Trout cod in Yanco Creek: Patterns of spawning, recruitment and population status in 2017/18. Summary of Findings Report

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Cover Image: Yanco Creek at Devlins Bridge, September 2017. Image: Clayton Sharpe

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Executive Summary

In 2014, trout cod were recorded throughout the upper reaches of Yanco-Colombo Creeks, from the Yanco-Murrumbidgee offtake to ~3km downstream of Morundah. This represented an expansion of the known range for the species in the mid-Murrumbidgee River valley, the population which was recovered by a conservation restocking program throughout the 1980's and 1990's (Lintermans 2007). The presented study was commissioned by Murray Local Lands Services to investigate if in 2017/18, the trout cod population in Yanco-Colombo Creeks was being supported by fish that spawned and recruited in the system, or by the drift of larvae from spawning that occurred in the nearby Murrumbidgee River, or a combination of both. The study sampled for the occurrence of trout cod spawning by sampling for their larvae at nine sites throughout the known range of trout cod in Yanco-Colombo Creeks and at two sites in the Murrumbidgee River upstream of the Yanco Creek offtake (to examine larval drift into the system), throughout the known breeding period (September - November/December) at fortnightly intervals in 2017. A follow-up survey by boat electrofishing and fyke netting was undertaken in March 2018 to explore if age 0+ fish recruited into the population from the 2017 spawning, with the number of young fish collected informing an assessment of recruitment potential. This monitoring also enabled the structure of the Yanco-Colombo Creek fish community to be examined, with species diversity and population structures recorded. The level of spawning and subsequent patterns of young of year (YOY age 0+ years) recruitment and population structures were then considered collectively in relation to the prevailing hydrology of Yanco-Colombo Creeks, whereby the influence of flow regime in the system upon trout cod ecology and population maintenance was explored.

Despite more than 6000 hours of sampling, trout cod larvae were not recorded in Yanco-Colombo Creeks or the Murrumbidgee River and so it was considered that trout cod did not spawn in the Yanco-Colombo system in 2017. The lack of spawning in 2017 was reinforced by the complete absence of trout cod in Yanco-Colombo Creek during the March 2018 survey. The absence of larvae, juvenile and adult trout cod indicates that in 2017, the population was not supported by localised spawning and YOY recruitment; therefore, addressing the overarching aim of this study.

In 2014 it was highlighted that the prevalence of extreme fluctuations in water level and discharge and very low winter flows that occur in Yanco-Colombo Creek were likely impacting upon trout cod ecology. In 2015, environmental water managers worked to mitigate extreme water level variability throughout the spring breeding period, demonstrating that adaptive river management can mitigate the adverse hydrological conditions thought to impact upon trout cod breeding requirements in Yanco-Colombo Creeks, albeit that population level responses were not able to be monitored in that year. The present study has however identified that the unfavourable hydrological character of the system for trout cod has prevailed throughout 2016-18 and has likely continued to affect the ecology of trout cod in Yanco-Colombo Creeks. There are however numerous ecological factors that are favourable to trout cod in Yanco-Colombo Creeks such as fast flowing water and high loadings of large and complex structural habitat including undercut banks, submerged trees and branches and good riparian condition. These attributes were documented in 2014. The prevalence of these factors in Yanco-Colombo Creek adds further weight, or increasingly highlights the influence of adverse hydrological conditions upon the persistence of trout cod in Yanco-Colombo Creeks. Therefore, the major recommendation from this study is for managers of the system to mitigate the overt and persistent hydrological variation that continues to occur in the Yanco-Colombo Creeks, and to prevent very low winter flows, if trout cod recovery is a future focus. A framework for mitigating the adverse hydrological character and supporting trout cod ecology and population recovery in Yanco-Colombo Creeks is provided as a priority management recommendation.

Table of Contents

1. Introduction

In 2013, the 'Billabong Creek Fish Baselining Survey' (Sharpe et al. 2013) detected a population of the endangered trout cod (*Maccullochella macquariensis* Figure 1) in Yanco Creek, near Morundah NSW. In 2014, targeted spatial surveys found the species distributed from the Yanco Creek offtake from the Murrumbidgee River, down Yanco Creek to Tarabah Weir[1] and in the Colombo Creek from the Yanco-Colombo junction downstream to ~1km below Morundah (Sharpe and Stuart 2014).

The 2014 study determined that the population was distributed throughout more than 50km of the upper Yanco-Colombo Creeks (Figure 2). The 2014 study recommended that understanding how the population is maintained – whether it be self-sustaining from local spawning and recruitment or dependent upon immigration, either as larvae, juveniles or adults, from the adjacent Murrumbidgee River, was paramount for effective management of the population into the future. This was especially relevant to hydrological management which, because of persistent overt oscillation of water levels and discharge throughout the spawning period and low flow during winter, has been identified as having a potentially detrimental impact upon the success of spawning and annual recruitment opportunities for trout cod within the Yanco-Colombo Creek system (Sharpe and Stuart 2014).

Figure 1. Trout cod (*Maccullochella macquariensis*). Source: Fishes of Australia (G. Schmida).

[1] Trout cod were not recorded in Yanco Creek downstream of Tarabah Weir

Trout cod distribution and a conceptual understanding of their ecology.

Trout cod is listed as endangered under Australian legislation (EPBC Act 1988). Once widespread throughout the southern tributaries of the Murray and Darling rivers, trout cod are now very patchily distributed in the Murray River and some tributaries (e.g. Goulburn and Murrumbidgee Rivers) and in the Macquarie River (NSW DPI 2006; Koehn et al. 2008). Populations crashed from the late 1800's and early 1900's in line with European settlement and associated habitat degradation, changes to flow regime, overfishing, and competition with exotic species amongst the major factors (Koehn et al. 2008). Where they still occur, trout cod are associated with fast flowing water and high loadings of large and complex structural habitat including submerged rocks, undercut banks, submerged trees and branches (snags) (Koehn and Nicol 2014). Koehn and Nicol (2014) reported that loadings of snags in the order of >70% coverage of the streambed that were located within 15% of the channel width closest to the bank, together with water velocities 0.3-0.6 m/s, were the key habitat elements for trout cod.

The maximum size reported for trout cod is 850 mm and 16 kg (Lintermans 2007; Truman 2007) although much larger individuals have been reported anecdotally (~25kg Truman 2007). Sexual maturity is reached at 3-5 years and about 320 mm in length for males and 400mm for females (Lyon et al. 2012). Studies examining the timing of spawning show that breeding can occur from September - December with water temperature > 15^{o}C required for spawning to occur. Spawning is not thought to be dependent upon flow cues, with spawning being confirmed outside of and during flood periods (Kohen and Harrington 2006). Spawning in the wild has however only been known to occur in flowing water (Koehn and Harrington 2006; King et al. 2010) and therefore flowing water is an important element in their reproductive ecology.

Koehn and Harrington (2006) considered that due to the short breeding period (September - October, sometimes November), recruitment success was highly susceptible to the match/mismatch between the timing in occurrence of larvae hence timing of spawning and the availability of suitable food (principally zooplankton), with starvation of larvae or early juveniles potentially a key factor in the strength of recruitment to populations. Likewise, the success of spawning and hence recruitment success could be acutely impacted by factors affecting the ecology of spawning, with disruption to nest selection, courtship and nest guarding all potentially affected by extraordinary flow variability during the spawning period (Sharpe and Stuart 2014). Rapid drops in water level during the breeding period have been identified as having the potential to affect courtship, cause nest abandonment and ultimately affect the survival of eggs (Stuart et al 2018). These factors are all related to the overarching hydrology of perennially managed flow regimes within the systems where trout cod persist.

In irrigation systems i.e. anabranches, creeks and rivers conveying irrigation water, extraordinary water level variability is known to occur in response to irrigation demand and extraction rates, whereby, for example, irrigation demand can increase rapidly for a variety of factors, forcing wide oscillations in water level at daily and often hourly scales (Mallen-Cooper et al 2014). This may be especially pertinent for trout cod, Murray cod and other nesting species in the relatively shallow Yanco Creek which is usually <2 m deep in the upper reaches where trout cod occur (Sharpe and Stuart 2014). NSW Office of Water data shows that in upper Yanco Creek (at Yanco off take) water levels can oscillate by more than 1.2 m, or half of the overall stream depth over a few days (Sharpe and Stuart 2014, Figure 3). Furthermore, recruitment success for trout cod and other species within Yanco Creek may be further impacted during

the winter period, when traditionally irrigation demand ceases, resulting in reduced flows and extremely low water levels (Figure 3). The impacts on young fish during periods of very low water level during winter include reduced food availability and increased exposure to predation.

Aims

The overarching aim of this study was to examine if the trout cod population in Yanco-Colombo Creeks is self-sustaining by examining patterns of trout cod spawning in Yanco-Colombo Creeks, throughout the known breeding period, and to establish if subsequent recruitment of young of the year (YOY) (age 0+ years) occurs in the following year. The findings from the study of spawning and YOY recruitment patterns in Yanco-Colombo Creeks are considered in relation to water level variability in the system in the context of the potential impacts to the ecology of spawning and recruitment. Overall, this study aims to identify management options that may enhance the status of trout cod and other native fish species in the Yanco-Colombo Creek system.

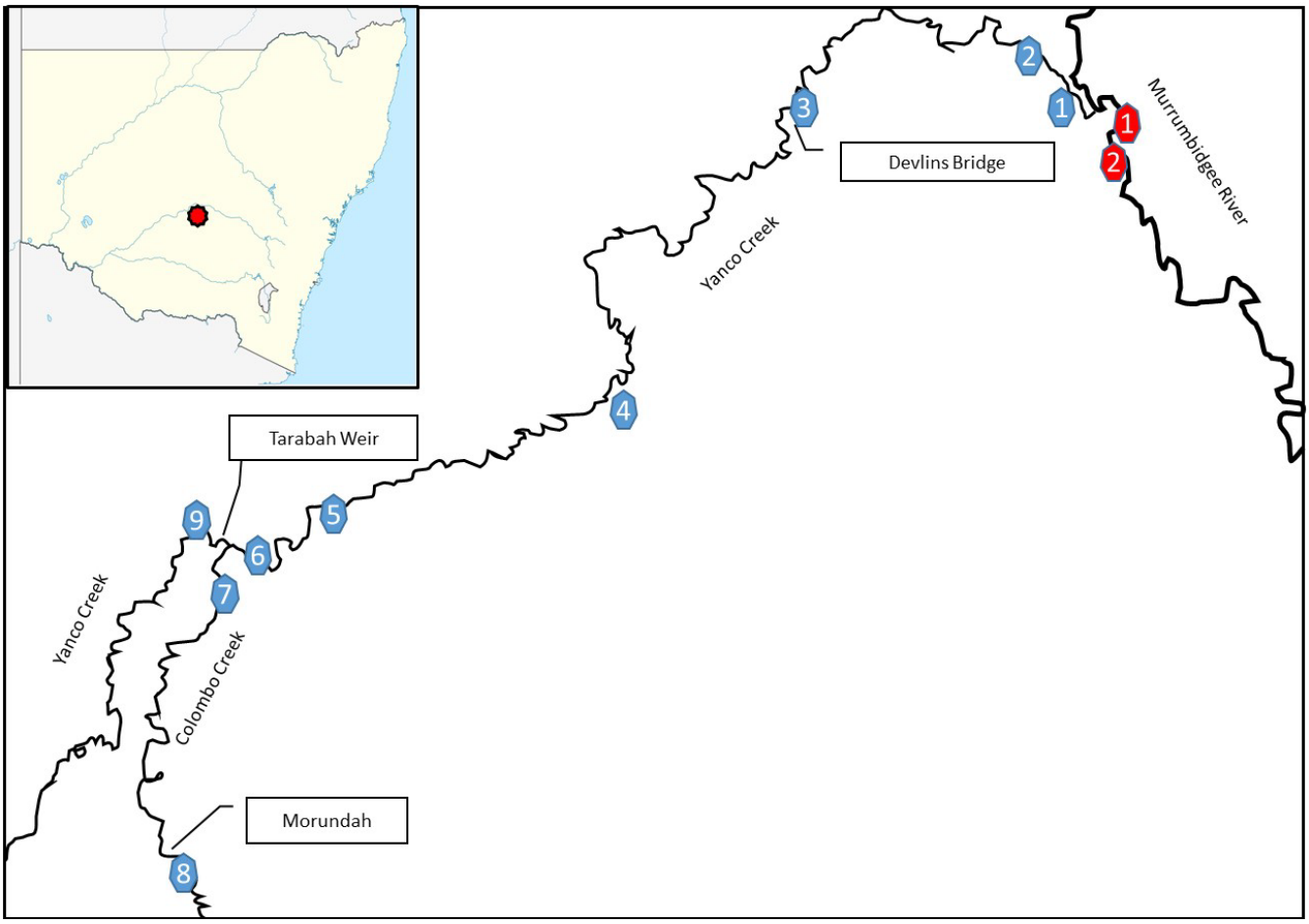

Figure 2. Study area showing sampling sites for Yanco and Colombo Creeks (blue icons) and the Murrumbidgee River (red icons) and the location of key landmarks.

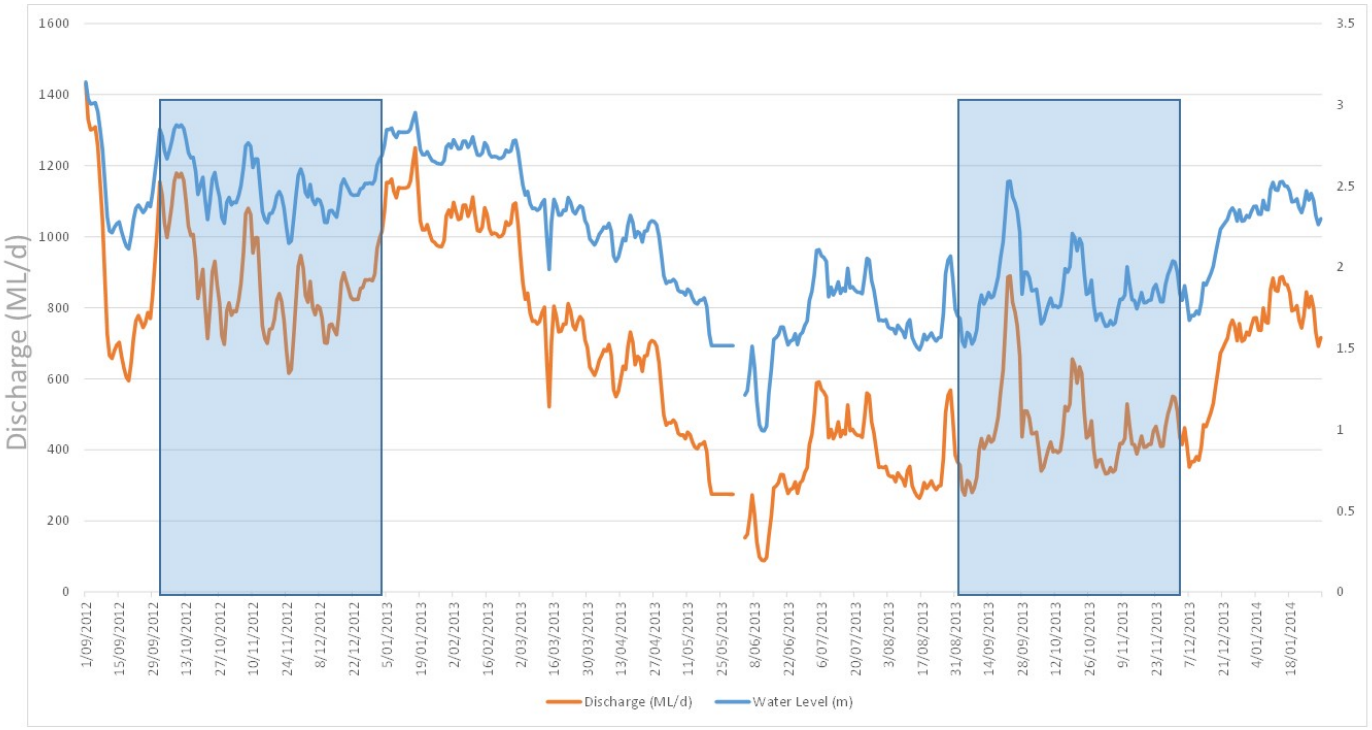

Figure 3. Average daily water level (metres) and discharge (ML/d) in upper Yanco Creek for the period September 2012 - January 2014. Note the wide oscillation in water levels during the Trout cod breeding period (highlighted in shaded area). Data source: NSW Office of Water.

2. Methods

To reiterate, the overarching aim of this study was to examine if the trout cod population in Yanco-Colombo Creeks is self-sustaining by determining if:

Spawning

- trout cod successfully spawned in Yanco-Colombo Creek in spring 2017, independently from spawning that may occur in the adjacent Murrumbidgee River.
- trout cod did not spawn in Yanco-Colombo Creek in spring 2017, but spawning occurred in the adjacent Murrumbidgee River and larvae drifted into Yanco Creek.

Addressing these questions will inform if the trout cod population in Yanco Creek is maintained by spawning that occurs within the system, or from larval drift into the system from the Murrumbidgee River, or a combination of both.

Recruitment

- YOY trout cod were present in the Yanco-Colombo Creek population during April 2018.

Addressing this question will inform if recruitment of YOY to the trout cod population in Yanco-Colombo Creeks occurred in 2018, therefore contributing to population maintenance.

2.1 Study area

The study area (Figure 2) was focused on the known distribution of trout cod in Yanco Creek; from the Yanco-Murrumbidgee offtake to 750 m downstream to Tarabah Weir (seven sites), from Tarabah Weir in Colombo Creek to ~3 km downstream of Morundah (two sites) (Figure 2) (Sharpe and Stuart 2014). In Yanco Creek, two sites were situated within the Yanco Creek offtake (Sites 1 & 2; 50 m and 200 m downstream from the offtake on the Murrumbidgee; Figure 2). A further two sites were selected in the Murrumbidgee River 200 m and 2 km upstream of the Yanco Creek offtake (Figure 2). Those sites (Yanco offtake sites 1 & 2 and Murrumbidgee River sites 1 & 2) were selected to inform the potential for larval trout cod to drift into Yanco Creek from the Murrumbidgee River.

Six (sites 1 and 3-7) of the same Yanco-Colombo Creek sites described above and the two Murrumbidgee River sites that were sampled for larvae were surveyed in March 2018 for YOY trout cod by electrofishing and fyke netting (detailed below). All sampling sites were confirmed with Murray LLS and NSW OEH project staff by field inspection during September 2017. Hydrological data for Yanco Creek offtake and Colombo Creek at Morundah was sourced from NSW Office of Water http://www.water.nsw.gov.au/realtime-data/hydro-rivers

2.2 Spatial and temporal patterns of spawning

Larval sampling at Yanco-Colombo Creeks and Murrumbidgee River sites was conducted fortnightly from 20 September - 9 December 2018, over four days / three nights per sampling event (6 sampling events). At each site, three replicates each of drift nets and light traps were deployed to catch recently spawned larvae. Drift nets were suspended just below the surface in flowing water to filter larvae drifting downstream and light traps incorporated a ‘glow stick’ to emit light to attract larvae (Figure 4).

Drift nets were 1.5 m long with an opening of 0.5 m in diameter and were constructed of 500 µm mesh that tapers into a removable reducing jar. Drift nets were suspended from snags to filter the top 0.5 m of the water column (Figure 4). Drift nets were deployed from late afternoon, left overnight and collected the following morning. Light traps were identical to those used by Humphries and Lake (2000) except that a 3.0 mm mesh was fitted across the opening to exclude small predatory fish (Figure 4) (Villizi et al. 2008). Light traps were constructed from clear Perspex®, had a removable collecting dish, and included a 24 hr yellow cyalume^{TM} light-stick (Figure 4). Light traps were set overnight within slack water littoral areas. Set and retrieve time for each net and trap was recorded, with soak times ranging from 16-22 hours.

All samples were preserved in 70% ETOH (ethanol) solution and returned to the laboratory for processing. Larval identification followed Serafini and Humphries (2004).

Figure 4. Examples of the larval nets and traps used in Yanco-Colombo Creeks in 2017. A drift net suspended from a snag (in the Darling River, main image). The contents are sieved and collected as a sample, preserved and identified in the laboratory (top right). Light traps prior to deployment showing the light emitted from glow sticks that attract fish larvae (bottom right). Three of each of these nets and traps were deployed overnight on each sampling occasion at nine sites in Yanco-Colombo Creek and two sites in the Murrumbidgee River from 20 September to 9 December 2017. Images: C. Sharpe

2.3. Trout cod population census and recruitment

Fish surveys targeting YOY trout cod spawned in 2017 were undertaken in Yanco-Colombo Creeks at seven of the same sites as for larval sampling (Figure 2), with Yanco Creek downstream of Tarabah

Weir not sampled due to lack of boat access (site 9) and likewise only one site at Yanco Offtake (Yanco Creek site 1) was surveyed (Figure 2). Data collected from the YOY survey enabled evaluation of the level of recruitment to the trout cod population from the 2017 spawning season and the structure of the Yanco-Colombo Creek fish community to be examined, from which a census, or current condition of fish populations (population profiles) could be explored.

Sampling for the fish community survey was conducted from 19 - 23 March 2018 using boat mounted electrofishing following Sustainable Rivers Audit (Davies et al. 2010) protocols at each survey site (12 x 90 sec electrofishing shots/site for a total of 18 minutes) and deployment of 4 x large meshed and 4 x small meshed fyke nets at each survey site. All nets were set in the afternoon and retrieved the following morning with set and retrieval time recorded. Large fyke nets had a central wing (8 m x 0.65 m) attached to the first supporting hoop (= 0.55 m) with a mesh entry (0.32 m, stretched) and a stretched mesh size of 28 mm. Small fyke nets had a stretched mesh size of 2 mm, dual wings (each 2.5 m x 1.2 m), with a first supporting hoop (= 0.4 m) fitted with a square entry (0.15 m x 0.15 m) covered by a plastic grid with rigid square openings (0.05 m x 0.05 m). All fish were identified following McDowall (1996) and Lintermans (2007). The native carp gudgeons were identified to genus level only (i.e. *Hypseleotris* spp.). Large-bodied fish species were measured for standard total length (TL) (nearest 1.0 mm) and released. Small-bodied species were counted and released immediately to minimise handling stress.

3. Results

3.1 Hydrology

Flow (ML/d) and water level (m) gauged at Yanco Creek offtake for the period 1 January 2017 - 30 April 2018, encompassing the 2017 spawning period and period of YOY recruitment is shown in Figure 5 and for Colombo Creek at Morundah in Figure 6.

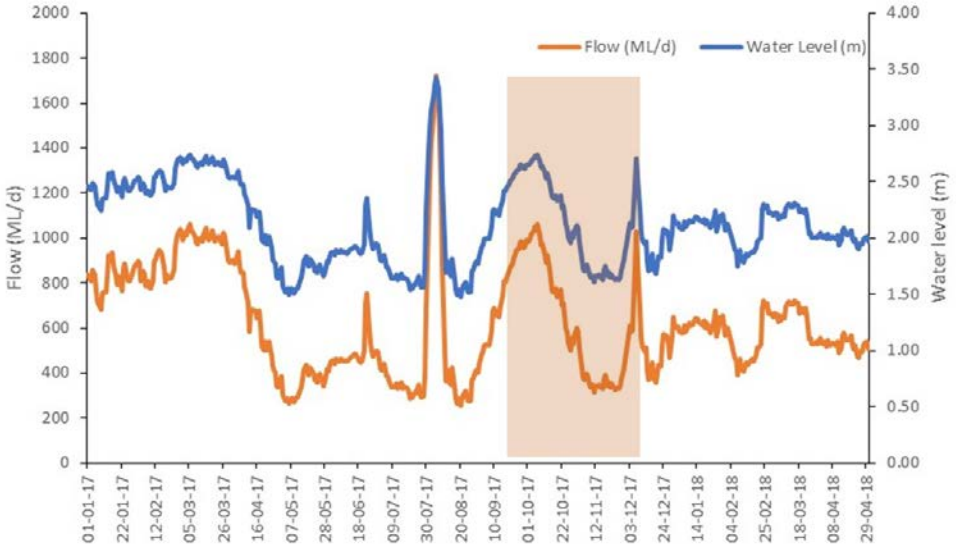

Figure 5. Flow (discharge ML/d) and water level (m) in Yanco Creek at the offtake from the Murrumbidgee River for the period 1 January 2017 to 30 April 2018. The period of sampling for trout cod larvae (20 September - 9 December 2017) is shaded.

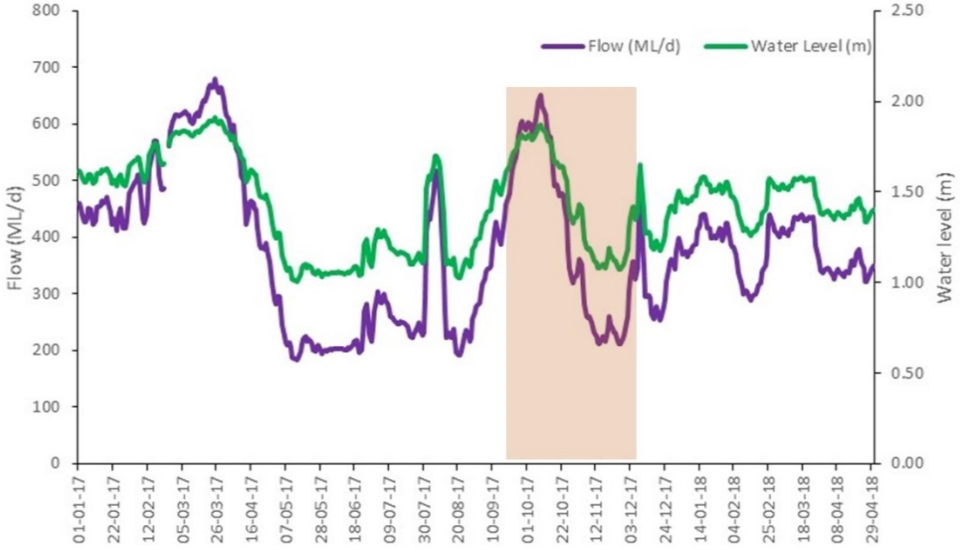

Figure 6. Flow (discharge ML/d) and water level (m) in Colombo Creek at Morundah for the period 1 January 2017 to 30 April 2018. The period of sampling for trout cod larvae (20 September - 9 December 2017) is shaded.

At Yanco Offtake, flow (ML/d) and water level (m) exhibited rapid increases and decreases throughout the trout cod spawning season (September - November) and the period of larval sampling, ranging from 316 ML/d to 1059 ML/d and 1.4 m to 3.4 m, respectively (Figure 5). A similar pattern of discharge and water level variability was observed for the stream gauge in Colombo Creek at Morundah (Figure 6). During the trout cod breeding period (September - November) there were three distinct flow peaks that rapidly increased and likewise rapidly decreased in both discharge and water level and these occurred during the larval sampling period (Figure 5). A flow pulse that peaked on 7 October 2017 forced water levels at the Yanco Offtake gauge to fluctuate by more than 1.3 m, or more than half of the average stream depth at the site (mean stream depth = 2.12 m; Sharpe and Stuart 2014). At Morundah, the magnitude of variation was somewhat less dramatic, with water level fluctuating 0.82 m during the same period (Figure 6). Overall, the most apparent hydrological features at both sites during the period of larval sampling and hence the breeding period for trout cod in Yanco-Colombo Creeks was wide and rapid variation in discharge and water levels (Figure 5). Furthermore, there were numerous instances when water level at Yanco Offtake decreased by more than 150 mm within 24-hour periods across the three flow oscillation events during the period of larval sampling (Figure 5).

3.2 Patterns of trout cod spawning in Yanco-Colombo Creeks

Trout cod larvae were not collected in Yanco-Colombo Creek despite a combined sampling effort of 6024.6 hours for drift net (DN) and light trapping (LT) combined across the nine sampling sites and six sampling events from September - December 2017 (Table 1).

Table 1. Sampling hours for 3 x drift net and 3 x light traps set at each Yanco-Colombo Creek sampling site per sampling event from September - December 2017.

SITE	TRIP 1	TRIP 2	TRIP 3	TRIP 4	TRIP 5	TRIP 6	TOTAL Hrs
1	19	17	15	17	16.5	19	
2	18.5	17	16	19	19	19.5	
3	17.5	18	16.6	14.5	19	18.5	
4	17	19	18.5	19	19.5	19	
5	19.5	19.5	20	19.5	18	19	
6	15	17	15.5	19	19.5	21	
7	15.5	18.5	19	21	19.5	19.5	
8	17.5	19	21.5	20	22	19.5	
9	17	18.5	21.5	22	19.5	22	
Hrs/Trip LT	469.5	490.5	490.8	513	517.5	531	3012.3
Hrs/Trip DN	469.5	490.5	490.8	513	517.5	531	3012.3
Hrs TOTAL/Trip	939	981	981.6	1026	1035	1062	6024.6

3.3 Patterns of spawning amongst the Yanco-Colombo fish community

The overall abundance for all larvae sampled across all sites and sampling events in Yanco-Colombo Creek was extraordinarily low, with only 24 larvae collected for the entire study (Table 2). Likewise, species diversity amongst larvae collected was low, with only four species collected (Table 2). The

number of larvae collected per netting hour was 0.0039. Because of the low number of larvae collected, larval data is presented as raw abundance per sampling site and sampling event relative to soak time.

Murray cod were the most abundant species collected as larvae (n = 12), all of which were classified as metalarvae (size range 10.0 - 12.0 mm total length). Australian smelt were the next most abundant species, albeit that only six individuals were collected (Table 2). There were no fish larvae collected at either of the Murrumbidgee River sites for the entire sampling period. Notably, only three carp gudgeon larvae and two carp larvae were collected.

Table 2. Raw abundance of fish larvae collected in Yanco-Colombo Creek for each of six sampling events from September - December 2017.

TRIP	Trout cod	Murray cod	Australian smelt	Carp gudgeon	Carp	unidentified
1	0	0	0	1	0	0
2	0	0	0	0	1	0
3	0	2	0	1	1	0
4	0	4	2	1	0	1
5	0	6	4	0	0	0
6	0	0	0	0	0	0

3.4 Population census to evaluate trout cod recruitment responses from spawning in 2017.

Trout cod were not collected in Yanco-Colombo Creek, either as adults, juveniles or YOY from 108 minutes of electrofishing and 816 hours of fyke netting across the seven sites surveyed over five days during March 2018. In the Murrumbidgee River, there was one juvenile sized trout cod (210 mm total length) collected by boat electrofishing. The lack of trout cod in Yanco-Colombo Creeks indicates that the population, if present, occurred at undetectable levels at the time of the March 2018 sampling. This contrasted with the most recent survey of the population in 2014, when 20 individuals were captured (Sharpe and Stuart 2013). The dramatic decline in the occurrence of the population across the range of sites where the species was previously recorded within Yanco-Colombo Creek indicates that sub-optimal conditions for the species persistence, let alone recruitment within the system, are occurring.

3.5 Fish community structure in Yanco-Colombo Creeks

A total of nine fish species (five native and four exotic) were collected across the seven Yanco-Colombo Creek survey sites. Among these only 35 individual native and 64 exotic fish were sampled (Table 3). Carp were the most abundant species collected overall (n = 40), followed by eastern gambusia (n = 26) (Table 3). Remarkably, Murray cod were the most abundant native fish species collected (15 individuals; Table 3) while only one golden perch was recorded (510 mm total length). Even more remarkable was the extremely low diversity and abundance of small bodied native fish species recorded in Yanco-Colombo Creeks, especially for species that are normally ubiquitously abundant, such as carp gudgeon and Australian smelt (Table 3). The very low species diversity and extremely low overall abundance amongst species is alarming and warrants immediate management consideration.

Table 3. Total number and community structure for fish in Yanco-Colombo Creeks sampled at six sites by boat electrofishing and fyke netting during March 2018. Collection records are highlighted. *NB Yanco Creek Sites 2 and 9 were not surveyed. Site 2 was immediately adjacent (150m) to site 1; site 9 was inaccessible at the time of sampling.

Site	Murray cod	Golden perch	Carp gudgeon	Australian smelt	Rainbow fish	Common carp	Eastern gambusia	Goldfish	Weatherloach	Redfin	Total NATIVE	Total EXOTIC	GRAND TOTAL
1	5	0	0	0	0	6	0	0	0	0	5	6	11
3	6	0	5	0	2	14	1	0	0	0	13	15	28
4	2		4	1	4	5	5	0	0	0	11	10	21
5	1	0	0	0	1	6	0	0	0	1	2	7	9
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	1	1	1	0	1	14	0	0	0	3	15	18
8	1	0	0	0	0	8	6	0	2	1	1	17	18
TOTAL	**15**	**1**	**10**	**2**	**7**	**40**	**26**	**0**	**2**	**2**	**35**	**64**	**105**

3.6 Population structures in Yanco-Colombo Creeks: Key points

The structure of the carp population in Yanco-Colombo Creeks consisted of a few YOY sized individuals < 100 mm fork length (n = 2) and the remainder (n = 38) of adult sized fish (>300 mm fork length) (Figure 7). With exception of individuals 200 - 300 mm fork length being absent, the remainder of size classes were present, and the population structure reflected a regular pattern of recruitment (Figure 7).

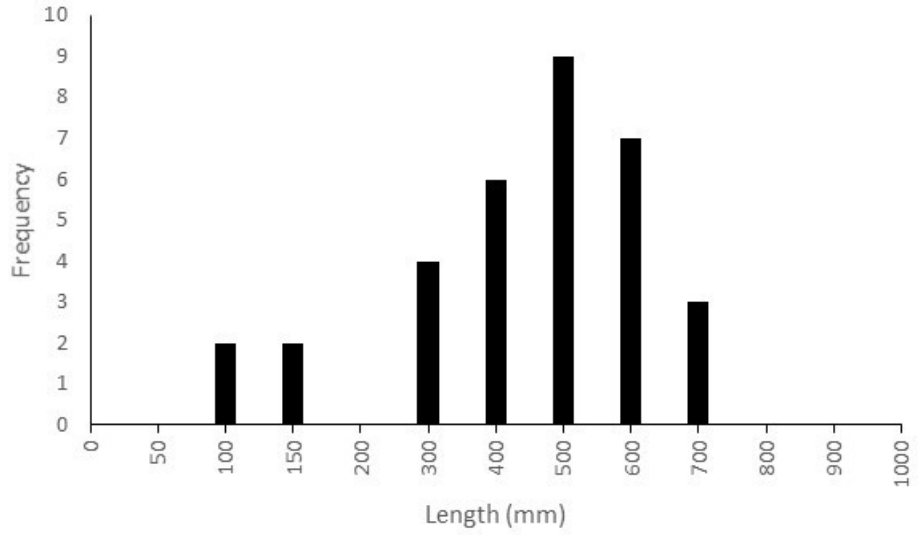

Figure 7. Length-Frequency distribution for carp sampled by boat electrofishing and fyke netting at seven sites in Yanco-Colombo Creeks during March 2018.

The Yanco-Colombo Murray cod population structure consisted of juvenile and adult sized individuals (Figure 8). YOY sized individuals (< 100 mm total length) were not collected. For the population structure overall, there were only a few individuals collected for each size class recorded and abundance was overall low (Table 3, Figure 8). The most abundant size classes were those within 200-300 and 300-400 mm classes (Figure 8). Individuals > 500 mm total length, or those greater than the minimum size at maturity recorded for Murray cod (Lyon et al. 2012), were considerably less abundant, with only 5 adult sized fish > 500 mm collected. The remainder of large bodied species, both native and exotic, were captured only as a few individuals and so the development of population profiles was not warranted (Table 3).

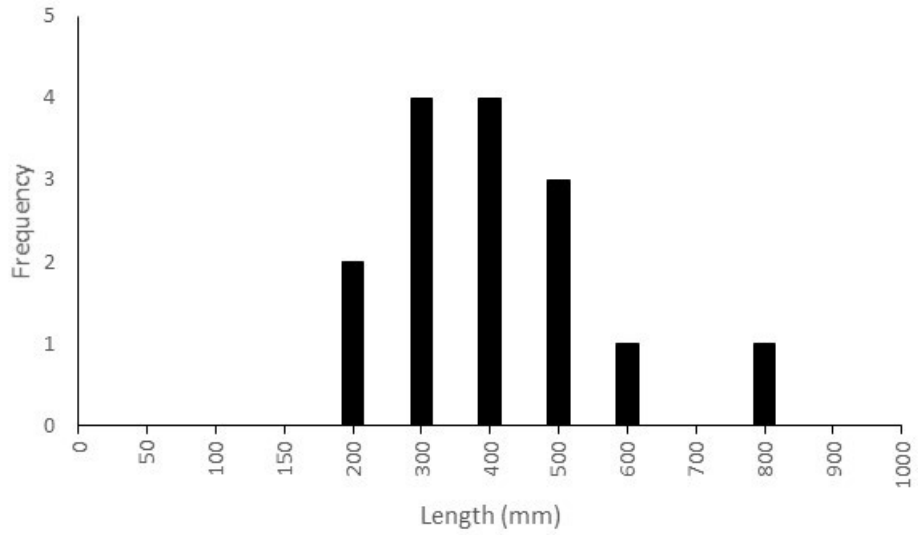

Figure 8. Length-Frequency distribution for Murray cod sampled by boat electrofishing and fyke netting at seven sites in Yanco-Colombo Creeks during March 2018.

4. Discussion

4.1 Hydrology and trout cod ecology in Yanco-Colombo Creeks

The absence of trout cod in Yanco-Colombo Creeks in 2018 represents a marked decline from surveys undertaken in 2014 by Sharpe and Stuart (2014), who recorded twenty trout cod in Yanco-Colombo Creeks, across a range of size classes, including juveniles and adults. The absence of larvae, juvenile and adult trout cod indicates that the population is currently not self-sustaining; therefore, addressing the overarching aim of this study. The reasons why trout cod abundance has declined to zero detectability in Yanco-Colombo Creek are beyond the scope of this study. However, in 2014 Sharpe and Stuart (2014) highlighted that without management intervention to mitigate the prevalence of adverse hydrological conditions, that the long-term sustainability of the Yanco-Colombo Creek trout cod population could be compromised, which by 2018 appears to have occurred. This is explored in more detail below.

Sharpe and Stuart (2014) identified extreme, irregular but persistent fluctuation in water levels as a major factor affecting the status of trout cod in Yanco-Colombo Creeks. They reported that water levels regularly fluctuated by more than half of the channel depth at Yanco Creek during the two-year period prior to their 2014 study. This feature of the Yanco-Colombo Creek hydrology continued to prevail and was persistent during the present study period. The oscillation in water level overserved during the present study reflected that described in 2014 by Sharpe and Stuart (2014) whereby extreme water level variation, every 10-14 days, by up to half of the channel depth, was persistent during the 2017 trout cod breeding period (September - December 2017). This coincided with trout cod spawning not being recorded within the system in 2017, albeit that the absence of trout cod larvae in Yanco-Colombo Creek from sampling during the 2017 breeding season and subsequently lack of young of year (YOY) recruitment during the March 2018 survey also reflects the absence of adults, as was determined by the March 2018 population census.

In their detailed assessment of habitat quality in Yanco-Colombo Creeks, Sharpe and Stuart (2014) described habitat characteristics that were favorable for trout cod, in particular moderate to fast flowing water; high hydrodynamic diversity including fast and slow flowing areas; moderate-high snag density (20 - 50 % channel cover); high snag complexity (multiple limbs, trunks and complete trees including rootballs) and good-very good riparian condition (18 - 40 m wide, minimal human/agricultural impacts). The prevalence of these factors in Yanco-Colombo Creek adds further weight, or increasingly isolates the influence of adverse hydrological conditions upon the persistence of trout cod in Yanco-Colombo Creeks. Therefore, the major recommendation from this study is for managers of the system to mitigate the overt and persistent hydrological variation that continues to occur in the Yanco-Colombo Creeks if trout cod recovery can occur.

4.2 Restoring trout cod in Yanco-Colombo Creeks; hydrological intervention

As described above, there are numerous ecological factors favourable to trout cod in Yanco-Colombo Creeks, and adverse hydrological patterns, rather than other factors, have been implicated in their decline. Hydrological intervention, in particular, mitigating overt hydrological (water level) variability and restoring over-winter flow has been recommended for the maintenance, and now recovery of trout cod in Yanco-Colombo Creeks (Sharpe and Stuart 2014).

Central to understanding how adverse hydrology affects the persistence of trout cod within the system is the conceptualisation, or a conceptual model of trout cod life history ecology and the hydrological requirements of the species. From this understanding the hydrological requirements of the species can be identified, examined against the prevailing hydrology and adverse characteristics identified and managed. A conceptual model of trout cod life history ecology is summarised in Table 4, below.

Table 4. A conceptual model of trout cod life history ecology, flow and habitat requirements in the southern, regulated Murray-Darling Basin.

HABITAT

- In the temperate reaches of northern Victoria and southern NSW (Murrumbidgee River, Murray River) trout cod spawn in September - October and sometimes November each year (Koehn et al 2008).
- Trout cod occupy **flowing reaches** of rivers and creeks with **hydraulic complexity/diversity and snags** and water velocity 0.3-0.6 m/s (Nicol et al. 2007).
- Trout cod spawn and recruit in flowing water **during stable flows**, **rising flows** and **floods** (Koehn and Harrington 2006).
- Trout cod eggs and larvae require a constant flow and very little daily variations in water level (<0.1 m) to maximise spawning success (i.e. avoid nest abandonment)

RECRUITMENT

- There is high mortality of young fish but those that survive their first summer and winter and grow to 90-140 mm long recruit into the sub-adult population (<250 mm) (Lyon et al. 2012).
- Maturity occurs at 3-5 years for males and females respectively and the species is long-lived (>16 years) (Lyon et al. 2012; Lintermans 2007)
- Females have relatively low egg numbers (mean fecundity) (Ingram and Rimmer 1993).

SPAWNING

- Trout cod are a nesting species and like Murray cod, spawn eggs onto hard surfaces such as snags in Yanco Creek
- Trout cod spawning occurs September - October/November each year (Koehn and Harrington 2006).
- Trout cod display complex pre-spawning courtship behaviour (Ingram and Rimmer 1993).
- Males guard nests (Koehn and Harrington 2006).

CONNECTIVITY

- Trout cod rarely move from a home site and spawning occurs in resident areas (Koehn and Nicol 2007).
- Juvenile and adult fish move less than 10m from home sites (Koehn and Nicol 2007).

In consideration of the life-history ecology of trout cod and mitigating adverse hydrological conditions that affect spawning and recruitment there are four main objectives:

1. Maintaining access and residency to optimal home and nesting sites (snags).
2. Restoring a perennial hydrograph, with higher winter flows and ‘stable’ spring/summer flows to maintain home sites for juveniles and adults, spawning sites and nursery areas for YOY.
3. Optimising hydrodynamic complexity throughout the creek.
4. Avoiding wide/broad oscillations in water levels and discharge rates, especially during the breeding period (August-December) so that nesting and spawning success is maximised and access to littoral habitats for larvae and YOY to shelter and feed during the nursery period (November – March).

These interventions are conceptualised against the actual 2017-18 Yanco Creek hydrograph in Figure 9.

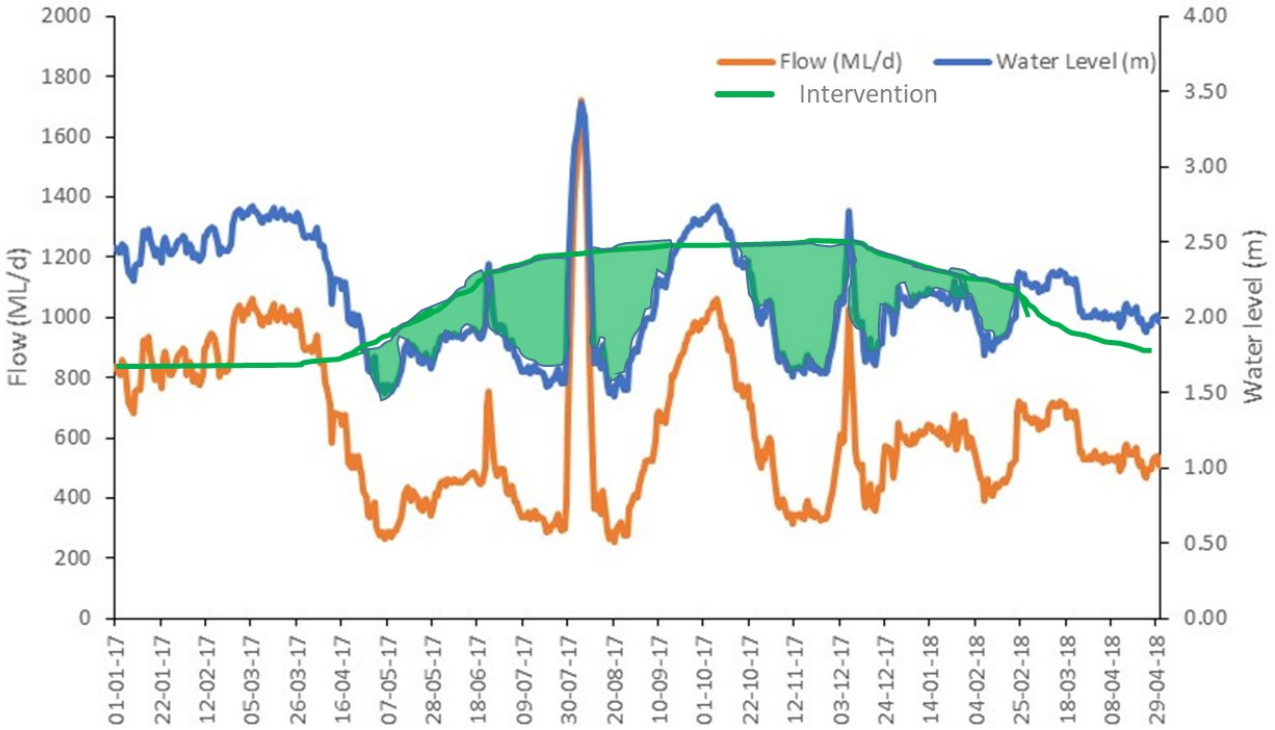

Figure 9. Flow (discharge ML/d) and water level (m) in Yanco Creek at the offtake from the Murrumbidgee River for the period 1 January 2017 to 30 April 2018. The recommended intervention in the hydrological character of Yanco Creek to optimise conditions for trout cod spawning and recruitment is represented by the green line and green shaded areas. Discharge is given in relation to water level for operational considerations.

It is acknowledged that restoring a perennial trout cod hydrograph may not currently be possible with the existing management of the system and constraints on flows. Initially aiming for a trout cod hydrograph a minimum of every three years, and annual wherever possible, is recommended.

For Yanco-Colombo Creeks, an effective way to represent the required changes to hydrology to support fish ecology is provided as a template in Table 5.

Table 5. A template for an annual hydrograph for Yanco-Colombo creeks, gauged at Yanco offtake, to support trout cod life history ecology, spawning and recruitment requirements. Application of the hydrograph annually would provide the best outcome for trout cod, however the frequencies provided in the table show more achievable e-water allocation frequencies.

Timing	Flow component	Volume ML/d	Frequency	Duration	Hydrodynamic objective	Ecological objective
1 May - 31 July	Autumn/winter baseflow	300-400ML/d	Annual 3-4 years	3 months	• Permanent flowing water • Maximise hydrodynamic complexity • Average channel velocity: >0.3 m/s	• Provide permanent base hydraulic flow and physical habitat conditions for Murray cod over-wintering • Enable mature fish to move to spawning habitat • Enhance YOY / juvenile survival
1 August - 31 October	Ramp up flow to bank full and steady peak	600 ML/d	2-3 years	3 months	• Maximise hydrodynamic complexity • Inundate benches and snags • Mean channel velocity: >0.4 m/s	• Post winter rise to initiate Murray cod egg maturation • Cue for fish to move to spawning habitat, court and mate • Initiate littoral production processes
1 November - 15 December	Hold steady bank full flow	1000 ML/d	Annual to Bi-annually	2.5 months	• Inundate benches and snags • Minimise hydraulic disturbance •Maximise hydrodynamic complexity •Tolerance: water level drop never exceeds >0.10 m/24h •Mean channel velocity: >0.3 m/s	• Enable males to guard nests and larvae to successfully hatch • Larvae/YOY to move to littoral areas and feed
15 December - 1 March	Return to normal operations but without strong daily fluctuation	800 ML/d	2-3 years	3.5 months	•Inundate benches and snags •Inundate littoral zone •Gradual drawdown (no water level drops >0.20 m/24h) •Average channel velocity: >0.3 m/s	•Larvae/YOY to feed and move to littoral areas •Maximise YOY survival •Maximise hydrodynamic complexity

4.3 Recommendations

The major recommendation from this study is to restore a flow regime to Yanco-Colombo Creek that supports trout cod ecology, by mitigating extreme discharge and water level variability that has persistently occurred, by following the template outline in Table 5, which was conceptualised in Figure 9. The key elements of the hydrograph for trout cod in Yanco-Colombo Creek are:

- High spring flow e.g. 1000 ML/d with low variation in water level <0.1 m / 24 hours and not exceeding 0.3 m for the period August-October
- High summer/autumn flow e.g. 8000 ML/d
- Moderate winter flow e.g. 600 ML/d

A second recommendation is for fish community surveys (monitoring) to be undertaken during March/April 2019 to confirm the occurrence or continued absence of trout cod in the Yanco-Colombo Creek system. Upon application of the optimised hydrograph presented here, annual monitoring of the Yanco-Colombo Creek fish community is required to evaluate progress toward its recovery, in particular for trout cod population recovery. Annual monitoring would inform the adaptive management of the Yanco-Colombo Creek hydrograph to maximise outcomes for the entire fish community.

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