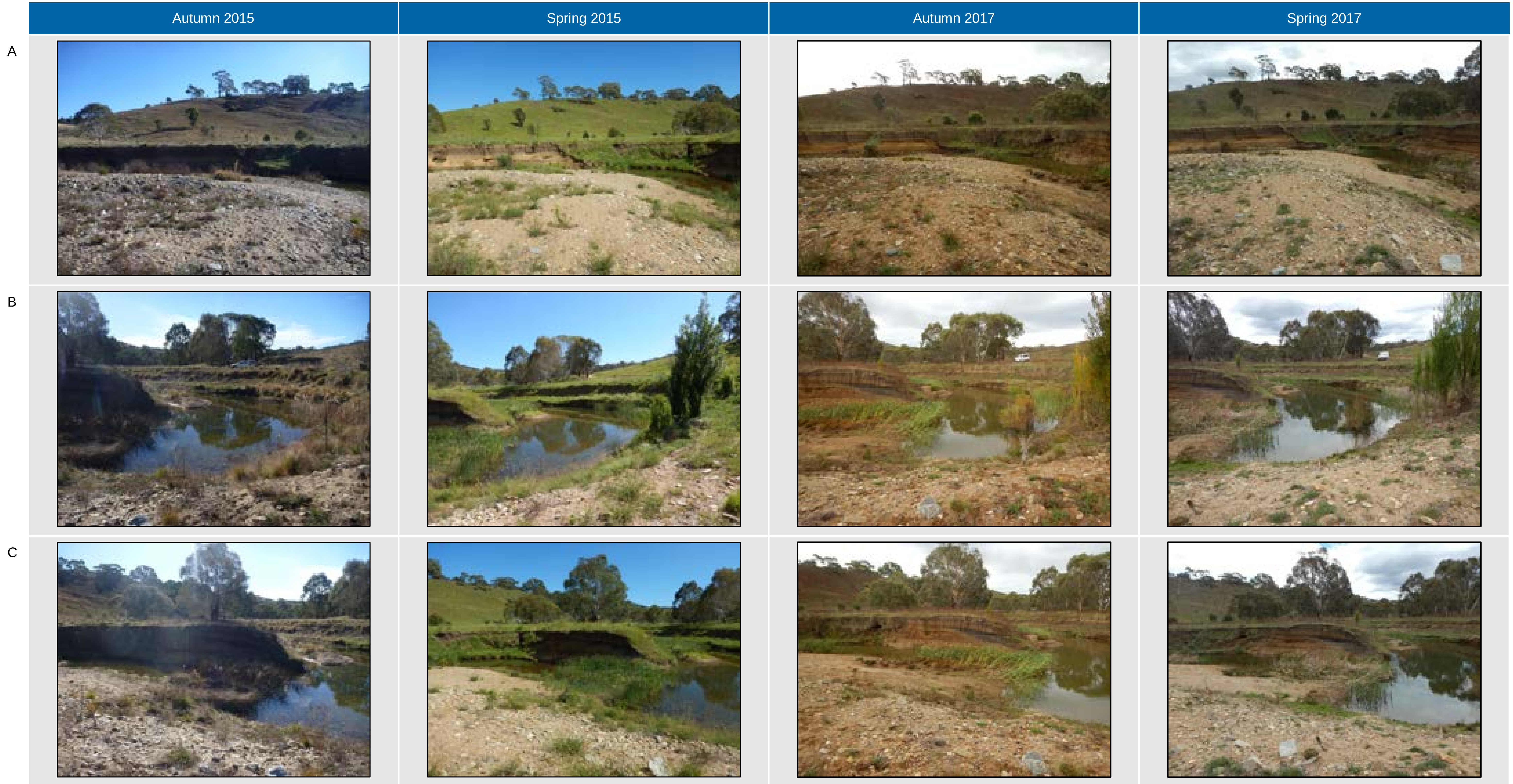


Plate 4-30 Geomorphology photo point 3 at BUR2c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

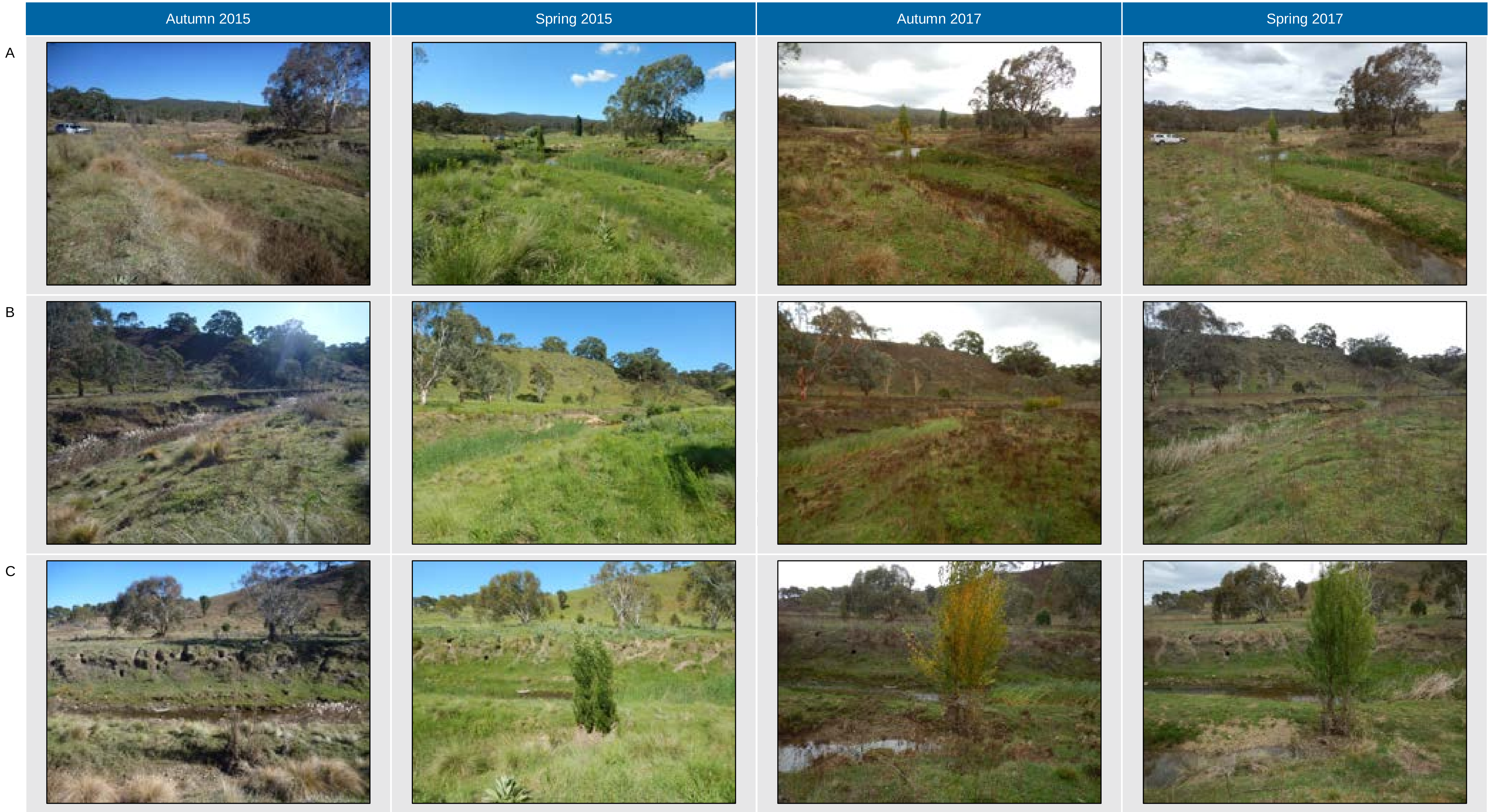


Plate 4-31 Geomorphology photo point 4 at BUR2c showing upstream (a), downstream (b) and across the channel (c) from autumn 2015 (left) to spring 2017 (right)

4.5 Macroinvertebrates

There were no riffle samples collected in this round of monitoring because of low flows and the absence of riffle habitat at both monitoring locations. The results from the edge habitat samples are presented below.

Since the last round of autumn monitoring (GHD, 2015e) taxa richness increased at both locations. There were five additional families collected at BUR1c, where taxa richness was 27 and one additional family at BUR2a, where taxa richness was 24 (Table 4-4). In contrast, EPT richness declined at both sites – by three families and 4 genera at BUR1c, which had 5 families and genera (Table 4-5) compared to eight families and nine genera in autumn 2015. BUR2c had six EPT taxa at both taxonomic levels compared to having seven families and nine genera in the last autumn reporting period.

Table 4-4. Number of taxa at family and genus level from riffle and edge habitats

Total Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
BUR1c	NS	NS	27 (22)*	29 (23)
BUR2a	NS	NS	24 (23)	29 (25)

Table 4-5. Number of EPT taxa at family and genus level from riffle and edge habitats

EPT Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
BUR1c	NS	NS	5 (8)	5 (9)
BUR2a	NS	NS	6 (7)	6 (9)

4.5.1 AUSRIVAS & SIGNAL-2

Despite the increase in taxa richness in the edge habitat at BUR1c, there was a decline in the average SIGNAL score for autumn 2018 (3.78) compared to autumn 2015 (4.5), indicating that there were more taxa which are tolerant to decreasing water quality were present. The mean SIGNAL score at BUR2c was also lower than the previous autumn monitoring round, but the decrease was not as pronounced as it was for BUR1c (See Appendix D).

AUSRIVAS results for both Burra Creek sites was Band B, though one of the subsamples from BUR2c returned a Band A. The resulting O/E50 scores for these sites show a significant decline in condition despite being still being assessed as Band B. In autumn 2015, the edge habitat was assessed as Band A at BUR1c, while at BUR2c, the resulting O/E50 scores that this site was at the higher end of the Band B band-width (Appendix D). The most obvious change between these monitoring periods is the change in flow conditions. The edge habitat in autumn 2018 was shallower, had a significantly reduced surface area and BUR1c was choked with macrophytes.

The increase in taxa richness, may have been a response of certain riffle taxa seeking refuge in the edge habitat during this hydrologically stressed period. The predicted/collected results from the AUSRIVAS model are presented in Appendix E, while a full taxonomic inventory can be found in Appendix F.

* Number in parentheses are the values from autumn 2015

Table 4-6. AUSRIVAS and SIGNAL-2 scores for autumn 2018

Site	Rep.	SIGNAL-2		AUSRIVAS O/E score		AUSRIVAS Band		Overall habitat assessment		Overall site assessment
		Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
BUR1c	**1**	NS	3.80	NS	0.78	NS	B	**NS**	**B**	**B**
	2	NS	3.78	NS	0.70	NS	B			
BUR2a	**1**	NS	4.55	NS	0.86	NS	A	**NS**	**B**	**B**
	2	NS	4.22	NS	0.70	NS	B			
	3	NS	4.44	NS	0.70	NS	B			

Table 4-7. Overall site assessments for Burra Creek sites since 2012

	Autumn 2012	Spring 2012	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014	Autumn 2015	Spring 2015*	Autumn 2018	Change since spring 2015
BUR1c	**B**	**B**	**B**	**B**	**B**	**A**	**B**	**X**	**B**	↓
BUR2a	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	↓

Note: * = calculated from mean O/E scores as recommended by GHD (2015).

4.6 Discussion

4.6.1 Water quality

Nutrient concentrations were all within the guideline values at BUR2c, compared to autumn 2015 where both NOx and total nitrogen concentration were above the recommended upper limit. At BUR1c, TN and TP were above the recommended guideline values in this monitoring period, which is likely to a be a consequence of the low flows meaning proportionally higher groundwater contribution, decomposing organic matter and less atmospheric aeration from flowing water. In the history of monitoring these sites, nutrient concentrations have tended to increase with decreasing flow; following runoff events and then conversely declined with time since previous runoff event.

EC was constantly above the guideline values at both sites, but is consistent with the historical range of values for Burra Creek particularly in autumn and summer.

Only two parameters did not meet the ANZECC & ARMCANZ (2000) guidelines at BUR2c in the autumn 2018 monitoring run. Of those, dissolved oxygen was only marginally below the guideline value of 90%. The most significant result was the low dissolved oxygen at BUR1c, which was all but depleted. Dissolved oxygen levels at this level can displace and impact the mortality of some biota unless they have traits capable of coping with low oxygen.

4.6.2 Photogrammetry

Periphyton

Periphyton has been included in the monitoring program for Burra Creek to monitor the effect which flow is having upon the 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.

Periphyton coverage was high at both sites, with >90% coverage across the reach and approximately 100% in the drying riffle habitat at both sites.

Vegetation

The use of photogrammetry for monitoring the change in the vegetation communities and coverage at the Burra Creek sites is considered to be 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 (2019), or with photos and observations recorded before and after the use of the M2G pipeline for operational purposes, should this occur within the next two years.

Significant new growth of vegetation was present across all sites monitored during spring 2015. Plant communities and composition observed in autumn 2017 were similar to previous assessments (GHD, 2015e; GHD, 2015f), with no noticeable increase in exotic species coverage. Significant channel encroachment was seen at both monitoring sites owing to the low flow conditions which have influenced much of the characteristics leading up to this monitoring period.

The main channel at BUR1c was severely impacted by macrophyte encroachment, meaning that the availability of edge and riffle habitat was significantly reduced. While there was some evidence of die-back, the increasing density of these macrophyte stands is going to require an increasing volume and flow to clear out the channel. There is a similar degree of encroachment occurring between the Williamsdale Road Bridge and the pool approximately 300m downstream of the bridge, which is significantly impairing the connectivity between channel units and potentially harbouring a large organic load which may further impact water quality.

Geomorphology

During the current maintenance phase of the M2G pipeline, the use of photogrammetry at the previously identified cross sections along Burra Creek are considered to be a robust method for the monitoring of potential changes in bank erosion and slumping. The photo points collected between autumn 2015 and spring 2017 will be used for comparison to future photo points (2019), or with photographs and observations recorded before and after the use of the M2G pipeline for operational purposes, should this occur within the next two years.

There were no signs of any significant geomorphological changes at the photo monitoring locations in Burra Creek between spring 2015 and the current monitoring period. The creek channel appeared to be stable as did the creek banks, with no obvious slumping or collapse observed from the photographs – even at the most vulnerable sites (i.e. Pool 29 and BUR2c).

4.6.3 Macroinvertebrates and AUSRIVAS

There were no riffle habitat samples collected in autumn 2018 due to low flow conditions and serve macrophyte encroachment into that habitat type.

Results from the edge habitat, while showing a decline in O/E50 scores (not AUSRIVAS Band), are indicative of the long term trends seen for these sites (Appendix D) and are comparable to the scores which occurred in autumn 2010 and 2011 when flows in Burra Creek were as low as they have been for the past 6 months.

The decline in SIGNAL-2 score in the edge habitat at BUR1c is due mainly to the absence of any taxa with SIGNAL scores greater than 6. As previously mentioned, the most significant result from the water quality analysis were the dissolved oxygen readings at BUR1c which showed approximately 5% saturation, which is likely to be one of the main reasons sensitive macroinvertebrate families were not collected from this location. One example is Leptophlebiidae (SIGNAL-2 = 8). Having external gills, they require flowing water or adequate levels of oxygen in the water for survival. This family was collected at BUR2c where dissolved oxygen was approximately 89%. At the time of sampling, base flows in Burra Creek had been declining for approximately 6 months, which has had an adverse effect on the quality of habitat which in turn has resulted in a decline in water quality and some of the key macroinvertebrate indicators used in this monitoring program. These changes are all natural and are not considered to be related to M2G.

5. Murrumbidgee Pump Station

5.1 Summary of sampling and river conditions

Both sites related to the Murrumbidgee Pump Station were sampled on 4 May 2018. Weather conditions were overcast in the morning, but cleared in the afternoon (Plate 5-1). The maximum temperature recorded at Canberra airport was 16.5°C (B.O.M, 2018).

Mean daily flow on the day was recorded at 55 ML/d at the Lobb's Hole gauging station (410761) and 108 ML/d at the Mt. MacDonald gauging station (410738) (Plate 5-2 and Plate 5-3).

One riffle and one edge sample was collected from each site. Site photographs are presented in Plate 5-1. Site summaries can be found in Appendix B, while the AUSRIVAS habitat data are available in Appendix C.

MUR28: Looking upstream (left) and looking downstream (right)

MUR935: Looking upstream (left) and looking downstream (right)

Plate 5-1. Photographs of the Murrumbidgee Pump Station sites during autumn 2018 sampling

5.2 Hydrology and rainfall

Total rainfall in autumn 2018 was 102.4 mm, which was less than half of that which fell in autumn 2015 (231.9mm). April was a particularly dry month, when only 8.2mm was recorded, making it the driest April since 2004 (2.6mm).

Full Rainfall and flow summaries for upstream and downstream of Angle Crossing in autumn 2018 are presented in Table 5-1 and Figure 5-1.

At the time of sample collection, the Murrumbidgee River was flowing below the long term median flow of 507 ML/d: (calculated for the period 2008-2018) at Mount MacDonald. Flows on the day of sampling were receding following a small rainfall event in late April (Figure 5-1). A number of environmental flows were manipulated from the Cotter Dam in April, which would have influenced MUR935, but not MUR28. The hydrograph for this period is shown in Figure 5-2.

March showed the most hydrological variability when there were peaks in the hydrograph of ~250 ML/d upstream of the Cotter River confluence and approximately 350 ML/ d at Mount MacDonald. While relatively large events in the context of the remaining period, historically these were minor events.

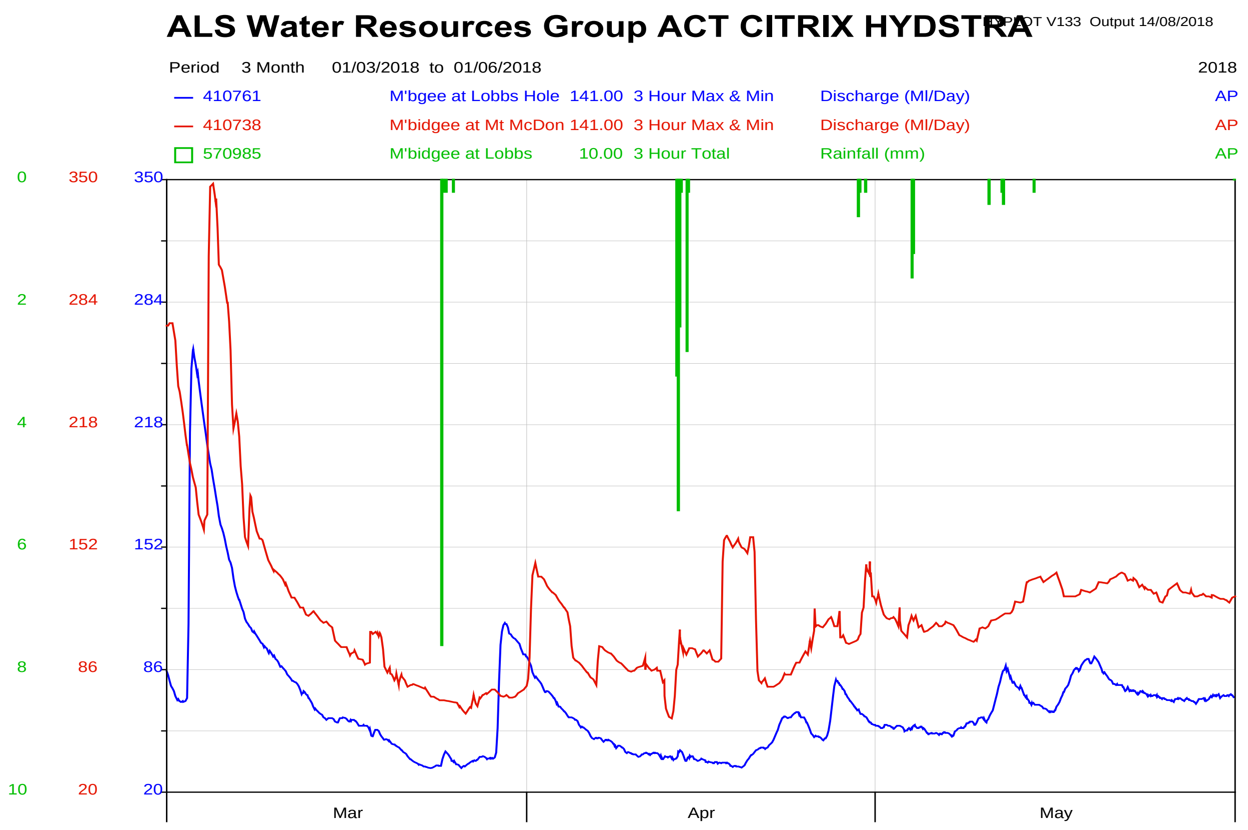


Figure 5-1. Autumn hydrograph of the Murrumbidgee River at Lobb's Hole (410761) and Mt. MacDonald (410738), including total rainfall for Lobb's Hole rain gauge (570985) from autumn 2018

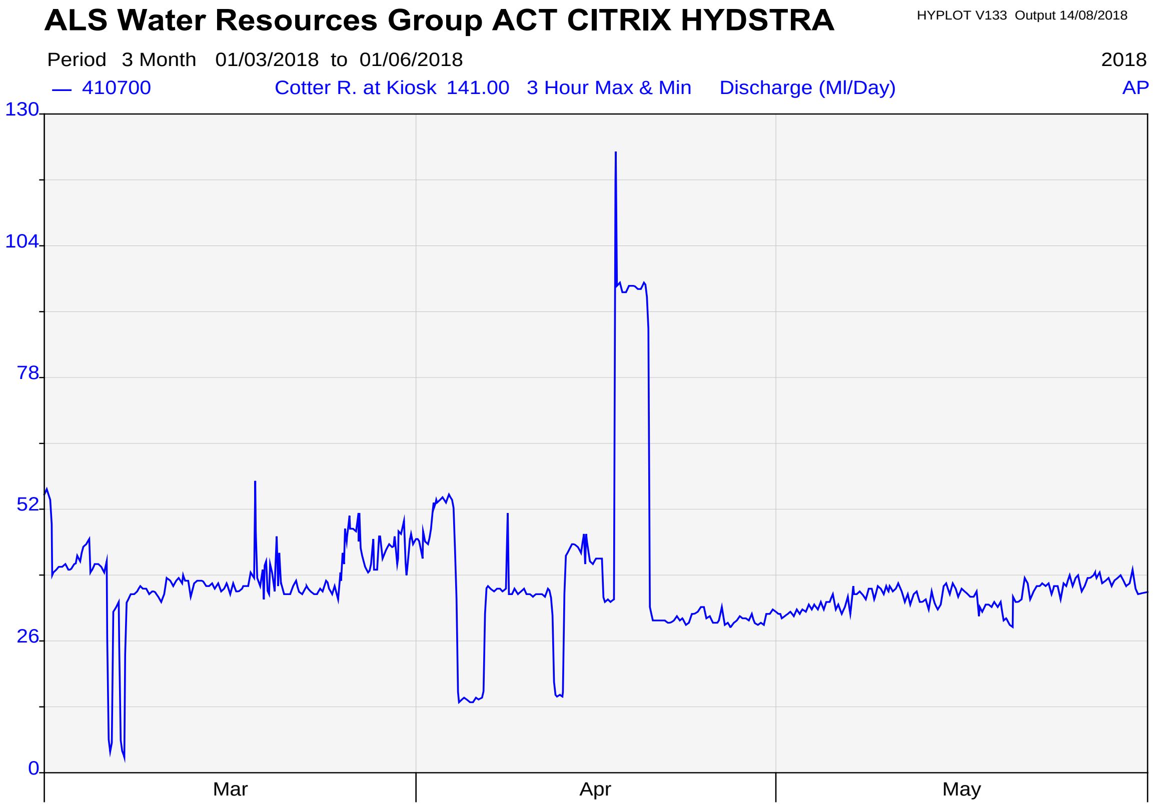


Figure 5-2. Hydrograph for the Cotter River downstream of the Cotter Dam (410700) for autumn 2018

Table 5-1. Autumn rainfall and flow summaries upstream and downstream of the MPS

	Lobb's Hole (410761)		Mt. MacDonald (410738)
	Rainfall Total (mm)	Mean Flow (ML/d)	Mean Flow (ML/d)
March	79.0	81.3	132.2
April	8.2	53.5	101.7
May	15.2	67.6	122.3
Autumn (mean)	102.4 (34.1)	67.8	118.9

2015 - 510 ML/d (19/5/2015)

2018 - 108 ML/d (4/5/2015)

Plate 5-2. The Murrumbidgee River upstream of the Cotter Road bridge and the MPS in autumn 2015 (top) and 2018 (bottom)

Note: Flow is mean daily flow recorded at Mt. MacDonald (410738)

2015 - 510 ML/d (19/5/2015)

2018 - 108 ML/d (4/5/2015)

Plate 5-3. The Murrumbidgee River downstream of the Cotter Road bridge, MPS on the right bank, in autumn 2015 (top) and 2018 (bottom)

Note: Flow is mean daily flow recorded at Mt. MacDonald (410738)

5.3 Water quality

5.3.1 Grab samples and *in-situ* parameters

The *in-situ* and grab sample water quality results are presented in Table 5-2. Like the previous autumn monitoring period, most of the parameters were within the ANZECC & ARMCANZ (2000) guidelines at both sites. The only exception was pH, which was marginally above the recommended upper value of 8.0 at MUR28.

Table 5-2. *In-situ* water quality results from MPS sites during autumn 2018

	Site	Date	Time	Temp. (°C)	EC (µs/cm) (30-350)	Turbidity (NTU) (2-25)	pH (6.5-8)	D.O.(% Sat.) (90-110)	D.O. (mg/L)	Alkalinity (mg/L)
Upstream	MUR28	4/5/2018	09.00	14.6	158.3	3.07	8.06	99.1	9.53	75
Downstream	MUR 935	4/5/2018	10.20	15.1	130.5	3.25	7.96	99.3	9.56	75

Note: ANZECC and ARMCANZ (2000) guidelines are in yellow parentheses; yellow cells indicate values outside of the guidelines

5.3.2 Continuous water quality monitoring

Lobb's Hole is the closest water quality gauging station to MUR28 and MUR935 and is used in this, the MPS component of the MEMP monitoring. Results from the gauged water quality data from Lobb's Hole have already been summarised in section 3.3.2, but if this is being read independently of the rest of the report, the continuous water quality results for Lobb's Hole in autumn 2018 are summarised below.

The continuous water quality monitoring from Lobb's Hole (410761) are presented in Figure 5-3. Turbidity at Lobb's Hole and upstream of Angle Crossing were relatively consistent during autumn. There was a spike in early March at Lobb's Hole, which was in response to the small rainfall event. There were no exceedances in turbidity at either location during autumn. pH was typically above the upper ANZECC value of 8.0 during autumn, with 62% of the daily mean values in exceedance of pH 8.0. There were no exceedances in electrical conductivity at either location. Dissolved oxygen was below the 90 % saturation 50% of the time at the upstream site (based on daily means) and only 9% of the time 99 days) at Lobb's Hole, which may be due to the location of the probes at either site because there was nothing observed on site which may have caused these differences.

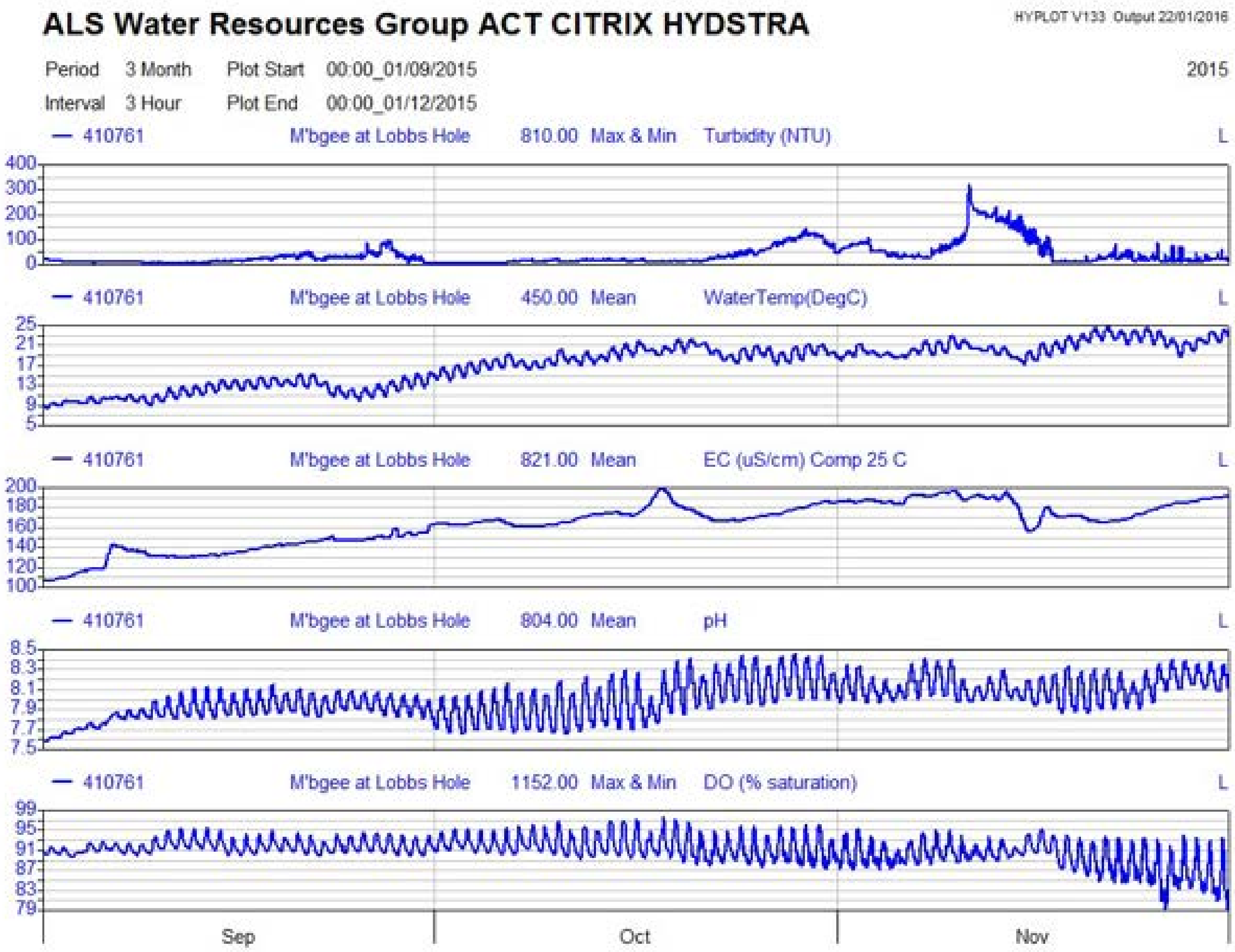


Figure 5-3. Continuous water quality records from Lobb's Hole (410761) for autumn 2018

5.4 Photogrammetry

5.4.1 Periphyton

MUR28

Periphyton coverage in the riffle habitat ranged from 80% to 95% coverage, giving it a category class of 65-90 % based on the average cover, which is the same categorisation as the site was given in autumn 2015. *Myriophyllum* spp. was the only submerged macrophyte species observed at this site and it had a very patchy distribution (<10% for the entire riffle habitat).

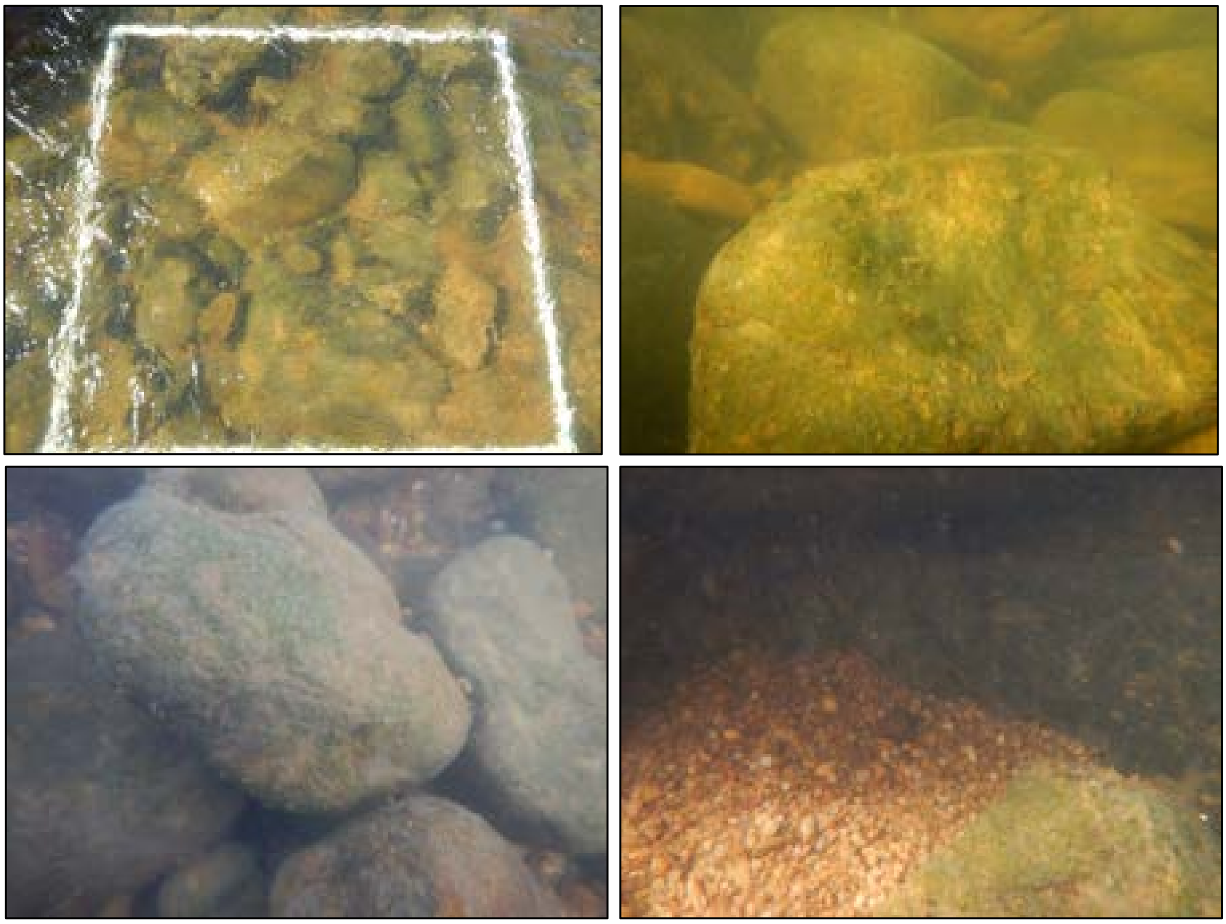


Plate 5-4. Photos showing periphyton coverage in the riffle at MUR28

MUR935

In autumn 2018, periphyton cover was approximately 35-65% in the reach and between 65-90% in the riffle, based on the average of five quadrat observations (Plate 5-5). Filamentous algae growth was present, but was restricted to the margins and slower moving sections of the riffle (mainly at the head). At the time of the autumn 2015 monitoring at MUR935, periphyton cover was estimated to be approximately 90% in the riffle, with 65-90% in the reach. *Myriophyllum* spp. was also noted as being present, but like MUR28, patchy in its distribution.

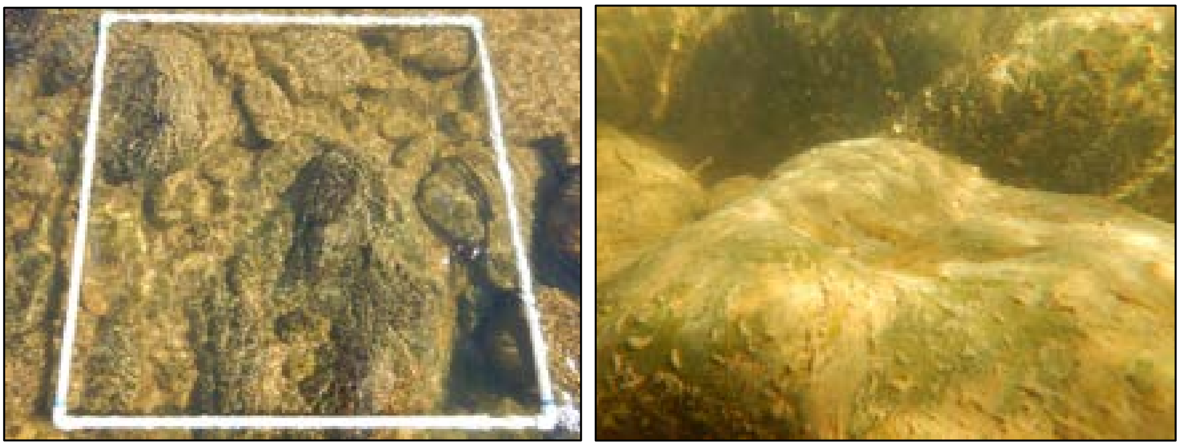


Plate 5-5. Photos showing periphyton coverage in the riffle at MUR935

5.5 Macroinvertebrates

There were two fewer families at MUR28 and four genera compared to the previous autumn monitoring period in 2015 (Table 5-3). In contrast, there was an increase of six families from the riffle at MUR935 and an increase of eight genera. Sensitive EPT taxa increased by one family and two genera at MUR28, but increased by one family and two genera at MUR 935 (Table 5-4).

In the edge habitat, there were increases in family and genus richness at both sites. At MUR28, EPT taxa increased by one family but declined by four genera (Table 5-4). At MUR935, the number of EPT taxa remained the same, but the number of EPT genera decreased by three.

All of the sensitive mayflies (i.e. Leptophlebiidae) which were collected, were found at both locations. The sensitive Stonefly (Gripopterygidae [Signal=8]) and the sensitive Caddisfly (Glossosomatidae [Signal=9]) were only found in the riffle habitat at MUR935.

Table 5-3. Number of taxa at family and genus level from riffle and edge habitats

Total Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
MUR28	19 (21)	20 (24)	24 (23)	31 (29)
MUR935	22 (16)	27 (19)	24 (21)	27 (25)

Table 5-4. Number of EPT taxa at family and genus level from riffle and edge habitats

EPT Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
MUR28	6 (7)	8 (10)	8 (7)	9 (13)
MUR935	8 (7)	12 (10)	8 (8)	9 (12)

5.5.1 AUSRIVAS & SIGNAL-2

Despite the variation in taxa richness at both sites, the AUSRIVAS bands remained the same (Band A) for both habitats and both sites (Table 5-5), which remains at Band A when compared to autumn 2015 (Table 5-6).

Between locations, there no obvious differences in the AUSRIVAS assessment. Both sites had close to reference macroinvertebrate communities. The main difference was that absence of Gripopterygidae from MUR28, and the absence of Tipulidae from MUR935 (Appendix E).

Average SIGNAL-2 scores were higher at the downstream site, MUR935, in the riffle habitat scoring compared to MUR28, owing to the presence of Gripopterygidae (Signal=8) and the sensitive Glossosomatidae (Signal=9).

Table 5-5. AUSRIVAS and SIGNAL-2 scores for autumn 2018

Site	Rep.	SIGNAL-2		AUSRIVAS O/E score		AUSRIVAS Band		Overall habitat assessment		Overall site assessment
		Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
MUR28	1	4.56	4.42	1.00	0.94	A	A	**B**	**A**	**B**
	2	4.56	4.69	1.00	1.02	A	A			
	3	4.56	4.45	1.00	0.86	A	A			
MUR935	1	4.89	4.18	1.00	0.88	A	A	**B**	**A**	**B**
	2	4.63	4.18	0.89	0.88	A	A			
	3	4.41	4.18	0.89	0.88	A	A			

Note: All MPS edge replicates were "nearly outside the experience of the model" (see Coysh et al. (2000) for details).

Table 5-6. Overall AUSRIVAS assessments for MPS sites since 2011

	Autumn 2011	Spring 2011	Autumn 2012	Spring 2012	Autumn 2013	Autumn 2015	Spring 2015	Autumn 2018	Change since spring autumn 2015
MUR28	**B**	**B**	**B**	**B**	**B**	**A**	**B**	A	↔
MUR935	**B**	**B**	**NRA**	**B**	**B**	**A**	**B**	A	↔

5.6 Discussion

5.6.1 Water quality

Water quality at the Murrumbidgee Pump Station sites showed an exceedance of pH at MUR28; however it should be noted that this value is not considered high in relation to the historical records from this site.

There is no indication of any lasting impacts related to the MPS or the releases from the Cotter Dam in April as the water quality parameters at both locations are highly comparable; although there is some dilution effect on EC evident at MUR935, but this effect is minimal as there is only a 20 us/cm difference between the two sites.

5.6.2 Photogrammetry

Periphyton

Periphyton has been included in the monitoring program for MPS to monitor the effect which flow is having upon the algal communities downstream of the abstraction point. The aim of this monitoring is to see, during operational pumping whether algal communities downstream of the MPS are increasing compared to upstream sites due to the reduction in flow through abstraction.

The photographs provided in section 5.4.1 provide an overview of the periphyton coverage using both quadrat and underwater aspects at both sites. The coverage at MUR28 and MUR935 for the overall reach and for the riffle habitat is consistent with that observed during autumn 2015 (GHD, 2015e). There are no obvious differences between locations, which will provide valuable baseline assessment data for future assessments, should MPS be in operational mode.

5.6.3 Macroinvertebrates and AUSRIVAS

Overall there were some minor differences in the taxa richness metrics between locations. There were some sensitive taxa collected at MUR935, which were not collected at MUR28. Two potential explanations for this is that the habitat quality at MUR935 was more compatible with the requirements of these taxa; however, although there was an overall increases in the site quality assessment score at MUR935 (increased from 98 to 104 since autumn 2015), but there was an equal increase at MUR28 (Appendix B) meaning that if improvement in habitat quality was the reason for the presence of Glossosomatidae and Gripopterygidae these taxa could be expected to be found at both sites given the sites proximity to on one another. The other potential explanation is that the environmental releases from the Cotter Reservoir either relocated some individuals from the Cotter River, or the additional flow over this site facilitated their local colonisation.

The variation in taxa richness and EPT richness did not change the AUSRIVAS bands from the previous autumn monitoring period as both sites and habitats are still assessed as Band A.

6. Conclusions

The purpose of the sentinel monitoring program is to provide a broad scale assessment of control and impact sites related to the Angle Crossing abstraction point, the discharge weir in Burra Creek and the Murrumbidgee Pump Station (MPS), located just downstream of the Cotter Road bridge. Specifically this program aims to *“provide confidence that the condition of the potential impact sites is broadly similar to non-impact sites across time”.*

Compared to the monitoring period in autumn 2015, the AUSRIVAS bands in this monitoring period are largely the same, despite a prolonged period of low flows in the region.

The Burra Creek sites were the most affected by the low flows, which was evidenced by the absence of riffle habitat and degrading water quality in the edge habitat, leading to some stress on the macroinvertebrate communities in terms of low numbers of EPT taxa and taxa with SIGNAL scores greater than 7. As well as declining water quality, the quality of the habitat was also in decline due to severe encroachment of the main channel by macrophytes. The overall site assessment for the Burra Creek sites was Band B at both sites, which is equivalent to the assessment in the previous autumn sampling (in 2015). However, there was a decline in the condition in the edge habitat at BUR1c from and A to Band B, which agrees with the observations relating to declining water and habitat quality.

In the Murrumbidgee River at Angle Crossing, the impacts of the prolonged low flow period were not evident from the macroinvertebrate assessment, as both sites had significant numbers of highly sensitive taxa and rheophilic (living in, or preferring, flowing water) taxa. The AUSRIVAS Bands were similar to previous autumn sampling runs, where Murrumbidgee flows have been higher. There were some areas in both reaches were macrophyte growth was exceeding 90% and there were some patches of large green filamentous algae, which can be indicative of low flow conditions. Water quality at Angle Crossing was normal (for these sites) and mostly within the ANZECC guideline recommendations.

The geomorphology photographic monitoring showed that the banks and channel features remained relatively stable over the four time periods that this monitoring has occurred. Between spring 2015 and autumn 2017 there has been some sand deposition upstream of the off-take, on the eastern side of the river, but otherwise, there have been no observable changes at the key photo point locations.

The MPS monitoring sites appeared to be the least affected by the ongoing low flow conditions in the broader catchment. This is likely due to the position in the catchment and also because MUR935 benefits from the releases from the Cotter Reservoir. Both sites were assessed as Band A, and both sites had high numbers of EPT and also a reasonable diversity of highly sensitive taxa. Photograph records of the current flow conditions compared to the previous sampling round show a definite change in water level, but this appears to have not affected the river health based on the current AUSRIVAS results.

There are no new recommendations to be put forward for the MEMP at this stage.

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Appendices

Appendix A - QC/QC results

Macroinvertebrate Identification QA/QC Data Sheet

Identifier: CA Processing Date: 6.7.18

Project #: 2316216 LIMS/Sample #: 113576 Sample Code: 111MVR19P

Site Name: Murrumbidgee River Site Code: MVR19

Collection Date: 3.5.18 Method/Habitat: Sweep Collected By: JC

Taxonomic Id Level: Genus Pass/Fail Rate: 92 % QA/QC By: ZB

Incorrect Identification	Correct Identification	Error Code

Number of Taxa (species/families): 20
Number Identified Incorrectly: 0
Percentage Correct: 100 %
Pass or Fail: Pass

Training Received For Incorrect Taxa? (Yes/No) QA Date: 11.7.18

Senior Taxonomist Identifier

Notes:
Please refer to .\General\Ecology Files\Quality Assurance\Quality Assurance for the Victorian River Health Program.pdf for an explanation of how rates are calculated.

Error Codes:
1. ID adult/larvae not identified
2. Complete misidentification
3. Could *reasonably* be identified to a finer taxonomic resolution
4. Identification has been taken too far based on specimen condition (small or damaged)*
5. Miscount*
6. Taxon not recorded on the data sheet
7. Inappropriate Identification based on larval exuviae, shells or if the specimen was obviously dead when collected

* These are NOT included in error rate calculations

Macroinvertebrate Identification QA/QC Data Sheet

Identifier: ZB Processing Date: N/A

Project #: 2316216 LIMS/Sample #: 113575 Sample Code: 111MUR19R

Site Name: Murrumbidgee River Site Code: MUR19R

Collection Date: 3/5/18 Method/Habitat: Kick/Riffle Collected By: JC

Taxonomic Id Level: Genus/FAM Pass/Fail Rate: 92% QA/QC By: CA

Incorrect Identification	Correct Identification	Error Code
—	—	

Number of Taxa (species/families): 29
Number Identified Incorrectly: 0
Percentage Correct: 100
Pass or Fail: PASS

Training Received For Incorrect Taxa? (Yes/No) QA Date: 11/7/18

Senior Taxonomist Identifier

Notes:
Please refer to .\General\Ecology Files\Quality Assurance\Quality Assurance for the Victorian River Health Program.pdf for an explanation of how rates are calculated.

Error Codes:
1. ID adult/larvae not identified
2. Complete misidentification
3. Could *reasonably* be identified to a finer taxonomic resolution
4. Identification has been taken too far based on specimen condition (small or damaged)*
5. Miscount*
6. Taxon not recorded on the data sheet
7. Inappropriate Identification based on larval exuviae, shells or if the specimen was obviously dead when collected

* These are NOT included in error rate calculations

Appendix B - Site summaries

Part 1: Angle Crossing

MUR18

Upstream Angle Crossing
3/5/2018 0950

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	Alkalinity (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
13	130.5	6.3	74	7.8	96.2	9.5

Mean Daily Flow: 55 ML/d

Recorded at the closest station (41001702), located on the Murrumbidgee River at upstream Angle Crossing.

Compared to previous monitoring periods:

Autumn 2015: ↓ Spring 2015: ↓

AUSRIVAS Results

	Autumn 2015	Spring 2015	Autumn 2018
Riffle Habitat	NRA	A	A
Edge Habitat	B	X	B
Overall Site Assessment	B	A	B

Riffle Habitat

- Silt and sand deposition in riffle habitat
- Change to channel following event in 2015 has seen some change to the channel units (
- Dominant substrate was cobble

Dominant Taxa

- Simuliidae
- Chironominae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Hydrobiosidae
- Elmidae
- Leptophlebiidae
- Gripopterygidae

Additional Comments

- Substrate had thick deposits of silt and periphyton
- *Myriophyllum* sp. was highly abundant

Edge Habitat

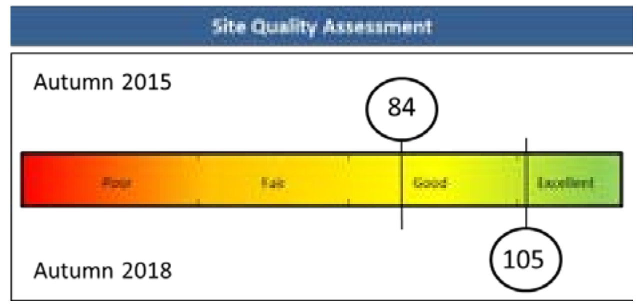
- Dominant trailing bank vegetation was overhanging native shrubs and roots

Dominant Taxa

- Hydroptlidae
- Chironominae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae



*Site assessment scores are derived from ACT AUSRIVAS field habitat sheets

MUR19

Downstream Angle Crossing
3/5/2018 1045

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	Alkalinity (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
12.5	129	4.5	79	7.7	98.0	9.7

Daily Flow: 55 ML/day

Recorded at the closest station (410761), located on the Murrumbidgee River at Lobb's Hole.

Compared to previous monitoring periods :

Autumn 2015: ↓ Spring 2015: ↓

AUSRIVAS Results

	Autumn 2015	Spring 2015	Autumn 2018
Riffle Habitat	B	NRA	B
Edge Habitat	B	A	B
Overall Site Assessment	B	A	B

Riffle Habitat

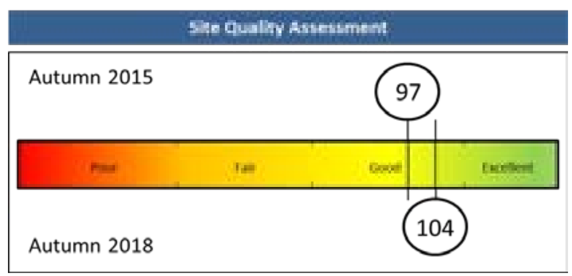
- *Myriophyllum* sp. was abundant and in places completely smothered the substrate
- Dominant substrate was pebble and cobble

Dominant Taxa

- Bivalvia
- Baetidae
- Simuliidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae



Edge Habitat

- Very few submerged macrophytes were present within the edge habitat
- Dominant trailing bank vegetation was overhanging

Dominant Taxa

- Hydroptilidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae

Additional Comments

The river level was very low at the time of sampling

Part 2: Burra Creek

BUR1c

Upstream Williamsdale Road
3/5/2018 1230

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	TDS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
13.0	472.9	21	NA	7.4	5.3	0.44

Alkalinity (mg/L)	NO_x (mg/L)	TKN (mg/L)	TP (mg/L)	TN (mg/L)	Total Iron (mg/L)	Total Manganese (mg/L)
236	<0.05	1.04	0.12	1.04	32.4	1.87

Daily Flow: 0.9 ML/day

Recorded at the closest station (410774), located on Burra Creek at Burra Road.

Compared to previous monitoring periods :

Autumn 2015:

Spring 2015:

AUSRIVAS Results

	Autumn 2015	Spring 2015	Autumn 2018
Riffle Habitat	B	X	NS
Edge Habitat	A	X	A
Overall Site Assessment	B	X	B

Riffle Habitat

- Poor quality, highly silted habitat
- Dominant substrate was silt

Dominant Taxa

- Not sampled

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Not sampled

Edge Habitat

- Dominant trailing bank vegetation was macrophytes (mainly *Schoenoplectus validus*)

Dominant Taxa

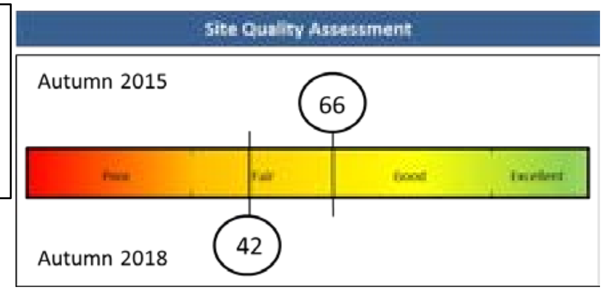
- Chironomidae
- Veliidae
- Baetidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- None present

Additional Comments

The channel was heavily inundated with macrophytes. Little to no flow and very poor habitat – both riffle and edge.



BUR2a

Downstream Williamsdale Road
3/5/2018 1320

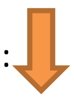
Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	TDS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
11.4	397	8.2	NA	7.6	89.3	8.9

Alkalinity (mg/L)	NO_x (mg/L)	TKN (mg/L)	TP (mg/L)	TN (mg/L)	Total Iron (mg/L)	Total Manganese (mg/L)
270	<0.05	0.22	0.01	0.22	0.97	0.09

Daily Flow: 0.9 ML/day

Recorded at the closest station (410774), located on Burra Creek at Burra Road.

Compared to previous monitoring periods:

Autumn 2015: 

Spring 2015: 

AUSRIVAS Results

	Autumn 2014	Spring 2015	Autumn 2018
Riffle Habitat	B	A	NS
Edge Habitat	B	A	B
Overall Site Assessment	B	A	B

Riffle Habitat

- Highly silted habitat
- Dominant substrate is cobble and silt

Dominant Taxa

- Not sampled

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Not sampled

Edge Habitat

- Dominant trailing bank vegetation was macrophytes (mainly *Phragmites australis* and *Schoenoplectus sp.*)

Dominant Taxa

- Baetidae
- Chironomidae
- Hydroptlidae

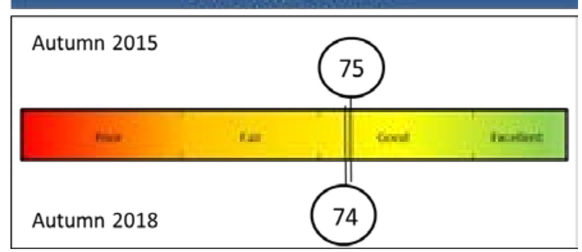
Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae

Additional Comments

High density macrophyte stands encroaching the reach from Williamsdale Road Bridge to approximately 300m downstream of the bridge. High silt content in the channel.

Site Quality Assessment



Part 3: Murrumbidgee Pump Station

MUR28

Upstream Cotter River Confluence
4/5/2018 0900

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	Alkalinity (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
14.6	158.3	3.1	80	8.06	99.1	9.5

Daily Flow:

55 ML/day
Recorded at station 410761, located on the Murrumbidgee River at Lobb's Hole.

108 ML/day
Recorded at station 410738, located on the Murrumbidgee River at Mt. MacDonald.

32 ML/day
Recorded at station 410700, located on the Cotter River at Cotter Kiosk (below the Enlarged Cotter Dam).

The variation in flows down the Cotter River limit the comparability of this site's flow between seasons, which is further complicated by the operation of the Bendora Scour Valve.

Riffle Habitat

- Dominant substrate was boulder and sand

Dominant Taxa

- Baetidae
- Chironominae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Hydrobiosidae
- Elmidae

Edge Habitat

- Dominant trailing bank vegetation was overhanging *Casuarina sp.* and blackberry

Dominant Taxa

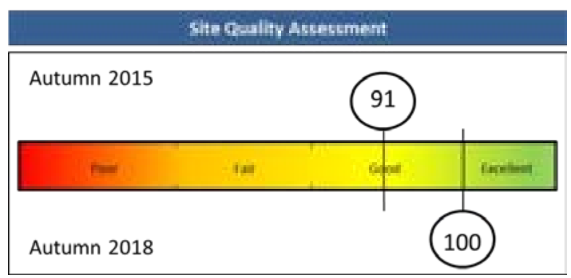
- Corixidae
- Chironominae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae

AUSRIVAS Results

	Autumn 2015	Spring 2015	Autumn 2018
Riffle Habitat	A	B	A
Edge Habitat	A	A	A
Overall Site Assessment	A	B	A



Additional Comments

Very low water level. Sparse edge habitat. A number of bedrock bars exposed farther upstream.

MUR935

Casuarina Sands
4/5/2018 1020

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	Alkalinity (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
15.1	130.5	3.2	85	7.9	99.3	9.4

Daily Flow:

55 ML/day
Recorded at station 410761, located on the Murrumbidgee River at Lobb's Hole.

108 ML/day
Recorded at station 410738, located on the Murrumbidgee River at Mt. MacDonald.

32 ML/day
Recorded at station 410700, located on the Cotter River at Cotter Kiosk (below the Enlarged Cotter Dam).

The variation in flows down the Cotter River limit the comparability of this site's flow between seasons, which is further complicated by the operation of the Bendora Scour Valve.

AUSRIVAS Results

	Autumn 2015	Spring 2015	Autumn 2018
Riffle Habitat	A	B	A
Edge Habitat	A	A	A
Overall Site Assessment	A	B	A

Riffle Habitat

- Dominant substrate is cobble

Dominant Taxa

- Baetidae
- Caenidae
- Chironominae
- Simuliidae
- Hydropsycidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Glossosomatidae (9)
- Hydrobiosidae

Additional Comments

- Periphyton coverage was high throughout the site. Some large sand deposits on the right hand bank, further limiting the available edge habitat.

Edge Habitat

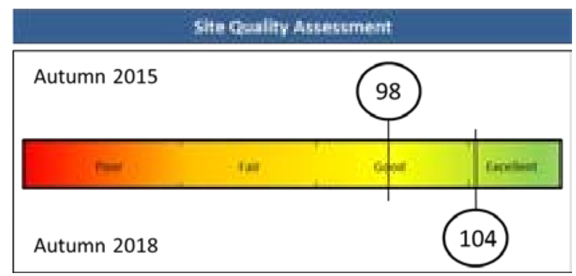
- High levels of detritus present in this habitat
- Dominant trailing bank vegetation was overhanging native shrubs and *Casuarina* sp.

Dominant Taxa

- Corixidae
- Chironominae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae



Appendix C - AUSRIVAS habitat information

Appendix C1. AUSRIVAS habitat information collected on site during autumn 2018

Site Code	BUR1c	BUR2a	MUR18	MUR19	MUR28	MUR935
Date	3/05/2018	3/05/2018	3/05/2018	3/05/2018	4/05/2018	4/05/2018
Time	12.30	13.20	9.50	10.45	9.00	10.20
Season	Autumn	Autumn	Autumn	Autumn	Autumn	Autumn
River	Burra Creek	Burra Creek	Murrumbidgee River	Murrumbidgee River	Murrumbidgee River	Murrumbidgee River
Location	upstream Williamsdale Road	downstream Williamsdale Road	upstream Angle Crossing	downstream Angle Crossing	upstream Cotter River Confluence	Casuarina Sands
Weather	fine	fine	fine	fine	rain	overcast and windy
Cloud cover (%)	20	20	0	10	100	60
Rain during the previous week?	yes	yes	yes	yes	yes	yes
Bank Height (m)	1.5	2.5	1.5	2	2	2
Bank Full Width (m)	18	28	100	100	100	80
Mode Stream Width (m)	2	3	22	30	24	36
Length of Reach	180	280	1000	1000	1000	800
Habitat in Reach						
% Riffle	0	0	20	30	5	10
% Pool	5	80	30	20	30	20
% Run	0	20	50	70	65	70
% Edge	10	30	10	15	10	5
% Macrophyte	100	90	10	15	5	5
Mean Riffle Depth (cm)	1.0	0.0	9.3	11.0	14.0	9.3
Mean Riffle Velocity (m/s)	0.0	0.0	0.7	0.7	0.6	0.4
Mean Edge Depth (m/s)	39.0	65.0	35.3	45.0	25.6	33.3
Mean Edge Velocity (m/s)	0.0	0.0	0.1	0.1	0.1	0.1
Riparian Vegetation						
Mean Riparian Width (m)	2	1.5	7.5	5	5	5
% Trees >10m	1	10	10	5	20	50
% Trees <10m	2	10	30	25	35	30
% Shrubs	5	20	50	70	30	40

% Grasses/Ferns/Sedges	90	90	20	30	30	60
% Shading	<5	6 - 25	< 5	< 5	< 5	< 5
% Native	30	40	30	60	70	70
% Exotic	70	60	70	40	30	30
Observations						
Water Odours	normal	normal	normal	normal	normal	normal
Water Oils	normal	normal	none	none	none	none
Turbidity	clear	clear	clear	clear	slight	clear
Plume	lots	lots	some	some	little	some
Sediment Oils	light	absent	absent	absent	absent	absent
Sediment Odours	normal	normal	normal	normal	normal	normal
Flow Level	No flow	low	low	low	low	low
Sediment Deposits	silt	none	sand, cobble, gravel	sand, silt	sand, silt	sand, silt
Local Erosion	moderate	moderate	moderate	some	some	some
Point Source Pollution	no	M2G, road	no	crossing, M2G	no	bridge, MPS, bendora scour valve, cotter confluence
Non Point Source Pollution	agriculture	agriculture	agriculture	agriculture	agriculture	agriculture, recreation
Dams/Barriers	no	no	no	no	no	no
River Braiding	no	no	no	no	no	no
Site Classification	broad valley	broad valley	steep valley	steep valley	steep valley	steep valley
Left Bank Land Use	grazing	grazing	grazing, native grassland (no grazing)	native forest	native forest	native forest
Right Bank Land Use	grazing, residential	grazing	native forest, native grassland (no grazing)	native forest, industrial	native forest, industrial	native forest, industrial, recreational
% Bar Cover	0	0	5	0	5	5
Reach - Substratum Description						
% Bedrock	0	10	10	5	20	30
% Boulder	0	15	10	10	20	10

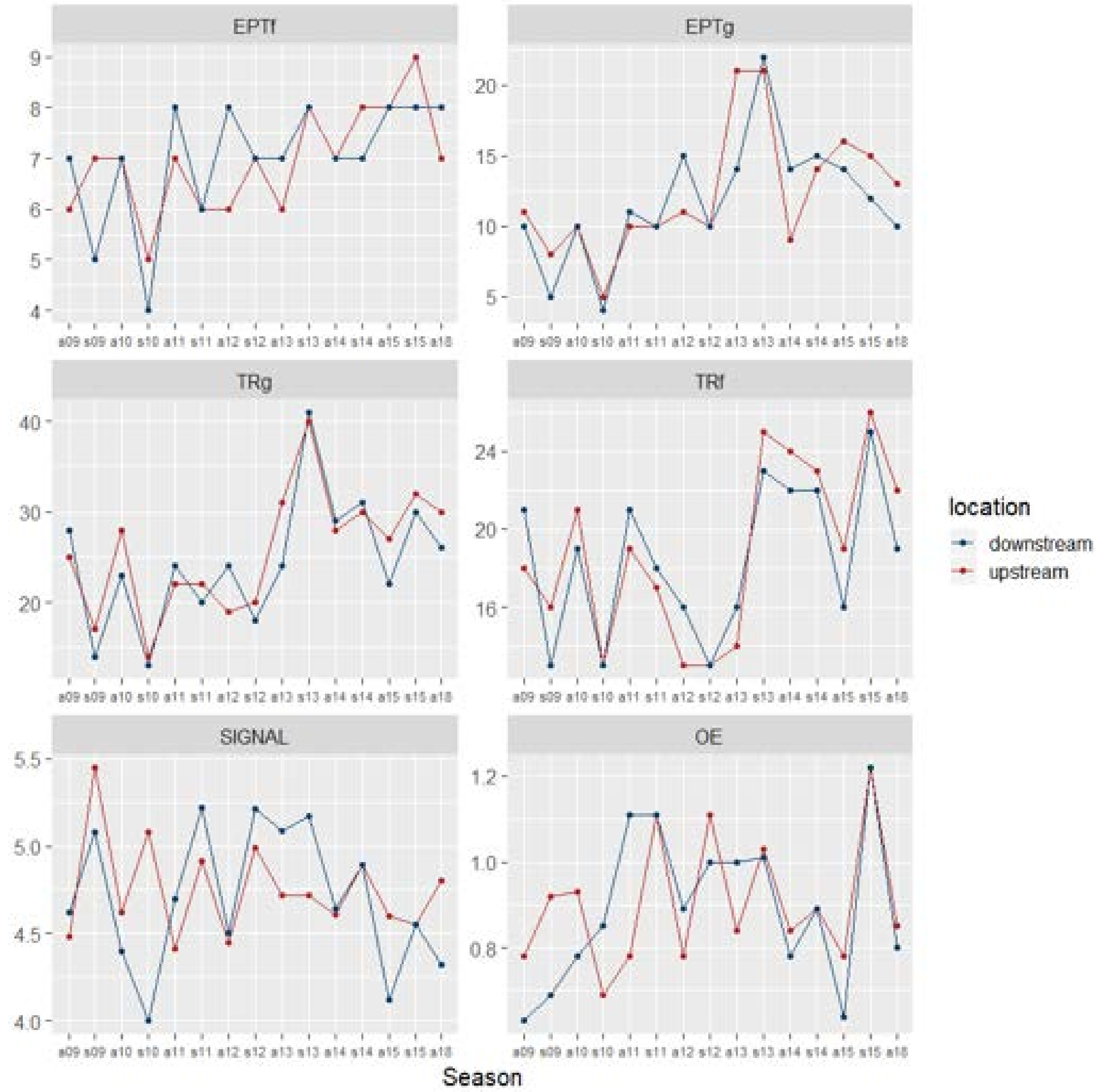
% Cobble	20	20	30	30	15	20
% Pebble	10	10	5	15	10	10
% Gravel	10	10	5	10	10	5
% Sand	20	5	30	20	20	15
% Silt	40	20	10	10	5	10
% Clay	0	10	0	0	0	0
% Detritus	20	15	10	10	10	10
% Muck/Mud	35	20	10	5	5	10
% Periphyton	65 - 90	> 90	65 - 90	35 - 65	35-65	35-65
% Moss	< 10	< 10	< 10	< 10	< 10	< 10
% Filamentous Algae	< 10	< 10	< 10	< 10	10-35	10-35
% Macrophytes	> 90	35 - 65	10 - 35	10-35	< 10	10-35
Riffle - Sustratum Description						
% Bedrock	0	10	5	0	20	10
% Boulder	0	15	10	5	10	20
% Cobble	5	30	50	40	30	40
% Pebble	5	0	15	15	15	10
% Gravel	0	15	15	10	15	5
% Sand	0	0	10	25	5	10
% Silt	80	30	5	5	5	5
% Clay	10	0	0	0	0	0
% Detritus	10	15	15	10	5	10
% Muck/Mud	20	15	5	5	0	5
% Periphyton	100	65 - 90	65-90	35 - 65	65 - 90	35 - 65
% Moss	< 10	< 10	< 10	< 10	< 10	< 10
% Filamentous Algae	65-90	< 10	< 10	< 10	< 10	< 10
% Macrophytes	100	10 - 35	10 - 35	35 - 65	< 10	< 10
Edge - Substratum Description						
% Bedrock	0	10	0	0	30	5
% Boulder	0	10	5	10	30	10
% Cobble	10	10	10	10	5	50
% Pebble	5	5	15	30	5	15
% Gravel	5	5	15	5	5	10
% Sand	0	10	35	25	10	5
% Silt	75	50	15	15	15	5
% Clay	5	0	5	10	0	0

% Detritus	30	10	20	20	20	5
% Muck/Mud	40	20	10	10	10	5
% Periphyton	100	> 90	100	65-90	100	35-65
% Moss	< 10	< 10	< 10	< 10	< 10	< 10
% Filamentous Algae	65-90	10-35	35-65	35-65	10-35	< 10
% Macrophytes	100	65-90	65-90	10 - 35	< 10	< 10
Macrophytes						
Submergent / Floating	yes	yes	yes	yes	yes	yes
Emergent	yes	yes	yes	yes	yes	yes
Habitat score	42	71	105	104	100	104

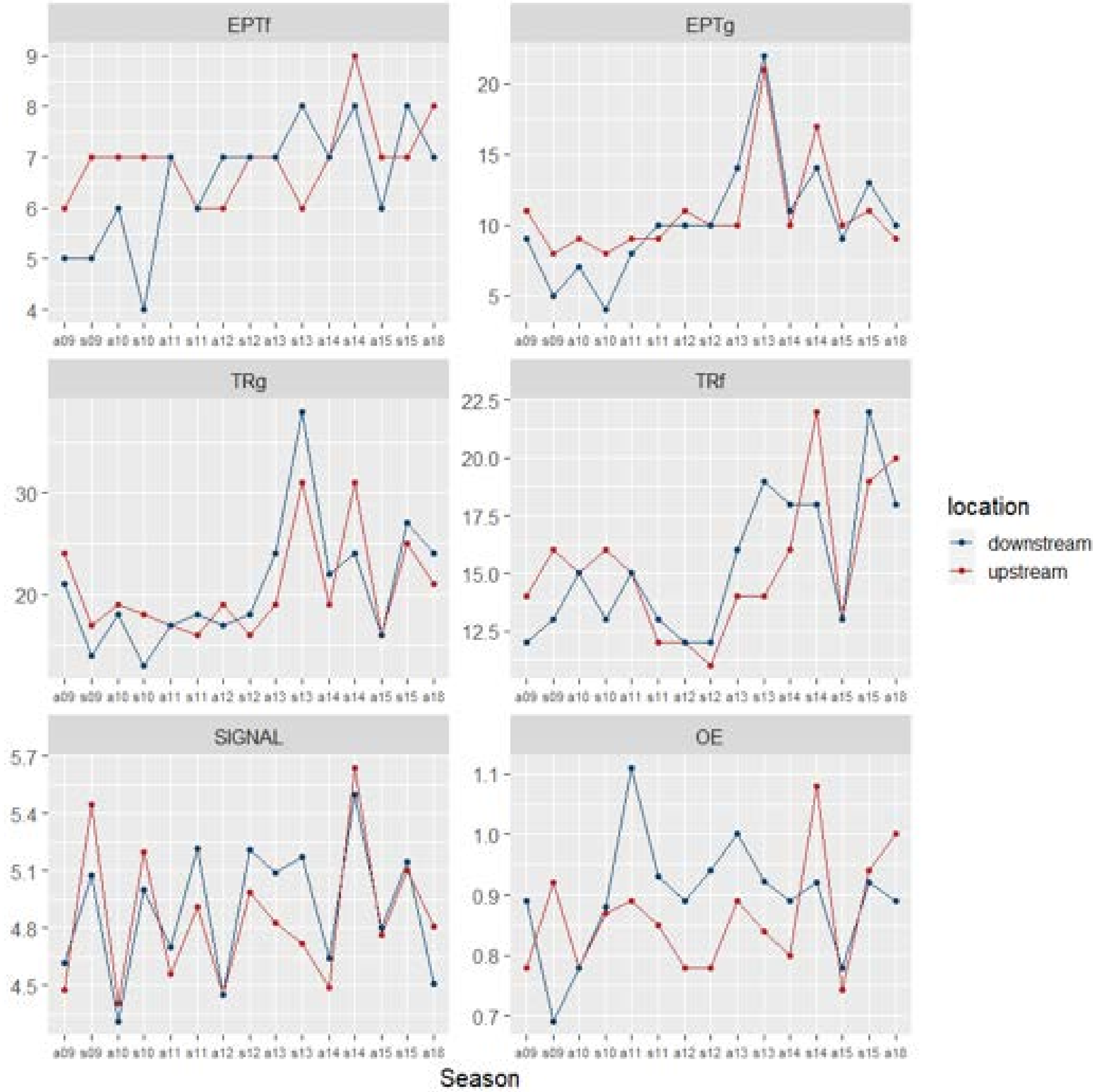
Appendix D - Historical macroinvertebrate indices

NOTE - MPS is not included at this stage due to the large data gaps. Values are means for each location.

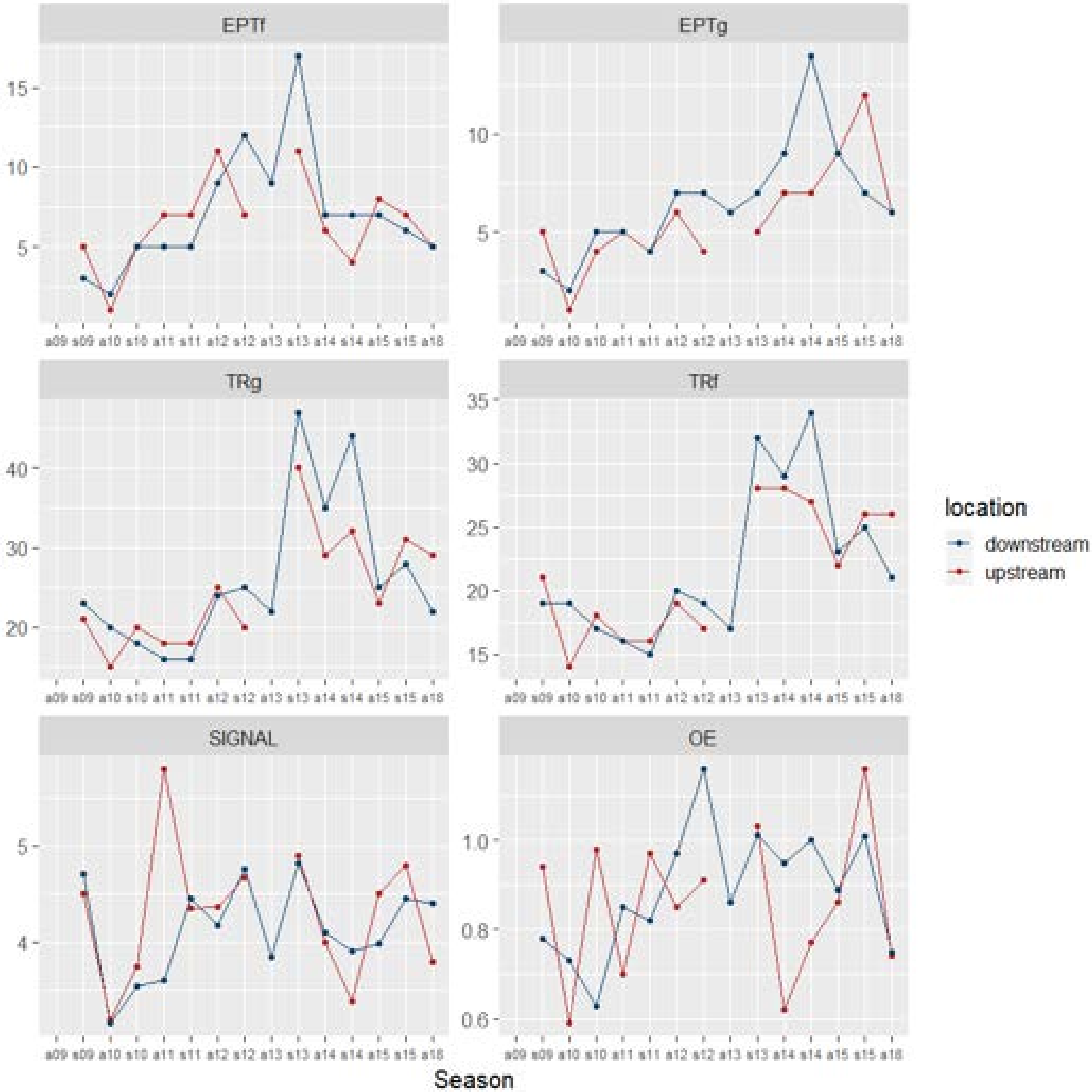
Angle Crossing EDGE - Macroinvertebrate indices between autumn 2009 and autumn 2018



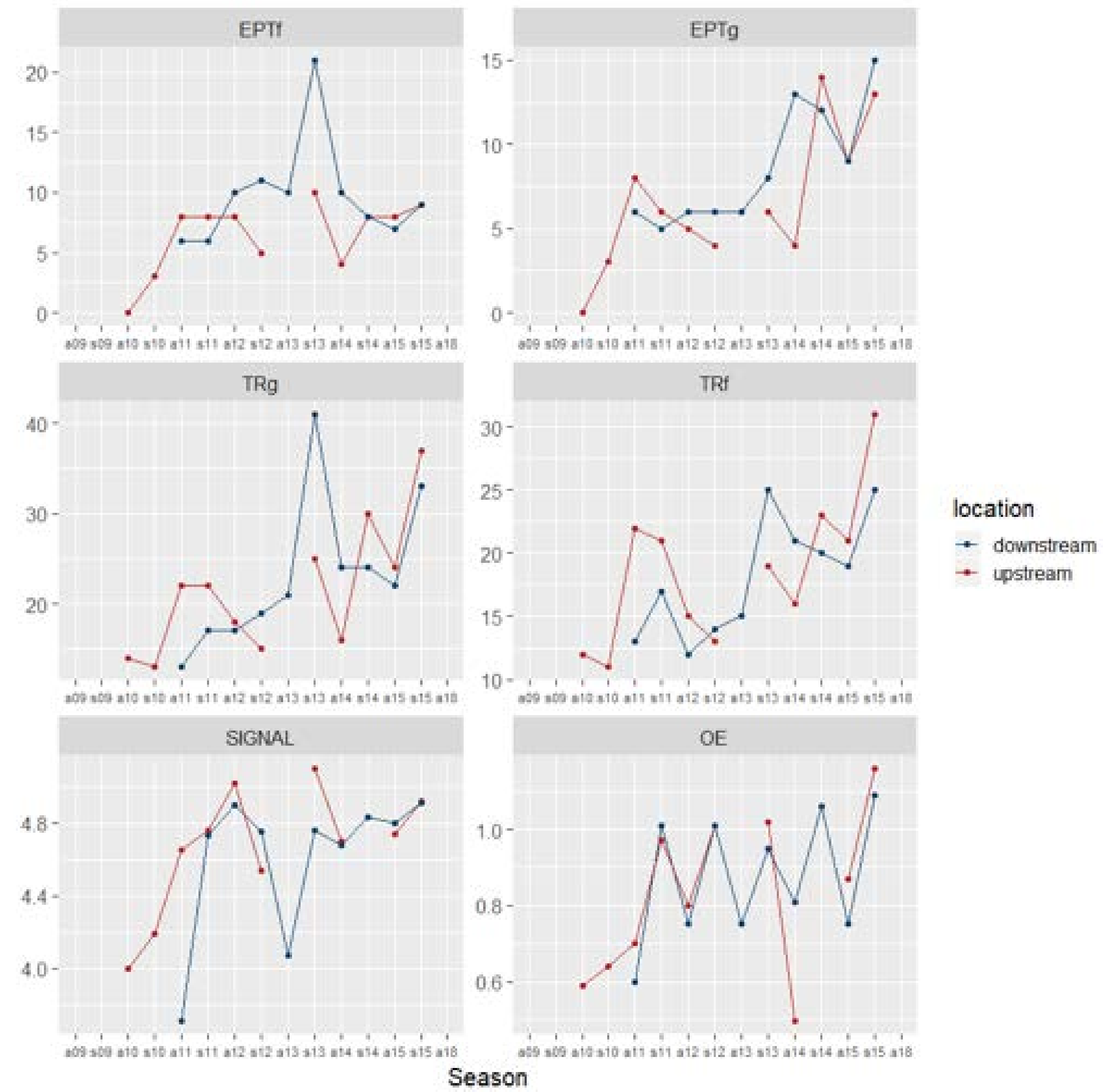
Angle Crossing RIFFLE - Macroinvertebrate indices between autumn 2009 and autumn 2018



Burra Creek EDGE - Macroinvertebrate indices between autumn 2009 and autumn 2018



Burra Creek RIFFLE- Macroinvertebrate indices between autumn 2009 and autumn 2018

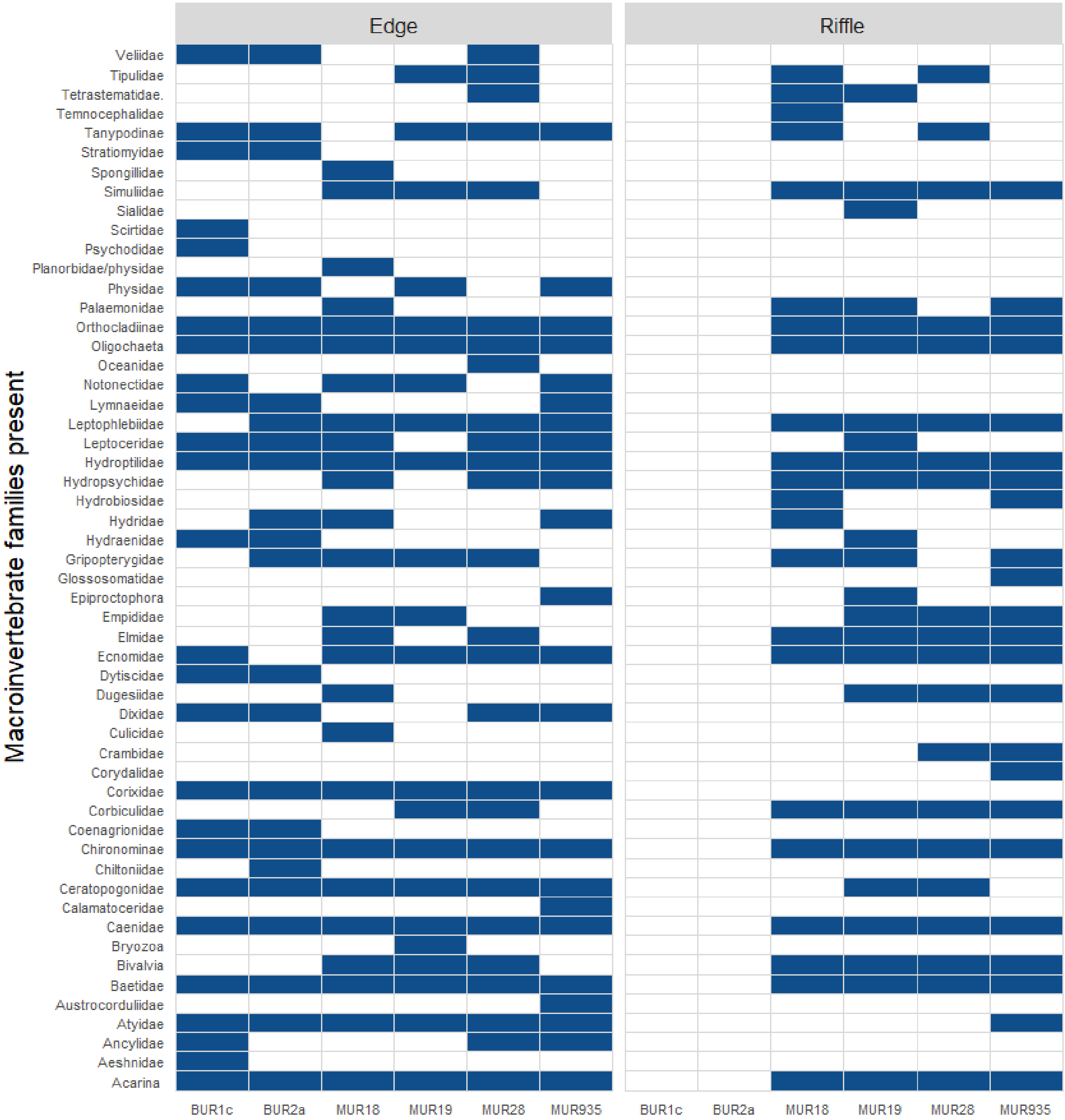


Appendix E - Taxa predicted to occur with >50% probability, but were not collected

Site	Taxa	Elmidae	Tipulidae	Gripopterygidae	Total number of missing taxa
	SIGNAL	7	5	8	
MUR18_1	Riffle				0
MUR18_2	Riffle		*0.80*		1
MUR18_3	Riffle	*1.00*	*0.80*		2
MUR19_1	Riffle		*0.80*		1
MUR19_2	Riffle		*0.80*	*0.60*	2
MUR19_3	Riffle	*1.00*	*0.80*	*0.60*	3
MUR28_1	Riffle			*0.60*	1
MUR28_2	Riffle			*0.60*	1
MUR28_3	Riffle			*0.60*	1
MUR935_1	Riffle		*0.80*		1
MUR935_2	Riffle	*1.00*	*0.80*		2
MUR935_3	Riffle	*1.00*	*0.80*	*0.60*	3

Site	Taxa	Planorbidae	Elmidae	Gripopterygidae	Synlestidae	Tanypodinae	Baetidae	Leptophlebiidae	Caenidae	Corixidae	Ecnomidae	Conoesucidae	Leptoceridae	Total number of missing taxa
	SIGNAL	2	7	8	7	4	5	8	4	2	4	7	6	
BUR1c_1	Edge	*0.54*	*0.63*	*0.66*	*0.62*			*0.96*				*0.57*		6
BUR1c_2	Edge	*0.54*	*0.63*	*0.66*	*0.62*			*0.96*			*0.57*	*0.57*		7
BUR2a_1	Edge	*0.54*	*0.63*		*0.62*						*0.57*	*0.57*		5
BUR2a_2	Edge	*0.54*	*0.63*	*0.66*	*0.62*				*1.0*		*0.57*	*0.57*		7
BUR2a_3	Edge	*0.55*	*0.63*		*0.62*				*1.0*		*0.57*	*0.57*	*0.97*	7
MUR18_1	Edge	*0.55*			*0.65*	*0.90*						*0.59*		4
MUR18_2	Edge	*0.55*			*0.65*	*0.90*				*0.62*	*0.59*	*0.59*		6
MUR18_3	Edge	*0.55*	*0.62*		*0.65*						*0.59*	*0.59*		5
MUR19_1	Edge	*0.55*	*0.62*	*0.69*	*0.65*		*0.90*					*0.59*	*0.97*	7
MUR19_2	Edge	*0.55*	*0.62*		*0.65*					*0.62*		*0.59*		5
MUR19_3	Edge	*0.55*	*0.62*		*0.65*							*0.59*	*0.97*	5
MUR28_1	Edge	*0.54*		*0.66*								*0.57*		3
MUR28_2	Edge	*0.54*										*0.57*		2
MUR28_3	Edge	*0.54*		*0.66*		*0.90*						*0.57*		4
MUR935_1	Edge	*0.54*	*0.65*	*0.66*								*0.58*		4
MUR935_2	Edge	*0.54*	*0.65*	*0.66*								*0.58*		4
MUR935_3	Edge	*0.54*	*0.65*	*0.66*								*0.58*		4

Appendix F - Taxonomic inventory



Appendix G - Habitat assessment scoring system

	Category			
Habitat variable	Excellent	Good	Fair	Poor
1. Bottom substrate/available cover	Greater than 50% rubble, gravel, submerged logs, undercut banks and other stable habitat	30-50% rubble, gravel or other stable habitat. Adequate habitat	10-30% rubble, gravel or other stable habitat. Habitat availability less than desirable	Less than 10% rubble, gravel or other stable habitat. Lack of habitat is obvious
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Embeddedness	Gravel, cobble and boulder particles are between 0 & 25% surrounded by fine sediment	Gravel, cobble and boulder particles are between 0 & 25% surrounded by fine sediment	Gravel, cobble and boulder particles are between 50 & 75% surrounded by fine sediment	Gravel, cobble and boulder particles are over 75% surrounded by fine sediment
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Velocity / depth category	Slow deep (<0.3 m/s & >0.5m); Slow shallow; Fast deep; Fast shallow; habitats all present	Only 3 of the four habitat categories present (missing riffles or runs receive lower score than missing pools)	Only 2 of the four habitat categories present (missing riffles/ runs receive lower score)	Dominating by one velocity/depth category (usually pool)
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Channel alteration	Little or no enlargement of islands or point bars and/or no channelisation	Little or no enlargement of islands or point bars and/or no channelisation	Moderate deposition of new gravel, coarse sand, on old and new bars; pools partly filled w/silt;and/or embankments on both banks	Heavy deposits of fine materials, increased bar development; most pools filled with silt; and/or extensive channelisation
	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
5. Bottom scouring and deposition	Less than 5% of the bottom affected by scouring and deposition	Less than 5% of the bottom affected by scouring and deposition	30-50% affected. Deposits and scours at obstruction and bends. Some deposition in pools.	More than 50% of the bottom changing nearly year long. Pools almost absent due to deposition. Only large rocks in riffle exposed
	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
6. pool/riffle, run/bend ratio	0-7 Variety of habitat. Deep riffles and pools	7-15 Adequate depth in pools and riffles. Bends provide habitat	15-25 Occasional riffle or bend. Bottom contours provide some habitat.	>25 Essentially a straight stream. Generally all flat water or shallow riffle. Poor habitat.
	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
7. Bank stability	Stable. No evidence of erosion or bank failure. Side slopes generally <30%. Little potential for future problem.	Moderately stable. Infrequent, small areas of erosion mostly healed over. Side slopes up to 40% on one bank. Slight potential in extreme floods	Moderately unstable. Moderate frequency and size of erosional areas. Side slopes up to 60% on some banks. High erosion potential during extreme/high flows	Unstable. Many eroded areas. Side slopes > 60% common. "Raw" areas frequent along straight sections and bends.
	10 9	8 7 6	5 4 3	2 1 0
8. bank vegetative structure	Over 80% of the streambank surfaces covered by vegetation or boulders and cobble	50-79% of the streambank surfaces covered by vegetation, gravel or larger material	25-49% of the streambank surfaces covered by vegetation, gravel or larger material	Less than 25% of the streambank surfaces covered by vegetation, gravel or larger material
	10 9	8 7 6	5 4 3	2 1 0
9. Streamside vegetation cover	Dominant vegetation is of tree form	Dominant vegetation shrub	Dominant vegetation is grass, sedge, ferns	Over 50% of the streambank has no vegetation and dominant material is soil, rock, bridge materials, culverts, or mine tailings
	10 9	8 7 6	5 4 3	2 1 0
Total habitat score				

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Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
1	Phil Taylor					

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