Establishing a monitoring program to determine carbon exchange during managed flood events in Gunbower Forest

Prepared by: Darren S. Baldwin
Rivers and Wetlands

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Report prepared for North Central Catchment Management Authority by *Rivers and Wetlands*

This report was prepared by
Darren S Baldwin trading as *Rivers and Wetlands* (ABN 5741766412)

This report was prepared for

Sophia Piscitelli
North Central CMA
Huntly Vic
Ph: 03 5440 1855
E-mail: sophia.piscitelli@nccma.vic.gov.au

For further information contact:

Dr Darren Baldwin
darren@riversandwetlands.com.au

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Sophia Piscitelli
North Central CMA
Huntly Vic
Ph: 03 5440 1855
E-mail: sophia.piscitelli@nccma.vic.gov.au

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Executive Summary

The purpose of this project is to design a monitoring program to address the question:

To what extent can carbon (energy) and nutrients derived from Gunbower Forest influence productivity in Gunbower Creek, with particular emphasis on maintaining and improving the native fish population in Gunbower Creek?

This report is divided into three sections.

- Section One gives an overview of possible indicators that could be used to address the overall objective of the monitoring program. Based on the advantages and disadvantages of the different approaches, and given the indicative budget for the monitoring program, it is recommended that loads, and if the budget allows, stream metabolism, be used as the key indicators in the monitoring program.
- Section Two discusses possible monitoring strategies to adopt based on six different flow scenarios and using the indicators identified in Section One.
- Section Three outlines a monitoring strategy for the 2018 flooding of Gunbower Forest, where flood water will enter Gunbower Forest through the Hipwell Road regulator, and outflows from the forest back into Gunbower Creek will be through the Yarran Creek regulator. There are a number of potential uncertainties around this approach. To minimise the risk, it is proposed that the first operation is treated as a feasibility study with respect to carbon input into Gunbower Creek. The study would have a reduced number of sampling sites, sampling occasions and analytes measured. Furthermore, it is proposed that sampling would be undertaken by North Central CMA staff (after suitable training).

Introduction

The purpose of this project is to design a monitoring program to address the question:

To what extent can carbon (energy) and nutrients derived from Gunbower Forest influence productivity in Gunbower Creek, with particular emphasis on maintaining and improving the native fish population in Gunbower Creek?

The design of the monitoring program follows the protocol suggested by Rolls et al (2017) which includes:

- Objective Setting
- Conceptual Modelling
- Target Setting
- Indicator Selection and
- Method Selection

The objective of this monitoring program is to maintain and improve native fish population in Gunbower Creek through the subsidy of energy and nutrients from Gunbower Forest to Gunbower Creek.

A conceptual model has been developed, based on the Flood-Pulse Concept (Junk et al, 1989), linking environmental flows and floodplain inundation with overall production in river reaches receiving flood return water (Baldwin et al, 2016). Briefly, as floodwater crosses a floodplain it liberates carbon and nutrients from the litter and soil. The nutrients fuel primary production (algal and macrophyte growth) while the carbon stimulates microbial growth. Wetting dried wetland soil also leads to the emergence of zooplankton from the sediment egg bank. The zooplankton feed on the microbial biomass, and the zooplankton are consumed by higher organisms. When the floodwater returns to the main river channel it is enriched in dissolved organic carbon, nutrients, bacteria, algae and zooplankton. This pulse off energy and nutrients stimulates primary and secondary production in the river reach, ultimately leading to an increase in fish biomass. Furthermore, larval fish eat zooplankton. If the pulse of zooplankton enters the river reach during a critical phase of larval fish development, it can improve recruitment (based on the Fundamental Triad model developed by Bakun, 1998).

This report is divided into three sections. Section One gives an overview of possible indicators that could be used address the overall objective of the monitoring program. Section 2 discusses possible monitoring strategies to adopt based on six different flow scenarios based on the indicators identified in Section 1. Section 3 outlines a monitoring strategy for the 2018 flooding of Gunbower Forest, where flood water will enter Gunbower Forest through the Hipwell Rd regulator, and outflows from the forest back into Gunbower Creek will be through the Yarran Creek regulator.

Section 1: Indicators

There are numerous indicators that can be used for determining the impact from floodplain inputs on in-stream productivity (Table 1). Each approach has their own strengths as well as limitations. This section collates the various methods/approaches that have been undertaken both in Australia and overseas that have been used to assess the role of floodplain-riverine connectivity on in-stream processes. It is of note that no one method will answer the questions posed.

Generally speaking there are three broad approaches to understanding the role of flood plain connectivity on riverine processes:

- Estimating the material flux from the floodplain to the river (Load estimates)
- Determining changes in in-stream metabolism in response to floodplain connectivity and,
- Biotic responses in the river channel including estimating the extent of incorporation of floodplain material in riverine biota.

Load Estimates

What is measured? Load estimates measures the amount of key components (e.g. dissolved organic carbon, particulate organic carbon, nutrients, zooplankton, algae) that are mobilized from the floodplain during a flood event and compare that to the amount in the river. Loads (amount per period time or total amount) are calculated by multiplying concentration by flow. Loads can be converted to total energy if the calorific value of the material is known (or is measured on a subset of samples).

What can it tell you? Load estimates can tell you how much additional material/energy flood return water is delivering to a river reach relative to base flows conditions.

What can't it tell you? Load estimates cannot tell you if the material is utilised in a river reach or if the material actually affects the trophic dynamics of the river reach, including whether or not it is impacting on fish communities.

Has the approach been used elsewhere in the Southern MDB? Yes. Load estimates for dissolved organic carbon, nitrogen, phosphorus, phytoplankton and zooplankton from Barmah Forest were made during the 2010 flood event (Nielsen et al., 2016), while estimates of carbon export during managed floods have been made in the Murrumbidgee River (Robertson et al, 2016) and in the Murray River at Chowilla (Wallace and Furst, 2016).

Effort: For reliable load estimates at least weekly sampling is required. Measuring DOC, nutrients and phytoplankton (estimated from chlorophyll *a*) concentrations requires very little additional processing time. Estimates of zooplankton density is labour intensive as the zooplankton tows need to be sorted - with only a few samples being processed in a given day. Estimating the calorific value of samples (see below) requires additional processing.

Approach		Relation to fish outcomes	Other studies in MDB	Other Comments
1. Load				Requires flow data including inflows from the floodplain
	Carbon	indirect	Yes	Need to determine bioavailability
	Nutrients	indirect	Yes	Surrogate for future algal growth
	Zooplankton	direct	Yes	Estimate weight from counts
	Algae	indirect	Yes	Estimate weight from Chlorophyll a
	Calorific value	indirect	No	May need to source appropriate laboratory for analysis
2. Metabolism				
	Stream metabolism	indirect	Yes	May not work in weir pools. Doesn't work in hypoxic water
	light dark bottles	indirect	Not common	Doesn't measure benthic metabolism
	Microbial metabolism	indirect	Not common	Requires radioactive reagents
3. Biotic responses				
	Increase in biomass/numbers	direct	Yes	"No change" doesn't necessarily mean that the flood didn't have an effect
	Shifts in basal resources	direct	Yes	Relies on stable isotope analysis, which can be problematic
	Change in food web structure	direct	No	Very expensive

Table 1 Summary of various approaches that could be used in the monitoring program looking at the impact of floodplain return water on the ecology of Gunbower Creek

Other issues: Based on Nielsen et al (2016) DOC is by far the largest pool of carbon exported from the floodplain, however, there is no simple way to estimate its bioavailability. There are a number of spectrophotometric methods that putatively can be used to estimate bioavailability of DOC, but these have been shown to be widely inaccurate in the Australian context (Baldwin and Vallo, 2015). Therefore, in order to estimate the fraction of the DOC that is readily bioavailable requires additional analysis (e.g. 5-day BOD analysis). Conversion of chlorophyll a concentration to phytoplankton biomass and zooplankton counts into zooplankton biomass relies on (not necessarily reliable) conversion factors, introducing some uncertainty in the load analysis. Nutrient loads have been used to estimate the amount of additional phytoplankton material they can produce (e.g. Baldwin et al, 2016), but again this is based on a number of assumptions that may not be met in a given situation. Furthermore, not all phytoplankton are nutritionally valuable as a food resource. For example, blue-green algae lack essential fatty-acids required by fish (Müller-Navarra et al, 2000); so a food web based on blue-green algae is unlikely to support a large biomass of fish.

An alternative approach to separating out DOC, zooplankton etc, is to quantitatively divide a water sample into various size classes (e.g. <45 µm, 45 -50, 50-250 µm) and directly measure the calorific content of the various fractions. The advantage of this approach is that it directly determines how much additional energy the flood return water is delivering to the river reach. The disadvantages of this approach are that it isn't routinely done elsewhere, so comparison to other sites will be again be based on a series of assumptions. Also, calorimetry (the technique used to determine the energy content) is not widely available in commercial laboratories.

Stream Metabolism

What is measured? Stream metabolism measures gross primary production (GPP) and community respiration (CR) in a river reach based on measures of the production and consumption of oxygen. GPP is an indicator of how much energy is being produced through photosynthesis while CR is an indicator of how much energy is being consumed through aerobic respiration. From GPP and CR measurements a third parameter - net daily metabolism- can be determined. Hence, measuring stream metabolism should address the question of whether or not connectivity between Gunbower Forest and Gunbower Creek improves productivity in the creek. The actual approach is relatively straightforward and the method well documented (e.g. Grace and Imberger, 2006). Dissolved oxygen probes and light loggers are deployed in the reach in question. The probes can be deployed for months, but require relatively frequently (fortnightly) cleaning, calibration and data downloading.

What can it tell you? This technique allows an estimate of how much material is being directly used by biota either to produce energy (primary productivity) or as an energy source (respiration).

What can't it tell you? The technique does not distinguish which organisms are respiring. It is impossible to say whether or not changes in energy production and consumption are directly or indirectly impacting on the native fish community. For example, all of the carbon may be being processed by bacteria and remain in the microbial loop. A recent review has suggested that terrestrially derived carbon is not important energy source in aquatic food webs (Brett et al, 2017), although this assertion has been questioned (Baldwin et al, 2016; Tanentzap et al, 2017). It also doesn't differentiate between benthic and planktonic production and respiration. Additional analyses can differentiate between planktonic and benthic production (e.g. light dark bottle assays) and microbial vs heterotopic production (microbial metabolism assays), but these add additional expense and time to the study. In addition, the microbial metabolism assays use radioactive materials and therefore, are not routinely undertaken.

Has the approach been used elsewhere in the Southern MDB? Yes. Measurements of stream metabolism have been undertaken throughout the southern MDB, including current assessments in the Loddon and Campaspe Rivers (M. Grace pers. comm), as well as part of the Commonwealth Environment Water Office (CEWO) Long-term Intervention Monitoring (LTIM) project on the Lachlan, Edwards, Goulburn and Murrumbidgee Rivers (Dyer et al, 206; Watts et al, 2016; Wassens et al 2016; Webb et al, 2017). Therefore, stream metabolism measurements in Gunbower Creek could easily be compared with similar sites across the southern MDB.

Effort: Do probes and light loggers are typically deployed for 2-3 weeks at a time, before they are cleaned, calibrated and the data downloaded. Data analysis is now essentially automated, so many months of data can be analysed in less than a day. The DO probes are relatively expensive (ca. $5000 each) which may be factored into any quote for service (either as a one-off purchase or rental charge).

Other issues: The technique cannot assess the amount of energy consumed through anaerobic respiration, which can occur in biofilms and in the sediments. Furthermore, the technique is not suitable in all situations. It cannot be used in standing waters so requires at least some flow in the system. It cannot be used if the system is stratified, so weir pools (potentially) maybe an issue, and the technique doesn't work well as the ambient DO approaches zero (i.e. during hypoxic episodes, which may occur near the outfall from the floodplain). Also, data from LTIM shows that changing in-channels flows does not necessarily impact on stream metabolism (Dyer et al, 206; Watts et al, 2016; Wassens et al 2016; Webb et al, 2017) so the technique may not be useful for exploring the impact of, for example, freshes. Furthermore, experience with LTIM suggests that not all data acquired can be fitted with any degree of certainty, potentially leaving gaps in the time sequence (Dyer et al, 206; Watts et al, 2016; Wassens et al 2016; Webb et al, 2017). Finally, data analysis may be compromised by re-aeration of water as it falls down weir walls.

Biotic responses in the receiving river reach

Biotic responses to flooding can be broadly classed into three groups

1. Increase in biomass and/or numbers of key species in a reach
2. Shift in basal resources to include sources derived from the floodplain
3. Changes in food web structure.

<u>Increase in biomass/numbers:</u>

What is measured? In this approach a quantitative assessment is made of the standing biomass of key or target organisms, for example adult of juvenile large body native fish, macroinvertebrates or biofilms at sites that have received flood return water compared to sites that haven't.

What can it tell you? This approach has the potential to tell you whether or not the target (in this case increased production to improve native fish populations) has been attained.

What can't it tell you? If there isn't an increase in fish numbers or biomass, this approach cannot tell you why. For example, there may have been an increase in larval fish biomass, but they are lost from the reach because of drift or predation. Alternatively, there are other stressors, such as cold-water pollution or lack of habitat may be impeding the success of the target organisms.

Has the approach been used in the southern MDB? Yes, assessments of community structure of organisms including native fish and macroinvertebrates are routinely undertaken throughout the Basin, for example the LTIM project (Dyer et al, 206; Watts et al, 2016; Wassens et al 2016; Webb et al, 2017). A recent study showed significant biofilm responses to flooding of Barmah Forest (Rees et al, 2018)

Effort: Typically, surveys are undertaken monthly, seasonally or annually depending on the river reach. A field campaign would typically last several days.

Other Issues: Although assessments of biotic composition are routinely undertaken, most are at best semi-quantitative, because getting an accurate assessment of the total standing stock of motile organisms is difficult. For example, fish populations are usually reported as catch per unit effort, rather than total standing stock. Furthermore, as alluded to above, a negative result (e.g. no increase in the number of juvenile native fish) doesn't mean that the flood return water didn't lead to an increase in juvenile natives, it may be that they have otherwise been lost to the river reach.

<u>Shift in Basal Resource using Stable Isotope Analysis (SIA)</u>

What is measured? In this approach the ratio of two stable isotopes of the same element (typically carbon for the assessment of basal resources) are measured in the tissue of organisms in a river reach. The method relies on the fact that biogeochemical reactions are marginally faster for the lighter isotope than the heavier isotope. Different basal resources have different ratios of ^{12}C to ^{13}C (referred to as $\Delta\ ^{13}C$). By examining the stable isotope signature in the population of interest (in this case native fish) it is possible to determine what percentage of energy is ultimately derived from a floodplain source (e.g. DOC) and what comes from an in-channel source (e.g. filamentous algae).

What can it tell you? This approach has the potential to tell where the energy supporting a given population is coming from.

What can't it tell you? While it is possible to differentiate between carbon coming from DOC from red gum leachate and phytoplankton, it can not necessarily differentiate between algae coming into a reach in floodwater and algae already present in the reach, or algae growing on nutrients derived from the floodplain compared to nutrients from upstream sources.

Has this approach been used in the Southern MDB? Although not routinely used, there have been a number of recent studies using stable isotopes to determine shifts in basal resources in response to flooding in the southern MDB (e.g. Rees et al 2018; Hladyz et al, 2012).

Effort: Typically, samples are taken on monthly, seasonally or annually. A number of samples of potential basal resources (phytoplankton, filamentous algae, litter etc) are collected as well as tissue samples from target organisms.

Other Issues: Although SIA has been used extensively in trophic studies of freshwater ecosystems, the approach is not without its issues. The stable isotope signature of basal resources can be highly variable (Rolls et al, 2017 and references therein). The signature can also be highly variable within a single organism (e.g. between the muscle and liver in fish). The method cannot discriminate between basal resources with similar signatures and stable isotope signatures can vary with environmental variables like temperature and salinity, and with decomposition making interpretation difficult without adequate replication in space and time (Rolls et al, 2017).

<u>Changes in food web structure</u>
What is measured? SIA (using carbon, nitrogen as well as other elements) of both tissue samples as well as specific molecules, in conjunction with other approaches, such as gut content analysis and laboratory studies can be used to map whole food webs in an environment.

What can it tell you? This type of analysis maps both the trophic linkages and strengths of those linkages in a specific environment.

What can't it tell you? This approach is extremely labour and resource intensive, so replication in time is usually prohibitive, meaning that temporal variability is often not considered.

Has this approach been used in the southern MDB? While SIA has been used to partially map food webs in the MDB (e.g. Hladyz et al, 2012) I am unaware of a complete food web being mapped for any river in the southern MDB.

Effort: This approach is extremely labour and resource intensive, requiring sampling and analysis of all taxa present in a river reach.

Recommendations:

Based on the preceding discussion and given the indicative budget available for the monitoring program, it is recommended that the most suitable indicators to adopt for determining the impact of flood return water on the biota in Gunbower Creek are loads and, if there are sufficient funds, measures of stream metabolism.

Section 2: Monitoring potential flow scenarios

In this section of the report, monitoring strategies (including indicators and methods) are discussed for a number of different managed-flow scenarios that are currently possible for Gunbower Forest and Gunbower Creek. The discussion includes indicative costs[1] for each of the indicators and methods.

Flow Scenarios

1. Baseflows.

In this scenario water is confined to Gunbower Creek. With respect to the project, the purpose of monitoring during baseflows is to establish how much the indicators of interest vary over the longer-term, and to establish a benchmark to determine how much the flow intervention changes the indicator of interest (e.g. flood return water delivered x kg of carbon to the creek, which is y % of the average annual load in the creek).
Suggested indicators would be loads of carbon and nutrients in the creek, as well as an estimate of stream metabolism. Long-term monitoring is expensive; however it is possible to use existing monitoring programs to achieve the desired outcome.

<u>Loads:</u> Dissolved organic carbon and nutrients are currently measured in Gunbower Creek at Koondrook (Site 407209), but only monthly (it was weekly prior to 2014). Monthly data is less desirable for determining loads than data captured more frequently as it can lead to significant inaccuracies. For example, analysis of long-term water quality monitoring data in the Murray River showed that estimates of annual loads could vary by up to 500% when going from weekly to 4 weekly sampling (Baldwin et al, 2013). However, the Murray-Darling Basin Authority, as part of its long-term water quality monitoring program measure dissolved organic carbon, total kjeldahl nitrogen, nitrate + nitrite, total phosphorus, soluble reactive phosphorus and chlorophyll a on a weekly basis at Torrumbarry (Site 409207b), immediately upstream of Gunbower Creek. While, there will be some variation in concentration of these constituents between Torrumbarry and Gunbower Creek, the site is close enough that the effect on loads is expected to be more accurate than relying on monthly data. To test this idea, I calculated daily loads of dissolved organic carbon based on flows at Koondrook and measured concentrations at Koondrook and Torrumbarry (interpolating between sampling dates at this site to align with sampling dates at Koondrook) for 2017 (Figure 1). Although there was some variation between load estimates on a single day, the annual variation (summing across the year) was less than 2.5%. The Torrumbarry water quality data can be combined with flows in Gunbower Creek to estimate loads in Gunbower Creek (e.g. Figure 2). Interpolation between weekly data can then be used to calculate yearly loads. Another advantage of using the Torrumbarry data is that it is freely available, there is a long sequence of data available, and it has gone through strict quality control protocols. The

[1] All estimated costs are indicative only and actual quotes will vary depending on the business model adopted by individual contractors.

disadvantage is that there is a slight delay (about 2 months) before the data is published on the Victorian Government's *Water Management Information* website.

This approach is inexpensive. It would take approximately 2 - 3 days to collate the currently available data, calculate loads and report on the findings. Annual updating of the database would then only take several hours each year. Therefore, it would cost between about $3000 - $6000 to set up the data base and < $1000/year for annual updates.

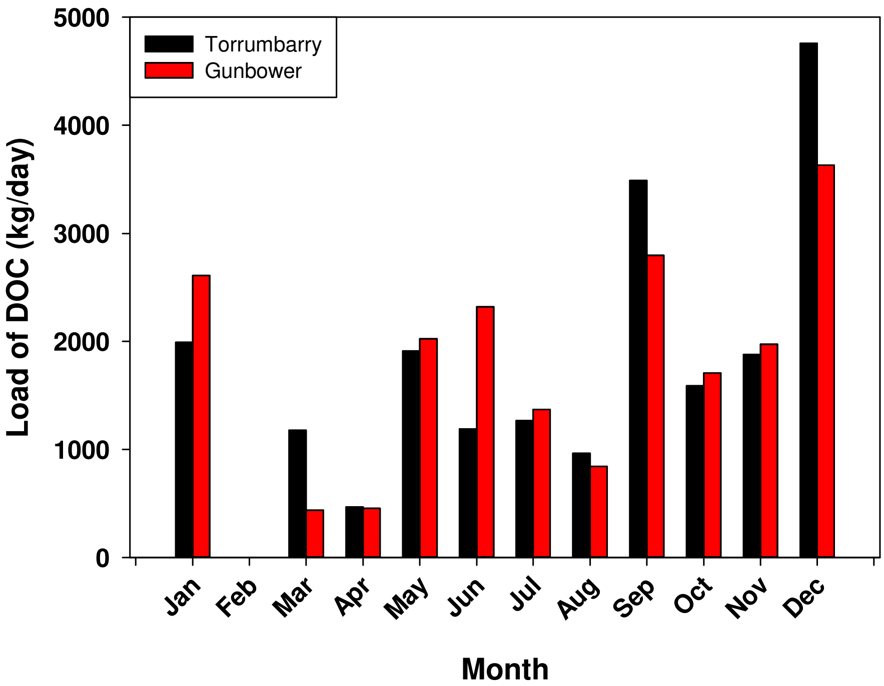

Figure 1: Loads of DOC in Gunbower Creek based on dissolved organic carbon concentrations measured at Torrumbarry on the Murray River and in Gunbower Creek.

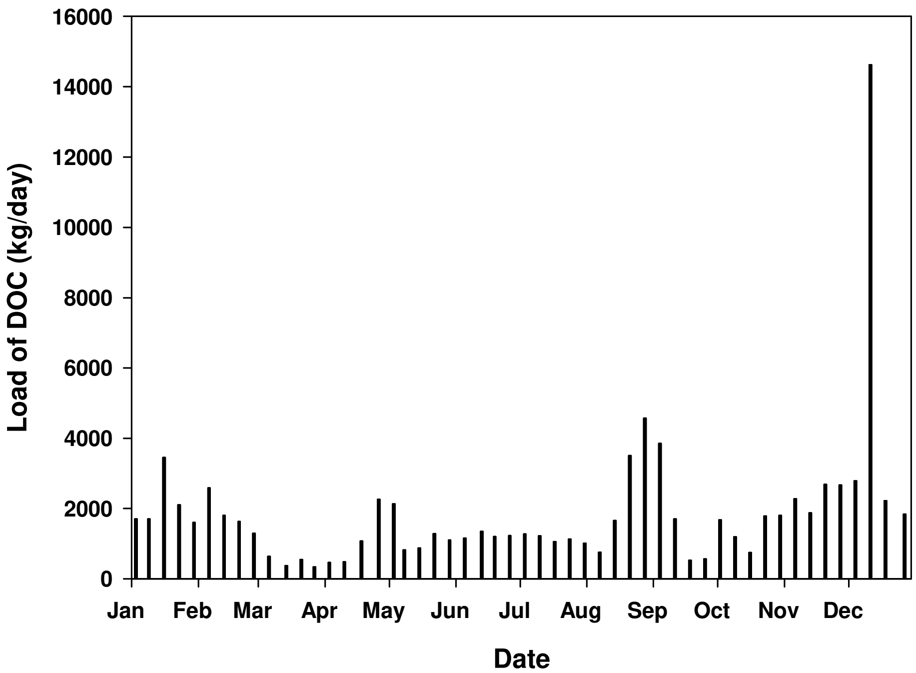

Figure 2: estimated loads of DOC in Gunbower Creek in 2017 based on DOC concentrations measured at Torrumbarry.

Stream Metabolism: To determine stream metabolism requires measures of water temperature, dissolved oxygen (DO; at relatively frequent intervals) and photosynthetic active radiation (PAR). North Central CMA has access to DO concentrations (taken at 15-minute intervals) and temperature at two sites on Gunbower Creek, 5 km downstream of Yarran Creek Regulator (Site 407368A) [2] and at Condidorios Bridge (Site 407332 A). Unfortunately, North Central CMA does not have access to PAR data. I would recommend that North Central CMA purchases and installs a PAR sensor with logger. One sensor centrally located is sufficient to cover all potential sites where stream metabolism would be measured. A suitable sensor, with data logger would cost about $2000 + installation (slightly more expensive if a telemetered logger is required). That way staff would have complete access to all the data required to determine stream metabolism, independent of any contractor, with the possible long-term view for North Central CMA staff to determine stream metabolism at its sites in-house. Data analysis and reporting by an external contractor would vary depending on the extent of data analysed, but $10,000 would be indicative. The ideal site for the PAR sensor would be secure, have a similar light climate to Gunbower Creek (i.e. have a similar level of shading) and not be exposed to artificial light.

[2] Although this site is within the Koondrook Weir pool, analysis of temperature data indicated that the site didn't stratify over the 2016/17 summer.

2. Hipwell Rd Regulator operating at full capacity, all Murray River and Gunbower Creek regulators closed.
In this scenario, most of Gunbower Island is flooded, with flood-return water entering Gunbower Creek at Chinaman's Bend, approximately 2.8 river kilometres upstream of the confluence of Gunbower Creek and the Murray River. Koondrook Weir (approximately 5.4 river kilometres upstream of the confluence of Gunbower Creek with the Murray River) does not currently have a fish ladder, so any impact of flood return water on the fish community in Gunbower Creek will be limited to the very bottom section of the creek. The flood-return water will obviously deliver nutrients and carbon to the Murray River, which may be of interest to river managers[3], but would appear to be outside the scope of the current project.

<u>Loads</u>: given the expense of load estimates (see page 7) and the potentially limited impact on the fish community in Gunbower Creek, under this flow scenario, estimates of loads entering the creek would not be recommended as a high priority investment. If a fish ladder is installed on Koondrook weir, this recommendation should be revisited.

<u>Stream Metabolism</u>: under this flow scenario the DO logger 5km downstream of the Yarran Creek Regulator (407368A) could be used as the control site, while the DO logger at Condidorios Bridge (407332A) as the impacted site. Comparison of measures of stream metabolism at the two sites (allowing for water travel time) would provide an estimate of the influence of flood-return water on the productivity of the lower section of Gunbower Creek.

3. Hipwell Road Regulator operating at reduced capacity[4] and Yarran Creek Regulator open.
The Yarran Creek Regulator on Gunbower Creek is approximately 47 river kilometres upstream of the confluence of Gunbower Creek with the Murray River. At high water levels in Gunbower Creek, and no inflows into the forest from upstream, the regulator can direct water into the forest. If the forest is flooded, and water level in Gunbower Creek is low, opening the regulator would allow flood-return water to enter Gunbower Creek. Under a reduced inflow through the Hipwell Rd Regulator, flood water might not reach the outfall at Chinaman's Bend, and therefore flood water would be directed from the forest through the Gunbower Creek and/or Murray River Regulators. The Yarran Creek Regulator has a capacity of 340 ML/day, but under the proposed scenario, inflows back into Gunbower Creek are expected to be much less than that. BRAT modelling was used to estimate the carbon return to Gunbower Creek, with inflows back into the creek varying between 10 and 160 ML day (Table 2). Over a 60-day period the modelling predicts the average daily input of carbon at 10ML/day inflows of about 70kg/day, while at 160 ML/day inflows the average carbon load would be 1070 kg/day (with a significant proportion of the carbon readily bioavailable.

[3] Although it may not be detectable. A BRAT modelling run, assuming 1600 ML inflow into the forest, starting in July and lasting 60 days, with the Murray River flowing at 5000 ML/day, suggests that at most there would be an increase in DOC concentration in the Murray River of about 0.1 mg/L, which, given the accuracy of the DOC analysis and the temporal variability in the Murray River, may not actually be detected.
[4] It is proposed that the Regulator would be operated to deliver 750ML/day into the forest in the second half of 2018.

This compares to an approximate base load of 760 kg day[5], much of which will be unreactive. Therefore, it is expected that inflows from the forest through the Yarran Creek Regulator would have an impact on the ecology of the creek.

Flood-return flow (ML/day)	Carbon load (kg/day)
10	66.7
20	133.6
40	267.6
80	536.6
160	1068.5

Table 2: Modelled carbon load entering Gunbower Creek from Yarran Creek, based on inflows

Loads: Loads should be estimated at sites:

- Hipwell Road Regulator,
- Gunbower Creek upstream off the Yarran Creek Regulator
- Yarran Creek forest-side of the regulator
- Gunbower Creek, downstream of the Yarran Creek Regulator (with the site co-located with the downstream DO logger).
- Gunbower Creek at Condidorios Bridge (preferable - this site will give an estimate of how much material was consumed or transformed during its transit of Gunbower Creek).

Accurate flow data (as volume/unit time) is required at all sites. Sample frequency should ideally be at least weekly but given that flows will likely last for 4-5 months, the indicative budget would preclude this sampling frequency. Therefore, the following sampling schedule is proposed, assuming a 4-month long flood event and 21-day travel time between inflows at the Hipwell Road Regulator and the Yarran Creek Regulator[6] :

- On opening of the Hipwell Rd Regulator
- Then at days 21 (corresponding to the opening of the Yarran Creek Regulator), 28, 35, 42, 56, 84, and 126 after the opening of the Hipwell Rd regulator.

This schedule concentrates sampling in the first 6 weeks following the Yarran Creek Regulator opening, when the majority of material is expected to be exported from the floodplain. A contingency for at least one extra sampling occasion could be factored in if the flood is expected to extend out beyond 4 months.
Analytes for load analysis would include:

- Dissolved organic carbon

[5] Assuming a flow of 200 ML/day upstream of the Yarran Creek Regulator, and a DOC concentration of 3.8 mg/L, the average DOC concentration at Torrumbarry in 2017.
[6] If the travel time is shorter, the Yarran Creek Regulator can be kept closed until day 21, If travel time is longer then the schedule can be set back by the appropriate time interval.

- Total nitrogen
- Dissolved nitrogen species (NOx, and ammonia)
- Soluble reactive phosphorus
- Total phosphorus
- Chlorophyll *a*
- Zooplankton biomass (preferred) or particulate organic carbon

In addition, carbon reactivity should be assessed based on biological oxygen demand.

Estimated costs for analyses would be $325[7] per sample per site if particulate organic carbon is analysed (Total ~ $16 000 including sampling blanks[8]) or $550 per sample per site if zooplankton biomass is measured (Total ~ $24 500 including sampling blanks). Sampling costs will vary according to the contractor's location and charge out rates. Assuming, 2 field staff, 1 day for travel time and 1 day for sampling, sampling costs would vary from about $30 000 to $50 000 (Table 3). This cost could be substantially reduced if North Central CMA staff are used for sampling. If the contractor uses the first 3 field trips for instructing North Central CMA staff, and staff complete the final five sampling occasions, this cost would be reduced to about $15 000[9]. $10 000 - $15 000 would be an indicative cost for data analysis and reporting.

	Cost per trip	Total Cost[a]
Staff Charge-out rate	$500 - $1,000 per person	$16,000 - $32,000
Travel allowance	$250 per person[b]	$8,000
Mileage	$660[c] - $1,000	$5,280 – 8,000
Consumables[d]	$50 - $100	$400 - 800

Table 3: Indicative costs associated with field sampling; costs will depend on individual contractors. [a]Assumes 8 trips. [b]Based on Australian Tax Office reasonable travel allowance for a tier 2 regional centre. [c] This is the Australian Tax office rate - some contractors may charge more. [d] Filter papers, sampling bottles etc.

Therefore, a monitoring program looking at loads from the forest to Gunbower Creek through the Yarran Creek Regulator, indicative budgets would be[10]:

- Between about $58,000 and $78,000 if sampling is carried out by an independent contractor and particulate organic carbon measured;
- Between about $66,500 and $89,500 if sampling is carried out by an independent contractor and zooplankton biomass measured;

[7] Indicative only; costs will vary between analytical laboratories

[8] A sampling blank is used to check for contamination during the sampling process.

[9] Assumes that a more senior contractor is involved in the training phase ($1500/day) and the first three sampling trips take 2.5 days to include the training component. North Central CMA may need to acquire some sampling equipment.

[10] Does not include CMA costs or charges.

- Between about $42,000 and $46,000 if sampling is undertaken in conjunction with North Central CMA staff and particulate organic carbon measured;
- Between about $49,500 and $53,500 if sampling is undertaken in conjunction with North Central CMA staff and zooplankton biomass measured.

Stream Metabolism: To determine stream metabolism under this flow scenario, a DO and temperature logger needs to be positioned in Gunbower Creek upstream of the Yarran Creek regulator as a control. Downstream DO and temperature can be logged using the DO logger already in place on Gunbower Creek, 5 km downstream of the Yarran Creek Regulator (Site 407368A). Costs of deploying the additional logger would depend on the sampling arrangements undertaken with the loads assessment (above). If the load assessment is not undertaken then trips will be needed for cleaning and downloading data from the additional logger. If the load assessment is undertaken, then cleaning and downloading of the DO logger can be scheduled in with load sampling program. Indicative costs for deployment would be between about $8000 and $45000 depending on whether or not load estimates are being undertaken simultaneously and whether or not some of the cleaning and data downloading is performed by North Central CMA staff (Table 4)

Item	Loads also being assessed	Loads not being assessed	North Central CMA staff can assist
Supply of DO probe	$0 - $5000[a]	$0 - 5000	$0 - 5000
Initial deployment of probe	$500 - 1000[b]	$3000 - 5000[c]	$3000 - 5000
Cleaning and data downloads	$0	$12000 - 20000	$0 - 250[d]
Data analysis and reporting	$7500 - 12000	$10000 - 15000	$7500 - $15000
Indicative cost	$8000 - 18000	$25000 - 45000	$10500 - 25250

Table 4: Indicative costs for undertaking an assessment of stream metabolism. [a] Not all contractors will charge for this if they have spare probes available. Alternatively, North Central CMA may consider purchasing their own probe which they can loan to contractors. [b]Based on an additional half day to deploy the DO probe(s). [c]Assumes 1day travel and 0.5 days to deploy probe. [d]Freight to return probe, reduces to $0 if the probe belongs to North Central North Central CMA.

4. Hipwell Road Regulator operating at reduced capacity and one or more additional regulators, as well as the Yarran Creek Regulator, are open.

Under these scenarios, additional flood-return water is introduced into either Gunbower Creek and/or the Murray River through the opening of additional regulators.

Loads: Assuming the same flow scenario as above, for each additional regulator that is open, the concentration of agreed analytes would be measured on the forest side of the regulator, which would add an additional $2600 (particulate organic carbon) or $4400 (zooplankton biomass; both are indicative) per regulator. In addition, the site downstream of the Yarran

Creek Regulator would be shifted to below the last regulator on Gunbower Creek that was opened. An additional site in the Murray River is probably not necessary, as the overall change in loads in the Murray River would probably be small.

River metabolism: If additional regulators are opened along Gunbower creek to allow flood-return water to enter Gunbower Creek, an additional DO and temperature logger should be deployed approximately 5 km downstream of the last regulator open on Gunbower Creek. If that site is unsatisfactory (because of satisfaction) then it may be possible to use the DO and temperature logger at Condidorios Bridge (407332A) to assess the impact of flood-return water[11]. This scenario still requires the deployment of a DO and temperature logger above the Yarran Creek Regulator.

5. Hipwell Road Regulator operating at full capacity and one or more additional regulators, as well as the Yarran Creek Regulator, are open.

In the scenario flood-return water would enter Gunbower Creek, from numerous regulators as well as the Chinaman's Bend outfall. As in the previous scenario, for each additional regulator that is open, the concentration of agreed analytes would be measured on the forest side of the regulator, which would add an additional $2600 (particulate organic carbon) or $4400 (zooplankton biomass; both are indicative) per regulator. In addition, loads entering Gunbower Creek from the Chinaman's Bend outfall would also need to be assessed. This will require an accurate knowledge of the volume of water leaving the forest at the outfall.

River Metabolism: To determine the effects of flood-return water on river metabolism on Gunbower Creek in this scenario would require deployment of a DO and temperature logger upstream of the Yarran Creek Regulator as a reference, while the DO and temperature logger at Condidorios Bridge (407332A) could be used to determine impact.

6. Natural overbank flooding, with or without the Hipwell Road Regulator open.

Commence to flows for effluents into Gunbower Forest start at between 13 000 and 15 000 ML/day in the Murray River, but at 25 000 ML/day inflows are less than 200 ML/day (data supplied by North Central CMA). With regulators open, flows of 25 000 ML/day would result in the inundation of more than 25 000 ha of Barmah and Millewa Forests (data supplied by GBCMA), resulting in the export of carbon and nutrients into the Murray River upstream of Gunbower Island. In other words, during flood events, exports of material from Gunbower Forest may be masked by substantially higher loads coming from upstream. However, it still would be preferable to get an assessment of the impact of Gunbower Forest on Gunbower Creek.

Loads: In this scenario, water samples would be taken at a site on the Murray River immediately upstream and downstream of the forest. An additional sample would be taken in Gunbower Creek upstream of the confluence with the Murray at Condidorios Bridge.

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[11] This logger is approximately 15 river kilometres downstream of the lowest regulator on Gunbower Creek (Little Gunbower Creek Regulator).

Sampling frequency would depend on the duration of the flood, but preferably would be fortnightly or less (especially at the start of the flood event when weekly sampling is suggested). This strategy is not without risk. As noted above, a signal attributable specifically to the flooding of Gunbower Forest may be masked by upstream loads.

River Metabolism: Given the potential loads of bioavailable carbon coming from upstream it is possible that DO in floodwaters would be low. As noted in Section 1 of this report, determining stream metabolism parameters from water with already low DO concentrations is problematical. Furthermore, deploying DO and temperature loggers during high flows is also problematical, as the loggers can be lost. For these reasons it is suggested not to measure stream metabolism under this flow scenario. If North Central CMA decides to deploy a PAR logger (see page 13) a small study could then be undertaken on the feasibility of determining stream metabolism during overbank flows by using the DO and temperature data collected during the flood event by the probes in Gunbower downstream of the Yarran Creek Regulator and at Condidorios Bridge.

Section 3: 2018 Monitoring program

Section 1 of this report discussed possible indicators to address the overall objective of the monitoring program, outlining the strengths and weaknesses of each indicator and what the approach could and couldn't tell you. Based on the objectives of the project and its indicative budget, it is recommended that priority should be given to determining the flux of material (carbon, nutrients, phytoplankton and zooplankton) and measures of stream metabolism in Gunbower Creek, rather than biotic responses like changes in community composition or biomass of selected species in the creek. Section 2 of this report looks at strategies for monitoring loads entering into Gunbower Creek as well as stream metabolism for six different flow scenarios involving the flooding of Gunbower Forest. In this section of the report a monitoring plan is presented specifically for the planned flooding of Gunbower Forest through Hipwell Road in 2018.

Planned 2018 Flooding of Gunbower Forest

North Central CMA is planning to flood the forest in 2018 by operating the Hipwell Road regulator at a target flow rate of ~750 ML/day from mid-June until October. However, when the irrigation season begins in mid-August, it is expected that inflows will be significantly reduced due to irrigation demand and capacity constraints on Gunbower Creek. Return water from the forest to Gunbower Creek will be through the Yarran Creek regulator.

While the monitoring program for 2018 should follow the strategy outlined for Scenario 3 in Section 2 of this report, a number of potential constraints are anticipated around returning water to the creek through Yarran Creek regulator.

- There is some uncertainty on whether or not operating the Hipwell Rd regulator at reduced capacity will deliver sufficient water to reach the Yarran Creek regulator.
- Travel times between the Hipwell Rd regulator and the Yarran Creek regulator are not certain.
- Water in Yarran Creek regulator must be higher than in Gunbower Creek for outflows to occur, which will likely depend on low flows in the creek (i.e. water reaching Yarran Creek prior to irrigation season).
- Finally, it is not known whether or not there will be sufficient flow through the Yarran Creek regulator into Gunbower Creek to cause an observable change in Gunbower Creek. Therefore, there is some risk there could be a significant investment in a monitoring program in 2018, with no discernible returns.

To minimise the risk, it is proposed that the first operation is treated as a feasibility study with respect to carbon input into Gunbower Creek. The study would have a reduced number of sampling sites, sampling occasions and analytes measured. Furthermore, sampling would be undertaken by North Central CMA staff (after suitable training). The advantages of undertaking the pilot prior to undertaking a full monitoring strategy (as outlined in Section 2 of this report) in subsequent years are:

- It could be done at a fraction of the cost of the full monitoring program
- If there are no inflows back into Gunbower Creek, the financial outlay by North Central CMA would be minimal compared to contracting an external party to sample to a fixed schedule.
- It can be used to determine whether or not it is feasible for North Central CMA staff to undertake the sampling program in subsequent years (which would reduce the cost of the monitoring program into the future - see Section 2).
- North Central CMA will have a realistic assessment of the size of the effect expected to be seen in Gunbower Creek in subsequent years.
- North Central CMA will have a better understanding of flow dynamics within the forest, making sampling scheduling easier in subsequent years.
- The decision on whether or not to implement a full monitoring program in the future would be based on actual data, rather than modelling.

However, the approach is not without disadvantages. The principal one is that the question of whether or not outflows from the forest impact on productivity in Gunbower Creek cannot be unequivocally answered in the first year of operation.

2018 Feasibility Study Monitoring Plan

The key objectives for the 2018 monitoring plan for this project should be to determine:

1. if the proposed watering plan can deliver water into Gunbower Creek through the Yarran Creek regulator.
2. the transit time for water to reach the Yarran Creek regulator once the Hipwell Road regulator is opened.
3. the <u>volume</u> of water flowing from Gunbower Forest into Gunbower Creek through the Yarran Creek regulator.
4. the loads of dissolved organic carbon, total phosphorus and total nitrogen entering Gunbower Creek from the Yarran Creek regulator.
5. how these additional carbon, phosphorus and nitrogen loads compare to historical annual loads in Gunbower Creek.
6. if opening the Yarran Creek regulator has a noticeable effect on dissolved oxygen concentration characteristics in Gunbower Creek downstream of the regulator.

Objective 1: Delivery of water to Gunbower Creek through the Yarran Creek Regulator

The purpose of this objective is to determine whether or not it is actually feasible to deliver water from the forest into Gunbower Creek through the Yarran Creek regulator, and the conditions required for this to occur. This will feed in to the decision about whether or not to undertake more rigorous monitoring during subsequent watering events. Objective 1 can be met by field observations by North Central CMA staff.

Objective 2: Determining water transit time

The purpose of this objective is to inform the sampling program during subsequent watering events. As outlined in Section 2, it was suggested that samples be taken when the Hipwell Rd regulator was first opened and then when water has reached the Yarran Creek regulator and the regulator is opened. (It is suggested that the Yarran Creek regulator remains closed until flood water reaches the regulator.) Objective 2 can be met by field observations by North Central CMA staff. The transit times needs to be documented.

Objective 3: Volume of water returned to Gunbower creek

The reasons for this objective are twofold. Firstly, to determine if water can actually flow from the forest into Gunbower Creek through the regulator. The regulator was designed to facilitate flows from Gunbower Creek into the forest. The second reason is to have an accurate estimate of water volume entering Gunbower Creek from the forest to calculate loads of key constituents (Objective 4). North Central CMA staff should consult with the operators of the structure to ensure accurate measures of the volume of water leaving the forest can be documented. This is critical if a full monitoring program (see Section 2) is undertaken during subsequent watering events.

Objective 4: Determining load of carbon and nutrients delivered to Gunbower Creek from Gunbower Forest

There are a number of reasons for this objective. Firstly, this will give an estimate of how much additional material (carbon, phosphorus and nitrogen) can be delivered from the forest to Gunbower Creek through the Yarran Creek regulator. Furthermore, it will give North Central CMA staff experience in water sampling and provide an indication of whether it is feasible for North Central CMA staff to undertake water sampling in subsequent watering events to reduce costs (see Section 2).

The proposed sampling regime has been reduced from that proposed for a full sampling program. The reasons for this is to reduce the amount of North Central CMA staff time required for this activity and to reduce analysis costs. The trade-off is that there is no estimate of the bioavailability of the material entering Gunbower Creek from the forest, and therefore the question of whether or not loads entering Gunbower Creek are used by organisms within the creek cannot be answered in 2018.

In 2018 samples should be taken at four sites:[12]

- In Gunbower Creek immediately upstream of the Yarran Creek regulator. These samples set the baseline for material in Gunbower Creek,

[12] The full sampling regime would include a 5th site - the inflow at the Hipwell Road regulator. The purpose of this additional site is to get a better understanding of how water quality changes during the transit through the forest compared to the transit through Gunbower Creek and the Cohuna Irrigation Channel. This is important information to address the overall objective of the monitoring program, but is secondary importance for the feasibility study

- In Yarran Creek at the regulator. These samples will be used to determine loads entering Gunbower Creek from Gunbower Forest
- In Gunbower Creek at the DO probe site 5 km downstream of the Yarran Creek regulator. These samples will be used as a check on load estimates from the previous two sites.
- In Gunbower Creek at Condidorios Bridge. These samples will give a preliminary estimate of how much carbon and nutrients are consumed or retained by organisms in Gunbower Creek downstream of the Yarran Creek Regulator.

If a natural flood occurs, additional samples would be taken in the Murray River immediately upstream of Gunbower Forest (or use the water quality data for Torrumbarry taking into account that it can take 2 - 3 months for the data to be published online).

Samples would be taken on the first day after the Yarran Creek regulator is opened, and then as often as North Central CMA staff visit Gunbower Forrest, preferably at least fortnightly. A draft Standard operating procedure for sampling is included in Appendix A.

Samples would be analysed for dissolved organic carbon, total phosphorus and total nitrogen. This is a reduction in the number of constituents proposed in Section 2. The reason is to reduce the number of samples that need to be filtered in the field, hence reducing the staff workload. Samples will need to be kept frozen prior to analysis.

Indicative costs:

North Central CMA staff training in field sampling	$1500
Filtration equipment	$500
Consumables (filter papers, acid washed sampling bottles etc)	$1000
Chemical analysis	$750/sampling occasion[13]
Data analysis and reporting	$5000

Objective 5: Understanding Historical Loads of constituents in Gunbower Forest

The purpose of this objective is to put the outputs from Objective 4 into perspective, i.e. how much additional material does operation of the Hipwell Road and Yarran Creek regulators add to Gunbower Creek compared to long-term annual loads. The rationale and proposed methodology is discussed in some detail under the heading "Baseflows" in Section 2. The cost for analysing and reporting on the long-term data set would be approximately $4000.

[13] Assumes a natural flood doesn't occur. It is proposed that North Central CMA is responsible for the collection, storage, freight and cost of analysis. This will simplify contracting as, the number of sampling occasions is currently unknown.

Objective 6: Impact of inflows on DO characteristics in Gunbower Forest

In addition to loads of constituents entering Gunbower Creek, In Section 2 it is suggested consideration be given to determining stream metabolism in Gunbower Creek upstream and downstream of the Yarran Creek regulator during forest inundation coupled with Yarran Creek regulator operation. However, to be of value, there must be a measured change in DO dynamics in response to flood return water. During the feasibility study it is suggested that diurnal changes in the DO concentration at the site 5 km downstream of the Yarran Creek regulator are monitored using the current *in-situ* DO probe. Modelling using the Blackwater Risk Assessment Tool suggests that at a flow of 100 ML/day leaving the forest through the Yarran Creek regulator, DO concentration in Gunbower Creek downstream of the regulator should decrease by about 2 mg/L, falling from about 10 mg/L to about 8 mg/L.[14] Therefore a response in DO concentration from inflows from the forest into Gunbower Creek is expected. Ideally, DO concentrations should be simultaneously measured in Gunbower Creek upstream of the Yarran Creek regulator.[15] However, as noted in Section 2, this would require the installation and maintenance of a DO logger, at some additional expense. For the purpose of the feasibility study it is suggested that spot measurements of DO, taken at the same time as water quality samples, at a site upstream of the Yarran Creek regulator and at the site of the DO probe 5 km downstream of the Yarran Creek regulator, should be enough to help inform the decision on whether or not to proceed with determining stream metabolism in Gunbower Creek during subsequent watering events. The cost of analysing and reporting on DO dynamics in Gunbower Creek would be included in the overall reporting for the project (outlined under Objective 4).

All data collected in the feasibility study (transit times, flows, loads etc) needs to be documented in order to help inform future monitoring strategies.

[14] Assumes total inflows of 42GL, 3000 ha of floodplain inundated, a litter load of 560 g/m^2, a flow of 200 ML/day in Gunbower Creek at the outfall, and a DO concentration in Gunbower Creek of 10 mg/L.

[15] In case the changes in DO are independent of any inflows.

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Appendix A: Draft Standard Operating Procedures for the 2018 Gunbower Creek Feasibility Study

General Water Quality

Equipment:

- Waders (optional)
- Multi-probe (CMA to supply)

1. If safe to do so, wade out in the creek to knee depth.
2. Use a calibrated multiprobe to take spot measurements of dissolved oxygen concentration, temperature, electrical conductivity and pH following manufacturer's instructions
3. Record values on the sampling log sheets (see below)

Total Nitrogen and Total phosphorus

Equipment:

- 250 ml wide-mouthed acid-washed HDPE screw capped bottle*
- Waders (optional)
- Sampling pole (optional)*
- Distilled water*
- Esky
- Freezer bricks
- Permanent marker

Method:

1. In the sampling log record the sample number, the site, the date, time and analyte (TN & TP)
2. On the bottle cap write the sample number using a black permanent marker
3. On the bottle write the sample number, the date, the site and the analyte in black permanent marker
4. Unscrew the cap
5. If safe to do so enter the water up to knee depth, otherwise use the sampling pole
6. Submerge bottle to a depth of about 10 cm upstream of where you are standing so as not to include any sediment disturbed on entering the Creek
7. Fill bottle up to about 1/4 of total volume
8. Cap the bottle shake the bottle for a few seconds, uncap the bottle and discard the contents.
9. Repeat steps 6 - 8 twice more.

10. Fill the bottle up to the shoulder, cap and store on ice in an esky until returned to North Central CMA where the bottle should be placed in a freezer.

At least at one site per sampling trip, create a sampling blank

1. In the sampling log record the sample number, the site (SB), the date, time and analyte (TN & TP) in pencil
2. On the bottle cap write the sample number using a black permanent marker
3. On the bottle write the sample number, the date, the site (SB) and the analyte in black permanent marker
4. Unscrew the bottle
5. Fill the bottle with about 50 ml of distilled water
6. Recap the bottle, shake for a few seconds, uncap and discard water
7. Repeat Steps 5 and 6 twice more.
8. Fill the bottle up to the shoulder, cap and store in an esky with freezer bricks until returned to North Central CMA where the bottle should be placed in a freezer.

Dissolved organic carbon

Equipment:

- Filtration apparatus*
- Hand vacuum pump*
- pre-fired 47 mm GF/C filter papers*
- Tweezers*
- 200 mL pre-fired amber glass bottles*
- Washed and fired tin foil*
- Waders (optional)
- Sampling pole (optional)*
- Distilled water*
- Esky
- Freezer bricks

Method:

1. In the sampling log record the sample number, the site, the date, time and analyte (DOC) in pencil
2. On the bottle cap write the sample number using a black permanent marker
3. On the bottle write the sample number, the date, the site and the analyte (DOC) in black permanent marker
4. Attach hand vacuum pump to the filtration unit

5. Unscrew the top water holder from the filter support base
6. Using tweezers place a pre-fired GF/C filter paper onto the filter support.
7. Re-attach top water tank
8. Sample water using HDPE 1L measuring cylinder in a similar way to the TN and TP sampling, rinsing the cylinder at least 3 times with creek water before taking the sample.
9. Add about 50 ml of creek water to the top water tank of the filtration
10. Using the hand vacuum pump, create sufficient vacuum so that all of the water in the top tank of the filtration is sucked into the bottom water tank.
11. Unscrew the bottom water tank, discard the filtered water and re-attach the bottom water tank to the filtration unit.
12. Repeat steps 9 - 11 two more times
13. Fill top tank with about 200 ml of creek water
14. Repeat step 10 and 11, but rather than discarding the filtrate, add about 25 ml to the amber glass bottle, cap, shake for a few seconds, uncap and discard the contents of the bottle. Fill, cap, shake, uncap and discard 25 ml samples of the filtrate two more times.
15. Add about 175 ml of the filtrate to the rinsed amber bottle, then, using tweezers place a sheet of pre-washed and fired aluminium foil over the mouth of the bottle, cap, and place in an esky with freezer bricks, return to the office and freeze.

At least at one site per sampling trip, create a sampling blank

1. Follow the procedure for dissolved organic carbon, except replace the creek water with distilled water. Note the sampling site as SB.

* Can be supplied by *Rivers and Wetlands*

Sampling Log
Yarran Creek Feasibility Study 2018

Sample #	Time	Site	Date	Analyte	DO	pH	EC	Temp

Site A = Gunbower Creek upstream of Yarran Creek regulator
Site B = Yarran Creek at the regulator
Site C = Gunbower Creek 5 km downstream of the Yarran Creek regulator
Site D = Gunbower Creek at Condidorios Bridge
SB = Sampling Blank