Construction of Fishways

Background Paper for Technical Workshop

August 2012

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1 INTRODUCTION

This paper relates to the federally funded Construction of Fishways Project, as part of the Coorong, Lower Lakes and Murray Mouth Program. The Project includes the design, construction and installation of new fishways in the barrages between Lake Alexandrina and the Coorong, and across Mundoo and Ewe Islands. These structures are presently obstacles to the migration of fishes within the Coorong, Lower Lakes and Murray Mouth (CLLMM) region. Fishways are engineered structures that facilitate the movement of fish between water bodies that have become isolated by barrages, levees and similar structures. Fish migration between different water bodies is important to support a number of biological and ecological processes, and therefore barriers to fish migration can lead to ecological degradation. Conditional funding for the Project of up to $2.9M was approved by the Commonwealth Government in April 2011. The Project will continue to 2015/16.

A Construction of Fishways Working Group was formed in late 2011 and has since meet on 3 occasions. The Working Group consists of representatives from The Department of Environment and Natural Resources, The Department for Water, SARDI, Murray-Darling Basin Authority, SA Water and Fishway Consulting Services. The Working Group will meet in June 2012 for a Technical Workshop. This Background Paper will provide the Working Group with a basis of information from which designs and locations for new fishways can be discussed at the Technical Workshop. This Paper will also provide as a reference throughout the Construction of Fishways Project.

The Working Group will oversee the design, installation, construction, installation and monitoring of the Project.

2 FISH ECOLOGY

2.1 Fish assemblage composition

The Coorong is a highly dynamic environment with many factors, most notably freshwater inflow and tidal incursion, influencing physico-chemical conditions (e.g. salinity) over a range of spatial (i.e. metres – 10's of kilometres) and temporal (i.e. hours – years) scales. The fish assemblage of the Coorong is correspondingly spatio-temporally variable (Zampatti *et al*. 2010). Approximately 80 species of fish have been recorded in the Lower Lakes and Coorong collectively (Higham *et al*. 2002), comprising a variety of life history strategies, sizes, and conservation and commercial importance. A large proportion of the recorded species (>30) are typically considered marine and are encountered irregularly, usually during times of low freshwater inflow and stable marine salinities within the Coorong. Of the remaining species over half potentially undertake movements between the Coorong and Lower Lakes. A total of 40 different species have been recorded entering the existing vertical-slot fishways on the Murray Barrages since 2006 (Table 1) (Bice *et al*. 2007; Jennings *et al*. 2008a; Jennings *et al*. 2008b; Zampatti *et al*. 2010; Zampatti *et al*. 2011a; Zampatti *et al*. 2012).

Table 1. Fish species captured between 2006 and 2012 at the entrances of the Goolwa and Tauwitchere vertical-slot fishways. Black circle denotes species presence. Maximum length sourced from McDowall (1996), Lintermans (2007) and Gomon *et al.* (2008).

Common name	**Scientific name**	**Goolwa vertical slot**	**Tauwitchere vertical slot**	**Maximum length (mm)**
Diadromous species				
Short-headed lamprey	*Mordacia mordax*	●	●	500
Pouched lamprey	*Geotria australis*	●	●	700
Congolli	*Pseudaphritis urvillii*	●	●	340
Common galaxias	*Galaxias maculatus*	●	●	190
Short-finned eel*	*Anguilla australis*	-	-	1100
Freshwater species				
Golden perch	*Macquaria ambigua*	●	●	760
Australian smelt	*Retropinna semoni*	●	●	100
Bony herring	*Nematalosa erebi*	●	●	470
Flat-headed gudgeon	*Philypnodon grandiceps*	●	●	115
Dwarf-flat-headed gudgeon	*Philypnodon macrostomus*	-	●	65

Carp gudgeon	*Hypseleotris spp.*	●	●	70
Common carp@	*Cyprinus carpio*	●	●	1200
Goldfish@	*Carrasius auratus*	●	●	400
Redfin perch@	*Perca fluviatilis*	●	●	600
Eastern Gambusia@	*Gambusia holbrooki*	-	●	60
Estuarine species				
Small-mouthed hardyhead	*Atherinosoma microstoma*	●	●	107
Lagoon goby	*Tasmanogobius lasti*	●	●	55
Tamar river goby	*Afurcagobius tamarensis*	●	●	110
Southern long-finned goby	*Favonigobius lateralis*	●	●	75
Blue-spot goby	*Pseudogobius olorum*	●	●	60
Bridled goby	*Arenogobius bifrenatus*	●	●	150
Greenback flounder	*Rhombosolea tapirina*	●	●	450
Long-snouted flounder	*Ammostetris rostratus*	-	●	300
River garfish	*Hyperhamphus regularis*	●	●	350
Black bream	*Acanthopagrus butcherii*	●	●	550
Marine species				
Yellow-eyed mullet	*Aldrichetta forsteri*	●	●	400
Flat-tailed mullet	*Liza argentea*	●	●	450
Mulloway	*Argyrosomus japonicas*	●	●	2000
Soldier fish	*Gymnapistes marmoratus*	●	●	180
Smooth toadfish	*Tetractenos glaber*	●	-	150
Sea sweep	*Scorpis aequipinnis*	●	-	400
Australian herring	*Arripis georgianus*	-	●	400
Australian salmon	*Arripis trutta*	●	●	750
Sandy sprat	*Hyperlophus vtitatus*	●	●	100

Blue sprat	*Spratelloides robustus*	●	-	120
Australian anchovy	*Engraulis australis*	-	●	150
Australian pilchard	*Sardinops sagax*	-	●	250
Pugnose pipefish	*Pugnaso curtirostris*	●	-	190
Southern garfish	*Hyperhamphus melanchir*	-	●	500
Zebra fish	*Girella zebra*	●	-	500
Tasmanian blenny	*Parablennius tasmanianus*	●	-	130

*@Denotes non-native species. *Has not been sampled in fishways but sampled immediately upstream (SARDI Unpublished Data).*

Of the species recorded at the entrances of existing fishways, movement between the Coorong and Lower Lakes varies between species in terms of importance (e.g. obligate vs. facultative life history process), motivation (e.g. reproduction, avoidance of unfavourable conditions), regularity, life stage (e.g. adult or juvenile), timing and direction (i.e. upstream and/or downstream) and the proportion of the population that undertake these movements. Accordingly, fish that may utilise fishways to move between the Coorong and Lower Lakes can generally be classified into the following three groupings:

- *Diadromous species* – Fish species that undertake regular, seasonal and life-stage-consistent movements between estuarine/marine and freshwater environments (McDowall 2008). These movements typically represent an obligate life history process and thus providing passage past instream barriers is fundamental to the persistence of these species. There are three forms of diadromy, of which anadromy and catadromy are represented in the fish fauna of the Coorong and Lower Lakes. Anadromy and catadromy are differentiated by the environment in which spawning takes place and the direction of movement undertaken by different life stages (Figure 1). Anadromy is characterised by adult marine residence, upstream migration into freshwater environments for the purpose of spawning and freshwater development of larvae and juveniles, followed by downstream juvenile migrations into estuarine/marine environments (e.g. short-headed lamprey, *Mordacia mordax*). Catadromy is characterised by adult freshwater residence, downstream migration into estuarine/marine environments for the purpose of spawning and estuarine/marine development of larvae and juveniles, followed by upstream migrations of juveniles into freshwater environments (e.g. congolli, *Pseudaphritis urvillii*).

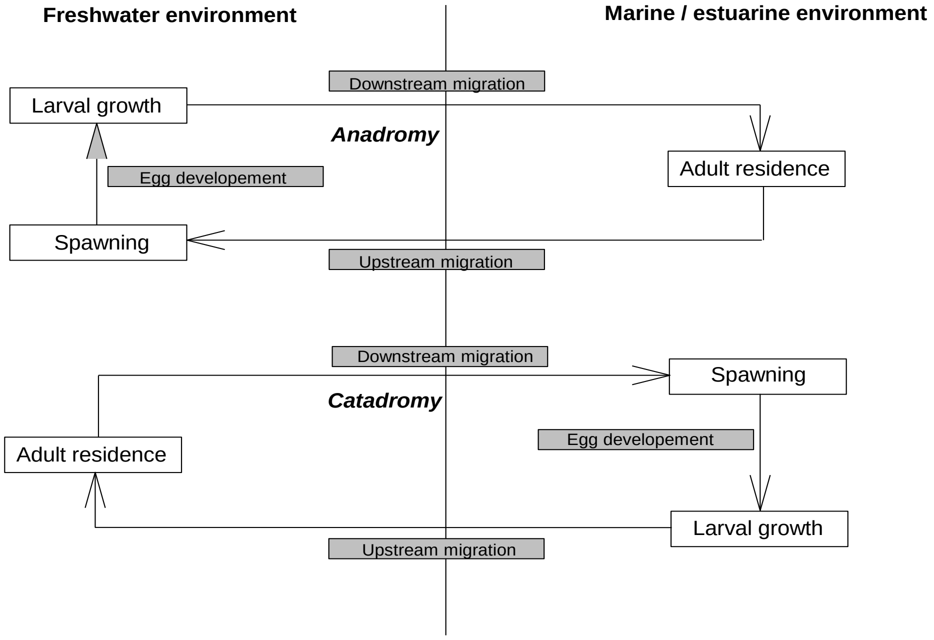

Figure 1. Conceptual model of anadromous and catadromous life history strategies.

- *Displaced obligate freshwater species* – During times of high freshwater discharge, freshwater fish species are regularly recorded in the Coorong (Zampatti *et al.* 2012). Movement into the Coorong from the Lower Lakes may be involuntary, via entrainment in outflow, or represent dispersive movements to exploit newly available habitat following decreases in estuarine salinity. Nonetheless, upon reductions or cessation of freshwater inflows, increasing salinity necessitates the return movement of obligate freshwater species (e.g. golden perch, *Macquaria ambigua*) into habitats with lower salinities. As such, return movements into the Lower Lakes are for the purpose of avoiding unfavourable conditions and are potentially necessary to avoid mortality.

- *Estuarine/marine species* – Most estuarine fish species have broad salinity tolerances (euryhaline) and may move between estuarine and freshwater environments. Some species within this group (e.g. small-mouthed hardyhead, *Atherinosoma microstoma*) have very wide tolerances and are able to complete their lifecycles in both environments, whilst others are less tolerant and movements into freshwater are likely to occur for only short periods of time. Such movements are unlikely to represent obligate life history processes but are probably for the purpose of feeding or as a defence against parasitism. Thus, such movements may not occur seasonally or with particular regularity.

2.2 Timing, size at migration and abundance

Timing of movement and size of fish at movement between the Coorong and Lower Lakes varies between species and such knowledge is fundamental to fishway design and operation. A summary of the timing of movement and size range of several species commonly sampled in the existing Murray Barrage fishways that are representative of the three different life history strategies is presented in Table 2. Local data, gathered from barrage fishway monitoring undertaken from 2006 – 2012 (Bice *et al.* 2007; Jennings *et al.* 2008a; Jennings *et al.* 2008b; Zampatti *et al.* 2010; Zampatti *et al.* 2011a; Zampatti *et al.* 2012) and other research projects in the region (Zampatti *et al.* 2011b), was used where possible. General information on the movement patterns of these species more broadly in south-eastern Australia was used where required (McDowall 1996).

2.3 Implications for fish passage

- There is a high diversity (>30) of fish species potentially moving between the Coorong and Lower Lakes, comprising a variety of life history strategies and life stages (young-of-year, juveniles, sub-adults and adults)
- A broad size range of fish from 20 to 600 mm total length, migrate at the barrages. Swimming ability is directly related to bodysize and for fish passage at the barrages, it can be can be divided into approximately three size groups:
    - *Small–bodied fish* 20-100 mm; very poor swimming ability, requiring very low water velocities and turbulence.
    - *Medium-bodied fish* 100-250 mm; moderate swimming ability.
    - *Large-bodied fish*[1] 250-600mm; high burst and prolonged swimming speeds.
- Whilst several medium and large-bodied fish species move between the Coorong and Lower Lakes, small-bodied fish species and life stages (<100 mm total length), numerically dominate the migratory fish community. This includes upstream migrating juveniles of catadromous species for whom movement between estuarine/marine and freshwater environments represents an obligate life-history process. Thus, fishway design should consider the swimming ability and behaviour of these species.
- Movement may occur at different times of the year for different species. As a minimum, fish passage should be facilitated from May – February to encompass known peak movement periods.

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[1] Although adult mulloway (500-1500 mm) are present in the marine and occasionally estuarine environment they are not expected to enter freshwater

- To facilitate the return movements of obligate freshwater fish species, fish passage needs to be facilitated during receding freshwater flows to the Coorong and upon the cessation of flows.

Table 2. Timing of downstream and upstream movement, and size range of individuals undertaking movements, for several fish species representative of the three different life history strategies. Timing of movement and length range data is sourced from Barrage fishway monitoring from 2006 – 2012.

Common name	**Scientific name**	**Timing of peak movement and length range**				**Specific comments**
		Downstream	**Length range (mm)**	**Upstream**	**Length range (mm)**	
Diadromous species						
Short-headed lamprey	*Mordacia mordax*	From July (September*)	165*	July* – November	340 – 435	Anadromous *Downstream migrant sampled upstream Goolwa Barrage in September 2008 (SARDI Unpublished data). *Upstream migration may commence prior to July
Pouched lamprey	*Geotria australis*	From July	?	July* – November	460 – 586	Anadromous *Upstream migration may commence prior to July
Common galaxias	*Galaxias maculatus*	May - November	>70	August - January	23 – 133*	Catadromous *fish 30 – 60 mm most common
Congolli	*Pseudaphritis urvillii*	June - September	>200	November - January	17 – 238*	Catadromous *fish 25 – 80 mm most common
Freshwater species						
Golden perch	*Macquaria ambigua*	During freshwater discharge to Coorong	Likely all sizes	During and immediately post freshwater discharge	42 – 480	
Bony herring	*Nematalosa erebi*	During freshwater discharge to Coorong	Likely all sizes	During and immediately post freshwater discharge	23 – 282	
Australian smelt	*Retropinna semoni*	During freshwater discharge to Coorong	Likely all sizes	During and immediately post freshwater discharge	17 – 86	

Table 2 continued.

Common name	**Scientific name**	**Timing of movement and length range**				**Specific comments**
		Downstream	**Length range**	**Upstream**	**Length range**	
Estuarine/marine species						
Lagoon goby	*Tasmanogobius semoni*	When connected	?	When connected (September – February*)	14 – 61	*Upstream movements recorded between September and February but could also occur outside of this period.
Tamar river goby	*Afurcagobius tamarensis*	When connected	?	When connected (September – February*)	10 – 100	*Upstream movements recorded between September and February but could also occur outside of this period.
Sandy sprat	*Hyperlophus vitattus*	When connected	?	When connected (September – February*)	18 – 96*	*Upstream movements recorded between September and February but could also occur outside of this period. *fish <50 mm in length comprise the majority of individuals
Small-mouthed hardyhead	*Atherinosoma microstoma*	When connected	?	When connected (September – February*)	17 – 91	*Upstream movements recorded between September and February but could also occur outside of this period.
Black bream	*Acanthopagrus butcherii*	When connected	?	When connected (November – January*)	31 - 465	*Upstream movements recorded between November and January but could also occur outside of this period.

3 HYDROLOGY

3.1 Background

An analysis of hydrology is used in fishway design firstly to ensure biological function - specifically to ensure fish passage is provided at the flows, water levels, season and periods when fish are migrating - and secondly because these criteria can be cost-sensitive.

There are, however, caveats on optimising hydrological parameters to reduce cost. Firstly, other factors such as dewatering for construction can sometimes have a far greater influence on cost than hydrological design criteria. Secondly, some fishway designs, such as fish locks, do not vary much in cost with differing water levels. Thirdly, optimising hydrological criteria can reduce the flexibility of a fishway to operate in changed conditions in the future; this happened at the present barrage fishways and at a number of sites in eastern Australia in the recent drought.

At the barrages one of the cost-sensitive areas is constructing outside the footprint of the barrage. Once a design is outside the footprint, changes in the length of the fishway are much less cost-sensitive.

3.2 Flow

Flow from the barrages from 1969 to the present is shown in Figure 2. Although the flows are variable there is strong seasonality with higher flows from late winter to early summer, which coincides with the peak migration season of June to January (see previous section on fish ecology) (Figure 3). Removing data for the recent drought (2002-2010) makes little difference to these broad seasonal patterns over the long time period; the impact of abstraction combined with droughts is at low flows where it greatly influences potential fish migration at the barrages.

The periods of zero flow in Figure 2 reflect abstraction as well as droughts. Figure 4 shows gauged and modelled natural flow to SA in the recent drought. The losses from the river and lakes under natural conditions are mainly from evaporation, occurring in the hottest months, with a maximum of 210 gigalitres per month (approximately 150 GL/month from the lakes (Shepherd 1971) and 60 GL/month in the river (Gippel 2006) from the SA border). The data shows that even in the recent severe drought, under natural conditions, there was very likely flow through the Murray mouth from late winter to early summer every year except 2006.

The modelled hydrology fits the migration data from the previous section on fish ecology. This refines the ecological objective for fish passage which, apart from restoring connectivity, prioritises restoration of fish movement from June to January, during high as well as low flows. It also suggests a maximum interannual break of migration of no greater than one year but this reflects flow, and connectivity and spawning of many species would have occurred every year prior to the barrages.

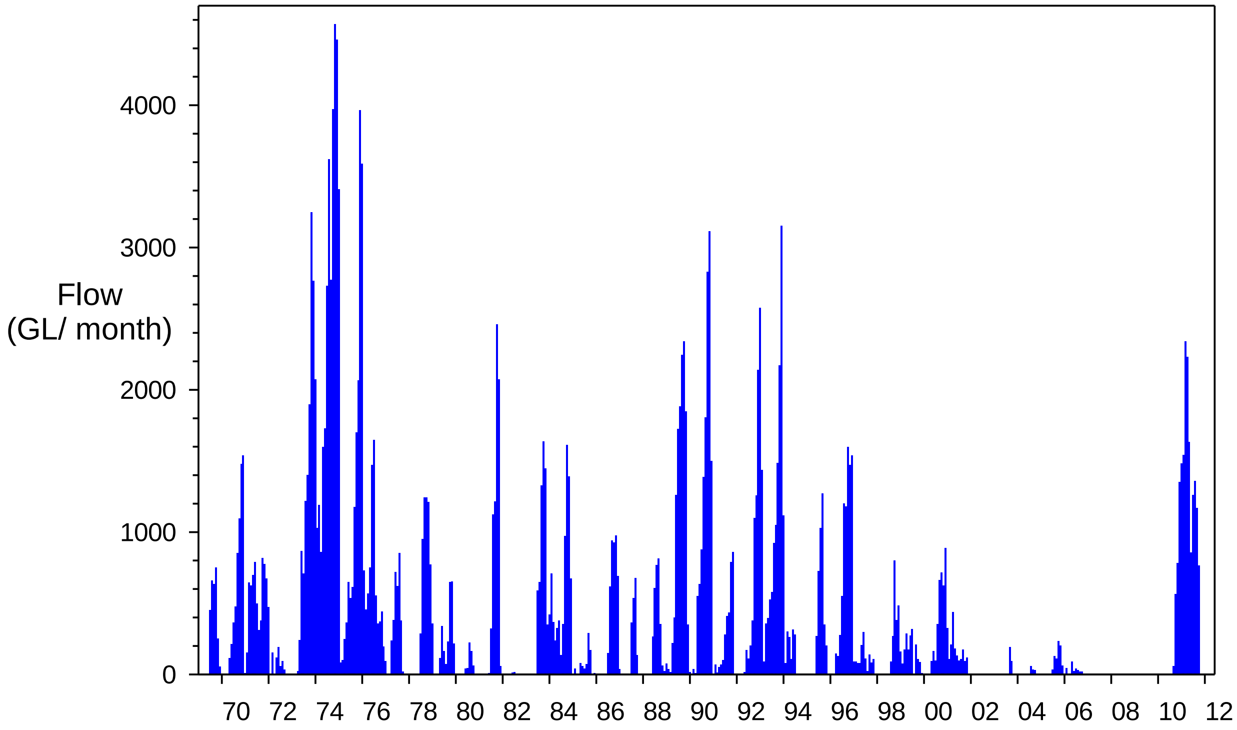


Figure 2. Monthly flow through the Murray River barrages from 1969 to 2012.

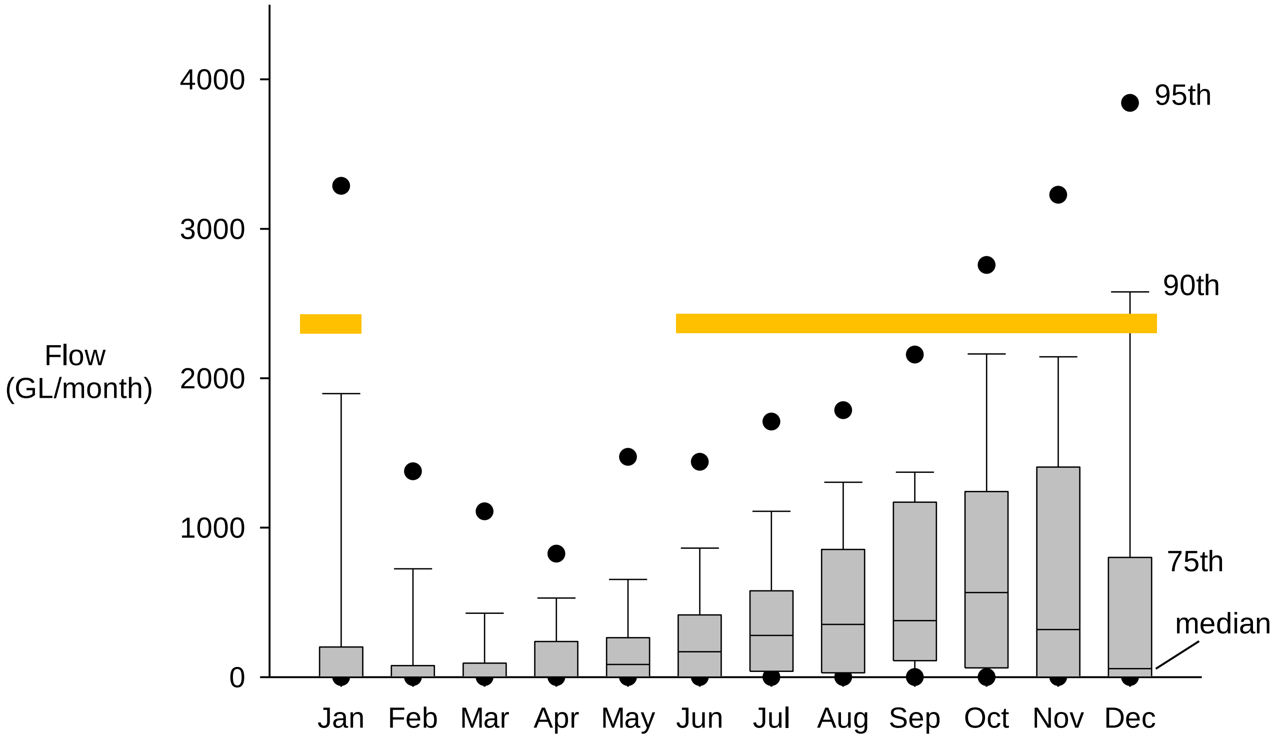


Figure 3. Box plot of monthly flows through the barrages (1969-2012), shown with the peak season of fish migration as an orange bar (season includes upstream and downstream movement).

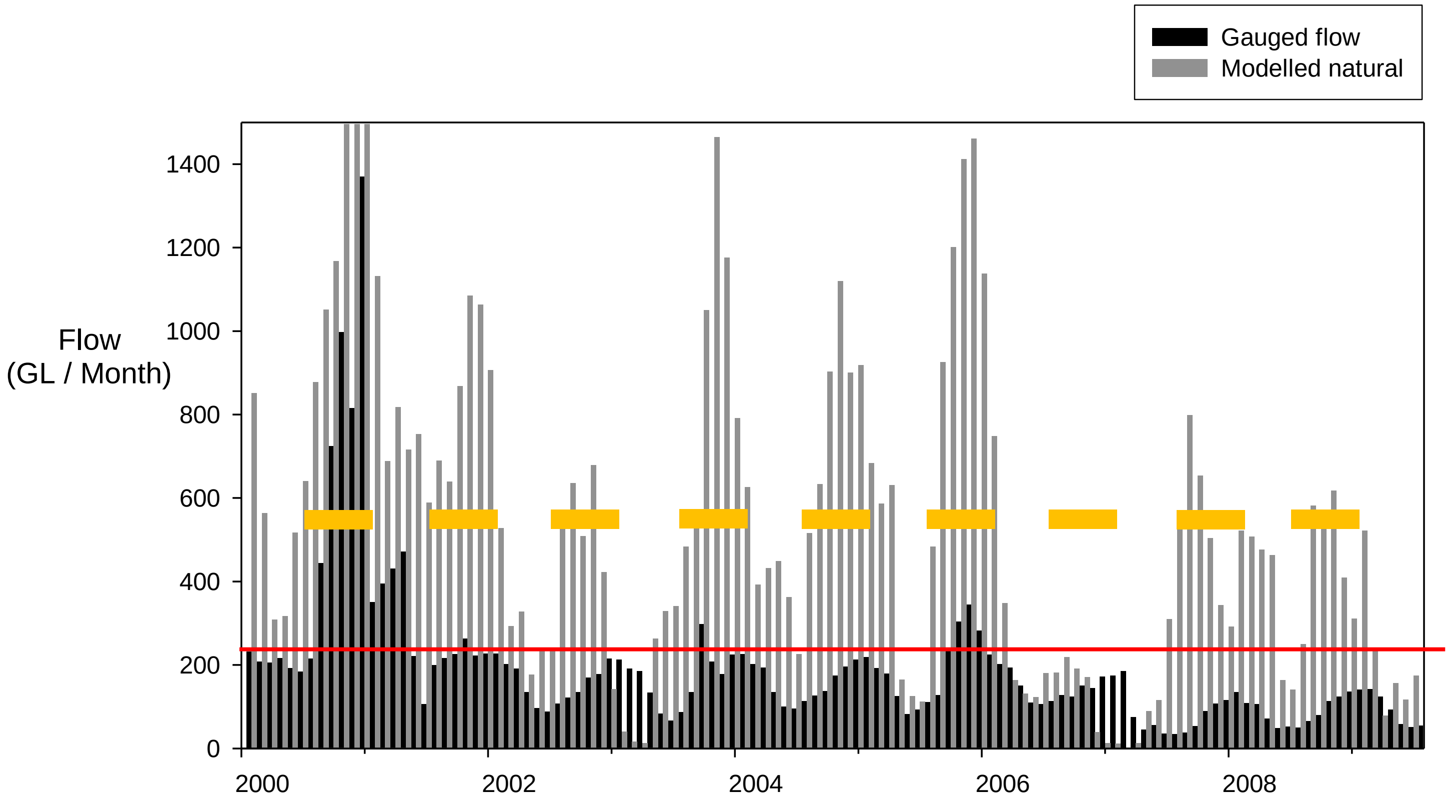


Figure 4. Comparison of gauged flow and modelled natural flow of the Murray River entering South Australia in the 2000-2009 drought, showing maximum losses from the border to the Murray mouth (red line) and the major season of fish migration at the barrages (orange bars).

3.3 Lake Levels (headwater)

Daily lake levels at Goolwa are plotted for 1974 to 2012 (Figure 5). Lake levels for Tauwitchere follow a similar pattern although there can be large daily variation due to wind seiche. Prior to January 2007, when lake conditions could be considered 'typical', the levels were largely within 0.3 m to 1.0 m (Figure 5). The levels are managed, rising from mid-winter to spring to store water and decreasing over summer as water is used. Although this is an artificial seasonality it corresponds with the conditions that would have occurred prior to the barrages, as lake levels would have reflected inflows. The seasonality varies from a low amplitude to a high amplitude (Figure 5): if inflows are greater than evaporation and abstraction, then the lake is kept high and the amplitude is low; if inflows are less than evaporation and abstraction the lake level drops over summer and the amplitude is high.

The extent and type of fish passage required is dependent on this seasonality of lake levels. The peak period of fish migration - June to January - coincides with initially high lakes levels and then declining levels over early summer, but not the lowest levels that occur in late summer and autumn (Figure 5, Figure 6).

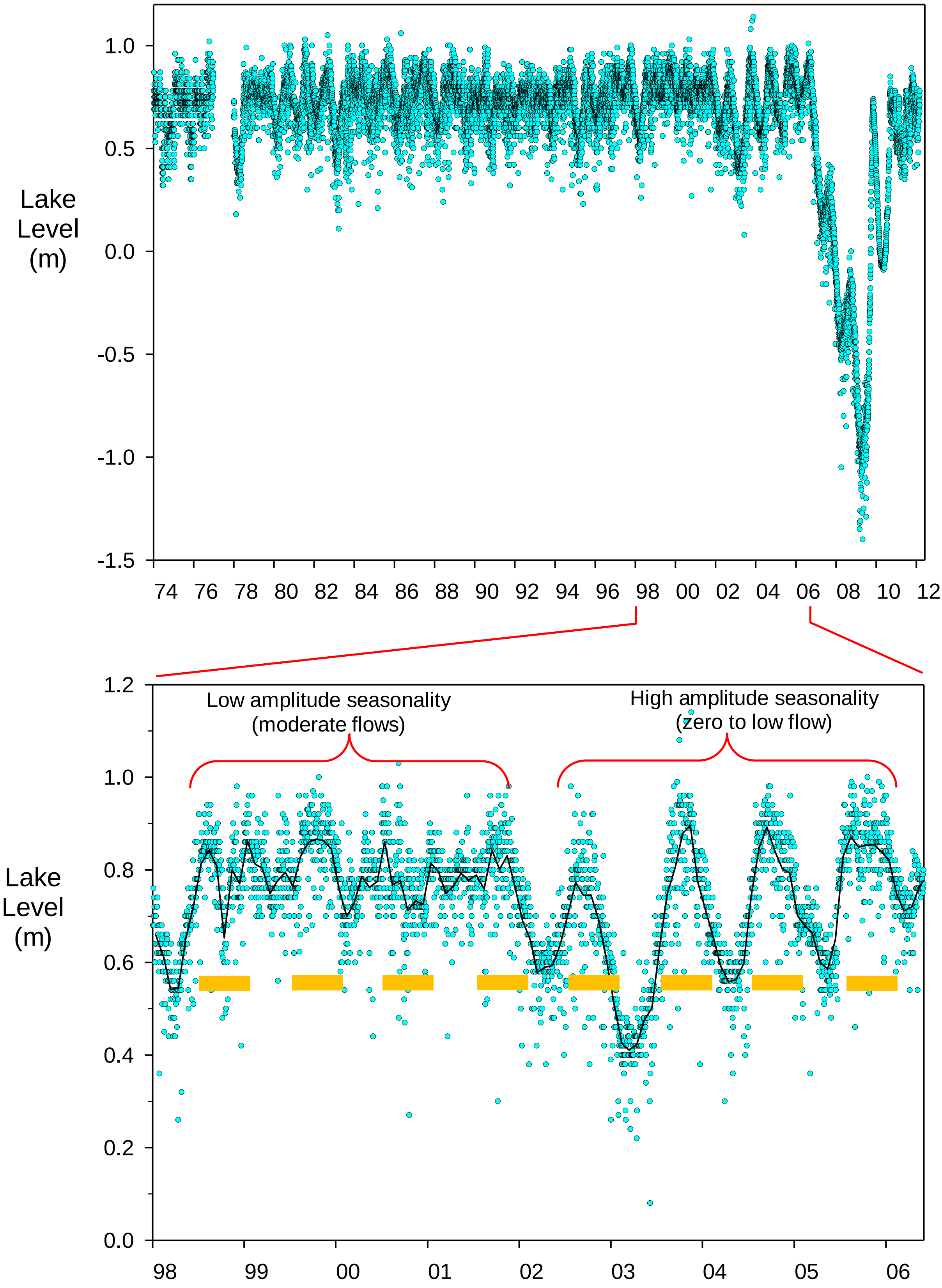


Figure 5. Lake levels at Goolwa from 1974 to 2012 and a subset from 1998 to 2006 showing the typical seasonal variation of the lake. The peak periods of fish migration (Jun - Jan) are shown as orange bars.

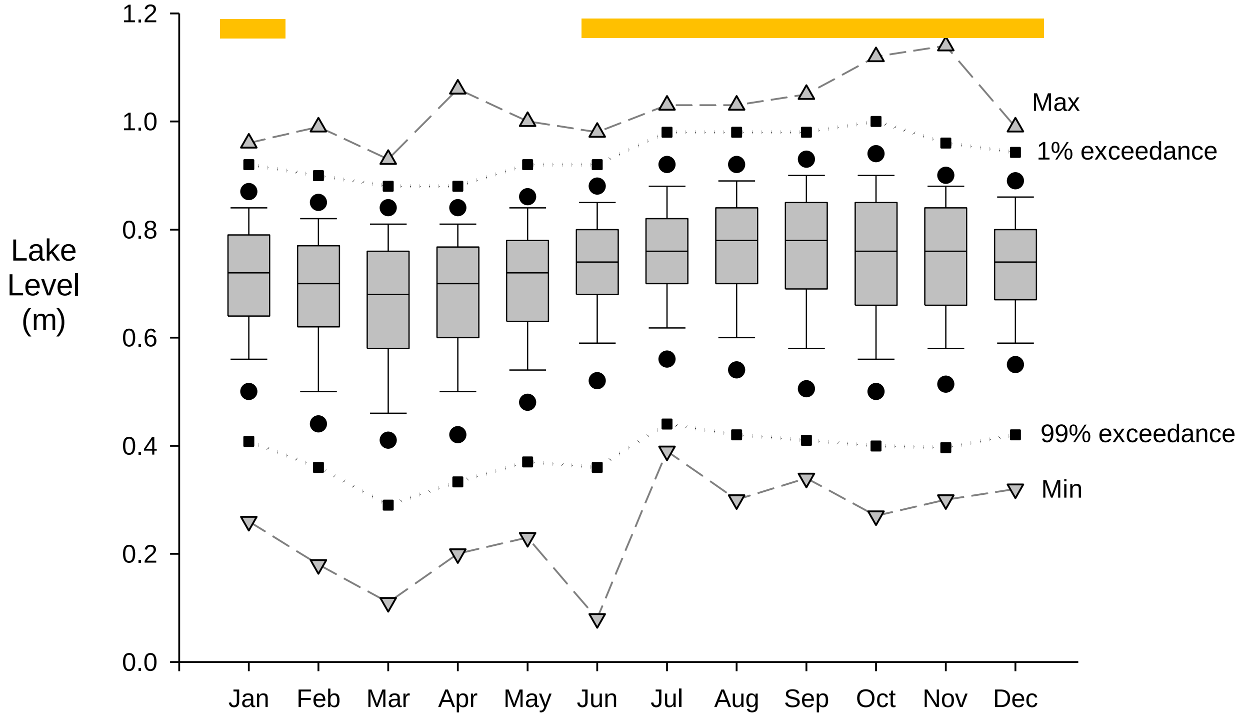


Figure 6. Box plot (showing values for median, 75th, 90th, 95th, 99th and maximum) of daily lake levels by month at Goolwa from 1974 to 2006. The peak period of fish migration (Jun - Jan) is shown as orange bars.

Flow has a direct influence on lake level. Whilst there is no passing flow at the barrages the lake can vary over the widest range, but if flow is released from the barrages the lake is above 0.7 m. At low to moderate flows the lakes varies over a small range of 0.2 m from 0.7 m AHD to 0.9 m AHD (Figure 7, Figure 8) and at higher flows the lake varies over the same range of 0.2 m but at a lower elevation of 0.5 to 0.7 m. This is different to natural conditions, where the lake would rise at higher flows and lower as flow was reduced.

The specific influences of these lake level fluctuations on fish passage are that:

i) for zero to very low barrage flows, fishways need to operate over a wide headwater range - for example 0.4 m to 1.0 m AHD would encompass 99.33 % of the time in the fish migration months - as well as use little water.

ii) for low to moderate flow releases (500-20,000 ML/d), which are an ecological priority, fishways that operate over a much narrower headwater range of 0.2 m can be used and they need to use more water to provide greater attraction for fish to compete with outflows.

A key variable in future lake levels is the Basin Plan. If more flow is released from the barrages, will the lake be more often above 0.7 m AHD and hence should fish passage be biased to this level?

The analysis of lake level and flow also shows that the spillways of the barrages, which are designed to only pass flow when the lake is very high, are likely to spill when there is little outflow elsewhere along the barrages (Figure 7). Hence, the spillways are likely to attract fish, which has often been reported for small-bodied fish, as they would be the major source of flow. Although these conditions do not occur frequently, the high level of fish attraction and potential fish movement mean that providing passage at the spillways, which can be done little modification, is an important component of a fish passage plan for the barrages.

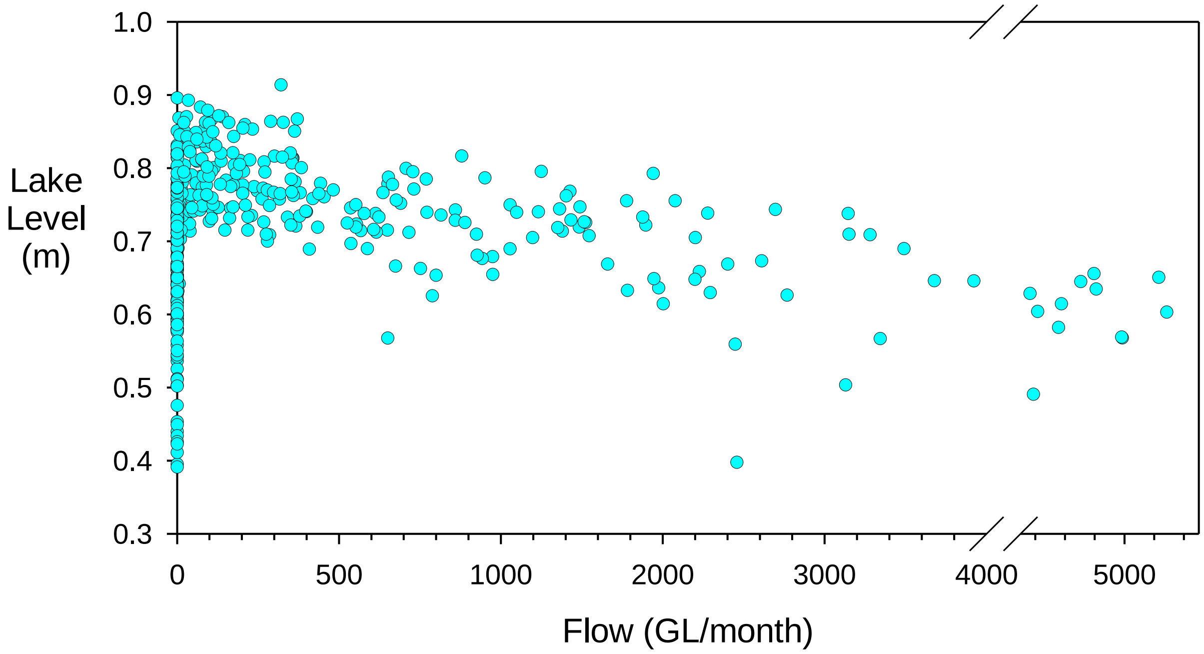


Figure 7. Lake level at Goolwa versus flow, from 1974-2006.

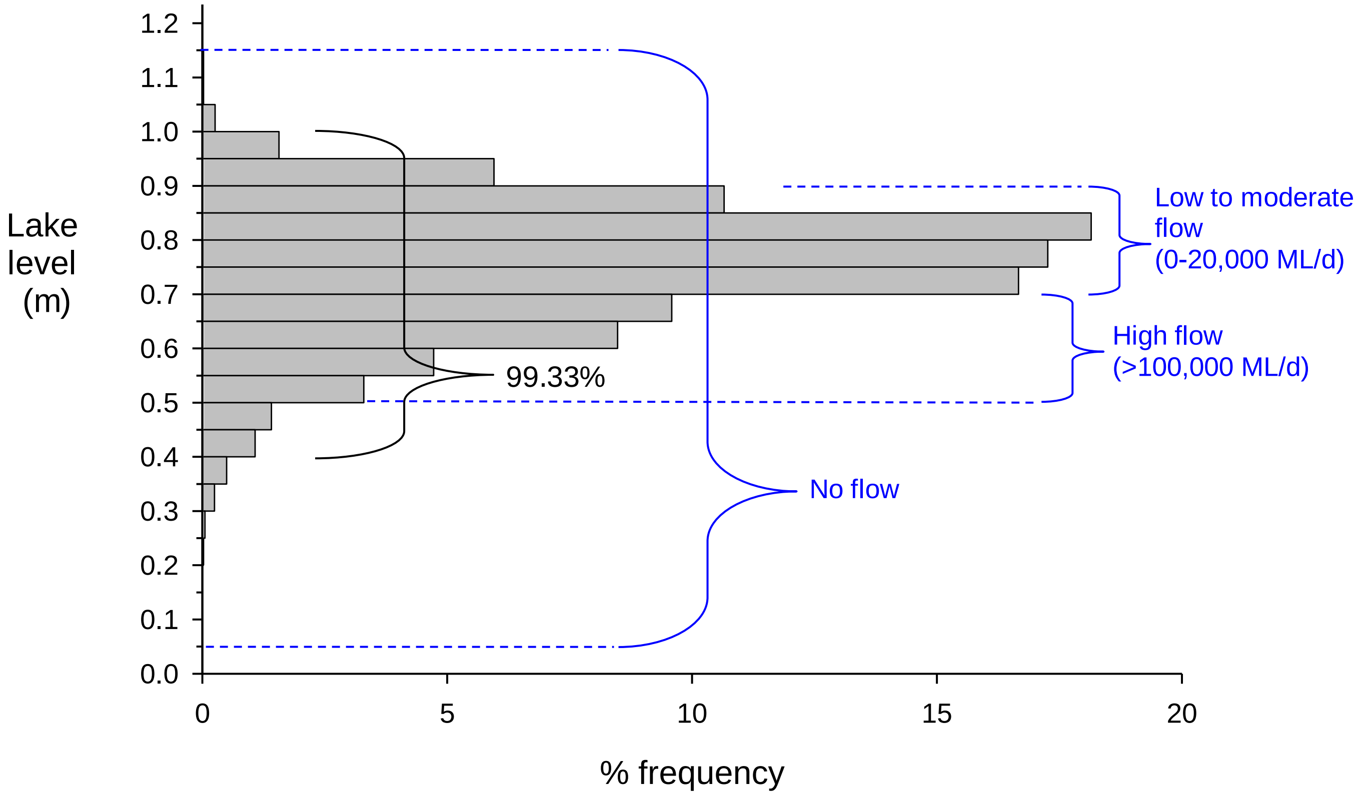


Figure 8. Percentage frequency of daily lake level at Goolwa from 1974-2006, in the peak migration months of June to January. Lake levels at different flows, from Figure 7, are shown in blue.

3.4 Tide Levels (tailwater)

The tides vary from -0.625 to +1.323 m AHD at Goolwa and from -0.45 to +1.03 m AHD at Tauwitchere; however, these are extreme events and at Goolwa the tide is above -0.30 m AHD for 99% of the time and above -0.15 m for 95% of the time, while at Tauwitchere it is above -0.25 m AHD for 99% of the time and -0.1 m AHD for 95% of the time (Figure 9).

The tide level is significantly influenced by outflows, with the lowest tides occurring when there is zero flow and both the high and low tides elevated by high flows, which is accentuated at Tauwitchere (Figure 10).

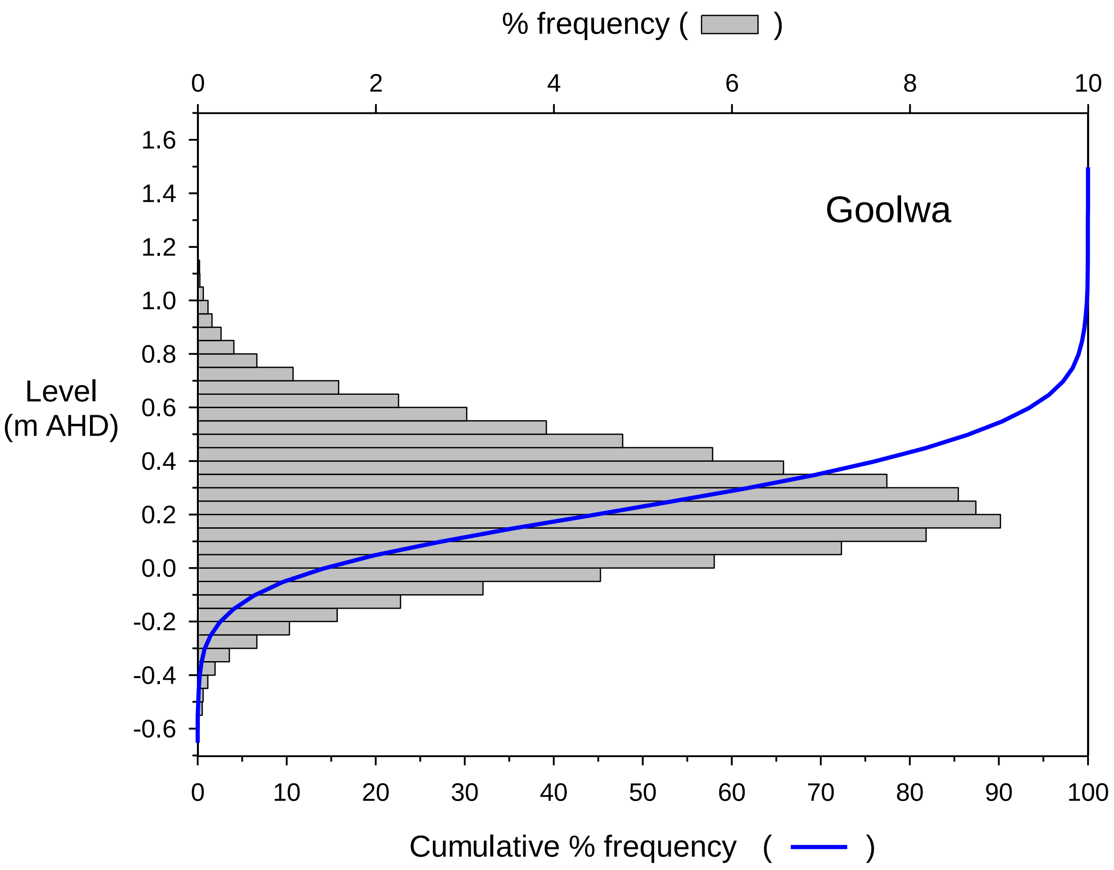
Typically tides vary with a small and high amplitude cycle each day superimposed on a lunar cycle of *neap* and *spring* tides (Figure 11). Because Tauwitchere is some distance from the Murray mouth there is a lag in tidal flow and this also interacts with wind seiche and outflows so there can be an additional cycle lasting a week or more where the tides are held at a higher or lower level (Figure 11).

Determining the appropriate tidal range for a fishway depends on the ecological objectives. At the barrages, fish can be seen migrating upstream at all tide levels in the peak migration season. Hence, to provide aquatic connectivity or *transparency* it is logical to provide passage of fish at all tides. However, for fishway designs based on gradient and length - which excludes fish locks - this can be costly, as a fishway operating for the lowest tide can be twice as long as a fishway operating for the mean tide.

In practice a compromise of operating for the *upper half of the tidal cycle within any one day* is usually applied to tidal fishways. This relates to the specific ecological objective of passing sufficient numbers of each life stage to sustain and improve native fish populations. The assumption is that, although predation of fish can occur during the lower half of the tide within a day, sufficient numbers of fish will pass during the upper half of the tide.

There are also specific diel (day/night) periods of migration. In particular, some native fish species only migrate during daylight, which applies to bony herring, Australian smelt and other small-bodied fish species in the Murray River. The diel behaviour of species at the barrages is unknown but it is very likely that some species will also only migrate during daylight. Hence, the design parameter for the tidal range for the barrage fishways can be refined to the *upper half of the tidal cycle within a diel (day/night) period, within any one day*.

Applying this principle to the barrages within a period of a low tidal cycle (i.e. low flow and *neap* lunar cycle) requires a minimum operating level of -0.4 m at Goolwa and -0.28m at Tauwitchere to provides 50% passage within any one diel period (Figure 12). This criterion may need to be further assessed in concept design if it is cost-sensitive. Further analysis could examine the number of consecutive days of delayed passage that was ecologically acceptable. Further monitoring could also evaluate the assumption of specific diel migration periods.



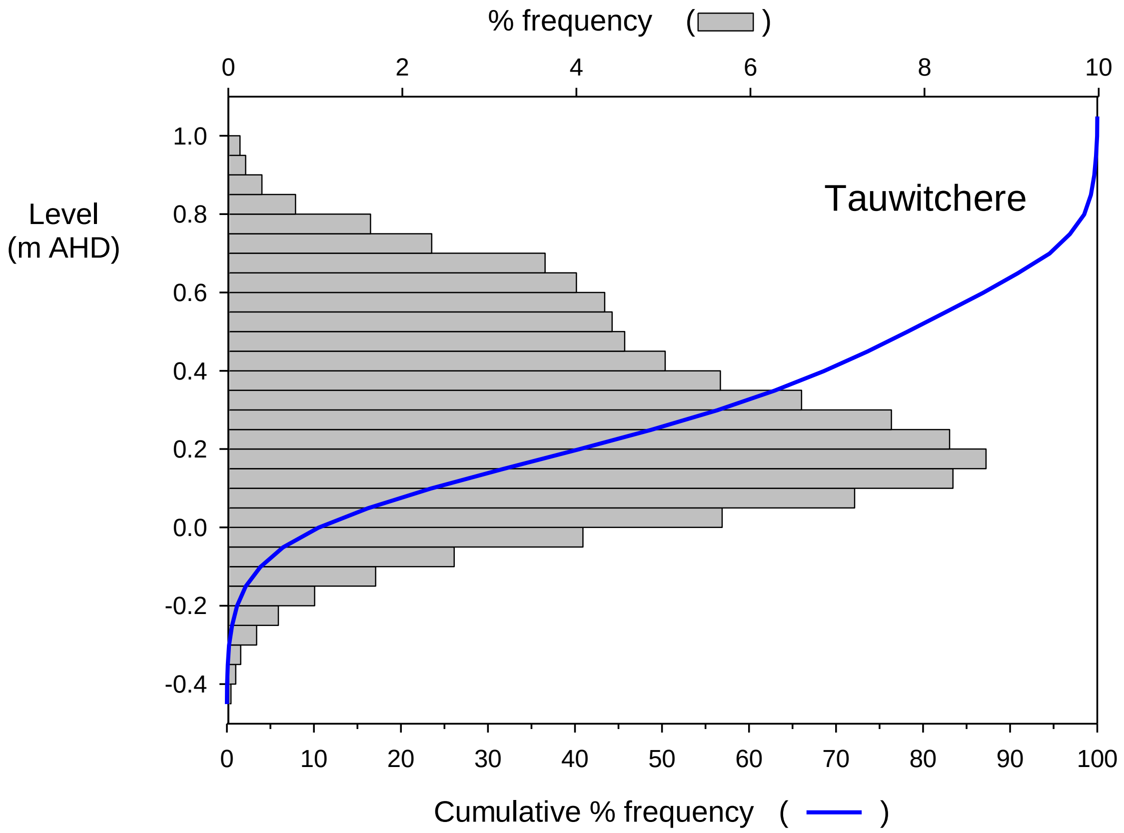


Figure 9. Frequency of hourly tidal data for Goolwa (1976-2012) and Tauwitchere (1980-2011).

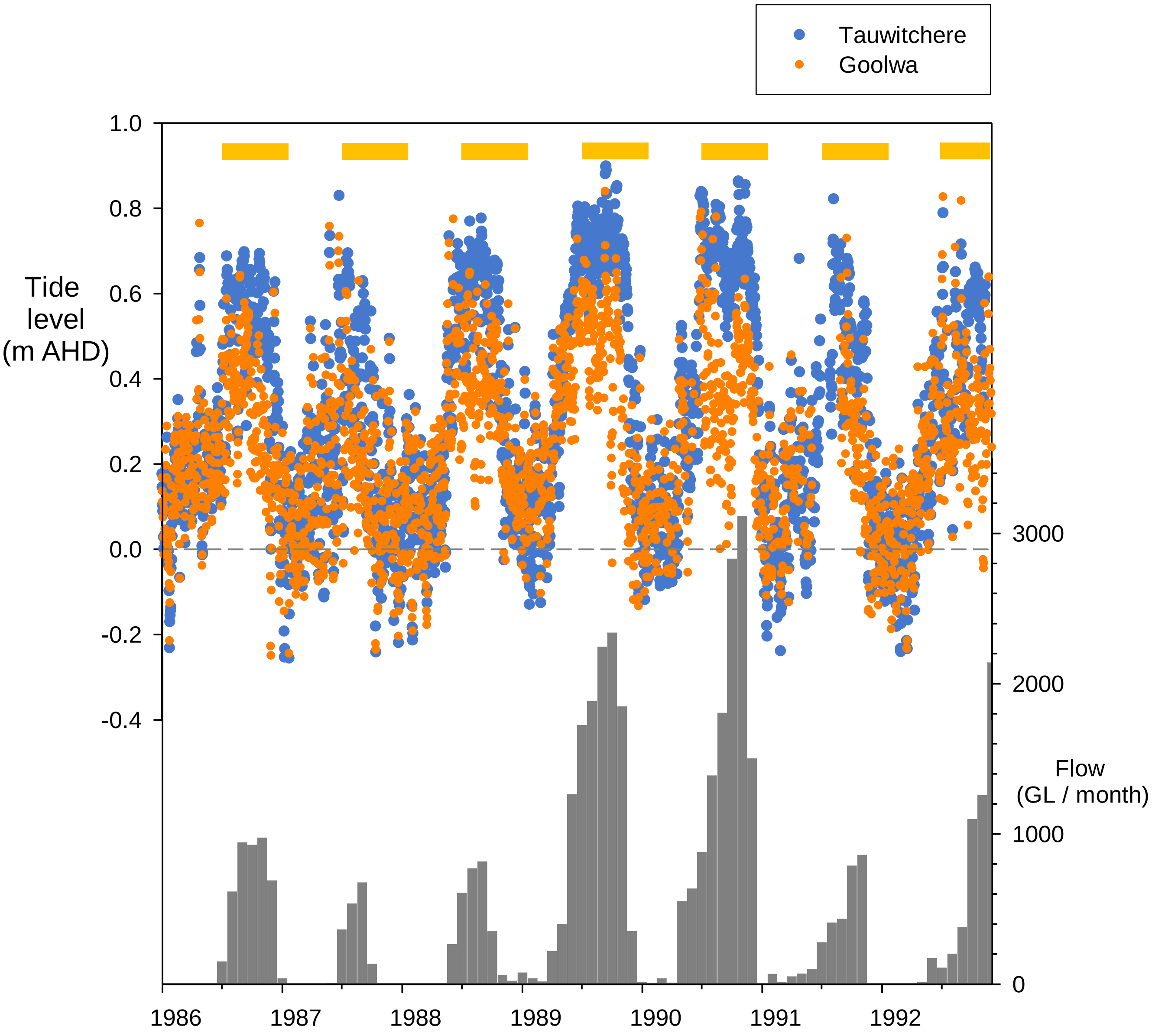


Figure 10. Daily mean tides at Goolwa and Tauwitchere shown with total monthly flow at the barrages. The peak period of fish migration (Jun - Jan) is shown as orange bars.

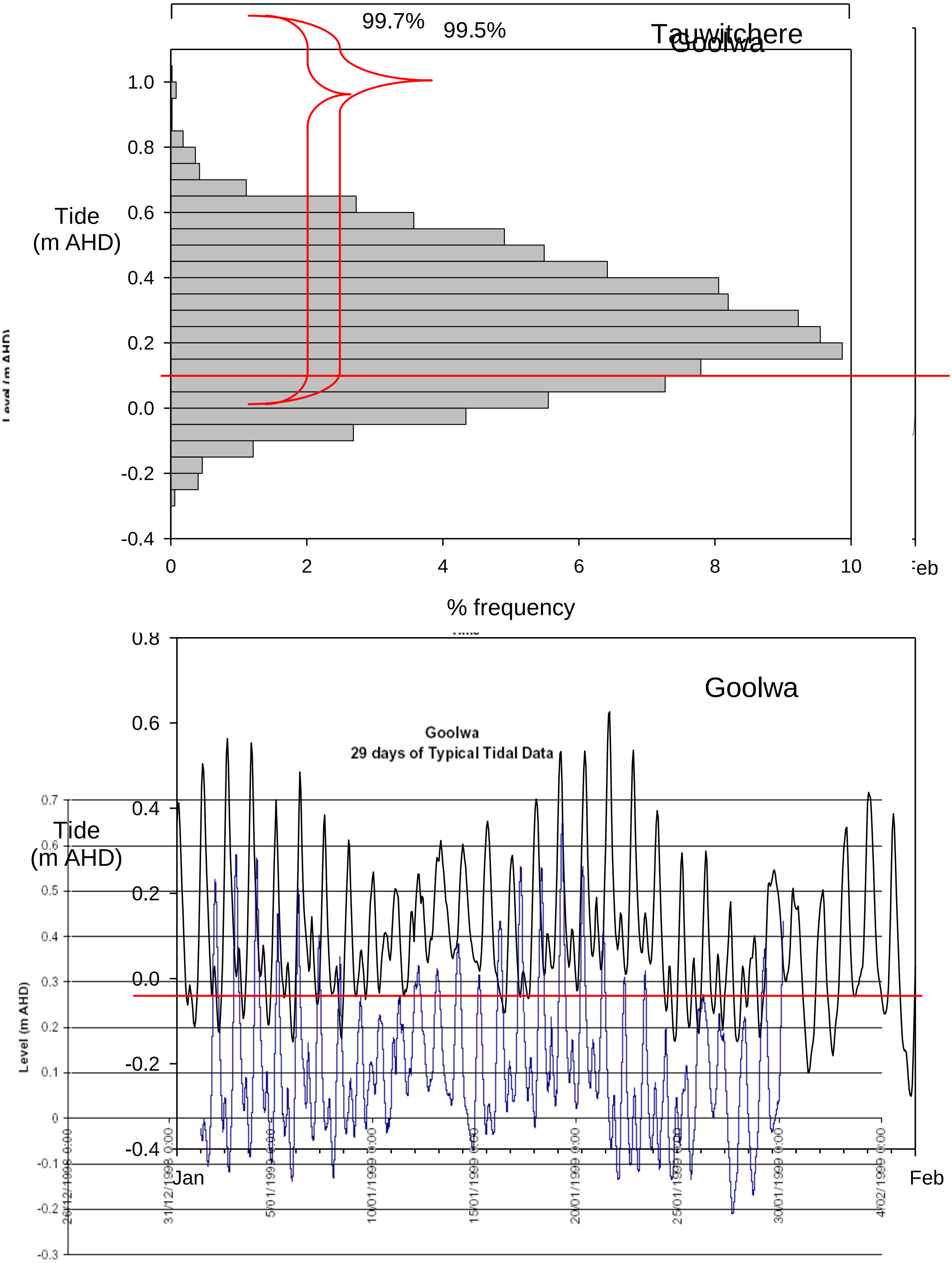
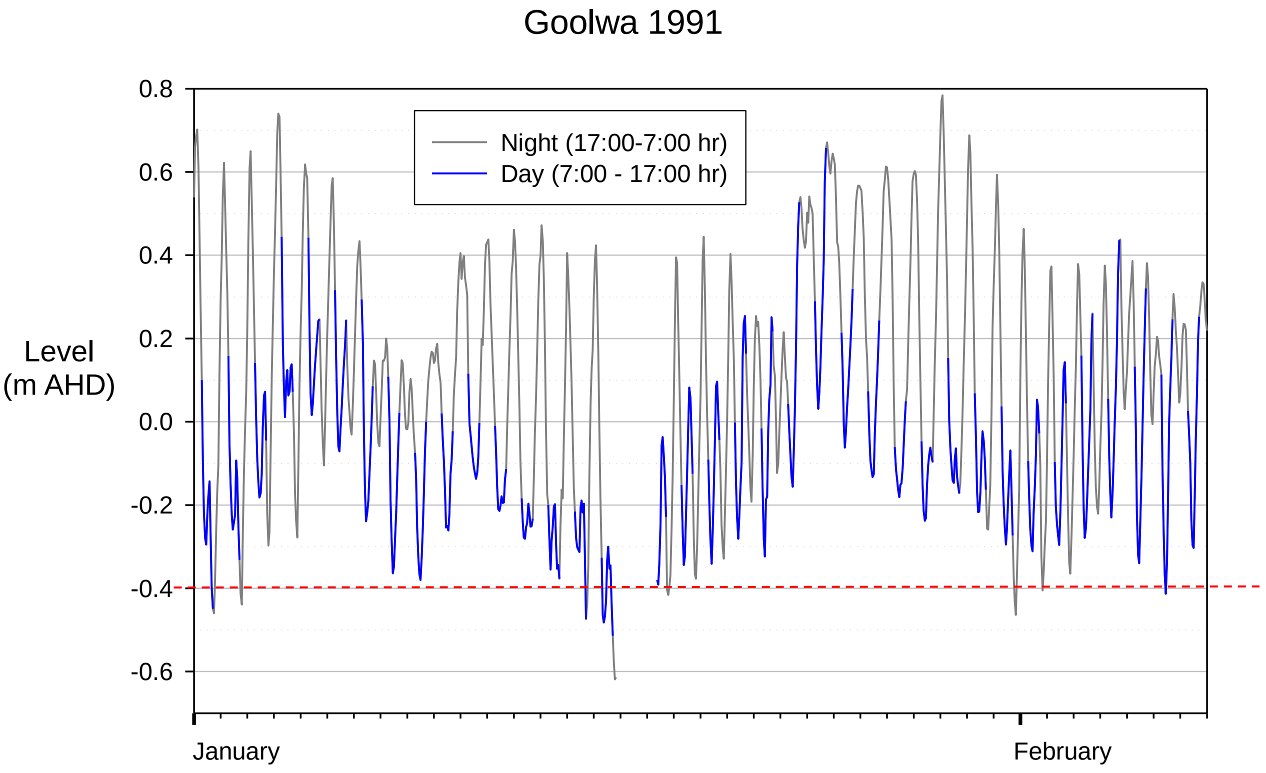


Figure 11. Hourly tidal data from Goolwa and Tauwitchere from January 1999 during a period of zero flow, showing a suppressed tidal cycle at Tauwitchere.



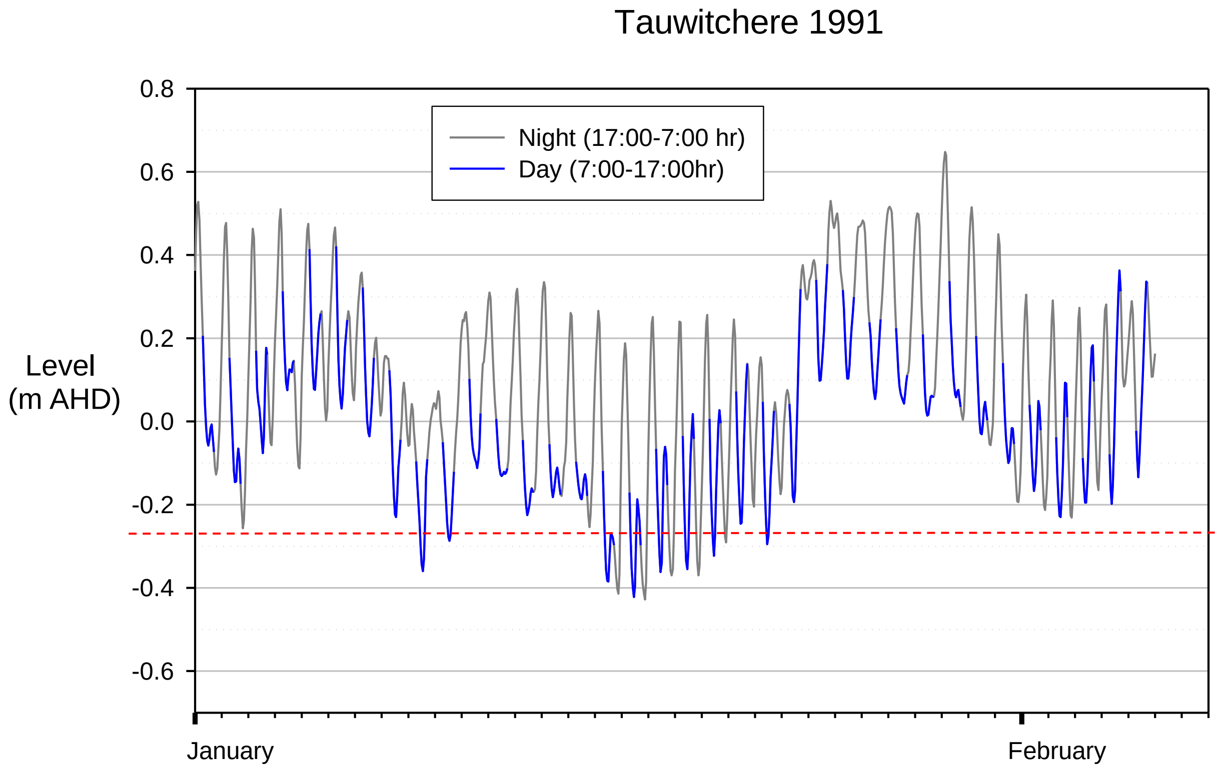


Fig. 12. Hourly tidal data during a low tidal cycle (Jan-Feb 1991). Blue line is daytime, grey line is night-time and the red dashed line is the level that provides 50% of passage for each diel period in the lowest tidal cycle.

3.5 Head Differential

As the lake and tide levels are affected by flow, so is the head differential (difference in upstream and downstream water levels). A plot of daily head differential at Tauwitchere with monthly flow (Figure 13) shows that the greatest head differential (0.9 to 1.1. m) occurs when there is low flow and lower head differential (zero to 0.5 m) occur at high flows (> 300 GL/month). The highest head differentials occur in the fish migration season and 99% of the time the head differential is less than 0.9 m (Figure 13).

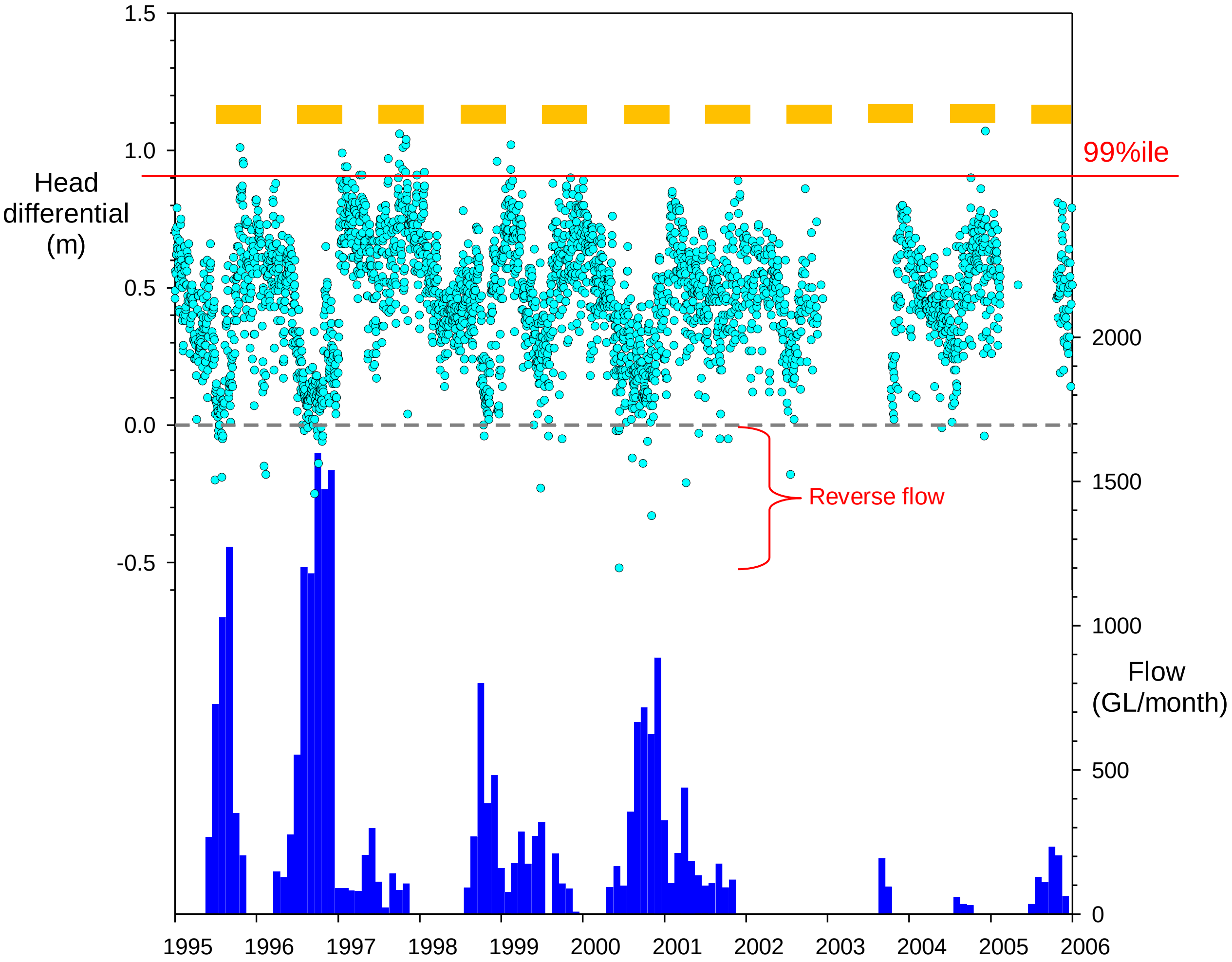


Figure 13. Daily head differential (difference in upstream and downstream water levels) at Tauwitchere compared with monthly flow. Note the trend of reduced head differential at high flows. The 99%ile for head differential is shown as a red line. The peak period of fish migration (Jun - Jan) is shown as orange bars.

3.6 Implications for Fish Passage and Fishway Design

As flow influences tidal level, as well as lake level, this refines the fish passage objectives:

i) At low flows the differential head (or difference in upstream and downstream water) is generally greatest, so fishways for these conditions need to accommodate a significant proportion of the greatest differential head (up to approximately 1.2 m) and use little water. These conditions can also occur at a wide range of lake levels, so the fishways also need to accommodate this.

ii) At high flows (e.g. > 10,000 ML/d or 300 GL/mn) the differential head is low (approximately < 0.5 m) and, from the earlier analysis, lake levels are within a narrow headwater range. Hence, fishways for these conditions: 1) could potentially operate over a smaller head differential (although further analysis is required), 2) need only operate over a narrow headwater range, and 3) can pass high volumes of water.

The objective of the tidal range for fishways is to enable fish migration for the upper half of the tidal cycle in each diel period within a day. Applying this to the barrage fishways provides an initial lower limit of -0.4 m for Goolwa and -0.28 m for Tauwitchere; however, further analysis in detailed design may be required if these criteria are cost-sensitive.

4 BARRAGE OPERATIONS

4.1 River Management / Future Operations

Notes from 28/3/12 Barrage Operations Technical Meeting

Tables from Draft Lake Operating and Water Release Strategy (+0.35m AHD updated to +0.4m AHD to reflect the State's position that the lowest level for the lakes will be +0.4m AHD).

Table 3 Revised surface water levels (minimum and maximum) for Lake Alexandrina and daily minimum flow release rates (critical and preferred) via the barrages. Note: These are preferred water levels under regulated conditions only. Unregulated flows are likely to occur particularly between September and February/March, producing higher lake levels.

Month (watering year)	**Target Lake Level**		**Minimum Water Discharge**	
	Minimum (m AHD)	**Maximum (m AHD)**	**Critical (ML/day)**	**Preferred (ML/day)**
July	0.50	0.60	500	2,000
August	0.60	0.65	500	2,000
September	0.60	0.70	1,500	2,000
October	0.60	0.70	1,500	2,500
November	0.60	0.75	1,500	2,500
December	0.60	0.70	1,500	2,000
January	0.60	0.70	1,500	2,000
February	0.50	0.60	1,500	2,000
March	0.40	0.50	0	2,000
April	0.40	0.50	0	2,000
May	0.40	0.60	0	2,000
June	0.50	0.60	500	2,000

Source: Leda Consulting 2009.

Table 4 Comparison of minimum and maximum water level targets for Lake Alexandrina.

Month	**Potential minimum water level**			**Potential maximum water level**		
	Icon Site EMP (m AHD)	**Proposed New (m AHD)**	***Difference (m)***	**Icon Site EMP (m AHD)**	**Proposed New (m AHD)**	***Difference (m)***
July	0.58	0.50	*-0.08*	0.84	0.60	*-0.24*
August	0.60	0.60	*0*	0.85	0.65	*-0.20*
September	0.60	0.60	*0*	0.84	0.70	*-0.14*
October	0.60	0.60	*0*	0.75	0.70	*-0.05*
November	0.60	0.60	*0*	0.71	0.75	*+0.04*
December	0.60	0.60	*0*	0.70	0.70	*0*
January	0.60	0.60	*0*	0.70	0.70	*0*
February	0.57	0.50	*-0.07*	0.69	0.60	*-0.09*
March	0.51	0.40	*-0.16*	0.64	0.50	*-0.14*
April	0.50	0.40	*-0.15*	0.60	0.50	*-0.10*
May	0.50	0.40	*-0.15*	0.65	0.60	*-0.05*
June	0.53	0.50	*-0.03*	0.76	0.60	*-0.16*

Source: Leda Consulting 2009. Icon Site EMP (DWLBC 2006). Proposed New (Leda Consulting 2009). Difference = Icon Site EMP – Proposed new.

Outcomes of discussion at Fishways Operations Workshop on 28 March 2012

SA Water prefers the water level to remain below +0.8m AHD as at this level, water spills onto the bitumen roads. An old practice was to take the water level up to +0.85m AHD (+0.8m AHD operationally) and draw it down over the summer.

DFW has a preferred barrage release pattern designed to maintain salinity dependent on the type of season (cycle). The conditions for barrage release are based upon how much water is around. The entitlement flow equals the environmental allocation but with flood flows there is much less control.

The general ratio of release is 35% through Goolwa Barrage and 65% through the other barrages. In drier conditions, more water is released towards the Coorong. Generally, the percentage of release at Goolwa and Tauwitchere remains the same so as to maintain the Murray Mouth.

SA Water can shut up to 50 gates in one day, though this makes for a very long day. When considering closure of the gates, the forecast for the next day(s) needs to be taken into account. The workload is much the same in opening consecutive gates vs. opening alternate gates.

Due to reverse flow we need a relatively simple closing system that considers planned environmental release and fishways.

"Our Philosophies that drive Barrage Operations"

Water Security – Water Levels (Minimum)
Water Quality – Salinity (reverse head)
Fish Passage – Fishways Open first
Coorong Benefits – Coorong water quality
– Food to mudflats
– Not too quick to change
Murray Mouth – Split between Goolwa, Tauwitchere and Ewe Island

Attraction Flow / Environmental Flow Rate

Boundary Creek is ecologically important and therefore 1 gate is left open at all times for salinity benefits. Having this 1 gate open doesn't have a significant impact re reverse flows, but more than 1 gate open may have an impact. It may be possible to use 1 bay – ½ fishway, ½ attractant flow. A salinity transect with bathymetry is seen in **Figure 29** in **Attachment 3**.

The radial gates are designed to be either open or closed. The vertical spindle gates are designed so that they can be partially open. SA Water tend to use the radial gates at Ewe Island and Tauwitchere as they are less vulnerable to storm events rather than the stop logs of vertical spindle gates. Radial gates are used more frequently as they are easier to operate and are required to be opened regularly for maintenance (see **Attachment 2** for the make up of each barrage)

At Mundoo, it is shallower on the sides, while the middle is deeper. Different species are attracted to each of these two types of depth zones. Consideration of what species we want to pass is necessary to determine location of fishway along the Mundoo structure. Suggestion that it may be best to locate the fishway to the side as to not retard flow during flood, such as what may occur if it is located in the middle. The velocity of flow can be quite high near the Mundoo gate.

At Goolwa Barrage, there is a limit as to how many gates can be operated quickly. The 5 gates right next to the fishway are always the first to be opened. It is important to alternate which gates are opened to spread the flow so as to not cause erosion, and also maintain the structure (reduce tube worm growth). The Hindmarsh Island side is preferable for a new fishway as people traffic is reduced as opposed to the Goolwa side.

Depths of the barrages needs consideration, especially for Mundoo and Goolwa as there are shallower and deeper sections at these structures. The other barrages have a single depth.

Spillway

The spillway concrete wall was installed in 2007 to prevent reverse flow at times of king tides. Photograph of positive flow in **Figure 30 (**see **Attachment 4**)

4.2 Management for broad ecological objectives

The Living Murray LLCMM Icon Site overarching vision is to facilitate:
'*A healthier Lower Lakes and Coorong estuarine environment'*

The Living Murray LLCMM Icon Site ecological objectives, as developed by the Murray-Darling Basin Ministerial Council in 2003 are:

- An open Murray Mouth;
- More frequent estuarine fish recruitment; and
- Enhanced migratory wader bird habitat in the Lower Lakes and Coorong.

The DENR Securing the Future: Long Term Plan's ultimate goal for the CLLMM region is to secure a future for the CLLMM site as a healthy, productive and resilient wetland system that maintains its international importance (DENR 2010).

DENR Long Term plan targets include:

- Lake Alexandrina and Lake Albert remain predominantly freshwater and operate at variable water levels;
- The Murray Mouth is predominantly kept open by end-of-system river flows;
- There is a return of salinity gradients along the Coorong that are close to historic trends with a corresponding response in species abundance;
- There is a dynamic estuarine zone; and
- The biological and ecological features that give the CLLMM wetlands their international significance, albeit a changed and changing wetland, are protected.

5 ECOLOGICAL OBJECTIVES AND TARGETS FOR NATIVE FISH

The Living Murray LLCMM Icon Site Native Fish Targets (from SA MDB NRM Board 2009- *Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Plan*):

F1: Maintain or improve recruitment success of diadromous fish in the Lower Lakes and Coorong
F2: Maintain or improve recruitment success of endangered fish species in the Lower Lakes (*Murray hardyhead, Southern pygmy perch, Yarra pygmy perch)*
F3: Provide optimum conditions to improve recruitment success of small-mouthed hardyheads in the South Lagoon
F4: Maintain or improve populations of black bream, greenback flounder and mulloway in the Coorong

6 FISH PASSAGE OBJECTIVES

The fish passage objectives are specific to movement of fish past a barrier and follow from the fish ecology and ecological objectives which include, broader population dynamics, recovery of those native fish species that have declined, and sustaining a diverse fish community.

Tidal barriers present a particular challenge for fish passage in Australia as there are usually many species that are either small or have juveniles migrating upstream. These small-bodied fish have poor swimming abilities and need fishways with low turbulence and low water velocities. The Murray River barrages are also unique in Australia and present further challenges for fish passage, specifically: it is the widest barrier on any river in the country; it can have water being released from several different locations; and the flow can vary from very high flows to a base flow of zero.

The ecological objectives for fish passage at the Barrages, which apply to both upstream and downstream movement, are to pass:

1) High biomass.

   The lower and tidal reaches of large rivers usually have high biomass of fish simply as a result of carbon and nutrient transport from upstream. The most obvious reflection of the high migratory biomass of fish at the barrages is the aggregation of birds feeding on fish. High biomass of fish can also arrive at the barrages in pulses, either post-spawning or in the recession of high flows.

2) Fish spread over a wide area.

   The multiple sites and the wide barrages result in fish that are migrating both upstream and downstream being attracted to several locations.

3) Large-bodied fish.

   Large-bodied fish (250-600 mm) are expected to use the fishways but there is little data on these fish at present. Some hydroacoustic work using a dual frequency identification sonar (DIDSON) showed that large-bodied fish were trap-shy in the fishways so present sampling may underestimate their movement. The recent acoustic tracking of congolli reveals the extensive movement of this species and their need to pass the barrages.

4) Small-bodied fish.

   The present work on the barrage fishways shows that the numbers, diversity and biomass of small-bodied fish passing or attempting to pass the barrage is extensive.

5) Fish at low flows.

   This objective reflects the past operation of the barrage, as well as the recent drought, when zero flows in summer were not uncommon. The intent of this objective is that a fishway is designed to use little water, so that operation can be continuous or extended when water is scarce.

6) Fish at high flows

The recession of high flows is a major period of upstream fish migration at the barrages. Passing fish at these flows requires high discharge through the fishway and integration with gate operation to optimise attraction.

7) Surface-dwelling fish

Some species, such as mullet, will only swim near the surface and will not enter a submerged entry of a fishway.

8) Bottom-dwelling (benthic) fish

Some species, such as congolli, are benthic. The behaviour of these species at fishways with surface entries is unknown. Generally, if there is a gradual decrease in depth approaching a fishway then benthic species will use it if there is sufficient depth. The specific knowledge gap at the Barrages is the behaviour of benthic fish that are migrating, either upstream or downstream, as they approach a deep vertical barrage such as Goolwa.

These ecological priorities differ for each of the barrage sites and are listed in Table 5 alongside potential fishway options. The two ecological objectives not presently addressed to some degree are *fish spread over a wide area*, which is a function of the number of fishways, and *passing small-bodied fish at high flows*, which requires a different type of fishway.

Table 5. Ecological objectives for Fish passage and Fishway Options at the Murray River Barrages. Dark green shading indicates that the objective has been achieved and light green shading indicates that the objective is partly achieved. Under fishway options, a tick indicates potential applicability and symbols indicate which ecological objective would be achieved. Grey fill is an installed fishway and an orange fill is installed but operating poorly.

SITE	ECOLOGICAL OBJECTIVES						FISHWAY OPTIONS								
	High biomass	Fish spread over a wide area	Large-bodied fish (250-600 mm)		Small-bodied (20-100 mm) and medium-bodied (100-250 mm) fish		Large vertical-slot	Small vertical-slot[2]	Rock-ramp[3]	Fish lock[4]	Trapezoidal Weirs	Denil[5]	Culverts	Navigation lock[6]	Barrage gates / stoplogs[7]
			Low flows	Moderate flows[8]	Low flows[9]	Moderate flows									
Goolwa	●	Φ	▲	Θ	Δ	■	✓ ● Φ ▲	✓ Φ Δ ■		✓ ● Φ Δ		✓ ● Φ ▲ Θ		✓[10] ▲ Δ	✓ Φ Θ ■
Mundoo			▲	Θ	Δ		✓[11] ▲								✓ Φ Θ ■
Boundary Ck					Δ	■		✓[11] Δ ■			✓ Δ[12] ■				✓ Φ Θ ■
Ewe Is.		Φ	▲	Θ	Δ	■	?	✓ Δ ■	?			✓ Φ ▲ Θ			✓ Φ Θ ■
Tauwitchere	●	Φ	▲	Θ	Δ	■	✓ ● Φ ▲[13]	✓ Φ Δ ■	✓[14] ● Φ Δ		✓ ● Φ Δ[12] ■	✓ ● Φ ▲ Θ			✓ Φ Θ ■
Hunters Ck					Δ			✓ Δ ■							
Spillways, other channels				Θ	Δ								✓ Δ	✓ Δ Θ[15]	

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[2] For low flows; could apply bristles if lamprey passage is poor.
[3] Three for different lake levels; requires automated gates.
[4] Self-powered; single tidal cycle.
[5] Note: short [~ 5 m] and steep [1:6] for large-bodied fish; at high flows with high, stable headwater (0.6 to 0.8m)
[6] May require modified valves to operate frequently.
[7] Mainly for downstream migration, but can be used for upstream passage during reverse flow.
[8] High lake level (mostly 0.7-0.9 m AHD) with small differential head.
[9] < 5 ML/d, low-flow fishway.
[10] Considered a cost effective adjunct to fish passage, with little modification.
[11] Could be a medium-sized vertical-slot
[12] Over a narrow headwater range
[13] Baffles need to be modified and extended.
[14] Review applicability of rock-ramps at the barrages.
[15] Remove temporary spillway wall.

7 FISHWAY OPTIONS

For the barrages there are eight main options for fish passage and fishway design: i) vertical-slot fishways, ii) rock-ramp fishways, iii) fish locks, iv) trapezoidal weirs, v) Denil fishways, vi) culverts, vii) navigation locks and viii) weir gates/stoplogs. Within each of these there is considerable variation and each individual site results in a unique configuration and application.

7.1 Vertical-slot fishway

7.1.1 Description

The vertical-slot fishway is one of the most common and successful fishway designs used world-wide. It is used throughout eastern Australia, notably in the Hume to Sea Fishway Program. The fishway is a channel divided into pools by baffles; the channel is usually rectangular in cross-section and the baffle has a vertical slot that runs the full depth. The baffle is designed to angle the jet of water across the pool to dissipate the energy of the water evenly (Figure 14). Vertical-slot fishways can be pre-cast concrete units or concrete poured on-site. The baffles can be pre-cast in concrete or made of compressed fibre sheet or aluminium.

In Australia the gradients or slopes vary from 1-on-32 to 1-on-15 and the pool sizes vary from 3 m long by 2 m wide to 1.3 m long by 1.1 m wide. There is a usually a minimum depth in the channel of one metre for large-bodied (> 500 mm long) and medium-bodied fish (250-500 mm long) but this can be shallower for small-bodied fish (20-150 mm). The channel is usually deeper at the downstream (tailwater) side to accommodate rises in river levels during higher flows.

The maximum water velocity in a vertical-slot fishway that fish need to negotiate occurs in the slot and this is determined by the difference in water level (head loss) each side of the baffle; a higher head loss creates a higher velocity. Hence, for small fish low head losses with low water velocity are used. In the fishway pool itself fish need to negotiate turbulence and this is determined by the energy of the water entering each pool (discharge by head loss) and the pool volume available to dissipate the energy. These two parameters – velocity and turbulence – are adjusted to meet the swimming ability of the fish assemblage at each site.

7.1.2 Advantages

- Can operate over a wide range of upstream (headwater) levels and downstream (tailwater) levels, so that that fish that are migrating during different river, lake or estuary levels can locate and use the fishway.
- Can be adapted to sites with differing minimum flows to maximise operating time. This is achieved by modifying the slope, head loss, slot width and slot depth.
- The full depth slot in the baffle enables the passage of bottom- and surface-dwelling species.
- It provides a high depth, including at minimal streamflow, for the passage of large fish.
- Can be designed with low water velocities and turbulence for small fish.
- Has the capacity to pass a high biomass of fish.
- Maintenance is low with well-designed trash racks.
- The flow pattern in each pool tends to be self-scouring.
- The internal hydraulics are consistent and predictable so that maintenance needs are easily detectable.

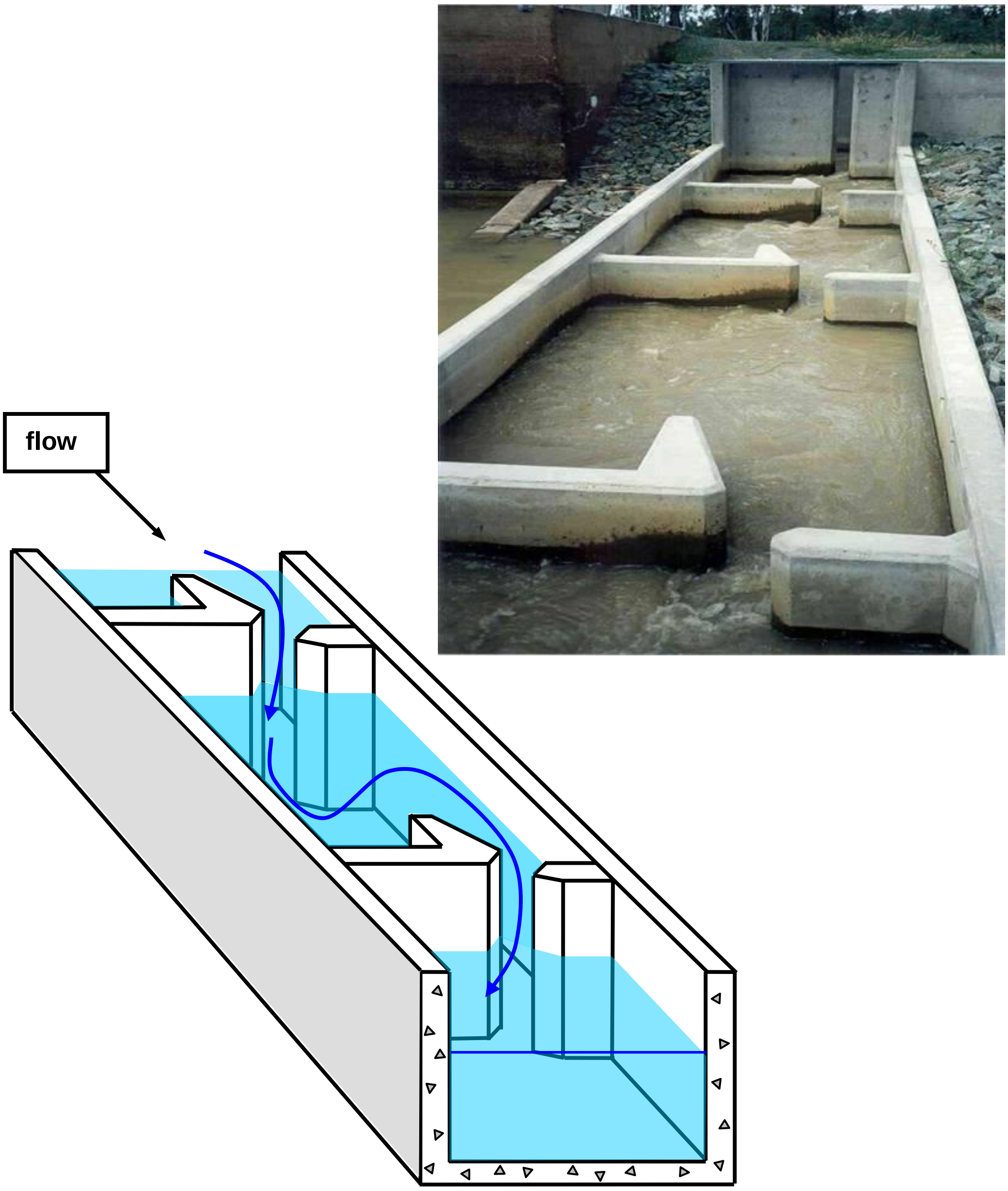


Figure 14. Diagram and photograph of a vertical-slot fishway.

7.1.3 Disadvantages

- Can have a high capital cost compared with other fishways (depends on design parameters e.g. pool size and gradient).
- Poor passage of crustaceans and other invertebrates (may be improved by lining the fishway with rocks), and other non-fish aquatic fauna (e.g. turtles).
- Poor passage of elvers (juvenile eels) except in low-slope designs with very low water velocities.
- At high tailwater in some designs there can low water velocity at the entrance and less efficient attraction of fish.

7.1.4 Present Application at the Barrages

- There have been two major applications of the vertical-slot design at the barrages:
  i) *Large vertical-slot fishway* for medium– to large-bodied fish 200-1000 mm, with high head losses per pool (~200 mm generating 2.0 m/s maximum velocity) and large pools.

  There is presently one at Goolwa and one at Tauwitchere.

  ii) *Small vertical-slot fishway* for small-bodied fish (20-150 mm), with low head loss (~50 mm generating 1.0 m/s maximum velocity), small pools and very low turbulence (25-29 Watts m^{-3}).

  There is presently one at Tauwitchere and one at Hunters Creek.

7.1.5 Status, performance and modifications required

- The large vertical-slot at Goolwa has been modified with inserts in the baffles (Figure 15) to reduce discharge and enable operation at low flows. This has an added advantage of reducing turbulence, and initial monitoring indicates that much smaller fish than expected can use this fishway. However, sampling over a full range of lake levels and with a quantitative exit (lake) sample is still required to confirm passage of small fish.

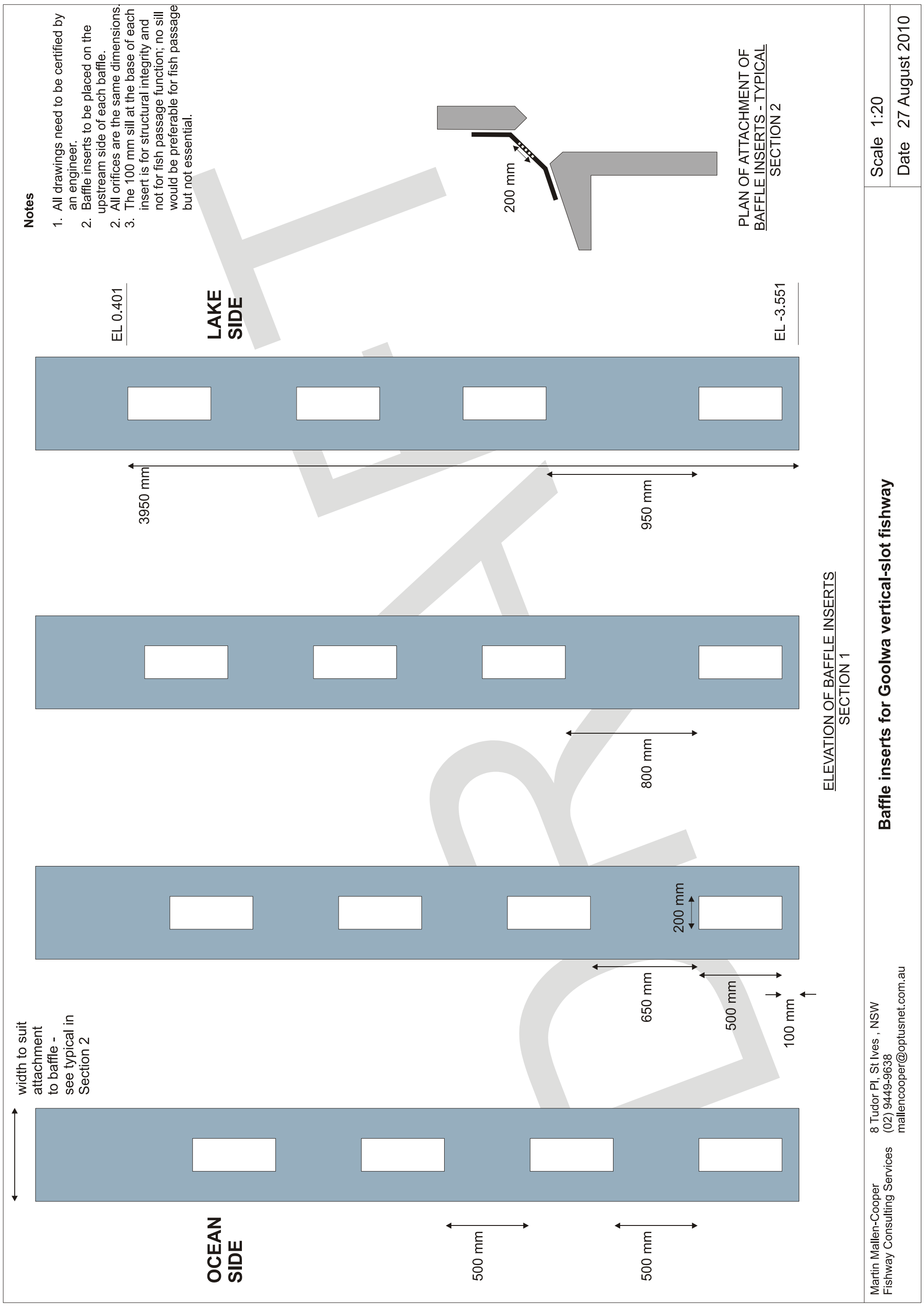
- The small vertical-slot fishways are passing very small fish as predicted, but attraction discharge is low. Attraction is not an issue at the Hunters Creek site, which has a low total flow, but is an issue at larger sites like Tauwitchere.

- The fishway at Tauwitchere requires minor modifications at the entrance to optimise attraction.

- The large fishway at Goolwa requires maintenance due to growth of tubifex worms, which is likely to be an ongoing requirement with all fishways.

7.1.6 Potential Application at the Barrages

1. Both the large and small vertical-slot fishways have potential for multiple applications at the barrages to address the ecological objectives of *fish spread over a wide area* during flow releases and passing a *high biomass*.
2. A specific advantage of the vertical-slot design at the barrages is that it can be configured to suit the footprint of the barrage bays.



Notes

1. All drawings need to be certified by an engineer.
2. Baffle inserts to be placed on the upstream side of each baffle.
2. All orifices are the same dimensions.
3. The 100 mm sill at the base of each insert is for structural integrity and not for fish passage function; no sill would be preferable for fish passage but not essential.

Figure 15. Inserts used in the large vertical fishway at Goolwa.

7.2 Trapezoidal weirs

7.2.1 Description

Trapezoidal weirs have been used for fish passage in North America and recently in NSW (Figure 16), following extensive physical and computer (CFD) modelling. These are similar to a pool-type fishway with a straight channel divided into pools with weirs. The shape of the weirs provides for the passage of high flows down the middle of the channel while maintaining fish passage along the sides; as small fish are attracted to the greater flow and high velocity in the middle of the fishway there are low velocity passages along each side. Precast-box culverts can be used and most debris appears to pass down the middle of the channel. It was specifically designed to pass small fish at a tidal site, integrate attraction flow, and provide accurate gauging.

7.2.2 Advantages

- Operates while passing high flows.
- Pre-cast construction.
- Low to moderate capital cost.
- Low maintenance.
- Accurate gauging.

7.2.3 Disadvantages

- Limited headwater range (e.g. 0.4 to 0.5 m) compared to a vertical-slot design.
- Wide footprint (~ 4 m) compared to other fishway designs but this is a suitable width for the barrage bays.
- Poor passage of non-fish aquatic biota.

7.2.4 Potential applicability for the Barrages

- One of the design issues to overcome for the passage of small fish at sites that have moderate to high flow is attraction into the fishway. Fishways for small fish generally have low discharge to keep water velocities and turbulence low. This fishway specifically passes high flow and provides attraction for fish.
- It would operate over a narrower range of headwater compared to the vertical-slot design, probably 0.4 to 0.5 m variation in lake level. Hence, it would suit the lake levels when flow is passing.
- If it was designed for moderate differential heads it could be built within the footprint of the barrage. If it was designed for large differential heads (i.e. at low flows and high lake levels) it would likely need to be built partly downstream and upstream of the footprint of the barrage to achieve the gradient for the maximum differential head.
- A suitable gradient is likely to be 1:20.

Figure 16. Example of a trapezoidal weir fishway on a coastal stream of NSW.

7.3 Denil fishways

7.3.1 Description

Denil fishways are systematically-roughened channels. Rather than separate pools, like pool-type fishways, they have closely-spaced 'U'-shaped baffles (Figure 17). The flow turns upon itself at the base of the baffle and this creates a low velocity zone that fish use to ascend. If a Denil fishway is over a certain length then resting pools are provided. The main advantage of Denil fishways is that they can be built on steeper slopes (e.g. 1-on-12 to 1-on-7) compared with pool-type fishways like the vertical-slot design.

Denil fishways are widely used in North America and Europe for the passage of adult herring and salmon. In Australia research has indicated the potential of Denil fishways for native fish and it has been applied to a few sites. The design tends to favour fish greater than 40-60 mm in length and the passage of bottom- and midwater–dwelling fish species. Poor passage has been reported of some surface-dwelling species.

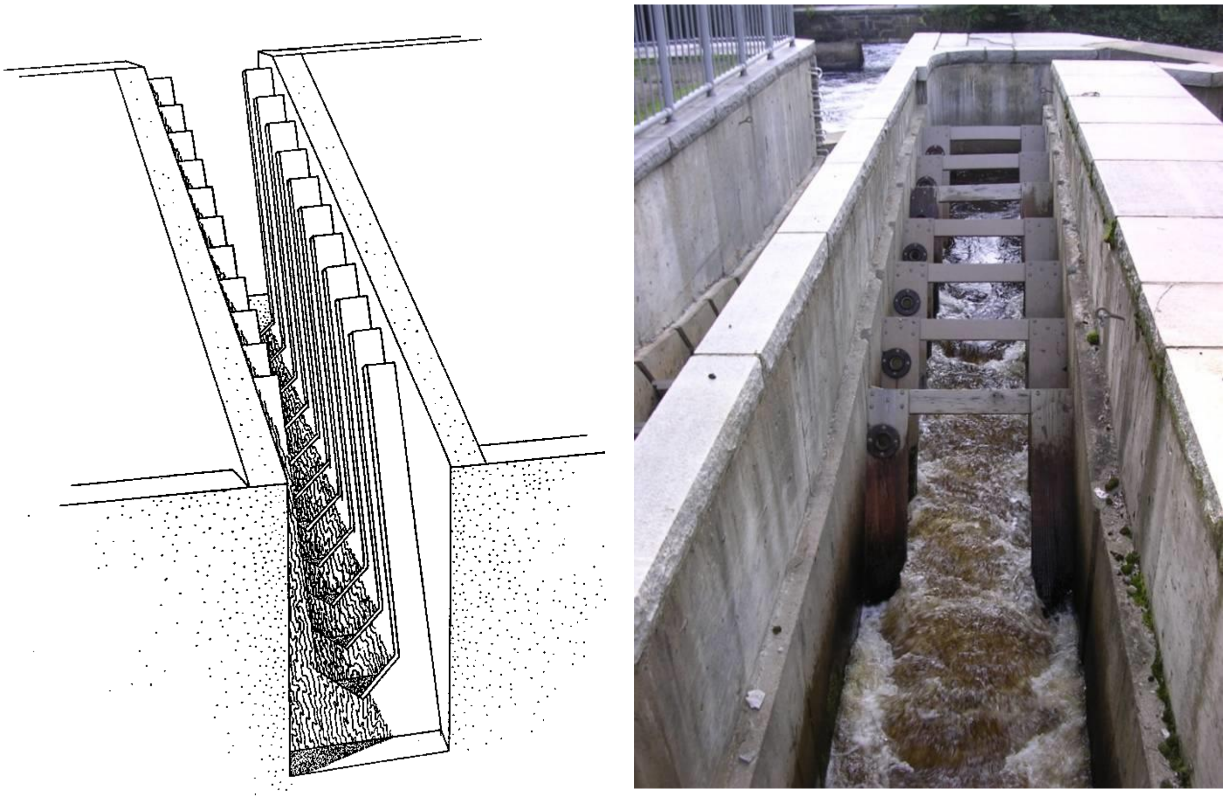


Figure 17. Diagram and photograph of a Denil fishway.

7.3.2 Advantages

- Low capital cost, especially at higher weirs.
- Small construction footprint.
- Can be pre-cast off-site, in fibreglass, aluminium or steel.

7.3.3 Disadvantages

- Limited headwater range. Small Denil fishways operate over a small headwater variation of approximately 0.25 m, whilst large Denil fishways for large fish (250-600 mm) operate up to 0.4 m of headwater variation.
- Initial biological assessment indicates passage of small fish (< 100 mm) is poorer than other fishways.
- Very poor passage of crustaceans and other invertebrates, and other non-fish aquatic fauna (e.g. turtles).
- Very poor passage of elvers (juvenile eels) except in low-slope designs with very low water velocities.
- Susceptible to blockage from floating debris, but can be mitigated with well-designed trash racks.
- Less data and experience with passage of native fish than other fishways.

7.3.4 Potential applicability for The Barrages

- Has potential at the Barrages as a fishway for large-bodied fish at high flows.

7.4 Rock-ramp fishways

7.4.1 Description

Rock-ramp fishways simulate the structure of a riffle or rocky creek. Overseas these are often referred to as 'nature-like fishways'. There are two main groups of rock-ramp fishways; they either occupy the *full width* of the stream (Figure 18), or a *partial width* of the stream (Figure 19). Full-width rock-ramp fishways are generally used in narrow streams as they are generally not cost-effective at wide streams. Partial-width rock-ramp fishways commonly have the downstream entrance at the base of the weir, with most of the fishway channel downstream of the weir and the exit near the weir abutment. If the channel passes around the weir on a low gradient these fishways are sometimes referred to *bypass channels*.

Rock-ramp fishways need to be well-engineered and are not simply rock dumped in the river. Some significant design points are: the rock needs to be sized to withstand storm events and high water velocities at the site; the preferred building technique is to have keyed-in boulders, where the friction and stability of the boulders increases with high velocity flooding; the rock-ramp channel needs to be lined with geotextile and 100 mm diameter gravel to protect the geotextile during construction; and at low streamflow sites a layer of impermeable Bentofix or Claymax is needed to prevent percolation of water directly through the rock-ramp. Alternatively the rocks can placed in a concrete channel.

The rocks in a rock-ramp fishway provide roughness that creates zones of low water velocity. Roughness is decreased when the large rocks in the fishway become submerged; the effective operating range is considered to be when the rocks are breaking the surface of the water.

Figure 18. A full-width rock-ramp fishway.

Figure 19. A partial-width rock-ramp fishway.

7.4.2 Advantages

- Can have a relatively low capital cost compared with other fishways but this depends on the design criteria, especially depth and width, and a nearby supply of large angular rock.
- Can be built on a relatively poor foundation.
- Provides good passage of climbing fish species and non-fish fauna such as crustaceans, invertebrates, and turtles.
- Depending on the depth and width, rock-ramp fishways have the potential to pass a high biomass.
- Full-width rock-ramp fishways in streams that do not have low minimum flows are almost free from maintenance.

7.4.3 Disadvantages

- Operates over a narrow range of upstream water levels (applies to partial-width designs only). Typically a variation in upstream water levels (headwater or weirpool) of 0.2 m can be accommodated in the design.
- Construction can be difficult. A rotating grab is useful in interlocking the rocks.
- Narrow tailwater range (applies to some partial-width designs only). This can be overcome by recessing the fishway into the weirpool or running the fishway parallel with the weir crest, which would locate the entrance at the base of the weir.
- In streams with very low flows or periods of no flow there is often encroachment of vegetation. Vegetation reduces the area of the rock-ramp fishway and disrupts the hydraulics, reducing fish passage efficiency and increasing maintenance.

- At low streamflow sites rock-ramp fishways have shallow depths that reduce passage of medium- and large-bodied fish, and can increase the risk of predation.
- Has a larger construction footprint compared with other fishways. The extent of this issue depends on land tenure and the topography of the surrounding land.
- Sedimentation after flooding. This depends on the bedload of the stream and the deposition patterns near the weir and fishway.
- Detecting when maintenance is needed can be more difficult than in other fishway designs. The hydraulics are more complex and more difficult to measure than other fishways. A detailed maintenance manual can address this aspect.

7.4.4 Present Application at the Barrages

- There is one rock-ramp fishway at Tauwitchere that is built within the barrage bay and downstream apron.

7.4.5 Status, performance and modifications required

- The existing rock-ramp fishway operates over a narrow range of lake levels and tide levels. Previous workshops have considered multiple rock-ramps and extending the length of one fishway for the lower tides.
- The fishway works well for small-bodied fish within the narrow headwater range.
- The present rock-ramp fishway could be extended and others added, or other fishway type could be considered.

7.4.6 Potential applicability for The Barrages

- A *full-width* rock-ramp fishway is unlikely to be applicable because the weir is wide and a large volume of rock would be required.
- Further *partial-width rock-ramp fishways* have potential for the Barrages.

7.5 Fish lock

7.5.1 Description

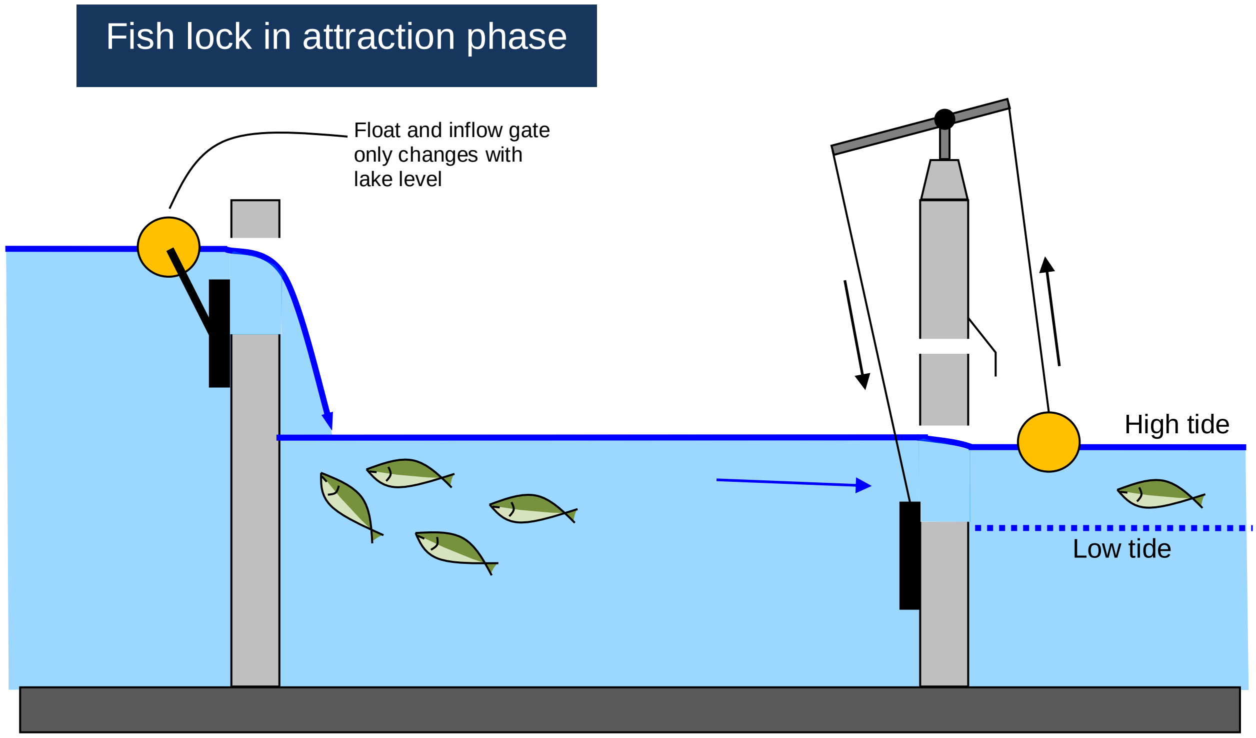
Fish locks are similar to navigation locks with a lock chamber, upstream and downstream gates, and valves to fill and drain the lock. They also operate in a similar way: for upstream migration the lower gates are open with attraction flow; fish move in; lower gates close; lock fills; upper gates open with attraction flow; and fish move out. They are often applied to high weirs, 7-15 m, but have recently been used at low level weirs on the Murray and Murrumbidgee rivers because they are very effective in passing large numbers of small-bodied fish. The valves and gates are usually controlled by a PLC and level sensors are used to provide data to the PLC.

For the Barrages a simpler version of a fish lock could be applied using robust float-operated gates (Figure 20), which have been used reliably for fish passage on floodgates for 10 years at over 100 sites in northern NSW (Table 6). The intent of this type of fish lock would be to cycle once at each high tide. Figure 21 shows a conceptual diagram of a fish lock for the barrages using this approach. The gates in a lock at the Barrages could lift out, which would make maintenance easier. The gates could also be simpler than the example in Figure 20, where the design was constrained by retrofitting to a floodgate.

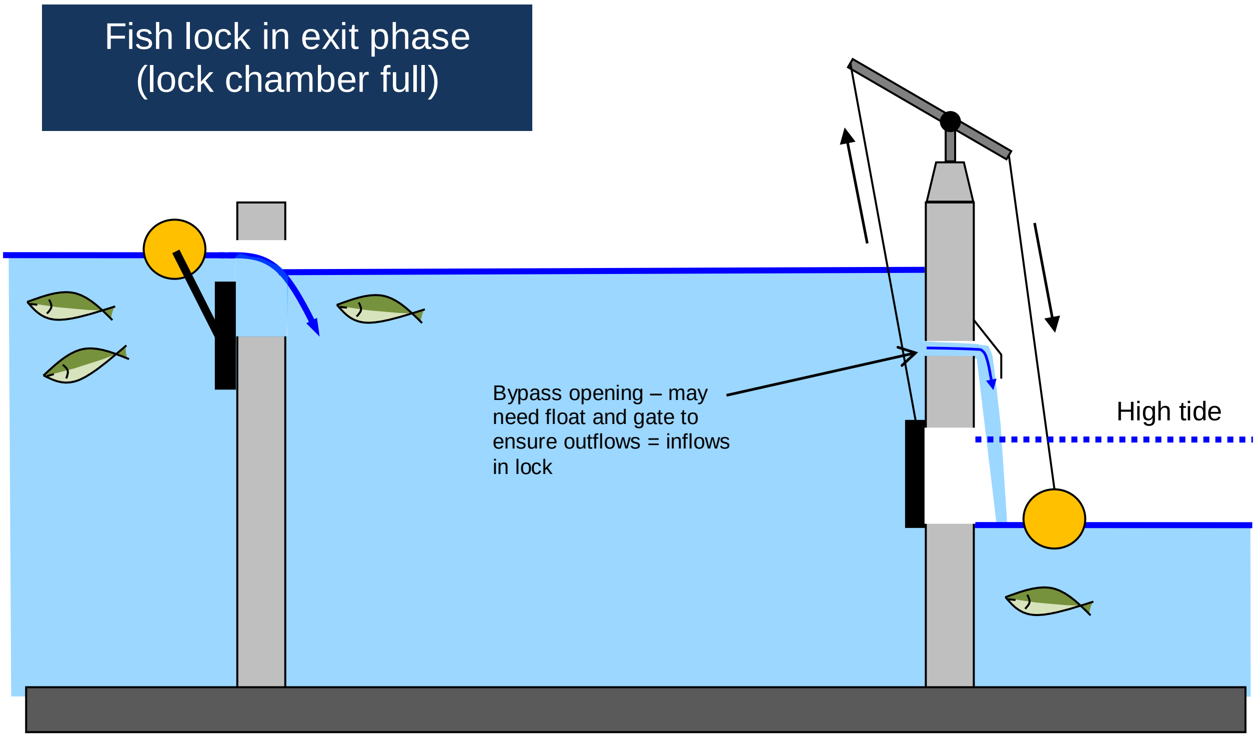
Figure 20. Float–operated gate used for fish passage on tidal floodgates in NSW.

Table 6. Location and number of float–operated gates installed in NSW for fish passage.

Catchment	Approximate number of float-operated tidal gates installed
Tweed	25
Richmond	6
Clarence	50
Kempsey	5
Port Macquarie / Hastings	40
Hunter	2
Shoalhaven	1


Fish lock in attraction phase

Float and inflow gate only changes with lake level


Fish lock in exit phase (lock chamber full)

Bypass opening – may need float and gate to ensure outflows = inflows in lock

Figure 21. Conceptual diagram of a fish lock for the barrages using float mechanisms to provide a single cycle per high tide.

7.5.2 Advantages

- The major advantage is that fish locks can pass very large numbers and biomass of small-bodied fish. This is largely because they are not on a gradient, like most fishways, so that any velocity and turbulence can be used in the design and the weakest swimming fish can use the lock.
- No power required.
- Fits easily within a barrage bay; potentially only end walls are required.

7.5.3 Disadvantages

- Gates and hinges would require maintenance.
- Growth of tubifex worms can be expected on the downstream gate at the freshwater / estuarine interface. A simple lift-out gate would be required to enable maintenance.

7.6 Navigation lock

7.6.1 Description

A navigation lock can act in the same way as a fish lock described above. The navigation lock at Goolwa has successfully been used for downstream passage of congolli and it can be used for upstream passage. For upstream migration the entrance is not optimal because it is located downstream of where migrating fish aggregate, at the *upstream limit of migration* near the stoplogs. However, it could be a useful adjunct to a broad fish passage plan. A trial of fish movement using trapping and hydroacoustic may be required to assess the usefulness for upstream migration. If it was used on a regular basis the valves may need to be replaced and the gate attachments upgraded. The Goolwa lock has potential because staff are nearby but the Tauwitchere lock is too remote to operate manually on a regular basis. Both the Goolwa and Tauwitchere locks could be automated but this would be very costly so they would likely remain a manual operation.

7.6.2 Advantages

- The infrastructure is already present.
- Potential capacity to pass a high biomass of fish if they can be attracted into the lock chamber.
- The entrance is full depth, for both upstream and downstream, which suits benthic and surface species.
- For downstream migration the entrance is well-located.

7.6.3 Disadvantages

- Entrance poorly located for upstream-migrating fish.
- Manual operation required unless automated, which would be costly
- Gate and valves my need upgrading.

7.7 Weir gates/stoplogs

7.7.1 Description

The weir gates and stoplogs potentially offer an effective passage for downstream migrants. At Tauwitchere the gates are close to the bed level upstream so that benthic species moving downstream would easily locate a route downstream but this could also be optimised for fish by using less gates with wider openings. At Goolwa the barrage bays are deep and removal of stoplogs at the surface may not provide for passage of benthic species. Biological assessment of fish behaviour during flow is probably required to assess the extent that downstream passage is occurring or is inhibited.

The weir gates and stoplogs can also be used to pass fish during reverse flows. In this case upstream-migrating fish swimming against the flow and aggregating below a barrage are swept upstream over the barrage during brief periods when the lake level is lower than the estuary. As this is not practical to do on a regular basis this should be viewed as an adjunct to upstream fish passage.

7.7.2 Advantages

- Potentially only a change in barrage operation is required.

7.7.3 Disadvantages

- Uneven gate openings may cause uneven flow patterns downstream and increase localised erosion.

8 SUMMARY OF OPTIONS

A comparison of the functions of the fishway options as they apply to the Barrages is provided in Table 7. The criteria includes the ecological objectives from Table 5 except '*fish spread over a wide area'* as this relates to the number and location of fishways. The ability of each fishway to function at differing lake levels and differential head is provided, whilst qualitative scores on constructability are provided.

The emphasis in the table is on comparative function. Further criteria on O& M and capital cost are required.

In summary:

- The large-vertical-slot remains an effective option for large fish at both high and low flows but not low tailwater.
- The small vertical-slot is effective for small fish at low flows, but not high flows.
- The effectiveness and application of the rock-ramp needs further discussion.
- A fish lock would provide excellent passage for small fish.
- Trapezoidal weirs would also provide good passage for small fish at high flows.
- Denil fishways would be effective for large fish at high flows.
- The spillways are important for small-bodied fish at high lake levels, and are simple to remediate.
- The navigation lock at Goolwa is effective for downstream migration and may also be useful for upstream, but requires manual operation.
- The barrage gates and stoplogs are probably the major method of downsteam movement and should be optimised, probably only by changing their operation.

Table 7. Comparison of functionality of different fishway options.

Key:

— — —	Very poor
— —	Poor
—	Fair
●	Good
● ●	Very good
● ● ●	Excellent

			FISHWAY / FISH PASSAGE OPTIONS								
			Large vertical-slot	**Small vertical-slot**	**Rock-ramp**	**Fish lock**	**Trapezoidal Weirs**	**Denil**	**Spillways**	**Navigation lock**	**Barrage gates, stoplogs** (for downstream passage)
Biology	**High biomass**	**Large-bodied fish**	● ● ●	— — —	— —	—	●	● ● ●	— — —	**?**	● ● ●
		Small-bodied fish	— — —	— —	● ● ●	● ● ●	● ● ●		● ●	● ● ●	● ● ●
	Large-bodied fish	**Low flows**	● ● ●	— — —	— — —	—	— —		— — —	● ●	● ● ●
		High flows	● ● ●	— — —	●	—	●	● ● ●	— — —	●	● ● ●
	Small- and medium-bodied fish	**Low flows**	— —	● ● ●	● ● ●	● ● ●	● ● ●	— — —	● ● ●	● ● ●	● ● ●
		High flows	● ● ●	—	● ● ●	●	● ● ●	— — —	— —	●	● ● ●
Hydrology		**Variable headwater** (a high score indicates the design is suitable for low and high flows, whilst a low score is suitable for moderate to high flows only)	● ● ●	● ● ●	—	● ● ●	●	●	— —	● ● ●	● ● ●
		Differential head (ability of design to function over a wide range of differential head and be built within a barrage bay)	●	● ● ●	— —	● ● ●	●	●	N/A	● ● ●	● ● ●
		Passes high discharge (providing high attraction for fish)	● ●	— — —	● ●	●	● ●	● ●	●	● ●	● ● ●
Constructability	**Application of design (simplicity)**		● ● ●	● ● ●	—	● ●	● ●	● ●	● ● ●	● ● ●	● ● ●
	Fits within barrage footprint		● ● ●	● ● ●	—	● ● ●	●	● ● ●	N/A	● ● ●	● ● ●
	Prefabrication		● ● ●	● ● ●	— — —	● ● ●	● ● ●	● ● ●	— —	— —	**N/A**

9 APPENDICIES

Attachment 1

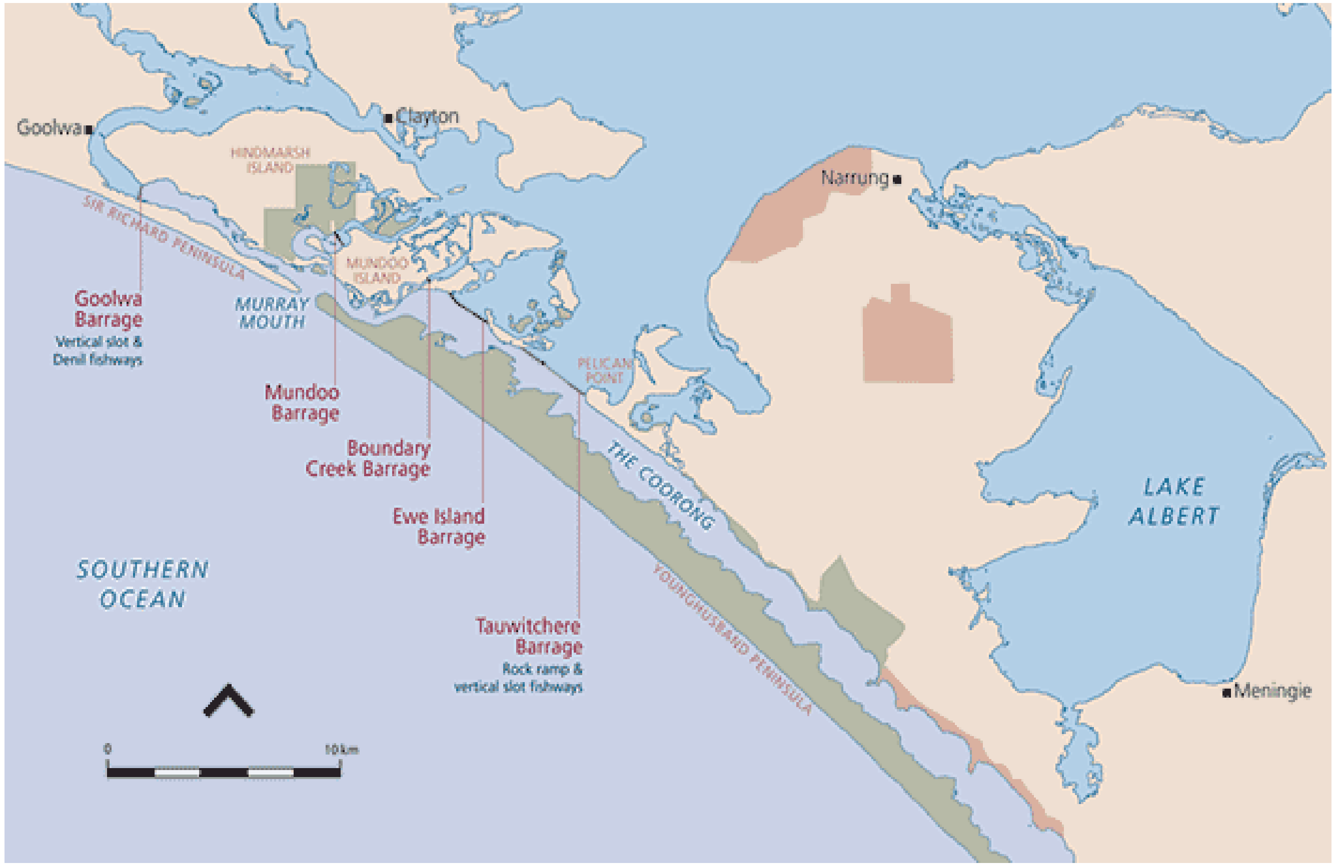


Figure 21: Locations of the Lower Lakes Barrages (source MDBC)

Attachment 2
Make up of the barrages

Goolwa Barrage

Figure 22. Goolwa Barrage from Hindmarsh Island

Figure 23. Aerial of Goolwa Barrage

Goolwa Barrage
Total 128 Openings
Starting from Goolwa end

1	Stoplog	21	Stoplog	41	Stoplog	54	Stoplog	74	Stoplog	94	Stoplog	114	Stoplog
2	Stoplog	22	Stoplog	42	Stoplog	55	Stoplog	75	Stoplog	95	Stoplog	115	Stoplog
3	Stoplog	23	Stoplog	43	Stoplog	56	Stoplog	76	Stoplog	96	Stoplog	116	Stoplog
4	Stoplog	24	Stoplog	44	Stoplog	57	Stoplog	77	Stoplog	97	Stoplog	117	Stoplog
5	Stoplog	25	Stoplog	45	Stoplog	58	Stoplog	78	Stoplog	98	Stoplog	118	Stoplog
6	Stoplog	26	Stoplog	46	Stoplog	59	Stoplog	79	Stoplog	99	Stoplog	119	Stoplog
7	Stoplog	27	Stoplog	47	Stoplog	60	Stoplog	80	Stoplog	100	Stoplog	120	Stoplog
8	Stoplog	28	Stoplog	48	Stoplog	61	Stoplog	81	Stoplog	101	Stoplog	121	Stoplog
9	Stoplog	29	Stoplog	Lock chamber	■	62	Stoplog	82	Stoplog	102	Stoplog	122	Stoplog
10	Stoplog	30	Stoplog	Nav pass	🟪	63	Stoplog	83	Stoplog	103	Stoplog		
11	Stoplog	31	Stoplog	Nav pass	🟪	64	Stoplog	84	Stoplog	104	Stoplog		
12	Stoplog	32	Stoplog	Nav pass	🟪	65	Stoplog	85	Stoplog	105	Stoplog		
13	Stoplog	33	Stoplog	Nav pass	🟪	66	Stoplog	86	Stoplog	106	Stoplog		
14	Stoplog	34	Stoplog	Nav pass	🟪	67	Stoplog	87	Stoplog	107	Stoplog		
15	Stoplog	35 STUCK 3 FT	Stoplog	Fish way	Fish way	68	Stoplog	88	Stoplog	108	Stoplog		
16	Stoplog	36	Stoplog	49	Stoplog	69	Stoplog	89	Stoplog	109	Stoplog		
17	Stoplog	37	Stoplog	50	Stoplog	70	Stoplog	90	Stoplog	110	Stoplog		
18	Stoplog	38	Stoplog	51	Stoplog	71	Stoplog	91	Stoplog	111	Stoplog		
19	Stoplog	39	Stoplog	52	Stoplog	72	Stoplog	92	Stoplog	112	Stoplog		
20	Stoplog	40	Stoplog	53	Stoplog	73	Stoplog	93	Stoplog	113	Stoplog		

Mundoo Island Barrage

Figure 24. Mundoo Barrage

Mundoo Island Barrage

Total of 26 openings
Starting from Hindmarsh Island end

1	Stoplogs	14	Stoplogs
2	Stoplogs	15	Stoplogs
3	Stoplogs	16	Stoplogs
4	Stoplogs	17	Stoplogs
5	Stoplogs	18	Stoplogs
6	Stoplogs	19	Stoplogs
7	Stoplogs	20	Stoplogs
8	Spindle Gates	21	Stoplogs
9	Spindle Gates	22	Stoplogs
10	Spindle Gates	23	Stoplogs
11	Spindle Gates	24	Stoplogs
12	Spindle Gates	25	Stoplogs
13	Spindle Gates	26	Stoplogs

Boundary Creek Barrage

Figure 25. Aerial image of Boundary Creek Barrage

Figure 26. Boundary Creek Barrage from boat view

Boundary Creek Barrage

Total 6 openings

Starting from Hindmarsh Island end

1	Stoplogs
2	Stoplogs
3	Stoplogs
4	Stoplogs
5	Stoplogs
6	Stoplogs

Ewe Island Barrage

Figure 27. Aerial image of Ewe Island Barrage happy to replace with better quality image

Ewe Island Barrage

Total 111 openings – 12 hydraulic, 47 manual, 52 stop logs, 59 gates
Starting from Hindmarsh Island end

1	Radial gate
2	Stoplog
3	Stoplog
4	Stoplog
5	Stoplog
6	Stoplog
7	Stoplog
8	Stoplog
9	Stoplog
10	Stoplog
11	Stoplog
12	Stoplog
13	Stoplog
14	Stoplog
15	Stoplog
16	Stoplog
17	Stoplog
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92	Radial gate
93	Radial gate
94	Radial gate
95	Radial gate
96	Radial gate
97	Radial gate
98	Radial gate
99	Radial gate
100	Hydraulic Radial Gate
101	Hydraulic Radial Gate
102	Hydraulic Radial Gate
103	Hydraulic Radial Gate
104	Hydraulic Radial Gate
105	Hydraulic Radial Gate
106	Hydraulic Radial Gate
107	Hydraulic Radial Gate
108	Hydraulic Radial Gate
109	Hydraulic Radial Gate
110	Hydraulic Radial Gate
111	Hydraulic Radial Gate

Tauwitchere Barrage

Figure 28. Aerial of Tauwitchere, Coorong on the left, Lake Alexandrina on the right

Tauwitchere Barrage
Total 322 Openings - 192 Gates, 130 Stoplogs
Starting from Hindmarsh Island end

322	Stoplog	287	Stoplog	252	Stoplog	217	Stoplog	182	Hydraulic Radial Gate
321	Stoplog	286	Stoplog	251	Stoplog	216	Stoplog	181	Hydraulic Radial Gate
320	Stoplog	285	Stoplog	250	Stoplog	215	Stoplog	180	Hydraulic Radial Gate
319	Stoplog	284	Stoplog	249	Stoplog	214	Stoplog	179	Radial gate
318	Stoplog	283	Stoplog	248	Stoplog	213	Stoplog	178	Radial gate
317	Stoplog	282	Stoplog	247	Stoplog	212	Stoplog	177	Radial gate
316	Stoplog	281	Stoplog	246	Stoplog	211	Stoplog	176	Radial gate
315	Stoplog	280	Stoplog	245	Stoplog	210	Stoplog	175	Radial gate
314	Stoplog	279	Stoplog	244	Stoplog	209	Stoplog	174	Radial gate
313	Stoplog	278	Stoplog	243	Stoplog	208	Stoplog	173	Radial gate
312	Stoplog	277	Stoplog	242	Stoplog	207	Stoplog	172	Radial gate
311	Stoplog	276	Stoplog	241	Stoplog	206	Stoplog	171	Radial gate
310	Stoplog	275	Stoplog	240	Stoplog	205	Stoplog	170	Radial gate
309	Stoplog	274	Stoplog	239	Stoplog	204	Stoplog	169	Radial gate
308	Stoplog	273	Stoplog	238	Stoplog	203	Stoplog	168	Radial gate
307	Stoplog	272	Stoplog	237	Stoplog	202	Stoplog	167	Radial gate
306	Stoplog	271	Stoplog	236	Stoplog	201	Stoplog	166	Radial gate
305	Stoplog	270	Stoplog	235	Stoplog	200	Stoplog	165	Radial gate
304	Stoplog	269	Stoplog	234	Stoplog	199	Stoplog	164	Radial gate
303	Stoplog	268	Stoplog	233	Stoplog	198	Stoplog	163	Radial gate
302	Stoplog	267	Stoplog	232	Stoplog	197	Stoplog	162	Radial gate
301	Stoplog	266	Stoplog	231	Stoplog	196	Stoplog	161	Radial gate
300	Stoplog	265	Stoplog	230	Stoplog	195	Stoplog	160	Radial gate
299	Stoplog	264	Stoplog	229	Stoplog	194	Stoplog	159	Radial gate
298	Stoplog	263	Stoplog	228	Stoplog	193	Stoplog	158	Radial gate
297	Stoplog	262	Stoplog	227	Stoplog	192	Radial gate	157	Radial gate
296	Stoplog	261	Stoplog	226	Stoplog	191	Hydraulic Radial Gate	156	Radial gate
295	Stoplog	260	Stoplog	225	Stoplog	190	Hydraulic Radial Gate	155	Radial gate
294	Stoplog	259	Stoplog	224	Stoplog	189	Hydraulic Radial Gate	154	Radial gate
293	Stoplog	258	Stoplog	223	Stoplog	188	Hydraulic Radial Gate	153	Radial gate
292	Stoplog	257	Stoplog	222	Stoplog	187	Hydraulic Radial Gate	152	Radial gate
291	Stoplog	256	Stoplog	221	Stoplog	186	Hydraulic Radial Gate	151	Radial gate
290	Stoplog	255	Stoplog	220	Stoplog	185	Hydraulic Radial Gate	150	Radial gate
289	Stoplog	254	Stoplog	219	Stoplog	184	Hydraulic Radial Gate	149	Radial gate
288	Stoplog	253	Stoplog	218	Stoplog	183	Vertical slot fishway	148	Radial gate

147	Radial gate	112	Radial gate	77	Radial gate	42	Radial gate	7	Hydraulic Radial Gate
146	Radial gate	111	Radial gate	76	Radial gate	41	Radial gate	6	Hydraulic Radial Gate
145	Radial gate	110	Radial gate	75	Radial gate	40	Radial gate	5	Hydraulic Radial Gate
144	Radial gate	109	Radial gate	74	Radial gate	39	Radial gate	4	Hydraulic Radial Gate
143	Radial gate	108	Radial gate	73	Radial gate	38	Radial gate	3	Hydraulic Radial Gate
142	Radial gate	107	Radial gate	72	Radial gate	37	Radial gate	2	Small vertical slot
141	Radial gate	106	Radial gate	71	Radial gate	36	Radial gate	1	Rock ramp
140	Radial gate	105	Radial gate	70	Radial gate	35	Radial gate		
139	Radial gate	104	Radial gate	69	Radial gate	34	Radial gate		
138	Radial gate	103	Radial gate	68	Radial gate	33	Radial gate		
137	Radial gate	102	Radial gate	67	Radial gate	32	Radial gate		
136	Radial gate	101	Radial gate	66	Radial gate	31	Radial gate		
135	Radial gate	100	Radial gate	65	Radial gate	30	Radial gate		
134	Radial gate	99	Radial gate	64	Radial gate	29	Radial gate		
133	Radial gate	98	Radial gate	63	Radial gate	28	Radial gate		
132	Radial gate	97	Radial gate	62	Radial gate	27	Radial gate		
131	Radial gate	96	Radial gate	61	Radial gate	26	Radial gate		
130	Radial gate	95	Radial gate	60	Radial gate	25	Radial gate		
129	Radial gate	94	Radial gate	59	Radial gate	24	Radial gate		
128	Radial gate	93	Radial gate	58	Radial gate	23	Radial gate		
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125	Radial gate	90	Radial gate	55	Radial gate	20	Radial gate		
124	Radial gate	89	Radial gate	54	Radial gate	19	Radial gate		
123	Radial gate	88	Radial gate	53	Radial gate	18	Radial gate		
122	Radial gate	87	Radial gate	52	Radial gate	17	Radial gate		
121	Radial gate	86	Radial gate	51	Radial gate	16	Radial gate		
120	Radial gate	85	Radial gate	50	Radial gate	15	Radial gate		
119	Radial gate	84	Radial gate	49	Radial gate	14	Radial gate		
118	Radial gate	83	Radial gate	48	Radial gate	13	Radial gate		
117	Radial gate	82	Radial gate	47	Radial gate	12	Hydraulic Radial Gate		
116	Radial gate	81	Radial gate	46	Radial gate	11	Hydraulic Radial Gate		
115	Radial gate	80	Radial gate	45	Radial gate	10	Hydraulic Radial Gate		
114	Radial gate	79	Radial gate	44	Radial gate	9	Hydraulic Radial Gate		
113	Radial gate	78	Radial gate	43	Radial gate	8	Hydraulic Radial Gate		

Attachment 3

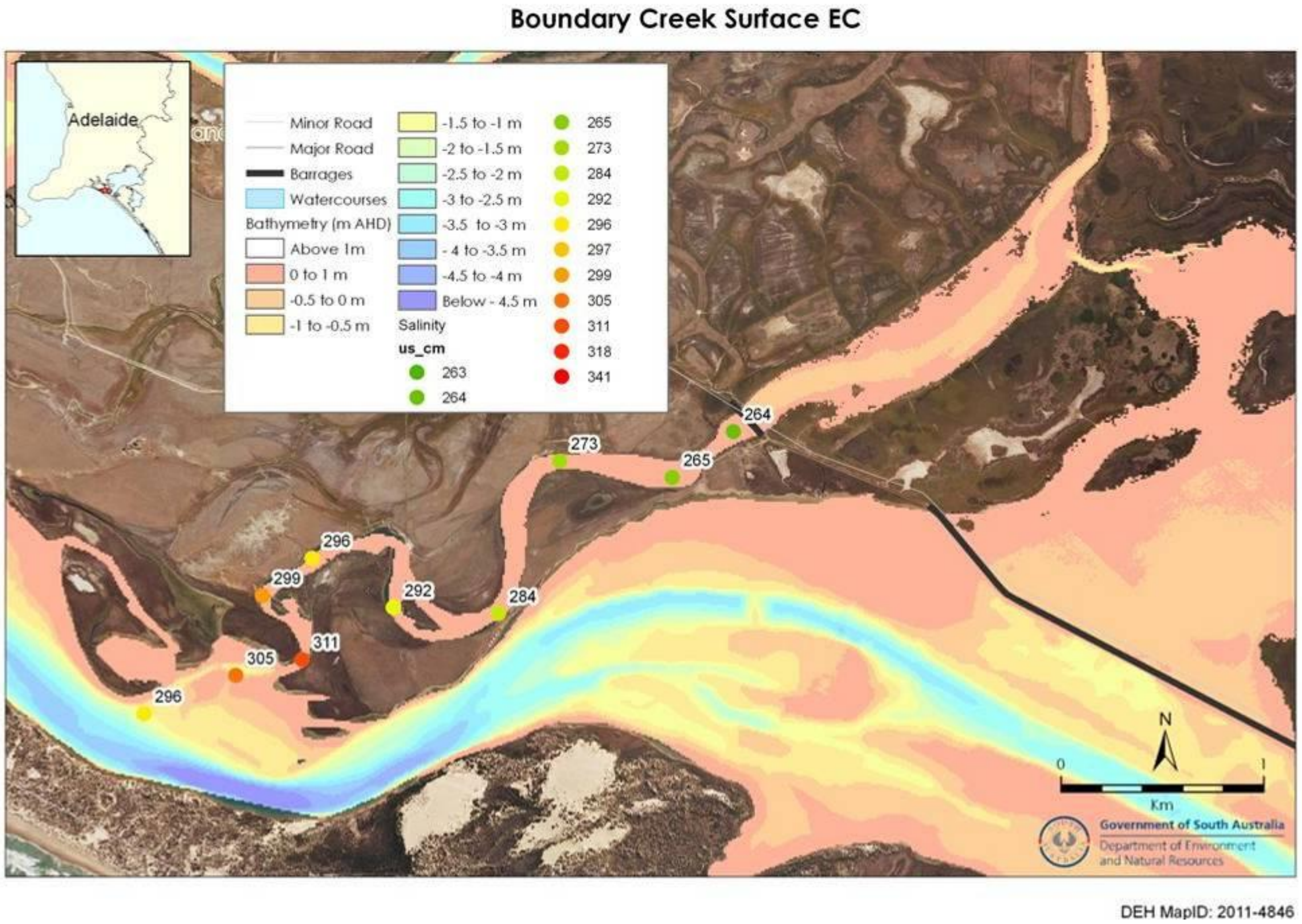

Figure 29. Bathymetry and salinity profile of Boundary Creek 20 April 2012

Attachment 4

Figure 30: Reverse Flow at the spillway site 17 August 2011

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