Ecosystem implications of a proposed drought flow regime for the lower Goulburn River

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Prepared for the Goulburn-Broken Catchment Management Authority

by

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Prepared by Peter Cottingham & Associates on behalf of the Goulburn Broken Catchment Management Authority

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COVER PHOTOGRAPH:
Goulburn River near Kerrisdale, October 2003. Photograph by Peter Cottingham.

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1 INTRODUCTION

The recent drought over much of southeastern Australia has resulted in a large decline in inflows to waterways across the Murray Darling river system. Inflows in 2006 were the lowest on record and inflows in the early part of 2007 have declined even further (Figure 1).

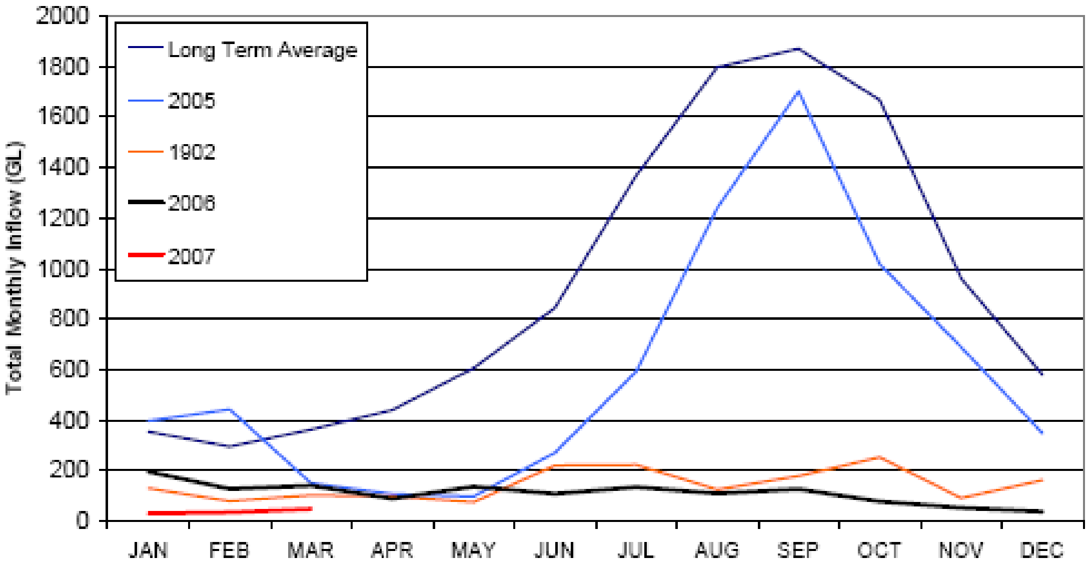

Figure 1: Long-term and recent inflows to the Murray Darling system (from MDBC 2007).

The widespread pattern of low inflows across the MDB was also evident for the Goulburn River during the 2006/07 water year. Reduced inflows and low storage levels in Lake Eildon (5.5% as of the 1st May 2007) will result in considerable difficulty for both water users and the environment should they persist. The Goulburn Broken CMA (the CMA) and other agencies have, therefore, been undertaking drought contingency planning for the 2007/08 water year. The contingency planning has included assessment of a repeat of the 2006/07 inflows as a worst case scenario.

Those involved in developing a drought response (e.g. the CMA, Department of Sustainability & Environment, Goulburn-Murray Water) have agreed that the priority when allocating water should go to:

1. Domestic water supply;
2. Water supply for livestock; and
3. The water market.

However, modelling based on current storage levels and the inflows of 2006/07 suggest that there will only be sufficient water to provide a constant flow of 300 ML/d year round at McCoy's Bridge. This assumes that water will only be diverted for domestic consumption, with little or no water diverted for stock or agriculture, and that storages would be dry at the end of the year.

Current plans assume that, as part of sharing the limited available water with consumptive users, the minimum Goulburn River flows at McCoy's Bridge (upstream of the River Murray junction) will be reduced to 300 ML/day for the whole of the 2007/08 year (Geoff Earl, Goulburn Broken CMA, *pers. comm.*). This compares with the current minimum flows specified in the Goulburn bulk entitlement of 400 ML/d from July to October and 350 ML/d[1] from November to June. The reduction in minimum flow would be implemented in May/June 2007 and continue until inflows improve significantly. The current minimum flows of 120 ML/d below Lake Eildon and 250 ML/d below Goulburn Weir will be maintained. The bulk entitlement for the Goulburn River includes an 30 GL reserve in Lake Eildon to manage issues such as poor water quality and algal blooms. However, the very low storage levels and the priority given to meeting domestic consumption means that this reserve is currently unlikely to be available for managing environmental risk.

In light of these expectations described above, the CMA has sought advice on the implications of the prospective temporary new flow regime from an ecosystem perspective. This advice was prepared at a workshop on the 27th April 2007 that included members of the Goulburn Scientific Panel (Cottingham et al. 2007), and Dr Nick Bond (Monash University). The CMA asked those attending to consider:

- The potential increase in risk to the environment from the proposed reduction in minimum flows;
- Whether a reduction in minimum flows to between 200 - 250 ML/d in winter/spring 2007 to allow an increase in summer/autumn flows (e.g. 350 ML/d, up from the proposed 300 ML/d, or as increased flow pulses in response to water quality or other triggers) would allow better management of overall environmental risk, within the same total volume of water available for the 2007/08 year;
- Any other options to minimise the overall environmental risk within the same total volume of water.

This report presents the findings and advice provided at the workshop, based on the premise that the proposed flow regime would apply only for the 2007/08 water year. Continued low inflows in the coming year would require a review of implications prior to 2008/09, recognising that relative threats posed by low-flow conditions to ecosystem values and condition may vary greatly in intensity should the drought persist (e.g. threats to short-lived versus long-lived species).

Environmental flow recommendations have been developed for the Goulburn River (Cottingham et al. 2003, 2007), including recommendations for flow components such as minimum flows and wetland watering events. Under normal circumstances, preference would be given to delivering the recommended environmental flow regime. However, under the current extreme climatic and hydrological conditions, the priorities shift from maintaining environmental values to minimising environmental risks, in particular focusing on short-term risks (i.e. within the next water year) caused by sustained and very low inflows to the Goulburn River.

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[1] Note that these flows are average monthly flows. The minimum flow on any day may be up to 50 ML/d less.

2 ISSUES AND RISKS RELATED TO ECOSYSTEM CONDITION IN THE LOWER GOULBURN RIVER

Drought can be considered as a ‘ramp’ disturbance to aquatic ecosystems (Lake 2003, 2000) where the severity of the disturbance increases as the drought progresses. Droughts can affect stream hydrology in many ways, for example by causing sequential drying in downstream, headwater or middle reaches and thus affecting hydraulic connectivity (longitudinal, lateral and vertical). The issues and risks associated with persistent drought flows were considered for two sections of the Goulburn River from (i) Goulburn Weir to Shepparton, and from (ii) Shepparton to the Murray River. These reaches are consistent with those used recently when developing environmental flow recommendations for the Goulburn River, where they were identified as Reach 4 and Reach 5, respectively (Cottingham et al. 2003, 2007).

The planned delivery of 300 ML/d at McCoy’s Bridge for 2007/08 is a flow regime that is quite outside historical records for the Goulburn River. Prior to this coming year, the historical record shows that although low flows were common over several months through summer and autumn, these tended to be interrupted by small freshes; low flows did not last through winter, which was a time for floods.

Ecological implications of sustained low flows throughout the whole year are best considered by focusing on the hydrologic and hydraulic characteristics that result from this. Biota and processes respond variously to velocity, depth and the duration of flow events; it is important to note that as flow decreases, the influence of channel topography on these attributes increases and become critical at flow cessation (e.g. Stanley et al. 1997, Gagnon et al. 2004). Information collated to develop environmental flow recommendations for Reaches 4 and 5 provided a number of insights on ecology-flow relationships at the proposed flow of 300 ML/d. These show that:

- Much of the wetted perimeter remains in the euphotic zone and is thus available for benthic production (Figure 2 and Figure 3). However, the area available varies considerably as low flows fluctuate, especially in Reach 4.
- Mean depth in each reach will be in the order of 1 m (Figure 4 and Figure 5). These shallow conditions are likely to be favourable for rooted macrophytes.
- The proportion of cross-sectional area with ‘fast’ flow (i.e. >0.2 m s) will be low (<15% at Reach 4 and <25% at Reach 5). Hydraulic conditions will have largely slow flow characteristics that favour macrophyte growth and serve as habitat for some invertebrates and fish (Figure 6 and Figure 7).

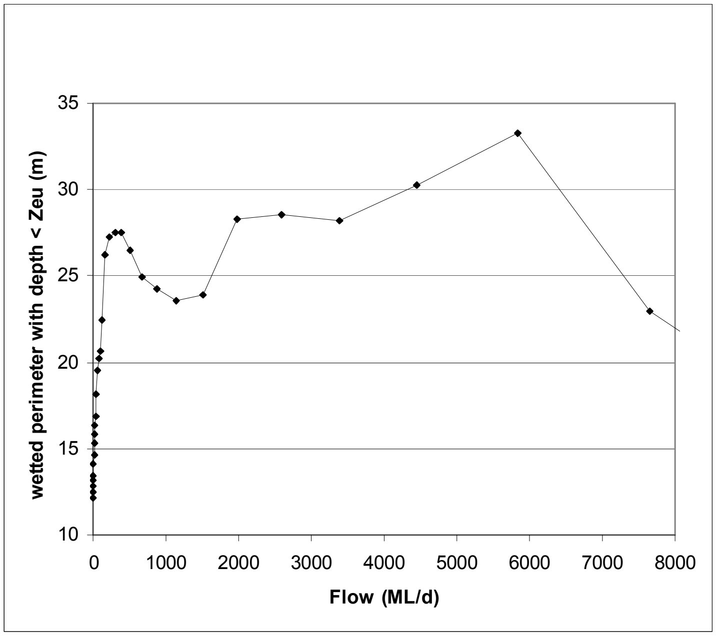

Figure 2: **Average wetted perimeter within the euphotic zone at Murchison (Reach 4).**

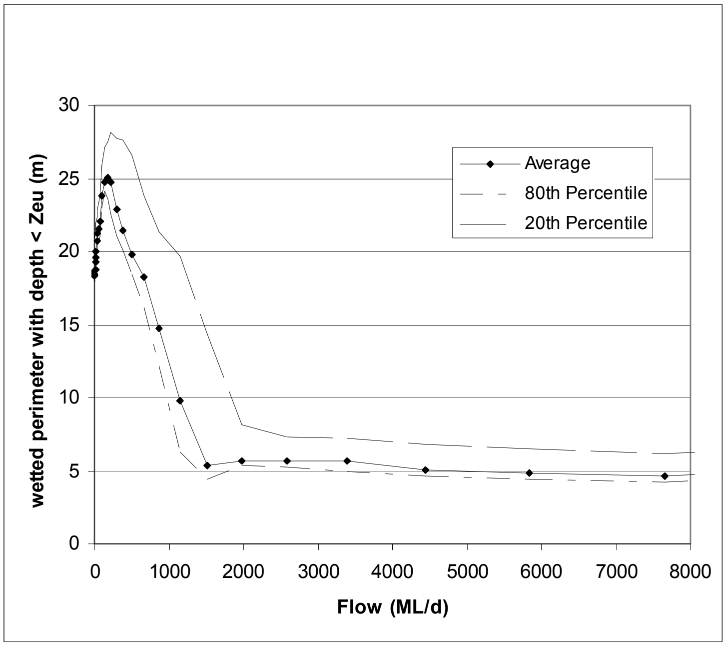

Figure 3: **Average wetted perimeter within the euphotic zone at Wyuna (Reach 5).**

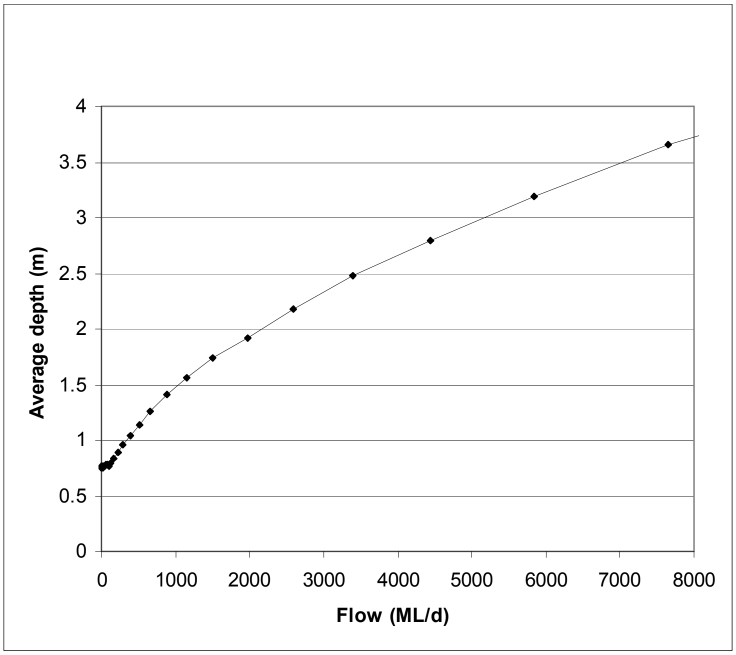

Figure 4: **Mean depth at Murchison (Reach 4)**

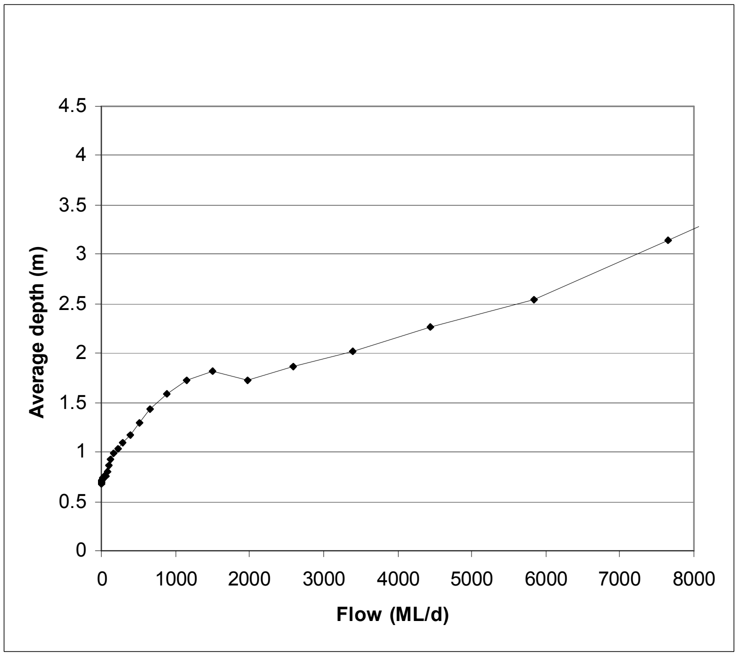

Figure 5: **Mean depth at Wyuna (Reach 5)**

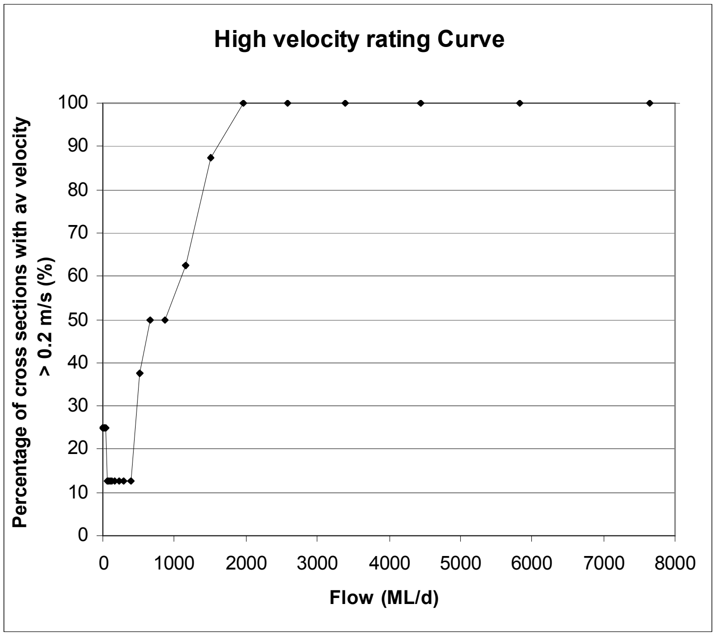

Figure 6: **Proportion (as a percentage) of cross-sections with mean velocity greater than 0.2 m/s at Murchison**

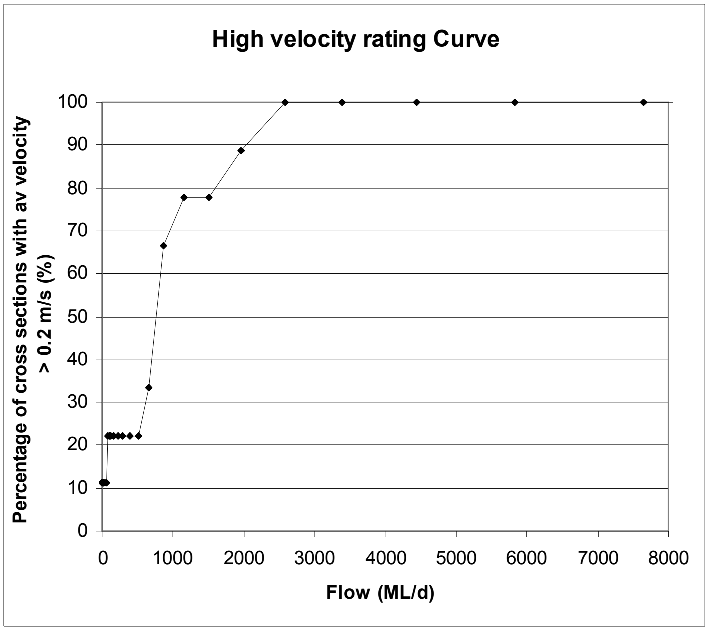

Figure 7: **Proportion (as a percentage) of cross-sections with mean velocity greater than 0.2 m/s at Wyuna**

Unlike other nearby river systems (e.g. Campaspe, Loddon), the proposed release pattern from Goulburn Weir will provide persistent flow along the lower Goulburn River, albeit at low levels. This means that at least some level of longitudinal connection will be maintained in the study reaches. However, the complete loss of lateral connectivity between the river channel and associated riparian zone and floodplain areas experienced in recent years will remain.

Given the conditions posed by the new flow regime, the following issues become important:

- Availability of deep pools as refugia for biota such as fish;
- Prevalence of favourable growing conditions for phytoplankton especially bloom-forming species and, therefore, an increased risk of algal blooms;
- Poor water quality (e.g. due to stratification of the water column in pools, concentration of contaminants from various sources), which can reduce habitat quality and may result in the death of biota such as fish;
- Growing conditions for submerged, floating and emergent macrophytes.

2.1 Approach to assessing ecosystem implications of the proposed drought flow regime

The proposed flow regime was considered in terms of:

- The requirements for biota to survive;
- Risk associated with various ecosystem responses to continued drought conditions and low flows;
- Other non-flow management issues that may ameliorate or exacerbate the impact of the proposed low flow regime (e.g. saline groundwater intrusion, wastewater discharge).

Potential threats posed by the flow regime were considered in terms of their likelihood of occurrence and ecosystem consequence, should they occur – a standard approach to assessing ecosystem risk (e.g. Hart et al. 2006, 2003). The threats considered were related to:

- Declining water quality, exacerbated by processes such as stratification;
- Cyanobacteria blooms;
- Increased sediment deposition;
- Potential loss of and disconnection between habitats for aquatic plants and animals;
- Barriers to migration by fish and other organisms;
- Density-dependent factors related to the congregation of organisms in remaining habitat.

This study has focussed on short-term ecosystem responses (e.g. 12-18 months); medium to long-term responses (e.g. greater than 2 years) were not considered in detail. However, if drought conditions persist beyond 2007/08, then additional consideration should also be given to issues such as:

- Erosion at the toe of the river bank (fretting) due to sustained flows;
- The on-going decline of riparian, floodplain and wetland systems, including factors such as seed and egg-bank attrition (e.g. Jenkins and Boulton 2007) and stress of established trees, which can undermine recovery potential once drought conditions break;
- Saline intrusions into pools.

2.2 Water quality issues

Water quality has been noted to decline in rivers during periods of drought. Nutrients and other water contaminants may become concentrated as discharge declines, increasing the potential for eutrophication and other water quality problems. For example, Chessman and Robinson (1987) noted that a lack of dilution for wastewater discharges resulted in marked deterioration of water quality (low DO, increased salinity) in the LaTrobe River, Victoria, during the 1982/83 drought. Ferrari et al. (2006) reported that eutrophication, fuelled by high nutrient concentrations and a lack of dilution, occurred in the Po River, Italy, during the drought of 2003. Also, the congregation of aquatic biota in refugia as drought progresses and available habitat diminishes can make them increasingly susceptible to spills or accidental releases of toxicants or contaminants with high biological oxygen demand (BOD) or chemical oxygen demand (COD).

The risks associated with poor water quality are summarised in Table 1. Particular attention is given to water stratification in the following section, given its potential to contribute to or exacerbate water quality issues. However, it should be remembered that poor water quality (e.g. low DO) can occur in the absence of stratification.

2.2.1 Water stratification

Water stratification occurs when water of different densities form layers that act as barriers to water mixing. This may be a result of differences in temperature (e.g. due to heating of surface water) or salinity (e.g. due to inputs of saline groundwater). The separation of the water column into different layers means that each layer becomes more susceptible to oxygen depletion, particularly in bottom waters where diffusion of oxygen is limited and BOD and COD is often greatest.

Stratification and any accompanying decline in water quality can result in both chronic and acute problems for biota. For example, should persistent stratification in pools result in very low DO in bottom waters, then this can limit habitat availability for fish[2]. This in turn can have chronic effects, for example increased susceptibility to factors such as predation from predatory birds (natural and from recreational fishing) or risk of disease affecting fish community structure and reducing the numbers that survive until conditions improve. However in extreme situations, hypoxic conditions may occur throughout the water column, potentially resulting in acute impacts that lead to fish kills that wipe out local populations. The congregation of biota in refugia such as pools increases the severity of such events. For example, hypoxia resulting from the decomposition of a large bloom of the water fern *Azolla* has been implicated in a large fish kill in the lower Broken Creek in 2002 (O'Connor 2004).

Stratification also promotes conditions conducive to algal blooms (e.g. Paerl 1988). Stratification and deoxygenation of the bottom waters can increase chemical reduction in bottom sediments, which increases the rate at which nutrients (especially P) and toxicants such as ammonia and heavy metals are released to the water column. However, there is little history of algal blooms or nuisance macrophyte growth in the Goulburn River, even though light and nutrient conditions are not considered to be limiting factors (Cottingham et al. 2007). This implies that the

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[2] Note: as DO can be affected by many factors, including BOD and COD, low DO can occur even if the water column is fully mixed

current flow regime has been sufficient to maintain retention times and/or restrict stratification such that nuisance blooms do not form.

McGuckin (1991) investigated water quality in pools (6 -10 m deep) along the Goulburn River between Shepparton and the Murray River on three occasions over the water year 1990/91. He found no evidence of salinity intrusion, and little evidence of thermal stratification or adverse water quality effects (e.g. high salinity, low dissolved oxygen) when irrigation season flows were above 500 ML/d. However, strong oxygen depletion (<5% saturation) was recorded in the bottom metre of two of the deep pools in the survey that followed a long period of low flows (down to 234 ML/d). Temperature stratification only occurred during one survey at one site and was relatively minor ($2^{o}C$ difference between the surface and the bottom water at 10 m depth). Even so, DO remained high throughout most of the water column in the two pools and posed no significant risk to biota. However, further monitoring of pool water quality was recommended to assess any changes during very low flow periods (e.g. during drought or when flows are between 250 - 400 ML/d).

When studying the growth characteristics of the cyanobacteria *Anabaena circinalis* in the Darling River, Mitrovic et al. (2003) found that thermal stratification in the river persisted when water velocity fell below 0.05 m/s. Applying this velocity to the Goulburn River suggests that discharge of approximately 100 ML/d or less could result in persistent stratification (Figure 8). This is well below the proposed discharge of 250 – 300 ML/d, but the specific conditions of the river need to be taken into account, as the nature of channel topography at low flows may be such that there are still low- or zero-flow zones where localised algal blooms can develop, even though average velocity is above 0.05 m/s.

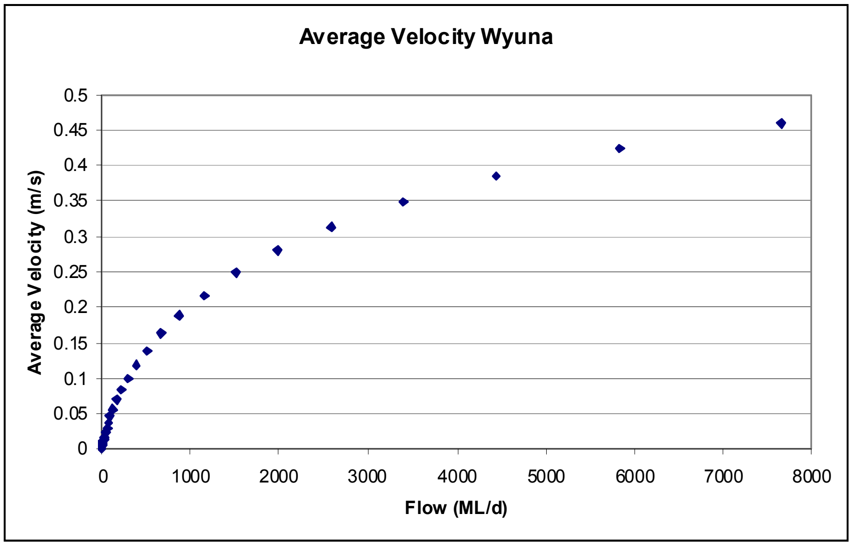

Figure 8: Average velocity versus flow in Reach 5.

Bormans and Webster (1997) have developed a model for predicting formation of persistent thermal stratification based on the influence of heating and mixing on the potential energy of flow in a river. In this model, the decrease in potential energy due to heating of the water is compared to the amount of flow-related turbulent energy available for mixing. If the rate at which the potential energy of the flow is decreasing as a result of heating is greater than the rate at which potential energy is being increased by mixing then the model predicts that the river will become stratified. The model is based on the following criteria:

$$R = \frac{U^3}{H\left(Q_{net} - \frac{2Q_I}{k_d H}\right)\frac{\alpha g}{\rho C_p}} \qquad (1)$$

R	Richardson number (-)
U	Flow velocity (ms^{-1})
H	River depth (m)
Qnet	Net heat flux (Wm^{-2})
QI	Short wave portion of incoming solar radiation (Wm^{-2})
kd	Vertical light extinction coefficient (m^{-1})
α	Thermal expansion coefficient for water (≈1.50×10-4K^{-1})
g	Acceleration due to gravity (≈9.81ms^{-1})
ρ	Density of water (≈1000kgm^{-3})
Cp	Specific heat of water (≈4218 Jkg^{-1}K^{-1})

Bormans and Webster (1997) consider that there is a threshold value of *R* below which persistent thermal stratification will occur, which they estimate to be *R* = 45,000.

The nature of the river channel in each study reach suggests that persistent thermal stratification is more likely in Reach 5 (than in Reach 4), as available data indicates pools are deeper and turbidity (and hence k_d) is greater (Cottingham et al. 2007, McGuckin (1991). Based on observed turbidity, the light extinction coefficient is estimated to be k_d = 4.43 m^{-1}. Survey data for Reach 5 (near Wyuna) identified a maximum pool depth at 300 ML/d of 3.9 m. The corresponding cross-section velocity in this pool is 0.04 m/s, which is below the velocity threshold suggested by Mitrovic et al. (2003). Data collected in a pool at Glenorchy in the Wimmera River indicates that Q_{net} = 70 Wm^{-2} and Q_I = 360 Wm^{-2} are typical values during periods of summer warming when persistent stratification is likely to occur. Using these environmental data resulted in an *R* = 1,660, which is below the threshold of 45,000 suggested by Bormans and Webster (1997). Hence, persistent thermal stratification is likely to occur at low flows in Reach 5 of the Goulburn River.

The lines of evidence for stratification considered above (the case history of very few algal blooms in the Goulburn River, the surveys of McGuckin (1991), and the empirical relationship developed from investigations in the Darling River and applied to the Goulburn River, and the predictive model of Bormans and Webster (1997) suggest that temperature stratification is likely in the deep pools of the Goulburn River at low flows. However, the resultant strength of stratification and its impact on DO concentration is difficult to predict. It is therefore recommended that instrumentation be installed to measure the onset of stratification and any changes in water quality in pools along the lower Goulburn River.

Table 1: Summary of risk associated with poor water quality

Risk	Likelihood	Consequence	Action
• Stratification ➢ Decreased DO ➢ Increased surface temperature ➢ Potential release of nutrients and toxicants such as ammonia	• Stratification in deeper pools is very likely • Strength of stratification and subsequent decline in DO and potential for release of nutrients and toxicants is difficult to predict	• Severe consequences for biota such as fish should hypoxia events occur	• Survey thalweg depth to identify deep pools • Monitor DO, temperature and EC in deep pools along Reach 5 • Isolate accidental pollution spills should they occur
• Algal blooms	• Low likelihood of algal blooms at proposed discharge and velocity on average, but greater potential in deeper pools.	• Likely to contribute or exacerbate consequences of stratification and lower DO • Reduction in the quality of habitat for biota such as invertebrates and fish	• Continue routine algae counts and Chlorophyll-a measurements
• Increased contaminant concentration	• Likelihood of contaminants associated with wastewater and runoff (e.g. stormwater) reaching levels of concern (e.g. ANZECC risk levels) was not assessed. • Likelihood of accidental spills or releases or contaminants unknown.	• Reduction in the quality of habitat for biota such as invertebrates and fish. • Severity will depend on concentration of various contaminants. Potential for severe consequences with accidental release (e.g. spills) of toxic contaminants or contaminants with high BOD or COD.	• Continue routine water quality monitoring • Develop dedicated water quality monitoring program to assess drought impacts • Real-time monitoring of DO, temperature and EC to allow rapid management response to declining water quality

Table 2: Summary of risk associated with fine sediment deposition

Risk	Likelihood	Consequence	Action
➢ Smothering of biota ➢ Decreased food quality for invertebrates and higher organisms ➢ Sediment load on submerged leaves of macrophytes can reduce photosynthesis, even result in decay and loss of such leaves.	• Likelihood of excessive deposition is unknown	• Decreased rates of riverine production (primary and secondary) • Loss of in-channel and water-column habitat • Decreased invertebrate diversity	• Observe changes to the extent of sediment deposition • Reserve water to manipulate flows to disrupt sediment layers

2.3 Increased sedimentation

The proposed flow regime will reduce average water velocity in each study reach. This will reduce the sediment carrying capacity of the river and may result in increased rates of fine sediment deposition on benthos, snags, biofilms and macrophytes. This smothering effect can reduce the availability and quality of habitat for biota such as invertebrates (Table 2) as well as being a direct mortality factor to a number of macroinvertebrate taxa. The extent and severity of smothering by sediments is currently unknown. It is therefore recommended that the river be managed to take advantage of any opportunities to disrupt sediment layers (e.g. occasional pulses of water above 300 ML/d) and so improve habitat quality.

2.4 Decreased habitat availability

Obligate aquatic biota such as fish and some invertebrates[3] are likely to congregate in refugia such as pools as flow decreases and habitat availability declines. This increases the threats associated with density-dependent factors, such as:

- increased competition for resources,
- Increased rates of illness or death from disease (e.g. EHN virus that attacks fish),
- increased parasitism,
- increased predation pressure.

While the temporary loss of available habitat and subsequent density-dependent effects are likely to impact on the number and condition of organisms, and may even lead to localised extinctions in some parts of the river, this effect is likely to be short-term so long as flow conditions improve within the next 12 months. The challenge for management under these extreme drought conditions is to ensure maximum resilience of the river ecosystem by sustaining these ‘seed’ communities in sufficient condition to support as rapid and complete recovery as possible. However, the longer the low inflows persist, then the longer the time required for river organisms to recover.

2.4.1 Fish

The proposed flow regime was considered from the perspective of habitat for different stages of the lifecycle.

The environmental flow recommendations of Cottingham et al (2003) included an increase in the minimum flow from 350-400 ML/d under the Bulk Entitlement to 610 ML/d to increase the amount of deep habitat (i.e. > 1.5 m deep) for fish. A flow of 300 ML/d will result in a ~65% reduction in deep habitat for fish compared with the recommended minimum flow of 610 ML/d (Figure 9).

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[3] Note that some invertebrates in large rivers, such as mussels, have very limited powers of mobility. This also applies to log-dwelling fauna such as elmid beatles.

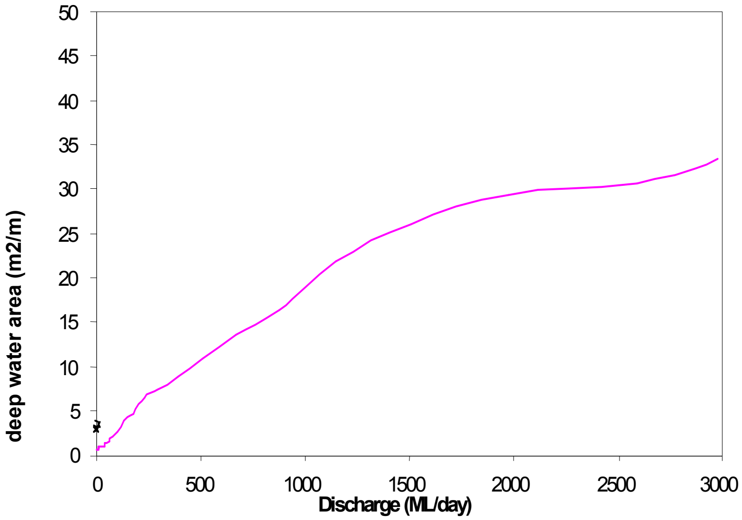

Figure 9: Deep-water habitat (>1.5m depth) available for fish in Reach 4.

Examination of thalweg depth from cross section survey data suggests that there will be sufficient depth along the river to allow movement by fish and other biota.
The minimum thalweg depth in Reach 4 at 200 ML/d is 0.4 m, while a flow of 300 ML/d in Reach 5 will maintain a minimum depth of 0.5 m. While the above information suggests that there will be sufficient depth for the movement of biota, it is based on limited survey data, especially for Reach 4 (examination of LIDAR data available for Reach 5 suggested that cross section data were representative for this reach (Cottingham et al. 2007)). In case cross section surveys have not captured all the variability in channel dimensions, a longitudinal survey to detect any sections hazardous to fish movement would be beneficial. It would also be prudent management to occasionally pulse the delivery of water from Goulburn Weir (i.e. above 300 ML/d). This will increase the likelihood that there is sufficient room for fish and other biota to undertake localised movements along the river, and will also contribute to biofilm dynamics at the littoral fringe. An increase in discharge from 300 – 400 ML/d in Reach 4 will increase stage height by 10 cm, and increase stage height in Reach 5 by 18 cm. Pulses must persist (e.g. for days to weeks) if they are to realise the desired change in stage height.

Overall, the proposal for a short-term reduction in winter flows to 250 ML/d can offer benefits in terms of increased flexibility in delivering flows in summer, a time when ecological risks are expected to be at their highest. Being able to deliver higher flow pulses would allow opportunities for localised movement by biota and would also increase the summer availability of shallow, slow-velocity habitats, which are considered important for species (e.g. some fish) that recruit during periods of low flow (consistent with the low flow recruitment hypothesis; Humphries et al. 1999, King 2004).

2.4.2 Invertebrates

The proposed flow regime is likely to reduce the habitat available for invertebrates. This, along with potential changes to water quality and increased sediment deposition is likely to have short-term effects on overall invertebrate community composition and abundance, although the effects on long-lived organisms such as mussels and Murray River crayfish may extend well into the future. Local extinctions of sensitive taxa are possible, but adaptations to climatic variability and variable hydrologic regimes (e.g. Boulton 2003, Brock et al. 2003) means that invertebrate populations are expected to recover in the medium term once the drought ends and inflows increase. For example, analysis of EPA data (Figure 10) suggests invertebrates respond to changes that persist for multiple years.

The group of organisms collectively known as aquatic invertebrates display a wide range of life-history strategies including such factors as:

- Longevity (mussels 50+ yrs; crayfish 10+yrs; insects and shrimps 2 yrs to 3 weeks; zooplankton weeks)
- Mobility
- Degree of dependence on the presence of water (totally obligate; amphibious; only some developmental stages aquatic)
- Drought-resistant/desiccation-resistant life forms (aestivating forms in some insects and desiccation-proof eggs amongst many micro-crustacea and rotifers) and desiccation-avoiding behaviour (burrowing by some macro-crustacea and mussels).

It follows that neither the response of invertebrates to the onset of drought nor the affect on them of its eventual duration is likely to be uniform. Despite this, a detailed assessment of the affects of drought on individual taxonomic groups is not warranted in the current situation because almost all the threats (and therefore their consequences for invertebrates) are not amenable to available management responses. In general terms the following groupings may be useful in designing a management strategy to limit damage to aquatic invertebrate communities:

1. Mobile obligate aquatic invertebrates will respond in much the same way as fish, tending to congregate in the remaining suitable habitat and subject to density-dependent forces (predation and competition for food and habitat) and unfavourable changes in water quality. Management of water quality (particularly DO, nutrients, salinity and other contaminants) and habitat diversity (e.g. refuge from predation and threatening high temperatures) are needed.
2. Adult aquatic bugs (Hemiptera) and beetles (Dytiscidae), though dependent on water, disperse aerially between suitable waterbodies (independently of drought conditions) and therefore optimise the use of available habitat and food resources.
3. Aquatic insects with non-aquatic adult stages will, to the extent possible, translocate to new habitat. Their aquatic larvae may concentrate in refuges, though this varies greatly between species. Reproducing adults will move towards suitable aquatic habitats to deposit eggs, but their numbers may also be reduced by the effects of drought in the non-aquatic environment. Survival of migrants and new recruits is determined in a similar fashion to that described for obligate aquatic invertebrates above.
4. Desiccation-resistant forms, such as micro-crustaceans and rotifers, that inhabit slack-water zones under normal conditions, produce desiccation-proof eggs. These mostly remain viable for a number of years ensuring rapid recolonisation in favourable conditions, although egg banks will decline and fewer taxa are likely to emerge if drought conditions persist (Jenkins and

> Boulton 2007)[4]. Production of resistant eggs is stimulated by triggers relating to the onset of dry conditions in many cases. Rapid draw-down may fail to provide these triggers under current conditions but, in reality, the density and condition of the current dormant egg-bank available for recovery after the current drought will have been strongly influenced by conditions over the past several years. A few insect species (some midge and beetle larvae) can aestivate in sediment in the absence of water, as can some bivalves. Some crustaceans (e.g. yabbies) can also burrow down to sub-surface water. However, few of these animals are likely to survive extended periods of drought.

The historic flow regime is already modified from natural and the change proposed for 2007/08 will not be large in relative terms. Past conditions will have been the main force in determining the resilience of the invertebrate community entering the current situation and its potential to rebound with the renewal of more substantial flows. Threats that should be avoided during 2007/08 include rapid falls in water level, excessive deposition of fine sediment (causing direct mortality to some species, suppressing food production and making other food and habitats – e.g. plant litter – unavailable), and water quality changes (e.g. that result in anoxia, concentration of contaminants, release of toxicants from the sediment and/or algal blooms).

Overall, the imposition of the proposed flow regime for one year poses little long term risk to invertebrate communities. However, drought and the proposed flow regime will pose increasing risk to invertebrate production and diversity should such conditions persist.

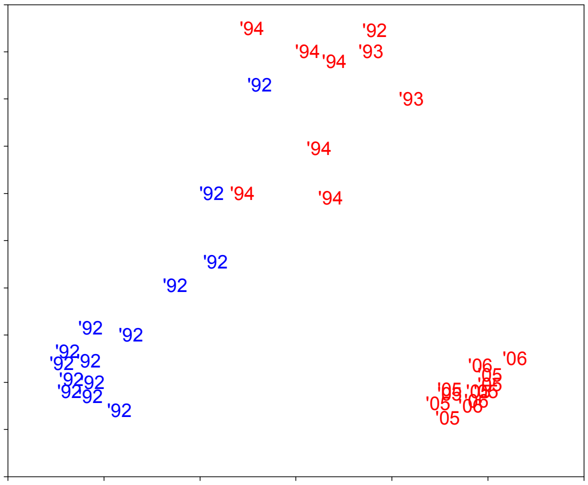

Figure 10: **MDS ordination of EPA invertebrate data. Separate grouping for 1990's data and 2000's data indicate decadal changes in community composition. Red symbols indicate data from rapid biological assessments, while blue symbols indicate data from artificial substrate assessments. (see Cottingham *et al.,* 2007 for further explanation and discussion)**

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[4] Drought-proofing is thus dependent on conditions during a number of preceding years, emphasizing the need to manage inter-annual variability in regulated rivers.

2.5 Macrophytes

For aquatic and amphibious plants, sustained low flows are likely to result in an increase in available habitat; the conditions will provide shallow depths, minimal disturbances in the form of freshes and/or being over-topped because of water level fluctuations, and adequate light and nutrients. In general, the character of the environment will move from that of a river channel with lotic characteristics to one more typical of a wetland with lentic characteristics. This means that conditions will be favourable for plants adapted to growing in wetland environments. These include species that can grow in moist or submerged soils, can maintain leaves on the water surface or above it (i.e. emergent macrophytes, floating-leafed and/or semi-floating stoloniferous macrophytes), and amphibious edge plants.

The lower average water velocity expected with a decrease in discharge may increase the rate of sediment deposition in the river channel. How this sedimentation affects the growing environment of plants is hard to predict because of the interplay of two processes:

1. Sediment deposition onto plants with submerged leaves will result in physiological stress for those species not adapted to growing under very low light; this could limit seedlings and submerged macrophytes such as Charophytes[5].
2. Sediment deposition may result in clarifying the water column, and hence promote conditions favourable for seedling emergence and re-growth from propagules.

The likelihood of an increase in macrophytes cover is hard to predict. Macrophytes are known to be present along the Goulburn River, and those present have considerable diversity in ecological strategies for survival. However, no macrophyte species appear to be abundant in Reaches 4 and 5; the reasons for this are not clear. The flow conditions proposed for 2007/08 could provide an opportunity for existing macrophytes to expand their range, or for new individuals to establish. The most likely species to take advantage of these conditions are those with wind-dispersed seeds and those with seeds and propagules carried to the river in stormwater discharge or runoff (e.g. *Azolla*). In terms of wind-dispersed seeds, one of the most likely candidates is cumbungi (*Typha* spp.), which produces several hundred thousand seeds per inflorescence that can be dispersed over a period of several months.

The consequences of plants establishing in channel depends on a range of factors, including:

- The species and growth-forms involved,
- Whether it is one patch or several,
- Whether it is a native species and if not, whether it is a species of concern.

For example, the development of small, fine, low biomass species such as Red Milfoil *Myriophyllum verrucosum* (native) will slow water flow, may affect DO concentration sufficiently to affect fish and other fauna (e.g. via respiration at night), but could provide a habitat (structure) for small fauna including

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[5] Note: the most common aquatic macrophyte observed along the river is *Vallisneria americana.* This species is known to survive quite well under prolonged conditions of very low light (Blanch et al. 1999).

macroinvertebrates. Such a species would not be disadvantaged by water level fluctuations of 10-20 cm. In addition, there are other species whose development could pose management problems. For example, low flows may provide opportunities for the growth of cumbungi (*Typha* spp., a native emergent macrophyte) across the river channel, which could result in slower water velocity and increased water loss through transpiration from leaves. Quantifying transpiration losses has been a technical challenge, with no simple rules-of-thumb yet available.

Unlike the other biota such as fish, phytoplankton and macro-invertebrates, there is currently no monitoring of in-channel macrophytes and no benchmark information against which to judge changes in response to altered flow regimes. Given the potential for ecological change, it is strongly recommended that a benchmarking of current condition be initiated and that regular monitoring is carried out. One possibility is to undertake a two-scale approach;

1. Broad scale and coarse resolution, giving information throughout Reaches 4 and 5, and could include photopoints;
2. Fine-scale mapping, associated with detailed cross-sectional surveys for hydraulic modelling done in Reaches 4 and 5.

Whatever approach is adopted, the methods employed should be documented and repeated at the end of 2007/08 in order to evaluate change over the year.

2.6 Other management issues

Other management considerations include:

- Continued disconnection of the river channel from its floodplain. Many of the issues and observations in relation to refuge pools in the river also pertain to the surviving wetlands adjacent to the river. These are important refuges for a subset of the macroinvertebrates and small-bodied fish and should be managed as potential sources of recolonisation. This means that water must be managed carefully, stock access should be managed, and efforts maintained to preserve habitat diversity and water quality.

- The congregation of fish in refugia such as pools increases the risk that recreational fishing may deplete local fish populations (fin fish and Murray cray). Monitoring of fish populations in large pools is recommended, as is the enforcement of current regulations on fishing seasons and catch limits. Should low inflows continue and populations start to decline rapidly, then actions such as reduced bag limits, establishment of ‘no go’ reaches, closed seasons, or even a complete ban on fishing may be warranted.

- Reduced food supply for waterbirds results in extreme pressure on remaining resources. Intensification of predation pressure, particularly on small-bodied fish species and macroinvertebrates, poses a significant threat to these animals, already under stress from the drought. Whilst the survival of waterbirds is an important consideration, the resultant cost to aquatic communities will be minimised if habitat complexity is maintained in the river. Important elements of this diversity include the availability of deep refuges (i.e.

deep water not put out of reach by anoxia or pollution), macrophyte cover in some shallow areas, and snags.

- Current conditions provide an opportunity to control noxious weeds, such as *Sagittaria graminea* (arrow head) and *Nymphaea mexicana* (Mexican water lily). While this is desirable, care will be required to avoid translocation of material that might propagate in other areas, or (if using chemical spays) to avoid contamination of nearby water bodies and features such as pools that serve as refugia.

- The current inflows across the MDB are the lowest on record. Should these conditions persist, there will be an increasing need to consider various management scenarios related to multiple, and often competing demands for water. It is recommended that stakeholders of the Goulburn-Broken catchment apply a formalised process of scenario analysis (e.g. foresighting, or multi-criteria analysis) to evaluate the implications of potential management options should the drought persist. This will make the rationale and trade-offs associated with decisions clear.

- Monitoring ecosystem response to the proposed flow regime will be crucial to managing risk to ecosystem assets and values. A dedicated monitoring and evaluation program should be established to monitor ecosystem attributes and variables and their response to ongoing drought in general and the proposed low flow regime in particular. Links should also be established with current Victorian Environmental Flow Monitoring & Assessment Program (VEFMAP) and its application in the Goulburn Broken basin. In addition, an investigation of the potential for saline groundwater intrusion to the river at very low flows would be valuable in terms of confirming the findings of McGuckin (1991).

- Fluctuation of water levels will be one of the few options available to managers in the event of widespread stratification of the water column, and is necessary for managing salinity, nutrient and other contaminant levels. It is recommendation that the volume of water and mode of delivery required to disrupt stratification be calculated so that an appropriate water bank can be established to manage risks such as destratification.

3 SUMMARY

The management of the lower Goulburn River in a prolonged drought is a difficult exercise. The proposed low flow regime of 300 ML/d (or less in some circumstances) poses a number of risks to the condition of the river and its associated values. Declining water quality and its effects (direct or indirect) is considered to pose the greatest risk to aquatic and riparian biota and ecosystem processes, and will require the greatest attention during the 2007/08 water year.

Overall, management of flows in summer is considered crucial to managing the risks associated with persistent low inflows to the Goulburn River. The proposal to release 250 ML/d (rather than 300 ML/d) over the winter-spring period and building a water 'bank' or 'reserve' to increase the flexibility of water releases over the summer-autumn period is considered to be prudent management, as environmental risks will be at their highest during summer. This water 'bank' should be preserved solely for managing ecosystem risks along the lower Goulburn River and should not be diverted for other purposes.

In summary:

- Highest priority should go to minimising the risk of lowered water quality, including very low DO concentration in deep pools and shallow, low-velocity areas.
- Most biota have strategies that will enable them to survive decreased habitat availability in the short term or recolonise from nearby refugia. Refugia such as pools (in the Goulburn River, its tributaries and any remaining associated wetlands) should be protected against pressures such as livestock access and water extraction.
- In the long term, although such refugia may allow the survival of individuals, for many species recruitment will be unlikely to occur. Together with further habitat loss, this poses a significant risk if the current conditions persist into future years.
- Other complementary management responses are recommended, including protection of habitat and refugia form livestock, and the control of noxious weeds.
- A dedicated monitoring and evaluation program is recommended, including benchmarking of current conditions, in order to assess the impacts of the proposed low flow regime and future recovery once conditions improve. Real-time monitoring of variables such as DO, temperature and salinity, will provide valuable information to support a timely management response should conditions in the river deteriorate (e.g. due to a rapid decline in water quality).
- The minimum summer flow of 300 ML/d is similar to the absolute minimum that has been identified as necessary to provide habitat for macroinvertebrates in a recent assessment of inter-valley transfers (Cottingham et al. 2007)[6]. However, adopting a single value has the potential to reduce low flow variability. It is recommended that opportunities to vary flow in excess of 300 ML/d be taken where possible to ensure sufficient depth for fish passage and to vary conditions for biofilm growth.

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[6] It is expected that the previous low flow recommendation of 610 ML/d (Cottingham et al. 2003) be reinstated once flows in the river recover from the current drought.

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