Fish Passage and Carp Control at Yatco Lagoon

A report for Loxton to Bookpurnong

Local Action Planning Committee Inc

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KINGFISHER RESEARCH

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Cover photo: Craig Ferber (LBLAP)

Summary

Yatco Lagoon is a shallow wetland adjacent to the Murray River approximately 454 km from the Murray mouth. The Yatco Wetland Landcare Group, including local landowners, irrigators, community members from Yatco township, local industries and NRM groups contracted MainStream Environmental Consulting Pty Ltd to develop a wetland management plan. Included was a detailed hydrological management (wetting and drying) regime. The objective of the present report was to inspect the existing regulators, their location, design and seasonal operation (including wetting and drying) to:

- maximise native fish populations,
- reduce carp populations.

The exchange of fish between river and floodplain is important in maintaining native fish biodiversity within the wetland. Lateral movement of fish into Yatco Lagoon is important to access the diversity of habitat offered by floodplains with heightened survival, feeding and reproduction opportunities. Naturally, exit of fish from Yatco Lagoon back to the Murray River usually occurs as flows recede and ensures that fish escape stranding. During a managed inundation, weir pool raising/lowering, or drying event careful management of regulators, or fishways, is required to enhance fish passage and reduce the risk of fish stranding.

Investigations to date indicate that Yatco Lagoon supports at least 11 fish species, including 8 native and 3 non-native. Studies undertaken elsewhere indicate that migration onto floodplains is stimulated by warm water temperatures in spring and hydrological management should be tailored to allow movement at this time. Water levels in Yatco Lagoon are regulated primarily by river level and connected to the main channel by a series of culverts. For fish to pass through these culverts between habitats, there needs to be sufficient depth, light, space, low water velocities and turbulence and hence limit any behavioural or physical impediments to movement.

Existing culverts

To maximise fish passage at the main embankment, box culvert regulator, minor modifications are recommended. These include:

- installing side baffle units
- addition of rocks to the bottom of the culverts to add roughness.

Operationally, the embankment culverts should be *free-flowing* with the gates *fully open* and all stoplogs removed. Under these conditions, when the wetland is filling from a dry

state, the culverts can potentially pass fish (upstream and downstream) particularly if the lagoon height is at Lock 3 pool level. If the culvert stoplogs or gates are not fully removed a remaining headloss is likely and this might limit fish passage. Furthermore, wind seiche (a standing wave in an enclosed waterway) can also cause a significant headloss through the culverts which might limit fish passage but be less detectable for visual observation.

Studies elsewhere, indicate that pipe culverts present a particular problem for fish passage. Those pipe culverts at the northern river-lagoon connector and the north-south connector are unlikely to pass the full range of fish species over a broad range of lagoon heights due to the design but also due to their construction and location within the wetland banks relative to the wetland bed and pool water height. Fish passage is likely to be impeded by high laminar water velocities, (expected during re-filling events) and tunnel effects (some fish are reluctant to enter very dark areas).

Hence, pipe culverts are a considerable risk to effective fish passage. To provide some baseline data on these effects, the pipe headloss (difference between upstream and downstream water levels), the potential for perching and fish accumulations might be monitored during the present (March 2009) re-filling event. I then recommend replacement of the pipes with best-practice optimised box culverts and a vertical-slot fishway. These fishways are primarily aimed to facilitate passage of fish from Yatco Lagoon to the Murray River during a drying event. The fish passage infrastructure to correspond to different hydrological events and different management scenarios are summarised in Table I below.

New culverts

Presented herein are a series of generic hydrological fish passage objectives for Yatco Lagoon: 1) filling, 2) steady, 3) falling and 4) flooding (or weir pool raising). Each of these hydrological events is addressed specifically in terms of providing effective fish passage.

The practical options and locations for two more regulators in the earthen bank and up to three additional regulators in the causeway area are scoped for implementation in this report. These regulators are mainly aimed at increasing fish passage opportunities. A specific engineering study is required to investigate whether the increase in cross-sectional area is adequate to pass flood flows. Three key options for providing best-practice fish passage options are presented:

1) High flow (or raised weir pool) stepped multiple culverts (EL 10.0 - 10.6 m),
2) Vertical-slot fishways for normal operations (EL 9.5 - 10.0 m), and
3) Optimised box culverts for all operating conditions.

During the present re-wetting event (March 2009) there is an opportunity to inspect water flows and fish accumulations (during a rise and fall in water levels within the wetland) to identify appropriate locations for regulators and fishways and assess any implications existing culverts have on the fish community attempting to enter.

Carp control

A significant aspect of improving the functioning of wetlands in the Lower Murray is managing carp populations and their impacts on water quality and submerged aquatic vegetation. At Yatco wetland, this has initially focused on hydrological manipulation and implementation of exclusion screens at the main earthen regulator to prevent carp accessing the wetland. No provision for carp exclusion has been made to the other regulators.

At Yatco Lagoon, carp screens and traps should be used at low to moderate flows. To prevent negative effects on native fish passage and movement between the wetland and river channel, they should be removed prior to high flows. These techniques need to be applied in an adaptive manner to minimise the impact on native fish - that is, applied in conjunction with ongoing monitoring and assessment. It is also important to note that these methods are for *controlling* adult carp abundance and their impacts not for *eradication*.

The three main strategies to achieve the listed objectives of the wetland management plan and manage carp populations comprise:

i) screens to exclude adult and sub-adult carp,
ii) the introduction of a wetting and drying regime, and
iii) harvest or destruction of carp accumulations.

Carp control screens and cages are most effective when integrated with the planned complete lagoon drying events. These aspects are covered in detail in the report.

Monitoring and maintenance

A key recommendation to improving fish passage in culverts is monitoring and adaptive management in response. A monitoring program should include:

i) Twice weekly measurements of headloss and depth at the regulators over the lagoon filling, steady state, and draining cycle.
ii) Observations of debris loads, depths and fish accumulations for future regulator/fishway sites (frequency) to optimise designs
iii) Integration of the monitoring with daily fishway and regulator operations.

Conclusion

Re-connection of Yatco Lagoon with the River Murray along with natural wetland wetting and drying cycles is part of a balanced river ecosystem. The present culverts at Yatco Lagoon are insufficient for providing fish passage. In addition, the existing carp screens are also inefficient. Fish passage from the river to the lagoon and carp control can be enhanced by designing and installing best-practice culverts, fishways and carp screens with consideration of the site hydrology and the biology of native and non-native fish. The fishways should facilitate passage of fish from Yatco Lagoon to the Murray River during a drying event. Restoration of native fish communities at Yatco Lagoon can then become a leading example of community driven actions toward the sustainability of river-floodplain ecosystems.

Major Recommendations

Earthen bank

1. Installation of a triple stepped culvert design for fish passage between EL 10.0 - 10.6.
2. Installation of a vertical-slot fishway within a box culvert for fish passage from Yatco Lagoon to the Murray River between EL 9.5 – 10.0. The fishway would operate at the initial stage of a wetland drying event by passing small amounts of trickle flow to attract fish and enable passage back to the Murray River.
3. For the existing and any new or additional box culverts (for pool level flows EL 9.5 – 10.0) to increase hydraulic capacity - optimisation (side baffles and rocks) to provide improved fish passage.
4. Installation of new carp control screens.

Causeway

1. Removal of the existing pipe regulators
2. Installation of a vertical-slot fishway between the main river connection and Yatco Lagoon to promote fish passage, particularly during a drying lagoon event
3. Installation of optimised box culverts between the main river connection and Yatco Lagoon to promote fish passage
4. Installation of optimised box culverts between the North and South lagoons to promote fish exchange.
5. Installation of new carp control screens.

Table I. Summary of fish passage and different management scenarios for facilitating fish passage at Yatco Lagoon during a range of hydrolgical conditions.

Fishway Type	Head differential	Water level	Biological Efficiency	Management scenario
Optimised culverts	Steady state (EL 9.9 m) and 0.1 m head difference (whenever river is up to +0.1 m)	Flooding	N/A	
		Normal operations	✓✓✓	Fish migration from drying lagoon to river in early summer
		Weir pool manipulations	✓✓	Fish migration during falling lagoon conditions (summer)
Fishway	Steady state (EL 9.9 m) and 0.5 m head difference (lagoon height EL 9.5-10.0 m)	Flooding	✓	Provide low fish passage functionality during flooding
		Normal operations	✓✓✓	Facilitate trickle flow fish migration during filling, steady state and drying (spring-summer)
		Weir pool manipulations	✓✓✓	Facilitate fish migration from lagoon to river during drying event
Stepped culverts	Flood flows (EL 10.0-10.6)	Flooding	✓✓✓	Facilitate bi-directional fish migration during elevated flow conditions
		Normal operations	N/A	Not used
		Weir pool manipulations	✓	Potential for use during high weir pool (>EL 10.0 m)

1. Contents

2. Introduction

Yatco Lagoon is a shallow wetland alongside the Murray River approximately 454 km from the mouth. There are two lagoons with a total area of 346 ha and these are separated by a causeway. The lagoons have regulating structures at to control flow and culverts through each system to enable road access. The major connection to the adjacent Murray River is near the town of Moorook and the lagoon has been permanently inundated since construction of Lock 3, at Overland Corner, in 1925.

Local irrigators with support from a number of local industries and NRM groups have developed a wetland management plan which includes a detailed wetting and drying plan. In addition, the irrigation pumps have been relocated to the Murray River and Yatco Lagoon now performs an important function within regional water savings initiatives (Gippel 2007; DLWBC 2008). Native fish are part of balanced wetland systems and providing fish passage is a major step in rehabilitating fish populations in the Yatco area.

2.1 Background and Objectives

On 25 February 2009, representatives from the Yatco Wetland Landcare Group, MainStream Environmental Consulting Pty Ltd and Kingfisher Research conducted a site inspection at Yatco Lagoon. The objective was to inspect the existing regulators, their location, design and seasonal operation (including wetting and drying) to:

- maximise native fish populations,
- reduce carp populations, and
- not compromise other aspirations contained in the draft management plan.

In addition, advice as to options and locations for two more regulators in the earthen bank and up to three additional regulators in the causeway area is required. To meet these objectives this report is divided into three parts: a) importance of floodplain habitats for fish, b) fish passage in culverts, c) carp management.

3. PART A: Importance of floodplain habitats for fish

Before discussing regulator design or operations it is necessary to review the fish species present in the Yatco Lagoon area and their ecology. The current drought has resulted in the complete drying of 50 plus floodplain wetlands through the operation of regulators and an absence of floodplain inundation, in the Lower Murray. At Yatco Lagoon and other floodplain wetlands, re-colonisation of fish from the Murray River into these wetlands is an important aspect of population recovery. Wetlands, lagoons and anabranches frequently contain excellent fish habitat and provide different habitats to the main river channel.

The exchange of fish between river and floodplain is also important in maintaining native fish biodiversity. Fish move between the floodplain and the Murray River via connecting channels and these unique flowing habitats are critical in enabling the physical movement of fish.

3.1 Regional fish passage: the big picture

The new vertical-slot and lock fishways for Lock 3 are due for completion in June 2009 and this will be the second in the South Australian series of upgraded fishways. New fishways for the remaining Locks (2-6) will be completed by 2011 (Barrett 2008). The new fishways will likely increase the number and diversity of fish migrating upstream and downstream in the main river adjacent to Yatco Lagoon under pool conditions. There is some potential that these migrating fish will use Yatco Lagoon, either as a temporary feeding habitat or as a thoroughfare during floods. Fish migrating upstream in the Murray River are attracted to the area of greatest discharge and in some floods this was historically Yatco Lagoon (Jeff Drogemuller, pers. comm.). Management of fish passage through Yatco Lagoon during floods is therefore addressed in detail below.

3.2 Why is Yatco Lagoon an important fish habitat?

Lateral movement of fish into Yatco Lagoon is important to access the diversity of habitat offered by floodplains with heightened survival, feeding and reproduction opportunities. Exit of fish from Yatco Lagoon back to the Murray River usually occurs as flows recede and ensures that fish escape stranding. New data also suggests that there is bi-directional movement of fish throughout the floodplain filling and drying event (Lyon et al. In press).

3.3 Yatco Lagoon fish assemblage

There are a total of 24 freshwater fish species in the lower River Murray in South Australia and 4 of these are non-native. At Yatco Lagoon, fish survey information is available from a survey in 2005 (Smith 2006). A total of 1368 fish of 11 species, including 8 native and 3 introduced were collected (Table 1). Abundance was dominated by Australian smelt (*Retropinna semoni*) and bony herring and more fish were collected in spring than autumn. There was some evidence of recruitment for bony herring and unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*), though spawning might have occurred in adjacent habitats.

More survey data is also available from November 2007 to August 2008 (Brad Hollis, SA MDB NRM Board, pers. comm.) Sampling with fyke nets and bait traps has yielded 673 fish, including 7 native and 4 introduced species. The broad patterns of abundance were similar to that collected by Smith (2005).

Long-term boat electro-fishing surveys (2000-2005) in the Murray River below Lock 3 has also confirmed the presence of three additional large-bodied native fish: Murray cod (*Maccullochella peelii peelii*), freshwater catfish (*Tandanus tandanus*), and silver perch (*Bidyanus bidyanus*). These three species might temporarily utilise Yatco Lagoon as a feeding habitat but probably only in small numbers. Shortheaded lamprey (*Mordacia mordax*) migrate through the Lock 3 area (Baumgartner et al. 2008) but are unlikely to occur in Yatco Lagoon.

3.31 Habitat associations: large-bodied fish

The large-bodied (>100 mm long) native fish are primarily found in the Murray River mainstem, tributaries, large anabranches and during high flows in smaller anabranches and larger floodplain habitats. These large native fish are less common in billabongs and lagoons with the exception of bony herring (*Nematalosa erebi*). By contrast, the large-bodied non-native fish, carp (*Cyprinus carpio*), goldfish (*Carassius auratus*) and redfin perch (*Perca fluviatilis*) are often found in both riverine and floodplain habitats with the latter habitat being preferred. When Yatco Lagoon refills bony herring and the non-native species will re-colonise.

Table 1. List of fish species in the Lower Murray and those recently collected from Yatco Lagoon in 2005 (Smith 2006). An asterisk *indicates a non-native species.

Large-bodied fish (>100 mm long)	Common name	Size range (mm) @ Yatco	Number collected @Yatco
Macquaria ambigua	Golden perch (callop)	384-405	4
Nematalosa erebi	Bony herring	47-422	214
Tandanus tandanus	Freshwater catfish		
Maccullochella peelii peelii	Murray cod		
Bidyanus bidyanus	Silver perch		
Geotria australis	Pouched lamprey		
**Cyprinus carpio*	*Common carp	*124-660*	33
**Carassius auratus*	*Goldfish	*55-170*	3
**Perca fluviatus*	*Redfin perch	*137-364*	10
Small-bodied fish (<100 mm long)			
Hypseleotris spp	Carp gudgeons	27-55	114
Craterocephalus stercusmuscarum fulvus	Unspecked hardyhead	17-55	153
Melanotaenia fluviatilis	Murray rainbow fish	23-54	37
Philypnodon grandiceps	Flat-head gudgeon	31-75	65
Philypnodon sp.	Dwarf flat-head gudgeon	33-45	8
Retropinna semoni	Australian smelt	35-70	1070
Ambassis agassizii	olive perchlet		
Craterocephalus fluviatilis	Murray hardyhead		
Galaxias rostratus	Murray jollytail		
Mogurnda adspersa	purple-spotted gudgeon		
Nannoperca australis	southern pygmy perch		
**Gambusia holbrooki*	*Gambusia	*20-49*	26

3.32 Habitat associations: small-bodied fish

The six native small-bodied (<100 mm long) native fish previously collected at Yatco Lagoon have broad flexible habitat requirements and can be expected in both the main river and in small and large floodplain habitats. When the Yatco Lagoon is filled, these species will quickly re-populate. Gambusia are a small non-native fish that compete with native fish and are abundant in most still and slow flowing habitat types. These fish produce live young and can breed up to four times each year. Young fish reach maturity within months and Gambusia can be expected to re-colonise Yatco Lagoon and population numbers rapidly expand.

3.4 Fish movement model

Consideration of fish passage through the Yatco Lagoon regulators depends on a model of fish movement that incorporates species, direction, timing, flow conditions and water levels. A generic fish movement model, for three hydraulic conditions is proposed to aid different management decisions. These three conditions are: 1). a managed wetting and evaporative drying event in Yatco Lagoon during normal pool levels. 2). A flood event. 3). A potential future weir pool manipulation situation, where Yatco Lagoon can be lowered more quickly than the Murray River (i.e. Lock 3 pool is drawn-down). Fish will likely become trapped if suitable fish passage is not provided (Figure 1) during these three event types. Generally, fish movements within Yatco Lagoon can be summarised as:

1. Fish movement into Yatco Lagoon is dominated by small-bodied species
2. Fish movement into deeper habitats (usually during high flow) includes large bodied fish (e.g. golden perch) as well as small-bodied fish.
3. Large-bodied native fish leave the lagoon as water levels fall or at the beginning of a natural flood recession, apparently cued by small drops in water level.
4. Small bodied fish have active bi-directional movement between the Murray River and Yatco Lagoon over a broad range of water levels. High numbers of fish generally enter the lagoon as it starts to fill and high numbers return to the river as the lagoon starts to drain.
5. Carp actively seek floodplain habitats in spring and summer to spawn.
6. Carp are generally the ‘first on – last off’ the floodplain during a flood or managed inundation compared to large bodied native fish. Carp actively use small wetlands.
7. Carp moving back into remnant pool habitats as the lagoon drains.

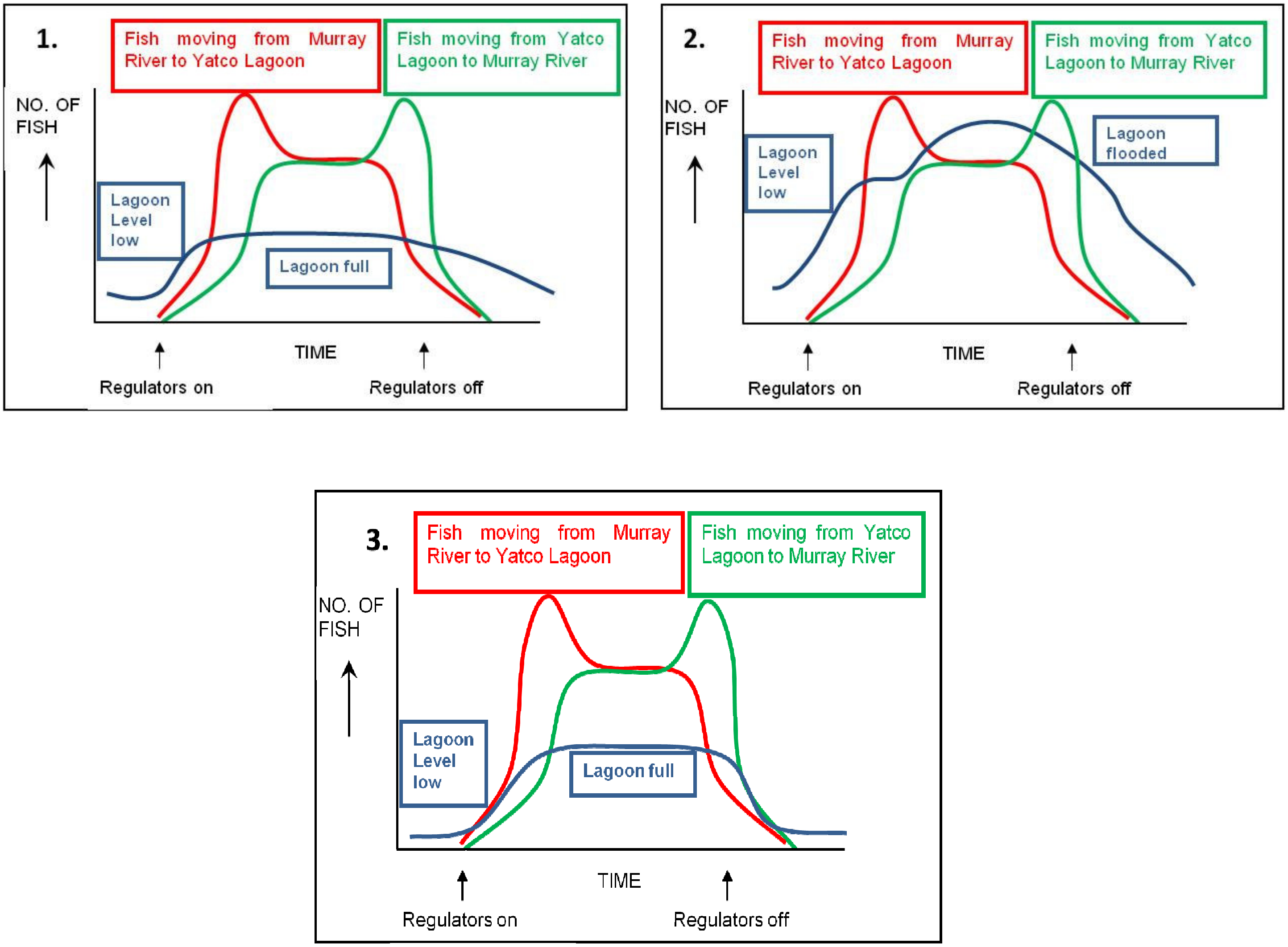


Figure 1. A generic fish movement model for the Murray River and Yatco Lagoon (modified from Lyon et al. In press). The model is for three hydraulic conditions : 1). a managed wetting and evaporative drying event in Yatco Lagoon during normal pool levels. 2). A flood event. Lastly, 3). A potential future weir pool manipulation situation, where Yatco Lagoon can be lowered more quickly than the Murray River (i.e. Lock 3 pool is drawn-down). Each of these three models would require a change of fishway infrastructure and management to enhance passage of fish from Yatco Lagoon to the Murray River. The corresponding changes are addressed below.

4. PART B: Background to fish migration in culverts

Fish passage through culverts is an important issue in Australia and there are some published guidelines, though these are generic in nature, contained in: ‘Fish passage requirements for waterway crossings (Fairfull and Witheridge 2003). There has been some culvert fish passage restoration in NSW and Queensland and these might be applicable at Yatco.

4.1 Culvert types

Fish passage in culverts is dependent on two broad design perspectives: 1) free-flowing culverts and 2) regulating culverts that control flow and water height. Regulating culverts often have high head differential, high water velocities and high turbulence. These culverts are used to raise or lower water in wetland habitats and can have considerable water level variation. The culverts at Yatco Lagoon are medium sized regulating pipe and box culverts with sliding gates or steel stoplogs.

At culverts the four major factors that control fish migration are: 1) water velocity, 2) turbulence, 3) water depth, 4) space, and 5) light.

1) Water velocity

Water velocity cannot exceed the swimming ability of the fish or passage is totally impeded. In culverts this is particularly important because of the greater distance to be negotiated compared to a fishway. Large native fish (>250 mm long) can negotiate up to 0.75 m s^{-1} for medium distances (i.e. 8-10 m) but small (30 mm long) native fish have a much reduced swimming capacity (i.e. 0.1 m s^{-1}) over the same distance. A general rule of thumb is that fish can swim at 3 times their body length (3BL) during prolonged efforts. For culverts such as those at Yatco Lagoon, similar to long fishway channels, the recommended water velocity is 0.15 m s^{-1} (Mallen-Cooper 2001).

2) Turbulence

Turbulence (energy dissipation) is determined by the discharge and velocity of the water entering the tailwater and the volume available to dissipate the power of that water, and is usually described as watts per cubic metre (W m^3). Recent research has shown that manipulating or reducing turbulence can greatly improve fish passage (Mallen-Cooper et al. 2008).

3) Depth

A depth of 1 m is required to pass all small and large bodied native fish, including large Murray cod. Small fish require a depth of 0.3 m or more and 0.7 m will be adequate for medium sized fish such as golden perch. Note that 0.3 m depth is also adequate for carp passage.

4) Space

Fish require adequate space when negotiating a culvert to avoid predators and also to avoid any behavioural inhibitions. A culvert space of 1.5 m wide by 0.7 m deep is adequate for passage of most fish species, except large Murray cod which are not expected at Yatco Lagoon during most flow conditions.

5) Light

Most native and non-native fish have strong diel movement patterns and several move almost exclusively when there is daylight (silver perch, bony herring and several small-bodied species). Non-native carp also move more strongly during daylight (Conallin et al. 2008). Several species require some light when migrating upstream and will not pass through tunnels, even during the day. Bony herring rarely pass through complete tunnels (Mallen-Cooper 1999) and presently similar trials being conducted for small-bodied species (Matt Jones, ARI, pers. com.).

At Yatco Lagoon the northern lagoon main embankment box culverts appear to provide an adequate amount of light so that bony herring could pass through. However, the causeway pipe culverts appear to be almost complete tunnels and might inhibit passage of bony herring and possibly other species. These issues will be addressed in further detail below.

4.1 Fish passage at Yatco Lagoon culverts

During the field inspection at Yatco Lagoon the culverts were not passing water and the lagoon was dry. Hence, there was no opportunity to assess their ability to pass fish using the five main criteria (discussed above): 1) water velocity, 2) turbulence, 3) water depth, 4) light and 5) space.

1) Water velocity

I recommend measurements of water velocity during the filling event at Yatco Lagoon. In the absence of a current meter (unless one is available from a local NRM group) the simplest method is to use *headloss* as a surrogate (Figure 2). Headloss, the difference in water velocity across the culvert, can be simply measured and used to estimate water velocity in both culverts and pipes (Table 2). If the pipe is sloped and water is free flowing then headloss is more difficult to measure.

2) Turbulence

An acceptable level of turbulence is less simply quantified for floodplain regulators than for fishways with known discharge and volume. Nevertheless, a turbulence of >30 W/m^3 will limit passage of some small fish (e.g. carp gudgeons) while bony herring and small golden perch can negotiate up to 60 W/m^3. Practically, if there is white water below the regulator then the risk of disorientation and failure to migrate is high.

3) Water depth

The minimum water depth required by both native and non-native fish as they negotiate a culvert is reasonably flexible. The native fish community will be dominated by fish <100 mm long which require 250-300 mm or greater. Carp can also negotiate this depth. Medium sized native fish (up to 350 mm long) require 400-500 mm depth. Large Murray cod will likely be absent except during flooding when depth will be greater than their minimum requirement of 1 m.

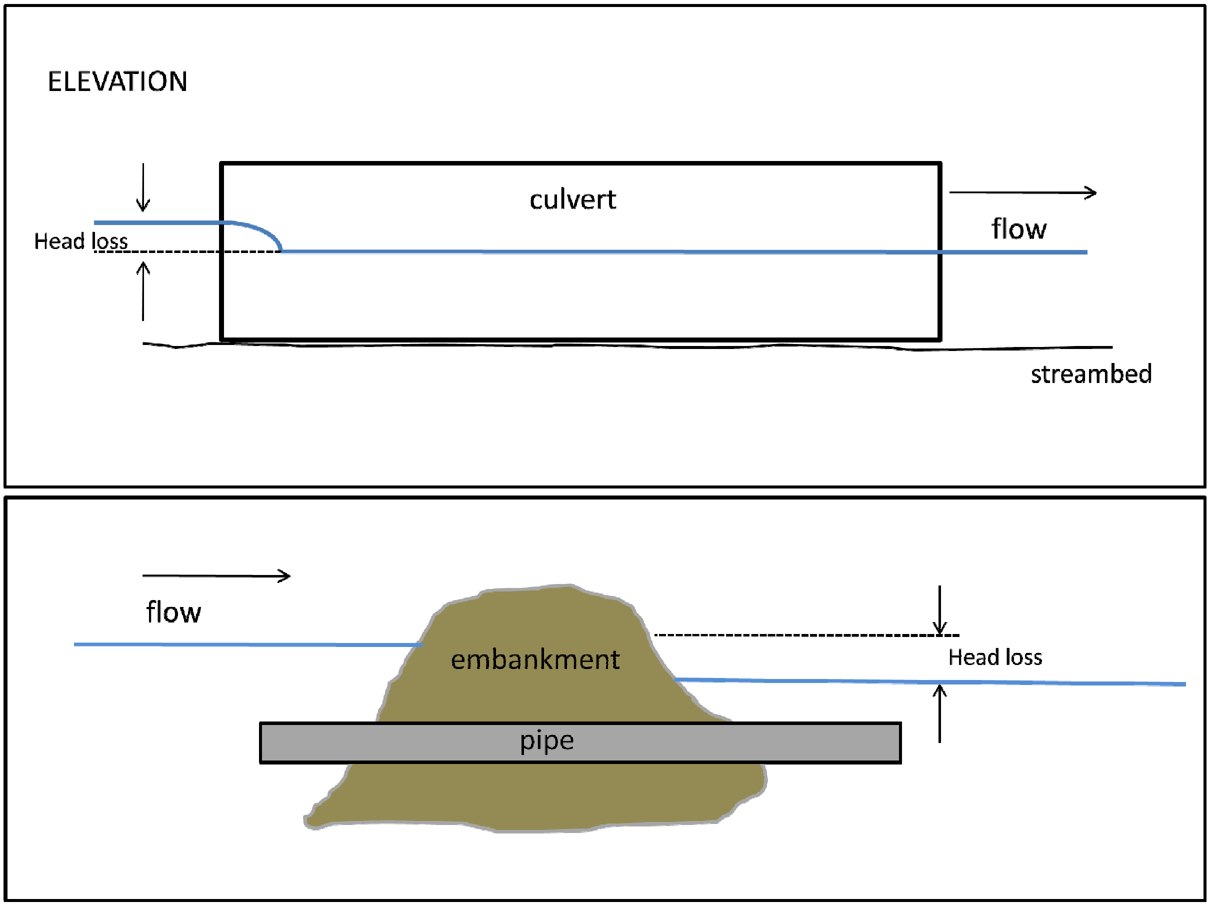


Figure 2. A guide to the field measurement of headloss at existing culverts (modified from Mallen-Cooper 2001).

Table 2. Headloss, water velocity and minimum fish sizes that might negotiate the culvert.

Headloss (mm)	**Max. water velocity (m s^{-1})**	**Fish length**
2	0.15	<80 mm
10	0.3	>100 mm
20	0.45	>150 mm
50	0.75	>250 mm
80	0.93	Impassable except to large fish (>400 mm)
100	1.05	Impassable except to largest fish (>500 mm)

4) Light

The main embankment regulator has acceptable light levels but in long narrow diameter pipes (e.g. < 0.75 m) light is usually absent. In this case bony herring are excluded, as are some silver perch and small-bodied fish. Carp passage through tunnels is largely unknown, recent data suggests they migrate and jump more strongly during daylight and dusk but there are also observations of nocturnal movement.

5) Space

Narrow diameter pipes have less *capacity* to pass large numbers of fish that sometimes accumulate below (e.g. during a draining event). Usually a culvert width of >1.5 m is sufficient to pass almost all native fish and 0.5 m might even be sufficient for small fish (<100 mm long).

4.2 Optimised culverts: designs to facilitate fish passage

There are several simple ways to design a culvert to facilitate fish passage and these can be summarised as:

- Generally box culverts provide greater fish passage opportunities than pipes
- Culverts which enable good light penetration and have water 'freeboard' are preferred
- Minimum culvert size of 1.5 m square provide solid fish passage options
- Culverts should be installed with *no* slope (match natural geology)
- Maintain natural stream depth, width and cross-sectional area
- Avoid water constrictions at the culvert and high water velocities
- The invert of the culvert entrance and exit should be counter-sunk (c. 30 cm) into the stream bed
- Generally culvert length should not exceed 6 m
- Scouring at the entrance or exit of the culvert should be avoided
- A 0.5 m high sloped water retention end-sill (concrete or sandbags) can be considered which raises tailwater thereby reducing turbulence and providing a refuge/plunge pool.

In summary a best-practice fish passage culvert should not modify any hydraulic aspect of the lagoon and re-create similar habitat within. Concepts are shown in Figures 3 and 4.

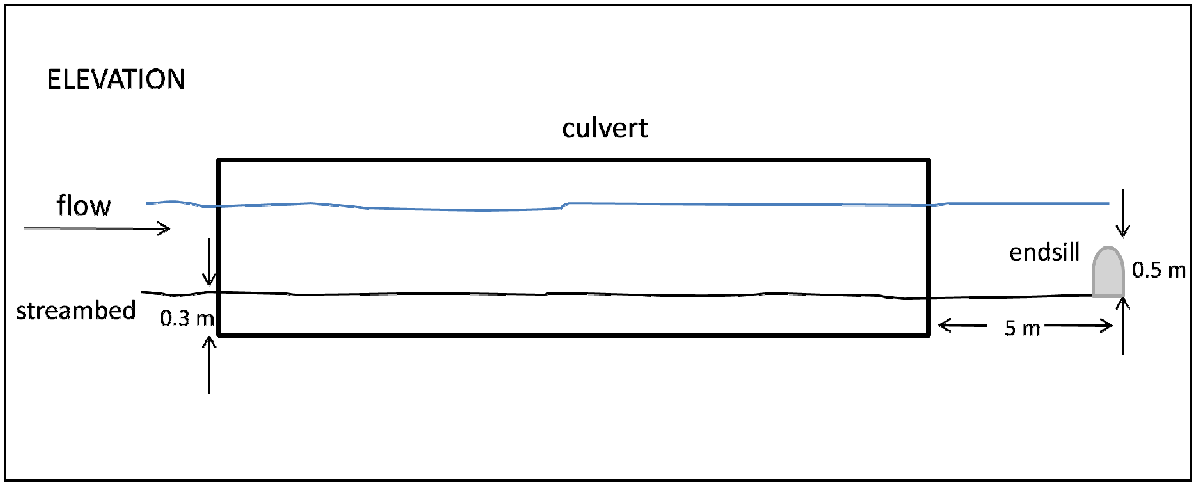


Figure 3. A box culvert counter-sunk by 0.3 m to enable stream bed material to accumulate. The culvert is gradient is flat.

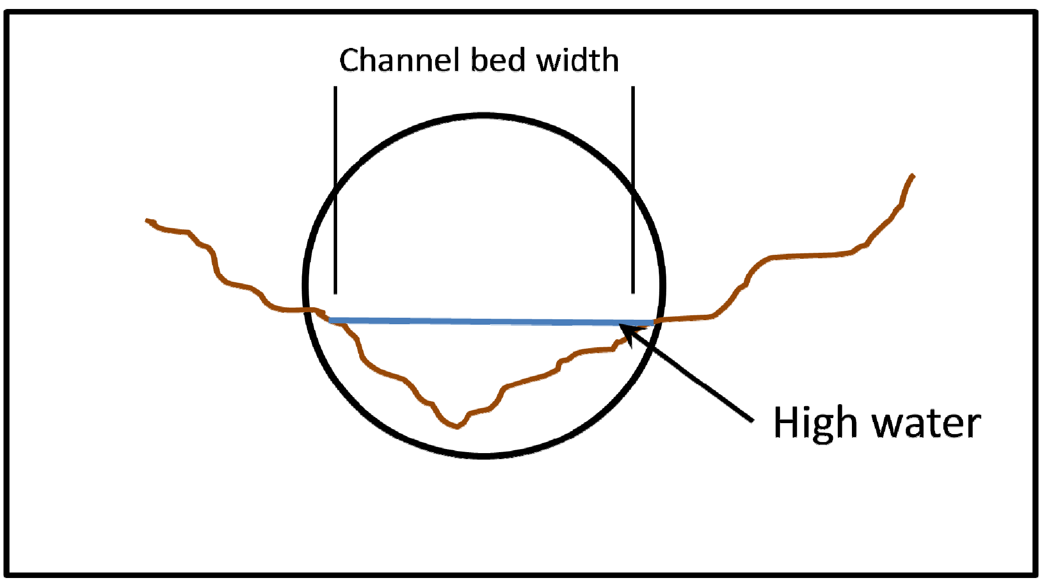


Figure 4. Cross-section of a pipe culvert showing the ‘channel bed width’.

4.3 Main embankment: northern lagoon

During the inspection of the Yatco Lagoon embankment culvert regulator (north end of northern lagoon) the objective was to visually assess the regulator and its potential hydraulics for efficient passage (upstream and downstream) of a broad size range of native fish species, while limiting entry by adult carp. On the day of the inspection Yatco Lagoon was dry.

4.3.1 Description of culvert regulator

The main embankment regulator divides the northern lagoon from the Murray River which closely approximates the pool level of Lock 3. The regulator consists of three 1.5 m square box culverts which are the whole road width (4.9 m; Figure 5). Water is regulated by two sluice gates situated on the upstream side. The third culvert (on the right looking downstream) has manual release drop boards. The total height of the regulating structure is 1.85 m from the culvert invert to the top of the deck unit. The total head across the structure from low water to high water is approximately 1 m (EL 9.3 -10.3) and the culvert depth is 1.65 m. There are 2.7 m long concrete aprons on both the upstream and downstream sides and spoil left from the coffer dam below. The middle culvert is covered by a metal grid deck. The design capacity of the culvert is approximately 500 ML/d when the river is full and Yatco Lagoon empty. Carp screens are presently installed on the downstream side of each culvert and these are manufactured from amplimesh (90 mm long by 40 mm wide). The screens can be manually rotated through 180^{o} for cleaning purposes and are addressed in further detail in Section 7.

4.3.2 Fish passage issues

The embankment culvert, as a regulating culvert, is a major barrier to fish passage. The two steel gates and stoplogs are a physical barrier to fish and the potentially high water velocities created at these structures are likely greater than the swimming ability of the fish.

The embankment regulator would also appear to have extremely high *laminar flow* through the three box culverts when opened. Laminar flow occurs when water flows parallel and uninterrupted through the culverts, resulting in smooth undisturbed flow with no eddies or local turbulence. In this situation there is no resting space for fish and they must swim constantly.

Figure 5. The two slide gates and stop logs in the three box culverts on the main embankment regulator. Photo courtesy Jason Higham (DEH).

4.3.3 Fish passage solutions

The northern lagoon embankment regulator, with three box culverts, is on a suitable gradient for fish passage, with good light penetration, and adequate width. To provide for fish passage I suggest the following operational and structural modifications:

4.3.4 Operational aspects

Firstly, operationally there is a partial solution for fish passage that should be immediately employed. The embankment culverts should be *free-flowing* with the gates *fully open* and all stoplogs removed. Under these conditions, when the wetland is filling from a dry state, the culverts can potentially pass some fish particularly if the lagoon is at pool level of Lock 3. However, wind seiche or culvert blockages (debris or regulating structures) can still result in a fish passage barrier. Free-flowing culverts have a number of operational and structural advantages over *regulating* culverts to enhance fish passage.

Operational recommendations

- Maximise culvert opening duration (do not open & shut at short intervals, i.e. leave open for weeks rather than days)
- Slowly open the stop logs or gates but then remove these structures entirely (i.e. slow opening reduces chances of entrainment of trash or fish and complete removal of stop logs reduces head loss)
- Operate the culverts with no headloss by maximising the tailwater height (Lock 3 level) but minimise turbulence

4.3.5 Structural aspects

Roughened culverts use rocks or baffles to break up the laminar flow, producing locally turbulent flow, and thereby pass small and medium sized fish. This option is of greatest use when the Lagoon and Murray River are at a steady state or water levels are within 100 mm differential head loss. There are several options to retro-fit roughness units and this depends on the fish species and range of flows over which the culvert operates. The options are:

- ➢ Retro-fit side culvert baffles which are advantageous where there is reasonable depth and variable headwater (Figures 6 and 7).
- ➢ Retro-fit small and large rocks which break up laminar flow and provide resting areas for fish (Figures 8 and 9). Importantly the large rocks must break the water surface and cannot be submerged. Hence even large rocks (0.6 m diameter) might not be useful for the main embankment regulator at Yatco Lagoon.
- ➢ Culverts and rock layers can be elevated or counter-sunk to operate during variable depth of flow.
- ➢ Where multiple culverts are present the fish passage operation can be designed with high and low flow stepped culvert systems.

Structural recommendations: box culverts

- Install twin side-baffles to break up laminar flows and provide improved passage for small fish.
- Install an end-sill for better water retention and hydraulic conditions.
- Re-installing the culvert at a lower level (0.3 m) is not feasible, therefore I suggest a contiguous layer of medium diameter (0.25 m) rocks to the base of the culvert

beneath the side-baffles. The rocks will add roughness for benthic fish and invertebrates.

- Remove downstream coffer dam spoil.

4.3.6 Risk

Note that the culvert side-baffles must still pass a high discharge into Yatco Lagoon, so they are short in width. Side baffles act as roughness elements, during all culvert flows, but do not replace a fishway. The side baffles would have most useful fish passage effects when the head differential is < 100 mm (between the Lagoon and Murray River height). Installing baffles for the passage of native fish would be an experimental option that would need some biological assessment.

Note that in rock roughened culverts there is reduced discharge and potential flooding over the culvert and road might occur. In that case, more culverts and increased maintenance might be required.

Figure 6. Culvert with retro-fitted one-side baffles. Baffles help to slow water velocity and create eddies for fish to rest in during their migration. These baffle units are cheap (AUD$50 ea) and could be retro-fitted to the main embankment regulator. Photo courtesy Tim Marsden (Queensland Fisheries).

Figure 7. New culvert to replace pipe with twin sided baffles. Photo courtesy Tim Marsden (Queensland Fisheries).

Figure 8. A box culvert with flow deflectors for enhancing passage of small fish. The debris was from a high flow event. Note that the flow deflectors break the water surface. This design is useful for culverts with low depth or where multiple culverts are set in a stepped (different elevations) for high and low flows. Photo courtesy Tim Marsden (Queensland Fisheries).

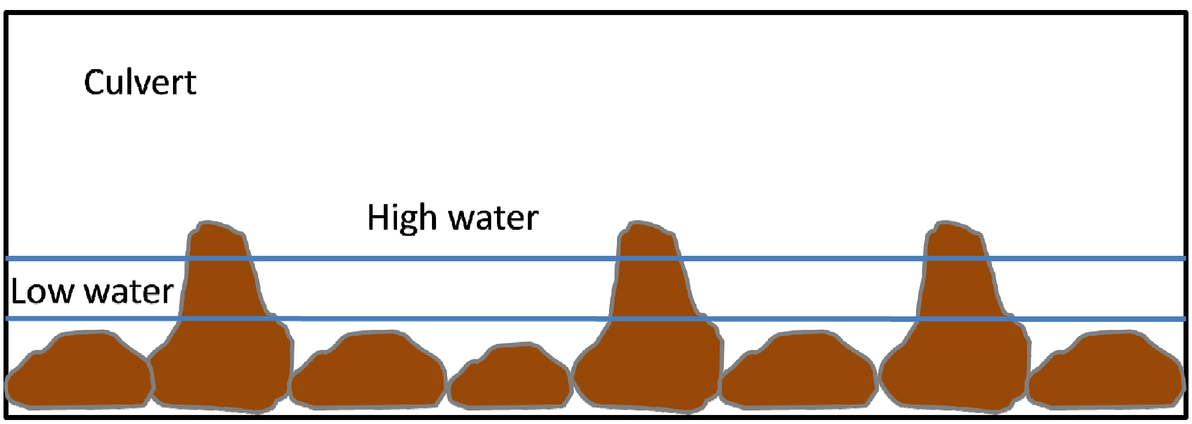


Figure 9. Rocks grouted or held in a culvert, with bed retention sills/bars, which provide for fish passage at low and high flows. This design is not applicable in deep water culverts unless there are multiple stepped options (as above). Concept from Mallen-Cooper (2001).

4.4 Pipe regulators: northern lagoon-river connector

4.4.1 Description of pipe culverts

There are three pipe culverts on the northern lagoon-dredged-creek-river connection (Figure 10). The permanent waters of the dredged creek have some fish habitat values and likely acts as a refuge when the lagoons dry out. The culverts from the dredged creek-river to the northern lagoon extend for approximately 7.5 m from an upstream point in the dredged creek. The three upstream pipe entrances have metal slide gates approximately 1.3 m high by 1.7, 1.55 and 1.15 m wide, respectively. The downstream pipe diameters are 1.3 by 1.3 by 0.92 m wide, respectively. The inverts of the pipe exits appear to be set at different levels and are not yet perched above the tailwater. However, there is some evidence of erosion below the pipes which might result in future perching. When opened the pipes produce extremely high laminar flow for several days (Figure 11).

Figure 10. The downstream pipe exits for the northern lagoon-dredged-creek-river connection. Photo courtesy Bill Phillips (MainStream Environmental Consulting).

Figure 11. High laminar flow through the northern lagoon-dredged-creek-river connection during the March 2009 re-wet. Photo courtesy Craig Ferber (LBLAP).

4.5 Pipe regulators: north-south connector

4.5.1 Description of pipe culverts

Adjacent to pipe culverts described above are another set of pipe culverts that join the northern and southern lagoons (Figure 12). These culverts cross the main northern-southern causeway and there are two buried pipes of 0.92 m diameter. The culvert exits would be perched above the tailwater until it begins to back-up. The pipes are approximately 7.6 m long and appear to be installed on a shallow gradient. The structure has two metal slide gates approximately 1.5 m high by 1.1 m wide. The invert of the slide gates is set approximately 0.5 m above the 2.4 m wide concrete apron at the upstream end. Hence, the culvert entrance becomes perched as the lagoon dries. A considerable amount of spoil left from the coffer dam is also evident at the upstream end.

Figure 12. The upstream (left) and downstream (right) culvert regulating structure on the north-south connector. Note the coffer dam spoil at the upstream end and the perched culverts at the downstream end. Photos courtesy Bill Phillips (MainStream Environmental Consulting).

4.5.2 Fish passage issues

Pipes present a particular problem for fish passage and those at the northern river-lagoon connector and the north-south connector are unlikely to pass the full range of fish species over a broad range of lagoon heights. Fish passage will likely be impeded by i) high laminar water velocities until high tailwater, ii) tunnel effect on several fish species, iii) inability to retro-fit internal baffles. These problems are exacerbated because some of the pipes appear to be on a slope and set at entrance and exit inverts that will not accommodate the full operational range of the lagoons. Nevertheless, there are several practical options to provide for fish passage.

4.5.3 Operational aspects

Similar to box culverts, if the pipe culverts can be operated as *free-flowing* with the gates *fully* removed. Under these conditions the pipe culverts can potentially pass some fish particularly if the tailwater height is full (i.e. at Lock 3 pool level). Some fish will likely in and out of the pipes and succeed in passing the culverts as long as there is no measurable headloss.

Operational recommendations

- Maximise pipe culvert opening duration (do not open & shut at short intervals, i.e. leave open for weeks rather than days)
- Slowly open the gates but then remove entirely (i.e. slow opening reduces chances of entrainment of trash or fish and complete removal of stop logs reduces head loss)
- Operate the pipe culverts with no headloss by maximising the tailwater height (to Lock 3 pool level) but minimise turbulence

4.5.4 Perched pipe culverts

Several of the pipe culvert inlets and outlets were set at a higher invert than the stream bed (north-south connector). Other pipes appeared to be at risk of perching above the stream bed due to downstream erosion. Without water on the downstream side of the pipes it was difficult to predict whether the pipes are in fact perched above the tailwater. Some perching would appear likely as the three variable diameter pipes (northern lagoon-river connector) were set at different inverts and this suggests that pipe design flows vary with tailwater. In some cases it seems likely that tailwater would be low while the pipes were still operational.

Perched culvert pipes completely block upstream fish passage and are a particular problem that cannot be fixed by modifying with internal baffles. The options are:

- Re-install pipes at a lower level
- Install grade control structures downstream (see Figure 13).
- Re-install optimised box culverts (as per Section 4.2)

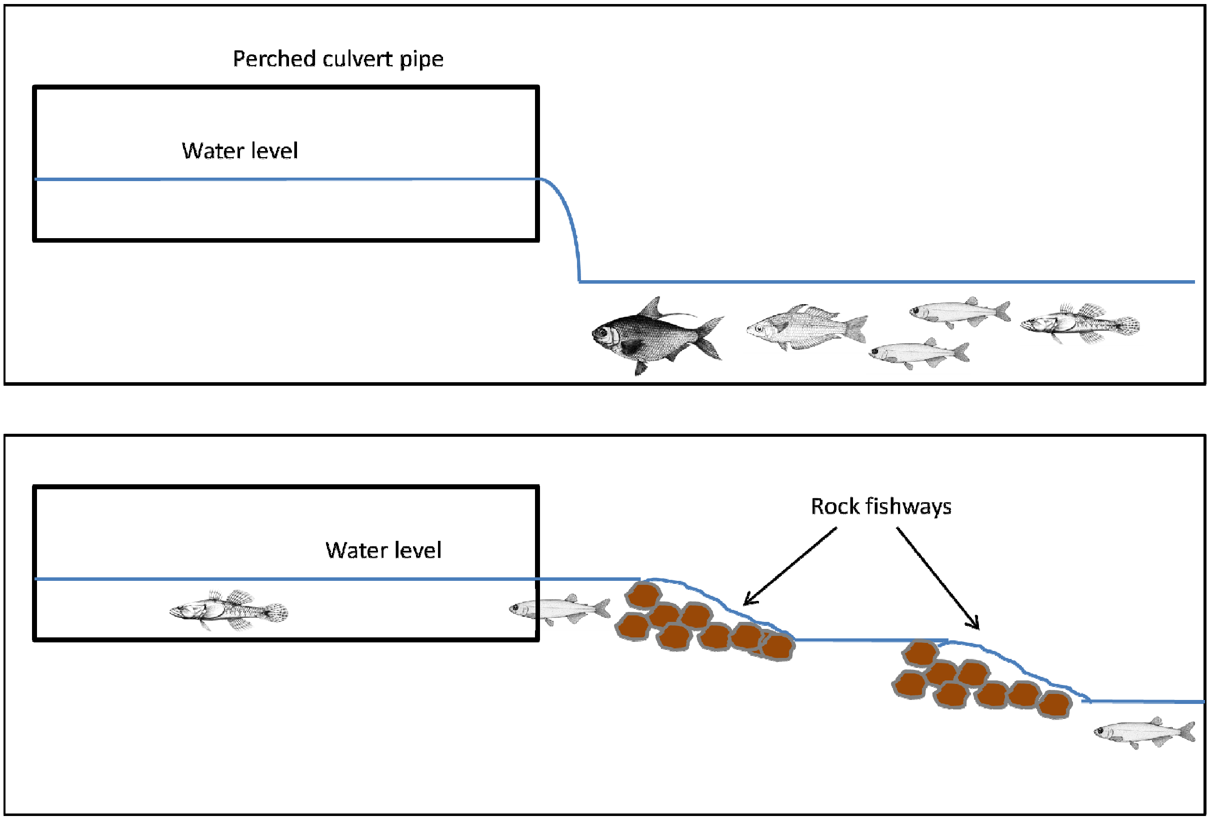


Figure 13. Perched pipe culvert (top) blocking fish passage and remedied with grade control structures (bottom).

4.5.5 Downstream grade control structure

A grade control structure is essentially a rock ramp fishway to increase the tailwater height into the pipe culverts. Rock ramp fishways have a low slope (1V:30H) and can operate for small head differentials (e.g. 1 m). Large rocks (e.g. 1 m) break up the flow at high discharge but the fishway can also operate at low flows and depths (0.3 m). Rock fishways should be carefully designed at Yatco Lagoon for stability and function.

4.6 Structural recommendation: pipe culverts

1. Monitor the headloss and fish behaviour at the pipe regulators throughout a re-filling event. If fish passage is restricted remove pipe culverts and install optimised box culverts utilising the guidelines herein (see Section 4.2).
2. Alternatively, operate the pipe culverts to fill tailwater (Lock 3 level) and thus provide fish passage for some fish species willing to negotiate the tunnel. Consider installing a grade control structure to maximise tailwater.
3. Remove any local coffer dam spoil.

4.6.1 Risk management

The pipe culverts are a considerable risk to fish passage (Figure 14) and would appear to have a limited operational range. The headloss and potential for fish accumulations should be monitored during the present re-filling event and I recommend that optimised box culverts be installed.

Figure 14. The present pipe culverts would likely impede fish passage due to a strong tunnel effects and sub-optimal hydraulics.

5. Regulator operations guide

Using the fish movement model described above (Section 3.4), the recommended approach (summarised in Table 3) is:

1. Provide passage for downstream migrating fish (into Yatco Lagoon) by minimising injury and mortality at the regulators and screens. This achieved by maximising depth (i.e. Lock 3 weir pool height) and regulator opening.

2. Provide passage of migrating fish (out of the wetland) by managing water levels to:
   a) Maximise periods where water levels are close to equal at the regulator (i.e. lagoon level is at Lock 3 pool height), and
   b) Stimulate fish to leave the wetlands, through the fishways or optimised culverts back to the main river, as the lagoon starts to dry. This can be achieved by beginning to drop water levels at the end of Spring (mid December).

3. Close the regulator at mid-December or Christmas

   a) Close regulator so there is a 150 mm lake level drop in the first 24 hours (only possible during a Lock 3 drawdown), allow to stabilise and then evaporative drawdown thereafter. Adaptively manage.
   b) Observe above & below regulator for native fish accumulation and then maintain fishway or optimised regulator flow if native fish are present. These fish passage trickle flows, through the fishway or baffled culvert, will likely provide a pathway for fish returning to the Murray River. The flows to enable fish passage might be intermittent or for a few days only and thus avoid re-filling or maintaining the lagoon height.
   c) Open in lagoon in winter (May/June onwards) or first flow event

5.1 Lock 3 weir pool manipulation

When the navigable pass and fishway upgrade works are completed at Lock 3 (likely June 2009) there is some potential to raise and lower the weir pool for stimulating local ecological responses. An operating strategy is presently being developed and there is potential to raise the weir pool to a maximum level of EL 10.39, or the top of piers (Brad Hollis, SA MDB NRM board, pers. comm.). This raising constitutes a 0.49 m maximum increase on the normal weir pool height of EL 9.9 m.

In terms of operating Lock 3 to benefit native fish passage at Yatco Lagoon there exists some scope to raise the weir pool to EL 10.2 m and thereby operate the recommended lower and middle stepped culverts. These culverts will facilitate bi-directional fish passage at Yatco lagoon earthen embankment. The level of the lagoon would need to be high as well.

Raising the weir pool and lagoon above EL10.0 m might also improve spawning and littoral habitat complexity for small-bodied native fish but will likely also increase carp spawning. This risk should be managed by raising and lowering the weir pool level as outlined in Table 3 & 4.

Lowering Lock 3 weir pool could also help facilitate fish passage from Yatco Lagoon back to the Murray River. For example, if the Lock 3 pool level were lower than Yatco Lagoon then large and small fish might be stimulated to leave Yatco lagoon with a sharp drop in water level (e.g. 150 mm in 24h). Practically, dropping the lagoon level by 0.1-0.15 m might not be achieved. However, a future vertical slot fishway would likely operate from EL 9.5 – 10.0 m and lowering the river simultaneously with drying of Yatco Lagoon will help facilitate fish passage back to the Murray River. A drop in the height of Yatco lagoon would likely stimulate large fish to leave and lowering the river within the operational range of the fishway would help facilitate fish passage.

Regulator	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Embankm-ent regulator	On river rise or NRM discretion, Embankment regulator opened incrementally (0.4 m wide opening to start) in a manner that mimics natural flow variability until culverts are fully open. Fill wetlands at 5 depth cm/day. Fill end-sill water retention bay. Short-term opening and closing provides little fish benefit.			Regulators remain fully open maximising extent of inundation and filling. Minimise turbulence below regulators by maximising tail water depth (Lock 3 pool level). Maximise openings for native fish passage and fishways remain open.				If possible reduce lake level by 150 mm over 1-2 days to cue exit of large and small native fish through fishway. Hold for 1 week - can be repeated. Fishway remains on. Inflows reduced incrementally to 20-50% of capacity for 2-3 weeks and then incrementally closed. Fishways remain on.		Fully closed – unless lagoon is operated as a fish refuge – then manage by adding small amounts of water to prevent drying.		

Table 3. Operational guidelines for Yatco Lagoon culvert regulators. Note that the drying phase is slightly later than that recommended by Gippel (2007). For water savings the drying phase could be started by mid-December. Note also that the May filling event does not mimic natural (i.e. spring/summer filling) and is based on carp management scenarios.

6. Extra regulators: options and locations

As part of the present report, advice was sought as to options and locations for two more regulators in the earthen bank and up to three additional regulators in the causeway area. Extra regulators, which enhance fish passage, are a priority for the earthen bank as this is the location where there has been a significant reduction in flow and fish passage.

More hydrological modelling is necessary to ensure high flows and floods can be passed safely at the earthen bank. This report does not investigate the number of regulators required to increase cross-sectional area and pass extra flow, in contrast it only addresses the fish passage element for existing and new regulators.

The primary aim of extra regulators is to increase the present capacity to discharge water. To show the basic hydrology of the earthen bank, as it relates to fish passage, Figure 15 summarises the four stages of a managed inundation (1. rising, 2. steady state, 3. falling) and 4). a natural flood (or weir pool raising).

From a fish passage perspective extra regulators and the four stages of lagoon hydrological management open up several different options for installing culverts and fishways that can efficiently enable bi-directional fish migration.

There are three key options for providing best-practice fish passage options:

1) High and low flow stepped multiple culverts
2) Vertical-slot fishway
3) Optimised box culverts

6.1 High and low flow stepped multiple culverts for natural flooding/weir pool raising

This concept has gained momentum over the last few years and is now also integrated into some rock fishways. To overcome high flows drowning out the culvert rocks a series of culverts are used with lower elevations for low flows and higher elevations for floods. The culverts still need to be installed at a flat gradient (1V:30H or greater) and a concept is shown in Figure 16. There is a contiguous layer of rocks (0.25 m diameter) in the culvert (or pre-fabricated concrete cones) with large rocks (0.8-1.0 m diameter) to break the water surface. Each culvert could operate for a 0.2 m rise in headwater before the next culvert became operational. This system would likely operate for the top 0.6 m of water variations (i.e. from EL 10.0 to 10.6) until the earthen bank is inundated. Expert engineering would be needed to formally define the operational design range.

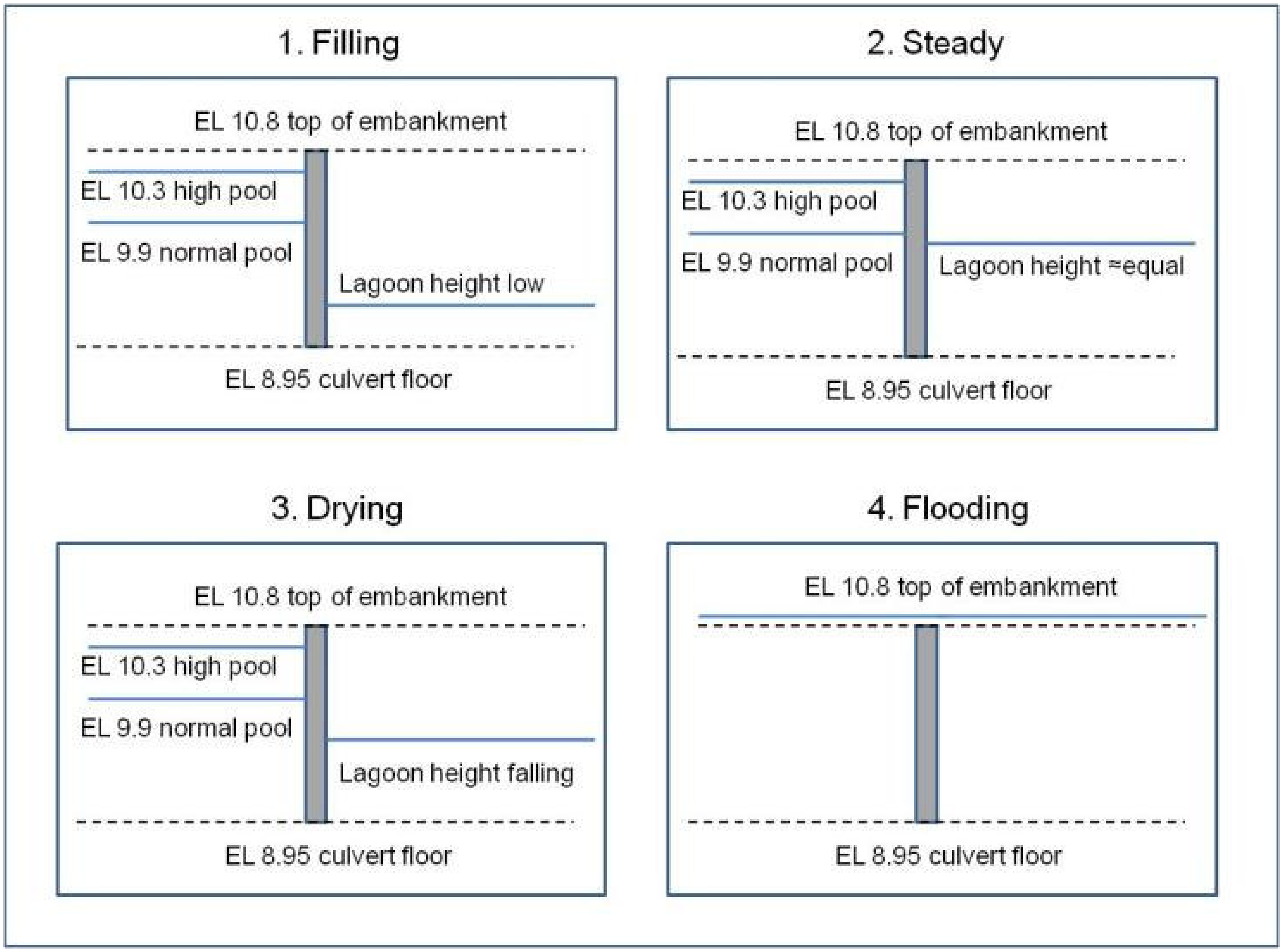


Figure 15. Three generic hydrological stages of a managed inundation and flooding at the earthen bank regulator. A fish passage solution for new and existing regulators might be designed using this flow model.

Note that the fish passage culverts (Figure 15 and 16) will have reduced discharge and during flooding extra culverts (without rocks) might be required to maintain flood capacity. The high discharge of the extra culverts can be integrated into the attraction for the fish passage system. Maintenance and access is also essential for the roughened culverts. An advantage of this system is that the high flow culverts do not need a gate so that manual operations are reduced.

6.2 Vertical-slot fishway for normal operations and weir pool manipulations

Vertical-slot fishways can be installed within a concrete box culvert and due to its limited ability to pass flow would require an additional culvert for flow discharge. A vertical-slot fishway is a series of baffles within the box culverts (Figure 17). These would be designed to facilitate fish passage from Yatco Lagoon back to the Murray River during falling wetland conditions. These conditions would occur during normal evaporative draining of Yatco Lagoon and during weir pool manipulation exercises. Preliminary design criteria are a pool size of 1.5 long by 1.5 m wide with a slot width of 0.2 m and a headloss between pools of 0.1 m. The new innovation of 'middle sills' (or variable width baffle inserts) could also be incorporated to enhance passage of small-bodied fish by reducing discharge and pool turbulence.

For a typical culvert length (6 m) the vertical-slot design could work for 0.4-0.5 m of water variation (approximately 50% of headwater variations; or EL 9.5-10.0). This is an option that would provide useful fish passage, back to the Murray River, during a falling lagoon operation and would also need specific engineering advice. The vertical-slot design can be relatively cheap, with pre-fabricated aluminium baffles and when integrated with Yatco lagoon management (i.e. drop water levels by 0.15 m to cue fish exit) then a 0.5 m operational range might be sufficient. During normal operations, when Yatco Lagoon drains by evaporation, the fall in water height will likely be only a few mm/day. To facilitate fish passage an adaptive approach is required which would operate fishways, with trickle flow, intermittently as fish try to escape the drying lagoon. The fishways will likely operate down to a lagoon level of EL 9.5 m.

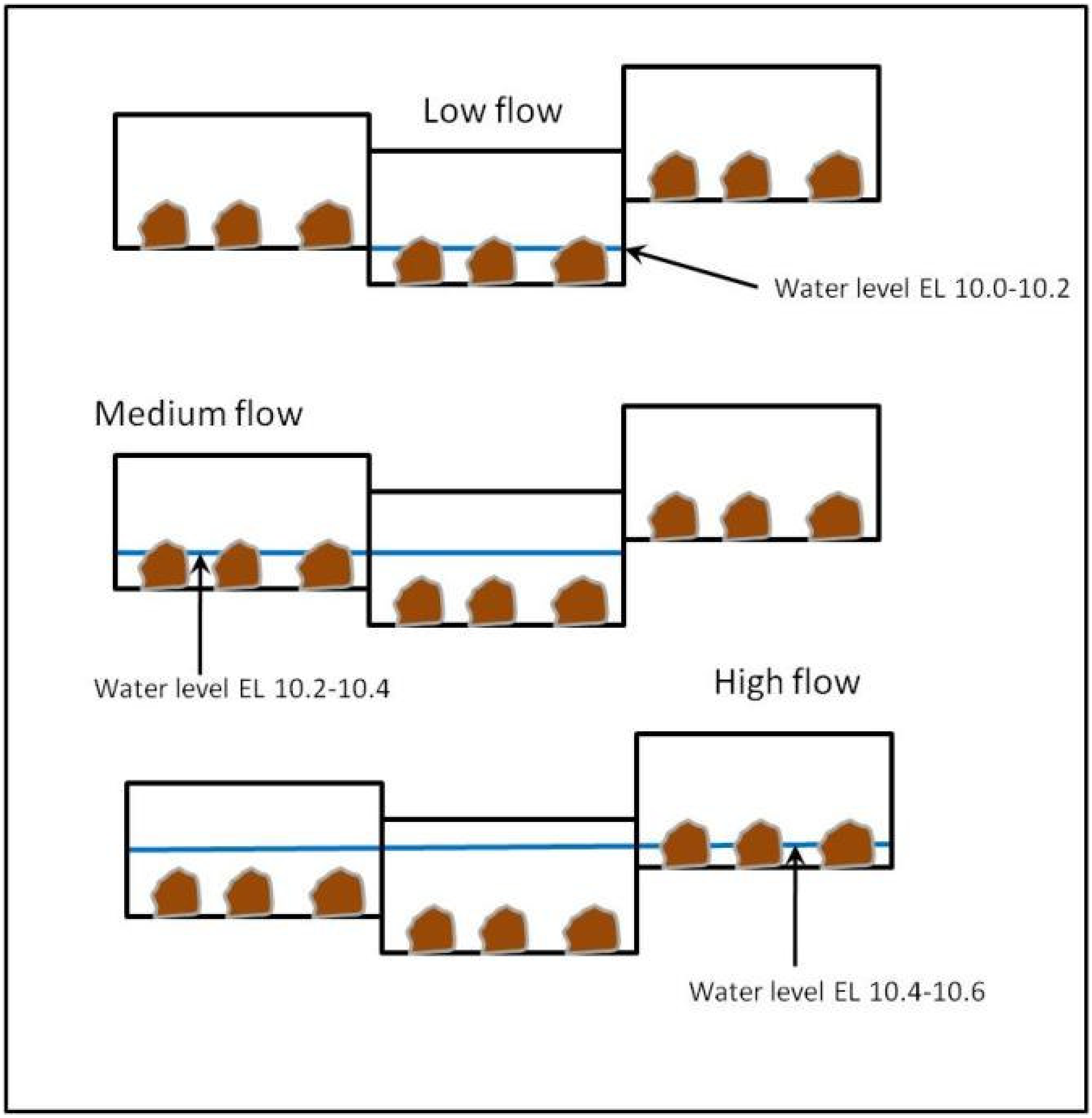


Figure 16. End view of stepped culverts for fish passage at low and high flows (concept originally from NHT culvert project). Each culvert would operate over a 0.2 m headwater range from EL 10.0 to EL 10.6 (drown-out of the earthen bank).

Figure 17. Chevron cones add roughness in a fish passage optimised box culvert. Note the concrete formwork sets the sill level at +50 mm increases for each of the triple-cone series. Also the high culvert sides maximise light penetration. Photo courtesy Tim Marsden (Queensland Fisheries).

Figure 17. A vertical-slot fishway with pre-fabricated baffles incorporated into a box culvert. Note the integration of the fishway entrance with the main flow from the open culvert. Photo courtesy Tim Marsden (Queensland Fisheries). At Yatco Lagoon earthen bank a vertical-slot fishway would likely operate between EL 9.5 and EL 10.0 and enable fish to return to the Murray River.

6.3 Optimised box culverts

Further installation of optimised box culverts would also increase the discharge capacity at the main embankment and at the causeway. If this option is chosen, or part of an integrated approach with Options 6.1 and 6.2 (above) then I suggest the guidelines outlined in Section 4.2. are utilised.

A serious limitation of optimised culverts (with rock roughened base) is that during high flows the large rocks are inundated, reducing roughness, and fish passage efficiency declines. This is also a deficiency observed in many rock ramp fishways. The optimised box culverts (with side baffles and rocks would provide better fish passage during normal filling, steady stage and falling (by evaporation) hydrological conditions.

6.4 Locations for extra culverts and fishways

The locations for extra regulating structures, and for fishways is reasonably flexible and essentially these structures should be sited to:

- Take advantage of any locally deep channels that fish will seek
- Take advantage of any habitats (e.g. large woody debris)
- Be sited in accessible areas for maintenance
- Have at least one fish passage system near any discharge culvert to take advantage of the extra attraction flow
- Fishways should be sited to minimise intrusion of flood debris and weeds
- Fish tend to take the most direct route when returning to the river

During the present re-wetting event (March 2009) there is an opportunity to inspect water flows and fish accumulations (during a rise and fall) and identify appropriate locations for regulators and fishways. At the north-south causeway the most appropriate site is on the mainstem of the lagoon (the deepest point) similar to the river-lagoon north culvert. At the main embankment regulator there are already some lower depressions where water and fish might accumulate and these might be appropriate locations.

During high flows (>20,000 ML/d), when large-bodied fish might swim through Yatco Lagoon, fish are attracted to the greatest flow and in most cases this would still be the main regulating structures. Additional water could be passed through the lagoon, in proximity to the fishways, to encourage migrating fish use. Providing improved fish passage through the lagoon and back to the Murray River is an important aspect of restoring the ecology of these aquatic systems.

6.5 Specific Recommendations for extra regulators

Earthen bank

5. Installation of a triple stepped culvert design for fish passage between EL 10.0 - 10.6.
6. Installation of a vertical-slot fishway within a box culvert for fish passage between EL 9.5 – 10.0. This would facilitate fish passage from Yatco Lagoon back to the Murray River via “trickle” flows.
7. For additional box culverts which operate at pool level (e.g. EL 9.5-10.0) and increase hydraulic capacity - optimisation (side baffles and rocks) to provide improved fish passage.

Causeway

6. Removal of the existing pipe regulators
7. Installation of a vertical-slot fishway between the main river connection and Yatco Lagoon to promote fish passage
8. Installation of optimised box culverts between the main river connection and Yatco Lagoon
9. Installation of optimised box culverts between the North and South lagoons to promote fish exchange

7. PART C: Carp management

7.1 A context for carp management

For any carp control exercise the underlying concept should be one of undertaking a range of management interventions to show the cumulative benefits of river rehabilitation on native fish populations. Hence, carp control is only undertaken in the context of native fish recovery. For Yatco Lagoon, a suite of these interventions might maximise and demonstrate the benefit of multiple actions. For community groups, there are several reading resources which are important before embarking on a carp control program. These include a scientific framework for carp management 'Managing the Impacts of Carp' (Koehn et al. 2000) and the 'National Management Strategy for Carp Control 2000-2005', prepared by the Carp Control Coordinating Group (CCCG 2000).

7.2 A general model of carp life-history

Adult carp actively move onto floodplains and are also mobile within the main channel of the Murray River. Lateral migrations to floodplains are for two major purposes: spawning and feeding. Carp lay their adhesive eggs in the shallow relatively warm waters of the floodplain, usually on vegetation that is more abundant than in the main river channel. Adult carp movements are relatively predictable, with a general model (Figure 18) of:

- Winter aggregations in main river refuges with a high degree of site fidelity
- Spring (mid-August onward) migration to floodplains as soon as they are accessible or upstream in the main river
- Spring/summer spawning (multiple events) associated with floodplain inundation (Smith 2005)
- Autumn movement from floodplains to the river as water recedes from the floodplain Large numbers of carp may be naturally stranded during these conditions.

Adult carp are generally characterised by a floodplain habitation strategy of "first on – last off' (Jones and Stuart 2008a).

Larval and juvenile carp drift downstream from floodplain spawning areas in the main river stem and also on the floodplain.

The implications for Yatco Lagoon carp management are:

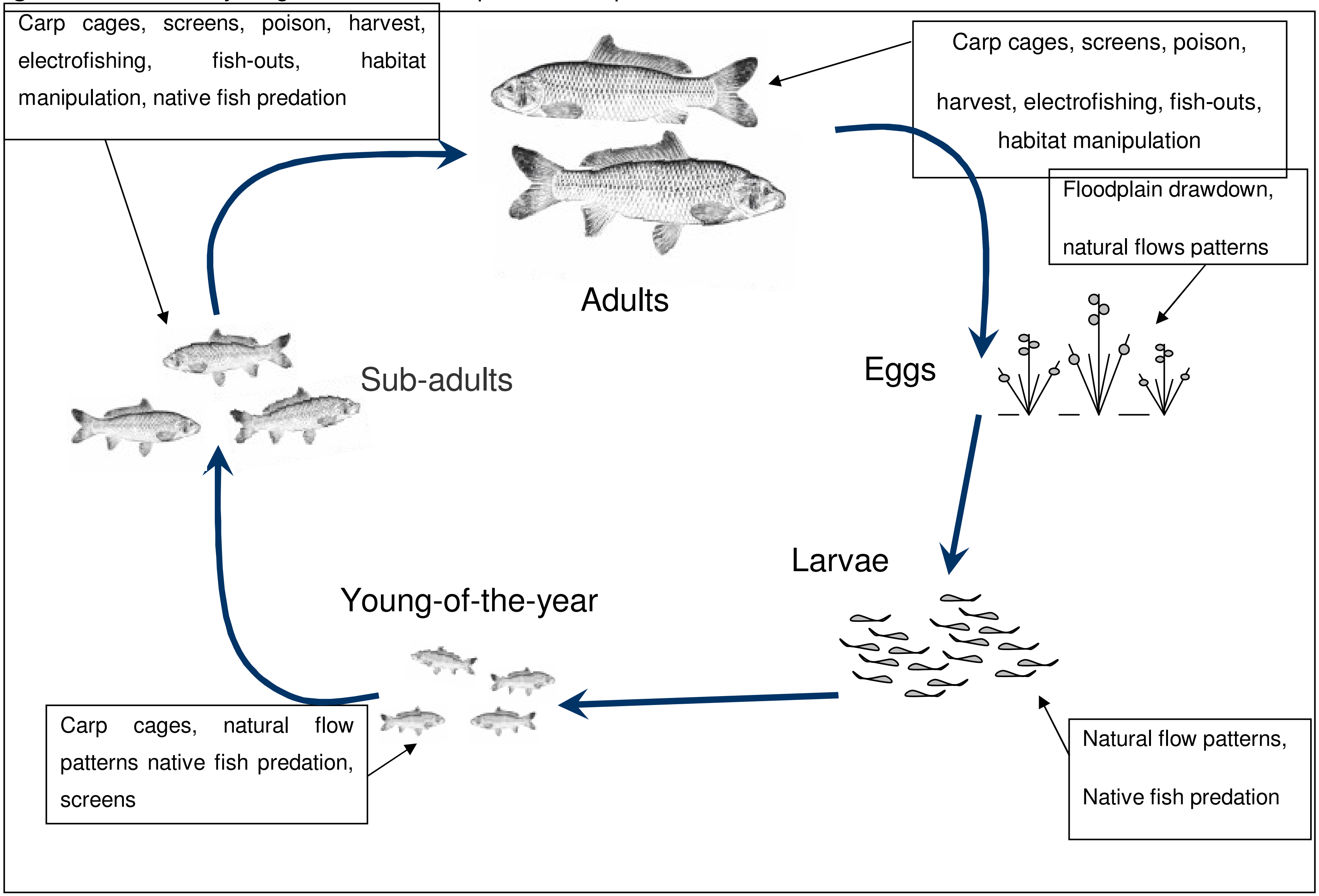
- Adult carp disturb macrophytes and suspend sediment and these fish are the priority for control.
- Fishways or culverts on wetland regulators may provide opportunities to cull carp populations;
- If spawning sites are identified, it is possible to reduce spawning activity by minimising access of adult fish and by manipulating water levels to expose and kill eggs through desiccation;
- Any inflows from the river into floodplain habitats can carry larvae, even with screens to stop larger fish.
- Unless all remnant water within Yatco Lagoon is completely desiccated, carp will remain and even spawn.
- Remnant pools can contribute considerable numbers of carp to Yatco Lagoon during the next fill event.

7.3 Carp management at Yatco Lagoon

At Yatco Lagoon the carp management strategy will be one of control rather than complete eradication. The two major objectives are to 1) minimise the number of adult and sub-adult carp entering/exiting the system and 2) minimise damage by adult carp on wetland values.

The three main strategies to achieve these goals and therefore manage carp populations comprise: i) screens to exclude adult and sub-adult carp, ii) the introduction of a wetting and drying regime, and iii) harvest or destruction of carp accumulations.

Figure 18. Life-history stages of common cap and their specific control measures.



7.4 Carp screens

In spring, as carp migrate from the main channel of the river into off-channel habitats to spawn there is a significant opportunity to prevent their entry with the use of carp screens. Regulator screens are a major tool in preventing adult carp access to spawning habitats.

7.4.1 Screen design

Screen design is unique to each regulator and should incorporate the appropriate parameters for the task. This includes the target size of migrating carp, ease of operation, maintenance, impact on native fish, and likely trash load (Figure 19 & 20). At Yatco Lagoon, during most filling events few large native fish are likely to require access, with the exception of bony herring. At Lock 1, there has been success utilising vertical-bar screens that allow passage of bony herring, small-bodied fish and juveniles of large-bodied fish (<250 mm long). The screens still enable passage of carp (<250 mm long).

There are few data for designing carp screens but from recent research (Smith et al. 2008) and experience at Lock 1 a basic design incorporates:

- Vertical bar screen with 42 mm internal bar spacing.
- Bar diameter to be strong enough to resist debris (e.g. >16 mm).
- Screens to be installed on the upstream face of the regulator
- Screens to be easily cleaned (e.g. rotational) and removed
- Inclined screens (e.g. 55^{o}) improve debris resistance
- Wide trash racks (e.g. 6-8 m) are useful for protecting the carp screens

Small carp can pass through the 42 mm diameter screens but if Yatco Lagoon is regularly drained, by evaporation, these fish might not grow to a size that disturbs the habitat. This strategy has been successful in reducing turbidity and increasing the aquatic vegetation of wetlands. During flooding the carp screens should be removed.

Figure 19. The carp screens presently installed at Yatco lagoon embankment regulator cause high headloss during filling and would be optimally located on the upstream side. Photo courtesy Craig Ferber (LBLAP).

Figure 20. End view of the carp screens on the triple box culvert on the earthen bank.

7.4.2 Wetting and drying cycle

The wetting and drying regime introduced into some wetlands is intended to restore a natural cycle. The lagoon is likely to be a key habitat for carp spawning and recruitment therefore any control of water levels would be beneficial for reducing spawning success. If the wetland was previously dry and a wetting regime was reinstated then this would be a benefit to fish. To limit ingress of larval and juvenile carp a winter filling cycle is recommended. It is important to note that Yatco Lagoon would have naturally filled in spring and summer and therefore the recommended filling in winter does not simulate natural conditions.

In terms of carp management, the justification for a winter fill is that if carp have access to off-channel habitats in spring and summer there is potential to limit carp entry (including small larvae/juveniles) and adult spawning. If natural values require a spring/summer filling event then a reduction in carp spawning success might be achieved by manipulating water levels. Carp lay eggs in shallow water and reducing water levels in wetlands just after carp have spawned would kill many eggs. The feasibility and impacts of this option should be investigated for Yatco Lagoon since the northern lagoon might not dry in a single season (Gippel 2007) and drying needs to be consistent with the Wetland Management Plan.

7.4.3 Harvest or destruction of carp accumulations

The new technology known as the William's carp separation cage (Williams' cage) has successfully been applied at a number of fishways on the mainstem of the Murray River where it automatically separates adult carp from native fish. Briefly, carp and native fish are trapped in a funnel cage after which carp leap into a second holding cage while native fish are automatically released. The Williams' cage has been highly successful at Lock 1 (Blanchetown) with over 75 tonnes of carp removed since late 2007 (Figure 21 and 22). A concept for a similar system is shown in Figures 20 and 21. Additionally, SARDI are presently concluding wetland trials with the jumping technology and also with a new carp 'pushing' innovation at Banrock wetlands.

Trapping and removal of carp at Yatco Lagoon has some potential but would likely require experimental trials to optimise the design and ensure native fish are protected. At this stage the trap cannot separate juvenile carp (<250 mm long). Carp cage infrastructure can be transferable at various key points within the Yatco Lagoon system and should be managed in an adaptive manner.

A key to successful carp management is a co-operative approach with professional fisherman. At Lock 1, carp are removed and frozen on-site by professional fishers (Garry Warwick and Damien Wilks) and a similar process could occur at Yatco Lagoon. During floods, when access is restricted, debris loads are elevated and when Yatco Lagoon becomes a major migratory pathway for large-bodied fish the carp cage (or screens) should be removed.

Table 4 describes the different management strategies for carp at Yatco Lagoon. The present management of wetting and drying wetlands to mimic a natural regime will disadvantage carp and should continue during the present regulated flow conditions.

Figure 21. The Williams' cage infrastructure at Lock 1 fishway.

Figure 22. Adult carp automatically trapped and commercially removed at Lock 1 fishway.

7.5 Yatco embankment regulator carp control

7.5.1 Sliding culvert screens

Screens are required to block passage of carp and guide toward the trapping system. The screens will allow passage of small fish (<250 mm long). The vertical-bar aluminium screens (40 mm internal diameter) shall be fitted to "C" section slide mounts on the culverts (Figure 23). It is preferable to have the "C" sections on both the upstream and downstream sides of the culvert for full flexibility.

7.5.2 Carp cage

The Williams' carp cage is *not* required until the culverts are installed and flow patterns noted – a final concept design will be presented at that stage (Figure 24). This will allow design flexibility, in terms of application and operation. The only pre-emptive planning should be to select two potential sites for locating the cage, with good vehicular access. These sites might require a concrete pad for sitting the cage. It is important to note that the Williams' cage is only proven for fish migrating *upstream* and downstream migrating fish will likely require a modified design (Anthony Conallin, SARDI, pers. com.).

Note: It is likely that a small truck mounted crane would be necessary. Without this truck a jib arrangement might be required.

7.5.3 Carp monitoring and disposal

Planning is required for ethically disposing of carp. On-site carp holding within the lagoon is recommended (within the holding cage), or freezing on site for small numbers. It is recommended that an agreement with a local carp processor (e.g. Charlie Carp) or commercial fisher be negotiated.

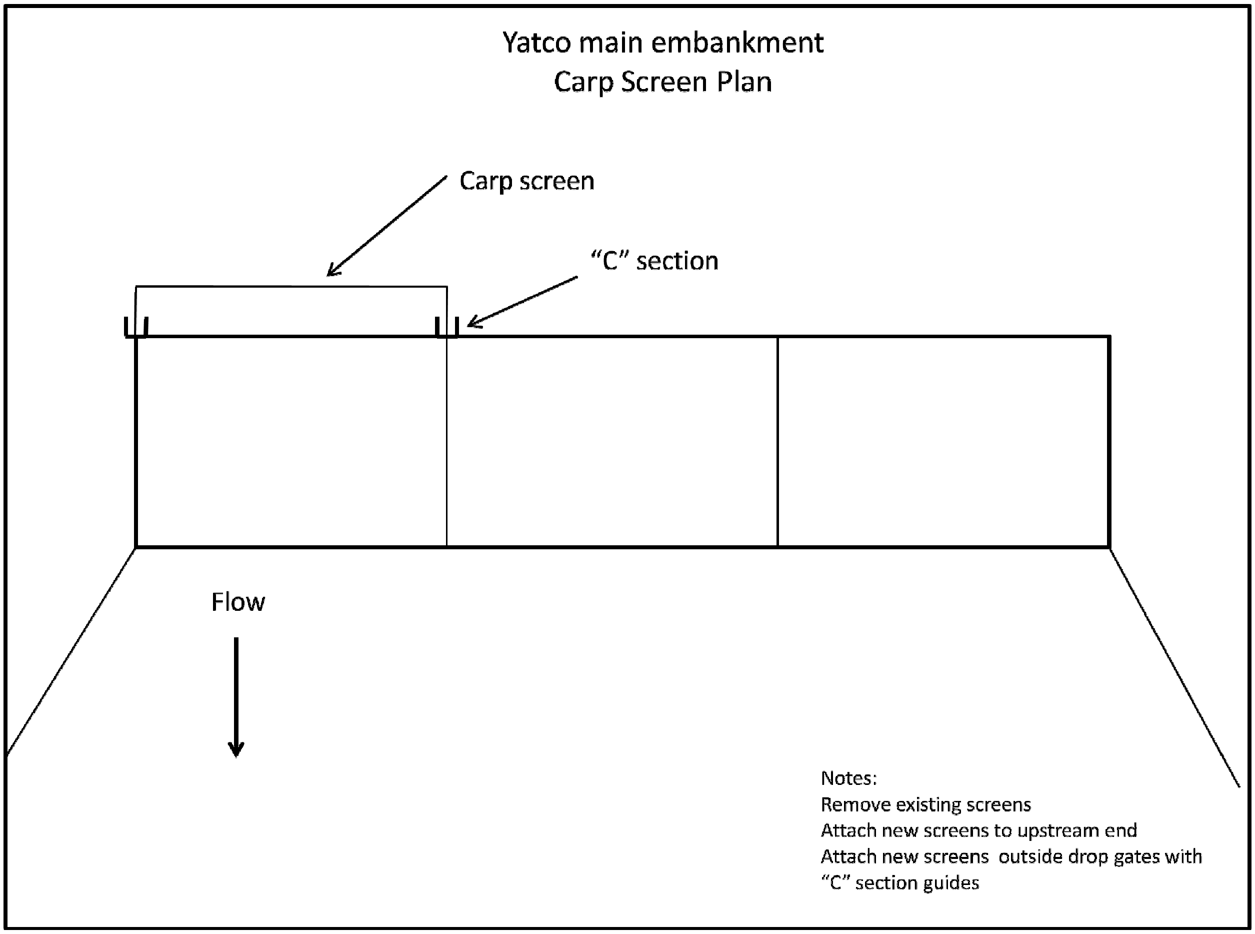


Figure 23. Plan view of a Williams' carp cage concept at Yatco main embankment regulator.

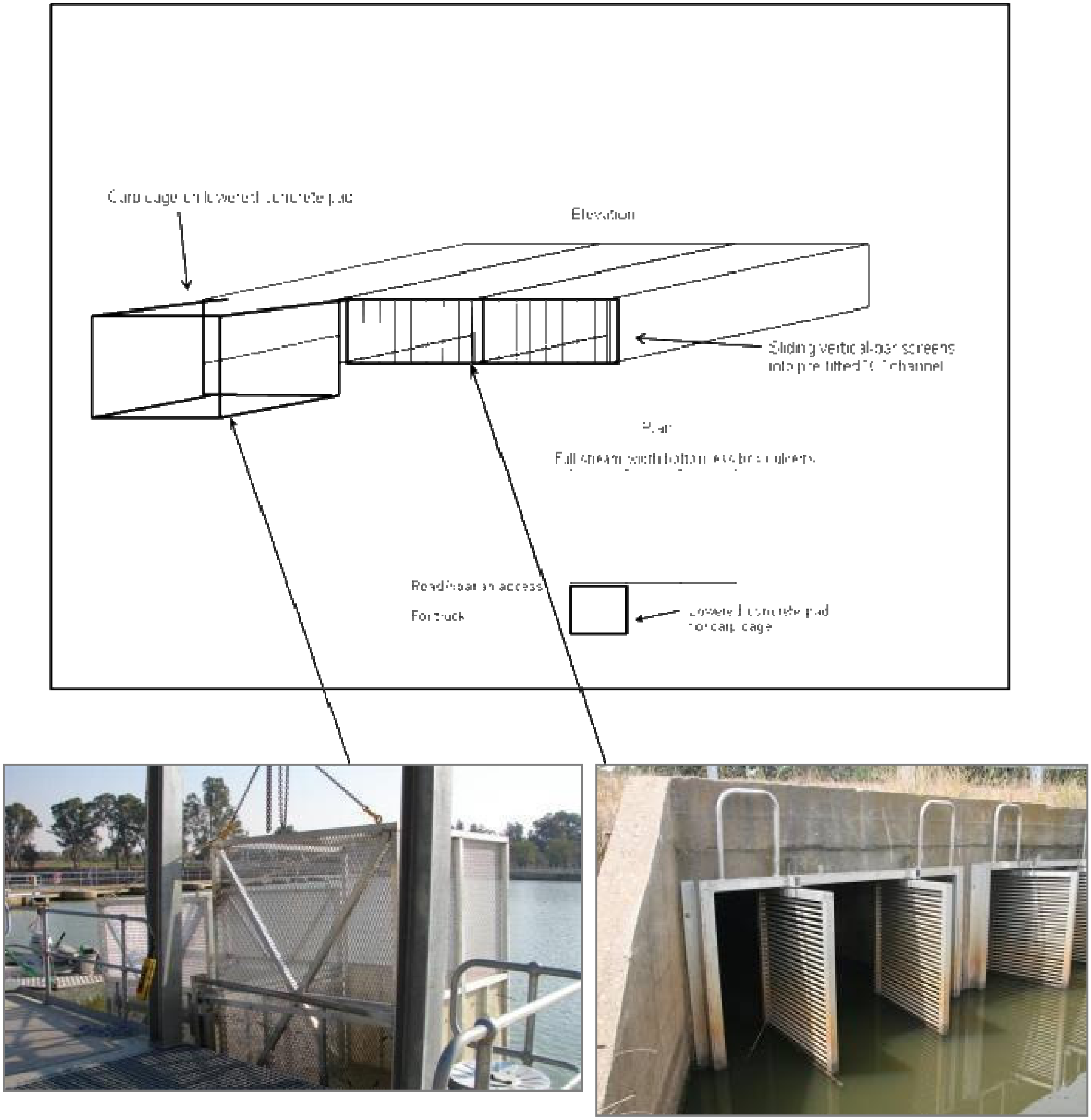


Figure 24. Cross-sectional view of a Williams' carp cage concept at a culvert crossing. Note the screens would be *vertical* bar mesh.

Culverts	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Carp control: **Wetting/drying**	Wetland filling event while few carp larvae and juveniles are present.			Experiment with raising water level by 300 mm over 24 h to initiate carp spawning and then dropping levels by 300 mm to dessicate eggs. Repeat, assess and adaptively manage.					Minimise filling of lagoon and marginal carp spawning habitats post Christmas. Begin wetland drawdown and prevent adult carp from exiting lagoon and harvest fish.			
Screens	Fit screens. Remove screens if major flood.			Screen maintenance.					Screen maintenance			
Carp cages	Organise commercial fishers, permits and carp disposal.			Fit carp cages to culverts. Remove cages if major flood.					Remove carp cages in late-December or at discretion.			

Table 4. Timetable of integrated methods for carp management at Yatco Lagoon. Note that natural filling of the lagoon would have occurred in spring and summer and a May filling event is based on carp management scenarios.

7.6 Screen maintenance

Accumulation of debris within culverts and on the screens can change hydraulic conditions and limit fish movement. It is suggested that a fortnightly visual inspection of the culverts be carried out, and immediately after a flow event. Large woody debris and other plant matter should be removed, small rocks and light sediment can remain. During a filling event the screens might require careful observation over the first week.

7.7 Summary

A significant aspect of rehabilitating wetlands is managing carp populations. At present this has focused on screens at regulators to prevent access of carp to these areas, and reintroducing a wetting and drying regime. At Yatco Lagoon carp screens and traps can be used at low to moderate flows (up to EL 10.6), but removing them at high flows to enable access for native fish. These techniques need to be applied in an adaptive manner with the minimum impact on native fish. It is also important to note that these methods are for *controlling* adult carp abundance and their impacts not for *eradication*. Planning and integration of the carp control techniques will maximise their effectiveness particularly if the lagoon is regularly cycled into a complete drying event.

8. Monitoring and maintenance

A key to improving fish passage in culverts is monitoring and maintenance. The monitoring program should include:

- Twice weekly measurements of headloss and depth at the regulators over the lagoon filling, steady state and draining cycle
- Observations of debris loads, depths and fish accumulations for future regulator/fishway sites
- Two monitoring events carp and native fish spawning and presence/absence in Yatco Lagoon (e.g. at one month after filling and during draining). The associated wetland channels make adequate comparisons for sampling.
- Culvert monitoring to detect fish behaviour to refine culvert design
- Regular inspection and maintenance of all culverts and fish passage facilities.
- Operation of the fishways and culverts linked with the monitoring.

9. Native fish rescue

Native fish and carp will naturally spread throughout Yatco Lagoon and stranding may occur if draw down is carried out at an inappropriate time (season) or too rapidly (Jones and Stuart 2008b). There is some risk that large-bodied native fish and carp will not be able to exit Yatco Lagoon.

There may be a requirement to capture fish within the lagoon and translocate them into the Murray River under these scenarios, particularly to protect against the loss of endangered or threatened fishes. To mitigate this risk a contingency plan is required and this might consist of the following steps:

- Strong communication between Yatco Wetlands Landcare Group, local NRM groups, SARDI and commercial fishers.
- Pre-set times for wetland drawdown.
- All deep refuge areas mapped and accessible.
- Commercial fishers or NRM agencies on-site for wetland draw-downs and native fish rescue.
- Development of an adaptive fish rescue plan (gear, harvest and release sites).
- Availability of appropriate gear for harvest and transport of native fish and carp.
- Standard documentation of fish rescue activities.

10. Yatco Lagoon: enhancing fish habitats

There are several ways to enhance the Yatco Lagoon habitats and foodweb values and the associated inflow channels for improved fish survival and recruitment. These methods will also largely fit with the present wetland management plan and for other rehabilitation objectives for the site. These are:

- Control of livestock and pest animals grazing on the wetland margins.
- Remove or control adult carp and invasive plants.
- Encourage growth of native macrophytes.
- Enhance large woody debris (LWD) abundance.
- Provide a diversity of hydraulic (still and flowing water) habitats.
- Consider introduction of gravel and sand substrates in several shallow marginal areas which might be adopted by freshwater catfish for nests.
- Monitor water quality (particularly salinity and acid soils)
- Promote flushing flow between the lagoons and to/from the Murray River
- Continue to encourage growth and native fringing/riparian vegetation health

11. Conclusion

Re-connection of Yatco Lagoon with the River Murray along with natural wetland wetting and drying cycles is part of a balanced river ecosystem. The present culverts at Yatco Lagoon are insufficient for providing fish passage. In addition, the existing carp screens are also inefficient. Fish passage from the river to the lagoon and carp control can be enhanced by designing and installing best-practice culverts, fishways and carp screens with consideration of the site hydrology and the biology of native and non-native fish. Restoration of native fish communities at Yatco Lagoon can then become a leading example of community driven actions toward the sustainability of river-floodplain ecosystems.

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