REVIEWING AND RESTORING FISH PASSAGE IN URBANISED WATERWAYS, SYDNEY CATCHMENTS

REPORT TO THE SYDNEY METROPOLITAN CATCHMENT MANAGEMENT AUTHORITY

Natural Heritage Trust
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Sydney Metropolitan CMA CATCHMENT MANAGEMENT AUTHORITY

NSW DEPARTMENT OF
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Cover photo: Low brick weir, Maddens Creek, Dharawal Nature Reserve (Upper Georges River Subcatchment).

EXECUTIVE SUMMARY

The highly modified nature of Sydney's catchments presents many challenges in the way we protect the environment and manage its natural resources. In particular, setting goals and targets for aquatic habitat conservation in the region requires clear understanding of the extent of aquatic habitat degradation and where we can achieve the best outcomes.

Stream connectivity and habitat diversity are critical components of healthy rivers. Many fish have evolved to be reliant on a variety of different habitat types throughout their life cycle. The free passage of fish within rivers and streams and between estuarine and freshwater environments is a critical aspect of aquatic ecology in coastal NSW.

This project identified instream structures that disrupt fish passage within the Sydney Metropolitan Catchment Management Authority region, prioritised them in order of importance and presented options for their remediation.

Fieldwork included assessment of instream structures across the 39 local government areas (LGAs) in the Sydney Metropolitan region (over 1954 sqkm). 356 instream structures were assessed in total, with 161 structures identified as requiring remediation. Structures recommended for action included 63 weirs, 41 road culverts, 14 other culverts, nine bed control structures and eight causeways.

A range of remediation options have been suggested for fish passage barrier sites including:

- Basic management/maintenance of sites (e.g. removal of sediment and debris blocking inlets, opening floodgates);
- Modification of structures (e.g. retrofitting low-flow channels, modifying outlet levels, installing fishways);
- Complete removal and replacement of structures (e.g. permanent removal of disused structures, replacement of causeways with bridges or culverts).

Results and remediation options are discussed on a subcatchment basis.

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TABLES

1. INTRODUCTION

The following report outlines the results of a project entitled "*Reviewing and Restoring Fish Passage in Urbanised Waterways – Sydney Catchments"*. The project was carried out by the NSW Department of Primary Industries (Fisheries Management) for the Sydney Metropolitan Catchment Management Authority, and funded by the Natural Heritage Trust program (Contract No. SS C3-NHT IPP).

1.1 Project aims and objectives

The project was originally designed to identify instream structures that disrupt fish passage within the (former) Southern Sydney Catchment Management Board (SSCMB) area and to present remediation options. The study would build upon previous assessments of weirs and tidal restrictions in coastal NSW, and support Management Actions from the Southern Sydney Catchment Blueprint 2003.

Subsequent changes in Natural Resource Management within New South Wales saw the SSCMB merge with the Sydney Harbour Catchment Management Board (SHCMB) to become the Sydney Metropolitan Catchment Management Authority (SMCMA), also incorporating the Hacking River catchment previously managed under the former Southern Rivers CMB.

Following written approval from the SMCMA in August 2004, the project outline was modified to reflect these changes in regional boundaries. The geographical scope of the project (originally covering subcatchments draining to Botany Bay) was extended to cover all waterways within the new CMA region.

Given the above project changes, the established objectives of the project were to:

a) Identify and assess instream structures in the Sydney Metropolitan Catchment Management Authority area that may be barriers to fish passage,
b) Prioritise instream barriers that restrict fish passage across the region,
c) Recommend remediation options to improve fish passage at all priority sites,
d) Encourage remediation of priority sites with structure owners, and
e) Promote "fish-friendly" principles for application in future instream works.

2. BACKGROUND

2.1 Fish passage in NSW

Stream connectivity and habitat diversity are critical components of healthy rivers. Many fish have evolved to be reliant on a variety of different habitat types throughout their life cycle. The free passage of fish within rivers and streams and between estuarine and freshwater environments is a critical aspect of aquatic ecology in coastal NSW.

Approximately 70 percent of the coastal fish species in southeastern Australia migrate as part of their lifecycles (Fairfull and Witheridge, 2003). These include key species such as Australian bass, sea mullet, short finned and long-finned eels, freshwater mullet and freshwater herring. Recent detailed research in the Murray Darling Basin has indicated that a much higher percentage of native fish undertake some migration than previously thought (L. Baumgartner, pers. com.).

Impeding fish passage through the construction of dams, weirs, floodgates and waterway crossings can negatively impact native fish by:

- interrupting spawning or seasonal migrations,
- restricting access to preferred habitat and available food resources,
- reducing genetic flow between populations,
- increasing susceptibility to predation and disease through accumulations below barriers,
- fragmenting previously continuous communities, and
- disrupting downstream movement of adults and impeding larval drift through the creation of still water (lentic) environments.

The importance of free fish passage for native fish is recognised under the *Fisheries Management Act 1994* (FM Act) which has provisions specifically dealing with the blocking of fish passage. In addition, the installation and operation of instream structures, and the alteration of natural flow regimes, have been recognised as *Key Threatening Processes* under the FM Act and the *Threatened Species Conservation Act 1995*.

These legislative tools, and associated NSW Government policies on fish passage[1], act to regulate the construction of structures that may be barriers to fish passage. In addition, reinstating connectivity between upstream and downstream habitats and adjacent riparian and floodplain habitats has become an essential part of aquatic habitat management and rehabilitation programs in NSW.

2.2 Types of obstructions to fish passage

There are many types of instream structures that can obstruct fish passage by creating a physical blockage, a hydrological barrier or by forming artificial conditions that act as a behavioural barrier to fish. The impact of instream structures on fish passage will vary depending on a) the design of the structure b) the nature of flow, debris and sediment movement in the waterway, and c) the swimming capabilities of fish (dependent on species and age) present in the waterway.

Some instream structures may be minor *obstructions* that block fish only at certain times or over certain periods (e.g. low-level fords or erosion control structures may prevent fish from moving along a waterway at low flows). Such structures may drownout out quickly and provide for fish passage at higher flows. Depending on where the structures are located in a catchment (i.e upper, middle or lower), the relative impact on local fish populations may also vary significantly.

Certain types of instream structures can obstruct fish passage over extended periods (months or years) and effectively isolate upstream and downstream fish populations. Such structures are generally called *barriers* and are often associated with structures such as dams and weirs.

Instream structures that span the whole channel (from bank to bank e.g. weirs, causeways) can impede natural flows and act as physical and hydrological barriers to fish movement thus isolating upstream and downstream habitats. Even structures such as road culverts and piped crossings can impact on fish passage if they are not designed correctly or adequately maintained.

Furthermore, structures installed in channel banks and floodplains such as levees, floodgates and other off-stream structures (e.g. detention basins and gross pollutant traps) can disrupt lateral connectivity by isolating seasonal or ephemeral habitats on floodplains and wetlands.

Behavioural barriers to fish passage can be created when natural channel conditions are modified extensively. This is most prevalent in urbanised catchments where some waterway reaches may be piped underground, creating areas of extended darkness which inhibit fish movement.

Waterways that have been channelised and concrete-lined may also inhibit fish movement due to the presence of artificial substrate and banks which may deter fish from traveling along the channel, and by reducing the area available for providing shelter, feeding and spawning sites.

Channelised and piped sections of waterways reduce the extent of aquatic habitat available and may also deter fish movement potentially isolating fish populations in natural river segments upstream and downstream.

2.3 Sydney's catchments and creeks

The Sydney Metropolitan CMA region is located on the east coast of New South Wales and includes all waterways draining to the coast between Narrabeen in the North, Stanwell Park in the south, and west to Blacktown covering approximately 1900sqkm. Eight broad subcatchments were identified within this study: Northern Beaches, Middle Harbour / Lane Cove Rivers, Parramatta River, Cooks River / North Botany, Upper Georges River, Lower Georges River, Woronora River and Hacking River.

[1] See Section 8 for References

The Northern Beaches area is the smallest of the subcatchment areas. It has a series of small creeks (including Manly Ck, Middle Ck, Deep Ck and Mullet Ck) that drain approximately 87sqkm of moderately cleared slopes and plateaus down to coastal lakes between Manly and Mona Vale. The lakes are intermittently opened to the sea and include Manly Lagoon, Curl Curl Lagoon, Dee Why Lagoon and Narrabeen Lake.

Middle Harbour and Lane Cove Rivers are northern tributaries to Port Jackson and flow through approximately 193 sqkm of narrow sandstone gorges, primarily within National Park (Lane Cove NP and Ku-ring-gai NP respectively). The majority of landuse in these subcatchments is low-medium density residential development, however the waterways are well vegetated and in a reasonably natural state.

Port Jackson is a drowned river valley with a deep open entrance and a marine/tidal dominated estuary. Parramatta River is the major tributary of the Port and drains an area in the west of approximately 295sqkm. This subcatchment includes waterways such as Duck River, Toongabbie Ck, Homebush Bay and tributaries to Iron Cove. The majority of the Parramatta River subcatchment is extensively developed and is drained by highly-modified channels (piped or channelised).

Botany Bay is a wide embayment with an extensive estuary in the tidal zone of several rivers including the Georges River, Woronora River and Cooks River, and some smaller creeks along the northern shores of Botany Bay ('North Botany'). The northern half of the bay is intensively developed for urban and industrial purposes. The main waterway that drains the Cooks River / North Botany subcatchment (approximately 163sqkm) is the Cooks River and its tributaries such as Wolli Creek, Cup and Saucer Ck and Alexandra Canal. These creeks have been extensively modified (piped, channelised and/or concrete-lined) to cope with elevated stormwater runoff. Few areas remain intact or in a moderately natural condition.

To the south, the Georges River catchment covers over 790sqkm and includes reasonably intact areas of bushland and also areas of substantial urbanisation and development. The Upper Georges River above Liverpool drains approximately 355 sqkm, including the relatively intact tributaries of O'Hares Ck, Stokes Ck, Punchbowl Ck and Peter Meadows Ck, and the highly-impacted tributaries of Bow Bowing Ck and Bunbury Ck.

Further downstream on the Lower Georges River, approximately two thirds of the 439sqkm catchment has been largely cleared and developed. The southern tributaries flow through forested subcatchments in Dharawal Nature Reserve and Holsworthy Military Reserve and include Harris Ck, Williams Ck and Deadman's Ck. These creeks are in good condition, whilst the northwestern (left bank) tributaries are somewhat degraded as they drain extensively cleared and highly modified catchments. These waterways include Hinchinbrook Ck, Cabramatta Ck, Clear Paddock Ck, Orphan School Ck and Prospect Ck.

The Woronora River system is the largest subcatchment of the Georges system and covers approximately 160sqkm. Waratah Rivulet and Heathcote Creek are upper catchment tributaries that drain through Heathcote National Park and Holsworthy Military Reserve with sandstone gorges, surrounded by forested plateau and hanging swamps. In the lower catchment, including Loftus Ck, Forbes Ck and Still Ck tributaries, land has been cleared and developed for residential and other purposes (approximately 16 percent of the overall catchment area) (HRC, 1999).

Port Hacking estuary in the south is a drowned river valley with an open entrance. The Hacking River, South West Arm Ck and Cabbage Tree Ck, drain approximately 206sqkm of forested catchments that are protected within the Royal National Park. The northern shore of the Port has small tributaries such as Dent's Ck, Coonong Ck and Alcheringa Gully that drain extensively cleared and developed urban catchments.

2.4 Sydney's aquatic habitat and biodiversity

The aquatic habitats of the Sydney region comprise freshwater, estuarine and marine environments. The extensive range of habitats supports a diverse assemblage of aquatic species including over 40 freshwater and estuarine fin fish species (refer Appendix A).

The region also supports an array of aquatic macroinvertebrates including insects, prawns, crayfish and freshwater mussels. The Small Sydney crayfish (*Euastacus australasiensis*) can be found in reasonably intact streams in Sydney, and other species such as the Freshwater shrimp (*Paratya australiensis*) provide an important food source for animals such as the platypus (Australian Museum, 2005). Adams emerald dragonflies[2] (*Archaeophyta adamsi*) are one of Australia's rarest dragonflies and are only known from a few sites in the greater Sydney region.

Over 30 species of frogs (including the threatened giant burrowing frog, green and golden bell frog[3] and the red-crowned toadlet[4]) and one freshwater turtle (Eastern snake-necked turtle - *Chelodina longicollis*) are found in Sydney's streams. In addition, platypus and water rats (both mammals specialised for freshwater aquatic habitats) can be found in creeks within the region.

All these aquatic species are dependent on healthy streams and access to diverse habitats for their survival. Freshwater fish habitats in Sydney include swamps, floodplains, wetlands, streams and rivers. These broad habitat types provide niche habitats such as pools and riffles, gravel beds, boulders, snags, aquatic vegetation, riparian vegetation and riparian overhangs and undercuts. Birds and terrestrial-based animal species rely on these habitats to support the food web within the broader ecosystem and also to provide fringe habitat.

Many freshwater and estuarine habitats in the Sydney region are essential for conserving aquatic biodiversity – and have been listed as Endangered Ecological Communities[5] in recognition of their rarity, vulnerability and their importance as both aquatic and terrestrial habitat. These communities include Coastal Saltmarsh, River Flat Eucalypt Forest, Swamp Schlerophyll Forest, Swamp Oak Floodplain Forest, Sydney Coastal Estuary Swamp Forest and Sydney Freshwater Wetlands.

The estuarine and marine areas of Port Jackson, Botany Bay and Port Hacking incorporate several habitat types including mudflats, saltmarsh, seagrass beds, mangroves, subtidal reefs, islands, rock outcrops, intertidal rock platforms, sandy beaches and open ocean.

The coastline of the northern beaches comprises small coastal lakes that are intermittently open and closed to the sea, supporting extensive seagrass beds and providing important nursery areas for fish species.

Ten Aquatic Reserves are located in and around Sydney. Towra Point Aquatic Reserve (Botany Bay), which covers 1400 hectares has the most diverse estuarine wetland complex remaining in the Sydney region. The reserve area protects mangroves, saltmarsh, seagrass, tidal mudflats, and terrestrial vegetation communities that form a complex and integrated ecosystem. Towra Point is listed under the Ramsar Convention on Wetlands of International Importance as the area supports populations of migratory wading birds, which roost and feed in and around the area.

2.5 Impacts on fish passage in Sydney

The rivers flowing to Sydney Harbour and Botany Bay drain the most urbanised and densely populated region in Australia, with in excess of 1.5 million residents and only 3-5% of the catchments conserved through formal reserves (SHCMB, 2003). The catchments are highly modified (extensive vegetation clearance, impermeable surfaces) resulting in elevated run-off, reduced water quality and loss of riparian and aquatic habitats.

With the inclusion of Southern Sydney's catchments, the population of the Sydney Metro CMA region exceeds three million people. The urban infrastructure required to support this population (including stormwater drains, flood mitigation systems and transport networks) is extensive and has directly impacted on the health and connectivity of the river systems. For instance, when the road network is overlain on the stream channels in the region, every point of intersection (where a road crosses a stream) represents a concentrated node of pressure on the waterway below. These pressures can include increased pollutant inputs, riparian vegetation clearance and the presence of instream barriers (e.g. inappropriately-designed road crossings such as that shown Photo 1).

[2] Listed as 'Vulnerable' under the Fisheries Management Act 1994.
[3] Both listed as 'Endangered' under the NSW *Threatened Species Conservation Act* 1995 (TSC Act) & 'Vulnerable' under the EPBC Act.
[4] Listed as 'Vulnerable' under the TSC Act.
[5] Listed under the NSW *Threatened Species Conservation Act* 1995.

Instream barriers such as weirs (Photo 2), floodgates (Photo 3), and causeways (Photo 8) in urban areas can potentially block many fish species from migrating upstream and moving between habitats. Other aquatic species such as platypus and turtles may be forced to cross roads to follow the stream, increasing their chances of predation and being hit by vehicles.

In addition, structures aiming to improve, maintain or monitor a waterway may also impact on fish passage in a system. Online GPTs (Photos 4), bed control structures (Photo 7) and river gauge stations (Photo 6) are constructed on waterways to minimise pollutants, provide bank and stream bed stability, and monitor water flows past a particular site respectively, but can also form physical barriers to fish passage.

Similarly, the stormwater network in the Sydney region and the way we undertake flood mitigation can have deleterious effects on aquatic habitats and stream connectivity. Many creeks in Sydney have been channelised (Photo 5) or piped underground to alleviate localised channel erosion and flooding pressure on surrounding developments. This can result in a direct loss of aquatic habitat and impact on stream connectivity. Viable aquatic habitats upstream (e.g. small floodplain wetlands and tributary creek systems) can become isolated from downstream waterways. Aquatic dwelling species including fish, frogs and turtles have reduced habitat available for feeding, breeding and shelter, which can lead to increased competition and predation.

3. PROJECT METHODS

3.1 Previous investigations

DPI (Fisheries Management) has previously undertaken studies investigating instream structures and their effects on river health and aquatic ecology. These studies were reviewed as part of the current project to identify knowledge gaps in respect to instream structures in the Sydney region.

Williams *et al.* (1996) identified the number and distribution of structures that impact tidal flow in coastal NSW. Structures included weirs, causeways, culverts, floodgates, agricultural drains and stormwater drains. The study identified seven regions in coastal NSW (*Region 5* included waterways from Gosford LGA south to Wollongong LGA). Table 1 outlines the number of structures identified as restricting tidal flow in Region 5. It must be noted that not all of these structures are necessarily obstructions or barriers to fish passage (e.g. bridges and culverts). There are however types of road crossings (including causeways, fords and some culverts) that may restrict tidal flow and also act as a barrier to fish passage.

Table 1. Tidal restriction structures and number which have rehabilitation potential (source: Williams *et al*, 1996)

Gosford/Sydney/Wollongong	Bridge	Culvert	Causeway	Ford	Weir	Floodgate	Total
# structures identified	207	302	8	1	28	14	560
# with rehabilitation potential	6	43	6	0	28	14	97

Thorncraft and Harris (2000) provided a Status Report on fish passage in NSW, summarising information from the Department of Land and Water Conservation NSW state government *Weirs Inventory* (database of licensed weir structures in NSW) and from previous reports such as Williams *et al.* (1996) (see Table 2).

Table 2. Classes of instream barriers in the Sydney region (source: Thorncraft and Harris, 2000)

Catchment	Weir or dam	Gated weir or regulator	Tidal barrier	Other*	Total no. of barriers
Sydney Coast-Georges River	48	0	40	3	91
Wollongong Coast+	28	0	22	7	57

* 'Other' refers to barriers such as road crossings and culverts, many of which had not yet been identified as problems for fish passage.
+ 'Wollongong Coast' refers to the Hacking, Lake Illawarra and Minnamurra catchments. Barrier statistics for the Hacking catchment alone were not available from the Thorncraft and Harris (2000) report.

In 2002 NSW Fisheries undertook a statewide review of weir structures identified in the DLWC Weirs Inventory. A total of 51 weirs were registered for the Sydney Catchment, with 28 found on named watercourses. The weir review report identified eight structures requiring a *detailed review*[6] to investigate structural or operational changes that could provide positive environmental benefits (NSW Fisheries, 2002).

Table 3. Barriers identified as requiring detailed review (source: NSW Fisheries, 2002)

Name	ID	04/05 Code +	Waterway	Proposed action
Parramatta Tidal/town weir	213/440000/B0037	PAR001	Parramatta River	Recommended for a fishway
Marsden St Weir	213/440000/B0039	PAR002	Parramatta River	Recommended for a fishway
Asylum Weir	213/440000/B0038	PAR004	Parramatta River	Recommended for a fishway
Testers/Ingleburn Weir	213/220000/B0047	CAM001	Georges River	Partial removal, depending on heritage & access
Woollen Mill Weir	NA	BAU002	Darling Mills Ck	Removal/ partial removal, depending on heritage & access
Lane Cove Weir	213/440800/B0034	KUR006	Lane Cove River	Fishway maintenance & monitoring program
Liverpool Weir	213/220000/B0046	LIV001	Georges River	Fishway maintenance & monitoring program
Parramatta Crossing	NA	PAR003	Parramatta River	Fish passage issues, hydrologic study

+ All sites from the 2002 study were revisited for this current (04/05) report. The 04/05 Code number refers to the relevant barrier code used in this report (see Appendix D for details on each structure).

In 2002, NSW Fisheries also reviewed four weirs in the Hacking River catchment including Otford Weir (McKell Ave Weir), Helensburgh Dam, Camp Gully Dam and Wilson's Creek Dam. None of these structures were recommended for *detailed review*.[7]

3.2 Desktop and field assessment

Instream structures identified in the 2002 Weir Review and the Williams *et al.* (1996) reports were re-visited and assessed as part of this project. In addition, the investigation was extended to include sites identified by:

a) Assessment of 1:25, 000 topographic maps for potential barrier sites,

b) Local Government Authorities within the Sydney Metropolitan area: Councils were asked to provide information on known barriers and potential obstructions for review across Sydney, particularly sites identified for future maintenance/ remediation works, and

c) Investigation of potential upstream and downstream barriers from other known sites.

The total number of sites identified for assessment in the Sydney region was 736, with the majority of fieldwork being conducted from June to November 2004. An assessment sheet was developed prior to fieldwork commencing, ensuring consistency in data collection (Appendix B). 356 sites were assessed during the study as potential barriers, with location details (GPS readings or map grid references) and digital photographs being recorded for each location.

3.3 Prioritising fish passage barriers

A prioritisation scheme was developed to assist in ranking instream structures requiring remediation (Appendix C). The scheme was developed to determine regional priorities by ranking sites based on the following categories: a) habitat value b) structure impact, and c) modification criteria. The ranking scheme takes into account various factors such as the quality and condition of the existing aquatic habitat, the likely impact of the structure on fish movement and modification possibilities (such as potential costs and ancillary uses).

[6] Detailed Weir Reviews are currently being undertaken by DPI (Fisheries Management) in all CMA regions across NSW, the results of which will be available in late 2005.

[7] All known Hacking River barriers, including Audley weir, have been reviewed further in this 2004/05 study.

Photo 1: Road Culvert with raised invert, Gwawley Creek, Lower Georges River subcatchment.

Photo 2: Weir, Darling Mills Creek, Parramatta River subcatchment.

Photo 3: Floodgate – Kelso Creek, Lower Georges River subcatchment.

Photo 4: Online GPT, Badoberong Creek, Lower Georges River subcatchment.

Photo 5: Concrete Channel, Sheas Canal, Cooks River / North Botany subcatchment.

Photo 6: River Gauge Station, Stokes Creek, Upper Georges River subcatchment.

Photo 7: Bed-Control Structure, Williams Creek, Lower Georges River subcatchment.

Photo 8: Causeway, Heathcote Creek, Woronora River subcatchment.

It is understood that many environmental, social, cultural and economic considerations would need to be reviewed before undertaking on-ground works. However, to obtain a rapid assessment on a regional scale, the application of the method outlined above was a simple and effective way of determining broad regional priorities.

Recommendations were made on how the structures could be modified to allow for effective fish passage. Local Councils will be provided with a list of priority structures and upgrade recommendations for consideration in future works programs. Other structure owners and waterways managers (primarily state government agencies) will be notified of priority structures identified in their management areas.

4. ASSESSMENT RESULTS

4.1 Summary of field assessments by Local Government Area

A complete data set from this study is available in a separate document entitled *Fish Passage Barriers Inventory - Sydney Catchments – CD Database*. Barrier type, priority scores, recommended actions and location information can be found there.
The discussion below focuses on trends within the data and the top priority sites for remediation.

The fieldwork included assessment of 356 instream structures across 39 local government areas (LGAs) in the Sydney Metropolitan region (over 1954 sqkm). Many of these structures were deemed to have a negligible impact on fish movement, although 161 structures were identified as requiring some type of remediation action.

Table 4 outlines the percentage area of each LGA within the Sydney Metropolitan CMA, the number of sites assessed in each, and the number of sites recommended for remediation.

Table 4. Summary of instream structures identified as fish passage barriers in the Sydney Metropolitan Catchment Management Authority region

Local Government Authority	LGA area as % of Study Area (1953.9 sqkm)	Total # of sites assessed as potential fish passage barriers	Total # recommended for remediation
Bankstown City	3.97	21	7
Blacktown	1.68	14	7
Botany Bay	1.38	6	5
Campbelltown	13.96	69	21
Canterbury City	1.72	2	2
Fairfield City	3.88	21	15
Holroyd	2.06	21	14
Hornsby	1.06	6	2
Hunters Hill	0.29	1	1
Hurstville	1.26	2	0
Kogarah	0.99	1	0
Ku-ring-gai Municipal	2.63	17	6
Lane Cove	0.53	9	2
Liverpool City	8.31	24	16
Manly	0.72	8	1
North Sydney	0.53	1	0
Parramatta City	3.14	26	15
Pittwater	0.70	6	3
Rockdale	1.54	20	6
Ryde	2.08	4	0
Shire of Baulkham Hills	2.25	12	6
Sutherland Shire	18.82	25	10
Warringah	4.87	14	7
Willoughby City	1.14	8	3
Wollondilly	3.85	5	3
Wollongong	6.30	11	9
Woollahra	0.63	2	0
		356	161

The number of sites assessed within each LGA generally reflected the geographical size of the area, with larger LGAs encompassing a greater number of drainage systems. The number of sites recommended for remediation also followed this trend, with larger LGAs having a greater number of sites recommended for remediation.

No fish passage barriers were identified in Ashfield, Auburn, Burwood, Camden, Canada Bay, Leichhardt, Marrickville, Mosman, Randwick, Strathfield, Sydney City and Waverley LGAs. These areas, with the exception of Mosman, Camden and Waverley LGAs, were identified as highly channelised or modified subcatchments.

Campbelltown, Liverpool City, Parramatta City and Fairfield City LGA's had the greatest number of sites recommended for remediation, whilst no sites were recommended for remediation in Hurstville, Kogarah, North Sydney, Ryde or Woollahra LGAs.

4.2 Types of fish passage barriers in Sydney's subcatchments

Several types of instream structures were assessed in the study including weirs, causeways, culverts, ford crossings, bed control structures, river gauge stations, piped sections, floodgates, levees, online GPTs and other infrastructure (such as sewage pipes).

The most common barrier types identified during this study were road culverts (120 sites), weirs (88 sites) and sections of waterway that were piped underground (36 sites). This largely reflects the high infrastructure density in the Sydney region including road and rail networks and urban flood mitigation measures. The remaining 112 sites comprised obstructions such as other culverts (e.g. sites where the waterway was piped under an embankment or railway line), levees, bed control structures, river gauge stations, and other infrastructure (such as sewage pipes crossing a waterway).

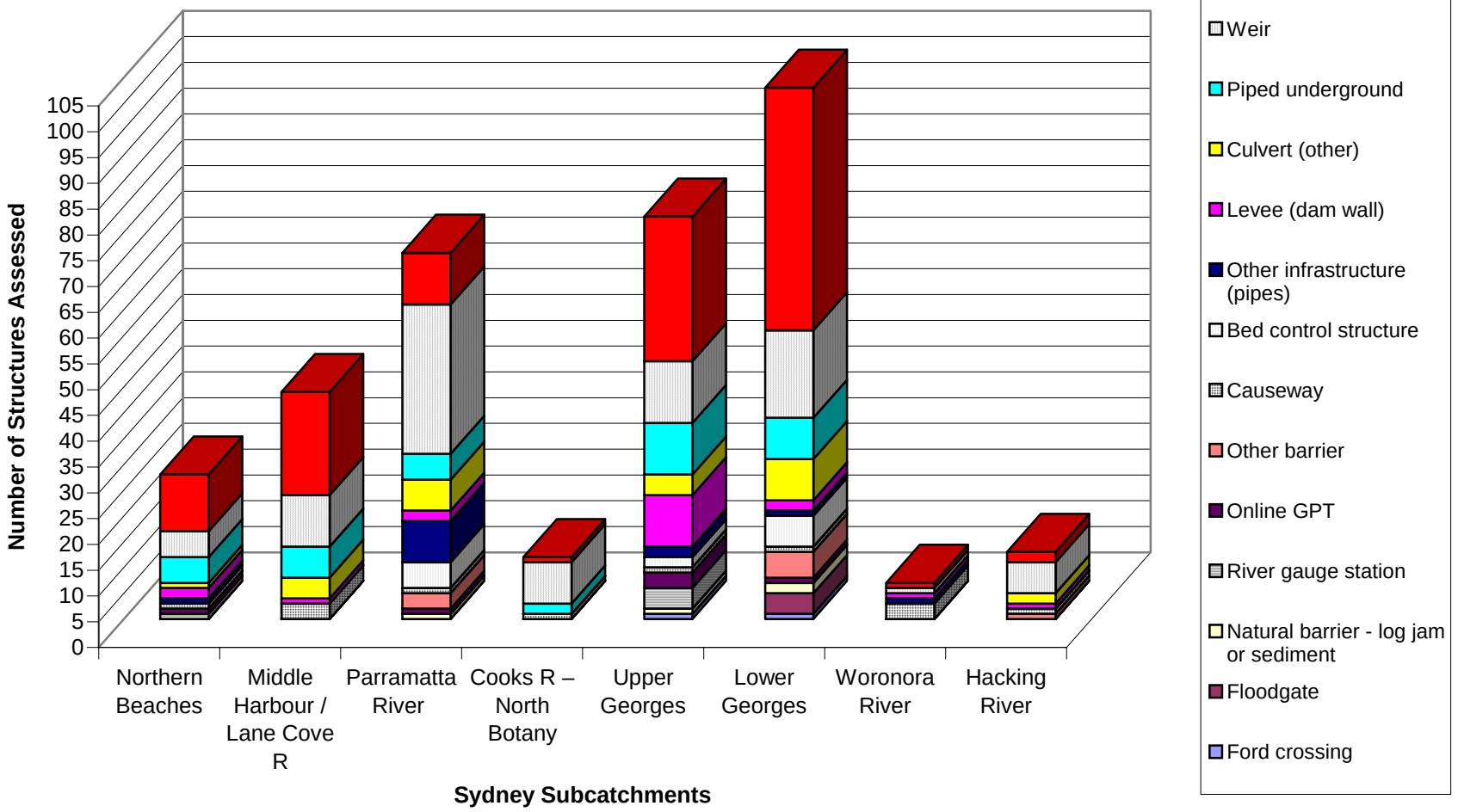
Table 5 outlines the number of fish passage barriers found in each subcatchment. Subcatchments with the most barriers identified included Lower Georges River (103 sites), Upper Georges River (78 sites) and Parramatta River (71 sites). Areas with few barriers recorded were generally the least-populated (Woronora River (seven sites), Hacking River (13 sites), and Northern Beaches (28 sites)). Figure 1 graphically illustrates these trends.

Table 5. Regional summary of instream structures by subcatchment

Fish Passage Obstructions	*Northern Beaches*	*Middle Harbour / Lane Cove R+*	*Parramatta River **	*Cooks R / North Botany^*	*Upper Georges ++*	*Lower Georges ***	*Woronora River*	*Hacking River*	*TOTAL*
Weir	5	10	29	8	12	17	1	6	88
Causeway	1	3	1	1	1	1	3	1	12
Culvert (road)	11	20	10	1	28	47	1	2	120
Culvert (other)	1	4	6		4	8		2	25
Ford crossing					1	1			2
Bed control structure			5		2	6			13
River gauge station	1				4				5
Piped underground∞	5	6	5	2	10	8			36
Floodgate						4			4
Levee (dam wall)	2	1	2		10	2	1	1	19
Natural barrier - log jam or sediment			1		1	2			4
Online GPT	1		1		3	1			6
Other infrastructure (pipes)	1		8		2	1	1		13
Other barrier			3			5		1	9
TOTAL	**28**	**44**	**71**	**12**	**78**	**103**	**7**	**13**	**356**
Estimated % of highly modified subcatchment	< 1	5	45 - 50	85 - 90	25	20	0.5	1	

+ Includes small tributaries between Lane Cove & Manly discharging into Port Jackson.
* Parramatta River, Toongabbie Ck, Duck River, Homebush Bay, Iron Cove/Canada Bay tributaries.
^ Cooks R, Wolli Creek, Botany wetlands & small northern tributaries discharging to Botany.
++ Main stem Georges River and tributaries above Liverpool weir (Liverpool).
** Main stem Georges River and tributaries such as Cabramatta Ck, Prospect Ck, Salt Pan Ck, and Little Salt Pan Ck (but not including Woronora River), joining below Liverpool weir, & other small creeks entering from the southern side of Botany Bay.
∞ Sites that were piped underground or channelised were noted but not prioritised for remediation purposes.

Figure 1. Fish Passage Obstructions in Sydney Subcatchments.



The exception to this rule was the Cooks River / North Botany subcatchment, which is densely populated and drains a large area (163sqkm). Few barriers were observed in this subcatchment (12 sites) because the majority of the subcatchment has been highly modified with nearly all waterways being piped or channelised, and few natural waterways remain. Piping and channelisation may form behavioural barriers to fish passage due to the change in substrate type, lack of cover from predators, or lack of light for extended distances. In this survey, channelised or piped sections of creek were noted where observed but not included in the barrier prioritisation process.

4.3 Summary of sites recommended for remediation

In this study, 195 fish passage obstructions were not recommended for remediation due to reasons such as:

- The site was located in *minimal fish habitat* (naturally marginal habitat rarely utilised by fish such as ephemeral waterways);
- The site was located in a heavily degraded or highly modified waterway where other factors play a larger role in dictating river health (e.g. concrete stormwater channels and piped waterways with little or no habitat value);
- The instream structure was deemed to be only a very minor obstruction to fish and only at certain times – fish would be able to negotiate the structure regularly.
- The structure was identified as a primary/essential piece of infrastructure where remediation works for fish passage would not be feasible or too cost-prohibitive (e.g. Woronora Dam – a major water storage facility).

161 sites in the Sydney region were identified as requiring remediation to allow effective fish passage (see Table 6 below). These excluded channelised and piped waterways, which require broader catchment planning rather than site-specific structure management.

A range of remediation options have been suggested for fish passage barrier sites including:

- Basic management/maintenance of sites (e.g. removal of sediment and debris blocking inlets; opening floodgates)
- Modification of structures (e.g. retrofitting low-flow channels; modifying outlet levels; installing fishways – see Appendix E for a description of fishway types)
- Complete removal and replacement of structures (e.g. removal of disused structures; replacement of causeways with bridges).

Table 6. Regional Action Summary based on the catchment and the type of structure

Fish Passage Obstructions	*Northern Beaches*	*Middle Harbour / Lane Cove R+*	*Parramatta River **	*Cooks R / North Botany^*	*Upper Georges ++*	*Lower Georges ***	*Woronora River*	*Hacking River*	*TOTAL*
Weir	**4**	**5**	**21**	**8**	**9**	**9**	**1**	**6**	**63**
Causeway		**3**		**1**	**1**	**1**	**1**	**1**	**8**
Culvert (road)	**5**	**4**	**3**		**9**	**19**		**1**	**41**
Culvert (other)	**1**	**2**	**5**		**1**	**5**			**14**
Ford crossing					**1**				**1**
Bed control structure			**3**			**6**			**9**
River gauge station	**1**				**4**				**5**
Floodgate						**1**			**1**
Levee (dam wall)					**3**			**1**	**4**
Natural barrier - log jam or sediment			**1**		**1**	**2**			**4**
Online GPT					**1**	**1**			**2**
Other infrastructure (pipes)			**2**			**1**			**3**
Other barrier			**2**			**4**			**6**
	11	**14**	**37**	**9**	**30**	**49**	**2**	**9**	**161**

Channelised or piped sections of creek were not assessed or prioritised because these sites were more a habitat based barrier, rather than a physical barrier. Further discussion of these sites occurs in the subcatchment summaries below.

Generally, subcatchments with a low population density and extensive areas of protected land (e.g. National Parks) had few structures requiring remediation. Woronora River subcatchment and Hacking River subcatchment had the least number of sites identified for remediation (2 and 9 sites respectively). The subcatchments with the greatest number of structures recommended for remediation were the Lower Georges River (49 sites), Parramatta River (37 sites) and Upper Georges River (30 sites). Section 5 provides subcatchment summaries in relation to remediation options.

Road culverts were the most common barrier type assessed in this study (120 sites), however, only 41 of these sites were identified as requiring remediation. In contrast, of the 88 weirs assessed in the study, 63 were flagged for remediation. Due to the design and function of a weir, these structures generally have a greater impact on fish passage than a culvert or low-level structure (ford or causeway). Weirs are generally located on perennial waterways (streams with consistent flow) and tend to be larger (higher) blockages than road crossings. As such, the relative impact of weirs on fish habitat is generally greater than those of road crossings.

5. DISCUSSION

5.1 Aquatic habitat management in urbanised catchments

The highly modified nature of Sydney's catchments presents many challenges in the way we protect the environment and manage its natural resources. In particular, setting goals and targets for aquatic habitat conservation in the region requires clear understanding of the extent of aquatic habitat degradation and where we can achieve the best outcomes.

On a broad scale, Sydney's waterways are some of the most impacted and degraded in the State. Given the intensity and extent of urban and industrial development in the region this is not surprising. The condition of individual waterways varies markedly however between subcatchments and individual streams. Whilst some streams have been piped and channelised, many others are still in good condition.

The necessity to protect and rehabilitate streams in the Sydney Region - even highly modified channels - has been highlighted in the Sydney Harbour Catchment Blueprint (SHCMB, 2003) and the Southern Sydney Catchment Blueprint (SSCMB, 2003) as shown overleaf.

Fish passage-related actions in NREM plans for the Sydney region.

Sydney Harbour Catchment Blueprint

- Develop and implement programs to maximise fish passage in watercourses throughout the Board area including:
  - Develop and implement guidelines for waterway crossings, stormwater treatments and flood management works, and
  - Review, prioritise, recommend and implement actions for all other barriers to fish passage (licensed and unlicensed) not included in the State Government Weir Review.
- Progressively implement the findings and recommendations of the completed NSW Government Weir Review for the urban area.
- Identify priority areas of aquatic habitat, and develop and implement management plans for these areas, including recommend rehabilitation activities if required.
- Research, identify and implement measures to improve instream habitats in channelised and non-channelised watercourses.

Southern Sydney Catchment Blueprint

- Review, prioritise and recommend action for all artificial barriers to fish passage (licensed or unlicensed) not included in the State Government Weir Review;
- Implement findings of the above review.
- Progressively implement the findings and recommendations of the completed NSW Government Weir Review for the urban area.
- Identify priority areas, both aquatic and terrestrial, requiring rehabilitation based on standard assessment procedures.
- Develop and implement guidelines for watercourse crossings, stormwater treatments and flood management works to ensure fish passage.
- Research, identify and implement measures to improve instream habitats in channelised and non-channelised watercourses.

This study contributes to the above management actions by achieving the following outcomes:

- Development of a fish passage barrier inventory for the Sydney Metropolitan region,
- On-ground application of a fish passage barrier assessment method,
- Identification of remediation options for barrier sites,
- Application of a prioritisation method to rank fish passage barriers, and
- Promote and educate the findings of the report.

5.2 Regional remediation priorities

This section of the report presents the major findings of this study on a subcatchment basis and highlights regional and subcatchment priorities for fish passage remediation.

Instream structures recommended for remediation (161 sites) have been identified as either 'high', 'medium' or 'low' priority according to their ranking score (refer to Map 1). Appendix D lists the top 50 priority sites for the Sydney Metropolitan region, with a subset of this information (the top 20 priority sites) shown in Table 7.

Some basic trends can be discerned from this. For instance, the top five sites, are all weirs on the mainstem of a major waterway, and have been recommended for remediation in previous reports. It is also noted that three of the five sites form the tidal limit of the particular waterway, and all bar one are in a protected or semi-protected area.

Overall the top 20 priority sites included 12 weirs, three bed control structures, two road culverts, one online gross pollutant trap (GPT) and long culvert, one floodgate, and one river gauge station. These sites were located throughout the Sydney Metropolitan CMA area in all eight subcatchments. 13 of the top 20 sites were located in protected areas such as National Parks, or areas of other suitable landuse.

Table 7. Priority fish passage barriers Sydney Metropolitan CMA region

Rank	Crossing ID	Waterway/ Subcatchment	Structure Type	Structure Name (if known)	Type/Issue/Recommendation
1	SUT014	Hacking River	weir (fixed crest)	Audley Weir*	Install a fishway.
2	KUR006	Lane Cove River	weir (fixed crest)	Lane Cove Weir*[@]	Install a low flow section in culvert adjacent fishway and monitor.
3	WOL006	Hacking River	weir (fixed crest)	Otford Weir / McKell Ave Weir[@]	Install a fishway / remove if not required.
4	CAM001	Georges River	weir (fixed crest)	Ingleburn Weir[@]	Remove or partially remove if structure is not required.
5	LIV001	Georges River	weir (with fishway)	Liverpool Weir*[@]	Continue monitoring fishway – if working, leave and continue maintenance, if not working correct problem(s).
6	SUT013	Woronora River	weir (fixed crest)	Pass of Sabugal (The Needles)[x]	Remove if structure is not required.
7	BAN001	Morgans Ck	road culvert	Henry Lawson Drive	Install central light hole.
8	LIV005	Cabramatta Ck	weir (partly breached)	none	Remove if structure is not required.
9	WAR002	Manly Lagoon	GPT, and long culvert at lagoon entrance	Manly Lagoon outlet culvert*	Reinstate channel to sea.
10	LIV023	Harris Ck (Georges River)	bed control structure	Gabion weir[+]	Remove if structure is not required.
11	BAN011	Kelso Ck	floodgate	Kelso Park wetland*	Remove if structure is not required / improve management of structure.
12	LIV024	Harris Ck (Georges River)	bed control structure	Gabion weir[+]	Remove if structure is not required.
13	WAR011	Middle Ck (Narrabeen Lagoon)	river gauge station	None	Remove if structure is not required.
14	BAN006	Yeramba Lagoon	weir (fixed crest)	None*	Install a fishway, or remove if structure is not required.
15	CAM002	Georges River	road culvert	Wedderburn Weir[@#]	Remove concrete sheet downstream side.
16	LIV020	Williams Ck	bed control structure	Gabion weir[+]	Remove if structure is not required
17	ROC020	Wolli Ck	weir (fixed crest)	Wolli Ck Weir*	Install a fishway, or remove if not required.
18	WOL010	Hacking River	weir and road crossing	"Otford Weir 1"	Remove / clear debris.
19	SUT020	Heathcote Ck	weir (fixed crest)	Lake Tallooma	Remove if structure is not required.
20	WAR006	Curl Curl Lagoon (Greendale Ck)	weir (fixed crest)	Ornamental weir in Curl Curl Lagoon	Improve rock placement in spillway / "fishway" section to allow fish movement.

* Also investigated as part of Tidal Flow Report (Williams *et al.* 1996) [+] Site identified by Department of Defence
[@] Also investigated as part of the Weir Report (NSW Fisheries 2002) [#] Site identified by Council staff
[x] Site identified by community member

5.3 Subcatchment priorities – issues and management options

The river health and quality of aquatic ecosystems in the Sydney region varies widely between catchments. Generally, waterways on the outskirts of the metropolitan area are in better condition than waterways closer to the city centre, however this is not always the case.

Areas to the west of the city are currently under pressure from urban development incorporating medium density housing, shopping and industrial areas. Previously these areas would have been subject to farming pressures (causing loss of riparian vegetation and increased nutrients). Urban expansion has lead to direct modification of these creeks (being piped under new developments, installation of flood retardant structures), the addition of stormwater outfalls and gross pollutant traps, and the provision of major infrastructure (such as road crossings and sewer pipes).

In contrast, waterways to the north, south and south west of the city are relatively protected, and remain in good to excellent condition due to their surrounding land use. These areas fall within National Parks (Ku-ring-gai Chase, Lane Cove, and Garigal National Parks in the north; Royal, Heathcote, Georges River National Parks, and Dharawal Nature Reserve in the south;), and specially protected areas such as Holsworthy Military Range and Woronora SCA Reserve, and therefore have intact terrestrial and riparian vegetation communities, and reasonable water quality.

Within inner city Sydney, waterways are highly modified, channelised, forming concrete drains that allow for rapid delivery of stormwater to the ocean. Large waterways, such as the Cooks River and Alexandria Canal, have also been lined with concrete to minimise bank erosion. Whilst these modifications do not form barriers to fish passage *per se*, they are likely to affect fish behaviour through the lack of shelter and food sources.

Northern Beaches Subcatchment

The Northern Beaches subcatchment extends from Manly Lagoon in the south to Narrabeen Lakes in the north. 28 sites were assessed in the area across 14 waterways. The majority of sites were road culverts (11 sites), weirs (five sites), and piped sections (five sites). 11 sites were recommended for action (shown on Map 2). Less than 1% of this subcatchment was affected by channelisation, indicating that the majority of waterways are reasonably intact. The top five priorities in the Northern Beaches subcatchment are shown in Table 8 below.

Table 8. Priority fish passage barriers Northern Beaches region

Rank	Crossing ID	Waterway	Structure Type	Type/Issue/Recommendation	Comments
1	**WAR002**	Manly Lagoon	Manly Lagoon outlet culvert*	Reinstate channel to sea	May have safety issues associated with removal. Channel is reinstated in sand during heavy rainfall events.
2	**WAR011**	Middle Ck	River gauge station	Remove if structure is not required	Structure in disrepair, directly adjacent Wakehurst Parkway.
3	**WAR006**	Curl Curl Lagoon (Greendale Ck)	Weir	Monitor effectiveness of (and improve) rock placement in fishway section to ensure movement of native fish	Structure within lagoon itself, near outfall of Greendale Ck.
4	**PIT003**	Mullet Ck	Weir	Requires further assessment	Warriewood wetlands are directly upstream and removal of this weir may endanger wetlands, causing them to dry.
5	**WAR001**	Brookvale Ck	Road culvert	Modify base of structure/ lower invert	Shallow water depth through structure. Structure may be tidal limit.

* Also investigated as part of Tidal Flow Report (Williams *et al.* 1996)

Manly Lagoon outlet structure was deemed the highest priority for the Northern Beaches subcatchment. This structure directs water from the lagoon out to sea alongside the sea baths at North Manly. The structure comprises a short channelised section and an online gross pollutant trap at the entrance to a long pipe culvert. During high flows, Warringah Council constructs a trench across the beach to aid flow release to the ocean, however, during low-medium flows, water remains within the channel and culvert.

The main issue with the structure in terms of fish passage is its length (approximately 120m). Flow velocity along the channel would be reasonably high and consistent due to the low boundary roughness of the channel. This could inhibit movement of fish (especially small species and juveniles). Tidal movement and wave action could counter this process at certain times, allowing fish to venture between the sea and the lagoon. Light within the culvert would also be minimal near the centre of the structure and may deter some fish.

One possible option is to reinstate the outlet to the sea by constructing an open channel. It is acknowledged, however, that other issues, such as safety concerns, need to be addressed. As an alternate option, light holes could be installed along the length of the structure and the culvert fitted with rock to increase boundary roughness and reduce flow velocities within the culvert.

The second priority in the northern beaches is a disused river gauging station on Middle Creek, and is more easily remediated. This structure, directly adjacent to Wakehurst Parkway, is recommended for removal. The structure leaks through the cement base and does not appear to be in operation. The surrounding waterway is in reasonably good condition and removal would open approximately 1.5km of suitable habitat upstream of the structure.

The third remediation priority is the rock weir in Curl Curl Lagoon. This structure marks the tidal limit of the lagoon, maintaining freshwater habitat upstream. The rocks on one side have been placed to form a rock ramp fishway, however it is unclear if this structure is effective in passing fish. Recommended action for the site includes monitoring the effectiveness of the structure and, if it is deemed ineffective, repositioning the rocks within the structure to reduce the vertical drop and provide resting sites for fish.

The fourth remediation priority for this subcatchment is located on Mullet Creek, a feeder stream of Narrabeen Lakes. The structure is a fixed crest weir that creates a weir pool upstream which stabilises water levels in an upstream wetland area called “Warriewood Wetlands”. Although this structure blocks fish passage, weir removal may endanger the wetlands. A second option would be to install a fishway, however this option would be costly. Further investigation is required to consider remediation options at this site.

The fifth priority structure recommended for remediation is a road culvert on Brookvale Creek, Manly Lagoon system. This shallow road culvert at Kentwell Road appears to mark the tidal limit. At the time of observation (just after a rainfall event), water depth in the structure was less than 200mm, particularly across the upstream-side apron. This water depth can limit the movement of some larger fish species, and considering observations were made following a rain event, this structure is likely to limit movement of smaller fish species in drier periods also. It is therefore recommended that either a low flow channel be fitted into the culvert, or the invert (base) of the structure be lowered to allow for greater flow depth within the structure.

Other structures within the Northern Beaches subcatchment were classified as obstructions to fish passage, but were not recommended for action due to their placement in the system (i.e. located high in the catchment in minimal fish habitat), or they were too costly or difficult to remediate (e.g. Manly Dam and creek sections piped under housing developments/shopping centres).

Middle Harbour / Lane Cove River Subcatchment

44 sites were assessed across 21 waterways in the Middle Harbour and Lane Cove River subcatchment. The majority of sites assessed were road culverts (20 sites), weirs (10 sites), and piped sections (six sites). 14 sites were recommended for remediation action (see Map 3).

Approximately 5% of streams in the area were channelised or piped. This small percent is largely due to the steep terrain and limited intensive development in the subcatchment, and the large percent of land protected in National Parks. The top five priority sites within this subcatchment are shown in Table 9.

Table 9. Priority fish passage barriers Middle Harbour / Lane Cove Subcatchment					
Rank	**Crossing ID**	**Waterway**	**Structure Type**	**Type/Issue/Recommendation**	**Comments**
1	**KUR006**	Lane Cove River	Weir*[@]	Improve fishway and install low flow section in culvert; further monitoring required.	Assessment of fishway required to determine efficiency. Modification may be required to allow for greater operation range, including installation of a low flow channel in weir culvert.
2	**LC002**	Stringy Bark Ck	Weir	Remove if structure is not required.	Low level weir, now used as walkway at low tide. Road crossing <100m upstream also allows access. Minimal habitat available upstream due to waterfall.
3	**KUR004**	Little Blue Gum Ck	Road culvert	Clear sand debris from culvert	Sand debris partially blocks one culvert – collects inside the downstream side of the culvert.
4	**KUR016**	Tributary to Coups Ck	Causeway	Remove if structure is not required.	Natural barriers likely to be present upstream, causeways and road culvert present downstream – little benefit from removal.
5	**KUR014**	Tributary to Coups Ck	Causeway	Remove if structure is not required.	Natural barriers likely to be present upstream, causeway and road culvert present downstream – little benefit from removal.
* Also investigated as part of Tidal Flow Report (Williams *et al.* 1996) [@] Also investigated as part of the Weir Report (NSW Fisheries 2002)					

The first priority for Middle Harbour / Lane Cove subcatchment is Lane Cove weir which marks the tidal limit on the mainstem of the Lane Cove River. Despite having a rock ramp fishway installed in late 1999, the weir still limits fish movement between salt and freshwaters. Following construction of the fishway, monitoring found that effective fish passage was only occurring at the top of the tidal prism (i.e. around high tide only). Due to a lack of water depth in the culvert at most flows, fish are prevented from being able to reach the fishway upstream. In addition, issues in relation the fishway (rock placement and leaking) need to be investigated to ensure effective fish passage at the site.

The second priority structure within this subcatchment is a low level weir structure located in the tidal zone of Stringy Bark Creek. This structure is currently used as a walkway to a small gressed area, although pedestrian access can only occur at low tide due to a shallow, low lying, section that allows water movement over the structure. It is recommended that this structure be removed as pedestrian access is available across a road culvert approximately 100m upstream. Removal of the structure will allow juvenile fish (observed during the site visit) easier access to the upstream section of this creek throughout the tidal cycle, and lessen their chances of predation.

The third priority site in this subcatchment only requires remediation through removal of debris from the culvert to improve fish passage efficiency. This site occurs slightly upstream of the tidal limit of Little Blue Gum Creek (its confluence is located immediately downstream of Lane Cove weir on Lane Cove River). Directly upstream of this site, the small creek meanders through sandy soils, some of which have been eroded and deposited both upstream of the culvert and within it on the downstream side. The presence of the sediment has effectively halved the efficiency of the culvert, but provided a low flow channel within it (by directing water along a narrower channel within the sediment). It is recommended that some of the sand debris is removed from the culvert to improve water movement under the road at higher flows, and a plan of maintenance developed for the site.

The fourth priority site is recommended for removal, although the benefits of doing so are likely to be minimal. The site, on an unnamed tributary to Coups Creek, is relatively high in the catchment, with several small barriers present downstream, including two low-level causeways. It is likely that there are several natural barriers present along the waterway (e.g. small waterfalls and rocky steps) reducing the overall benefit of any remediation works (particularly if fish cannot reach the site from downstream). Further investigation is required to determine the benefits of removing this structure. Any remediation activities for this structure should also surrounding structures to ensure fish passage.

Parramatta River Subcatchment

Parramatta River subcatchment includes the mainstem of the Parramatta River, its tributaries and small waterways entering into Parramatta River estuary and Port Jackson from the south from Parramatta to Vaucluse.

73 sites were assessed in the subcatchment across 21 waterways. The majority of sites were weirs (29 sites), road culverts (10 sites), other infrastructure (pipes - eight sites) and culverts other than roads (seven sites). Of the 73 sites, 39 were recommended for action and are shown on Map 4. It was estimated that approximately 45-50% of this subcatchment was affected by stream modification and channelisation. This is due to the low lying topography within this subcatchment, and the highly developed and populated nature of this area. Table 10 lists the top five priority sites within this subcatchment.

Table 10. Priority fish passage barriers Parramatta River Subcatchment

Rank	Crossing ID	Waterway	Structure Type	Type/Issue/Recommendation	Comments
1	**PAR001**	Parramatta River	Weir*[@]	Install fishway (Charles St Weir)	Tidal limit. Fishway on works program for 2005.
2	**PAR003**	Parramatta River	Weir[@]	Install fishway (Parramatta Crossing / Kiosk Crossing)	Third weir in series of four. Fishway on works program for 2005.
3	**PAR004**	Parramatta River	Weir[@]	Install fishway (Asylum Weir)	Final weir in series of four. Fishway on works program for 2005.
4	**PAR012**	Toongabbie Ck	Weir[#]	Remove if structure is not required.	No apparent use. In parkland area.
5	**PAR002**	Parramatta River	Weir[@]	Install fishway (Marsden St Weir)	Second weir in series of four. Fishway on works program for 2005.

* Also investigated as part of Tidal Flow Report (Williams *et al.* 1996) [#] Site identified by Council staff
[@] Also investigated as part of the Weir Report (NSW Fisheries 2002)

Four of the five priority sites within this subcatchment occur on the mainstem of the Parramatta River, with the fourth (PAR012) located on a major tributary (Toongabbie Creek). At the time of writing, plans for constructing fishways on all four Parramatta River weirs were underway by Parramatta City Council including:

- Vertical slot fishways proposed for Charles St tidal weir (PAR001) and Kiosk Crossing weir (PAR003)
- Rock ramp fishway proposed for Asylum weir (PAR004)
- Lock style fishway for the tallest of the weirs – Marsden St weir (PAR002).

The installation of fishways on the four Parramatta weirs will open over 4km of previously inaccessible habitat to native fish species, allowing them to readily access fresh and saltwater habitats for the first time since the early 1800s.

The fourth priority structure (PAR012, weir on Toongabbie Creek) is recommended for removal. It appears that this structure is no longer required, and removal would allow fish further access to freshwater habitats upstream.

Following the modification of the four mainstem Parramatta weirs, structures upstream of Asylum weir would become of higher priority as they will then represent the most downstream sites limiting fish access to upstream habitat.

It should be noted that within the Parramatta River subcatchment, the overall top two priority sites assessed (a large flood mitigation weir on upper Darling Mills Creek, and Lake Parramatta on Hunts Creek) were not recommended for action due to their size and therefore the high cost of remediation. Both sites have a significant area of good quality habitat available upstream, but the likely cost-benefit ratio was too high to recommend action.

Cooks River / North Botany Subcatchment

The Cooks River / North Botany subcatchment encompasses the highest population density and greatest area of industrial development of the eight subcatchments described here. It was estimated that 85-90% of the area has been affected by stream modification and channelisation, reflecting the highly developed nature of this region.

12 sites were assessed across six waterways in the region. The majority of sites assessed were weirs (eight sites). 9 sites were recommended for action (see Map 5). Table 11 lists the top five priority sites within this subcatchment.

Table 11. Priority fish passage barriers Cooks River / North Botany Subcatchment

Rank	Crossing ID	Waterway	Structure Type	Type/Issue/Recommendation	Comments
1	**ROC020**	Wolli Creek	Weir*#	Install fishway or remove if structure not required.	Tidal limit for Wolli Ck. Need to assess heritage values.
2	**BOT008**	Mill Stream	Weir	Install fishway.	Tidal limit of Lachlan Swamps system.
3	**BOT004**	Mill Stream	Weir	Install fishway (cost /benefit low).	Major structure, possible minimal benefit.
4	**BOT006**	Mill Stream	Causeway	Lower level, or remove if structure not required.	Easily remediated.
5	**ROC021**	Bardwell Ck	Weir[x]	Remove if structure not required.	Bardwell Valley Golf Club looking at removing this structure in the future. Average habitat, weir present downstream.

* Also investigated as part of Tidal Flow Report (Williams *et al.* 1996) # Site identified by Council staff
@ Also investigated as part of the Weir Report (NSW Fisheries 2002) x Site identified by Community member

The top priority site within this subcatchment is Wolli Creek weir at Turrella. This structure forms the tidal limit of Wolli Creek, and maintains a freshwater system upstream. The structure was most likely built to allow access across Wolli Creek to the adjacent Chinese Gardens (no longer present), although ownership of the structure remains unclear.

An alternative elevated walkway has since been installed, allowing for the possibility of remediating the site. Initial discussions with Council and the Wolli Creek Preservation Society have indicated that removal is not a preferable option, and installation of a fishway may be possible in the future, opening approximately 1.5km of freshwater habitat up to fish species. Further discussions with all parties are needed before remediation of this site can occur.

The second, third and fourth priority sites within this subcatchment are all located in the Mill Stream / Lachlan Swamps area. Most of this area has been relatively protected from development due to the location of two golf courses around the swamps, although several weirs have been constructed along its length to provide permanent water features.

The second priority site in the subcatchment is a combined weir/culvert structure that forms the tidal limit of the Lachlan Swamps / Mill Stream system. Installation of a fishway at this site would allow fish to access to the freshwater habitat upstream, although the distances are relatively minor unless all weirs on Mill Stream are remediated (less than 500m for this site).

The third priority site in this subcatchment is recommended for installation of a fishway. This site is the uppermost weir on Mill Stream / Lachlan Swamps, and is a much larger (higher) structure than those present downstream. Because of its height (approximately 4m), the cost to remediate the site using a fishway would be expensive and, without the remediation of the weirs downstream to allow for fish passage, of minimal benefit.

Unlike the weirs on Mill Stream, the fourth priority site is easily remediated. This site is a low rock rubble causeway across the creek just upstream of the Sydenham / Bankstown railway line. Remediation of this site requires removal of the rock debris present, or strategic placement of the rocks to allow fish passage. However, as with the other barriers in this system, without remediation of the downstream barriers little benefit will be gained from remediating this site alone. Within Mill Stream / Lachlan Swamps, all other barriers should be considered when determining remediation options for a particular site.

The fifth priority site is a weir on Bardwell Creek, which is owned by Bardwell Valley Golf Club. Removal of the structure will allow access to approximately 1km of upstream habitat. However, as with the sites on Mill Stream, this site is upstream of another weir, which forms an ornamental lake in a small park downstream. These two sites are the only structures in the downstream section of Bardwell Creek, and, following remediation of Wolli Creek weir, would become a higher priority, and allow for fish passage between Bardwell Creek and the estuary.

Upper Georges River Subcatchment

78 sites were assessed in the Upper Georges subcatchment across 34 waterways (see Map 6). The majority of sites assessed were road culverts (28 sites), weirs (12 sites), piped sections (10 sites), and levees (dam walls) (10 sites). Of the 78 sites, 30 were recommended for action. It was estimated that one-quarter of this subcatchment (25%) was affected by stream modification and channelisation, with rapid development occurring in the western suburbs surrounding Campbelltown. A large proportion of the subcatchment is protected within Holsworthy Military Range, Dharawal Nature Reserve and Dharawal State Conservation Area. Table 12 lists the top five priority sites within the subcatchment.

Table 12. Priority fish passage barriers Upper Georges River Subcatchment

Rank	Crossing ID	Waterway	Structure Type	Type/Issue/Recommendation	Comments
1	**CAM001**	Georges River	Weir (Ingleburn Weir)[@]	Investigate options for partial or total structure removal. Detailed weir review required.	Remediation option subject to heritage issues being addressed.
2	**LIV001**	Georges River	Weir (Liverpool Weir)*[@]	Monitor effectiveness of fishway; Maintenance of fishway; Review options if fishway ineffective.	If structure is successfully passing fish then it may not be a barrier. If not, Liverpool weir, as the tidal barrier, is catchment's highest priority.
3	**CAM002**	Georges River	Road culvert[@#] (Wedderburn Weir)	Remove downstream concrete sheet, retrofit culvert to allow fish movement	Community support indicated.
4	**WLL005**	Georges River	Weir (Mahrneyes waterhole)	Remove weir if no longer required.	Structure above a waterfall therefore minimal benefit.
5	**WOL001**	Maddens Ck	Weir	Remove weir if no longer required.	Several small weirs located in vicinity. Review existing use.

* Also investigated as part of Tidal Flow Report (Williams *et al.* 1996) [#] Site identified by Council staff
[@] Also investigated as part of the Weir Report (NSW Fisheries 2002)

The top priority site, Ingleburn weir, is located on the Georges River and is a barrier to fish at most flows despite being partially breached. Rock rubble from the weir creates a step greater than 10cm and increased turbulence. Many native fish species have difficulty negotiating rises greater than 10cm. Due to the structure being breached, remediation of this site is potentially inexpensive – strategic placement of rock debris could allow for fish passage.

The second priority site, Liverpool Weir, was built in 1836. On completion, it fixed the upper boundary of the estuary, altering tidal flow in the mid-reach of the river, and inhibiting the passage of migrating fish (DIPNR, 2004). A vertical slot fishway was installed in 1997 to improve fish passage through the structure. The fishway is currently being monitored to test its effectiveness in passing fish – if the fishway is not functioning effectively, the structure would be the first priority in the subcatchment. If the fishway is passing fish effectively, then the next barrier upstream (Ingleburn weir) would remain the highest priority structure in this subcatchment.

Photo 9: Manly Lagoon outlet structure and online GPT,
Northern Beaches subcatchment.

Photo 10: Partially silted road culvert,
Little Blue Gum Creek,
Middle Harbour / Lane Cove River subcatchment.

Photo 12: Marsden Street Weir,
Parramatta River subcatchment.

Photo 13: Ingleburn Weir,
Georges River,
Upper Georges River subcatchment.

Photo 11: Wolli Creek Weir,
Wolli Creek
Cooks River / North Botany subcatchment.

Photo 14: Breached Weir,
Cabramatta Creek,
Lower Georges subcatchment.

Photo 15: Pass of Sabugal Causeway,
Woronora River, Woronora River subcatchment.

Photo 16: Audley Weir,
Hacking River, Hacking River subcatchment.

Wedderburn weir is the third priority structure in the subcatchment. The structure is a culvert road crossing with seven 1.5m diameter low-flow cells. At high flows, water banks up behind the structure creating a weir effect and limiting fish passage. The structure has a concrete apron on the downstream-end which creates a drop of approximately 20cm. This drop off, and the shallow water depth in the culvert, would inhibit fish passage through the structure at low flows. It is recommended that the apron be removed or modified to produce a low flow channel, and that low-flow cells be installed within the culvert.

The fourth remediation priority in the Upper Georges subcatchment is a weir on the Georges River at "Mahrneyes waterhole", bordering the Holsworthy Military Reserve. The structure is recommended for removal if no longer required, however it is located directly above a natural waterfall reducing the overall benefit of removing the structure.

Maddens Creek weir within Dharawal Nature Reserve is the fifth remediation priority in the subcatchment. It is the furthest downstream weir in a sequence of three small weirs located along the waterway. Any future remediation works (such as weir removal) should be reviewed in light of proposals to also modify the two barriers above Madden's Creek weir, and that several natural barriers are likely to be present downstream.

Lower Georges River Subcatchment

The Lower Georges River subcatchment encompasses the Georges River below Liverpool, and tributaries that enter the river in this area (not including the Woronora River subcatchment). 89 sites were assessed across 37 waterways. The majority of sites assessed were road culverts (47 sites) and weirs (17 sites). 49 sites were recommended for action (see Map 7).

It was estimated that 20% of this subcatchment was affected by stream modification and channelisation, indicating that the majority of the waterways in the region remain relatively intact. This is largely due to the protection offered by National Parks and special areas such as the Holsworthy Military Range. Table 13 lists the top five priority sites for this subcatchment.

Table 13. Priority fish passage barriers Lower Georges River Subcatchment

Rank	Crossing ID	Waterway	Structure Type	Type/Issue/Recommendation	Comments
1	**BAN001**	Morgans Ck	Road culvert	Install central light hole.	Relatively minor tidal creek within Georges River National Park. Long culvert under Henry Lawson Drive.
2	**LIV005**	Cabramatta Ck	Weir	Remove if structure not required.	Breached weir. Easily remediated through placement of rock debris.
3	**LIV023**	Harris Ck	Bed control structure+	Remove if structure not required.	Gabion weir structure on works program for removal in 2005.
4	**BAN011**	Kelso Creek	Floodgate*	Improve management / lower pipe invert / remove if structure not required.	Easily remediated through improved management of structure (timing of opening and closing).
5	**LIV024**	Harris Ck	Bed control structure+	Remove if structure not required.	Gabion weir structure on works program for removal in 2005.

* Also investigated as part of Tidal Flow Report (Williams *et al.* 1996) + Site identified by Department of Defence

The first priority structure in the subcatchment is a road culvert on a small tidal creek within Georges River National Park. Although the structure does not limit tidal movement between the upstream and downstream side of the structure, it is possible that it could form a behavioural barrier to fish movement due to a lack of light within the culvert itself. It is suggested that light holes could be installed in the culvert to improve conditions for fish passage.

The second priority site, a weir on Cabramatta Creek, is also easily remediated. This structure is no longer required and is breached on one side, leaving rock rubble that may limit fish movement past the structure due to rises of 10cm or more. The structure is the most downstream barrier present on Cabramatta Creek, and may also form the tidal limit. Remediation of this site could include complete removal, removal of the rock rubble, or rearrangement of the rock rubble to allow for fish passage.

Removal of bed control structures on Harris Creek in Holsworthy Military Range could also be undertaken with relative ease. These structures (priority sites three and five), along with three others on Williams Creek (ninth, thirteenth and fourteenth priority sites within the subcatchment), were installed approximately ten years ago to stabilise soil erosion occurring as a result of military training exercises. Recent inspections indicate that the channel has stabilised and all but one structure could be removed. It is proposed that the remaining structure be modified to allow for fish passage. The Department of Defence is investigating removal of the gabion weirs in the near future.

The fourth priority site in the subcatchment is a floodgate on Kelso Creek, adjacent Henry Lawson Drive, Panania. If removal of the structure is not feasible, improved management of the floodgates (by automatically opening the gates at certain times during the tidal cycle) could allow fish passage to occur through the structure without compromising the structure's functionality. Lowering the invert of the pipes and retrofitting them internally with rocks could improve fish passage past the floodgates at low tide.

Woronora River Subcatchment

The majority of Woronora River subcatchment falls in "special area" (SCA Water Reserve) or National Park (Heathcote National Park). Due to its protected nature, only approximately 0.5% of the subcatchment was considered affected by stream modification and channelisation.

Woronora Dam reservoir covers a large proportion of the upper catchment area. The dam is clearly a barrier to fish but, due to its use as an essential water storage structure, and the predicted cost of modifying the structure for fish passage, no action was recommended.

Overall, seven sites were assessed in this subcatchment, with only two sites recommended for action (listed in Table 14 and shown on Map 8).

Table 14. Priority fish passage barriers Woronora River Subcatchment

Rank	Crossing ID	Waterway	Structure Type	Type/Issue/Recommendation	Comments
1	**SUT013**	Woronora River	Weir[x], Pass of Sabugal	Remove if structure is no longer required.	Fire access track – natural barriers downstream; bass observed either side of the structure.
2	**SUT020**	Heathcote Ck	Weir	Possible structure removal, if no longer required.	Weir pool wetland is in excellent condition – structure removal could impact on this habitat. Further assessment required.

[x] Site highlighted by Community member

The top priority site on the Woronora River is the "Pass of Sabugal" (or "The Needles") crossing, a low-level concrete causeway with a low-flow pipe. The structure is set on a slightly elevated natural rock platform and is the downstream-most artificial barrier in the system. At low flows, a series of pools are present along the natural drop off below the structure. Australian bass (*Macquaria novemaculeata*) have been observed in these pools, and upstream of the causeway, indicating that the structure is not a complete barrier (fish may be able to swim upstream at moderate flows). At low flows this structure may act as an obstruction to fish passage due to elevated flow velocity through the pipe. It is recommended that the structure be completely or partially removed if no longer required.

The second priority site in this subcatchment is a weir on Heathcote Creek, a tributary of the Woronora River in Heathcote National Park. Removal of the weir is recommended if the structure is no longer required. However, extensive wetlands are present upstream, and the impact of weir removal on these areas must be investigated. In addition, it is uncertain whether there are natural barriers downstream of the structure – further investigation is required to determine if weir removal is feasible.

Hacking River Subcatchment

The Hacking River catchment is one of the most intact systems in Sydney and offers the best opportunity to protect and enhance the region's freshwater and estuarine habitats.

13 sites were assessed in this subcatchment across eight waterways. The majority of sites assessed were weirs (six sites), with two road culverts, two other culverts (fire track culverts), one dam, one causeway and a bridge. Of the 13 sites assessed, nine were recommended for action (refer Map 9), with two sites not regarded as fish passage barriers. Approximately 1% of this subcatchment was affected by stream modification and channelisation, indicating that the majority of waterways in this region are intact - due to the large proportion of the subcatchment within the Royal National Park. Table 12 lists the top five priority sites for this subcatchment.

Table 15. Priority fish passage barriers Hacking River Subcatchment

Rank	Crossing ID	Waterway	Structure Type	Type/Issue/Recommendation	Comments
1	**SUT014**	Hacking River	Weir* (Audley Weir)	Installation of fishway; Monitor fishway effectiveness & ensure maintenance.	Top priority site. Fishway to be installed 2005. Until Audley weir allows for fish passage, remediation of other Hacking structures is not a priority.
2	**WOL006**	Hacking River	Weir / Road crossing[@] (Otford / McKell Av Weir)	Remove if structure no longer required; Detailed weir review to determine remediation options; Cost/benefit analysis reqd.	Next man-made barrier on Hacking River up from Audley weir. Existing uses of the structure must be determined to see if removal is an option.
3	**WOL010**	Hacking River	Weir / Road crossing	Remove if structure no longer required. Clear debris.	"Otford Weir 1" near railway station; most upstream weir.
4	**WOL012**	Hacking River	Weir / Road crossing	Replace with large culvert.	Major weir ("Otford Weir 2"), approx 4m high, currently has small overflow pipes at top of weir crest.
5	**WOL009**	Hacking River	Causeway (Otford town road crossing)	Install larger culverts / remove downstream apron.	Next barrier up from WOL010. Downstream apron causes obstruction.

* Also investigated as part of Tidal Flow Report (Williams *et al.* 1996) [#] Site identified by Council staff
[@] Also investigated as part of the Weir Report (NSW Fisheries 2002)

All five high priority sites for the Hacking River subcatchment occur on the mainstem of the Hacking River. Audley weir was also ranked as the top priority barrier in the Sydney Metropolitan CMA region (see Table 7). The structure is the furthest downstream barrier in the reasonably intact river system, with extensive habitat available upstream. At the time of writing, a fishway had been proposed for the crossing, with final designs being developed.

In the event that Audley weir is modified to allow for fish passage, the next known barrier upstream, Otford / McKell Avenue weir, would become a higher remediation priority. Using the prioritisation scheme developed for this study, Otford / McKell Avenue weir was classified as the number three priority in the Sydney Metropolitan CMA region, and number two in the Hacking River system. Remediation of the Otford / McKell Avenue site preferably would involve removal, although this may not be possible due to the presence of a picnic area adjacent to the upstream weir pool. A detailed weir review is currently being undertaken for this site to explore other remediation options.

The remaining three high priority sites in this subcatchment are all located near the township of Otford, in the Upper Hacking River catchment. The third priority is a weir/road crossing structure near the Otford railway station ("Otford Weir 1"). The structure itself is two-tiered, with the weir wall upstream of the road crossing section, which is at approximately half the height of the weir crest. Water passes over the weir crest and is captured in a drain at the base of the weir wall, where it is transported under the road surface and out on the downstream side of the structure. Both drops are approximately 1.5m. The drains have a grill cover, which collect leaves and other debris, and can cause water to move over the road surface at times. It is recommended that the weir section of this structure be removed, and large culverts installed under the road surface to facilitate water and fish movement.

Located further downstream is another weir/road crossing structure on the Hacking River ("Otford Weir 1"). The structure is approximately 4m high (from the downstream bed level to the crest of the weir), and has four overflow pipes approximately 15cm diameter at the crest of the weir. This structure is at the end of a pubic road and leads to private property. It is recommended that this structure be replaced with large culverts.

The number five priority structure within the Hacking River system is the most upstream barrier on the Hacking River at the township of Otford. The causeway structure is likely to prevent fish passage as a result of shallow water depth across a cement apron on the downstream side. In addition, flow velocity through the structure is likely to be high during moderate flows, further preventing fish movement. It is recommended that the downstream apron on this structure be removed or modified, and the culvert size increased. Remediation of surrounding structures would be necessary to gain any benefit from works on this structure.

6. SUMMARY

Data collected from the overall inventory is available in a separate Microsoft Excel file entitled *Fish Passage Barriers Inventory-Sydney Catchments–CD Database*. The recommendations in relation to remediation options for each site have been provided as a basic indication of the scale and extent of remediation required (e.g. complete structure removal, retrofitting, minor modification, maintenance etc).

Details in relation to undertaking fish passage barrier remediation can be obtained from several source documents including:

- *Why do fish need to cross the road? Fish passage requirements for waterway crossings.* (Fairfull & Witheridge, 2003),
- *Fish passage requirements for waterway crossings – Engineering Guidelines*. (Witheridge, 2002),
- *Redundant Weir Removal: The Branch River Crossing – A case study.* (WWF Australia, 2003),
- *Duck Creek Crossing Removal Case Study*. (WWF Australia, 2005).

Appendix E provides a description of the three types of fishway described within this text.

Permit and works approvals requirements in relation to road crossing construction, modification and maintenance in NSW can be found in:

- *Policy and Guidelines for Fish-Friendly Waterway Crossings* (NSW Fisheries, 2003), and
- *Policy and Guidelines for Aquatic Habitat Management and Fish Conservation* (NSW Fisheries, 1999).

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9. APPENDICES

Appendix A – Freshwater & Estuarine Fin Fish, Sydney & South Coast NSW

Scientific Name	Common Names	Status	Migration[8] and habitat
Acanthopagrus australis	Yellowfin bream Silver bream	Common	Amphidromous; coastal marine; estuaries and inshore reefs
Afurcagobius tamarensis	Tamar River goby	Common	Estuaries, coastal lakes & lower freshwater river reaches
Aldrichetta forsteri	Yellow-eye mullet	Common	Marine and estuarine; brackish coastal lakes & lower freshwater reaches
Ambassis marianus	Estuary perchlet Glass perchlet	Common	Local migration; brackish mangrove estuaries & tidal creeks
Amniataba percoides	Banded grunter	Exotic; Noxious listing, NSW	Freshwater habitats
Amoya bifrenatus	Bridled goby	Common	Estuarine & marine waters
Anguillia australis	Short-finned eel	Common	Catadromous; coastal rivers & wetlands
Anguilla reinhardtii	Long-finned eel	Common	Catadromous; coastal rivers
Arrhamphus sclerolepis	Snub-nosed garfish	Common	Coastal bays & brackish estuaries
Atherinosoma microstoma	Smallmouthed hardyhead	Common	Unknown migration pattern; coastal estuarine & fresh waters
Carassius auratus	Goldfish	Exotic	Widespread in lowland rivers
Cyprinus carpio	Common carp	Exotic; Noxious listing	Still gentle flowing rivers in inland NSW & some catchments along the coast.
Galaxias brevipinnis	Climbing galaxias	Uncertain; Distribution contracted	Amphidromous; headwaters & forested streams
Galaxias maculatus	Common jollytail	Common	Catadromous; coastal streams, lakes & lagoons – salt & fresh water environs
Galaxias olidus	Mountain galaxias	Common	Local migration; moderate & high elevations in coastal & inland rivers.
Gambusia holbrooki	Gambusia, Plague minnow	Exotic Noxious listing	Widespread in coastal & inland NSW
Gerres subfasciatus	Silver biddy	Common	Marine estuaries & bays, brackish coastal rivers & lakes.
Gobiomorphus australis	Striped gudgeon	Common	Amphidromous; coastal streams generally at lower elevations.
Gobiomorphus coxii	Cox's gudgeon	Common	Potamodromous; freshwater reaches of coastal rivers.
Hypseleotris compressa	Empire gudgeon	Common throughout its range	Unknown migration; lower reaches of coastal rivers.
Hypseleotris galii	Firetailed gudgeon	Common	Potamodromous; freshwater reaches of coastal streams.
Liza argentea	Flat-tail mullet	Common	Estuaries & sea beaches
Lutjanus argentimaculatus	Mangrove Jack	Common	Estuaries & tidal river reaches
Macquaria australisica	Macquarie perch	Listed as Threatened Species in NSW	Potamodromous; Hawksebury R, Shoalhaven R & inland NSW.
Macquaria colonorum	Estuary perch	Uncertain	Amphidromous; estuarine areas in coastal rivers & lakes
Macquaria novemaculeata	Australian bass	Uncertain	Catadromous; Coastal rivers up to 600m altitude.

[8] Migration patterns of freshwater fish include: *Potamodromous* – fish that migrate wholly within fresh water; *Anadromous* – fish that spend most of their life in the sea and migrate to fresh water to breed; *Catadromous* - fish that spend most of their life in fresh water and migrate to the sea to breed; *Amphidromous* - fish that migrate between sea and fresh water, but not for the purpose of breeding.

Monodactylus argenteus	Diamondfish Silver batfish	Common	Bays, mangrove estuaries, tidal creeks & lower reaches of freshwater streams
Mordacia mordax	Shortheaded lamprey	Moderately abundant in some rivers	Anadromous; coastal rivers from Hawkesbury River to southern catchments.
Mordacia praecox	Non-parasitic lamprey	Uncertain	Anadromous; has been found in Moruya & Tuross rivers in NSW
Mugil cephalus	Striped mullet Sea mullet	Common	Amphidromous; lower reaches & estuaries of coastal catchments
Myxus elongatus	Sand mullet	Common	Amphidromous as juveniles; estuaries & brackish waters in lower river reaches
Myxus petardi	Freshwater mullet	Common	Catadromous; freshwater reaches of coastal rivers north of Georges River into QLD
Notesthes robusta	Bullrout	Limited abundance but not threatened	Catadromous; tidal estuaries & fresh waters
Oncorhynchus mykiss	Rainbow trout	Exotic	Local migration; montane regions along the Great Dividing Range
Perca fluviatilis	Redfin perch	Exotic	Still and slow-flowing waters in inland rivers and southern coastal NSW
Phalloceros caudimaculatus	Speckled mosquito fish	Exotic	Still ponds & pools amongst dense aquatic vegetation – known only at Long-reef, Sydney and Perth.
Philypnodon grandiceps	Flathead gudgeon	Common	Unknown migration; inland & coastal waters especially lakes & dams
Philypnodon sp.	Dwarf flathead gudgeon	Common	Unknown migration; coastal & inland streams
Platycephalus fuscus	Dusky flathead	Common	Amphidromous; marine & estuarine waters
Potamalosa richmondia	Freshwater herring	Not common but not considered under threat	Catadromous; estuaries & coastal fresh water rivers
Prototroctes maraena	Australian grayling	Listed as Threatened Species federally.	Amphidromous; coastal waterways from Hawkesbury River south to Victoria;
Pseudaphritis urvillii	Congolli	Abundant throughout its range	Catadromous; south coast NSW; freshwater and estuarine.
Pseudogobius sp	Blue-spot goby	Common	Sheltered estuaries & coastal lakes
Pseudomugil signifer	Pacific blue-eye	Common	Amphidromous; eastern draining catchments
Redigobius macrostoma	Largemouth goby	Common	Amphidromous; estuaries, coastal rivers & some freshwater streams
Retropinna semoni	Australian smelt	Common	Potamodromous; Inland & coastal freshwater
Tandanus tandanus	Freshwater catfish	Common	Local migration; known in the Hawkesbury & Hunter systems as well north coast & inland.
Valamugil georgii	Fantail mullet	Common	Marine & estuarine waters from Port Hacking to QLD.

Sources: Thorncraft & Harris (2000), McDowall (1996), Allen *et al.* (2002) and Yearsley *et al.* (2001).

Appendix B – Urban Waterways Fish Passage Barrier Assessment Form

URBAN WATERWAYS FISH PASSAGE - DESKTOP ASSESSMENT FORM

ASSESSOR: _____DATE: _____CROSSING ID: _____
CATCHMENT: _____ WATERWAY: _____
STREAM ORDER: _____ ELEVATION: _____ LGA: _____

1. LOCATION INFORMATION

1a Location: Nearest Town: _____ Road Name (or Nearest Road): _____

1b Section of Catchment *(please circle)***:** Upper Middle Lower

1c Approximate upstream catchment area (km^2) _____

2. FISH BARRIER IMPACTS

2a. Fish Barrier Type *(circle)*

Bridge - single or multiple span or arched structure raised above channel bed.

Culvert - cell to convey water underneath roadway: **Pipe / Box**

Pipe - cylindrical-celled culvert (other than roadway).

Weir -in stream structure designed to back water upstream: **Fixed Crest / Adjustable Release** structure

Causeway - low-level crossing designed to convey water over roadway surface; may have low-flow pipe.

Ford – low level crossing formed directly on the channel bed in a shallow section of a watercourse.

Floodgate - gated levee to regulate flow between floodplain and stream channel.

Other *(circle)* GPT (gross pollutant trap) Floating / Fixed bed control structure channelised section levee Natural (eg log jam/debris) Other_____

2b If barrier blocks fish passage, approximately how much habitat upstream would become available if crossing was modified to allow for fish passage _____m

2c Approximate distance to the next potential obstruction to fish passage:

Upstream _____m **Is it Natural / Man-made?**

Downstream _____m **Is it Natural / Man-made?**

3. OWNERSHIP DETAILS

3a Ownership of this obstruction & land on which the structure lies *(circle)*:

Federal State Local Government Private Landholder

3b Owner of the next potential obstruction *(circle)*:

Upstream:	Federal	State	Local Government	Private Landholder
Downstream:	Federal	State	Local Government	Private Landholder

4. ENVIRONMENTAL CONSIDERATIONS

4a Threatened and protected aquatic species present *(circle)*:

Olive perchlet	Eastern freshwater cod	Purple spotted gudgeon	Oxleyan pygmy perch
Macquarie perch	Australian grayling	Black cod	Estuary cod

4b. Other key aquatic species present: _____

_____

Also attach predicted (or real) species list for the River or catchment from "Fishfiles" or "Freshwater Fish Database". Include recreational and commercial fish species and other key species such as platypus, turtles and waterbirds (if identified in the field).

4c. Environmental status: _____

Include terrestrial threatened species, critical habitat, conservation rating and protected area status (eg Marine Protected Areas, State Environment Planning & Policy reserves, National Parks) if known.

URBAN WATERWAYS FISH PASSAGE - FIELD ASSESSMENT FORM

ASSESSOR: _____DATE: _____ CROSSING ID: _____
STREAM CLASS: _____GPS or GRID ref: _____
PHOTO NUMBERS: _____

1. LOCATION INFORMATION

1a Surrounding Land Uses *(please circle)***:** Industrial / Urban / Park / Forested / Grazing / Cropping

Description of land use _____

1b Structure Accessibility (Easement / Public Road / Other_____)

2. STRUCTURE DETAILS

2a Structure Description _____

Culvert type	No. of cells	Size of cells	Width (bank to bank)	Width (up-down)	Height
_____	_____	_____	_____m	_____m	_____m

Construction material *(circle)*: Concrete / Timber / Steel / Rock / Gravel / Sand-Fines

2b If a Road – Is it Sealed? *(circle)*: Sealed Unsealed N/A **Is it in Use?** Yes / No

3. FISH BARRIER IMPACTS

3a Is there a fishway? Yes / No **Type:_____ Working?** Yes / No
3b Fish Passage: Does the site potentially or actually block fish passage? Yes / No

3c If yes, what type of blockage *(circle)*:
Drop (>10cm) Increased Velocity Minimal Flow Depth (< 200mm) GPT Lack of Light
Slope (>1:20) Increased Turbulence Debris (large woody / sediment / plant material / rubbish)

3d If yes, is it *(circle)*: a complete barrier / major obstacle / moderate obstacle / minor obstacle

3e Does water exist upstream of the site: Yes / No **If yes, is this due to the structure?** Yes / No
If yes, what is the **average length** of pool _____m and **depth** of the pool _____m

3f Is there flow over/through the site: Yes / No

3g If yes, what is the water flow like? *(circle)*
Vertical Fall (height____m) Steep Cascade High Velocity through Pipe Tidal Low flow
Gentle Incline Moderate Cascade Moderate Velocity through Pipe No flow (stable)
***Height** - measure from downstream water level to crest of structure – if no water downstream then measure from downstream substrate to crest*

3h If location of the next obstruction is not the one identified in the desktop study please record the new location (GPS or road name): Upstream: _____
Downstream: _____ **Ownership:** _____

4. HABITAT DETAILS

4a Is this the tidal limit? Yes / No Is it **upstream / downstream** from here?

4b Bank Height at crossing, measured from the base of channel to top of bank (maximum height of water before flooding occurs). If one bank is higher than the other, record the height of the lower bank. _____m

4c Channel Width at crossing, measured from mid bank to mid bank _____m

4d Habitat features: (substrate type: pools, riffles, gravel beds, boulders, macrophytes, snags, undercuts, riparian overhangs)
_____

4e Condition of aquatic habitat *(circle)*: excellent good fair poor very poor

5. COMMENTS (EXTRA SITE / STRUCTURE INFO)

_____
_____

6. RECOMMENDATIONS

_____
_____
_____

Appendix C – Fish Passage Barrier Prioritisation Scheme – Sydney Region

WATERWAY OBSTRUCTIONS PRIORITY RANKING SCHEME FOR THE SYDNEY METROPOLITAN CMA CROSSING ID:_____

CATCHMENT:_____ WATERWAY:_____ TOWN:_____ ASSESSOR:_____

A) STREAM HABITAT VALUE CRITERIA				
Primary aquatic habitat rating	**5**	**3**	**1**	**SCORE**
Habitat Class	1-2	3	4	
Stream Order	3-4	2	1	
Location in the system	Tidal/core habitat	Non-tidal/non-core habitat		
Threatened species	Known habitat	Within range (suitable habitat)	Within range (unlikely habitat)	
Secondary aquatic habitat rating	**3**	**2**	**1**	
Downstream obstructions	None	Few (1-3)	Many (3 or more)	
Distance to next barrier downstream	Greater than 1km	1km - 500m	Less than 500m	
Upstream habitat – stream length opened up	Abundant (>2km)	Moderate (500m - 2km)	Limited (<500m)	
Instream habitat condition	Excellent / Good	Fair	Poor	
Riparian condition	Excellent / Good	Fair	Poor	
Environmental Status	Protected Area (e.g. NP)	Suitable land-use	Other	
			SUBTOTAL	

B) STRUCTURE IMPACT CRITERIA					
Environmental effect rating		**3**	**2**	**1**	**SCORE**
Physical barrier	**Vertical drop/ step OR Slope**	> 300mm Steeper than 1:10	100 – 300mm 1:10 – 1:20	< 100mm 1:20 or less steep	
	Debris		Present	Absent	
Hydrological barrier	**Velocity**	High	Medium	Low	
	Flow depth	<100mm	100 – 200mm	>200mm	
	Drown – out rate	Rare (< once per year)	Occasional (2x - 6x / year)	Frequent (6x or more)	
Light penetration & substrate condition		High behavioural impact	Medium behavioural impact	Minor – no impact	
Water quality impacts and controls		Significant impacts/ not sealed – or no controls	Moderate impacts but managed – unsealed but with controls	Minimal impact/ adequate controls	
				SUBTOTAL	

C) MODIFICATION CRITERIA				
Structure use and remediation cost rating	**3**	**2**	**1**	**SCORE**
Structure use	Structure is no longer needed	Structure serves some purpose	Essential structure	
Ancillary uses	None known	Possible	Confirmed uses	
Remediation works required	No or minor structural changes / Maintenance / removal of debris	Moderate changes / retrofitting / removal (not replacement)	Complete replacement	
			SUBTOTAL	

ID'D BY (or report):_____ SECONDARY NAME (if any):_____ **TOTAL**

Appendix D – Priority List of Top 50 Fish Passage Barriers in Sydney

Site ID	Locale	Structure Type	Recommendation Summary	Ranking TOTAL*
SUT014	Audley Weir, Hacking River	Weir	FISHWAY	**60**
KUR006	Lane Cove Weir, Lane Cove R	Weir	INSTALL LOW FLOW SECTION TO FISHWAY & MONITOR	**56**
WOL006	McKell Avenue, Hacking River	Weir	REMOVAL / FISHWAY	**55**
CAM001	Ingelburn Weir, Georges River	Weir	PARTIAL / TOTAL REMOVAL	**54**
LIV001	Liverpool Weir, Georges River	Weir	CONTINUE MONITORING	**54**
SUT013	Pass of Sabugal, Woronora R	Causeway	REMOVE	**53**
BAN001	Morgans Ck, Henry Lawson Dve	Road Culvert	CENTRAL LIGHT HOLE	**52**
LIV005	Cabramatta Ck, Warwick Farm	Weir	REMOVE	**52**
WAR002	Manly Lagoon outlet, Manly	Other Culvert	OPEN CHANNEL	**52**
LIV023	Harris Ck, Holsworthy MR	Gabion Weir	REMOVE	**51**
BAN011	Unnamed Ck, Kelso Park	Floodgate	REMOVE	**50**
LIV024	Harris Ck, Holsworthy MR	Gabion Weir	REMOVE	**50**
WAR011	Middle Ck, Wakehurst Parkway	River Gauge	REMOVE	**50**
BAN006	Yeramba Lagoon, Picnic Point	Weir	FISHWAY / REMOVE	49
CAM002	Wedderburn Weir, Georges R	Weir	FISHWAY	49
LIV020	Williams Ck, Holsworthy MR	Gabion Weir	REMOVE	49
ROC020	Wolli Ck Weir, Wolli Creek	Weir	FISHWAY / REMOVE	49
WOL010	Otford, Hacking River	Road & Weir	REMOVE / CLEAR DEBRIS	49
SUT020	Lake Tallooma, Heathcote Ck	Weir	REMOVE?	49
WAR006	Curl Curl Lagoon, Greendale Ck	Rock Weir	IMPROVE FISHWAY, MONITOR	49
WLL005	'Mahrneyes Hole', Georges R	Weir	REMOVE	49
WOL001	Maddens Creek, Dharawal NR	Weir	REMOVE	49
PAR001	Charles St Weir, Parramatta R	Weir	FISHWAY	48
PAR003	Parramatta Kiosk, Parramatta R	Weir	FISHWAY	48
PAR004	Asylum Weir, Parramatta River	Weir	FISHWAY	48
SUT004	Oyster Gully Ck, Kareela	Road Culvert	LOWER INVERT	48
WOL012	Private Drive, Hacking River	Road & Weir	REPLACE WITH LARGE PIPES AT BASE (rather than remove)	48
LIV021	Williams Ck, Holsworthy MR	Gabion Weir	INSTALL FISHWAY	47
LIV022	Williams Ck, Holsworthy MR	Gabion Weir	REMOVE	47
PAR012	Toongabbie Ck, Old Toongabbie	Weir	REMOVE	47
WOL009	Otford Town Rd, Hacking River	Road Culvert	INSTALL LARGER CULVERTS	47
WLL001	Stokes Ck, Dharawal NR	River Gauge	REMOVE	47
WLL002	O'Hares Ck, Dharawal NR	River Gauge	REMOVE	47
BOT008	Mill Stream, Lachlan Swamps	Weir	FISHWAY	46
CAM004	Stokes Ck, Dharawal NR	River Gauge	REMOVE	46
CAM005	O'Hares Ck, Dharawal NR	River Gauge	REMOVE	46
CAM043	Myrtle Ck, Minto Heights	Ford	CREATE LOW FLOW PATH	46
LC002	Stringy Bark Creek, Lane Cove Nth	Weir	REMOVE	46
LIV003	Cabramatta Creek, Liverpool	Infrastructure / Weir	REMOVE	46
LIV004	Cabramatta Creek, Liverpool	Weir	REMOVE	46
PAR002	Marsden St Weir, Parramatta R	Weir	FISHWAY	46
PIT003	Mullet Ck, Warriewood Wetlands	Weir	NOTHING / REMOVE	46
WOL011	Otford, Hacking River	Road Culvert	REMOVE DEBRIS, INCREASE PIPE SIZE, LOWER SLOPE	46
WAR001	Brookvale Ck, North Manly	Road Culvert	NOTHING / LOWER INVERT	46
WAR007	Dee Why Lagoon	Weir	REMOVE	46
WOL002	Maddens Ck, Dharawal NR	Weir	REMOVE	46
KUR004	Little Blue Gum Ck, Fullers Bridge	Road Culvert	CLEAR CULVERT	45
PAR015	Toongabbie Ck, (Wentworthville	Weir	REMOVE	45
PAR020	Duck River, South Granville	Weir	REMOVE	45
SUT021	Coote Ck, Royal NP	Weir	REMOVE	45

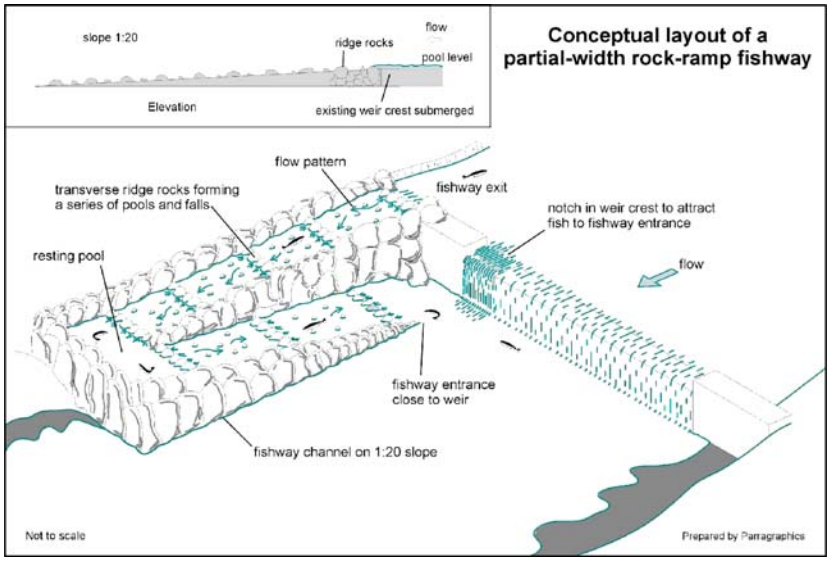
*Ranking score obtained from the total of the habitat criteria, structure impact criteria and modification criteria used in the assessment process (Appendix C).

Appendix E – Conceptual Diagrams of Fishways Employed in Australia

Rock ramp fishways

Rock ramp fishways were developed as a simple and relatively low-cost adjunct to more formally engineered fishway designs, particularly for overcoming low barriers and subsequently in association with stream erosion control works. This type of fishway is particularly valuable for providing fish passage at existing low weirs. They are generally built on slopes that attempt to match the surrounding geomorphic features within the waterway (although these are typically between 1:20 and 1:30 slope).

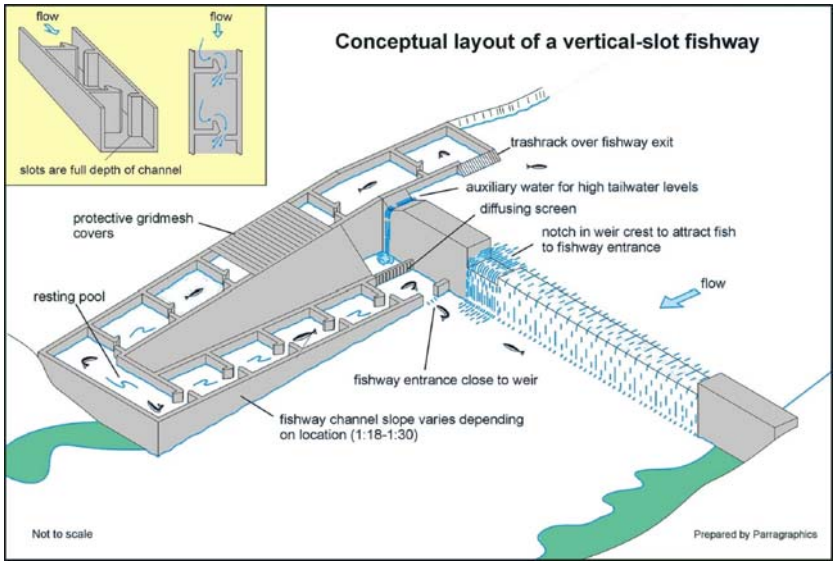
In this style of fishway, large rocks are placed to form a series of small pools and falls at about 2m intervals. Fish ascend the fishway by darting through sections of high water velocity occurring between large "tombstone" rocks, and resting in the pools created by the rock ridges, continuing through to the next section until they exit.



Vertical slot fishways

Vertical slot fishways comprise a more engineered and controlled version of a rock ramp fishway where resting pools are essentially concrete cells, with the entrance/exit to/from each of the pools being a vertical slot at either end. The maximum water velocity occurs as water falls through each slot, with the downstream pool acting to dissipate hydraulic energy as well as providing resting areas for ascending fish. The slope of the channel and the interval between slots controls the water velocity through each slot, thus the fishway can be designed to suit the swimming ability of particular ascending fish.

Vertical slot fishways have flexibility of operation over varying headwater and tailwater levels, as well as allowing fish to pass through the fishway at any depth. This type of fishway is more expensive than a rock ramp fishway, and requires larger volumes of water to operate.

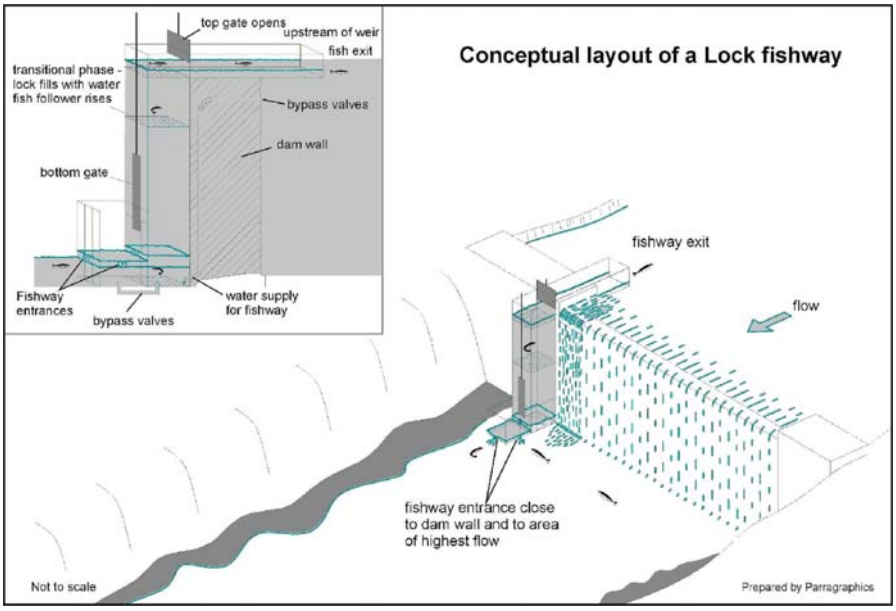


Appendix E – Conceptual Diagrams of Fishways Employed in Australia

Lock fishways

Lock fishways are employed on very large (high) structures where other fishway designs become too expensive to install. Lock fishways operate by attracting fish through an entrance similar to a rock ramp or vertical slot fishway, but instead of swimming up a channel, fish accumulate in a holding area at the base of the lock. This holding area is then sealed and slowly filled with water to reach a level equal to the water upstream of the barrier. Fish are then able to swim out of the lock at the upstream pool level.

The first lock fishway in New South Wales waters was on the Murray River at Yarrawonga Weir, and has been shown to be effective in transporting fish over the 12m high weir. The Deelder fish lock (or Deelder fishway) is a variation of the lock fishway for use on lower barriers. This type of fishway is proposed for the Marsden Street weir on the Parramatta River at Parramatta, and a functioning Deelder fishway is present on the Murrumbidgee River at Balranald in the state's west.



Reference:

Thorncraft, G. and Harris, J.H. (2000) *Fish passage and fishways in NSW: A Status Report.* Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000.

Appendix F – Map 1: Fish Passage Barriers in the Sydney Region – Remediation Site Assessments

INSERT SEPARATE A3 MAP PAGE:

- *Map 1 Sydney Metro CMA region FINAL 230305.pdf*

Appendix G – Maps 2 - 9: Fish Passage Barriers in Sydney's Subcatchments

INSERT SEPARATE A3 MAP PAGES:

- *Map 2 Northen Beaches region FINAL 230305.pdf"*
- *Map 3 Middle Harbour_Lane Cove subcatchments FINAL 230305.pdf*
- *Map 4 Parramatta River subcatchment 230305.pdf*
- *Map 5 Cooks_Nth Botany subcatchment 230305.pdf*
- *Map 6 Upper Georges River subcatchment 230305.pdf*
- *Map 7 Lower Georges River subcatchment 230305.pdf*
- *Map 8 Woronora River subcatchment 230305.pdf*
- *Map 9 Hacking River subcatchment 230305.pdf*


aquatic habitat rehabilitation
making more fish
...naturally