Campaspe Flow Objectives

NORTH CENTRAL CMA

Revised environmental flow objectives for the Campaspe River

| Final

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Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to review the environmental flow objectives and environmental flow recommendations for the Campaspe River downstream of Lake Eppalock in accordance with the scope of services set out in the contract between Jacobs and the NCCMA. That scope of services, as described in this report, was developed with the NCCMA.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the NCCMA and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the NCCMA, the 2006 FLOWS study for the Campaspe River and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

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No new hydraulic models were developed for this project.

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1. Introduction

SKM (2006a) used the FLOWS method to determine the environmental flow requirements for the Campaspe River downstream of Lake Eppalock. Since then, the Campaspe River has experienced severe drought and record floods. Lake Eppalock nearly dried during the drought and the NCCMA was unable to deliver most of the recommended flows and sections of the Campaspe River contracted to a series of isolated pools. Sections of the river became highly saline, the health of River Red Gums along much of the river declined and emergent plants such as Phragmites and Typha encroached into the river channel. The 2011 and 2012 floods scoured most of the established vegetation from the channel and conditions now are quite different compared to the time of the original FLOWS study. Those changes combined with the improved understanding of likely responses to environmental flows gleaned from programs such as the Victorian Environmental Flows Monitoring Program (VEFMAP) and Campaspe River Saline Pools Monitoring Program mean that some of the original flow recommendations are out of date.

The Victorian Government has secured a 22 GL environmental water allocation for the Campaspe River. Lake Eppalock is now full and therefore the NCCMA is well placed to deliver a wider range of environmental flows to the Campaspe River. The NCCMA is developing an Environmental Water Management Plan (EWMP) to guide the use of environmental water in the Campaspe River. The EWMP needs to be based on approved environmental flow recommendations for the river and therefore the NCCMA has engaged Jacobs and other members of the original Environmental Flows Technical Panel (EFTP) for the Campaspe River (see Table 1-1) to review the flow objectives and environmental flow recommendations for the three environmental flow reaches downstream of Lake Eppalock.

Table 1-1: Environmental Flows Technical Panel members involved in the 2014 review

Environmental Flows Technical Panel Member	Technical discipline	Member of 2006 Campaspe FLOWS study
Dr Andrew Sharpe (Jacobs)	Project leader, macroinvertebrates and water quality	Yes
Prof Paul Boon (Dodo Environmental)	Instream and riparian vegetation	Yes
Dr Paul Humphries (Charles Sturt University)	Fish	Yes
Dr Peter Sandercock (Jacobs)	Geomorphology	No – replaced Dr Bruce Abernethy
Lisa Walpole (Jacobs)	Hydrologist	No – but assisted by Simon Lang who was the hydrologist on the 2006 project.
Dr Melody Serena (Australian Platypus Conservancy)	Platypus	No – Platypus were not specifically considered in the 2006 study.

1.1 Approach

The EFTP conducted three tasks to inform the environmental flows review:

1. Three members of the EFTP (Andrew Sharpe, Paul Boon and Paul Humphries) and representatives from the NCCMA (Louissa Rogers, Darren White, Michelle Maher and Bree Bissett) revisited all of the original FLOWS sites on 1st August 2014 to inspect the current condition of the river. Peter Sandercock did not attend the site inspections as he recently visited all sites as part of a geomorphology assessment for VEFMAP. Melody Serena also did not attend, but viewed photographs taken by the EFTP. Field notes and photos taken during that site inspection are included in Appendix A of this report.
2. Five members of the EFTP, the four NCCMA representatives listed above and Caitlin Davis from the Victorian Environmental Water Holder participated in a two day workshop on 7-8th August 2014 to update the environmental flow objectives and environmental flow recommendations for the three environmental flow reaches downstream of Lake Eppalock. Peter Sandercock was unable to attend the workshop, but provided written input in advance. Andrew Sharpe facilitated the workshop and recorded the agreed outcomes.

3. All members of the EFTP prepared a report (this report) to document the outcome of the workshop and present the revised environmental flow objectives and flow recommendations for the Campaspe River downstream of Lake Eppalock.

1.2 The report

This report presents the updated environmental flow objectives and environmental flow recommendations for the three environmental flow reaches of the Campaspe River downstream of Lake Eppalock. Chapter 2 of this report describes our conceptual understanding of the flow requirements for native fish, aquatic and riparian vegetation, macroinvertebrates, water quality and Platypus in the Campaspe River. Chapter 3 summarises the environmental flow objectives for each reach. Chapter 4 summarises the updated environmental flow recommendations for each reach.

The report does not include all of the information that would normally be included in an Environmental FLOWS report and should be read as an addendum to the reports produced during the 2006 FLOWS study (SKM 2006a, c, b).

2. Conceptual understanding of flow requirements for selected environmental values

2.1 Fish

There are, broadly, three life history strategies in fishes: opportunistic, periodic and equilibrium (Winemiller and Rose 1992). The model developed around these strategies attempts to explain the responses of organisms to a changeable environment, especially as they pertain to time and size of maturity and how offspring are packaged (i.e. size and number). The strategies can be described by the following traits:

'Opportunistic' species – small, short-lived species that mature early, make a large reproductive effort, but with low fecundity per batch and a small investment of energy per offspring, move relatively little as adults and only disperse locally as larvae (e.g. Carp Gudgeons and Australian Smelt);

'Periodic' species – relatively large, long-lived species that mature late and make a moderate reproductive effort, with high fecundity per batch and a small energetic investment per offspring, move relatively frequently as adults and disperse widely as larvae (e.g. Bony Herring, Golden Perch and Silver Perch);

'Equilibrium' species – species of variable size, maturing at medium to late stages, with low fecundity per batch and a large energetic investment per offspring, often with parental care; some species move substantially as adults and larvae and some species are relatively sedentary (e.g. Murray Cod, River Blackfish).

Species with different strategies can exist in the same reaches of rivers, since different conditions, both spatial and temporal, provide advantages for one strategy over another. Thus, Murray Cod, an equilibrium species, Golden Perch, a periodic species, and Australian Smelt, an opportunistic species, can all persist in relative abundance in the same reach of a river. Larger periodic and equilibrium species are able to move to more favourable habitats if conditions are not optimal. Opportunistic species are smaller and less able to move large distances, but, over time, they can recolonise new areas. For fishes in highly variable, unpredictable inland rivers, mobility is a necessity for continued persistence (Puckridge *et al.* 1998).

All species of fish, from all three life history strategies, will be affected by the flow regime of the river in which they live, to some degree. But the direct relationship between flow and persistence of fishes is not well understood. We know that most species do not require a particular flow to spawn, however, Humphries *et al.* (1999) have identified a group of low-flow specialists (e.g. Carp Gudgeons and Murray Rainbowfish), which seem to spawn during mostly during the predictable low flow period of rivers in the southeastern Murray-Darling Basin. Golden Perch and Silver Perch (periodic species) are probably the only native species that are likely to have some degree of relationship with flow when spawning, but even for these, there is a lot of uncertainty, Recent studies have shown that spawning and recruitment of Golden Perch can occur at a range of flows (Mallen-Cooper and Stuart 2003; King 2005; Balcombe *et al.* 2006; Roberts *et al.* 2008; King *et al.* 2009). There is evidence, however, that some species (e.g. Murray Cod), may accrue some advantage from floodplain inundation because of the food produced and washed back into the main channel (King *et al.* 2009). Moreover, floodplain inundation seems to support dispersal and recruitment of small, opportunistic species on the floodplain itself (Tonkin *et al.* 2008).

The early life stages of fish require nursery habitats where they can develop, grow and mature. For many species, slackwaters – areas of no or negligible flow – are ideal nursery habitats. These provide sheltered, usually warm, food-rich areas conducive for survival and growth (King 2004). Either the adults spawn there or larvae move there themselves. The swimming abilities of larvae vary greatly, but are certainly much poorer than those of juveniles and adults. Most larvae, however, can make relatively large scale movements by drifting in river currents. In some species, the adults spawn upstream and rely on the flow of rivers to disperse the young. The larvae of Murray Cod, Golden Perch and Silver Perch are considered obligate 'drifters' (Humphries and King 2004), and with some degree of control over how and where they drift.

2.1.1 Flow requirements of fishes from the three life history strategies

In summary, flow-ecology relationships are not well understood for freshwater fishes of the Murray-Darling Basin. Because of this, it would mostly be best to err on the side of caution and use the unregulated flow regime of the Campaspe River as a guide to what types of flows are released, when and for how long. Generally we can summarise the needs for fish species in each life history strategy as the following:

Opportunistic low flow specialists (e.g. Carp Gudgeons, Murray Rainbowfish) – period of time between November and February (ideally) when slackwater habitat is maximised and undisturbed by freshes.

Opportunistic generalists (e.g. Flathead Gudgeons, Australian Smelt) – minimal flow requirements, although dispersal can be facilitated by connectivity between habitats. However, for species that could recolonise the Campaspe River, such as Southern Pygmy Perch, floodplain inundation can enhance dispersal and recruitment.

Periodic (e.g. Golden Perch, Silver Perch) – although there is much uncertainty, these species may benefit from substantial rises in flow around their normal spawning time (likely between October and March), which would allow wide dispersal of eggs and larvae, should spawning take place.

Equilibrium sedentary (e.g. River Blackfish, Freshwater Catfish) – minimal flow requirements, although conditions of nests during spawning may be enhanced by some water movement.

Equilibrium movers (e.g. Murray Cod, Trout Cod) – flow requirements are mostly related to the prevention of washing out of nests during the incubation and early life stages (likely between early October and early December), and a requirement for some flow so that the larvae leaving the nest can disperse.

For all species, irrespective of life history strategy, providing a diversity of flows at appropriate times of the year, is likely to enhance the fish assemblage in the Campaspe River. This would include flows able to drown-out the Campaspe Weir and Campaspe Siphon and allow fish movement upstream and downstream.

With the removal of the Echuca gauging weir and if the many threats to fish are removed, including providing fish passage through the two remaining weirs, the potential to increase the richness of fish species throughout the Campaspe from the Murray to Lake Eppalock, are great. Figure 2-1 lists the species currently in each reach of the river and the possible species, should the threats be removed. These are based on assessments of species that have been recorded from the Campaspe River historically (Humphries and Lake 2000).

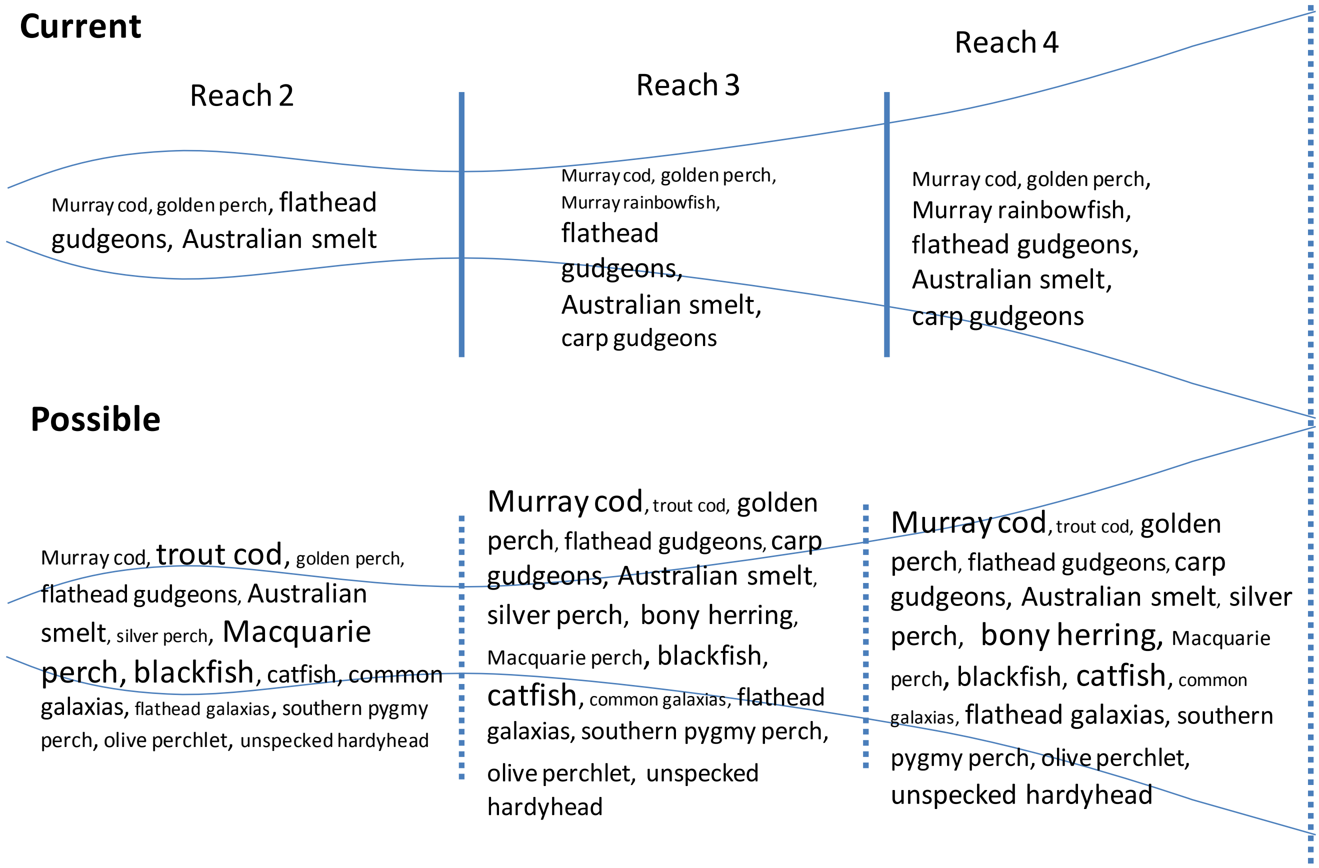

Figure 2-1: Schematic representation of the current Campaspe River fish fauna and the possible fish fauna that could occur if current threats are removed. Size of font indicates relative abundance for that species in each reach (i.e. compare between font size within species across different reaches, not between species within the same reach).

2.1.2 Environmental objectives

Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
Increase population size (with appropriate age structure) of native fish with periodic, equilibrium and opportunistic life history strategies that have been recently recorded in this reach e.g. Golden Perch, Murray Cod and Australian Smelt.	These species would have historically been abundant in the reach
Facilitate recolonisation by native species that have been presumed lost e.g. Trout Cod, River Blackfish, Macquarie Perch	These species would have historically been abundant in the reach. The ability to achieve this objective will depend on opportunities for fish passage past the Campaspe Weir that will allow fish to move into the reach from the Murray and Reaches 3 and 4

2.1.3 Threats to meeting objectives

Threat	Outcome
Inappropriate water regime	Flows that are too low may not inundate enough slackwaters for fish larvae, or provide sufficient habitat for adults of large species. Rapidly fluctuating flows may strand fish Flows that are consistently too high may destroy slackwater habitats
Pest species, such as Carp, European Perch, Gambusia	High abundance of pest species may limit native species abundance. For example, Carp lock up carbon at a lower level in the food web and it cannot be exploited. This carbon would normally flow up the food web and support more native fish. Redfin Perch will prey on small native fish and Gambusia will fin-nip small-bodied native fish such as Southern Pygmy Perch and potentially exclude them from their preferred habitat.
Barriers, such as dams	Dams are a barrier to upstream and downstream movement of fish. Although many species may not need to move as part of their life history, providing unfettered access allows interchange of genes and recolonisation, when river reaches are affected by some sort of disturbance.
Cold water releases from dams	Slower growth rates and lower rates of productivity. In some cases, fish may not spawn if temperatures are too low.
Recreational fishing	Recreational fishing can reduce numbers of target species, which can be a problem if the river is reduced to pools, such as during a drought.
Stocking of hatchery fishes	Hatchery stocking can cause problems with genetics and can mask broader problems with fish abundance and richness.
Small numbers of native species	A small number of native species in the river means that, even though conditions might be conducive for spawning and recruitment, there are not sufficient individuals for them to be able to find each other to reproduce.

2.1.4 Monitoring needs

Fish monitoring should focus on five things:

1. The use of slackwater habitats by small-bodied fish and fish larvae under low flow conditions during summer. The monitoring should look at fish diversity and abundance as well as changes in the abundance of food such as zooplankton. It should also aim to determine what flows flush larvae out of slackwaters, the appropriate interval between those flows to allow larvae to become competent swimmers and the preferred timing of those flows to maximise recruitment to the adult population. Monitoring should also examine how flows affect the dispersal of young life stages of fish.
2. The production of eggs and larvae by species such as Golden Perch and Silver Perch that have a periodic life history strategy to determine whether they spawn in response to high flows in spring or early summer.

This monitoring should use a combination of methods including regular larval drift samples before and after the planned flows are released.

3. Fish movement in response to high flows that allow movement between reaches and that potentially provide a chemical cue to fish in the Murray or other connected systems. This monitoring may use tag and release methods, radio transmitters or pit tags and associated recorders. There is already a large pool of large bodied fish in the lower Loddon River, Murray River and Goulburn River that have been caught and fitted with pit tags and it would be relatively inexpensive to install a pit tag recorder in Reach 4 upstream of the old gauging weir to detect any of those fish that move into the Cammpaspe River.
4. Annual adult fish surveys will still be important for tracking changes in the fish community over time. Those data should be analysed by examining the number of sites in each reach where particular species are caught. Species that are regularly caught at many sites will be considered widespread, whereas those that are only caught at a few sites will be considered to have small populations even if the number caught on any particular occasion is high.
5. Monitoring should examine broader changes in foodwebs in response to different flow regimes and the influence of Carp on those foodwebs. These questions are particularly relevant as they will help to determine whether the environmental flows are creating the right conditions for native fish and may highlight other factors that prevent expected improvements to the fish community.

2.2 Aquatic and riparian vegetation

2.2.1 Diversity of and typology for aquatic and riparian vegetation

Almost all published information on the responses of water-dependent vegetation to wetting and drying is sorted taxonomically. In other words, information on plant responses is available for individual species, and usually only for common, widespread or economically significant species such as Common Reed *Phragmites australis* or Giant Rush *Juncus ingens* or River Red Gum *Eucalyptus camaldulensis*. As outlined below, such species-specific information may be secondarily sorted into responses for broad taxonomic-structural groups, such as trees and shrubs, grasses, rushes and reeds, and herbs and forbs. The taxonomic approach has been used in almost all existing studies, including the most comprehensive syntheses on vegetation-water regimes responses in south-eastern Australia by Roberts and Marston (2011) and Rogers (2011). A species-by-species approach was used also in the investigation of River Red Gum Forests by the Victorian Environmental Assessment Council (2006), and the detailed study of the flooding requirements of vegetation in the Barmah Forest by Ward (1994).

An alternative approach is to examine hydrological requirements at the level of broad taxonomic, structural or functional groups. It has the advantage of providing some guidance on wetting and drying regimes for the large number of plant species for which specific hydrological information is not available. Inevitably, however, it has the potential disadvantage of being too generic and lacking in detail. A number of schemes have been developed to classify aquatic and riparian vegetation into discrete groups and to clarify their response to environmental conditions. Early in the 20th century, a distinction between r and K factors in controlling (human) population growth was developed by Pearl and Reed (1920), It was later applied to plants; species that produced abundant, but small, seed and had wide dispersal capacity are known as r-selected species: they are typically early colonizers of new environments and eventually give way to subsequent species with more specialised environmental requirements (Harper 1977). In contrast, K-selected species are thought of as specialists that typically grow in resource-limited environments where there is intense competition among neighbouring plants for space and resources. Grime (2001) differentiated among stress-tolerant, competitor, and ruderal species in his C-S-R model. Van der Valk (1981) developed an ‘environmental sieve’ schema based on annual versus perennial life histories, sexual versus clonal reproduction, and hydrological requirements.

In Australia, the Plant Functional Group (PFG) typology of Brock and Casanova (1997) has been widely used; it distinguishes among terrestrial, amphibious, and submerged taxa, which do not tolerate flooding, tolerant flooding and drying, and do not tolerate drying, respectively. The PFG approach has been used recently to examine the effects of different water regimes on vegetation in Dowd Morass, a brackish-water wetland in the western part of the Gippsland Lakes (Raulings *et al.* 2010, 2011). A similar approach using broad plant groupings was used by Naventeri and Kambouris (2008) for Parks Victoria

Other typologies also based on broad structural-taxonomic groups are used commonly used in Australia. A recent one is that by Rogers (2011), which includes groups such as trees and shrubs (i.e. woody vegetation, including *Eucalyptus*, *Callistemon*, *Leptospermum*, *Melaleuca* spp.); grasses (e.g. *Phragmites*), rushes and sedges (e.g. *Bolboschoenus*, *Cyperus*, *Eleocharis* and *Juncus* spp.); and aquatic herbs (e.g. *Ludwigia*, *Marsilea* and *Vallisneria* spp.).

For the purposes of the current flow investigation we grouped aquatic and riparian (i.e. water-dependent) vegetation into four groups:

- more-or-less submerged angiosperms, which require long periods of standing water for survival, including taxa such as *Vallisneria australis*, *Myriophyllum* spp. and *Potamogeton* spp
- fringing reeds, with a focus on *Phragmites australis*
- other fringing rushes and sedges (e.g. robust, emergent taxa, often rhizomatous)
- woody taxa (e.g. ringing shrubs and trees), with a focus on River Red Gum *Eucalyptus camaldulensis*.

2.2.2 Hydrological requirements of aquatic and riparian vegetation

The hydrological requirements of these four structural groups are reasonably well known (Roberts and Marston 2011; Rogers 2011). Submerged angiosperms require annual flooding, typically of 50−100 cm, for prolonged periods. Many can withstand temporary drying, either because they possess desiccation-resistant organs (e.g. the turions of *Triglochin procerum*) or the surface layer of masses of drying leaves protects the still-living plants nearer the sediments (e.g. *Vallisneria australis*).

Reeds, *Phragmites australis*, are a focus because they are common in the steam-side zone and provide valuable habitat. *Phragmites australis* has one of the widest hydrological niches of all riparian plants, and typically grows best under fluctuating water levels, in water up to 2 m deep. Adults can withstand prolonged inundation (if some vegetative material remains aerial), but also prolonged dry periods.

Rushes and sedges are a floristically diverse group but typically require annual inundation for 2−4 months over spring to summer in water up to ~ 30 cm deep. Some taxa are advantaged by inundation in late winter or early spring (e.g. *Bolboschoenus fluviatilis*) whereas others (e.g. *Eleocharis spacelata*) will mainly benefit from flooding in late spring or early summer when temperatures are warmer; other taxa require near-permanent inundation (e.g. *Typha* spp.) and some more terrestrial conditions (e.g. *Poa* spp.). The ecological consequence of these various hydrological requirements in the rushes and sedges is that mosaics of vegetation can be expected, in time and in space, according to wetting and drying regimes.

In the Campaspe River system, River Red Gum is the riparian tree species of most interest, although a number of other genera in the family Myrtaceae also occur along the stream sides (e.g. *Callistemon* spp.). The water requirements of River Red Gum are well known, with variations in flooding intensity and duration prompting a shift between forest and woodland plant assemblages. Unlike many taxa of aquatic and riparian plants (Hatton *et al.* 2008), River Red Gum is not clonal and recruitment requires floods in spring or summer, with plant establishment thought to be maximized if floods occur in consecutive years. Roberts and Marston (2011) and Rogers (2011) detail the hydrological requirements of River Red Gum in terms of i) the maintenance of adult specimens and ii) successful sexual recruitment.

2.2.3 Impacts of different wetting and drying regimes

The various hydrological requirements of these four plant groups means that different taxa will be advantaged or disadvantaged under different flow and climatic regimes. Under a prolonged dry climate, similar to that experienced during the original flows assessment of 2005/06 (SKM 2006a, c), fringing taxa of robust emergent rhizomatous plants (e.g. *Phragmites* and *Typha* spp.) are likely to encroach into the former in-stream channel. Slow-flowing pools may develop large stands of submerged taxa, such as of *Triglochin*. Recruitment of River Red Gum is likely to be minimal, and the health of adult trees likely to suffer if flooding does not occur for periods longer than ~5−7 years.

The onset of a flood will, if severe enough, scour the emergent rhizomatous taxa that had formerly colonised the stream channel. New, unvegetated sandy benches and other areas may be created by the passing of the flood, and be available for subsequent colonisation by reeds, rushes, and sedges. Submerged plants may be scoured as well, but might find it hard to recolonise denuded sediments if flows remain too high or if the only sediment left after surfaces layers have been scoured is hard clay. Riparian trees, however, will be rejuvenated by inundation and their canopy will become more dense. Recruitment of River Red Gums high up the bank may also occur at the highest level of the flood waters. This phenomenon is shown in Figure 2-2 below.

Figure 2-2: Massed recruitment of River Red Gum (yellow arrow) high up the bank at English's Bridge. Photograph by Paul Boon 1/08/2014.

2.2.4 Establishment and maintenance of aquatic and riparian vegetation

The establishment of aquatic and riparian plants requires three sets of conditions:

1. A source of propagules, such as seed or in the case of clonal taxa, broken fragments of plants, that can be brought into the stream from elsewhere in the catchment, either as a flux carried from upstream areas with the current or as imports by animals, especially birds, from other locations.

2. Appropriate physico-chemical conditions (e.g. hydrological conditions, water quality, sediment characteristics).

3. Appropriate biological conditions (e.g. absence of competition from other plant taxa, absence of grazing by domestic stock or by feral/native animals).

In the case of the Campaspe River, a viable hypothesis is that grazing, by domestic stock (e.g. cattle, sheep), or by feral animals (e.g. rabbits), or by native animals (e.g. kangaroos, wallabies) has limited the establishment of riparian vegetation after the 2010/11 flood. Figure 2-3 shows as an example the effect of stock access on River Red Gum recruitment at Doakes Reserve

Figure 2-3: Successful recruitment of River Red Gum at Doaks Reserve in an area of the riparian zone fenced from stock access (left hand photograph) in comparison with an absence of recruitment in an adjacent unfenced area (right hand photograph). Photographs by Paul Boon 1/08/2014.

2.2.5 Threats to meeting objectives (Vegetation)

Threat	Outcome
Inappropriate water regime	Inability to deliver bankfull and/or overbank flows may compromise condition of adult River Red Gum and limit recruitment of juveniles into the population. There may be (negative) impacts also on the diversity and condition of understorey vegetation if riparian inundation is too infrequent. Freshes and other flows that create high stream velocities may limit re-establishment of in-stream (submerged) vegetation.
Grazing pressure and stock access	Grazing by domesticated, feral and/or native herbivores (e.g. cattle, sheep, rabbits, kangaroos and wallabies) may prevent the establishment of emergent vegetation on benches and in the riparian zone. The effects may be caused by direct grazing pressure (most likely) or sediment pugging (less likely). Severe grazing pressure might have impacts also on submerged aquatic vegetation via direct herbivory and physical disturbance.
Pest species such as Carp	High abundance of Carp may limit the establishment and subsequent maintenance of in-stream (submerged) vegetation.

Threat	Outcome
Upstream barriers such as dams	Dams may present a barrier to downstream movement of plant propagules and the source of seeds or plant fragments required for the recolonisation of areas denuded by recent floods. Dams and other instream barriers can also starve downstream reaches of sediment. High flows and floods may over time scour loose, friable material from the streambed and low benches leaving hard clay that is more difficult for aquatic and riparian plants to colonise.
Inappropriate sediment properties	Sediments may have been altered markedly by previous droughts and floods, and now be difficult for plants to colonize into. Sediments, for example, may have had the upper loose/friable layers stripped by floods and only a hard clay layer may remain.

2.2.6 Monitoring needs

Monitoring should focus on two processes:

- long-term changes in aquatic and riparian vegetation under various climatic regimes
- the effectiveness of environmental flows and other factors in facilitating vegetation recovery.

The first question is critical because the Campaspe River is in a region of Australia that experiences marked alternating drought and flood regimes and we know little about the specifics of vegetation dynamics under these long-term cycles. What types of vegetation dominate in prolonged dry periods and what types dominate under wetter periods? How long does it take for robust emergent rhizomatous plants to colonize a desiccated stream channel during a drought; floods of what magnitude are required to scour this vegetation out of the channel?

The second question addresses the relative roles played by hydrological versus non-hydrological (so-called ancillary) factors. If vegetation does not respond as expected to the introduction of the recommended flows, why not? Is it because biological factors, especially stock access and grazing, limit the recovery of vegetation? Are sediments too hard for submerged taxa to recolonize? Is there a sufficient source of propagules from upstream to allow recovery after loss of a particular plant community?

Such questions need to be framed in the nature of a specific hypothesis (otherwise the actions will be mere surveillance rather than *bona fide* monitoring). They can be tested with, for example, the establishment of exclusion zones on river banks to control grazing pressure whilst still allowing the passage of the recommended flows.

2.3 Platypus

Platypus live-trapping surveys have not to date been conducted along the Campaspe River downstream of Lake Eppalock. However, persons engaged in fish surveys captured Platypus as by-catch in the late 1990s at several locations between Lake Eppalock and Elmore (John Douglas, pers. comm.), at Doakes Reserve, English's Bridge and Campaspe Park from 2000 to 2003 (Luciano Serafini, pers. comm.), and in recent years near Axedale (Peter Sandercock, pers. comm.). More than half of landholders owning river frontage between Lake Eppalock and the Campaspe Siphon who were interviewed by APC staff in the early 2000s reported seeing Platypus on an occasional or more frequent basis, consistent with resident animals being present. In contrast, landholders living downstream of the Campaspe Siphon mainly reported one-off sightings or 2-3 sightings in a single short period, suggesting that dispersing juveniles or older vagrants (e.g. males searching for mates) were observed. The Campaspe River is predicted to be the most important source of migrants currently needed both to bolster the small Gunbower population and to foster re-colonisation of the Murray River and its anabranches downstream of Echuca.

The Platypus's flow requirements have generally not been subject to direct study, and therefore must be inferred based on other aspects of its biology.

Diet and foraging. It is well-established that the Platypus eats a diverse array of mainly benthic macro-invertebrates, with Trichoptera consistently comprising the most commonly consumed taxa at lotic sites (Faragher *et al.* 1979; Grant 1982; McLachlan-Troup *et al.* 2010). Non-breeding adults ingest the equivalent of about 15-30 % of their body mass in food each day, rising to 50% or more of maternal body mass during mid- to late lactation (equating approximately to December-February) (Krueger *et al.* 1992; Holland and Jackson 2002). Platypus reproductive success is also expected to vary with the amount of food available to females in the months leading up to the August-October breeding season: a positive relationship has been shown to hold between rainfall (serving as a surrogate for stream flow) in March-July and the number of juveniles captured annually in streams near Melbourne in the mainly dry to very dry period from 1997 to 2007 (Serena and Williams in press). Home ranges of adult females have been documented to encompass up to 4.5 km of channel, with those of adult males extending up to 15.1 km in length (Gardner and Serena 1995; Serena *et al.* 1998).

Predation risk. Platypus are predicted to be most vulnerable to predators (e.g. foxes) when travelling through very shallow water or across dry land (Grant and Bishop 1998). In practice, a recent Victorian study found that Platypus mortalities due to predation were recorded throughout the year apart from mid-winter to mid-spring (July to October), when unregulated streams typically flow most strongly (Serena and Williams 2010).

General habitat requirements. Platypus appear to discriminate against using shallow riffle habitats when foraging (McLachlan-Troup *et al.* 2010), possibly because it increases their vulnerability to predators. Similarly, Grant (2004) found that Platypus preferentially forage in water deeper than 1.5 metres and strongly avoid depths of less than 0.5 metres. Habitat features that are positively associated with Platypus foraging activity include the presence of medium and large native trees on the banks, instream woody habitat, coarse particulate organic matter, stable undercut (or notched) banks, and inorganic substrates that are coarser than sand (Serena *et al.* 2001; Grant 2004). Habitat features that predict the location of Platypus burrows include bank notching (or structurally similar features such as undercut large trees at the bank edge) and moderate-to-dense vegetation overhanging the water (Serena *et al.* 1998). Given these requirements, it is likely to be important to provide a flow regime that influences riparian and in-stream vegetation in at least two ways. First, it should promote the growth of native riparian trees, shrubs and other understorey plants growing near the water. Second, it should maintain areas of relatively open water, clear of dense emergent vegetation, in the deeper parts of the channel where Platypus prefer to feed.

Risks associated with flooding. Although adult Platypus are generally expected to survive a flood; flood-related mortalities sometimes occur (Connolly *et al.* 1998). More importantly, depending on the magnitude and duration of flows, flooding can substantially reduce Platypus reproductive success from the time that females incubate eggs (starting in September) through at least the end of February (Serena and Williams 2010, in press). A lactating female blocks the tunnel leading to her nesting chamber with consolidated soil 'pugs' to help protect her offspring from drowning if water levels rise for a short period (Burrell 1974). However, this measure will be ineffective if flood waters persistently remain above the level of the nesting chamber. For example, the occurrence of two over-bank flood events along the Shoalhaven River in late December 1991 and early January 1992 is presumed to have contributed to an otherwise puzzling absence of juveniles in that breeding season (Grant *et al.* 2004). Females do not use pugs to block the burrow entrance once juveniles approach the age when they are ready to enter the water (January-early February), potentially resulting in high mortality if flooding occurs at this time or shortly thereafter when juveniles are still weak swimmers. For example, the mean juvenile capture rate recorded in Melbourne streams following a major flood in early February 2005 was less than 10% of the corresponding capture rate in the previous three years (Serena and Williams 2010).

The management objective for Platypus in the Campaspe River downstream of Lake Eppalock is to develop a productive breeding population that is reliably self-sustaining and regularly generates surplus juveniles that can safely disperse to the Murray River and its anabranches, contributing to the establishment of a larger regional metapopulation. Flow requirements will align closely with those for macro-invertebrates, given that successful breeding by Platypus depends on their having access to an ample food supply. In addition:

Flows should be high enough throughout the year to minimise the likelihood that resident animals and their offspring are killed by predators (particularly foxes), and to provide a continuous aquatic corridor for safe passage by dispersing juveniles in late autumn and early winter.

Freshes scheduled in spring or summer should be coupled to a preceding event of similar or greater magnitude in August, i.e. around the time that breeding females are choosing nursery burrow sites, to encourage females to locate nesting chambers above the maximum height of the subsequent fresh.

The duration of substantial freshes scheduled in spring or summer should be limited insofar as possible to the minimum length of time needed to carry out their designated environmental function.

Bank-full flows or over-bank flooding should be scheduled when possible to avoid the Platypus reproductive period from September through February. If it is deemed necessary to carry out such an event in the period when Platypus are raising young, it should be scheduled as early as possible in this period to reduce the amount of energy wastefully invested by females in a failed round of reproduction.

There should be adequate flow through autumn and early winter to ensure sufficient food for females to develop fat reserves prior to the breeding season.

Flows should meet the needs of riparian shrubs, trees and ground cover plants and maintain sufficient open water in the middle of the channel to allow Platypus to forage and move safely between feeding areas. The flow requirements for vegetation have already been discussed in Section 2.1.4.

2.3.1 Knowledge gaps

No information is currently available regarding Platypus population density or reproductive success in any part of the Campaspe River downstream of Lake Eppalock, with very limited information available regarding the species' distribution. Controlled studies on the effect of the magnitude, timing and duration of spring and summer freshes on Platypus reproductive success have never been carried out.

2.3.2 Monitoring needs

Platypus are difficult and expensive to monitor through live-trapping techniques: nets have to be checked regularly overnight for welfare reasons, the number of individuals captured per site is characteristically very low, and animals can become net-shy (i.e. actively avoid capture) after being captured on one or a few occasions. Accordingly, the best strategy for generating baseline population data and subsequently monitoring this species may involve carrying out a few carefully targeted live-trapping sessions while also establishing an ongoing program of community-based monitoring based on visual sightings.

2.3.3 Threats to meeting objectives

Threat	Outcome
Inappropriate water regime	Flows that are too low may not provide enough food or foraging habitat for Platypus and therefore reduce breeding effort, increase competition and increase their exposure to predators. High flows during the breeding season may drown young in their burrows or drown juveniles that are not strong swimmers.

Threat	Outcome
Cleared land in catchment and stock access	Lack of riparian vegetation may increase exposure to predators and reduce suitable burrow sites. Platypus generally form meta-populations and land clearing and other activities that make rivers or sections of rivers unsuitable for Platypus can isolate individual populations and limit opportunities for individual animals to disperse from their birth area to colonise new territories. This lack of exchange reduces genetic diversity and increases the risk that local populations will disappear.
Predators	Foxes, dogs and cats are a major threat to Platypus. Their risk of predation is increased during very low flows when animals are forced to move further and cross dry land or exposed shallow sections of the river in search of food.
Illegal fishing activities	Platypus that are caught in opera house nets, gill nets or drum nets will drown.
Barriers such as dams	Barriers force Platypus to travel across land and therefore increase their exposure to predators.
Irrigation pumps	Many instances have been reported of Platypus dying after being sucked into irrigation pumps. The risk is particularly great for lactating females and their offspring when pumps are located in cut-back areas of the bank that provide suitable vertical habitat for breeding burrows. Cages, or equivalent structures should be placed around the opening of the inlet pipes to prevent Platypus (and other wildlife such as turtles) from being sucked into pumps.

2.4 Aquatic macroinvertebrates

Most previous studies have not been able to demonstrate a clear link between flow regime and typical measures of macroinvertebrate community composition and condition (e.g. Ausrivas and SIGNAL scores) in lowland rivers. The only exceptions appear to be cases where a lack of flow has caused massive deterioration in water quality such as very high salinity (e.g. Lind *et al.* 2006, 2007), or where a lack of flow causes streams, or certain habitats within streams to completely dry (see Boulton 2003; Stubbington *et al.* 2009).

The macroinvertebrate community in the Campaspe River downstream of Lake Eppalock dominated by species that can tolerate relatively poor water quality (DSE 2004; DEPI 2013) and is typical of many lowland rivers in Northern Victoria (Marchant *et al.* 1997; McGuckin and Doeg 2001). In its own right, the macroinvertebrate community in the Campaspe River does not have high intrinsic value, but macroinvertebrates are integral to the food web of the Campaspe River. They are an important food source for fish, Platypus and other aquatic biota and play a significant role in breaking down coarse particulate organic material, nutrient spiralling and other ecological processes (Wallace and Webster 1996). Rather than setting a target condition for macroinvertebrate communities (e.g. to increase the abundance and diversity of families that are sensitive to low water quality), the aim in the Campaspe River should be to maintain a diverse range of macroinvertebrate functional feeding groups to drive ecological processes and maintain or increase overall macroinvertebrate biomass to ensure it is sufficient to support higher order predators such as fish and Platypus.

The River Continuum Concept (RCC) (Vannote *et al.* 1980) predicts that the relative proportion of functional feeding groups will change from headwater streams to lowland reaches. The Campaspe River downstream of Lake Eppalock is probably typical of the middle part of the catchment if we consider it in the context of its position in the Murray River catchment. Therefore according to the RCC the macroinvertebrate community in these reaches should be made up of about 50 % collectors, 35 % grazers, 10 % predators and 5 % shredders, with the relative proportion of grazers and shredders declining further downstream (Vannote *et al.* 1980). The RCC does not necessarily translate well to Australian temperate rivers and therefore these predictions need to be considered with care. According to the MDFRC (2006) rivers in the Cleared Hills and Coastal Plains Bioregion (which includes the Campaspe River downstream of Lake Eppalock) should commonly support shredders (9 families), filtering collectors (3 families), gathering collectors (5 families), scrapers (12 families), predators (18 families) and macrophyte piercers (1 family), but the relative biomass of each group is not predicted.

Invertebrate species within different functional groups use a variety of instream habitats, but the most significant habitats in the Campaspe River downstream of Lake Eppalock are likely to be submerged wood, submerged and emergent macrophytes, and slackwater habitats where leaf litter and other organic matter settles. For example, Benke *et al.* (1985) reported that instream woody habitat contributed 60 % of total invertebrate biomass and 16 % of total invertebrate production in a low gradient river in Georgia, USA despite accounting for less than 4 % of the total benthic habitat. The relative abundance and distribution of these habitats and the amount of carbon inputs from falling leaf litter and primary production are likely to influence the relative abundance and biomass of different functional feeding groups and therefore the total biomass of macroinvertebrates. Different functional groups are likely to use different habitats and therefore we may expect that changes to the quality or quantity of particular habitats (due to flow or other factors) will have a marked effect on some functional feeding groups and no effect on other functional feeding groups. We assume that providing a range of important habitats and carbon sources we will maximise the biomass of macroinvertebrates and therefore maximise the carrying capacity of the system for fish, platypus and other target aquatic values.

The Campaspe River currently has a large load of wood within the river channel that can provide a substrate for biofilm growth and food and habitat for macroinvertebrates. It also has many slackater habitats across a range of low flow magnitudes. Prior to the floods, the Campaspe River supported very dense stands of emergent vegetation such as Typha and Phragmites and patches of submerged plants such as Myriophyllum, Valisneria and Triglochin. The floods scoured virtually all of these emergent and submerged plants from the channel and they are yet to return, which potentially means an important macroinvertebrate habitat and food source is missing or in very low abundance. It is not clear what role flow and other factors will play in determining the relative abundance and quality of instream and submerged vegetation and even if there is likely to be a static level of such vegetation in the Campaspe River. It may be that these plants would be naturally scoured by high flows and then gradually increase in abundance and distribution during periods of prolonged low flow, thereby creating a dynamic rather than static distribution.

The main objective for macroinvertebrates should be to maintain or provide a range of in-stream habitats:

Flows should permanently inundate some wood and periodically inundate other wood as wetting and drying will be important to drive biofilm production. Water levels should fluctuate so rapidly that they strand macroinvertebrates or force them below the photic zone. Moreover, turbidity should not be too high to allow primary producers to grow on snags.

Flows should be high enough to connect all channel habitats, but not too high such that they limit the quality and quantity of slackwater habitats.

Low flows should be provided to allow submerged and emergent macrophytes to become established, but high flows may also be needed to periodically scour vegetation.

There should be sufficient flow to flush fine sediment or prevent fine sediment from smothering hard substrates that macroinvertebrates use for food or habitat.

2.4.1 Knowledge gaps

We currently don't know the total biomass of macroinvertebrates or the relative biomass of different functional feeding groups in each reach of the Campaspe River. Moreover, we don't know what the biomass could be and how it varies with flow.

2.4.2 Environmental objectives

Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
Maintain/increase productivity of macroinvertebrates and macroinvertebrate functional feeding groups to drive productive and dynamic foodwebs. * * Knowledge gap – we don't know the target quantum for relative biomass or productivity of different functional feeding groups or the current levels of those.	Macroinvertebrates are a critically important component of the foodweb. They make carbon from leaf litter and primary producers such as diatoms, algae and macrophytes available to higher order consumers such as fish and Platypus. Different functional groups serve different ecological functions; e.g. shredders convert fallen leaves to Coarse and Fine Particulate Organic Matter that can be consumed by other biota and allows material to more readily move downstream; filter feeders can affect nutrient spiralling rates by sieving food from the water column.

2.4.3 Threats to meeting objectives

Threat	Outcome
Inappropriate water regime	Flows that are too low may not inundate enough instream woody habitat or provide a variety of aquatic habitats including slackwaters for macroinvertebrates. Rapidly fluctuating flows may disrupt macroinvertebrate life cycles and reduce food abundance Flows that are consistently too high may destroy slackwater habitats
Cleared land in catchment and stock access	Increase nutrient loads and sediment that may reduce habitat and food for macroinvertebrates Lack of riparian vegetation may also reduce supply of leaf litter and snags in the future
Pest species such as Carp	High abundance of Carp may reduce macroinvertebrate biomass
Barriers such as dams	Dams are a barrier to downstream movement of food (especially Coarse and fine particulate organic matter) because leaf litter inputs are generally highest in headwater reaches.
Cold water releases from dams	Slower growth rates and lower rates of productivity. Only one generation per year rather than 2 or more.

2.4.4 Monitoring needs

Monitoring will need to be quantitative because the focus is on biomass rather than presence/absence. Monitoring will also need to target specific habitats. We should therefore consider using artificial substrates such as constructed snags, leaf packs or macrophyte stems. The question we would ask is there a change in macroinvertebrate biomass in these habitats under different flow regimes or is biomass determined more by the total amount of any given habitat. Monitoring may also look at biofilm production on substrates that macroinvertebrates are excluded from.

One problem with biomass monitoring is that biomass is likely to change throughout the season due to changes in water temperature, therefore monitoring conducted before and after particular flow events will be confounded. It is potentially more of a research question than a monitoring question.

2.5 Water quality

The two main flow related water quality objectives for the Campaspe River are preventing hypoxic blackwater events and managing saline pools. Managed flow releases from Lake Eppalock have the potential to lower water temperatures in the Campaspe River as far downstream as Axedale (SKM 2008). This is an operational issue associated with delivering environmental flows and should be addressed by using the multi-level outlet to ensure water is released from near the surface of the reservoir rather than below the thermocline. High nutrient concentrations are also an issue in parts of the Campaspe River, and especially the Coliban River, but should be addressed through land management actions rather than environmental flows.

2.5.1 Blackwater events

Hypoxic blackwater events are characterised by high levels of dissolved organic carbon (DOC), which lead to low dissolved oxygen (DO) in the water column and potentially widespread fish and crustacean death (Hladyz *et al.* 2011). Blackwater events generally occur when ephemeral streams with high loads of accumulated leaf litter are inundated or when high flow events wash large amounts of leaf litter into the river from the adjacent bank, benches and floodplain. Microbes rapidly consume the available carbon and it is their respiration that severely depletes oxygen levels in the water column. Microbial activity is higher in warm temperatures and is also governed by the amount of available organic material. The three factors that determine the likelihood and severity of a blackwater event are therefore the magnitude of the high flow or re-wetting event, the timing of that event and the amount of accumulated organic material. Blackwater events are more likely to occur following high flow events in summer (Howitt *et al.* 2007). Heavy localised rainfall in January 2001 flushed deoxygenated water from Mt Pleasant Creek and Forest Creek into the Campaspe River and caused a large fish kill between Runnymeade and the Campaspe Weir (McGuckin 2001).

Blackwater events occur naturally in lowland rivers and wetlands in south-eastern Australia. The main concern from an environmental flow perspective is to reduce the likelihood that managed flow releases will trigger a blackwater event. The best way to reduce that risk is to deliver one or more flow events in winter or spring that are at least as large as the biggest managed flows that will be delivered in summer or autumn. Delivering high flows in the cool months will flush accumulated leaf litter from banks and benches and therefore reduce the amount of organic material that is likely to be washed into the river by summer environmental flow releases.

2.5.2 Salinity

Sections of the Campaspe River, particularly downstream of the Campaspe Siphon, receive saline groundwater. Under low flow conditions, pools in the lower Campaspe River stratify and electrical conductivity can rise to close to 12,000 µS/cm (SKM 2010). McGuckin (1990) surveyed most deep pools in the Campaspe River between the Campaspe Weir and Echuca. He observed that at flows up to 50 ML/day water at the bottom of deep pools could be as high as 14,000 µS/cm and water at the surface closer to 3,000 µS/cm (McGuckin 1990). Moreover, McGuckin (1990) noted that flows greater than 200 ML/day thoroughly mixed all pools in the Campaspe River, but he did not measure conditions at a range of lower flow and therefore could not determine the minimum flow required to mix the pools.

SKM (2010) demonstrated that during the drought, flows of approximately 44 ML/day were sufficient to mix pools in the lower Campaspe River. Subsequent monitoring by the NCCMA suggested that flows as low as 35 ML/day may be sufficient to temporarily mix stratified pools. The difference between the recent studies and McGuckin’s study can be explained by the much higher groundwater levels in 1990, which would have created a much stronger pressure gradient between the surrounding water table and the stream and therefore delivered much more saline groundwater to the river. Groundwater levels throughout Victoria, including the Campaspe River catchment declined significantly during the drought and as a result groundwater contributions to streamflow also fell. One of the main causes of high groundwater levels is inefficient application of irrigation water. The Campaspe Irrigation District has been decommissioned and therefore groundwater levels in the catchment are unlikely to return to the levels observed in the early 1990s. Given the flow required to mix stratified pools is related to groundwater levels, we can assume that in the future, the average flow required to mix saline pools in the lower Campaspe River will be greater than needed during the drought and less than needed in the early 1990s. Without more specific information, we suggest that flows greater than 35 ML/day are needed to mix stratified pools in dry years when the water table is low and flows greater than possibly 70-100 ML/day may be needed if water tables are higher. There is likely to be a lag between catchment rainfall and water table levels, so it may be necessary to continue to deliver higher to mix stratified pools in the first few years of a dry period and lower flows may be adequate to mix stratified pools in the first few years after a prolonged drought is broken.

2.5.3 Environmental objectives

Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
Reduce risk of blackwater events associated with environmental flow releases in summer	Blackwater events can lead to fish kills and severe stress to other aquatic fauna. Blackwater events are natural, but we do not want environmental flows to trigger an event. High flows in cool months to clear organic loads will reduce the likelihood of blackwater events during summer.
Control salinity and stratification in deep pools in the lower Campaspe River	High salinity and low dissolved oxygen levels are a threat to aquatic biota. Minimum flows are needed to maintain a lens of freshwater across saline pools during summer and to periodically mix stratified pools.

2.5.4 Threats to meeting objectives

Threat	Outcome
Inappropriate water regime	The operation of Lake Eppalock reduces the magnitude and frequency of high flow events in the downstream reaches of the Campaspe River and has the potential to allow large loads of leaf litter and other organic matter to accumulate in the river channel and on benches and floodplain habitats. If high flow events occur in warm months they may wash the accumulated leaf litter into the stream and trigger a blackwater event. Lower flows also reduce the degree of mixing of saline pools
Land-use	Irrigation practices and land clearing increased groundwater levels in the Campaspe River catchment through the 1980s and 1990s. Groundwater levels dropped during the drought and improved irrigation practices are likely to mean that levels will not return to the peaks recorded in the 1990s. They may however, still rise above the level recorded during the drought. Any rise in groundwater level has the potential to increase saline groundwater intrusions to the Campaspe River and therefore increase salinity levels and stratification in the river.
High nutrients	Not to deal with through flow. Especially high issue in Coliban River But Echuca weir was green during drought

2.5.5 Monitoring needs

Continuous electrical conductivity probes in selected pools will help determine the flow required to maintain a lens of freshwater across the top of stratified pools and the flow magnitude required to mix stratified pools in any given year. Ideally, probes will be deployed at multiple depths throughout the water column to measure the extent of stratification and to measure how stratification changes under different flows. If the cost of this monitoring is an issue, the North Central CMA may consider using a combination of electrical conductivity probes and water temperature monitoring probes (which are relatively inexpensive) at each site. The proposed set up would use electrical conductivity and temperature probes near the water surface and near the bottom of selected pools, and multiple temperature probes at regular intervals throughout the water column. Data collected from these probes would record the electrical conductivity at the surface and bottom of pools under different flow conditions and the water temperature probes would record the depth of the thermocline (and therefore the approximate level at which the pool stratifies) under different flows.

Continuous dissolved oxygen monitoring during summer flow releases will provide an early warning of blackwater events. More water may need to be released from storage to dilute blackwater events if they begin to occur.

2.6 Geomorphology

The main geomorphological objectives are to maintain channel form, replenish sediment on benches, scour sediment from pools, flush fine silt and sediment from riffle habitats and other hard substrates such as submerged wood and macrophytes. Bankfull and overbank flows cannot be delivered through environmental flow releases, but they will be important for shaping floodplain habitats, replenishing sediment on floodplains and periodically scouring macrophyte beds.

Large Dams pose a significant threat to geomorphological objectives by reducing the magnitude and frequency of high flow events and by trapping sediment, which is needed to replenish benches, bars and floodplain habitats in downstream reaches (Marren *et al.* 2014).

2.6.1 Environmental objectives

Objective (habitat, flora, fauna, process)	**Justification (e.g. intrinsic value or link to other value)**
Maintain channel form, replenish benches and scour pools to maintain their depth	Channel form and habitat heterogeneity are critical to providing habitat and food for aquatic and riparian flora and fauna.
Replenish floodplain habitats	Overbank flows help maintain floodplain habitats such as wetlands and deliver silt to replenish soils on the floodplain.
Clean substrates including rocks, submerged wood and macrophytes	Regular flows that clean silt and fine sediment from hard surfaces will increase their suitability for macroinvertebrates and biofilm production and lead to an overall increase in biological productivity and diversity.

2.6.2 Threats to meeting objectives

Threat	Outcome
Inappropriate water regime	The operation of Lake Eppalock reduces the magnitude and frequency of high flow events in the downstream reaches of the Campaspe River and therefore channel benches and pools may not be scoured as frequently and substrates may not be flushed as regularly. Over time, the reduction in high flows may cause the channel to constrict and reduce the abundance and diversity of slackwater habitats, deep pools, riffles and runs.
Dams	Lake Eppalock, Campaspe Weir and the Siphon Weirpool are large sediment traps that mean large flows may not carry sufficient sediment load to refresh benches bars etc. This is particularly true for sections of the river immediately downstream of these dams or weirs.
Lack of instream and riparian vegetation	A lack of instream or riparian vegetation could expose the channel and floodplain to increased erosion during high flow events and limit the amount of sediment that can be trapped on floodplains, benches and bars. Dense stands of emergent macrophytes may armour the bed and therefore prevent natural scouring processes from clearing pools and maintaining channel capacity.
Land clearing and livestock access	Increased sediment load from cleared land filling pools etc. Also weakens bank structure and makes it more prone to erosion

3. Objectives

3.1 Reach 2

	Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
Macroinvertebrates	Maintain/increase diversity and productivity of macroinvertebrates and macroinvertebrate functional feeding groups to drive productive and dynamic foodwebs. * * Knowledge gap – we don't know the target quantum for relative biomass or productivity of different functional feeding groups or the current levels of those.	Macroinvertebrates are a critically important component of the foodweb. They make carbon from leaf litter and primary producers such as diatoms, algae and macrophytes available to higher order consumers such as fish and Platypus. Different functional groups serve different ecological functions; e.g. shredders convert fallen leaves to Coarse and Fine Particulate Organic Matter that can be consumed by other biota and allows material to more readily move downstream; filter feeders can affect nutrient spiralling rates by sieving food from the water column.
Water quality	Minimise risk of blackwater events associated with managed flow releases in summer	Blackwater events can lead to fish kills and severe stress to other aquatic fauna. Blackwater events are natural, but we do not want managed flows to trigger an event. High flows in cool months to clear organic loads will reduce the likelihood of blackwater events during summer.
Geomorphology	Maintain channel form, deposit sediment on benches and scour pools to maintain their depth	Channel form and habitat heterogeneity are critical to providing habitat and food for aquatic and riparian flora and fauna. In particular the deep pools through this reach provide a critical drought (and potentially flood) refuge for aquatic fauna and flora.
	Maintain floodplain topography	Overbank flows cannot be delivered through environmental flows, but will occur naturally and will help maintain floodplain habitats such as wetlands by scouring surfaces and delivering silt to replenish soils on the floodplain.

	Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
	Flush accumulated silt and sediment from substrates including rocks, submerged wood and macrophytes	Regular flows that flush silt and fine sediment from hard surfaces will increase their suitability for macroinvertebrates and biofilm production and lead to an overall increase in biological productivity and diversity.
Fish	Increase population size (with appropriate age structure) of native fish with periodic, equilibrium and opportunistic life history strategies that have been recently recorded in this reach e.g. Golden Perch, Murray Cod, Australian Smelt.	These species would have historically been abundant in the reach
	Facilitate recolonisation by native species that have been presumed lost e.g.Trout Cod, River Blackfish and Macquarie Perch.	These species would have historically been abundant in the reach. The ability to achieve this objective will depend on opportunities for fish passage past the Campaspe Weir that will allow fish to move into the reach from the Murray and Reaches 3 and 4
Vegetation	Re-establish instream aquatic plants e.g. Triglochin	Instream plants were common throughout the reach prior to the 2011/12 floods, but are now rare. They are an important component of the stream ecosystem and provide habitat, sediment stability and support foodwebs.
	Promote growth of emergent littoral macrophytes (e.g. Phragmites, rushes, reeds and sedges) on benches and edges of channel, but limit their encroachment into the middle of the channel	Fringing emergent plants were common throughout the reach prior to the 2011/12 floods, but are now rare. They are an important component of the stream ecosystem and provide habitat, sediment and bank stability and support foodwebs.
	Maintain adult River Red Gum and facilitate recruitment of juveniles into the population (We assume that by providing flows to maintain River Red Gum populations we will also maintain the associated shrub layer that includes Bottle Brush and Tee Tree)	River Red Gum trees provide carbon to fuel foodwebs, shade, instream woody habitat to the river, and provide habitat for fauna.

	Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
Platypus	Maintain/increase resident breeding population by facilitating successful recruitment at least every second year and promote safe dispersal by juveniles.	The Campaspe River is an important source of juvenile platypus to facilitate recolonisation of the Murray River and strengthen the Gunbower population. This reach supports resident breeding populations, but they are likely to have declined during the drought.

3.2 Reach 3

	Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
Macroinvertebrates	Maintain/increase diversity and productivity of macroinvertebrates and macroinvertebrate functional feeding groups to drive productive and dynamic foodwebs. * * Knowledge gap – we don't know the target quantum for relative biomass or productivity of different functional feeding groups or the current levels of those.	Macroinvertebrates are a critically important component of the foodweb. They make carbon from leaf litter and primary producers such as diatoms, algae and macrophytes available to higher order consumers such as fish and Platypus. Different functional groups serve different ecological functions; e.g. shredders convert fallen leaves to Coarse and Fine Particulate Organic Matter that can be consumed by other biota and allows material to more readily move downstream; filter feeders can affect nutrient spiralling rates by sieving food from the water column.
Water quality	Minimise risk of blackwater events associated with managed flow releases in summer	Blackwater events can lead to fish kills and severe stress to other aquatic fauna. Blackwater events are natural, but we do not want managed flows to trigger an event. High flows in cool months to clear organic loads will reduce the likelihood of blackwater events during summer.
	Control salinity and stratification in deep pools	High salinity and low dissolved oxygen concentrations are a threat to aquatic biota. Minimum flows are needed to prevent pools stratifying or to at least maintain a lens (0.5-1.0 m) of freshwater (<3000 EC) across saline pools during summer and freshes are needed to periodically mix stratified pools.

	Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
Geomorphology	Maintain channel form, deposit sediment on benches and scour pools to maintain their depth	Channel form and habitat heterogeneity are critical to providing habitat and food for aquatic and riparian flora and fauna.
	Maintain floodplain topography	Overbank flows cannot be delivered through environmental flows, but will occur naturally and will help maintain floodplain habitats such as wetlands by scouring surfaces and delivering silt to replenish soils on the floodplain.
	Flush accumulated silt and sediment from substrates including rocks, submerged wood and macrophytes	Regular flows that flush silt and fine sediment from hard surfaces will increase their suitability for macroinvertebrates and biofilm production and lead to an overall increase in biological productivity and diversity.
Fish	Increase population size (with appropriate age structure) of native fish with periodic, equilibrium and opportunistic life history strategies that have been recently recorded in this reach e.g. Golden Perch, Murray Cod, Murray Rainbowfish.	These species would have historically been abundant in the reach
	Facilitate recolonisation by native species that have been presumed lost e.g. Trout Cod, River Blackfish, Macquarie Perch.	These species would have historically been abundant in the reach. The ability to achieve this objective will depend on opportunities for fish passage past the Campaspe Siphon that will allow fish to move into the reach from the Murray and Reach 4
Vegetation	Re-establish instream aquatic plants e.g. Triglochin	Instream plants were common throughout the reach prior to the 2011/12 floods, but are now rare. They are an important component of the stream ecosystem and provide habitat, sediment stability and support foodwebs.
	Promote growth of emergent littoral macrophytes (e.g. Phragmites, rushes, reeds and sedges) on benches and edges of channel, but limit their encroachment into the middle of the channel	Fringing emergent plants were common throughout the reach prior to the 2011/12 floods, but are now rare. They are an important component of the stream ecosystem and provide habitat, sediment and bank stability and support foodwebs.

	Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
	Maintain adult River Red Gum and facilitate recruitment of juveniles into the population (We assume that by providing flows to maintain River Red Gum populations we will also maintain the associated shrub layer that includes Bottle Brush and Tee Tree)	River Red Gum trees provide carbon to fuel foodwebs, shade, instream woody habitat to the river, and provide habitat for fauna.
Platypus	Maintain/increase resident breeding population by facilitating successful recruitment at least every second year and promote safe dispersal by juveniles.	The Campaspe River is an important source of juvenile platypus to facilitate recolonisation of the Murray River and strengthen the Gunbower population. This reach supports resident breeding populations, but they are likely to have declined during the drought.

3.3 Reach 4

	Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
Macroinvertebrates	Maintain/increase diversity and productivity of macroinvertebrates and macroinvertebrate functional feeding groups to drive productive and dynamic foodwebs. * * Knowledge gap – we don't know the target quantum for relative biomass or productivity of different functional feeding groups or the current levels of those.	Macroinvertebrates are a critically important component of the foodweb. They make carbon from leaf litter and primary producers such as diatoms, algae and macrophytes available to higher order consumers such as fish and Platypus. Different functional groups serve different ecological functions; e.g. shredders convert fallen leaves to Coarse and Fine Particulate Organic Matter that can be consumed by other biota and allows material to more readily move downstream; filter feeders can affect nutrient spiralling rates by sieving food from the water column.
Water quality	Minimise risk of blackwater events associated with managed flow releases in summer	Blackwater events can lead to fish kills and severe stress to other aquatic fauna. Blackwater events are natural, but we do not want managed flows to trigger an event. High flows in cool months to clear organic loads will reduce the likelihood of blackwater events during summer.

	Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
	Control salinity and stratification in deep pools	High salinity and low dissolved oxygen concentrations are a threat to aquatic biota. Minimum flows are needed to prevent pools stratifying or to at least maintain a lens (0.5-1.0 m) of freshwater (<3000 EC) across saline pools during summer and freshes are needed to periodically mix stratified pools.
Geomorphology	Maintain channel form, deposit sediment on benches and scour pools to maintain their depth	Channel form and habitat heterogeneity are critical to providing habitat and food for aquatic and riparian flora and fauna.
	Maintain floodplain topography	Overbank flows cannot be delivered through environmental flows, but will occur naturally and will help maintain floodplain habitats such as wetlands by scouring surfaces and delivering silt to replenish soils on the floodplain.
	Flush accumulated silt and sediment from substrates including rocks, submerged wood and macrophytes	Regular flows that flush silt and fine sediment from hard surfaces will increase their suitability for macroinvertebrates and biofilm production and lead to an overall increase in biological productivity and diversity.
Fish	Increase population size (with appropriate age structure) of native fish with periodic, equilibrium and opportunistic life history strategies that have been recently recorded in this reach e.g. Golden Perch, Murray Cod, Carp Gudgeons.	These species would have historically been abundant in the reach
	Facilitate recolonisation by native species that are presumed lost e.g. Silver Perch, Bony Herring.	These species would have historically been abundant in the reach. We note that the recent replacement of the Echuca flow gauge weir with a rock ramp fishway should allow more species to recolonise this reach.
Vegetation	Re-establish instream aquatic plants e.g. Triglochin	Instream plants were common throughout the reach prior to the 2011/12 floods, but are now rare. They are an important component of the stream ecosystem and provide habitat, sediment stability and support foodwebs.

	Objective (habitat, flora, fauna, process)	Justification (e.g. intrinsic value or link to other value)
	Promote growth of emergent littoral macrophytes (e.g. Phragmites, rushes, reeds and sedges) on benches and edges of channel, but limit their encroachment into the middle of the channel	Fringing emergent plants were common throughout the reach prior to the 2011/12 floods, but are now rare. They are an important component of the stream ecosystem and provide habitat, sediment and bank stability and support foodwebs.
	Maintain adult River Red Gum and facilitate recruitment of juveniles into the population (We assume that by providing flows to maintain River Red Gum populations we will also maintain the associated shrub layer that includes Bottle Brush and Tee Tree)	River Red Gum trees provide carbon to fuel foodwebs, shade, instream woody habitat to the river, and provide habitat for fauna.
Platypus	Maintain existing resident population and facilitate safe dispersal by juveniles from this reach and upstream reaches to the Murray River.	The Campaspe River is an important source of juvenile platypus to facilitate recolonisation of the Murray River and strengthen the Gunbower population. Upstream reaches support strong breeding populations of platypus, there may be some resident populations in this reach.

4. Updated environmental flow recommendations

4.1 Reach 2: Campaspe River from Lake Eppalock to Campaspe Weir.

The following flow recommendations relate to the flow gauge at Barnadown.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
Cease-to-flow	0 ML/day	1-5 weeks	1-2 events between January and April in dry years acceptable, but avoid cease-to-flow in more than 2 consecutive years Not at all in wet years	We do not specifically recommend a cease-to-flow event for the reach, but note that it will be acceptable in some years if there is limited environmental water. If the river is allowed to stop flowing, it will be necessary to monitor water quality in pools to ensure conditions don't deteriorate too much (e.g. dissolved oxygen drops below 4 mg/L). If water quality deteriorates water will need to be released from Eppalock.	Likely to be detrimental to water quality, prevent re-colonisation by instream vegetation, stress macroinvertebrates in riffle habitats and limit Platypus dispersal if occurs in later summer early autumn. Deep pools will be a critical refuge for all aquatic biota during cease-to-flow events	We cannot identify a specific ecological function that we would want a cease-to-flow event to achieve. We note that the Campaspe River would have naturally ceased to flow for 2-4 weeks in about 50% of years and for up to 3-4 months in the driest 20% of years. We do not suggest the CMA should deliberately create a cease-to-flow event, but in very dry years it may be acceptable to have a short cease-to-flow event if it allows other flow components (e.g. summer freshes) to be delivered. The relative merits of avoiding a cease-to-flow event or delivering summer freshes in a dry year will need to be made on a case by case basis taking account of current conditions and anticipated risks at that time. We need to do research or monitoring to better understand the consequence of cease-to-flow events in consecutive years for fish and platypus.
Summer low flow	10-50 ML/day	6 months Dec-May	Vary the magnitude of flow within the prescribed range throughout Dec-May. Higher magnitude in Dec,	Target average low flow of 20-30 ML/day in average years. In dry years the low flow can be closer to 10 ML/day for most of the season.	**General:** The low flow is critical for maintaining a variety of aquatic riverine habitats. Provides sufficient volume of water to	A low flow of 10 ML/day should provide a depth of 20-30 cm in the thalweg of riffle/run habitats. A flow of 50 ML/day increases water depth by approximately 20 cm. Low flows that exceed 50 ML/day

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
			gradual decline through Jan-Feb then gradual rise from Mar-May	In wet years or in years when flow needs to be transferred downstream the flow can be closer to 50 ML/day for most of the season Need to avoid sudden and frequent fluctuations in low flow magnitude to avoid disrupting slackwater habitats or stranding biota in habitats that are likely to dry. Flows greater than 50 ML/day may be too high for slackwater habitats	engage riffle and run habitats for macroinvertebrates, fish and aquatic plants and foraging habitat for platypus. High diversity and abundance of habitat is important for river foodwebs; it determines the potential biomass of macroinvertebrates and food for fish and platypus. **Water quality:** Maintains water in deep pools and maintains water quality or at least a layer of freshwater at the top of those pools. **Fish:** Maintains slackwater habitats which are productive areas for zooplankton and nursery habitats for many native fish, especially opportunistic low flow specialists such as Carp Gudgeon and Murray Rainbowfish. **Macroinvertebrates:** Varying low flow magnitude over the season will inundate fallen wood to varying degrees, which will promote growth of biofilms, support macroinvertebrates and provide habitat for fish. **Vegetation:** Maintaining a connecting flow through the whole reach for most of the time will limit the encroachment of emergent macrophytes into the middle of the channel (i.e. deepest, fastest flowing	may flush slackwater habitats.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					portion of the channel) and allow native instream vegetation to colonise the channel margins. **Platypus:** Connecting flow through reach will also allow platypus to safely move between pools while foraging and ensure adequate food for lactating females.	
Summer fresh	50-200 ML/day Aim for 75-125 ML/day in an average flow year	1-3 days at peak with moderate ramp up and slower ramp down	3 events per year 1 event Dec-Feb with peak at 1 day 2 events Mar-May with peak at 2-3 days	The summer low flow aims to increase water depth by 15-30 cm compared to the summer low flow and therefore its magnitude will vary each year. In years when the low flow is 10 ML/day the fresh only needs to be 50-75 ML/day. In years when the summer low flow is around 50 ML/day the summer fresh should be 125-200 ML/day. Aim for 75-125 ML/day in average years when summer low flow is 20-30 ML/day. Do not actively deliver more than 1 fresh in Dec-Feb to avoid disturbing slackwaters during main fish larval rearing phase. This recommendation may be ignored if water quality deteriorates in dry years. In those circumstances several small freshes (50-75 ML/day may be released to flush pools. More frequent events are OK after February in any year and may help facilitate platypus dispersal. The summer fresh should be no greater	**General:** The average summer fresh will provide flow through the second flow path on the right hand side of the island at Doaks Reserve, but will not wet the higher second flow path at English's Bridge. **Vegetation:** Inundate the lower banks and low benches to wet the soil and promote establishment, growth and survival of fringing emergent macrophytes such as Phragmites, reeds and sedges. **Fish**: Promote local movement adult fish to access alternative habitats. The autumn freshes will be particularly important for facilitating dispersal of juvenile fish including species with 'opportunistic' and 'equilibrium' life history strategies. **Macroinvertebrates:** Wash organic matter into stream to drive aquatic foodwebs	We have based the summer fresh recommendations on an overall objective of increasing water depth by 15-30 cm compared to the summer low flow. This approach ensures some flow variability each year and more closely mimics natural variation between wet and dry years. These flows will inundate various benches, bars and fallen wood throughout the reach. We note the potential conflict between delivering freshes to grow and maintain littoral vegetation and replenish biofilms on submerged wood and the risk that these events may disturb slackwater habitats and any fish larvae or juveniles in those habitats. Any freshes during Dec-Feb have the potential to wash fish larvae from slackwater habitats. Opportunistic species are likely to have multiple cohorts each season, so 1 fresh during that time should not significantly affect overall recruitment, but monitoring may be needed to assess the effect of these flows on developing fish larvae and to determine whether there is a

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
				than the maximum flow in the previous winter/spring to reduce risk of blackwater.	Wet submerged wood and flush fine silt and old biofilms to promote new biofilm growth and increase macroinvertebrate productivity **Platypus:** Facilitate downstream dispersal of juvenile platypus in Apr-May to colonise other habitats in the Murray River.	particular time when the risks to developing fish are particularly high or low.. We have emphasised the need for 3 events each year over the next 5-10 years to help re-establish fringing vegetation that was removed during the 2011/12 floods. Once those plants are established, the number of freshes may be revised.
Winter low flow	50-200 ML/day Aim for 100 ML/day in average flow years	6 months Jun-Nov	Vary the magnitude of flow within the prescribed range throughout Jun-Nov to match the natural flow regime. Ramp the flow up slowly from June to deliver the highest magnitude in Jul-Sep, then gradually drop flow through Oct-Nov.	Target average low flow of 100 ML/day in average years. In dry years the low flow can be closer to 50 ML/day for most of the season. In wet years or in years when flow needs to be transferred downstream the flow can be closer to 200 ML/day for most of the season Need to avoid sudden and frequent fluctuations in low flow magnitude.	**General:** The average winter low flow will provide flow through the second flow path on the right hand side of the island at Doaks Reserve, but will not wet the higher second flow path at English's Bridge. **Vegetation :** Prevent plants from encroaching into the middle of the channel (winter flows should maintain open water in the thalweg throughout the whole reach). Prevent terrestrial plants colonising the lower sections of the river bank and low benches in the channel Maintain soil water in the river bank to water established River Red Gum and woody shrubs such as Bottlebrush and Tea Tree. Water and help establish littoral vegetation such as Bolboschoenus. **Fish:** Allow localised fish movement	Second flow path at Doakes Reserve will have flow for at least June to November in wet years.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					throughout the reach. The peak movement period is August to November as water temperature increases. **Platypus:** Facilitate long distance movement by male platypus especially during the Aug-Oct breeding season. Provide foraging opportunities across a wide range of habitats for females to develop fat reserves prior to breeding. **Macroinvertebrates:** Once water temperatures increase (generally September-Nov) the depth provided by winter low flows will inundate a wide variety and large abundance of habitats that will support high macroinvertebrate productivity.	
Winter small fresh	1000-1500 ML/day	1-2 days at peak Note – this event may need a duration of 7 days to facilitate fish movement in downstream reaches	2 per year (1 in Jul-Aug & 1 in Sep-Oct) in average to dry years. Not expected in very dry years.	The timing of the second flow should vary each year. It may be delivered in November in some years, but should not be delivered in November often or in consecutive years to avoid flushing slackwater habitats that may support developing fish larvae. This small fresh will be replaced by a large fresh in some years. If this event is not delivered then the maximum summer event in the following season should not exceed the highest winter low flow event to reduce likelihood of a blackwater event.	**General:** Redistribute fine sediment on benches and bars in the bottom of the channel and scoured aged biofilms from hard surfaces included submerged wood. **Water quality:** Flush accumulated leaf litter from bank and low benches to reduce risk of blackwater events during managed flow releases in summer. **Vegetation:** Wets the bank to help maintain soil moisture for established River Red Gum and woody shrubs such as	Flow of 1000 ML/day will increase water depth by 60-70 cm through most habitats compared to the maximum winter low flow magnitude of 200 ML/day, but won't inundate many low/mid channel benches and therefore is not expected to promote much River Red Gum recruitment. There is probably little difference in ecological outcome for flows between 1000 and 1500 ML/day (the volume that can currently be released from Eppalock outlet) in Reach 2, but there may be value in delivering flows between 1000 and 1500 ML/day to meet ecological objectives (especially for fish) in Reach 3 and Reach

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					Bottlebrush and Tea Tree First winter event will have little effect on vegetation, but Sep-Oct event is in growing season and will help riparian species become established low on the bank and limit colonisation by terrestrial plant species These flows will also help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path. **Fish:** Facilitate fish movement throughout whole reach and if artificial barriers are removed could allow fish to move to and from other reaches including the Murray River, which is important to maintain existing populations and support recolonisation by species that are presumed lost from the reach. Fresh in Sep-Oct may trigger Periodic spawners such as Golden Perch and Silver Perch to either spawn or move to the Murray River to spawn. **Platypus:** Fresh prior to egg-laying (ideally Aug) encourages females to select a nesting burrow higher up the bank to reduce risk of high flow later in the year flooding the burrow when juveniles are present. **Macroinvertebrates:**	4.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					Flushing organic matter into the stream in winter and spring will allow it to be conditioned for consumption and breakdown by bacteria and invertebrates when water temperature increases and hence support the riverine foodweb.	
Winter large fresh	1800-2000 ML/day	2-3 days at peak Note – this event may need a duration of 7 days to facilitate fish movement in downstream reaches	2 events per year in 2 consecutive years twice per decade. First event each year in Jul-Aug (preferably Aug) to wet the bank and benches, second event each year in Sep-Nov to stimulate RRG recruitment. Try to avoid delivering the event in November too often as it may flush developing fish larvae and juveniles from slackwater habitats. These events replace the small winter fresh when delivered	Important to deliver events in consecutive years because first event intended to trigger River Red Gum recruitment and second year intended to help new recruits from first year become established. It will be optimal to provide two recruitment cycles per decade. If that is not possible then provide two events in two consecutive years at least once per decade and other events as needed to ensure no more than 4 years and preferably no more than 3 years without a watering event to maintain established trees. This maintaining flow is only needed once in a year and can be delivered at any time of year.	**General:** This flow is large enough to inundate benches and secondary flow paths in the lower part of the channel. Redistribute fine sediment on benches and bars in the bottom of the channel and scoured aged biofilms from hard surfaces included submerged wood. **Water quality:** Flush accumulated leaf litter from bank and low benches to reduce risk of blackwater events during managed flow releases in summer. **Vegetation:** Primary aim of these higher flows is to promote RRG recruitment on benches in the channel. The event in Jul-Aug is too early to trigger recruitment, but it wets the soil to condition it for the Sep-Nov event, which is intended to trigger recruitment. These flows will also help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path.	Flow of 1800-2000 ML/day will increase water depth by 80-100 cm through most habitats compared to the maximum winter low flow magnitude of 200 ML/day. Unlike the small fresh it will inundate low and mid channel benches and is therefore likely to promote River Red Gum recruitment in those habitats.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					Fish: Facilitate fish movement throughout whole reach and if artificial barriers are removed could allow fish to move to and from other reaches including the Murray River, which is important to maintain existing populations and support recolonisation by species that are presumed lost from the reach. Fresh in Sep-Oct may trigger Periodic spawners such as Golden Perch and Silver Perch to either spawn or move to the Murray River to spawn. **Platypus:** Fresh prior to egg-laying (ideally Aug) encourages females to select a nesting burrow higher up the bank to reduce risk of high flow later in the year flooding the burrow when juveniles are present. **Macroinvertebrates:** Flushing organic matter into the stream in winter and spring will allow it to be conditioned for consumption and breakdown by bacteria and invertebrates when water temperature increases and hence support the riverine foodweb.	
Bankfull flow	10,000 - 12,000 ML/day or maximum that can be delivered without causing	1-2 days at peak	Only need to deliver in the year after a natural bankfull or overbank flow event. Can be delivered at any time of year	Unlikely that these events can be delivered regularly, so recommendation is to wait for a natural event and then deliver this event in the following year to help any new River Red Gum and	**Vegetation:** The main objective of this event is to help any riparian plants (especially River Red Gum) that established in the	

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
	flooding in downstream reaches			other riparian plants that recruited during the natural event get established.	natural event get established so that they can withstand prolonged periods without inundation in subsequent years. These events will also help to scour vegetation from the middle of the channel and therefore maintain an open clear flow path. **Geomorphology:** Bankfull flows are channel forming. They will scour sediment from pools to maintain their volume and depth and replenish benches and bars within the channel. **Fish:** Bankfull flows that drown out artificial barriers will allow fish to disperse between reaches and if delivered in Sep-October are likely to trigger Golden Perch and Silver Perch to spawn and/or migrate to preferred spawning habitats.	
Overbank flows	Greater than 12,000 ML/day	As natural	As natural	Cannot deliver or control overbank flows	**Geomorphology:** Overbanks flows are channel forming. They will scour sediment from pools to maintain their volume and depth and replenish benches and bars within the channel. They will also help maintain floodplain habitats, move sediment between the stream and the floodplain and wash organic material from the floodplain into the stream. **Vegetation:**	Overbank flows serve an important ecological function, they cannot be delivered, but will provide a benefit to the river when they occur naturally. We note that their frequency has been reduced by Lake Eppalock and now occur only when Lake Eppalock spills.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					The main objective of this event is to help any riparian plants (especially River Red Gum) that established in the natural event get established so that they can withstand prolonged periods without inundation in subsequent years.	

4.2 Reach 3: Campaspe River from Campaspe Weir to Campaspe Siphon

The following flow recommendations relate to the flow gauge at Campaspe Weir.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
Cease-to-flow	0 ML/day		No recommended	We do not recommend a cease-to-flow event in this reach because there are fewer deep refuge pools than Reach 2 and there is also some saline (up to 5,000 EC) groundwater intrusion that will affect water quality and increase stratification in pools if there is no surface flow.	Likely to be detrimental to water quality, prevent re-colonisation by instream vegetation, stress macroinvertebrates in riffle habitats and limit Platypus dispersal if occurs in later summer early autumn.	We cannot identify a specific ecological function that we would want a cease-to-flow event to achieve. We note that the Campaspe River would have naturally ceased to flow for 2-4 weeks in about 50% of years and for up to 3-4 months in the driest 20% of years, but think the risks of deliberately creating a cease-to-flow event in this reach are too high given the need to improve the condition of environmental values.
Summer low flow	10-50 ML/day	6 months Dec-May	Vary the magnitude of flow within the prescribed range throughout Dec-May. Higher magnitude in Dec, gradual decline through Jan-Feb then	Target average low flow of 20-30 ML/day in average years as this should be enough to prevent pools from stratifying. In dry years the low flow can be closer	**General:** The low flow is critical for maintaining a variety of aquatic riverine habitats. Provides sufficient volume of water to	A low flow of 10 ML/day should provide a depth of 20-30 cm in the thalweg of riffle/run habitats. A flow of 50 ML/day increases water depth by approximately 20 cm. Low flows that

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
			gradual rise from Mar-May	to 10 ML/day for most of the season, but this may lead to stratification in some pools. In wet years or in years when flow needs to be transferred downstream the flow can be closer to 50 ML/day for most of the season Need to avoid sudden and frequent fluctuations in low flow magnitude to avoid disrupting slackwater habitats or stranding biota in habitats that are likely to dry. Flows greater than 50 ML/day may be too high for slackwater habitats	engage riffle and run habitats for macroinvertebrates, fish and aquatic plants and foraging habitat for platypus. High diversity and abundance of habitat is important for river foodwebs; it determines the potential biomass of macroinvertebrates and food for fish and platypus. **Water quality:** Maintains water in deep pools. Flows above 20 ML/day are likely to prevent pools from stratifying. **Fish:** Maintains slackwater habitats which are productive areas for zooplankton and nursery habitats for many native fish, especially opportunistic low flow specialists such as Carp Gudgeon and Murray Rainbowfish. **Macroinvertebrates:** Varying low flow magnitude over the season will inundate fallen wood to varying degrees, which will promote growth of biofilms, support macroinvertebrates and provide habitat for fish. **Vegetation:** Maintaining a connecting flow through the whole reach for most of the time will limit the encroachment of emergent macrophytes into the middle of the channel (i.e. deepest,	exceed 50 ML/day may flush slackwater habitats. Monitoring during the drought demonstrated that flow of 20-30 ML/day sufficient to prevent pools stratifying in this reach. Higher flows may be needed to prevent stratification if groundwater levels are higher and therefore water quality and stratification should be monitored when flows are released.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					fastest flowing portion of the channel) and allow native instream vegetation to colonise the channel margins. **Platypus:** Connecting flow through reach will also allow platypus to safely move between pools while foraging and ensure adequate food for lactating females.	
Summer fresh	50-200 ML/day Aim for 75-125 ML/day in an average flow year	1-3 days at peak with moderate ramp up and slower ramp down	3 events per year 1 event Dec-Feb with peak at 1 day 2 events Mar-May with peak at 2-3 days	The summer low flow aims to increase water depth by 15-30 cm compared to the summer low flow and therefore its magnitude will vary each year. In years when the low flow is 10 ML/day the fresh only needs to be 50-75 ML/day. In years when the summer low flow is around 50 ML/day the summer fresh should be 125-200 ML/day. Aim for 75-125 ML/day in average years when summer low flow is 20-30 ML/day. Do not actively deliver more than 1 fresh in Dec-Feb to avoid disturbing slackwaters during main fish larval rearing phase. This recommendation may be ignored if water quality deteriorates in dry years. In those circumstances several small freshes (50-75 ML/day may be released to flush pools. More frequent events are OK after February in any year and may help	**General:** Flush fine silt and sediment from submerged wood and other hard surfaces. **Vegetation:** Inundate the lower banks and low benches to wet the soil and promote establishment, growth and survival of fringing emergent macrophytes such as Phragmites, reeds and sedges. **Fish**: Promote local movement adult fish to access alternative habitats. The autumn freshes will be particularly important for facilitating dispersal of juvenile fish including species with ‘opportunistic’ and ‘equilibrium’ life history strategies. **Macroinvertebrates:** Wash organic matter into stream to drive aquatic foodwebs Wet submerged wood and flush fine silt and old biofilms to promote new	We have based the summer fresh recommendations on an overall objective of increasing water depth by 15-30 cm compared to the summer low flow. This approach ensures some flow variability each year and more closely mimics natural variation between wet and dry years. These flows will inundate various benches, bars and fallen wood throughout the reach. We note the potential conflict between delivering freshes to grow and maintain littoral vegetation and replenish biofilms on submerged wood and the risk that these events may disturb slackwater habitats and any fish larvae or juveniles in those habitats. Any freshes during Dec-Feb have the potential to wash fish larvae from slackwater habitats. Opportunistic species are likely to have multiple cohorts each season, so 1 fresh during

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
				facilitate platypus dispersal. The summer fresh should be no greater than the maximum flow in the previous winter/spring to reduce risk of blackwater.	biofilm growth and increase macroinvertebrate productivity **Platypus:** Facilitate downstream dispersal of juvenile platypus in Apr-May to colonise other habitats in the Murray River.	that time should not significantly affect overall recruitment. We have emphasised the need for 3 events each year over the next 5-10 years to help re-establish fringing vegetation that was removed during the 2011/12 floods. Once those plants are established, the number of freshes may be revised.
Winter low flow	50-200 ML/day Aim for 100 ML/day in average flow years	6 months Jun-Nov	Vary the magnitude of flow within the prescribed range throughout Jun-Nov to match the natural flow regime. Ramp the flow up slowly from June to deliver the highest magnitude in Jul-Sep, then gradually drop flow through Oct-Nov.	Target average low flow of 100 ML/day in average years. In dry years the low flow can be closer to 50 ML/day for most of the season. In wet years or in years when flow needs to be transferred downstream the flow can be closer to 200 ML/day for most of the season Need to avoid sudden and frequent fluctuations in low flow magnitude.	**General:** Keep submerged wood and other hard surfaces clear of fine silt and sediment.. **Vegetation :** Prevent plants from encroaching into the middle of the channel (winter flows should maintain open water in the thalweg throughout the whole reach). Prevent terrestrial plants colonising the lower sections of the river bank and low benches in the channel Maintain soil water in the river bank to water established River Red Gum and woody shrubs such as Bottlebrush and Tea Tree. Water and help establish littoral vegetation such as Bolboschoenus. **Fish:** Allow localised fish movement throughout the reach. The peak movement period is August to	

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					November as water temperature increases. **Platypus:** Facilitate long distance movement by male platypus especially during the Aug-Oct breeding season. Provide foraging opportunities across a wide range of habitats for females to develop fat reserves prior to breeding. **Macroinvertebrates:** Once water temperatures increase (generally September-Nov) the depth provided by winter low flows will inundate a wide variety and large abundance of habitats that will support high macroinvertebrate productivity.	
Winter small fresh	1000-1500 ML/day	1-2 days at peak Note – this event may need a duration of 7 days to facilitate fish movement in downstream reaches or if fish passage is provided at the Campaspe Siphon	2 per year (1 in Jul-Aug & 1 in Sep-Oct) in average to dry years. Not expected in very dry years.	The timing of the second flow should vary each year. It may be delivered in November in some years, but should not be delivered in November often or in consecutive years to avoid flushing slackwater habitats that may support developing fish larvae. This small fresh will be replaced by a large fresh in some years. If this event is not delivered then the maximum summer event in the following season should not exceed the highest winter low flow event to reduce likelihood of a blackwater	**General:** Redistribute fine sediment on benches and bars in the bottom of the channel and scoured aged biofilms from hard surfaces included submerged wood. **Water quality:** Flush accumulated leaf litter from bank and low benches to reduce risk of blackwater events during managed flow releases in summer. **Vegetation:** Promote recruitment and maintenance of River Red Gum on	Flow of 1000 ML/day is sufficient to inundate low benches in only some parts of the Reach (e.g. Bryants Lane), it is not sufficient to inundate benches throughout the whole reach (e.g. Spencer Road site).

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
				event.	low benches in some parts of the reach. First winter event will have little effect on vegetation, but Sep-Oct event is in growing season and will help riparian species become established low on the bank and limit colonisation by terrestrial plant species These flows will also help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path. **Fish:** Facilitate fish movement throughout whole reach. It will not drown the Campaspe Siphon and therefore these flows are not large enough to facilitate recruitment of Golden Perch and Silver Perch or allow species that are presumed lost to recolonise the reach from the Murray River. **Platypus:** Fresh prior to egg-laying (ideally Aug) encourages females to select a nesting burrow higher up the bank to reduce risk of high flow later in the year flooding the burrow when juveniles are present. **Macroinvertebrates:** Flushing organic matter into the stream in winter and spring will allow it to be conditioned for consumption and breakdown by bacteria and	

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					invertebrates when water temperature increases and hence support the riverine foodweb.	
Winter large fresh	1500-2000 ML/day	7 days at peak to facilitate fish movement between reaches and to and from the Murray River	For River Red Gum recruitment and maintenance deliver 2 events per year in 2 consecutive years twice per decade, with no more than 4 years without an event. First event each year in Jul-Aug (preferably Aug) to wet the bank and benches, second event each year in Sep-Nov to stimulate RRG recruitment. Try to avoid delivering the event in November too often as it may flush developing fish larvae and juveniles from slackwater habitats. For fish, recruitment and dispersal we recommend two events per year at least every 3-4 years	Important to deliver events in consecutive years because first event intended to trigger River Red Gum recruitment and second year intended to help new recruits from first year become established. It will be optimal to provide two recruitment cycles per decade. If that is not possible then provide two events in two consecutive years at least once per decade and other events as needed to ensure no more than 4 years and preferably no more than 3 years without a watering event to maintain established trees. This maintaining flow is only needed once in a year and can be delivered at any time of year, although will be best for fish recruitment if it is delivered in spring (i.e. Sep-Oct). This regime also provides adequate frequency to support recruitment of fish such as Golden Perch and Silver Perch every 3-4 years.	**General:** This flow is large enough to inundate benches and secondary flow paths in the lower part of the channel. Redistribute fine sediment on benches and bars in the bottom of the channel and scoured aged biofilms from hard surfaces included submerged wood. **Water quality:** Flush accumulated leaf litter from bank and low benches to reduce risk of blackwater events during managed flow releases in summer. **Vegetation:** Promote RRG recruitment on benches in the channel. The event in Jul-Aug is too early to trigger recruitment, but it wets the soil to condition it for the Sep-Nov event, which is intended to trigger recruitment. These flows will also help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path. **Fish:** Facilitate fish movement throughout whole reach, drown the Campaspe	Flows greater than 1500 or 1600 ML/day are needed to inundate low benches through the whole reach, engage the billabong at Spencer Road site and drown the Campaspe Siphon to provide fish passage between this reach and the Murray River

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					Siphon to allow fish to move between this reach and the Murray River to maintain existing populations and support recolonisation by species that are presumed lost from the reach. Fresh in Sep-Oct may trigger Periodic spawners such as Golden Perch and Silver Perch to either spawn in the Campaspe River or move to the Murray River to spawn. **Platypus:** Fresh prior to egg-laying (ideally Aug) encourages females to select a nesting burrow higher up the bank to reduce risk of high flow later in the year flooding the burrow when juveniles are present. **Macroinvertebrates:** Flushing organic matter into the stream in winter and spring will allow it to be conditioned for consumption and breakdown by bacteria and invertebrates when water temperature increases and hence support the riverine foodweb.	
Bankfull flow	8,000 ML/day or maximum that can be delivered without causing flooding in downstream reaches	1-2 days at peak	Only need to deliver in the year after a natural bankfull or overbank flow event. Can be delivered at any time of year	Unlikely that these events can be delivered regularly, so recommendation is to wait for a natural event and then deliver this event in the following year to help any new River Red Gum and other riparian plants that recruited during the natural event get	**Vegetation:** The main objective of this event is to help any riparian plants (especially River Red Gum) that established in the natural event get established so that they can withstand prolonged periods without inundation in	

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
				established.	subsequent years. These events will also help to scour vegetation from the middle of the channel and therefore maintain an open clear flow path. **Geomorphology:** Bankfull flows are channel forming. They will scour sediment from pools to maintain their volume and depth and replenish benches and bars within the channel. **Fish:** Bankfull flows that drown out artificial barriers will allow fish to disperse between reaches and if delivered in Sep-October are likely to trigger Golden Perch and Silver Perch to spawn and/or migrate to preferred spawning habitats.	
Overbank flows	Greater than 12,000 ML/day	As natural	As natural	Cannot deliver or control overbank flows	**Geomorphology:** Overbanks flows are channel forming. They will scour sediment from pools to maintain their volume and depth and replenish benches and bars within the channel. They will also help maintain floodplain habitats, move sediment between the stream and the floodplain and wash organic material from the floodplain into the stream. **Vegetation:** The main objective of this event is to	Overbank flows serve an important ecological function, they cannot be delivered, but will provide a benefit to the river when they occur naturally. We note that their frequency has been reduced by Lake Eppalock and now occur only when Lake Eppalock spills.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					help any riparian plants (especially River Red Gum) that established in the natural event get established so that they can withstand prolonged periods without inundation in subsequent years.	

4.3 Reach 4: Campaspe River from Campaspe Siphon to Murray River

The following flow recommendations relate to the flow gauge at Campaspe Siphon.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
Cease-to-flow	0 ML/day		No recommended	We do not recommend a cease-to-flow event in this reach because there are fewer deep refuge pools than Reach 2 and there is also some saline (up to 14,000 EC) groundwater intrusion that will affect water quality and increase stratification in pools if there is no surface flow.	Likely to be detrimental to water quality, prevent re-colonisation by instream vegetation, stress macroinvertebrates in riffle habitats and limit Platypus dispersal if occurs in later summer early autumn.	We cannot identify a specific ecological function that we would want a cease-to-flow event to achieve. We note that the Campaspe River would have naturally ceased to flow for 2-4 weeks in about 50% of years and for up to 3-4 months in the driest 20% of years, but think the risks of deliberately creating a cease-to-flow event in this reach are too high given the need to improve the condition of environmental values.
Summer low flow	10-50 ML/day	6 months Dec-May	Vary the magnitude of flow within the prescribed range throughout Dec-May. Higher magnitude in Dec, gradual decline through Jan-Feb then gradual rise from Mar-May	Target average low flow at least 30 ML/day in average years as this should be enough to prevent pools from stratifying. In dry years the low flow can be closer to 10 ML/day. This will lead to stratification in some pools, but should	**General:** The low flow is critical for maintaining a variety of aquatic riverine habitats. Provides sufficient volume of water to engage riffle and run habitats for macroinvertebrates, fish and aquatic plants and foraging habitat for	A low flow of 10 ML/day should provide a depth of 20-30 cm in the thalweg of riffle/run habitats. A flow of 50 ML/day increases water depth by approximately 20 cm. Low flows that exceed 50 ML/day may flush slackwater habitats. Monitoring during the drought

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
				maintain a layer at least 0.5 m deep of freshwater at the top of the pools. In wet years or in years when flow needs to be transferred downstream the flow can be closer to 50 ML/day for most of the season. Need to avoid sudden and frequent fluctuations in low flow magnitude to avoid disrupting slackwater habitats or stranding biota in habitats that are likely to dry. Flows greater than 50 ML/day may be too high for slackwater habitats	platypus. High diversity and abundance of habitat is important for river foodwebs; it determines the potential biomass of macroinvertebrates and food for fish and platypus. **Water quality:** Maintains water in deep pools. Flows above 30 ML/day are likely to prevent pools from stratifying. **Fish:** Maintains slackwater habitats which are productive areas for zooplankton and nursery habitats for many native fish, especially opportunistic low flow specialists such as Carp Gudgeon and Murray Rainbowfish. **Macroinvertebrates:** Varying low flow magnitude over the season will inundate fallen wood to varying degrees, which will promote growth of biofilms, support macroinvertebrates and provide habitat for fish. **Vegetation:** Maintaining a connecting flow through the whole reach for most of the time will limit the encroachment of emergent macrophytes into the middle of the channel (i.e. deepest, fastest flowing portion of the channel) and allow native instream vegetation to	demonstrated that flow of 30-35 ML/day sufficient to prevent pools stratifying in this reach. Higher flows may be needed to prevent stratification if groundwater levels are higher and therefore water quality and stratification should be monitored when flows are released.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					colonise the channel margins. **Platypus:** Connecting flow through reach will also allow platypus to safely move between pools while foraging and ensure adequate food for lactating females.	
Summer fresh	50-200 ML/day Aim for 75-125 ML/day in an average flow year	1-3 days at peak with moderate ramp up and slower ramp down	3 events per year 1 event Dec-Feb with peak at 1 day 2 events Mar-May with peak at 2-3 days	The summer low flow aims to increase water depth by 15-30 cm compared to the summer low flow and therefore its magnitude will vary each year. In years when the low flow is 10 ML/day the fresh only needs to be 50-75 ML/day. In years when the summer low flow is around 50 ML/day the summer fresh should be 125-200 ML/day. Aim for 75-125 ML/day in average years when summer low flow is 20-30 ML/day. Do not actively deliver more than 1 fresh in Dec-Feb to avoid disturbing slackwaters during main fish larval rearing phase. This recommendation may be ignored if water quality deteriorates in dry years. In those circumstances several small freshes (50-75 ML/day may be released to flush pools. More frequent events are OK after February in any year and may help facilitate platypus dispersal. The summer fresh should be no greater than the maximum flow in the previous winter/spring to reduce risk of	**General:** Flush fine silt and sediment from submerged wood and other hard surfaces. **Vegetation:** Inundate the lower banks and low benches to wet the soil and promote establishment, growth and survival of fringing emergent macrophytes such as Phragmites, reeds and sedges. **Fish**: Promote local movement adult fish to access alternative habitats. The autumn freshes will be particularly important for facilitating dispersal of juvenile fish including species with ‘opportunistic’ and ‘equilibrium’ life history strategies. **Macroinvertebrates:** Wash organic matter into stream to drive aquatic foodwebs Wet submerged wood and flush fine silt and old biofilms to promote new biofilm growth and increase macroinvertebrate productivity	We have based the summer fresh recommendations on an overall objective of increasing water depth by 15-30 cm compared to the summer low flow. This approach ensures some flow variability each year and more closely mimics natural variation between wet and dry years. These flows will inundate various benches, bars and fallen wood throughout the reach. A flow of 50 ML/day fills the channel to the toe of the lowest benches in the reach. A flow of 100 ML/day just covers most low level benches throughout the reach. A flow of 200 ML/day inundates low benches by approximately 15 cm. We note the potential conflict between delivering freshes to grow and maintain littoral vegetation and replenish biofilms on submerged wood and the risk that these events may disturb slackwater habitats and any fish larvae or juveniles in those habitats. Any freshes during Dec-Feb have the potential to wash fish larvae from slackwater habitats. Opportunistic

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
				blackwater.	**Platypus:** Facilitate downstream dispersal of juvenile platypus in Apr-May to colonise other habitats in the Murray River.	species are likely to have multiple cohorts each season, so 1 fresh during that time should not significantly affect overall recruitment. We have emphasised the need for 3 events each year over the next 5-10 years to help re-establish fringing vegetation that was removed during the 2011/12 floods. Once those plants are established, the number of freshes may be revised.
Winter low flow	50-200 ML/day Aim for 100 ML/day in average flow years	6 months Jun-Nov	Vary the magnitude of flow within the prescribed range throughout Jun-Nov to match the natural flow regime. Ramp the flow up slowly from June to deliver the highest magnitude in Jul-Sep, then gradually drop flow through Oct-Nov.	Target average low flow of 100 ML/day in average years. This flow will just inundate low benches throughout most of the reach. In dry years the low flow can be closer to 50 ML/day for most of the season. In wet years or in years when flow needs to be transferred downstream the flow can be closer to 200 ML/day for most of the season Avoid sudden and frequent fluctuations in low flow magnitude.	**General:** Keep submerged wood and other hard surfaces clear of fine silt and sediment. **Water quality:** Flow is sufficient to prevent pools stratifying. **Vegetation :** Prevent plants from encroaching into the middle of the channel (winter flows should maintain open water in the thalweg throughout the whole reach). Prevent terrestrial plants colonising the lower sections of the river bank and low benches in the channel Maintain soil water in the river bank to water established River Red Gum and woody shrubs such as Bottlebrush and Tea Tree. Water and help establish littoral vegetation such as Bolboschoenus.	

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					Fish: Allow localised fish movement throughout the reach. The peak movement period is August to November as water temperature increases. **Platypus:** Facilitate long distance movement by male platypus especially during the Aug-Oct breeding season. Provide foraging opportunities across a wide range of habitats for females to develop fat reserves prior to breeding. **Macroinvertebrates:** Once water temperatures increase (generally September-Nov) the depth provided by winter low flows will inundate a wide variety and large abundance of habitats that will support high macroinvertebrate productivity.	
Winter small fresh	1000-1500 ML/day	Up to 7 days at peak to allow fish to move between this reach and the Murray River	2 per year (1 in Jul-Aug & 1 in Sep-Oct) in average to dry years. Not expected in very dry years.	The timing of the second flow should vary each year. It may be delivered in November in some years, but should not be delivered in November often or in consecutive years to avoid flushing slackwater habitats that may support developing fish larvae. This small fresh will be replaced by a large fresh in some years. If this event is not delivered then the maximum summer event in the following season should not exceed the highest	**General:** Redistribute fine sediment on benches and bars in the bottom of the channel and scoured aged biofilms from hard surfaces included submerged wood. **Water quality:** Flush accumulated leaf litter from bank and low benches to reduce risk of blackwater events during managed flow releases in summer. **Vegetation:** Promote recruitment and maintenance	We don't know the flow that will specifically trigger Golden Perch and Silver Perch to either spawn in the Campaspe River or move from the Campaspe River to the Murray River to spawn. Specific monitoring should be undertaken to measure movement (use pit tags) and larval production (drift nets) under different flows. These results can then be used to inform required flow magnitudes for Reach 3.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
				winter low flow event to reduce likelihood of a blackwater event.	of River Red Gum on low benches throughout the reach. First winter event will have little effect on vegetation, but Sep-Oct event is in growing season and will help riparian species become established low on the bank and limit colonisation by terrestrial plant species These flows will also help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path. **Fish:** Facilitate fish movement throughout whole reach and allow fish to move between this reach and the Murray River to maintain existing populations and support recolonisation by species that are presumed lost from the reach. Fresh in Sep-Oct may trigger Periodic spawners such as Golden Perch and Silver Perch to either spawn in the Campaspe River or move to the Murray River to spawn. **Platypus:** Fresh prior to egg-laying (ideally Aug) encourages females to select a nesting burrow higher up the bank to reduce risk of high flow later in the year flooding the burrow when juveniles are present. **Macroinvertebrates:**	

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					Flushing organic matter into the stream in winter and spring will allow it to be conditioned for consumption and breakdown by bacteria and invertebrates when water temperature increases and hence support the riverine foodweb.	
Winter large fresh	1500-2000 ML/day	7 days at peak to facilitate fish movement between reaches and to and from the Murray River	For River Red Gum recruitment and maintenance deliver 2 events per year in 2 consecutive years twice per decade, with no more than 4 years without an event. First event each year in Jul-Aug (preferably Aug) to wet the bank and benches, second event each year in Sep-Nov to stimulate RRG recruitment. Try to avoid delivering the event in November too often as it may flush developing fish larvae and juveniles from slackwater habitats. For fish, recruitment and dispersal we recommend two events per year at least every 3-4 years	Important to deliver events in consecutive years because first event intended to trigger River Red Gum recruitment and second year intended to help new recruits from first year become established. It will be optimal to provide two recruitment cycles per decade. If that is not possible then provide two events in two consecutive years at least once per decade and other events as needed to ensure no more than 4 years and preferably no more than 3 years without a watering event to maintain established trees. This maintaining flow is only needed once in a year and can be delivered at any time of year, although will be best for fish recruitment if it is delivered in spring (i.e. Sep-Oct). This regime also provides adequate frequency to support recruitment of fish such as Golden Perch and Silver Perch every 3-4 years.	**General:** This flow is large enough to inundate benches and secondary flow paths in the lower part of the channel. Redistribute fine sediment on benches and bars in the bottom of the channel and scoured aged biofilms from hard surfaces included submerged wood. **Water quality:** Flush accumulated leaf litter from bank and low benches to reduce risk of blackwater events during managed flow releases in summer. **Vegetation:** Promote RRG recruitment on benches in the channel. The event in Jul-Aug is too early to trigger recruitment, but it wets the soil to condition it for the Sep-Nov event, which is intended to trigger recruitment. These flows will also help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path. **Fish:**	We don't know the flow that will specifically trigger Golden Perch and Silver Perch to either spawn in the Campaspe River or move from the Campaspe River to the Murray River to spawn. Specific monitoring should be undertaken to measure movement (use pit tags) and larval production (drift nets) under different flows. These results can then be used to inform required flow magnitudes for Reach 3.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					Facilitate fish movement throughout whole reach and allow fish to move between this reach and the Murray River to maintain existing populations and support recolonisation by species that are presumed lost from the reach. Fresh in Sep-Oct may trigger Periodic spawners such as Golden Perch and Silver Perch to either spawn in the Campaspe River or move to the Murray River to spawn. **Platypus:** Fresh prior to egg-laying (ideally Aug) encourages females to select a nesting burrow higher up the bank to reduce risk of high flow later in the year flooding the burrow when juveniles are present. **Macroinvertebrates:** Flushing organic matter into the stream in winter and spring will allow it to be conditioned for consumption and breakdown by bacteria and invertebrates when water temperature increases and hence support the riverine foodweb.	
Bankfull flow	8,000 ML/day or maximum that can be delivered without causing flooding in downstream reaches	1-2 days at peak	Only need to deliver in the year after a natural bankfull or overbank flow event. Can be delivered at any time of year	Unlikely that these events can be delivered regularly, so recommendation is to wait for a natural event and then deliver this event in the following year to help any new River Red Gum and other riparian plants that recruited during the natural event get established.	**Vegetation:** The main objective of this event is to help any riparian plants (especially River Red Gum) that established in the natural event get established so that they can withstand prolonged periods without inundation in	

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					subsequent years. These events will also help to scour vegetation from the middle of the channel and therefore maintain an open clear flow path. **Geomorphology:** Bankfull flows are channel forming. They will scour sediment from pools to maintain their volume and depth and replenish benches and bars within the channel. **Fish:** Bankfull flows that drown out artificial barriers will allow fish to disperse between reaches and if delivered in Sep-October are likely to trigger Golden Perch and Silver Perch to spawn and/or migrate to preferred spawning habitats.	
Overbank flows	Greater than 12,000 ML/day	As natural	As natural	Cannot deliver or control overbank flows	**Geomorphology:** Overbanks flows are channel forming. They will scour sediment from pools to maintain their volume and depth and replenish benches and bars within the channel. They will also help maintain floodplain habitats, move sediment between the stream and the floodplain and wash organic material from the floodplain into the stream. **Vegetation:** The main objective of this event is to help any riparian plants (especially	Overbank flows serve an important ecological function, they cannot be delivered, but will provide a benefit to the river when they occur naturally. We note that their frequency has been reduced by Lake Eppalock and now occur only when Lake Eppalock spills.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	Notes
					River Red Gum) that established in the natural event get established so that they can withstand prolonged periods without inundation in subsequent years.	

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Appendix A. Field inspection notes prepared by Michelle Maher NCCMA.

Subject	**Campaspe River EWMP Field Visit Notes**
Attendees	Dr Andrew Sharpe (Jacobs), Dr Paul Boon (Dodo Environmental), Dr Paul Humphries (Charles Sturt University), Bree Bisset, Darren White, Louissa Rogers and Michelle Maher (North Central Catchment Management Authority)
Date	1 August 2014

The purpose of the field visit was for the Environmental Flows Technical Panel to inspect the Campaspe River downstream of Lake Eppalock and the Coliban River on 1 August 2014. The aim of the field visit was to revisit the FLOWS sites to gain an appreciation for how the river has changed since the 2006 FLOWS study. A workshop to review the ecological and hydrological objectives is scheduled for 7 and 8 August 2014. These field notes summarise the findings and discussion on the day.

Site 1: Echuca Weir	**Reach: 4 (Fishway)**	**Time: 8:40am**
Notes Hydrology: • Unregulated flows currently backed up from the Murray River • 140 ML/day release from the Campaspe Siphon Fishway: The rock ramp fishway has replaced the old concrete weir that was constructed in the early 1990s and is the first fishway on the Campaspe River. 45 km of river channel upstream of the fishway has been opened for fish passage and can now freely move between the Murray River and the Reach 4. Platypus present in the weir pool 2 Silver perch caught in 2014 VEFMAP fish survey		
 Photo of the fishway – rocks covered by flow		
Site 2: Campbell's Road	**Reach: 4 (FLOWS site)**	**Time: 9:00am**

Notes
• Discussion that there was excessive Typha growth in the channel at this site in 2005
• Grazing exists on the LHS of the river
• Couple of River Red Gum (RRG) seedlings but surprising how limited this is
• Typha has gone, scour and currents have undermined the rhizome bed
• One new snag (maybe due to lower velocity flooding/low gradient)
• No new vegetation – no rhizomes left
• It is concerning that there is no regeneration of aquatic vegetation (Water Ribbons or Phragmites)
• There are some big pools in this reach
• This site is also a High Summer Flow monitoring site (400ML/day) – erosion pins, flow habitat types, quadrats and photo points
• Discussion was had about the fish objective
  ○ Rising flow will cue fish movement
  ○ Smell/chemical will trigger fish to move to new habitat, not just high flow		

- Campaspe River will provide good refuge habitat now that the fishway in in place (Murray River is a much higher energy stream)
- Potential change in fish community includes: Silver Perch, Golden Perch, Trout Cod and Murray Cod
- **Action:** have a look into what fish are caught/recorded in this section of the Murray River
- Need slackwaters to protect young

* Macroinvertebrates: shift in focus to main functional groups (e.g. decomposers, scrappers). There are lots of Shrimp in the river. Platypus prefer Caddisflies.
* 2005 study: Community dominated by collector/gatherers.
* Monitoring discussion
  - Need macro biomass to be measured quantitaively (Sticky paper traps, artificial substrates) rather than presence absence as is typical of AusRivas or SIGNAL
  - Stable isotope analysis is not an appropriate measure as all of the vegetation is C3
  - Stream metabolism – what is the base of the food web?


Photo looking downstream


Photo looking upstream

Site 3: Cox's Reserve	Reach: 4 (Landcare revegetation site)	Time: 10:00am

Notes

* Landcare revegetated riparian zone
* Known Squirrel Glider habitat
* Typha blockage was here previously (**Action:** Darren to supply photo for workshop)
* Some Juncus and Schoenoplectus
* Little bit of Phragmites around the bend (upstream) and lots of dead Phragmites stands at the waters edge

Site 4: Strathallan	Reach: 4 (FLOWS site)	Time: 10:20am

Notes

* Good loading of instream wood
* LHS fenced off, RHS is about to be fenced off (Caring for Campaspe Project)
* Bottlebrush (Callistemon spp.) tree. Discussion on the absence of Wattles.
* Good diversity of hydrological habitats at this site
* RRG regeneration
* Current recommendation for summer low flow is 20ML/day recommendation for slackwater habitat is on the low side, however the current 140ML/day release is too fast for a lot of species. There are some areas where slackwater habitat is still present.
* Summer high flow monitoring site - erosion pins, flow habitat types, quadrates and photo points


Photo looking downstream


Photo looking upstream

Site 5: Spencer Rd	Reach: 3 (FLOWS site)	Time: 11:00am

Notes

- No fish passage from the Murray River to this site (substantial impediment is the Campaspe Siphon)
- Designs exist to open up an additional 15km of river for fish passage (~$1million). Unless we deal with the Siphon we are not going to get fish movement.
- The Campaspe Weir is no longer required by GMW (CID gone) and this structure will fail eventually. However the weir pool is valued recreationally (refuge pool).
- Providing flow for movement is not a priority due to the Siphon.
- Rubbish dumping at this site
- Some sandy sections in this reach
- Dormant Phragmites
- Murray River Rainbowfish – high abundance surveyed in 2014 was something that you can't predict will happen. This species use slackwater habitats and associated with macrophytes. It is unlikely that they will persist in the longer term (without the ability for them to move through the system).
- Not disturbing slackwater habitats should be an ecological objective (risks and tolerances)
- If the Campaspe Siphon barrier was removed then the fish objectives would be the same as Reach 4.
- There is no passing flow requirement in Reach 3, therefore use of the Environmental Entitlement is very important
- Now that the CID is closed there will be more pressure from pumping (direct from the river)
- Action: Lou to follow up with Floodplain team that there is a requirement for "Hammerheads" at the end of pumps to protect aquatic species
- Previous Murray Cod stocking site
- Used to be big beds of submerged macrophytes – Myriophyllum and Triglochin have gone now (don't like fast flow)
- Ten years ago – the river exhibited wetland habitats.
- Typha slowing the flow of water? Flow velocities too high?
- Previous objectives were to prevent excessive Typha (and terrestrialisation) growth. The FLOWS study was obsessed with drought, stratification of pools, Blackwater events and slackwater habitats.
- No reason for flows over summer from a vegetation perspective.
- There is a tension with regard to the requirements during summer – summer freshes to inundate benches Vs slackwater habitats
- New sand bench at the site (refer to photo)
- Still no submerged vegetation and no regeneration of RRGs
- Vegetation objectives: discussion around maintaining of species present, is there too much emphasis on spreading via seed, more likely colonial spreading. Can't encourage aquatic vegetation to grow. Fragmentation of plants just happens.
- Murray River Rainbowfish – at what flow is the Siphon overtopped?

 Photo looking downstream	 Photo looking upstream	 New sand bench

Site 6: Bryant's Lane	Reach: 3 (FLOWS site)	Time: 12:20am

Notes:

- No native understorey vegetation, banks covered with Capeweed
- Again surprised by lack of Wattles, a couple of Bottlebrush trees

- Looks like the instream vegetation (Typha and Phragmites) has been scoured
- The lack of instream recruitment could also be impacting the slow fish recovery
- In this high flowing river you would still expect to see Triglochin and Myriophyllum

 Photo looking downstream	 Photo looking upstream	
Site 7: English's Road	**Reach: 2 (FLOWS site)**	**Time: 1:00pm**

Notes

- Approx. 800ML/day being released from Lake Eppalock (Winter High Flow commenced on Tuesday 29th July)
- Evidence of stock access on both sides of the river
- Small stands of Phragmites/Typha on the edge
- Discussion on high flow (1,000ML/day) is not going to aid RRG recruitment (current flow recommendation)
- Secondary channel at this site not engaged at current flow, need a large flood.
- RRGs have recruited higher on the bank due to high floods

 Photo looking downstream	 Photo looking upstream	
Site 8: Backhaus Lane	**Reach: 2 (Deep pool)**	**Time: 2:30pm**

Notes:

- Additional site visited due to deep pool (identified in SKM fieldwork in 2012) – 1.7km long and 6.8m deep) and aquatic vegetation still at site.
- Water quality continuous probe shell will remain but probes have been removed (will be used in drought conditions)
- Small amount of Triglochin at the waters edge (there has been lots previously)
- Some small RRGs under water
- Eel Grass – important habitat for Flathead Gudgeon
- DEPI fish stocking site

 Triglochin at waters edge		
Site 9: Doaks Reserve	**Reach: 2 (FLOWS site)**	**Time: 3:00pm**

Notes:

- 2006 FLOWS study, this site was full of Typha
- Grazing impact: RRG recruitment (thick stands – refer to photo), other areas this has been actively removed or grazed.

• High Redfin abundance • Galaxiids caught after Lake Eppalock spilled • Platypus seen during surveys • Very large RRGs, hard to age, however Rutherford (late 90s) suggested that they range between 200-300 years old.		
 RRG recruitment and impact from stock/clearing	 Photo looking downstream	 Photo looking upstream