Department of Primary Industries

Fishway options for weirs of the Northern Murray-Darling Basin

REPORT TO THE MURRAY-DARLING BASIN AUTHORITY

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Fishway options for weirs of the Northern Murray Darling Basin. Report prepared for the Murray-Darling Basin Authority.

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More information

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Cover photo background: Tilpa Weir (M. Hobson, NSW Department of Primary Industries - Fisheries); inset: migrating Hyrtls tandan (Neosiluris hyrtlii) aggregating below Cunnamulla Weir (A. Berghuis, Qld Department of Agriculture, Fisheries and Forestry).

Job Number: 11687

Executive Summary

Barriers to migration have been identified as a major contributor to the decline of native fish species within the Murray Darling Basin. Recognition within the Murray-Darling Basin Authority's (MDBA's) Native Fish Strategy of their impacts on river health and their listing as a key threatening process in state and Commonwealth threatened species legislation is evidence of their impact on aquatic biodiversity.

To this end, the MDBA have made significant investment in improving fish passage along the Murray River and associated anabranches through the Lake Hume to the Sea program and the Living Murray Initiative. These investments have attracted international recognition for their strategic approach to riverine restoration and their implementation of world-leading technology.

Despite the improvements along the Murray River, this investment has not been matched in the Northern Murray-Darling Basin. At present, the movement of fish within and between river systems north of Menindee Lakes remains significantly restricted by dams and weirs without adequate fish passage.

The Northern Murray-Darling Basin also represents a different ecosystem, with semi-arid and arid rivers, and a fish assemblage that is unique to the region. With the increasing knowledge of the fish ecology in these rivers and the progression of research on fishways in the last five years, an opportunity now exists to strategically address the barriers in this region, with innovative fishway designs that are more cost-effective and more water efficient, with the same or increased functionality.

This project identified 12 of the highest priority sites for improved fish passage in the northern Basin and developed both concept designs and costings for remediation of five of these. Spanning river systems in both NSW and Queensland, the project has provided a clear direction for strategic investment in fish passage infrastructure to deliver substantial improvements in river health.

Fishway concepts were specifically designed to suit the fish assemblage and semi-arid ecology of the northern Basin and considered constructability, materials, regional context, maintenance and ownership. From these designs cost estimates were developed, with contingencies, to enable the financial and practical scope of a significant infrastructure project to be assessed.

The project identified that there are two feasible approaches to rehabilitating fish passage in the northern Basin:

Strategy 1) **Provide fish passage at the top 11 priority structures to reinstate 2,086 km of river channel.**

The total cost is estimated at $14.56 million.

The program would address priority barriers in the Darling, Dumaresq, Condamine and Warrego rivers (Figure 1). This would greatly improve conditions for native fish by targeting sites adjacent to existing fishways to get multiple benefits, or by reconnecting long reaches of high quality habitat.

Strategy 2) **Provide a strategic, holistic, program re-establishing broad-scale river connectivity of over 3,242 km.**

The total cost is estimated to be approximately $70 million.

In this program we have selected the Darling River and the three key tributaries, all of which have high quality habitat; within these rivers there are 42 mainstem structures requiring remediation (Figure 1). All of these weirs, except eight, are below 4.5 m in height. The remaining eight structures are 5.8 m to 12.1 m high and require fish locks or fish lifts. Providing fishways at the eight high-level structures is estimated to cost $32.5 million, which is an estimate derived from other recent projects; the remaining 34 structures are estimated to cost $32.3 million, which is an extrapolation from the costs generated in the present study. These estimates provide an indication of the scope of a broader project. If the broader project was considered viable, a more detailed estimate based on concept designs, as per the present project, would be essential.

Monitoring of the performance of these structures is important to optimise each design and ensure that the investment is resulting in real changes in the fish community; this is likely to add $5 million over time to the project.

Hence, the total cost of the Northern Basin Fish Passage Program is approximately $70 million. This is a comparable cost to the Hume to Sea program but 42 barriers would be addressed rather than 15, and over 3,242 km of river would be opened up to fish movements.

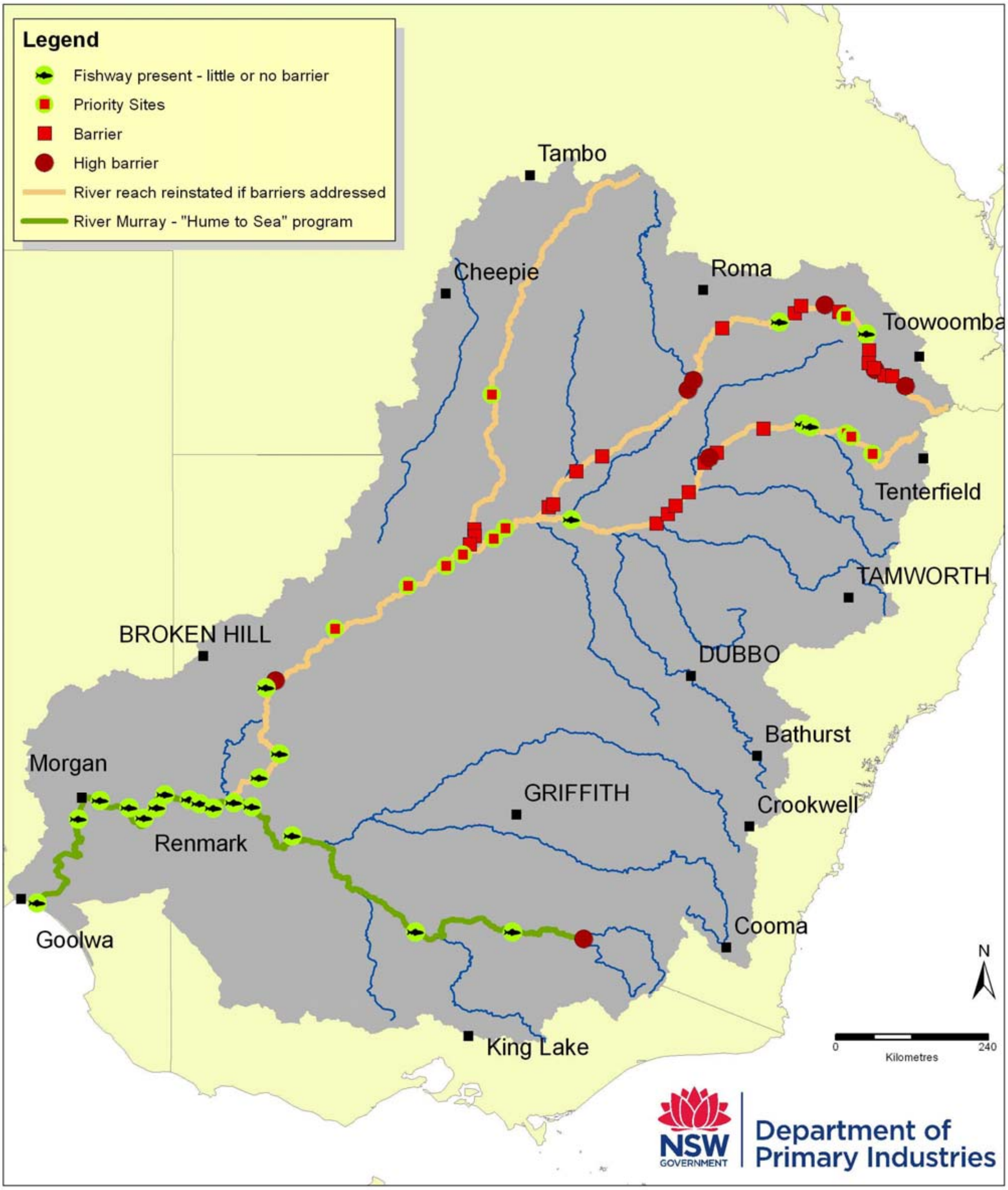
The broad-scale strategic approach is feasible largely because the main stem barriers of the rivers are not numerous and most are low-level weirs between 1.5 m and 4.5 m high. Most of these sites also do not have the high dewatering costs of the 'Hume to the Sea' program.

Like the 'Hume to the Sea' program this approach is aimed at ecosystem rehabilitation. In this case it is an arid river ecosystem and it has not previously received significant investment in rehabilitation.

The reinstatement of fish passage in the mainstem Darling and major tributaries would provide immense benefit to fish communities throughout the catchment and make a major contribution to ecosystem restoration. At a broader level it integrates:

- **Natural heritage**,
- **Cultural heritage**, as native fish are an important part of aboriginal culture, especially in arid rivers.
- **Sustainable agriculture and water resource management**, because essential infrastructure for water delivery and harvest is retained, whilst the most significant ecological impact of these structures is addressed.

Figure 1 Priority structures identified in the Northern Murray-Darling Basin and benefits associated with remediation



Note: Some listed barriers include old ineffective fishways. Boggabilla Weir is shown with a fishway, however this is ineffective for passing small fish and has been included in the total remediation costs as part of a Northern Basin Fish Passage Program (Strategy 2).

Caveat – Estimated Project Costs

Costings and designs presented in this report should be reviewed before progressing to construction stage of any site.

Detailed cost estimates of the preferred fish passage option at each priority site have been prepared here by subcontractors SMEC. A breakdown of these estimates is provided in Appendix 1 of their report (Appendix 2 of this report).

The cost estimate for each site contained a value for contingencies of 30% and all costs were based on the designs specified and December 2010 pricing.

Any modifications to the designs presented, or a delay in implementation may impact on the costs of construction due to increases in the costs of raw materials, labour, transport etc.

Cost estimates for the alternative option, where provided, were based on a standardised table of rates for materials and estimated quantities. As such these estimates should be viewed as 'ballpark' figures and are provided for comparative purposes only.

In addition, any ongoing costs, such as maintenance and cleaning of the structures are not included as these will be dependant on the final design (e.g. if trash racks are included or not).

This report estimated the cost of construction for priority sites to be between $0.356 million and $0.424 million per vertical metre structure height. In addition, Bourke Weir was estimated to cost $0.6 million per vertical metre and Cunnamulla Weir $0.9 million per vertical metre due to its remoteness. Sites where fish locks were recommended had an estimated cost of $4.5 million per fish lock.

Recent examples of remote fishway construction costs

Recent trends have seen significant increases in construction CPI (consumer price index) over and above general levels of inflation, leading to a rapid increase in costs where onground works were delayed for any period of time. This environment is likely to continue into the future.

The per metre cost of construction is a factor of the fishway's functionality; whether it is required to pass part or all of the fish community and whether fish passage will be provided under all flow conditions or only part of the hydrograph. Ultimately these issues will need to be considered by the funding body.

Since cost estimates were provided for this report two weirs on the lower Darling River in NSW (Burtundy Weir and Weir 32) have had fishways constructed. As these weirs are in remote locations, the cost of their construction can be used as a guide for the likely costs of weirs in the northern Basin. At these sites the cost per vertical metre varied from $0.46 million at Burtundy Weir to $0.78 million at Weir 32 (Mallen-Cooper, M., *pers. comm.*, 27/07/12).

Therefore, given the following assumptions:

- the estimated cost of construction per vertical metre for Bourke and Cunnamulla Weirs remains as stated ($0.6 million and $0.9 million per vertical metre respectively)
- the estimated cost for fish locks was increased to $5 million (an increase of $500,000 per site)
- the cost of construction of all other priority sites is based on costs incurred at Burtundy ($0.46 million per vertical metre) and Weir 32 ($0.78 million per vertical metre).

The total cost of construction for Strategy 1 may range from $18.51 million to $28.26 million and Strategy 2 from $72.74 million to $95.86 million using current cost estimates.

It is again reiterated that prior to progressing with construction at any site, structure designs will need to be finalised, with costings based on these new designs and current material, labour and transport costs.

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1. INTRODUCTION

1.1 Background

It is well recognised that freshwater fish populations have declined in the Murray-Darling Basin (MDB), with 26 of the 46 recognised fish species listed as threatened and once common species, such as silver perch, declining by over 90% in 50 years. Extensive research has brought a deeper understanding of the causes of these declines and advances in remediation measures have accelerated in the last two decades.

One of the major identified threats to fish populations in the MDB is barriers to migration. The installation of such barriers is deemed a "key threatening process" under the NSW Fisheries Management Act 1994 and in Queensland requires approval under the Fisheries Act 1994.

The Murray-Darling Basin Authority (MDBA) and its earlier organisations (Murray-Darling Basin Commission and River Murray Commission) have a long history of recognising this impact on fish and attempting to remediate it through the construction of fishways. Some of the earliest fishways in Australia were built on the River Murray at Lock 6 in 1930 and at Lock 15 in 1937. However, these were based on the swimming ability of salmonids and passed few native fish. In the early 1990's the RMC established a Working Group on Fish Ladders to investigate the latest research findings and by the mid-1990's, funded the construction of a fishway at Torrumbarry Weir. This fishway was specifically designed for the swimming ability of native fish and was a spectacular success. The results had a "ripple effect" on fish passage in eastern Australia, with numerous water agencies utilising the new designs.

In 2001 the MDBC initiated the world–recognised "Hume to the Sea" fish passage program, which aims to restore fish migration along 2225 km of the River Murray through the construction of fishways at 15 weirs. The program has a strategic holistic view and a strong ecological basis, recognising that fish migration is frequently over hundreds of kilometres and occasionally over 2000km. However, at a Basin-wide scale the program is centred on the River Murray and the southern half of the Murray-Darling Basin. This has partly been driven by the need to utilise capital funds on structures owned and operated by River Murray Water, the internal business unit of the MDBA that is responsible for water delivery. This limitation, however, has recently been overcome at Stevens Weir on the Edward River where a new fishway is being built. The weir is owned by NSW State Water Corporation but the fishway is funded by MDBA – both parties negotiated an agreement on ownership, operation and maintenance to address this critical fish passage priority.

The northern half of the Basin has the longest river of the system - the Darling River and its source tributaries – but does not have the same strategic program of fish passage. The funding and construction of fishways within the State jurisdictions has been largely determined by the relevant legislation, which usually refers to a new weir or dam, or one being modified. Hence, fishway construction has tended to be opportunistic, generally being addressed when old weirs need refurbishment or replacement. Additional, smaller strategic sites have sometimes been addressed by Catchment Management Authorities in NSW and Natural Resource Management Groups in Queensland.

A strategic program of fish passage centred on the Darling River and major tributaries is needed in order to address the fish passage barriers in this region and provide similar benefits as the Hume to Sea project. The aim of the present project was to assess the feasibility of restoring fish passage in the northern Basin.

1.2 Project scope

In late 2009, the NSW Department of Primary Industries and the Department of Qld Department of Agriculture, Fisheries and Forestry were commissioned by the Murray Darling Basin Authority (MDBA) to develop concept designs and engineering costings for 10 of the highest priority weirs in the Northern Murray-Darling Basin.

A total of 12 weirs were identified as priority sites for provision of fish passage within the Northern Murray-Darling Basin, and are shown in Table 1 and Figure 1. These weirs were chosen because of their anticipated high benefit/cost. The river reaches where the weirs are located have high ecological value with: known native fish populations; high quality fish habitat; and long river reaches that would be reinstated for migration, either because of few nearby barriers or because of nearby weirs with fishways. The cost of fishways for the priority structures was anticipated to be relatively low because the weirs are low–level structures; the two exceptions are Cunnamulla Weir (4.5 m) and Chinchilla Weir (9.1 m) but fish passage at these weirs would have major ecological benefits and hence they were initially included.

Table 1 Priority weir sites in the Northern Murray-Darling Basin.

NSW (Darling River)	**NSW / Qld border (Dumaresq River)**	**Qld (Warrego and Condamine Rivers)**
Wilcannia Weir	**Glenarbon Weir**	**Cunnamulla Weir (Warrego R)**
Tilpa Weir	**Cunningham Weir**	Chinchilla Weir (Condamine R)
Louth Weir	Bonshaw Weir	**Warra Town Weir (Condamine R)**
Weir 20A		
Weir 19A	** detailed design and costing complete*	
Bourke Weir*		

Of the structures listed above, those on the Darling and Dumaresq rivers were of similar construction type, possessed similar hydrology, and similar fish fauna. Therefore to deliver better value for money and avoid repetition, one site from each system was selected for in-depth analysis, and used as a surrogate for the other similar structures within the same waterway. These sites were Tilpa Weir (Darling River), which acted as a surrogate for Wilcannia, Louth, 20A and 19A Weirs, and Glenarbon Weir (Dumaresq River), which acted as a surrogate for Bonshaw Weir. All other sites were considered stand-alone high priority structures. Bourke Weir on the Darling River was identified as a priority structure, but was not included in further analysis as detailed designs and preliminary costings for this site are complete (Mallen-Cooper and Smit, 2007).

The present project investigated the detail of feasibility, identifying fishway designs that would be applicable to generic types of weir (e.g. sheet pile with rock-fill face) in the northern Basin. At key representative weir sites, fishway concept designs were developed; these were specifically designed to suit the fish assemblage and semi-arid ecology of the northern Basin and considered constructability, materials, regional context, maintenance and ownership. From these designs cost estimates were developed, with contingencies, to enable the financial and practical scope of the project to be assessed.

This report and the accompanying Options Analysis & Concept Design Report completed by SMEC (Appendix 2), provides fish passage options for priority sites, with concept design drawings and costings applied to those sites shown in bold in Table 1.

1.3 Chinchilla Weir

During the course of the project Chinchilla Weir was removed from consideration due to the high cost of developing fish passage options for this site alone.

The Chinchilla Weir structure has a MEL (Minimum Energy Loss) design, which attributes the structure with a unique amphitheatre–like shape. The MEL design concept aims to pass large floods with minimal energy loss and therefore minimal upstream flooding (Chanson, 2003).

The structure itself is 9.1m high and comprises compacted earthfill overflow embankment with a 410 m long crest (Chanson, 2003; Berghuis, 2009). The structure wall is built on a 1:3 slope, which makes it impractical to construct a traditional rock-ramp or vertical-slot fishway. Design options available are therefore a fish lock or a fish lift.

However, being an earth fill, concrete-capped structure, the weir wall is likely to require substantial reinforcement if a fish lock design was to be considered. These constraints therefore favour a fish-lift design which is relatively lighter, or a design that is built into the bank and does not directly impact on the weir.

Due to these constraints and complexity, the costs outlined by all contractors tendering for the design component of this project were well above the current project budget while Chinchilla was included in the list of priority weirs. A decision was therefore made to remove this weir from current consideration. However, it is still deemed a high priority for fish passage in the northern Basin, and has been included in Strategy 2 for addressing structures of the northern Basin.

1.4 Final report

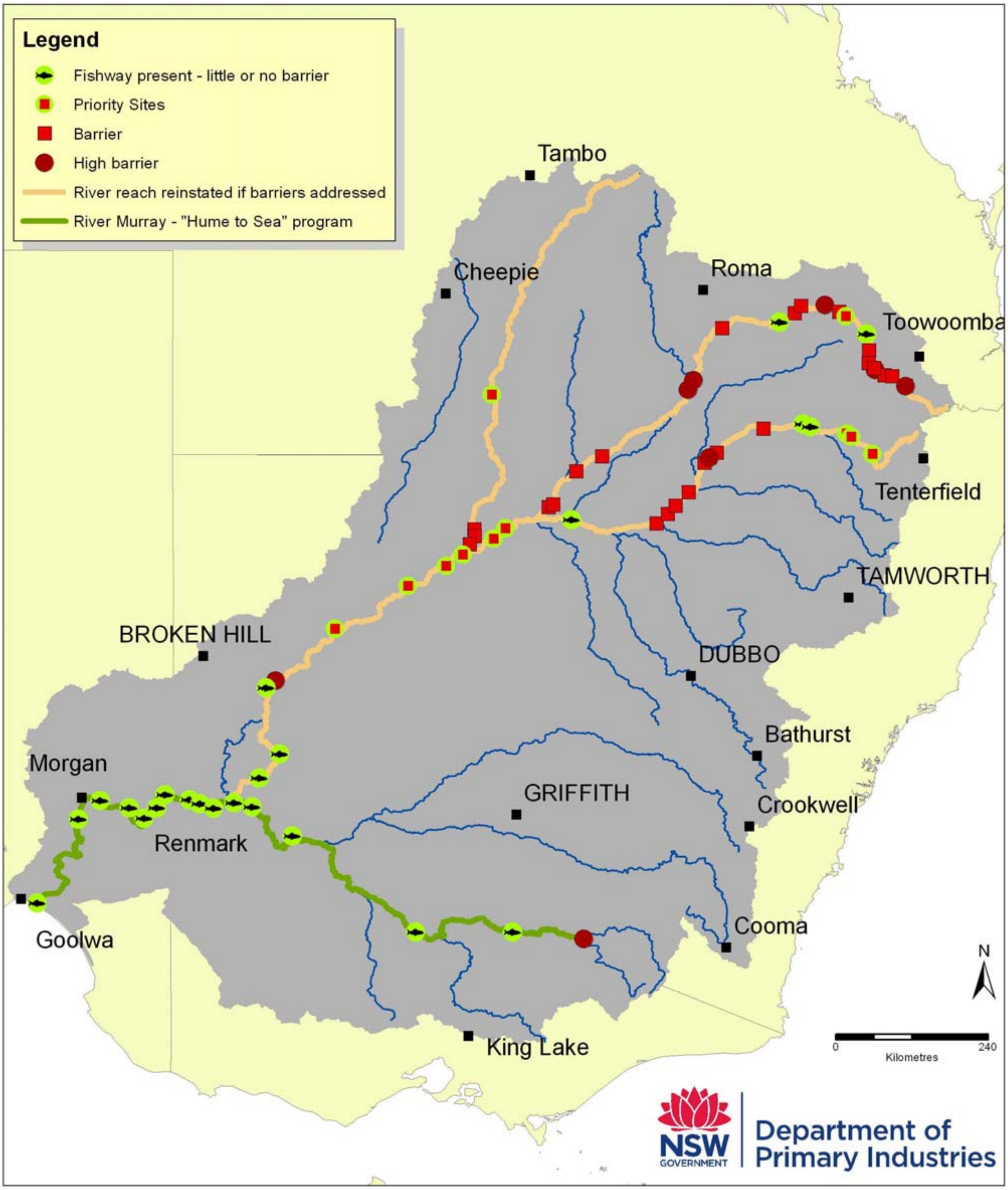
Using representative sites and excluding Chinchilla and Bourke weirs, this report provides detailed costings and concept designs for five priority sites in the northern Basin, and presents two implementation strategies for providing fish passage in this region.

As detailed in the Options Analysis & Concept Design Report completed by SMEC (Appendix 2), the cost estimates provided are for specified designs, and are based on December 2010 pricing. Modification of the designs presented, or a delay in implementation, may impact on the costs of construction due to increases in the costs of raw materials, labour, transport etc.

It should be noted that prior to undertaking remediation options recommended in this report, further investigations will be required at each site including detailed geotechnical investigations and development of detailed structure designs.

In addition, as with any long-medium term project, increases in construction costs and inflation should be taken into account in project budgets.

Figure 2 Priority structures identified in the Northern Murray-Darling Basin and benefits associated with remediation



Note: Some listed barriers include old ineffective fishways. Boggabilla Weir is shown with a fishway, however this is ineffective for passing small fish and has been included in the total remediation costs as part of a Northern Basin Fish Passage Program (Strategy 2).

2. MIGRATORY FISH OF THE NORTHERN MURRAY DARLING BASIN

2.1 Species diversity

Data sources

Data on species diversity were obtained from capture records for: the Darling and Warrego Rivers (MDBA Sustainable Rivers Audit – data to 2009); the Condamine River (Moffat, D., *pers. comm.*, 10/12/09 - sampled within Chinchilla Weir pool, including 2-3 km upstream of the weir wall); Charlies Creek, a Condamine River tributary 7 km downstream of Chinchilla Weir (Hutchinson, M., *pers. comm.*, 10/12/09); and the Dumaresq River (NSW DPI Freshwater Fish Database). Other records and reports included Thorncraft and Harris (1996), Moffat and Voller (2002), Lintermans (2007), Balcombe *et al*. (2006), Hutchison (2008), and Rolls and Wilson (2010).

Table 2 includes species for the Northern Murray-Darling Basin in all three major geographic zones – the upland, foothills and lowlands. The priority fish passage sites selected for the present study are in the foothills and lowlands of the northern Basin.

Predicted and observed diversity

A total of 26 native species and seven introduced fish species are predicted to occur in the Northern Murray-Darling Basin (NSW DPI Freshwater Fish Database). However, two of the predicted native fish species, pouched lamprey and flat-headed galaxias, may not naturally occur in the northern Basin. The migratory pouched lamprey is predicted to occur in the mainstem Darling River, but it has not been recorded at any site. The natural distribution of the pouched lamprey is in cooler southern coastal streams and it would not be expected to penetrate to the upper Darling River. However, the species is anadromous, meaning it moves upstream into freshwater river reaches from the sea or estuary to breed, and is therefore likely to have been severely disadvantaged by the presence of instream barriers, which may also explain its absence from Darling River samples. The species is considered rare in the southern Basin and has only recently been captured from near the Goolwa barrages and Lower Lakes in South Australia (Lintermans, 2009).

Flat-headed galaxias are also predicted to occur in the Darling River, but there are no records from this river system. Lintermans (2009) states that this species is only known from the Southern Murray-Darling Basin where records of it occurring are patchy – it is therefore unlikely to be found in the mainstem Darling River in the north.

Rendahls catfish is also an uncommon record, although it has recently been recorded from a number of sites within the Condamine River system. It is sometimes confused with Hyrtl's tandan, particularly as juveniles and sub-adults. Rendahls catfish is found in wet tropical and sub-tropical coastal rivers and was not considered a catfish of semi-arid streams. Identification was confirmed from sites within the Condamine, downstream of Chinchilla Weir, where catches of this species have occurred as they move to off river habitats or up tributary streams (Hutchison, M., *pers comm*., 10/12/09).

Three of the native fish species listed in Table 2, mountain galaxias, Darling River hardyhead and river blackfish are considered upland species. Hence, they have not been collected, or are expected, near the study sites, although it is possible they may still occur in low abundance.

Given the five native species above that are either not expected to occur in the northern Basin or are mainly upland species, a total of 21 native fish species are expected in the lowlands and foothills of the northern Basin.

Of the eight introduced species, four are expected in the lowlands and foothills. Brown trout, rainbow trout and redfin use the cooler water of the upland rivers of this region.

There are also no records of tench in the northern Basin and it is not expected. Tench prefer cooler waters in the southern Basin although it has been recorded along the length of the Murray River.

Abundance within the study area

A total of 17 native and three introduced fish species have been sampled or observed in the vicinity the priority weirs in the Northern Murray-Darling Basin (Table 2). Species diversity is richest from the Condamine River with 12 native species known to occur there, although three of these are also stocked into the system. The mainstem Darling River (from downstream of Wilcannia to upstream of Bourke) and the Dumaresq River (from Boggabilla Weir to upstream of Bonshaw Weir) both have had 11 species of native fish sampled or observed. Species richness was lowest in the Warrego River around the Cunnamulla (Allan Tannock) Weir, where only seven native fish species have been captured or observed. All waterways investigated also had introduced carp, gambusia, and goldfish present, with the exception of the Dumaresq River where goldfish have not been recorded.

Species common to all sites are Australian smelt, bony herring, gudgeon sp., Murray-Darling rainbowfish, and golden perch. Two species – olive perchlet and southern purple-spotted gudgeon - were predicted to occur at all sites, but had not recently been recorded in the immediate vicinity of the weirs in the present study (Table 2). However, olive perchlet is common in other studies of the rivers in the northern Basin (Thorncraft and Harris, 1996; Hutchison, 2008) and southern purple-spotted gudgeon is reported to be present in the Macintyre, Moonie and Condamine–Balonne rivers (Moffat and Voller, 2002; Lintermans, 2007).

Murray cod and spangled perch have been captured at all sites except the Warrego River near Cunnamulla Weir, but both these species have been captured elsewhere in the Warrego River upstream of Cunnamulla Weir (MDBA Sustainable Rivers Audit – data to 2009), and although not captured, spangled perch have been observed below Cunnamulla Weir (Berghuis, A., *pers. obs*., 03/08/10). Silver perch are predicted to occur at all sites and are known from all catchments in the northern Basin (Moffat and Voller, 2002), but have not been captured recently from the Warrego near Cunnamulla, at sites upstream, or from any site upstream of Boggabilla Weir in the Dumaresq River and its tributaries. Silver perch have declined in the southern half of the Basin (Lintermans, 2007) and the lack of recent occurrences in the northern Basin may either be a function of limited sampling or a real decline in abundance.

Long-finned eels are only found in the upper catchments of the Condamine Balonne system and are uncommon (Moffat and Voller, 2002). Eels migrate to the sea to spawn and juveniles migrate into freshwater. However, as these fish have never been reported along the Darling River they are more likely to have crossed the Great Dividing Range from coastal Queensland rivers, rather than migrated up from the Murray River mouth.

Table 2 Recorded and predicted fish of the Northern Murray-Darling Basin including recent records near priority weirs.

	Potamodromous Migrations (Except Note 1 below)			**Probable length migrating upstream**	**Distribution** ■ = present. □ = predicted			
	Upstream migrations of adults to spawn or juveniles to counter downstream drift as larvae	Active upstream and downstream migrations in arid and semi-arid rivers to seek food and refuge	Dispersal movements - to maximise distribution, seek habitat, reduce competition	⌘ 30-100 mm ♦ 100-500 mm ▌>500 mm	**Darling River**	**Warrego River**	**Condamine River**	**Dumaresq River**
Australian smelt	●		●	⌘	■	■	■	■
Bony herring	●	●	●	⌘	■	■	■	■
Carp gudgeon sp.	●	●	●	⌘	■	■	■	■
Darling River hardyhead		●	●	⌘			□	■
Dwarf flathead gudgeon		●	●	⌘			■	
Flat-headed galaxias		●	●	⌘♦	□			
Flathead gudgeon		●	●	⌘	□	□	□	■
Flyspecked hardyhead		●	●	⌘	■	□		■
Freshwater catfish		●	●	⌘♦▌	■	■	□	■
Golden perch	●	●	●	⌘♦▌	■	■	■	■
Hyrtl's tandan	●	●	●	⌘♦	■	■	■	
Long-finned eel	●		●	▌			■	
Mountain galaxias		●	●	⌘♦				□
Murray cod	●		●	⌘♦▌	■	□	■	■
Murray hardyhead	●	●	●	⌘	□			
Murray-Darling rainbowfish	●	●	●	⌘	■	■	■	■
Olive perchlet	●[1]	●	●	⌘	□	□	■	□
Pouched lamprey			●		?			
Rendahl's tandan		●	●	⌘			■	
River blackfish	●	●	●	⌘♦				□
Silver perch			●	⌘♦	■		■	□
Sthn purple-spotted gudgeon			●		□	□	□	□
Southern pygmy perch	●	●	●	⌘	□			
Spangled perch		●	●	⌘♦	■	■	■	■
Unspecked hardyhead		●	●	⌘			■	

Table 1 (continued)	Potamodromous Migrations (Except Note 1 below)			Probable length migrating upstream	Distribution ■ = present. □ = predicted			
	Upstream migrations of adults to spawn or juveniles to counter downstream drift as larvae	Active upstream and downstream migrations in arid and semi-arid rivers to seek food and refuge	Dispersal movements - to maximise distribution, seek habitat, reduce competition	⌘ 30-100 mm ♦ 100-500 mm ▌>500 mm	Darling River	Warrego River	Condamine River	Dumaresq River
Brown trout ☹		●	●					□
Carp/Goldfish Hybrid ☹		●	●	⌘♦▌	□	□	□	□
Common carp ☹		●	●	⌘♦▌	■	■	■	■
Gambusia ☹		?	●	⌘	■	■	■	■
Goldfish ☹		?	●	⌘	■	■	■	□
Rainbow trout ☹	●		●	♦				□
Redfin ☹		?	●	⌘♦	□			□
Tench ☹		?	●	⌘♦	□			
Total Native Fish Species Recorded					**11**	**7**	**12**	**11**
Total Native Fish Species Predicted					**18**	**14**	**17**	**16**

(Species names and conservation status are presented in Appendix A.)

[1] Anadromous

? Uncertain migration, distribution or identification

☹ Introduced species

Uniqueness of the northern Basin

Compared to the southern Basin, the northern Basin has semi-arid to arid rivers, and a different climate and geography which results in a different fish assemblage. Seven species found in the southern Basin (trout cod, Macquarie perch, flat-headed galaxias, southern pygmy perch, two-spined blackfish, short-headed lamprey, pouched lamprey and common galaxias) are not found in the north, whilst spangled perch and Hyrtl's tandan and Rendahl's tandan are only found in the northern Basin.

Significantly, four threatened species found across the Basin appear to be more abundant in the north. Both southern purple-spotted gudgeon and olive perchlet were, until very recently, considered extinct in the southern Basin. Each species is now known from single population in the south. Numerous populations of both species are, however, present in the north of the Basin. Silver perch and catfish have also declined significantly in the southern Basin but are also known to be relatively common in the north.

The northern Basin is a distinctive ecosystem of the Murray-Darling Basin. It has not only a unique assemblage of native fish but it may also now represent a stronghold of four threatened species.

2.2 Fish ecology and migration

The fish ecology of the northern Basin reflects the varied hydrology that differs greatly from the southern half of the Basin. The Darling River is semi-arid, with flow for 95% of the time and median and maximum zero-flow spells of 13 and 131 days (1943-1991), whilst the Warrego River is arid, with flow for only 57 % of the time and median and maximum zero-flow spells of 64 and 302 days (1992-1909). High flows are more variable in frequency than the southern half of the Basin but generally occur annually in wet decades and between 3 to 6 years in dry decades.

The Macintyre and Darling rivers have high flows in late winter and spring. The Condamine and Warrego rivers are more likely to get summer floods which are influenced by wet tropical storms, sometimes resulting in flooding of localised areas.

The hydrology differs greatly from the Murray River in the southern Basin which has continual flow and very seasonal high flows generally in spring. With periods of zero flow and less predictable flow in the northern Basin, fish need to be highly mobile and responsive to flow to optimise migration opportunities. These fish need to move to take advantage of feeding in temporarily inundated habitats, either longitudinally in the river channel and semi-terminal lakes or laterally into off-channel wetlands. As flows recede, returning to seasonal refuge habitats is critical for survival to avoid being trapped in shallow habitats that dry out.

Adult fish of a range of species, including large-bodied fishes (golden perch, silver perch, Hyrtl's tandan, Murray cod, spangled perch) and small-bodied fishes (carp gudgeons, olive perchlet, Murray-Darling rainbowfish) often migrate upstream in spring and summer in response to increasing flows and this is thought to be related to spawning (Table 2). Moving upstream would optimise the spread of drifting larvae to suitable habitats. For these species an upstream migration of juveniles and sub-adults often also occurs, presumably to compensate for this downstream drift (Table 2).

Dispersal movements of fish (Table 2) are often overlooked as migration or as a key process in fish population dynamics and recovery. The proportion of a fish population that disperses varies considerably. In general it is a small proportion but it is very significant as those few individuals can start a new population elsewhere. This is obviously critical when a population is recovering from drought.

Prior to the construction of weirs along these rivers, population recovery following droughts would have been rapid as there were few, if any, natural barriers in the lowlands and foothills. Even localised small flows would have reconnected waterholes and enabled fish to recolonise. At present, these dispersal movements are restricted to large floods when the weirs are submerged. Hence, opportunities to recolonise have been reduced, since the construction of weirs, from close to 100% of the time when there is flow, to less than 5% of the time. If a particular species is cued to disperse at low to moderate flows and not in floods, then the opportunities are further reduced and the impacts on the population are potentially much greater.

In comparison to the southern Basin, the northern Basin represents a different, more arid, ecosystem where fish have different migration patterns. Many of the longitudinal migrations that are well known in the southern Basin are present but there is another layer of complexity where fish need to be more opportunistic, highly attuned to flows, and migrations are needed to optimise temporary feeding opportunities, seek dry-season refuges and recolonise rivers and wetlands following droughts – all of which are essential for survival.

2.3 General implications for fishway design

Generally the swimming ability of the smaller species will be less than larger species, therefore water velocities within a fishway need to be kept lower to allow them to pass. Turbulence in the fishway can further inhibit movement of smaller bodied species.

For large-bodied species, pool depths need to be sufficient and slot widths/ridge rock gaps need to be wide enough to allow fish to enter the fishway and be comfortable whilst there. If gaps are too narrow, fish will be physically blocked from entering the fishway. If fishway pools are too shallow, large-bodied fish may avoid entering the fishway or quickly retreat out as they avoid "threatening" conditions.

The largest migratory species found in the Murray-Darling Basin is the Murray cod (*Maccullochella peelii*) which is reported to grow 1.8 m in length (McDowall, 1996) but is more commonly up to 1.3 m. This species has been captured at all sites except near Cunnamulla Weir, although there have been records of this species occurring upstream (MDBA Sustainable Rivers Audit – data to 2009). To accommodate this species, slot widths and pool depths must be great enough to allow breeding adults of this species to move through a fishway without expressing behavioural avoidance. Adult Murray cod are between 500-1300 mm in length (Lintermans, 2009); hence fishways need to be able to pass these fish, as well as smaller fish species. Vertical-slot fishways on the Murray River have slot widths of 300 mm and minimum pool depths of 1.5m, which restricts the passage of fish to those that are 1m or less (e.g. Stuart *et al.*, 2008); the intent is to enable the passage of the majority of adult fish whilst optimising fishway cost.

The smallest migratory fish found at this location is the Australian smelt (*Retropinna semoni*) which is a mid-water dweller potentially growing to 100 mm, but more likely to 40-60 mm (McDowall, 1996; Lintermans, 2009). There are also a number of small species present at these locations that undertake local migrations and have been shown to move upstream through a fishway on the mainstem Murrumbidgee River (e.g. flyspecked hardyhead, gudgeon *Hypseleotris* spp. complex, and Murray-Darling rainbowfish: Baumgartner and Harris, 2007). The gudgeons (including flathead gudgeons) are generally bottom dwellers and will therefore use boundary layers created by rough surfaces to move through a fishway. These species will negotiate shallow water to pass an obstruction. These species generally grow to less than 100 mm, and their poorer swimming ability needs to be accommodated in fishway design.

Medium-sized migratory species known from these sites include golden perch, silver perch, spangled perch, and bony herring. The maximum size of these species range from 760 mm (golden perch) to 330 mm (spangled perch), although generally adults range in size from 400 mm (golden perch) to 150 mm (spangled perch). These species all have good swimming abilities and will therefore be able to tolerate relatively high water velocities within a fishway, compared with the small-bodied fishes.

Another medium-sized fish found at all priority sites except in the Condamine is the freshwater catfish. This species is known to undertake local movements, and will readily utilise fishways (Berghuis, 2010).

Hyrtl's tandan has been captured in the mainstem Darling, Warrego and Condamine Rivers, whilst Rendahl's tandan is reported in the Condamine system only (including the Balonne River area). These species have not been well studied in the Murray-Darling Basin, consequently little is known of their ecology (Lintermans, 2009). For Hyrtl's tandan, spawning is thought to be stimulated by increasing water levels, and upstream movements recorded in coastal Queensland streams are thought to be associated with spawning (Lintermans, 2009). For Rendahl's tandan, spawning in the Northern Territory occurs in muddy, lowland lagoons, with fish moving upstream to refuge habitat in the dry season (Lintermans, 2009). Both these species have been identified migrating upstream at Reilly's Weir fishway on the Condamine River and should therefore be considered when developing fish passage designs at priority locations.

In addition to small-sized adults, juveniles of larger species (e.g. bony herring, *Nematalosa erebi*) may attempt to movement upstream and therefore fishway design needs to cater for their swimming abilities (Baumgartner and Harris, 2007; Stuart *et al*., 2008).

Stuart *et al*. (2008) recorded 27 mm juvenile bony herring attempting to move through a vertical-slot fishway on the River Murray and Australian smelt as small as 31 mm reaching the fishway exit. The vertical-slot fishway monitored by Stuart *et al*. (2008) was built on a 1:32 slope with large pools (3 m long by 2 m wide), possessing an average turbulence of 42 Wm^{-3}, and maximum water velocities of 1.4 ms^{-1}. Similar design criteria would be required for the fishway designs in the northern Basin.

2.4 Specific site considerations

The following should also be taken into consideration in fishway development at these sites.

2.4.1 Darling River

No specific considerations are required for the Darling River sites.

2.4.2 Warrego River

Although the closest site where Murray cod have been sampled in the Warrego during the Sustainable Rivers Audit was 79.5 km upstream, it is possible that this species will occur at Cunnamulla Weir. Murray cod should therefore be considered when developing fish passage designs for this structure.

2.4.3 Condamine River

Rendahl's tandan has been captured in the Condamine only. Although nothing is known of its ecology in the Murray-Darling Basin, in the Northern Territory it spawns in muddy lowland lagoons and undertakes migratory movements to refuge habitats (Lintermans, 2009). In the Condamine system, Rendahl's tandan has been captured moving from the river to off-river wetlands, in the wetlands themselves, or in up tributary streams. Rendahl's tandan should therefore be considered in fish passage designs developed for this system. If a fishway is designed for Hyrtl's tandan it is very likely it would also pass Rendahl's tandan.

Little is known of unspecked hardyhead movement requirements, however Lintermans (2009) notes that this species has been recorded trying to move through fishways in the Murray and Murrumbidgee rivers. This species only grows to 78 mm (more commonly 50 - 60 mm), and prefers still or slow flowing waters.

Although predicted to occur, Darling River hardyhead are unlikely to occur in this vicinity and are more likely constrained to the far north east corner of the NSW section of the Murray-Darling Basin (Moffatt, D., *pers. comm*., 17/03/10). Similarly, flathead gudgeon in the mainstem Condamine River are also likely to be very limited in their occurrence (Moffatt, D., *pers. comm*., 17/03/10).

2.4.4 Dumaresq River

River blackfish, rainbow and brown trout are also predicted to occur in the Dumaresq River, but are likely to be restricted to near its headwaters, upstream of the sites being investigated.

2.5 Migratory fish behaviour in the Northern Murray-Darling Basin

Fish that are migrating upstream will move up to a barrier and stay within a short distance of that barrier. Small fish will often stay within one metre of a weir at low flows, while larger fish will congregate within a few metres, depending on the river morphology downstream.

2.5.1 Implications for the design of a fishway

The fishway entrance needs to be close to the downstream face of the weir wall, where fish will congregate, and there needs to be some method of attracting fish to the fishway entrance (attraction flow).

If the river tailwater rises considerably during a high river/flood event, the entrance needs to be locatable at the majority of flows. Some sites have the potential for large variations in headwater and tailwater, with water backing up to the weir wall considerably during high flows.

2.6 Range of flows over which fish are migrating in the Northern Murray-Darling Basin

Most of the fish in the Murray-Darling Basin breed in response to increased water temperatures (e.g. Australian smelt, rainbowfish, gudgeon species, hardyhead), however some of these also require (or are benefited by) increases in water levels/flows. These tend to be the larger bodied species such as golden, silver, and spangled perch, and Murray cod (Lintermans, 2009). Certainly there are numerous observations of high levels of migration during high flows and aggregations of fish below weirs are common in these conditions.

Some smaller species appear to migrate to spawn and certainly most of the smaller species will move at low flows to disperse into new habitats. In addition, many smaller species and juveniles of the larger species will undertake upstream movements in order to recolonise areas following flooding flows when they may have been displaced downstream.

2.6.1 Implications for the design of a fishway

Fishways need to operate over the full range of river flow conditions and where practical, up to drownout of the weir.

To accommodate movement of small species at low flows and larger species at higher flows, the fishway entrance needs to be located close to the weir over these flow ranges and not be disguised by high river flow. Multiple entrances may be required as flow conditions change to allow fish to find the fishway entrance.

Boggabilla Weir on the Macintyre River currently has an existing vertical-slot fishway which allows limited fish passage. Fish passage is restricted due to excessive turbulence within the fishway pools and due to insufficient headwater range. Current management of the weir pool upstream aims to keep the headwater level within the operating range of the fishway, but the inherently high turbulence continues to limit fish passage to larger species and size classes (Berghuis and Broadfoot, 2005).

It is therefore recommended that this fishway be upgraded should a holistic approach to fish passage within the northern Basin be implemented (Strategy 2 below).

2.7 Conservation priorities in the Northern Murray-Darling Basin

At a Federal level, the migratory Murray cod (*M. peelii*) is listed as a vulnerable species under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). This species can undertake long migrations upstream in order to breed before returning to the same reach (Koehn *et al.*, 2009); therefore any fishway design should take into account the migratory requirements of this species.

In the Qld Murray-Darling system only river blackfish (predicted to occur) is listed under legislation as a “no take” species, however a number of species are listed under the NSW Fisheries Management Act 1994 as threatened, and therefore warrant conservation consideration in waterways that link to NSW waterways.

The NSW Fisheries Scientific Committee has determined that freshwater catfish (*Tandanus tandanus*) and olive perchlet (*Ambassis agassizii*) form Endangered populations within the

Murray-Darling Basin under the Fisheries Management Act 1994. Freshwater catfish are moderately-sized fish, growing up to 900 mm, but more commonly less than 500 mm (Lintermans, 2009). This species undertakes local movements and readily uses fishways. Dispersal of adults and juveniles would be critical in drought recovery.

Olive perchlet are small fish growing to 70-90 mm, which school near dense vegetation or woody debris in still or slow moving waters of rivers, creeks and wetlands during the day, and disperse at night to feed (Fisheries Scientific Committee, 2001). As with freshwater catfish, this species is known to undertake local movements and use fishways, and dispersal would be a critical for population recovery and maintenance.

Southern purple-spotted gudgeon (*Mogurnda adspersa*) is another small species (~70 mm: McDowall, 1996) that has been identified by the NSW Fisheries Scientific Committee as Endangered (Fisheries Scientific Committee, 2008), and has the potential to occur near Bonshaw Weir. This species is found in still or slow moving waters, of rivers, creeks and wetlands, often associated with vegetation, rocks and snags. This species is unlikely to undertake movements en masse but, dispersal of individuals would be important in drought recovery and population maintenance, so this species would need to be accommodated in fishway design.

The NSW Fisheries Scientific Committee has determined that silver perch (*Bidyanus bidyanus*) is a vulnerable species (Fisheries Scientific Committee, 2000) due to population decline throughout its former range. This species commonly grows to 300-400 mm (McDowall, 1996). Unlike the more sedentary species mentioned above, silver perch are known to undertake breeding migrations, travelling large distances upstream to breed and preferring fast flowing waters and rapids (McDowall, 1996).

2.7.1 Implications for the design of a fishway

The presence of Federally and State listed threatened species and populations at the majority of these sites means that the level of risk of unsuitable fishway design and poor performance needs to be minimised. Fishway design at these sites should as a priority provide for fish passage of the threatened migratory species Murray cod and silver perch, and allow for the movement of freshwater catfish.

3. DISCUSSION

3.1 Prioritisation and feasibility

Assessment of structures within the northern Basin had previously identified 12 priority sites within four sub-catchments. These structures were identified as priority sites due to their impact on migrating fish fauna, their potential benefit-cost ratio, and the river length that would be reinstated should the fish passage be provided at the site. In the case of the mainstem Darling and Dumaresq river weirs, multiple sequential sites were chosen to allow for a more strategic investment approach in order to reinstate access to a greater length of river with high quality habitat. Priority structures are listed in Table 1.

Priority structures in the northern Basin were assessed by fisheries and natural resource management (NRM) experts in Queensland and New South Wales, including:

- Qld Murray-Darling Committee (community-based, not-for-profit organisation delivering NRM services across the Basin);
- the Condamine Alliance, (regional NRM body focussing on the Condamine catchment);
- South West NRM (community-based organisation and designated regional body for NRM in South West Queensland);
- Native Fish Strategy Coordinator (Qld);
- Adam Butcher (Qld DAFF Fisheries Scientist);
- Adam Vey (Senior Conservation Manager, NSW DPI Fisheries);
- Martin Mallen-Cooper (fishway consultant).

Of the 12 priority weir sites identified, five were investigated for feasibility of fishway installation and identification of fishway designs that would be directly applicable to five of the other sites plus generic types of weir (e.g. sheet pile with rock-fill face) in the northern Basin. Of the two remaining sites, one has existing detailed design and cost estimates (Bourke Weir), while the second (Chinchilla Weir and gauge) requires further investigations – the costs of which were not possible within the budget for this project.

Fishway concept designs were developed at key representative sites which were specifically designed to suit the fish assemblage and semi-arid ecology of the northern Basin. Designs considered constructability, materials, regional context, maintenance and ownership, and allowed the development of cost estimates, with contingencies, to enable the financial and practical scope of the project to be assessed.

Detailed analysis of fish passage options for these structures, including concept design drawings are presented in Appendix 2.

The study found that installing fishways at these structures was very feasible. Two outstanding features of the region, from a design and construction viewpoint, are that:

i) most of the barriers are low-level weirs between 1.5 and 4.5 m high, with the exception of eight structures - Menindee Main Weir (11.5 m), Cunnamulla Weir (4.5 m), Jack Taylor Dam (7.5 m high), Beardmore Dam (12.1 m), Chinchilla Weir and gauge (9.1 m and 1 m), Lemon Tree Weir (6 m), Talgai Weir (6 m), Comilaroy Weir and gauge (8 m and1 m), and Boggabilla Weir (5.8 m).

ii) almost all of the sites do not have the high dewatering costs of the 'Hume to the Sea' program.

From a broad-scale strategic viewpoint, it is significant that the main stem barriers of the rivers are not numerous (approx. 42 in the lowlands of the main rivers). The thousands of barriers often quoted for the Basin includes all tributary barriers and wetland regulators. Of these thousands of barriers, restoring main stem fish passage would have the most significant positive impact on fish populations.

The feasibility of addressing these barriers has increased in the last decade with recent research in the area providing insights into the fish ecology and fish passage needs (Moffat and Voller, 2002; Lintermans, 2007; Balcombe *et al.*, 2006; Hutchison, 2008; and Rolls and Wilson, 2010), which then flows onto effective fishway design. Significantly, there has also been research funded by the MDBA which has improved fishway design and reduced cost (Mallen-Cooper *et al.*, 2008); recent fishways on the Darling River have been built on gradients of 1:20 but are providing close to the functionality of the 1:32 gradient fishways on the Murray River.

3.2 Implementation strategies

There are two approaches to rehabilitating fish passage in the northern Basin: either providing fish passage at the top 11 barriers or, providing a strategic, holistic, program aimed at re-establishing broad-scale river connectivity, similar to the Hume to Sea program.

Strategy 1. Address top 11 priority barriers: estimated cost $14.56 million.

Addressing the top 11 barriers links river reaches with existing fishways or links high quality habitat (Figure 1). It would complete the Darling reach north of Menindee, almost the full length of the Warrego River, and re-establish connectivity in two critical reaches in the Condamine and Dumaresq rivers. At this stage Chinchilla Weir has not been included in this strategy although it remains a high priority.

Addressing these priority barriers would **reinstate 2,086 km of mainstem river channel** (more if considering tributaries) and improve conditions for native fish in this part of the system. This will benefit common and threatened native fish species which make obligatory migrations each season, as well as those that undertake dispersal movements which are essential for drought recovery and sustaining populations in the long term.

Within the Darling River system, by addressing the six priority structures identified (Wilcannia, Louth, Tilpa, 20A, 19A, Bourke weirs), the project adds value to an existing fishway project at Brewarrina Weir and reinstates a distance of 826 km between Menindee Main Weir and Walgett Weir on the Barwon River.

Similarly, within the Dumaresq River, by addressing three mainstem weirs (Glenarbon, Cunningham, and Bonshaw weirs) an area between Boomi Weir (Macintyre River) and Nundubbermere Falls opens up a distance of 339 km to medium to large migrating fish, although will be restricted to 256 km for small fish until Boggabilla Weir fishway is upgraded.

Within the Condamine River system, Warra Town Weir and Chinchilla Weirs have been identified as priority sites. Under low flow conditions, the next barrier downstream from Warra Town Weir is Warra Stream Gauge Weir (13 km downstream) and under medium and high flows it is Chinchilla Weir (51 km downstream). Upstream of Warra Town Weir the next fish passage barrier is Tipton Weir (91.5 km upstream). Therefore by addressing Warra Town Weir, a total distance of fish passage reinstated will be 155.5 km at medium flows, or 104.5 km at low flows.

On the Warrego River, Cunnamulla Weir represents the only major barrier in the system in Qld. Downstream of this site there are a number of smaller bywash dams in NSW, some on the main channel, others on the braided sections of the Warrego River. The nearest mainstem bywash dam barrier is 277.4 km downstream. As there are no barriers upstream of Cunnamulla Weir, by addressing this single structure 816 km of the Warrego River is reinstated to native fish passage.

A summary of the recommended options and estimated costs for remediation are presented in Table 3. To address these 11 priority structures, the estimated cost is $14.56 million (Table 3).

Table 3 Estimated costs for individual structures.

Weir	Reach	Recommendation	Weir Height (m)	Cost Estimate ($ million)#
Wilcannia Weir	Darling	Vertical-slot fishway	3.9	$1.38
Tilpa Weir	Darling	Vertical-slot fishway	3.5	$1.41
Louth Weir	Darling	Vertical-slot fishway	2.4	$0.85
20A Weir	Darling	Vertical-slot fishway	4.0	$1.42
19A Weir	Darling	Vertical-slot fishway	4.5	$1.62
Bourke	Darling	Vertical-slot fishway	3.9	$1.80
Cunnamulla Weir	Warrego	Vertical-slot fishway	4.5	$2.76
Warra Town Weir	Condamine	Full-width rock-ramp fishway	3.0	$0.72
Glenarbon Weir	Dumaresq	Vertical-slot fishway	2.0	$0.80
Cunningham Weir	Dumaresq	Removal of structure	3.0	$0.65
Bonshaw	Dumaresq	Vertical-slot fishway	2.9	$1.15
TOTAL				**$14.56**

 # please refer to Caveat – Estimated Project Costs

To develop this estimate we used the costs from the present study converted to an average cost per metre structure height, and added a cost estimate for Bourke Weir of $1.8 million, which used a 2007 cost estimate of $1.12 million (Mallen-Cooper and Smit, 2007), and considered recent design modifications and inflation.

The river distance opened by providing fish passage is a useful indicator of the Benefit/Cost (Table 4). The greatest cost of addressing a single structure is that for Cunnamulla Weir ($2.76 million), however this is tempered with the large river distance that will be reinstated 816 km), and therefore this structure represents the best value for money ($3,382 / km). Conversely the cheapest site to address was determined to be the removal of Cunningham Weir ($650,000), which if addressed on its own would reinstate native fish access to only 60.7 km of river ($10,708 / km).

If all 11 structures were addressed, the estimated total cost of $14.56 million would result in a cost of $6,980 per kilometre of river opened up. This cost would be much less when river tributaries were included in the total stream length reinstated for native fish passage.

These data therefore confirm the scope, feasibility and high benefit/cost of a northern Basin fish passage program that addresses the top 11 priority barriers, compared to addressing individual structures on an ad hoc basis as has been occurring to date.

Table 4. Cost-benefit for addressing priority structures in each reach.

River Reach	Cost ($ million)#	Km opened	Cost / km ($)
Darling River (6 weirs)	$8.48	826	$10,266
Dumaresq River (3 weirs)	$2.60	339*	$7,670
Condamine River (1 weir)	$0.72	105	$6,857
Warrego River (1 weir)	$2.76	816	$3,382
TOTAL	**$14.56**	**2,086**	**$6,980**

*256km for small species/size classes, due to operation of Boggabilla Weir vertical-slot fishway.

 # please refer to Caveat – Estimated Project Costs

Strategy 2. Holistic Northern Basin Fish Passage Program re-establishing broad-scale river connectivity: estimated cost $70 million.

The benefits of a strategic, holistic, program is shown in Figure 1. The intent is that all barriers along the Darling, Warrego, Condamine / Balonne and Dumaresq rivers are provided with fish passage, providing complete connectivity along these rivers from their foothills to the junction with the Murray River and with the Hume to Sea program, **reinstating 3,242 km of mainstem river channel**.

In this proposed Northern Basin Fish Passage Program we have selected key rivers with high quality habitat; within these rivers there are 42 mainstem structures requiring remediation (Figure 1). All of these weirs, except eight, are below 4.5 m in height. The other eight structures are 5.8 m to 12.1 m high, and one of these (Boggabilla Weir, Macintyre River) possesses a vertical-slot fishway which requires upgrading to reduce turbulence and pass small fish species and size classes.

The remaining seven structures therefore form major barriers to fish movement within the northern Basin; separating the lower and upper Darling reaches (Menindee Main Weir [11.5 m]), dividing the Barwon River (Comilaroy [8 m]), splitting the Balonne River into three reaches (Jack Taylor Dam [7.5 m high] and Beardmore Dam [12.1 m]), and fragmenting the Condamine River (Chinchilla Weir [9.1 m], Lemon Tree Weir [6 m], and Talgai Weir [6 m]. The height of these structures restricts the remediation options available to either fish locks or fish lifts.

The design of fish locks in Australia has continually improved over the last 15 years and their fish passage effectiveness is now considered excellent. In eastern Australia eight high-level fish locks have been built on weirs ranging in height from 7.9 m (Claude Wharton Weir, Qld) to 15 m (Ned Churchward Weir, Qld). Most of these have been assessed for their effectiveness, and they pass a wide range of fish. Recent cost of fish locks have been $2 million to $7 million, depending on the constructability of the site and the modifications needed to integrate the lock with the weir. Adjustments to the vertical-slot fishway at Boggabilla Weir has been estimated at $1 million.

If the eight high structures were to be addressed as part of a holistic Northern Basin Fish Passage Program, it is estimated to cost $32.5 million (using an average of $4.5 million per fish lock, plus $1 million for Boggabilla Weir). The cost of the other 34 low-level barriers is estimated at $32.3 million, based on a simple extrapolation from the present study using an average cost per fishway. The capital cost of the program, therefore, is estimated at $64.8 million. These estimates provide an indication of the scope of a broader project. If the broader project was considered viable, a more detailed estimate based on concept designs, as per the present project, would be essential.

Monitoring of the performance of these structures is important to optimise each design and ensure that the investment is resulting in real changes in the fish community; this is likely to add $5 million over time to the project. Hence, the total cost of the Northern Basin Fish Passage Program is approximately **$70 million**. This is a comparable cost to the Hume to Sea program but 42 barriers would be addressed rather than 11, and over 3,242 km of river would be opened up to fish movements. As mentioned earlier with any long-term project, increase in construction costs due to inflation should be taken into account in project budgets.

4. CONCLUSION

The Northern Murray-Darling Basin represents a different ecosystem to the southern Basin, with semi-arid and arid rivers which have a different fish assemblage with different migration patterns. With the increasing knowledge of the fish ecology in these rivers and the progression of research on fishways in the last five years, an opportunity now exists to strategically address the barriers in this region, with innovative fishway designs that are more cost-effective and more water efficient, with the same or increased functionality.

The present project has clearly identified the feasibility and benefits of providing fish passage in this region. The key features that make a fish passage program feasible are:

- the main stem barriers not numerous (42 for a broad-scale program reinstating over 3,242 km of river).
- most of the barriers are low-level weirs between 1.5 m and 4.5 m high, with the exception of only eight structures.
- most of the sites do not have high dewatering costs.

There are two approaches to remediation of fish passage, either:

Strategy 1) address the top 11 priority barriers for $14.56 million,

or

Strategy 2) establish a holistic broad-scale program aimed at ecosystem restoration for $70 million.

This would make a major contribution to the recovery of native fish populations. At a broader level a Northern Basin Fish Passage program would integrate:

- **Natural heritage**,
- **Cultural heritage**, as native fish are an important part of aboriginal culture, especially in arid rivers, and
- **Sustainable agriculture and water resource management**, because essential infrastructure for water delivery and harvest is retained, whilst the most significant ecological impact of these structures is addressed.

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APPENDIX 1. Fish Species Names and Conservation Status

Capture source records: MDBA Sustainable Rivers Audit, data to 2009; Moffat, D., *pers. comm*., 10/12/09; Hutchinson, M., *pers. comm*., 10/12/09. Predicted fish source: I&I NSW Freshwater fish database (McDowall, 1996; and Allen *et al*., 2002).

☹ = introduced species. CE = critically endangered, E = endangered, EP = endangered population, V = vulnerable, NT = no take (Qld), C1 = class 1 noxious fish (NSW), C3 = class 3 noxious fish (NSW), N = noxious (Qld).

RECORDED SPECIES Common name	Species	Status (Federal)	Status (NSW)	Status (Qld)
Australian smelt	*Retropinna semoni*			
Bony herring	*Nematalosa erebi*			
Darling River hardyhead	*Craterocephalus amniculus*			
Dwarf flathead gudgeon	*Philypnodon macrostoma*			
Flathead gudgeon	*Philypnodon grandiceps*			
Flyspecked hardyhead	*Craterocephalus stercusmuscarum*			
Freshwater catfish	*Tandanus tandanus*		EP	
Golden perch	*Macquaria ambigua*			
Gudgeon sp.	*Hypseleotris spp.*			
Hyrtl's tandan	*Neosilurus hyrtlii*			
Murray cod	*Maccullochella peelii*	V		
Murray-Darling rainbowfish	*Melanotaenia fluviatilis*			
Rendahl's tandan	*Porochilus rendahli*			
Silver perch	*Bidyanus bidyanus*		V	
Spangled perch	*Leiopotherapon unicolor*			
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*			
Common carp ☹	*Cyprinus carpio*		C3	N
Gambusia ☹	*Gambusia holbrooki*		C1	N
Goldfish ☹	*Carassius auratus*			
PREDICTED SPECIES Common name	**Species**	**Status (Federal)**	**Status (NSW)**	**Status (Qld)**
Mountain jollytail	*Galaxias olidus*			
Murray hardyhead	*Craterocephalus fluviatilis*	V	CE	
Murray jollytail	*Galaxias rostratus*		CE	
Olive perchlet	*Ambassis agassizii*		EP	
Pouched lamprey	*Geotria australis*			
Purple-spotted gudgeon	*Mogurnda adspersa*		E	
River blackfish	*Gadopsis marmoratus*			NT
Southern pygmy perch	*Nannoperca australis*		E	
Brown trout ☹	*Salmo trutta*			
Carp/goldfish hybrid ☹	*Cyprinus spp.*			N
Rainbow trout ☹	*Oncorhynchus mykiss*			
Redfin perch ☹	*Perca fluviatilis*		C1	
Tench ☹	*Tinca tinca*			

APPENDIX 2. Options Analysis & Concept Design Report (SMEC)