REDUCING THE IMPACT OF ROAD CROSSINGS ON AQUATIC HABITAT IN COASTAL WATERWAYS – HAWKESBURY-NEPEAN, NSW

REPORT TO THE NEW SOUTH WALES ENVIRONMENTAL TRUST

NSW DEPARTMENT OF
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Cover photo: Swallow Tail Pass Fire Trail causeway with excessive headloss over Tarlo River (Upper Hawkesbury-Nepean subregion, Wollondilly River catchment).

EXECUTIVE SUMMARY

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.

Waterway crossings can affect the health of aquatic habitat and fish populations in several ways. Structures such as causeways, pipes and culverts, can prevent fish passage by creating a physical blockage, a hydrological barrier, or by forming artificial conditions that act as behavioural barriers to fish. Road crossings have also been linked to increases in sediment and other inputs from adjacent floodplains and slopes. Furthermore, some structures can adversely affect fish by altering natural flow patterns, disrupting localised erosion and sedimentation processes, and affecting instream habitat condition.

Although current policy within NSW legislates the incorporation of fish passage into the design of all new instream structures, a legacy of poorly designed structures exists that detrimentally affects fish migration. As a result, the NSW Department of Primary Industries (NSW DPI) initiated a comprehensive investigation funded by the NSW Environmental Trust to specifically address the impact of road crossings upon fish passage and stream connectivity in coastal catchments. Detailed field assessments were conducted for over 6,800 waterway crossings in NSW coastal catchments, with over 1,400 identified barriers prioritised in terms of their impact on aquatic biodiversity, benefits should the structure be remediated, and the ease of structure remediation.

Fieldwork in the Hawkesbury-Nepean region included assessment of 480 waterway crossings, with some of the primary findings including:

- 99 crossings identified as obstructions to fish passage throughout the Hawkesbury-Nepean CMA region.
- 62 of these were recommended for remediation including:
    - 30 structures in the Upper Hawkesbury-Nepean subregion, and
    - 32 structures in the Lower Hawkesbury-Nepean subregion.
- The greatest number of obstructions to fish passage were identified within the Hawkesbury City (25 sites), City of Lithgow (14 sites), and Goulburn Mulwaree (13 sites) local government authorities.
- Causeway crossings were the most common type of fish passage obstruction in the region (59% of obstructions assessed).
- Pipe culvert crossings and box culvert crossings were also commonly found to prevent fish passage (18% and 10% respectively).
- Of the structures recommended for remediation, over half were causeways (69%), followed by pipe culverts (15%) and box culverts (11%).

A ranking scheme for waterway crossing sites was developed to determine priorities for action in relation to fish passage. Crossings were ranked ‘high’, ‘medium’ and ‘low’ priority, with 19 high priority structures identified – the majority of which (16 sites or 84%) were found within the lower subregion, with 83% of these (10 structures) being causeways.

The Hawkesbury City local government authority had the greatest number of high priority sites (9 sites), with all other local government areas possessing no greater than two sites. Baulkham Hills Shire, Penrith City, Upper Lachlan Shire (2 sites each), and Blacktown City, City of Lithgow, Singleton Shire, and Wollondilly Shire local government authority (1 site each) accounted for the remaining high priority structures.

Four structures were identified as being obsolete, one of which was a high priority causeway that has since been removed.

Three sites were identified as sediment input sites that did not act as fish passage obstructions. Several other sites were both sediment input sites and fish passage obstructions.

Recommendations for structure remediation included:

- Basic management/maintenance of sites (e.g. removal of sediment and debris blocking inlets);
- Modification of structures (e.g. retrofitting low-flow channels, installing fishways, sealing road approaches);
- Complete replacement of structures (e.g. causeways replaced with bridges or culverts); and
- Permanent removal of redundant (disused) structures.

The results of this investigation, including management recommendations are discussed herein.

ACKNOWLEDGEMENTS

This project was funded through the NSW Government's Environmental Trust Program and undertaken by the NSW Department of Primary Industries Fisheries (Conservation and Aquaculture).

The NSW DPI Fisheries (Conservation and Aquaculture) Aquatic Habitat Rehabilitation Program team managed the project including research, fieldwork and report preparation, with valuable assistance from regional NSW DPI Fisheries (Conservation and Aquaculture) Conservation staff. Personnel involved in data collection, data analysis and report writing were: Scott Nichols, Shaun Morris, Dr Matthew Gordos, Charlotte Grove, and Sarah McGirr. Maps were produced by Ben Maddox.

The Hawkesbury-Nepean Catchment Management Authority, State Forests (Department of Primary Industries), Department of Environment and Conservation, and local Councils provided extensive advice and assistance toward the project.

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TABLES

1. INTRODUCTION

The following document outlines results of a project entitled '*Reducing the impact of road crossings on environmental flows, water quality and fish passage in coastal NSW*'. The project was carried out by the NSW Department of Primary Industries Fisheries (Conservation and Aquaculture), and funded by the NSW Environmental Trust Program (Contract No. ET-H08030). This particular document is a report to the Hawkesbury-Nepean Catchment Management Authority (HNCMA), providing results of the study relevant to the Hawkesbury-Nepean region. Results for the Northern Rivers, Hunter/Central Rivers, Sydney Metropolitan, and Southern Rivers CMA regions are available in separate reports.

1.1 Project aims and objectives

This project was developed to identify and prioritise waterway crossings for remediation action in all coastal-draining catchments of NSW. This document outlines the findings of the study relevant to the HNCMA region.

The primary objectives and outcomes of the project were to:

- Identify and assess the impacts of road crossings on aquatic habitat within the HNCMA;
- Complete a field inventory of road crossing obstructions and identify other environmental impacts on aquatic habitat associated with road crossings;
- Develop an aquatic habitat management database and establish environmental auditing protocols for assessing road crossings;
- Demonstrate options for remediation and improved management of road crossings;
- Encourage remediation of priority sites with structure owners, and promote "fish-friendly" principles for application in future instream works;
- Establishment of remediation demonstration sites at two key road crossing sites within the HNCMA region; and
- Increase awareness of the importance of fish passage and aquatic habitat management for road management authorities and the broader community.

1.2 Study area

This report outlines the project results for the HNCMA region. The region includes all coastal (eastern) draining waterways that extend from the headwaters of the Macdonald River above Putty in the north down to Lake George in the south.

For reporting purposes two geographic zones within the region have been identified to highlight catchment and sub-catchment issues and priorities. These zones are:

1) Upper Hawkesbury-Nepean subregion; and
2) Lower Hawkesbury-Nepean subregion.

The geographical setting of each zone and the aquatic habitat issues related to these areas are outlined in Section 2.4. Management outcomes and recommendations from this study will be presented on a CMA, subregion, and LGA basis.

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 NSW DPI Fisheries research in the Murray-Darling basin has indicated that a much higher percentage of native fish undertake some form of migration than previously thought (Baumgartner, *in prep.*). In the coastal catchments of NSW, it is likely that this trend will be continued as our knowledge of coastal fish biology and behaviour develops through ongoing research and monitoring.

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.

For fish that have large-scale migrations in their life cycles, particularly anadromous and catadromous species, preventing fish passage can cause local extinctions above barriers and reduce population numbers downstream (Thorncraft and Harris, 2000).

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 Waterway crossings as barriers 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. Barrier types can include dams, weirs, levees, stream gauging stations, waterway crossings, erosion-control structures and floodgates.

This report specifically focuses on waterway crossings. 'Waterway crossing' is a collective term for bridges, roads, causeways, culverts and other similar structures that can cause both direct and indirect impacts on fish and aquatic habitats (refer Photos 1-8). During their construction, habitat can be physically damaged by the removal of riparian and in-stream vegetation and disturbance to the bed and bank of the waterway which can increase sedimentation. An indirect impact of waterway crossings includes the localised extinction of a species from a waterway as populations become isolated, recruitment limited, and the ability of a species to survive reduced.

[1] See Section 7 for References

The extent to which waterway crossings impact on the movement of fish in rivers can depend on a) the design of the road crossing structure; b) the nature of flow, debris and sediment movement in the waterway; and c) the swimming capabilities of resident fish.

In general, ***bridges*** and ***arch structures*** have the least impact on fish passage as they normally involve limited disturbance to the stream flow (Fairfull and Witheridge, 2003), thus allowing fish to pass underneath the structure over a wide range of hydrological conditions. Bridges that are built too low however, or structures with piers and footings that constrict the channel, can affect aquatic habitat and flow conditions underneath the structure.

Culverts are waterway crossings with ***pipes*** or ***box-shaped*** cells designed to convey flow underneath the roadway. Significant modification to the channel bed and changes to flow conditions are often associated with culvert installation. Increased flow velocity and turbulence and reduced flow depth may prevent fish from swimming through the structure. Warren and Pardew (1998) found that fish movement was inversely related to flow velocity at crossings and that culvert crossings exhibited the highest velocities of crossing types assessed. Some culverts may also have a step at the downstream end of the structure that creates a *waterfall effect* preventing fish from moving upstream at low flows. This waterfall effect may be a result of poor installation (the pipe being set higher than the stream bed level), or through the erosion of the stream bed on the downstream side, and the formation of a scour pool directly adjacent the culvert. Culverts can also hinder fish movement through lack of lighting and debris build up across the opening (caused by sediment or organic debris).

Causeways are a type of low-level crossing generally constructed at or near bed-level and are designed to convey water across the road surface as sheet flow. Some causeways however are raised well above bed-level and essentially act as a weir, preventing fish movement upstream. Causeways with low-flow pipes may also prevent fish passage due to high flow velocity, lack of lighting and blocking of the pipe opening.

Fords are a type of waterway crossing that directly incorporates the channel bed (termed “wet crossings”). Some fords are formed naturally at shallow points along a river, whilst others may be constructed with concrete or gravel. Such crossings generally pass fish when the river is flowing, however at very low flows fish passage may be hindered due to inadequate flow depth over the channel/road surface.

In tidal reaches, waterway crossings (especially those over drains) commonly incorporate **floodgates** that restrict fish passage between flood events. Floodgates include hinge-flap, winch, sluice, and auto-tidal designs. Between flood events, floodgates are generally maintained in the closed position thus ensuring a complete blockage to fish migration between estuaries and tidal tributaries. Although recorded during the investigation, floodgates have been treated as a separate management issue and were therefore not included in the road crossing audit or prioritisation.

Photo 1. Causeway with high invert (headloss) and shallow water depth
(Wheeny Ck, Lower Hawkesbury-Nepean subregion)

Photo 2. Pipe culvert with high invert (headloss)
(Fitzgeralds Ck, Lower Hawkesbury-Nepean subregion)

Photo 3. Box culvert on unsealed road producing sediment inputs
(Cullenbong Ck, Upper Hawkesbury-Nepean subregion)

Photo 4. Box culvert with high invert (headloss), and low flow depth
(Megalong Ck, Upper Hawkesbury-Nepean subregion)

Photo 5. Ford with high invert (headloss)
(Webbs Ck, Lower Hawkesbury-Nepean subregion)

Photo 6. Pipe culvert with high invert (headloss) and increased water velocities
(Cattai Ck, Lower Hawkesbury-Nepean subregion)

Photo 7. Redundant causeway with inadequate pipes adjacent working bridge
(Mulwaree R, Upper Hawkesbury-Nepean subregion)

Photo 8. Pipe culvert with excessive debris
(Kemps Ck, Lower Hawkesbury-Nepean subregion)

2.3 Other impacts of waterway crossings

In addition to preventing fish passage, road crossings can impact on aquatic habitat by affecting water quality; disrupting natural flows and channel processes; as well as impacting on terrestrial species.

Road networks within forested areas, in particular unsealed roads and tracks, have been identified as significant sources of runoff and sedimentation. The extent to which water quality is affected is a function of the degree of hydrologic connectivity between sediment sources and the stream network (Farabi *et al*., 2004; Takken *et al*., 2004). Waterway crossings are an important part of sediment delivery pathways and, in the absence of adequate erosion and sedimentation controls (e.g. diversion drainage, vegetated swales or sediment basins), runoff generated from road surfaces may be carried directly to streams at these points. Similarly, road maintenance procedures can affect the rate at which sediment is delivered to streams (e.g. sediment spoil from the grading of unsealed roads left by the side of the road in direct proximity to waterways). In the case of low-level crossings such as fords, sediments can be directly disturbed by vehicles within the stream channel itself.

Road crossings can also impact on waterways by altering natural flow patterns, disrupting localised erosion and sedimentation processes, and affecting instream habitat condition. These impacts are most evident with structures resembling weirs and dams (e.g. large raised causeways). Such crossings can produce a *weir-pool effect* upstream of the structure, thereby creating a lentic (still) stream environment which can impede larval drift. The prevalence of these structures has reduced the capacity of eggs and larvae to reach preferred nursery habitat. Still-water environments can in turn, promote sediment accumulation and increase the potential for algal blooms. Alien species such as carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*), have generalist habitat requirements and thrive in these disturbed habitats. In contrast, many native fish species have specialist flow requirements. As a consequence, in flow-modified waterways native fish fauna diversity, abundance, breeding success and ratio to introduced species is lower than less flow-modified streams (Gherke and Harris, 2001).

Even very localised changes to channel flow conditions caused by road crossings can impact on instream habitat condition. For instance, increased flow velocities through culverts and piped crossings can lead to erosion downstream. Such changes can destroy instream habitat features through the infilling of pools, scouring of riffles, and undermining and removal of instream vegetation.

Impacts on riparian vegetation are also evident where waterway crossings create stable upstream weir pools. The lack of variation in water level can reduce the diversity of riparian vegetation and disrupt wetting and drying patterns crucial to the life history of many riparian species. Stable pools (such as those resulting from road crossings and weirs) tend to favour exotic plant species such as willows, resulting in reduced bank stability, increased erosion and channel widening.

Road crossings can also adversely affect terrestrial species. As with fish, land-based animals need to move between habitats to feed, breed, and to avoid predation and competition. Riverine corridors are used as natural byways for the movement of many land-based animals. Road crossings that are designed without terrestrial passage components may effectively isolate upstream and downstream riparian habitats. Crossings with raised and barricaded approaches prevent terrestrial species from following streams *over* the road surface. Low bridges and culverts without accessible vegetated banks or *dry cells* prevent land-based animals from moving *under* road crossings. Lack of riparian connectivity, including cleared easements adjacent to roadways at road crossings, can also deter animals from venturing across roads to follow waterways.

The following study primarily focuses on the impacts of road crossings on stream connectivity in the Hawkesbury-Nepean region (see Sections 3 and 4). Other impacts (as listed above) were considered as part of the assessment process.

2.4 Waterways of the Hawkesbury-Nepean region

The HNCMA region covers an area of approximately 22,000sqkm. It extends beyond Lithgow in the west, bounded by the Great Dividing Range and drains into Broken Bay in the east, stretching seaward to three nautical miles. The area supports a population of over 800,000 people, with a number of large urban centres and agricultural regions causing significant pressure on natural resources through direct use and modification (HNCMA, 2005).

The Hawkesbury-Nepean region extends from the headwaters of the Macdonald River above Putty in the north down to Lake George in the south. For reporting purposes this large area has been divided into two geographic zones (or subregions), highlighting catchment and sub-catchment issues and priorities. These two subregions are the:

- Upper Hawkesbury-Nepean subregion; and
- Lower Hawkesbury-Nepean subregion.

Map 1 displays the boundaries of these two subregions.

Upper Hawkesbury-Nepean subregion

The Upper Hawkesbury-Nepean subregion extends from the town of Wallerawang in the upper Coxs River catchment in the north, to Lake George and the Mulwaree River catchment in the south and covers an area of approximately 10,030sqkm. This subregion is split between the Sydney Basin, and the South Eastern Highlands Bioregions: the Sydney Basin Bioregion encompasses the eastern portion of the subregion, including Lake Burragorang, and all water storages of the upper Nepean and their respective tributaries; the South Eastern Highlands Bioregion encompassing the upper reaches of waterways in this subregion including Mulwaree River, Wollondilly River, and Coxs River (DEC, 2004).

The Upper Hawkesbury-Nepean subregion contains storages that significantly contribute to the water supply of the Sydney metropolitan area and its surrounds. Lake Burragorang (located at the border of the Upper and Lower Hawkesbury-Nepean subregions), and the Nepean, Avon, Cordeaux, and Cataract Dams in the east supply approximately 97% of Sydney's drinking water (CRCMC and WCMC, 2003). To ensure the high quality of water being supplied, the catchments for these storages have been designated Water Supply Special Areas, conserving the condition of the aquatic environment (refer Map 1). This has led to minimal impacts on waterways of these catchments, although (due to their size) the infrastructure associated with these storages have the potential to significantly impact the movement of fish past the dam walls.

This Upper Hawkesbury-Nepean subregion accommodates approximately 90,000 residents, who utilise the region for urban and agricultural activities, including tourism, residential development, grazing, and horticulture (CRCMC and WCMC, 2003). The major regional centres located within the upper subregion include Goulburn in the south, Bowral in the east and Lithgow in the north. The Goulburn and Bowral areas accommodate approximately 22,000 and 14,000 people respectively, with landuse in these areas dominated by agriculture, especially wool production and grazing (Goulburn Mulwaree Council, 2006; Highlands NSW, 2006). Lithgow has a similar population to that of Goulburn (21,000 people), with grazing, mining and electricity production dominating landuse, particularly in the Wallerawang and Lower Portland areas, which supply 23% of the state's power (CRCMC and WCMC, 2003). The Lithgow area also supports a thriving tourism industry, predominantly due to the surrounding Greater Blue Mountains World Heritage Area, which extends south into the subregion and attracts millions of visitors each year. The world heritage area totals over one million hectares and plays a significant role in conserving the natural heritage and cultural values of the region (Blue Mountains City Council, 2004).

The Upper Hawkesbury-Nepean subregion can be divided into eight local government authorities (LGAs), including significant proportions of the Wollondilly Shire, Wingecarribee Shire, Goulburn Mulwaree, and Upper Lachlan Shire LGAs, as well as parts of the City of Lithgow, Blue Mountains City, Oberon, and Wollongong City LGAs. The Upper Hawkesbury-Nepean subregion also encompasses thirteen subcatchments, including major areas of the Wollondilly River, Coxs River, upper Nepean River, and Mulwaree River.

The Wollondilly River catchment is the largest catchment area in this subregion, encompassing an area of 2,701sqkm that covers the majority of the central region in the upper Hawkesbury-Nepean.

The area includes the tributaries of Sooley Creek in the upper section, Guineacor Creek in the middle section, with the Tarloo and Jooriland Rivers in the middle and lower areas, respectively. These systems drain directly into the Wollondilly River, which feeds into Lake Burragorang and supplies the majority of Sydney's water. The waterways meander through State Forests and National Parks, including the Tarlo River and Blue Mountains National Parks, which, along with the declaration of Water Supply Special Areas in the lower end of the catchment minimises human impact on the aquatic environment (refer Map 1).

The Coxs River catchment covers a combined area of 1,700sqkm in the northwest section of the upper subregion. The major tributaries of the catchment include Marrangaroo Creek in the upper section, the Jenolan River in the middle, and Cedar Creek in the lower part of the catchment. These systems and associated smaller waterways drain directly into Coxs River, which then also run into Lake Burragorang. The headwaters of the Coxs River are protected from urban and rural development by the presence of State Forest areas, whilst waterways of the lower catchment are protected by the Kanangra-Boyd and Blue Mountains National Parks.

The upper Nepean River catchment covers an area of approximately 983sqkm and represents the most eastern catchment of the Upper Hawkesbury-Nepean subregion. The area is dominated by the Nepean River, which is serviced by the three major tributaries of Cataract, Cordeaux, and Avon Rivers. These systems drain into their respective water storages, with the four dams in this catchment also contributing to Sydney's water supply. This has resulted in the majority of the catchment and its waterways gazetted as Water Supply Special Areas, thereby protecting the condition of these systems, and minimising human impacts on these waterways.

Mulwaree River catchment represents the southern-most area of the Upper Hawkesbury-Nepean subregion, covering an area of approximately 791sqkm. The area encompasses the major waterway of Mulwaree River, which drains into the Wollondilly River, and is serviced by the major tributaries of Crisps Creek in its upper section, Covan Creek in its middle area, and Gundry Creek in its lower section. The upper section of the catchment also contains Lake Bathurst, which acts as an important waterbird habitat during wet periods. No protected areas are located in this catchment, with the surrounding grazing land offering the waterways of the Mulwaree River catchment minimal protection from potential human impacts.

Lower Hawkesbury-Nepean subregion

The Lower Hawkesbury-Nepean subregion extends from the Macdonald River catchment and outskirts of Gosford in the north, to Camden and Picton in the south, and covers an area of approximately 12,000sqkm. This subregion falls wholly within the Sydney Basin Bioregion and encompasses seventeen subcatchments, including the major areas of the Macdonald River, Colo River, lower Nepean River and Hawkesbury River (DEC, 2004).

This subregion supports approximately 700,000 residents, in addition to over three million visitors each year predominantly due to the surrounding Greater Blue Mountains World Heritage Area, which covers the centre of the subregion. The remainder of the subregion is dominated by urban development, as well as significant agricultural and extractive industries (HNLGAG, 2003).

The subregion contains major urban centres that are associated with residential development in western Sydney, including Penrith (177,554 people), Camden (50,000 people) and Richmond (17,000 people). These centres support a range of landuses dominated by residential and industrial development, as well as agricultural and extractive practices. Intensive agricultural activities such as dairy, poultry, flower and market gardens, extensive grazing, and fruit operations that occur in the subregion, are estimated to be worth approximately one billion dollars and supply the majority of Sydney's fresh produce (HNLGAG, 2003). The major waterway of the subregion, the Hawkesbury River, has historically played a significant role in supplying aggregate for Sydney's construction industry, including soil, sand, gravel, clay and shale (HNLGAG, 2003). These extraction activities in areas such as Penrith and Camden have impacted significantly on the condition of aquatic habitat in the area.

In addition to the aggregate extraction industries, the Hawkesbury River (which is the state's largest estuary, spanning a distance of 145km), also supports major commercial and recreational fishing industries. The Hawkesbury River also has an 'estuary general fishery', which allows a diverse range of aquatic species to be taken including school prawns, eastern king prawns and squid species (NSW Fisheries, 2003a). The area also plays an important role in oyster production, being the third largest district in the state, with an annual value of approximately four million dollars (NSW DNR, 2004). Recently, in 2004, an outbreak of QX disease (caused by *Marteilia sydneyii*) amongst oyster leases in the Hawkesbury estuary severely impacted oyster production in this area, and continues to have implications for both production and movement of shellfish between some NSW estuary leases (NSW DPI, 2006).

Recreational fishing is also a major industry that impacts on the aquatic biota of the subregion, with an estimated 43,000 anglers fishing in the estuary annually targeting popular estuarine species such as bream and mullet (NSW DPI, 2005).

The Lower Hawkesbury-Nepean subregion takes in 19 local government authorities, some of which are shared with the Upper Hawkesbury-Nepean. LGAs covering the majority of the area of the subregion include Hawkesbury City, Singleton Shire, City of Lithgow, Blue Mountains City, Wollondilly Shire, Penrith City, Council of the Shire of Hornsby, and Gosford City. The remainder of the subregion includes parts of Cessnock City, and Wingecarribee Shire Councils, and those Councils on the outskirts of Sydney such as Camden, Campbelltown City, Liverpool City, Fairfield City, Blacktown City, Council of the Shire of Baulkham Hills, Ku-ring-gai, Warringah, and Pittwater.

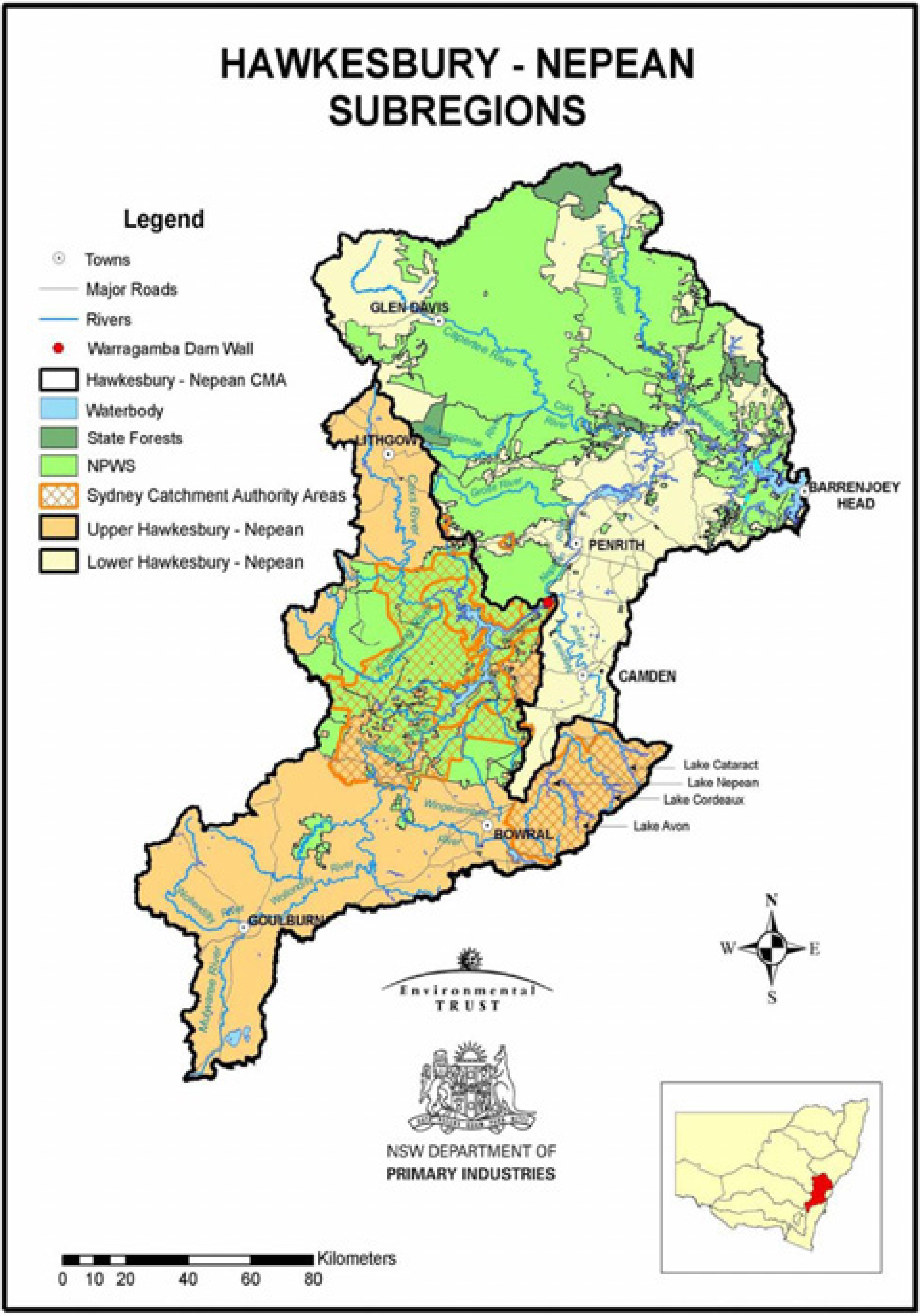
The Macdonald River catchment is the largest in the Lower Hawkesbury-Nepean subregion, covering an area of 1,909sqkm. Macdonald River drains directly into the Hawkesbury River and is serviced by Boggy Swamp Creek in the upper reaches, Melon Creek in the mid catchment, and Mogo Creek nearer its confluence with the Hawkesbury. The headwaters of the Macdonald River and its upper tributaries are partly protected by the presence of State Forests, while the middle and lower waterways of the catchment run through Yengo National Park, which dominates this part of the Macdonald River catchment (refer Map 1).

The second largest catchment – that of the Colo River - covers most of the central region in the lower Hawkesbury-Nepean, over an area of 1,460sqkm. The tributaries of Colo River include Wollangambe River and Bungleboori Creek in its upper reaches, and Tootie Creek in the lower section. These waterways run through reasonably protected areas dominated by the presence of State Forests and National Parks, including the Blue Mountains National Park in the upper part of the catchment and the Wollemi National Park in the lower reaches.

The lower Nepean River catchment covers an area of approximately 778sqkm and represents the most southern section of the Lower Hawkesbury-Nepean subregion. The Nepean River, which drains into the Hawkesbury River and is serviced by the major tributaries of Stonequarry Creek in its upper reaches, Wattle Creek in the mid reaches, and Mulgoa Creek in the lower part of the catchment. The catchment has no areas classified as State Forest, and only minimal areas protected by National Parks, including the small areas of Bents Basin State Conservation Area, and Gulguer National Park in the mid section. This offers the waterways of the catchment minimal protection from potential urban and agricultural impacts.

Despite being afforded minimal protection in the mid-lower reaches of the Nepean River, the upper reaches of this catchment (including its tributaries) are located in the Upper Hawkesbury-Nepean subregion where they generally protected. In this area these waterways are dammed to supply Sydney's water requirements, and are protected as Water Supply Special Areas, thereby minimising human impacts on this part of the catchment. The same is also true for the Warragamba River, which is also dammed in the Upper Hawkesbury-Nepean subregion (Lake Burragorang), and is protected within a Water Supply Special Area (refer Map 1).

The Hawkesbury River catchment represents the most eastern area of the Lower Hawkesbury-Nepean subregion, covering an area of approximately 731sqkm. The upper section of this catchment includes the major tributary of Howes Creek, whilst the middle section contains the junctions of the Colo and Macdonald Rivers. These systems drain directly into the Hawkesbury River, which enters Broken Bay along with Mooney Mooney and Mangrove Creek systems. Waterways found in the upper reaches of the Hawkesbury River catchment are relatively unprotected, with no National Parks or State Forest Reserves present. The lower and mid sections of the Hawkesbury River and its tributaries however are afforded some protection predominantly through the presence of the Marramarra National Park, and small sections of the Brisbane Water and Ku-ring-gai Chase National Parks (refer Map 1). At the junction of the Hawkesbury River and the ocean, the Barrenjoey Head Aquatic Reserve protects the estuarine and coastal waters of the catchment.



Map 1. Hawkesbury-Nepean CMA subregions.

2.5 Aquatic biodiversity in the Hawkesbury-Nepean region

The Hawkesbury-Nepean region comprises freshwater, estuarine and marine environments that contain an extensive range of aquatic habitats including montane streams, lowland floodplain wetlands and coastal lagoons. Within these broad habitat types, niche habitats such as pools and riffles, gravel beds, snags, aquatic vegetation and riparian vegetation are present, diversifying the habitat available to aquatic species in the Hawkesbury-Nepean catchment.

There is a variety of aquatic and riparian vegetation that is present within the majority of the Hawkesbury-Nepean catchment. Estuaries within the region are characterized by the presence of mangrove and saltmarsh communities, with swamp oak (*Casuarina glauca*), common reed (*Phragmites australis*) and paperbark (*Melaleuca quinquenervia*) also found along freshwater margins (DEC, 2004). Riparian vegetation in the catchment is dominated by stands of river oak (*Casuarina cunninghamiana*), with water gum (*Tristania laurina*) also present along the river and creek banks of the wetter and more protected areas (DEC, 2004).

This extensive range of aquatic and riparian habitat supports a diverse assemblage of species, including over 50 species of finfish (see Appendix A). Nine of these species are introduced, competing with the native fish species found within the catchment. The pressures from introduced species, as well as other factors such as reduced water quality, increased fishing pressure, and habitat degradation, have resulted in a decline in the population densities of native fish both within the Hawkesbury-Nepean, and elsewhere. The native fish populations in the Hawkesbury-Nepean catchment consist of potamodromous species that undertake migration wholly within freshwater systems, catadromous species who migrate between freshwater and sea, and amphidromous species, that complete non-breeding migrations between freshwater and sea (Harris *et al.*, 1994). This has resulted in the potential widespread distribution of native fish throughout the entire catchment.

Of these native species, seven are listed as threatened in NSW waters. Important indigenous freshwater species including Macquarie perch[2] (*Macquaria australasica*), and the Australian grayling[2] (*Prototroctes maraena*) have been recorded in the Hawkesbury-Nepean catchment, with pressures such as habitat degradation, competition, and predation from introduced fish species affecting their populations. Three threatened species also recorded from the catchment: Silver perch[3] (*Bidyanus bidyanus*), Murray cod[3] (*Maccullochella peelii peelii*), and Trout cod[4] (*Maccullochella macquariensis*) are found in the Hawkesbury-Nepean catchment as a result of stocking. Key threatened estuarine species, including the Black Cod[2] (*Epinephelus daemelii*) and the Green sawfish[5] (*Pristis zijsron*), are also likely to occur in the Hawkesbury estuary - both of these species have been affected by commercial and recreational fishing impacts, and the degradation of critical estuarine habitats.

The region also supports an array of aquatic macroinvertebrates including insects, prawns, crayfish and freshwater mussels. The macroinvertebrate communities of the Hawkesbury-Nepean catchment are moderately to significantly impaired, predominantly due to the pressures associated with river regulation, water extraction and agricultural landuse issues (Bishop *et al.*, 2002). Both the threatened Adams emerald dragonfly[2] (*Archaeophya adamsi*) and Sydney Hawk dragonfly[3] (*Austrocordulia leonardi*) have an expected distribution within the Hawkesbury-Nepean catchment, with records indicating their presence in the lower subregion of the catchment. These rare dragonflies have only been recorded on limited occasions, with activities such as habitat degradation and water pollution significantly affecting their populations. Over 60 species of frogs are also found in the region including several threatened species such as the Giant burrowing frog, the Green and golden bell frog, the Giant barred frog, the Red-crowned toadlet, the Stuttering frog, Littlejohn's tree frog and the Booroolong frog.

All these species are dependent on healthy waterways and access to a range of diverse aquatic habitats for their survival. In recognition of this, numerous river and floodplain communities of the Hawkesbury-Nepean catchment have been listed as an Endangered Ecological Community[5] (EEC), including freshwater wetlands in the Sydney Basin, montane peatlands and swamps, Swamp oak floodplain forest, Swamp Sclerophyll forest on coastal floodplains, River flat Eucalypt

[2] Listed as 'Vulnerable' under the *EPBC Act* and protected under the FM Act.
[3] Listed as 'Vulnerable' under the NSW *Fisheries Management Act*, 1994 (FM Act).
[4] Listed as 'Endangered' under the *EPBC Act* and protected under the FM Act.
[5] Listed as 'Endangered' under the NSW *Threatened Species Conservation Act* 1995.

forest on coastal floodplains, and coastal saltmarsh in the Sydney Basin. This listing includes all native fish and aquatic invertebrates, as well as other aquatic and terrestrial biota that are associated with these communities - recognising the rarity, vulnerability, and ecological importance in the region (DEC, 2006).

As with rivers and lakes, these wetland, saltmarsh, and swamp communities are subject to pressures such as fragmentation, flood mitigation, draining and infilling, and modification of freshwater and tidal flows due to installation of artificial structures (e.g. weirs, dams). Therefore, aquatic habitat rehabilitation, in particular reinstating stream connectivity, is essential for maintaining aquatic biodiversity and protecting the integrity of these habitats in the Hawkesbury-Nepean catchment. This particular project was designed to identify locations where the greatest environmental gains could be made when undertaking such remediation works.

3. PROJECT METHODS

3.1 Previous investigations

The initial phase of the project involved the collection of data for inclusion in the *NSW Coastal Road Crossings Inventory* - a database of waterway crossing sites that have been identified as requiring remediation (from a fish passage and/or aquatic habitat perspective).

Fish passage and instream structure reviews have previously been undertaken in coastal NSW by Williams and Watford (1996), Pethebridge *et al.* (1998), Thorncraft and Harris (2000) and NSW Fisheries (2002). These projects predominantly investigated the presence and impact of larger instream structures such as weirs, with over 100 weir and dam structures identified in the Hawkesbury-Nepean CMA region (Thorncraft and Harris, 2000; NSW Fisheries, 2002). The Initial Weir Review conducted by NSW Fisheries assessed 116 weir structures, recommending that 41 of them undergo further detailed review to investigate possible remediation actions (NSW Fisheries, 2002). The current project used the previous studies as baseline data and updated their findings within a road crossing perspective.

3.2 Desktop and field assessment

Fieldwork in this study included on-ground assessment of road crossing sites identified through the following desktop assessments:

a) Assessment of 1:25,000 topographic maps for the Hawkesbury-Nepean region. Sites where roads traversed waterways of Stream Order 4 or greater were flagged for assessment;

b) LGA data provided additional sites for review. Councils were asked to provide information on known road crossing barriers and potential obstructions across the region, particularly sites identified for future maintenance/ remediation works; and

c) Road crossing obstructions and barriers identified in previous studies, including Williams *et al.* (1996) and Pethebridge *et al.* (1998) reports.

Approximately 480 sites were initially identified for assessment in the Hawkesbury-Nepean region, although sites within marginal habitat (ephemeral streams, headwaters or upland swamps) were removed from this initial list.

Fieldwork in the Hawkesbury-Nepean region was conducted from January to September 2005. An assessment sheet was developed prior to fieldwork commencing, ensuring consistency in data collection (Appendix B). This assessment sheet was converted into a digital format, allowing data to be collected and stored on a handheld PDA (“Personal Digital Assistant”) device in the field. In the field road crossings were identified and mapped as data layers using GPS software. Information collected for each site was linked to the mapped point and stored in an underlying database. All information collected could then be retrieved or updated at a later date (in the field or office) by clicking on the mapped point, and accessing the underlying database. Locating sites was facilitated through the use of data layers indicating waterways, roads, and towns.

Data collected for each structure included: structure type and description; ancillary uses of the crossing (e.g. bed control); road type (sealed vs. unsealed); whether the structure was a barrier to fish passage, and if so what type; aquatic and riparian habitat condition; channel morphology (e.g.

width and depth); and surrounding land use. Location information (e.g. section of the catchment), structural details (e.g. ownership, number of barriers downstream, available upstream habitat), and further environmental considerations (ranges of threatened and protected species and wildlife reserves – Marine Parks, SEPP wetlands, aquatic reserves) were also determined.

Location details (GPS readings or map grid references) were recorded and digital photographs taken for each site. All data recorded in the road crossing audit was downloaded into the NSW Department of Primary Industries Fisheries (Conservation and Aquaculture) Fish Habitat Database prior to comparative analysis to determine regional remediation priorities.

3.3 Prioritising fish passage obstructions

A prioritisation scheme was developed to assist in ranking road crossing structures requiring remediation (Appendix C). The scheme was developed to determine regional priorities based on the following categories: a) habitat value, b) structure impact, c) environmental value, and d) modification criteria.

All data within the four criteria listed above (data listed in Appendix C) were weighted according to their relative value (e.g. sites with a Habitat Class 1 received a greater weighting than other sites where the Habitat Class was less; sites within protected areas such as Water Reserves or National Parks and State Forests, were seen to have a greater value than other land uses such as local reserves or farm land; and sites where the structure was obsolete received a greater weighting than sites where the structure was still in use).

Data within the Habitat Value Criteria and Structure Impact Criteria determined the quality and amount of habitat available to fish, how impacted the catchment was as a result of man made structures, and the actual impact the structure was having on fish movement. These criteria therefore, directly indicate the effect the structure has on fish movement and the likelihood of the structure being a site where fish passage is required. Environmental Value Criteria and Modification Criteria described the local environment surrounding the structure.

The overall prioritisation process therefore placed a greater emphasis on data within the Habitat Value and Structure Impact Criteria, with all data from these two criteria being weighted more than those from the Environmental Value and Modification criteria.

Final scores for each site were determined by calculating the sum of all four criteria. The prioritisation process was applied to all road crossings within the Hawkesbury-Nepean CMA region that were identified as fish passage obstructions and possessed a recommended remedial action.

Results are presented in Section 4 illustrating overall CMA results, LGA trends, and subregion priorities.

Recommendations were made on how the structures could be modified to allow for effective fish passage, and are discussed in Sections 4.5 - 4.7. It is expected that data collected from this project, and the recommendations made within it, will guide local and state government agency expenditure and allow remediation works to be incorporated into future work programs.

LIMITATIONS TO RAPID ASSESSMENT TECHNIQUES

In this study, rapid assessment of road crossings provides a ‘snap shot’ view of environmental conditions at a site. Due to the large number of road crossings in the Hawkesbury-Nepean region, detailed assessments of each structure could not feasibly be conducted.

For the purposes of informing future planning, the application of a rapid assessment technique (the fieldwork methodology and desktop prioritisation outlined above) was a simple and effective way of highlighting the extent of the problem and determining broad regional priorities.

It is understood however, that many environmental, social, cultural and economic considerations would need to be reviewed before undertaking any on-ground works recommended within this report. In particular, detailed environmental assessments and cost-benefit analyses would need to be conducted before on-ground works were pursued.

4. ASSESSMENT RESULTS

4.1 Overall project assessment results

Statewide, over 6,800 structures were visited in coastal draining waterways of NSW, with over 1,400 structures identified as barriers to fish passage. The most common type of road crossing barriers that were identified during this study along the coastal draining waterways of NSW were causeways and pipe culverts, with box culverts and fords also acting as barriers to fish passage.

4.2 Types of road crossing obstructions in the Hawkesbury-Nepean region

A complete data set from this study is available in the accompanying CD (*Road Crossings Inventory Hawkesbury-Nepean CMA 2006*) and includes data on road crossing location information, environmental data and recommended remediation action. The discussion below focuses on trends within the data and the top priority sites for remediation.

Approximately 480 sites were visited in the Hawkesbury-Nepean region. Of these, a total of 99 road crossings were identified as obstructions to fish passage, with 62 structures recommended for remediation (refer Appendix G – Map 2).

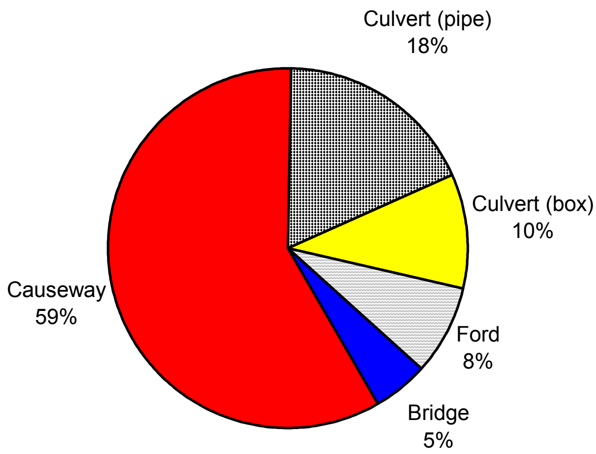


Figure 1. Structure types identified as fish passage barriers in the Hawkesbury-Nepean region.

Several types of road crossings were assessed in the study including causeways, pipe culverts, box culverts, fords and bridges. Several sites identified had combination designs – for example, box culverts placed on top of causeways. Within the Hawkesbury-Nepean region, the most common road crossing barriers identified were causeways (59% of all structures identified), with pipe culverts and box culverts being the next most common barrier types (18% and 10% of all identified barriers respectively – refer Figure 1).

Of the structures with recommended remediation actions, 69% of sites were causeways (43 sites), 14% were pipe culverts (9 sites) and 11% were box culverts (7 sites). These figures reflect the severity of each of the structure types on fish passage, and the frequency of use of these structures within the Hawkesbury-Nepean region.

Causeways and pipe culverts are all cheaper alternatives to other structures such as box culverts and bridges, and are therefore more likely to be employed as road crossings – especially on smaller waterways. Causeways and pipe culverts are also more likely to be fish passage barriers than other structure types due to the formation of sheet flow across causeways, and the creation of a waterfall effect on the downstream side; as well as the presence of high, linear, water velocities through pipes, and the creation of a waterfall effect on the downstream side if the pipe is set incorrectly (above bed level). For these, therefore, it is likely that a greater number of causeways and pipe culverts were identified as fish passage barriers than other structures within the Hawkesbury-Nepean region.

4.3 Summary of road crossing results by subregion

In this study, many road crossings were identified as an obstruction to fish passage but not recommended for remediation due to reasons such as the site being located in *minimal fish habitat* (naturally marginal habitat rarely utilised by fish such as ephemeral waterways – Class 4 habitat), or that 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). Table 1 outlines the number of road crossing obstructions identified and recommended for remediation in both subregions of the Hawkesbury-Nepean CMA area.

Table 1. Action summary – waterway crossing obstructions & remediation recommendations

	Upper Hawkesbury-Nepean subregion		*Lower Hawkesbury-Nepean subregion*		*TOTAL*	
Fish Passage Obstruction	Tot+	RR*	Tot+	RR*	Tot+	RR*
Causeway	38	25	20	18	58	43
Ford	1	0	7	1	8	1
Culvert (box)	5	3	5	4	10	7
Culvert (pipe)	5	2	13	7	18	9
Bridge	0	0	5	2	5	2
TOTAL	**49**	**30**	**50**	**32**	**99**	**62**

+ Total number of road crossings identified as a potential fish passage obstruction.
* Number of structures recommended for future remediation.

As can be seen in Table 1 and Figure 2, the number of barriers identified and recommended for remediation was relatively even despite the size of the subregion, although the Lower Hawkesbury-Nepean subregion (the larger of the two subregions), possessed marginally greater obstructions both identified and recommended for remedial action.

Within the Lower Hawkesbury-Nepean subregion, the greatest number of obstructions recommended for remedial action were causeways (20 sites) and pipe culverts (13 sites). This follows a similar trend to the LGA breakdown in Section 4.4, with Hawkesbury City LGA driving the number of structures within this subregion. The similarity in the number of barriers identified and recommended for remediation is interesting, given that the Lower Hawkesbury-Nepean subregion is characterised by both a significantly higher population, resulting in more concentrated road infrastructure, and the presence of National Parks over much of the subregion (nearly half of the total area), which affords many of the waterways in this region protection from development.

This contrasts to the Upper Hawkesbury-Nepean subregion, which covers a smaller area, possesses a sparser population, and has less of its area protected within the reserve system. The presence of a greater number of larger waterways in an agriculturally dominated area, has led to a significant number of waterway crossings within this subregion. Within the Upper Hawkesbury-Nepean subregion, causeways were by far the most common form of fish passage barrier recommended for remedial action (25 sites), followed by box culverts, and pipe culverts (3 and 2 sites respectively).

4.4 Summary of road crossing results by LGA

This project assessed approximately 480 road crossing sites across the 23 local government authorities (LGAs) that comprise the Hawkesbury-Nepean CMA region (approximately 22,000sqkm), with 99 sites identified as potential fish passage obstructions. Nine local government authorities were found to have no fish passage obstructions recorded (Campbelltown, Cessnock, Fairfield, Hornsby, Ku-ring-gai, Oberon, Pittwater, Warringah and Wollondilly). Of the 99 sites identified as fish passage obstructions, many were deemed to have a negligible impact on fish movement, leaving 62 structures recommended for some form of remedial action.

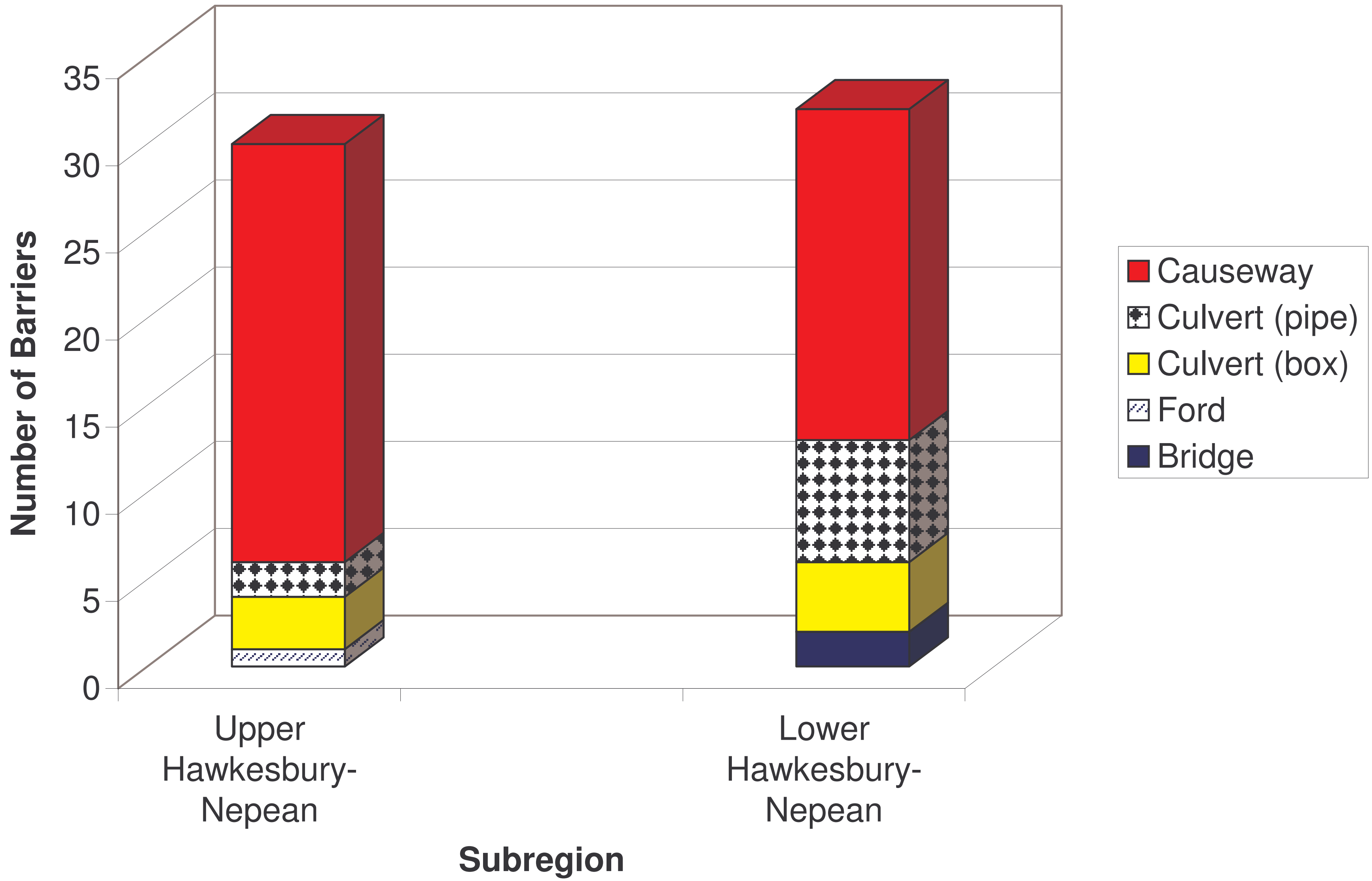


Figure 2. Fish passage obstructions with recommended remedial actions in Hawkesbury-Nepean CMA subregions.

Table 2 outlines the percentage area of each LGA within the Hawkesbury-Nepean CMA region, the number of sites identified as obstructions in each, and the number of sites recommended for remediation, whilst Figure 3 highlights the number of actioned sites within each LGA.

Table 2. Waterway crossing assessments by LGA, Hawkesbury-Nepean CMA.

Local Government Authority (LGA)	LGA area within CMA (sqkm)	LGA area as % of Study Area	Total # of sites identified as fish passage obstructions	Total # recommended for remediation
Baulkham Hills	**356**	**1.63**	**6**	**5**
Blacktown	**207**	**0.95**	**2**	**2**
Blue Mountains	**1,432**	**6.56**	**4**	**4**
Camden	**200**	**0.92**	**1**	**1**
Campbelltown	**38**	**0.18**	**0**	**0**
Cessnock	**378**	**1.74**	**0**	**0**
Fairfield	**25**	**0.12**	**0**	**0**
Gosford	**755**	**3.46**	**3**	**0**
Goulburn Mulwaree	**1,649**	**7.56**	**13**	**8**
Hawkesbury	**2,775**	**12.72**	**25**	**12**
Hornsby	**485**	**2.23**	**0**	**0**
Ku-ring-gai	**33**	**0.16**	**0**	**0**
Lithgow	**3,592**	**16.46**	**14**	**8**
Liverpool	**143**	**0.66**	**4**	**4**
Oberon	**999**	**4.58**	**0**	**0**
Penrith	**404**	**1.85**	**5**	**4**
Pittwater	**94**	**0.43**	**0**	**0**
Singleton	**1,463**	**6.70**	**1**	**1**
Upper Lachlan	**1,700**	**7.79**	**10**	**6**
Warringah	**57**	**0.26**	**0**	**0**
Wingecarribee	**2,249**	**10.31**	**8**	**5**
Wollondilly	**2,482**	**11.38**	**3**	**2**
Wollongong	**294**	**1.35**	**0**	**0**
TOTAL	**21,822**	**100**	**99**	**62**

The greatest number of obstructions to fish passage were identified within the Hawkesbury City (25 sites), City of Lithgow (14 sites), and Goulburn Mulwaree (13 sites) local government authorities. The City of Lithgow, and Hawkesbury City LGAs are the largest and second largest local government authorities within the Hawkesbury-Nepean CMA region, encompassing an area of 3,592sqkm (16.46%of the total area), and 2,775sqkm (12.72% of the total area) respectively. Goulburn Mulwaree LGA is the sixth largest with an area of 1,649sqkm (7.56% of the total area). The number of barriers identified within these LGAs therefore partly reflects the size of each LGA, but are also likely to reflect the nature of the catchments within these LGAs. The Hawkesbury City local government authority in the lower subregion, and the City of Lithgow, and Goulburn Mulwaree LGAs in the upper subregion incorporate the major waterways of the Hawkesbury River and Wollondilly River respectively, as well as a number of their tributaries.

Along the low-lying waterways in the upper subregion (such as the Mulwaree and Wollondilly Rivers), and the upper tributaries of the upper and lower subregions (such as Coxs River and Webbs Creek), causeways and pipe culverts are most likely to be more prevalent as they are cheaper to construct, and facilitate easier passage over these waterways than ford crossings or bridges. As discussed earlier, they are therefore more likely to form fish passage barriers than other structures, resulting in a greater number of problem sites identified in the LGAs where these types of waterways are found.

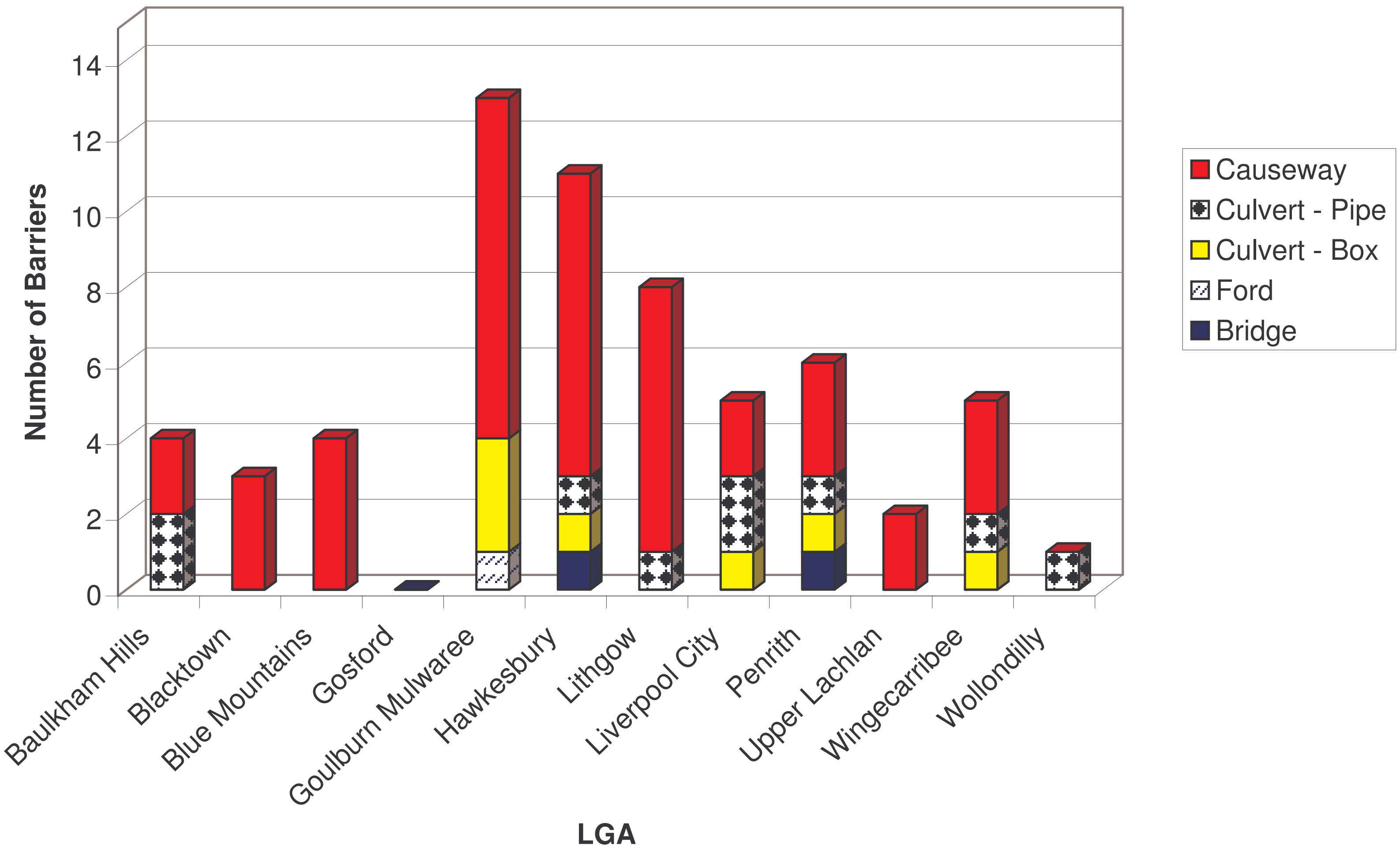


Figure 3. Actioned structure types identified as fish passage barriers in the Hawkesbury-Nepean region by local government authority (LGA).

As shown in Figure 3 and Table 2, the greatest number of sites recommended for remedial action were also within Hawkesbury City (12 sites), City of Lithgow (8 sites), and Goulburn Mulwaree LGAs (8 sites). The vast majority of actioned sites within these three LGAs were located outside of protected areas such as National Parks, State Forests, and Water Supply Special Areas, with many waterways within Goulburn Mulwaree and City of Lithgow LGAs being impacted by rural and semi-urban development, therefore leading to the construction of a greater number of poor crossings. Within the Hawkesbury City LGA approximately half the number of identified sites were recommended for action. This is possibly due to many of the barriers within this LGA being low-level ford crossings and bridges, which are less likely to have a significant impact on fish passage at medium – high flows.

Nine LGAs in the Hawkesbury-Nepean CMA region had no instream structures identified as barriers to fish passage (Table 1). This is a result of both the relatively small area of these LGAs in the CMA region, and the lack of waterways of stream order 4 and above being present. One of the LGAs with the lowest numbers of sites identified as fish passage barriers (3 sites) and recommended for remediation action (0 sites) was Gosford City LGA, which comprises only 755sqkm (3.46%) of the Hawkesbury-Nepean CMA area. In contrast, Liverpool City, which is one of the smallest LGAs in the CMA (143sqkm or 0.66% of the total area), had four sites identified as fish passage obstructions, all of which were recommended for remedial action. This is likely to be a result of recent increases in residential development, and associated road infrastructure within this LGA.

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);
- Modification of structures (e.g. retrofitting low-flow channels, installing fishways);
- Complete replacement of structures (e.g. causeways replaced with bridges or culverts); and
- Permanent removal of redundant (disused) structures.

4.5 Hawkesbury-Nepean road crossing remediation priorities by subregion

Setting goals and targets for aquatic habitat rehabilitation in the Hawkesbury-Nepean CMA region requires a clear understanding of the extent of aquatic habitat degradation and where we can achieve the best outcomes. The method of prioritising roads crossings (outlined in Appendix C) is an adapted model to cater for specific aquatic habitat and biodiversity features found in the rivers and creeks of the Hawkesbury-Nepean CMA.

This section of the report presents the major findings found during structure prioritisation for the study, highlighting priorities for fish passage remediation on a subregional and LGA basis.

All 62 instream structures that were recommended for remediation were determined to be either ‘high’, ‘medium’ or ‘low’ priority sites according to an objective prioritisation process (refer to Appendix G: Maps 3-4). This process resulted in 19 sites being classified as high priority and 31 sites as medium priority; all other sites were regarded as having lesser importance with regard to fish passage in the Hawkesbury-Nepean region. Sites that were regarded as a lesser priority should still be considered for remediation, although the urgency for remediation is not as great. These sites should be included on the owner’s maintenance schedules and remediated when possible.

Of the priority sites identified in Hawkesbury-Nepean region, the majority of high and medium priority structures were found to be causeways (13 high priority and 21 medium priority structures), whilst pipe culverts (2 sites), box culverts (2 sites), a single ford crossing, and a single bridge comprised the remaining high priority structure types. The remaining medium priority sites comprised 6 pipe culverts, 3 box culverts, and a single bridge.

Causeways and pipe culverts are more likely to cause fish passage obstructions due to the creation of headloss, flow depth, and velocity issues across the structure. Flow depth is generally only a problem for causeway structures where water moves across the surface of the structure. A headloss barrier can occur for both structure types due to the lack of low flow sections or cells within the structure, or the formation of scour pools on the downstream side of the structure.

Velocity barriers can occur within pipe culverts where long distances of moderate-high velocity water passes through the structure, requiring fish to expend a large amount of energy when attempting to move against the stream flow.

Table 3 outlines the number of high and medium priority road crossing obstructions that were identified in both of the subregions.

Table 3. High and medium priority sites - Hawkesbury-Nepean subregions		
Subregion	**High Priority**	**Medium Priority**
Upper Hawkesbury-Nepean	3	18
Lower Hawkesbury-Nepean	16	13
TOTAL	**19**	**31**

As shown in Table 3, the lower subregion contained a significantly greater number of high priority sites, with only three located in the upper subregion. The Upper Hawkesbury-Nepean subregion did possess a slightly greater number of medium priority sites, however the distribution of these sites were relatively evenly distributed throughout the whole of the CMA region.

Of the high priority sites, nearly half (8 sites or 47%) were located in the lower part of the Hawkesbury-Nepean catchment, close to (or within) the vicinity of tidal influence. A general aquatic habitat management principle is to initially address obstructions to fish passage lower in a catchment before addressing those higher in a catchment. The premise behind this principle is two-fold: barriers in the lower catchment are likely to affect catadromous[6] and anadromous[6] species more than those higher in the catchment, and that waterways are larger closer to their estuary, allowing a greater amount of critical habitat to be made available following remediation of a structure in this section.

Nearly ¾ (73%) of the high priority sites identified in this study were also located where rare or threatened species are known to occur, or are within their range. For the Hawkesbury-Nepean CMA region, these species comprise Macquarie perch and Australian grayling. Both of these species migrate as part of their life cycle: the Australian grayling being amphidromous[7] (juveniles return upstream to freshwater habitats after being swept downstream as larvae); and the Macquarie perch being potamodromous[7].

Reasons for the decline of the Australian grayling are thought to include the presence of instream barriers that can effectively stop upstream movement of juveniles, hence the greater need to remediate instream barriers such as roads and weirs that occur within its range. Reasons for decline of the Macquarie perch include destruction of habitat through infilling of deep holes and smothering of spawning beds as a result of sedimentation, cold water releases causing spawning failures, and altered flow regimes and river regulation (presence of dams and weirs) leading reduced opportunities for dispersal.

The known distribution for both the Australian grayling and Macquarie perch occurs in habitat with an intact riparian and aquatic zone, and a natural flow regime. Both the Upper and Lower Hawkesbury-Nepean subregions have large areas of protected habitat, either as Aquatic Reserves (Lower), Water Supply Special Areas (Upper), or National Parks and State Forests (both subregions, although the majority of these areas are within the Lower subregion), providing good to excellent aquatic and riparian habitat for these species. In contrast, the infrastructure associated with the major storages of Warragamba Nepean, Avon, Cataract, Cordeaux Dams would be negatively impacting on these species, reducing dispersal opportunities within these waterways (despite zoning providing habitat protection).

[6] *Catadromous* - fish that spend most of their life in fresh water and migrate to more saline waters to breed (estuaries/ocean); *Anadromous* – fish that spend most of their life in the sea and migrate to fresh water to breed (Juveniles of catadromous species are more likely to be affected by fish passage obstructions lower in the catchment as they are poorer swimmers, and must negotiate barriers whilst migrating against the direction of flow)

[7] *Amphidromous* - fish that migrate between the sea and fresh water, but not for the purpose of breeding.
Potamodromous - fish that migrate wholly within fresh water.

Three of the high priority sites were located in State protected areas (National Park or Water Supply Special Areas), one site was located in a regional reserve, and the remaining high priority sites were located in areas surrounded by rural or urban development, where local governments or private landholders are responsible for management of these structures.

4.6 Hawkesbury-Nepean road crossing priorities by LGA

Table 4 outlines the number of high and medium priority road crossing obstructions identified in the local government authorities of the Hawkesbury-Nepean CMA region (only those LGAs which possessed sites with recommended management actions are shown). As shown in Table 4, the Hawkesbury City LGA contained a significantly greater number of high priority sites (9 sites), with all other local government authorities possessing two high priority sites or less. Hawkesbury City LGA is located on the lower end of the Hawkesbury-Nepean River, and possesses a number of major tributaries including the Colo and Macdonald Rivers, where poor road crossings can have a significant impact on fish passage.

Medium priority sites were spread throughout the various LGAs, with the Goulburn Mulwaree and Wingecarribee Shire possessing the greatest number sites (5 sites each), followed by Blue Mountains City, and City of Lithgow LGAs (4 sites each).

Table 4. High and medium priority sites - Hawkesbury-Nepean LGAs

Local Government Area	High Priority	Medium Priority
Baulkham Hills	2	3
Blacktown	1	1
Blue Mountains	0	4
Camden	0	1
Goulburn Mulwaree	0	5
Hawkesbury	9	2
Lithgow	1	4
Liverpool	0	3
Penrith	2	2
Singleton	1	0
Upper Lachlan	2	1
Wingecarribee	0	5
Wollondilly	1	0
TOTAL	**19**	**31**

Sites that were not high or medium priority, but were recommended for remediation, should still be included in local council work plans and maintenance schedules.

4.7 Hawkesbury-Nepean road crossing remediation options and top priority sites

The high priority sites for the Hawkesbury-Nepean CMA region have been further analysed on a regional scale, exploring remediation options to restore fish passage, with Table 5 summarising their information and Appendix D (Table 9) listing their information in more detail, with Appendix E (Table 10) also outlining the medium priority sites. Overall the high priority sites included thirteen causeways, two box culverts, two pipe culverts, one ford, and one bridge structure.

Of the high priority sites identified within this study, two sites were determined to be obsolete structures. One of these sites, a redundant causeway on South Creek at St Marys (third highest priority site in the Hawkesbury-Nepean CMA region), has since been removed as part of a joint venture between NSW DPI Fisheries (Conservation and Aquaculture) and Penrith City Council through the "demonstration site" of this project (a description of this project can be found in a companion report: "*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*"). The other, a pipe culvert on the Coxs River near Lidsdale, could be remediated easily, and for minimal cost, and could potentially reinstate up to approximately 10km of upstream habitat.

Prior to removal of a structure consultation with adjacent and upstream landholders is required to determine if the structure is serving an ancillary purpose, such as creating a freshwater environment upstream of the site in an area that would have previously been saline. It is possible that the freshwater pool is being used by adjacent landholders to provide water for irrigation, stock, or domestic purposes; and that removal of the structure will affect their ability to access a freshwater source. In this case, the provision of off-stream water storages, and watering points, in addition to riparian stock fencing may also be required, and will contribute to the overall project costs.

In addition to obsolete structures, nine sites were found to be fish passage obstructions at least partially due to the presence of debris (sediment build up, or plant material including large woody debris). At one site, debris was determined to be the only obstruction to fish passage. Continued maintenance of these structures, in addition to other recommended management actions, will ensure continued fish passage with minimal financial requirement.

This is in contrast to three high priority structures identified that were located on waterways of 10m or greater, and therefore require reasonably more major works (with significant financial contribution) to provide for fish passage. Such recommendations include the construction of a bridge, and installation of box culverts with low flow cells.

Nearly ¾ of the high priority structures (14 sites) within the Hawkesbury-Nepean require replacement of or complete removal of smaller structures (<10m wide), thereby requiring less financial contribution. Generally works recommended for these structures also include the installation of box culverts with low flow cell(s), increasing the number of cells within a structure, and lowering the invert of the existing structure.

Table 5. Summary of high priority sites – Hawkesbury-Nepean region

Rank	Crossing ID	Waterway	Structure Type	Road Name	Recommendation
1	HAWK039	Fitzgeralds Creek	Causeway	Trail off Riverside Road	Remove / Box culvert with low flow cells
2	HAWK048	Wheeny Creek	Causeway	Comleroy Road	Bridge
3[#]	HAWK029	South Creek	Causeway	The Kingsway	Remove
4	HAWK010	Macdonald River	Causeway	Road off Upper MacDonald Rd	Bridge
5	HAWK030	South Creek	Causeway	Stoney Creek Road	Box culvert with low flow cells
6	HAWK021	Cattai Creek	Causeway	McClymonts Road	Box culvert with low flow cells
7	HAWK049	Condon Creek	Culvert - Pipe	Putty Road	Box culvert with low flow cells
8	HAWK042	Roberts Creek	Ford	Roberts Creek Road	Box culvert with low flow cell
9	HAWK040	Redbank Creek	Culvert - Box	Terrace Road	Reduce invert height
10	HAWK018	Longneck Creek	Culvert - Box	Cattai Road	Management of dropboards
11	HAWK089	Tarlo River	Causeway	Swallow Tail Pass	Box culvert with low flow cells
12	HAWK045	Monkey Creek	Causeway	Fire trail off Sylvai Road	Box culvert with low flow cells
13	HAWK041	Howes Creek	Causeway	Tennyson Road	Box culvert with low flow cells
14	HAWK033	O'Haras Creek	Causeway	Firetrail off O'Hares Creek Road	Box culvert with low flow cells
15	HAWK081	Wollondilly River	Causeway	Farm track off Arthurleigh Road	Box culvert with low flow cells
16	HAWK012	Macdonald River	Bridge	Upper Macdonald Road	Debris maintenance
17	HAWK053	Coxs River	Culvert - Pipe	Track off Newnes Rd	Remove / Box culvert with low flow cells
18	HAWK015	Webbs Creek	Causeway	Webbs Creek Road	Box culvert with low flow cells
19	HAWK043	Howes Creek	Causeway	Old East Kurrajong Road	Box culvert with low flow cell

[#] This site has now been removed through the "demonstration site" of this project

Of the high priority sites listed above, many have a recommendation of "[multiple] box culvert[s] with low flow cell[s]". This remediation option aims to improve the cross-sectional area of a structure, so as to minimise high water velocities that occur when water is funnelled into cells that are too small.

In addition, the provision of low flow cells enable fish to traverse the structure under low flow conditions. A low flow cell is set into the bed of the waterway, so that during low flow conditions this cell is the only one that is inundated. During low flow conditions, water is directed through this cell, with additional cells becoming operable as water levels rise. Surrounding substrate remains in the base of the cell, further minimising the impact of the structure on fish movement by minimising behavioural reluctance to traverse the structure.

In the Hunter/Central Rivers CMA region, Dixons Crossing on the Karuah River was remediated as part of the demonstration site component of this project in collaboration with the Roads and Transport Authority (RTA), and Great Lakes Council. Dixons Crossing was a low level causeway identified as a fish passage barrier due to excessive headloss and water velocity (through a single pipe culvert) – refer Figure 4a. The structure was remediated through the installation of multiple box culverts with three centrally located low flow cells (Figure 4b). Further information regarding remediation of this site can be found in a companion report ("*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*").

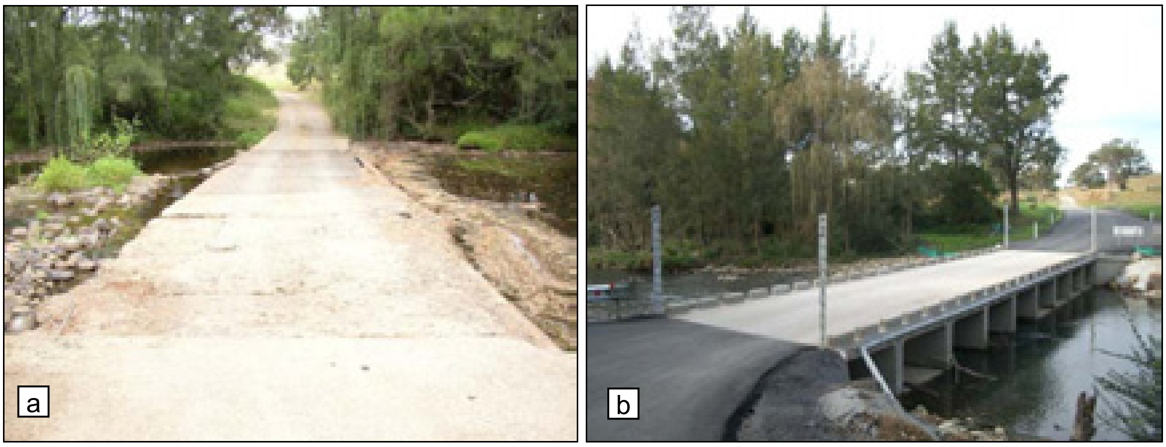


Figure 4. Dixons Crossing causeway (Karuah River) prior to (a), and following (b) remediation – note three central low flow cells.

Alternative technologies can also be employed to provide fish passage where traditional methods are unfeasible (e.g. due to funding restrictions). Several causeway crossings on the Gloucester River (Hunter/Central Rivers CMA region) have been remediated by Gloucester Shire Council through the construction of modified partial width rock ramp fishways adjacent the crossings (Figure 5 and Appendix F). These modified fishways run along the downstream edge of the causeway and have their upstream exit at a low flow point on the causeway structure itself (low flow depression in the causeway capping). This means that fish must still negotiate a shallower section of water across the top of the causeway.

Figure 5. Faulkland Road Crossing modified partial width rock ramp fishway (a) during construction, (b) completed work.

A causeway on Bucketts Road, Gloucester River, is being remediated as part of the demonstration site component of this project, with further information on this project being found in a companion report ("*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*").

Other technologies that can provide fish passage at a potentially lesser cost include installation of "Doolan Decks" (prefabricated modular concrete and wood strut based bridges), and Super Cor® Box (high weight bearing wide corrugated iron cells) (Richmond Valley Council, 2006; Big R Manufacturing, 2004). Further information on these alternatives is available from NSW DPI Fisheries (Conservation and Aquaculture).

4.8 Hawkesbury-Nepean sediment input sites

During this study, several sites were identified as both fish passage barriers and as sediment input sites. In addition, three sites were identified as sites that were contributing to the sediment loading of a waterway without forming a fish passage barrier (Macdonald River, Upper Macdonald River Road; Ganbenang Creek, Ganbenang Road; Wollondilly River, Wombeyan Caves Road). All these sites are within unprotected areas such as rural land. It is recommended that these sediment input sites be investigated and remediated as part of regular maintenance works to minimise loss of fish habitat through the smothering of aquatic vegetation, riffles and deeper pools within a waterway.

Sediment inputs from Wombeyan Caves Road crossing over the Wollondilly River (known as "Goodmans Ford") have been addressed as a joint venture between NSW DPI Fisheries (Conservation and Aquaculture), Sydney Catchment Authority, and Wingecarribee Shire Council, through the "demonstration site" component of this project. This project sealed road approaches, installed sediment retention basins, and constructed diversion drainage adjacent to this river crossing. Further details on these projects can be found in a companion report: "*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*".

Prior to undertaking rehabilitation projects, including remediation of fish passage obstructions, there are several steps that should be followed to determine the viability of the project, including setting of objectives, feasibility of the project, formulation of designs, and methods of evaluation. These steps are discussed in Section 5.

5. STEPS IN STREAM REHABILITATION PROJECTS

This study provides baseline data for the rehabilitation of stream connectivity in the Hawkesbury-Nepean CMA region. The following section illustrates how this report can inform and lead to on-ground stream rehabilitation works. For this purpose, a *12 Step Stream Rehabilitation Process*, taken from the Manual for Rehabilitating Australian Streams (Rutherfurd *et al.*, 2001), has been adopted here to outline the main stages of undertaking on-ground fish passage projects.

The Rutherfurd stream rehabilitation process includes the following steps:	
1. Visions and goals	7. Setting measurable objectives
2. Gain support	8. Feasibility
3. Assess stream condition	9. Detailed design
4. Identify problems and assets	10. Evaluation
5. Priorities	11. Implementation
6. Strategies	12. Maintenance and evaluation

Steps 1 – 5 Visions and goals, gaining support, assessing stream condition, identify problems and assets, priorities:

This report has provided information to successfully complete steps 1 to 5 in the process of rehabilitating fish passage barriers by achieving the following:

- Establishment of a vision for reinstating stream connectivity and improving fish passage in coastal waterways of NSW;
- Providing a source document for stakeholders outlining major findings and providing management recommendations for regional groups and local government; promotion of the report findings will offer an opportunity to gain broad regional and local support for future initiatives;
- Identifying specific road crossings that are obstructions to fish passage across the Hawkesbury-Nepean region; and
- Establishing and implementing a method of prioritising fish passage obstructions at the regional and subregion/catchment scale.

Steps 6 to 12 in the stream rehabilitation process need to be undertaken by relevant stakeholders (private landholders, Councils, state government and the CMA) with the aim of achieving on-ground outcomes. The following is a summary of how those steps can be achieved for road crossing remediation in coastal NSW.

Step 6 – 8 Strategies, setting measurable objectives, and feasibility:

Strategies for rehabilitation, in this instance options for remediating road crossings, need to be set out within an overall rehabilitation plan that involves outlining specific project objectives. In this investigation, rapid assessments were conducted for waterway crossings to provide a ‘snap shot’ view of environmental conditions at a site. Due to the number of structures in the Hawkesbury-Nepean region, detailed assessments of each structure were not feasible. For the purposes of informing future planning, the application of a rapid assessment technique (the fieldwork methodology and desktop prioritisation outlined above) was a simple and effective way of highlighting the extent of the problem and determining broad regional priorities. It is understood however, that many environmental, social, cultural and economic considerations need to be reviewed before undertaking on-ground works recommended within this report. Additional pertinent considerations include:

- Location of other instream structures (e.g. weirs and dams) and natural barriers within the waterway that were overlooked during the initial assessment;
- Existence of sensitive habitats in the vicinity of proposed works;
- Impact of structure removal/modification on channel bed and bank stability;
- Presence of Acid Sulfate Soils;

- Impacts of mobilising sediment stored behind the crossing;
- Impacts on water quality (e.g. from contaminated sediments) and water chemistry (e.g. at tidal barriers) upon upstream and downstream habitats;
- Additional uses for the structure (e.g. pumping pool, bed-control structure, floodgate);
- Benefactors and stakeholders – identifying support and opposition; and
- Estimated costs of various remediation options.

The above factors must be considered well before detailed designs for remediating a fish passage barrier can be considered.

Step 9 – Detailed design:

Design guidelines in relation to undertaking 'fish friendly' road crossing projects can be found in:

- *Why do fish need to cross the road? Fish passage requirements for waterway crossings.* (Fairfull and Witheridge, 2003); and
- *Fish passage requirements for waterway crossings – Engineering Guidelines*. (Witheridge, 2002).

Fairfull and Witheridge (2003) provide a comprehensive overview of the best way to plan, design and construct waterway crossings to minimise impacts on fish passage and aquatic habitats. NSW DPI Fisheries requires that these national guidelines be followed by anyone intending to design and construct a waterway crossing in NSW. For engineers, Witheridge (2002) also provides a comprehensive and useful engineering guide to the design and construction of 'fish and fauna friendly' waterway crossings. Both documents were developed with the input of a national steering committee of experts in the field of road design, construction and fish passage.

Table 6 is adapted from Fairfull and Witheridge (2003) and provides a summary of preferred waterway crossing designs depending on waterway CLASS (see Appendix C - Table 7 for characteristics of different waterway classes).

Table 6. NSW DPI preferred waterway crossing type in relation to waterway class

Waterway Classification	Minimum Recommended Crossing Type	Additional Design Information
CLASS 1 Major fish habitat	Bridge, arch structure or tunnel	Bridges are preferred to arch structures.
CLASS 2 Moderate fish habitat	Bridge, arch structure, culvert [1] or ford	Bridges are preferred to arch structures, culverts and fords (in that order). [1] High priority given to the 'High Flow Design' procedures presented for the design of these culverts—refer to Design Considerations section of Fairfull and Witheridge, 2003.
CLASS 3 Minimal fish habitat	Culvert [2] or ford	[2] Minimum culvert design using the 'Low Flow Design' procedures; however, 'High Flow Design' and 'Medium Flow Design' should be given priority where affordable.
CLASS 4 Unlikely fish habitat	Culvert [3],causeway or ford	Culverts and fords are preferred to causeways (in that order). [3] Fish friendly waterway crossing designs possibly unwarranted. Fish passage requirements should be confirmed with NSW DPI Fisheries.

In contrast to road crossing designs, NSW DPI Fisheries does not use a generic classification system to stipulate remediation designs for highly-engineered structures such as fishways. Rather, decisions are based on the specifics of the biology and hydrology of the waterway and the conservation value of the site to determine the most appropriate course of action. Design advice is provided on a case-by-case basis.

Step 10 – 12: **Evaluation, implementation, monitoring and maintenance:**

Steps 10 to 12 are common steps in any project management process and include establishing an evaluation procedure, implementing the plan and assessing the success of the project. These stages include developing a timeline, allocating responsibilities, finalising funding, conducting on-ground works and organising an evaluation schedule.

For road crossing remediation works, establishing a working group (comprising representatives from relevant government agencies and other associated parties) to ratify a remediation works plan is an effective way of ensuring that the plan meets project objectives.

Permit and works approval 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, 2003b); and
- *Policy and Guidelines for Aquatic Habitat Management and Fish Conservation* (NSW Fisheries, 1999).

The financing of on-ground rehabilitation works can be achieved through several avenues of cost-sharing between stakeholders and value-adding to existing programs/projects. Funding opportunities include State and Federal environmental grants for aquatic habitat rehabilitation projects. The NSW Department of Primary Industries Fisheries (Conservation and Aquaculture) can assist road managers, structure owners and community groups interested in applying for funding related to stream connectivity and fish passage projects in NSW.

6. RECOMMENDATIONS

This study contributes to the management of aquatic habitats in the Hawkesbury-Nepean region of NSW by achieving the following outcomes:

- Development of a road crossing remediation inventory,
- On-ground application of a road crossing assessment method,
- Identification of remediation options for road crossing sites,
- Application of a prioritisation method to rank fish passage obstructions, and
- Promote and educate the findings of the report.

A complete data set from this study is available in the accompanying CD (*Road Crossings Inventory Hawkesbury-Nepean CMA 2006*) and includes data on road crossing location information, environmental data and recommended remediation action. 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).

A companion report outlines the results of on-ground works ("demonstration sites") undertaken as part of this project ("*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*").

Recommendations:

- The Hawkesbury-Nepean CMA, local government, other structure owners, and NSW DPI should investigate the feasibility of remediating the high priority sites identified in this report. Detailed assessments of each individual site will be required prior to significant monetary investment at these locations;
- Sites that are obsolete, or where debris is creating a fish passage barrier, are able to be remediated with minimal financial outlay, and minimal stakeholder negotiation – these sites could therefore be remediated in the near future;
- Sites lower in the system, or those occurring on waterways with few other barriers, should be remediated in preference to sites where a large number of barriers are present downstream of the site;
- Sites where rare or threatened species are present within the catchment should be remediated in preference to sites outside the distribution of these species; and
- Sites identified as producing sediment input into a waterway should be investigated, as continual sediment input into the waterway can lead to the destruction of fish habitat.

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8. APPENDICES

Scientific Name	Common Names	Status	Migration[8] and habitat
Acanthopagrus australis	Yellowfin bream Silver bream	Common	Amphidromous; coastal marine; estuaries and inshore reefs.
Acanthogobius flavimanus	Yellowfin goby	**EXOTIC**	Freshwater reaches of streams just above tidal influence.
Amniataba percoides	Banded grunter	**EXOTIC; NSW NOXIOUS LISTING**	Freshwater habitats – in Clarence River, has potential to spread to the Hawkesbury-Nepean region.
Anguilla australis	Short-finned eel	Common	Catadromous; coastal rivers and wetlands.
Anguilla reinhardtii	Long-finned eel	Common	Catadromous; coastal rivers.
Atherinosoma microstoma	Smallmouthed hardyhead	Common	Unknown migration pattern; coastal estuarine and fresh waters.
Bidyanus bidyanus	Silver Perch	**NSW THREATENED SPECIES (*VULNERABLE*)**	Large scale migration; Habitat is predominantly in lowland and slope waterways. Present as a result of stocking.
Caranx sexfasciatus	Bigeye trevally	Common	Marine; juveniles common in mangrove estuaries, tidal creeks and can enter freshwater.
Carassius auratus	Goldfish	**EXOTIC**	Widespread in lowland rivers.
Carcharhinus leucas	Bull shark	Common (not abundant)	Estuaries, lower reaches of rivers; coastal waters.
Chanos chanos	Milkfish	Common	Amphidromous; Warm water marine and estuarine species, will travel up rivers.
Cyprinus carpio	Common carp	**EXOTIC; NSW NOXIOUS LISTING**	Still gentle flowing rivers in inland NSW and some catchments along the coast.
Elops hawaiensis	Giant herring	Common	Sheltered embayments and estuaries.
Epinephelus daemelii	Black cod	**NSW THREATENED SPECIES (*VULNERABLE*)**	Inshore marine caves and rocky reefs; larger juveniles around rocky shores in estuaries (natural distribution to south of Bega NSW).
Galaxias brevipinnis	Climbing galaxias	Uncertain; Distribution contracted	Amphidromous; headwaters and forested streams.
Galaxias maculatus	Common jollytail	Common	Catadromous; coastal streams, lakes and lagoons – salt and fresh water environs.
Galaxias olidus	Mountain galaxias	Common	Local migration; moderate and high elevations in coastal and inland rivers.
Gambusia holbrooki	Gambusia, Plague minnow	**EXOTIC; NOXIOUS LISTING**	Widespread in coastal and inland NSW.
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.
Hypseleotris spp.	Gudgeon	Common	Unknown migration; lower reaches of coastal rivers.
Macquaria australasica	Macquarie perch	**NSW THREATENED SPECIES (*VULNERABLE*)**	Potamodromous; Hawkesbury River, Shoalhaven River and inland NSW.

[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.

Appendix A – Freshwater & Estuarine Fin-fish of the Hawkesbury-Nepean, NSW

Maccullochella macquariensis	Trout cod	**NSW THREATENED SPECIES (*ENDANGERED*)**	Potamodromous; prefer deep flowing freshwaters with woody debris. Present as a result of stocking.
Macquaria novemaculeata	Australian bass	Uncertain	Catadromous; Coastal rivers up to 600m altitude.
Maccullochella peelii peelii	Murray cod	**FEDERALLY THREATENED SPECIES (*VULNERABLE*)**	Potamodromous; Habitat predominantly in lowland and slope waterways. Present as a result of stocking.
Megalops cyprinoids	Oxeye herring	Common	Amphidromous; marine and estuarine, juveniles and small adults frequent freshwater reaches.
Melanotaenia duboulayi	Duboulay's rainbowfish	Common	Potamodromous; Still, clear waters east of the Great Dividing Range.
Misgurnis anguillicaudatus	Oriental wetherloach	**EXOTIC**	Still and slow-flowing freshwaters with muddy substrate.
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 and Tuross Rivers in NSW.
Mugil cephalus	Striped mullet	Common	Amphidromous; lower reaches and estuaries of coastal catchments.
Mugilogobius platynotus	Flat backed goby	Common	Estuaries, can tolerate freshwater but mainly a marine species.
Myxus petardi	Freshwater mullet	Common	Amphidromous as juveniles; estuaries and brackish waters in lower river reaches.
Notesthes robusta	Bullrout	Limited abundance but not threatened	Catadromous; tidal estuaries and fresh waters.
Oncorhynchus mykiss	Rainbow trout	**EXOTIC**	Local migration; montane regions along the Great Dividing Range.
Philypnodon grandiceps	Flathead gudgeon	Common	Unknown migration; inland and coastal waters especially lakes and dams.
Philypnodon sp.	Dwarf flathead gudgeon	Common	Unknown migration; coastal and inland streams.
Potamalosa richmondia	Freshwater herring	Not common but not considered under threat	Catadromous; estuaries and coastal freshwater rivers.
Prototroctes maraena	Australian grayling	**FEDERALLY THREATENED (*VULNERABLE*)**	Catadromous; coastal freshwater systems.
Pristis zijsron	Green sawfish	**NSW THREATENED SPECIES (*ENDANGERED*)**	Amphidromous; lower reaches and estuaries of coastal catchments. Last confirmed sighting in 1972.
Pseudomugil signifer	Pacific blue-eye	Common	Amphidromous; eastern draining catchments.
Retropinna semoni	Australian smelt	Common	Potamodromous; Inland and coastal freshwater.
Rhabdosargus sarba	Tarwhine	Common	Coastal waters, often entering estuaries.
Rhadinocentrus ornatus	Softspined rainbowfish	Common	Potamodromous; Inland and coastal freshwater.
Salmo trutta	Brown trout	**EXOTIC**	Restricted to cooler waters; montane waterways above 600m elevation.
Scatophagus argus	Spotted scat	Common	Estuarine and coastal, mangrove creeks, lower reaches of freshwater streams.
Selenotoca multifasciata	Banded scat	Common	Estuarine and coastal, mangrove creeks, lower reaches of freshwater streams.
Tanichthys albonubes	White cloud mountain minnow	**EXOTIC**	Temperate freshwaters.
Tandanus tandanus	Freshwater catfish	Not common	Potamodromous; Still and slow moving freshwaters in mid to lowland slopes.

Sources: McDowall (1996), Thorncraft and Harris (2000), Yearsley *et al.* (2001), Allen *et al.* (2002), NSW Fisheries (2002a, 2002b), and NSW DPI (2005a, 2005b, 2005c).

Appendix B – Desktop and Field Assessment Form

COASTAL NSW WATERWAY CROSSINGS – DESK TOP ASSESSMENT FORM

ASSESSOR: ________________**DATE:** __________ **CROSSING ID:** ______________________
CATCHMENT: ______________**WATERWAY:** ____
STREAM ORDER: ___________**ELEVATION:** _______ **LGA:** ____________________________

---

1. LOCATION INFORMATION

1a Location: Nearest Town: ______________________Road Name: ____________________________

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

1c Upstream catchment area (sq. km) _________________

---

2. STRUCTURE DETAILS

2a Structure ownership (please circle): Federal State Local Government Private Landholder

2b Distance to the next potential barrier: Upstream ___________km Downstream __________km

2c Owner of the next potential obstruction (please circle):
Upstream: Federal State Local Government Private Landholder
Downstream: Federal State Local Government Private Landholder

2e If crossing blocks fish passage, how much habitat upstream would become available if crossing was modified to allow for fish passage _____________km

---

3. ENVIRONMENTAL CONSIDERATIONS

3a Threatened and protected aquatic species present (please circle):
Olive perchlet Eastern freshwater cod Purple spotted gudgeon Oxleyan pygmy perch
Macquarie perch Black cod Australian grayling Estuary cod

3b Other key aquatic species present: ____
____

NB. Use *Fishfiles* or *Freshwater Fish Research Database*. Include recreational and commercial fish species and key species such as platypus, turtles and waterbirds (if identifies in the field).

3c Environmental status: ____
____

NB. Include terrestrial threatened species, critical habitat, conservation rating (HCV etc) and protected area status (eg. MPA's, SEPP, and significant wetlands, reserves, NP's and wilderness listings) if known.

ADDITIONAL COMMENTS IF REQUIRED:____
____
____
____
____
____
____
____

Appendix B – Desktop and Field Assessment Form

COASTAL NSW WATERWAY CROSSINGS – FIELD ASSESSMENT FORM

ASSESSOR: ________________DATE: ____________CROSSING ID: ______________________
CLASS: ___________________GPS (or Grid ref and map number) ___________________________
PHOTO NUMBERS: ____

---

1. LOCATION INFORMATION
1d Surrounding Land Uses (please circle)**:** Forested / Grazing / Cropping / Urban / Rural / Industrial
Description of land use:____

---

2. STRUCTURE DETAILS
2a Road Type (please circle): Sealed / Unsealed

2b Structure Type (please circle):
Bridge - single or multiple span or arched structure raised above channel bed.
Culvert - pipe or box shaped cell to convey water underneath roadway.
Pipe - cylindrical-celled culvert.
Weir - instream structure designed to back water upstream.
Causeway - low-level crossing designed to convey water over road; 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.

2d Structure Description
No. of cells or pipes _____________Height (from downstream bed level to structure crest).______m
Width (bank to bank) _____________________m Width (upstream to downstream)__________m
Construction material (please circle): Concrete / Timber / Steel / Rock / Gravel / Sand/Fines

2e Ancillary purposes (e.g. bed-control structure, pumping pool) ________________________________

---

3. ENVIRONMENTAL CONSIDERATIONS
FISH PASSAGE
3a Does the crossing potentially block fish passage (please circle): Yes / No
If yes what type of blockage (please circle one or more):

Vertical drop: est (mm) _______				**Slope** (est grade): ______
Velocity:	High	Moderate	Low	If known, Velocity (m/s) _________
Turbulence:	High	Moderate	Low	**Debris:** Present / Absent
Flow depth through structure (mm): ___________				**Light:** None / Minimal / Adequate

Other: ____

3b Is there **flow over/through** the structure: Yes / No **3c** Does water pool upstream of the structure: Yes / No
If yes, what is the average length of pool ___________m and depth of the pool __________m

3c Is there **terrestrial passage** under or over the structure: Yes / No

3d Location of next obstruction if different to desktop study (GPS or road name or Grid reference and map name and number): Upstream _______________________ Downstream _______________________

HABITAT
3e Bank Height _____m; c**hannel width** _____m; **low flow channel width** _____m and **depth** _____m

3f Habitat features (substrate type, pools, riffles, gravel bed, boulders, macrophytes, snags, undercuts, riparian overhangs etc): ____

3g Condition of aquatic habitat:	**excellent**	**good**	**fair**	**poor**	**very poor**
3h Condition of riparian zone:	**excellent**	**good**	**fair**	**poor**	**very poor**

---

4. COMMENTS (channelised, erosion, saltation, reduced water quality, riparian and aquatic pests etc):
____
____

---

5. RECOMMENDATIONS: ____
____

Appendix C – Prioritisation Process

Throughout NSW, the Department of Primary Industries Fisheries (Conservation and Aquaculture) applies a basic 'CLASS' system to assign aquatic habitat values to waterways. Table 7 outlines the characteristics of each waterway class. This criterion was used in the prioritisation scheme as one of the main criteria to determine the habitat value of road crossing sites in the Hawkesbury-Nepean CMA region.

Table 7. NSW DPI classification of fish habitat in NSW waterways

Classification	Characteristics of waterway class
CLASS 1 Major fish habitat	Major permanently or intermittently flowing waterway (e.g. river or major creek); habitat of a threatened fish species or 'critical habitat'.
CLASS 2 Moderate fish habitat	Named permanent or intermittent stream, creek or waterway with clearly defined bed and banks with semi-permanent to permanent waters in pools or in connected wetland areas. Marine or freshwater aquatic vegetation is present. Known fish habitat and/or fish observed inhabiting the area.
CLASS 3 Minimal fish habitat	Named or unnamed waterway with intermittent flow and potential refuge, breeding or feeding areas for some aquatic fauna (e.g. fish, yabbies). Semi-permanent pools form within the waterway or adjacent wetlands after a rain event. Otherwise, any minor waterway that interconnects with wetlands or recognised aquatic habitats.
CLASS 4 Unlikely fish habitat	Named or unnamed waterway with intermittent flow following rain events only, little or no defined drainage channel, little or no flow or free standing water or pools after rain events (e.g. dry gullies or shallow floodplain depressions with no permanent aquatic flora present).

Data utilised in each of the four criteria are shown in Table 8.

Habitat value data for a site also provided an indication of the quality of habitat for fish (including the size of the waterway, and location in the system), how impacted the site and catchment were from human activity (number of barriers downstream, and distance to next barrier downstream), and how the remediation of the structure would benefit fish (amount of habitat potentially made available upstream of the site).

The structure impact criteria indicated the physical impact of the structure on fish passage. True/false values were assigned to each of the data, in addition to an actual height value for headloss.

Table 8. Data employed to determine road crossing criteria

Habitat Value Criteria Waterway Class Section of Catchment Number of Road Barriers Downstream Distance to next Road Barrier Downstream Habitat Available Upstream	**Structure Impact Criteria** Headloss Slope Presence of Debris (Woody or Sediment) Velocity Flow Depth Light
Environmental Value Criteria Low Flow Channel Width Aquatic Habitat Condition Riparian Habitat Condition Sealed/Unsealed Road Presence of Rare or Threatened Species Environmental Status	**Modification Criteria** Is Structure Obsolete? Ease of Remediation Any Additional Uses?

Appendix C – Prioritisation Process

A headloss across the structure of greater than 100mm can affect the migration of native fish, as can a slope greater than 1:20 (in estuarine / lowland environments, where upstream movement of juvenile fish is most crucial, this figure can be as low as 1:30). Similarly, long distances where high linear velocities are encountered (such as in long pipe culverts) can inhibit fish movement. Physical limitations on the ability of a fish to pass a structure also occur where the crossing outlet itself is blocked by woody debris or sediment, or where the depth of water in the structure is minimal (n.b. depth requirements vary depending on the size of resident fish. Large bodied natives (such as Macquarie perch) may require depths greater than 200mm). A lack of light within a structure can potentially form a behavioural barrier to some native fish species, regardless of the flow conditions and water depth within the culvert.

Data employed in the environmental value criteria described the local habitat condition (channel width, aquatic vegetation and riparian vegetation condition), and thus the local habitat features available for fish. The surrounding land use (whether the site was within a National Park, Water Reserve, State Forest or was farming land), and whether rare or threatened species were actually or potentially present within the catchment also contributed to the environmental value of a site.

The likelihood of sediment contribution to the waterway as a result of road design (e.g. unsealed approaches, lack of sediment controls) also formed part of the environmental value criteria due to its potential impact on instream habitat. Sediment inputs into a waterway either from road crossings directly, or from drainage works associated with them, may impact on native fish habitat through the smothering of aquatic vegetation, riffles, or infilling of deep pools within a waterway.

The modification criteria took into account additional uses for the site that may decrease remediation options available (e.g. if the structure was acting as a bed control structure or providing a pumping pool for water extraction upstream of the site), the ease of remediation (the recommended action for the site and how costly this would be), and if the structure was required (an obsolete structure being more likely to be remediated through removal than a structure that was still in use).

The scoring system used to prioritise sites according to the above criteria is presented overleaf.

Appendix C – Prioritisation Process

							SCORE
INITIAL PRIORITISATION							
A) STREAM HABITAT VALUE CRITERIA							**SCORE**
Primary aquatic habitat rating							
Habitat Class		1	2	3	4		
Location in the system		Tidal	Lower	Middle	Upper		
Downstream obstructions		0	1-2	3 - 5	> 5		
Upstream habitat – stream length opened up (>/= 4th order)		> 20 km	10 – 20 km	5 - 10 km	1 - 5 km	< 1 km	
B) STRUCTURE IMPACT CRITERIA							
Environmental effect rating							
Physical barrier	Headloss	> 1000 mm	500 - 1000 mm	250 – 500 mm	100 - 250 mm		
	Slope	"True"					
	Debris	"True"					
	Blockage	"True"					
Hydrological barrier	Velocity	"True"					
	Flow depth	"True"					
Behavioural barrier	Light penetration	"True"					
						SUBTOTAL	
SECONDARY PRIORITISATION							
C) ENVIRONMENTAL CRITERIA							
Secondary aquatic habitat rating							
Low-flow channel width		> 15 m	10 – 15 m	5 - 10 m	< 5 m		
Instream habitat condition		Good		Fair			
Riparian condition		Good		Fair			
Point Sediment Impacts		Unsealed		Sealed			
Threatened species		"True" Class 1-2 (within range, likely habitat)		"True" Class 3 (within range, unlikely habitat)			
Landuse / Environmental Status		National Park = 1	State Forest = 2	Rural = 3			
D) MODIFICATION CRITERIA							
Structure use and remediation cost rating							
Obsolete Crossing		"True"					
Ease of Remediation		Maintenance	Box Culvert Low Flow Channel	Bridge			
Ancillary uses		Flood mitigation = 1	Bed Control = 2	Pump pool, Irrigation = 3			
						SUBTOTAL	
						TOTAL	

Appendix D – High Priority Sites in the Hawkesbury-Nepean CMA

Table 9. High priority fish passage obstructions in Hawkesbury-Nepean region

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
1	HAWK039	Lower HN, Penrith City	Fitzgeralds Ck	Trail off Riverside Rd	-33.7143	150.6549	2	Causeway	HL, D, V, L	Remove / Box culvert with low flow cells	28
2	HAWK048	Lower HN, Hawkesbury City	Wheeny Ck	Comleroy Rd	-33.4564	150.7220	2	Causeway	HL, LF	Bridge	19
3#	HAWK029	Lower HN, Penrith City	South Ck	The Kingsway	-33.7658	150.7672	2	Causeway	HL, LF	Remove	34
4	HAWK010	Lower HN, Hawkesbury City	Macdonald R	Rd off Upper MacDonald Rd	-33.2695	150.9431	2	Causeway	HL, D, V	Bridge and remove redundant structure downstream	2
5	HAWK030	Lower HN, Blacktown City	South Ck	Stoney Ck Rd	-33.6910	150.7861	2	Causeway	D, V	Box culvert with low flow cells	11
6	HAWK021	Lower HN, Shire of Baulkham Hills	Cattai Ck	McClymonts Rd	-33.6137	150.9303	2	Causeway	HL, V, L	Box culvert with low flow cells	1.5
7	HAWK049	Lower HN, Singleton Shire	Condon Ck	Putty Rd	-32.9390	150.6338	2	Culvert - Pipe	HL, LF	Box culvert with low flow cells	4
8	HAWK042	Lower HN, Hawkesbury City	Roberts Ck	Roberts Ck Rd	-33.5061	150.7671	2	Ford	D, LF	Box culvert with low flow cells	5
9	HAWK040	Lower HN, Hawkesbury City	Redbank Ck	Terrace Rd	-33.5731	150.7304	2	Culvert - Box	HL, V, LF	Reduce invert height	2
10	HAWK018	Lower HN, Hawkesbury City	Longneck Ck	Cattai Rd	-33.5722	150.8906	2	Culvert - Box	D	Remove / Management of dropboards	1.5
11	HAWK089	Upper HN, Upper Lachlan Shire	Tarlo R	Swallow Tail Pass	-34.4659	150.0108	2	Causeway	HL, LF	Box culvert with low flow cells	53
12	HAWK045	Lower HN, Wollondilly Shire	Monkey Ck	Fire trail off Sylvai Rd	-33.9793	150.5591	2	Causeway	D, V, L	Box culvert with low flow cells	12
13	HAWK041	Lower HN, Hawkesbury City	Howes Ck	Tennyson Rd	-33.5217	150.7611	2	Causeway	V, L	Box culvert with low flow cells	6
14	HAWK033	Lower HN, Shire of Baulkham Hills	O'Haras Ck	Firetrail off O'Hares Ck Rd	-33.6341	151.0009	2	Causeway	HL, D, LF, L	Box culvert with low flow cells	5
15	HAWK081	Upper HN, Upper Lachlan Shire	Wollondilly R	Farm track off Arthurleigh Rd	-34.5367	150.0514	1	Causeway	S	Box culvert with low flow cells	10
16	HAWK012	Lower HN, Hawkesbury City	Macdonald R	Upper Macdonald Rd	-33.2423	150.9400	2	Bridge	D	Debris maintenance	12
17	HAWK053	Upper HN, City of Lithgow	Coxs R	Track off Newnes Rd	-33.3800	150.0798	2	Culvert - Pipe	V	Remove / Box culvert with low flow cells	10
18	HAWK015	Lower HN, Hawkesbury City	Webbs Ck	Webbs Creek Rd	-33.3217	150.9075	3	Causeway	HL, S, LF	Box culvert with low flow cells	16
19	HAWK043	Lower HN, Hawkesbury City	Howes Ck	Old East Kurrajong Rd	-33.5240	150.8069	2	Causeway	D, V	Box culvert with low flow cells	6

* HL = Headloss; V = Velocity barrier; LF = Low flow depth; S = Slope >1:20; D = Woody or sediment debris; L = Light.
# This site has now been removed through the “demonstration site” of this project

Appendix E – Medium Priority Sites in the Hawkesbury-Nepean CMA

Table 10. Medium priority fish passage obstructions in the Hawkesbury-Nepean region

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
20	HAWK084	Upper HN, Goulburn Mulwaree	Wollondilly R	Private Rd off Mill Rd	-33.5858	150.9404	2	Causeway	HL, S, LF	Box culvert with low flow cells	10
21	HAWK083	Upper HN, Goulburn Mulwaree	Wollondilly R	Bulls Pit Rd	-33.1963	151.0166	2	Causeway	V	Increase culvert size and reinstate low flow cells	14
22	HAWK036	Lower HN, Blue Mountains City	Glenbrook Ck	Glenbrook Rd	-33.6312	150.8482	2	Causeway	LF	Box culvert with low flow cells	4
23	HAWK076	Upper HN, Wingecarribee Shire	Paddys R	Inverary Rd	-33.7957	150.6184	2	Causeway	S, D, V	Box culvert with low flow cells	13
24	HAWK104	Upper HN, Wingecarribee Shire	Nepean R	Private track off Tourist Rd	-33.7659	150.8596	2	Causeway	HL, LF	Remove / Replace with larger box culvert and reduce invert height	2.5
25	HAWK037	Lower HN, Penrith City	Mulgoa Ck	Martin St	-33.4333	150.9447	2	Bridge	HL, LF	Remove debris at base	11
26	HAWK034	Lower HN, Blacktown City	Eastern Ck	Reserve Rd off Knox Rd	-33.8080	150.6543	2	Causeway	HL, D, V, L	Maintenance / Replace with box culvert	8
27	HAWK020	Lower HN, Shire of Baulkham Hills	O'Haras Ck	Midden Valley Rd	-33.6181	150.2338	3	Culvert - Pipe	D, V	Box culvert with low flow cells	3
28	HAWK031	Lower HN, Hawkesbury City	Killarney Chain of Ponds	Commercial Rd	-33.7747	150.6576	3	Causeway	HL, LF, L	Box culvert with low flow cells	6
29	HAWK022	Lower HN, Shire of Baulkham Hills	Unnamed trib of Hawkesbury R	River Rd	-33.5929	150.9444	3	Culvert - Box	L	Increase size of cells	2
30	HAWK055	Upper HN, City of Lithgow	Blackheath Ck	Blackheath Ck Rd	-33.6117	150.2421	2	Causeway	D, V	Remove	1
31	HAWK068	Lower HN, Liverpool City	South Ck	Fifteenth Ave	-33.6366	150.1363	3	Causeway	D, V	Large box culverts with low flow cells	12
32	HAWK075	Upper HN, Wingecarribee Shire	Black Bobs Ck	Private Rd off Bunnigalore Rd	-33.7088	150.2351	2	Causeway	S	Box culvert with low flow cells	55
33	HAWK105	Upper HN, Wingecarribee Shire	Nepean R	Moresby Hill Rd	-33.7322	150.2355	2	Culvert - Box	HL, D	Reduce invert height	2.5
34	HAWK077	Upper HN, Wingecarribee Shire	Paddys R	Firetrail off Old Argyle Rd	-33.7306	150.2433	2	Culvert - Pipe	D, V	Box culvert with low flow cells	18

* HL = Headloss; V = Velocity barrier; LF = Low flow depth; S = Slope >1:20; D = Woody or sediment debris; L = Light.

Appendix E – Medium Priority Sites in the Hawkesbury-Nepean CMA

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
35	HAWK008	Lower HN, Hawkesbury City	Mogo Ck	Mogo Ck Rd	-33.6740	150.1508	3	Causeway	HL	Box culvert with low flow cells	12
36	HAWK064	Upper HN, Blue Mountains City	Pulpit Hill Ck	Five Mile Creek Rd	-33.9645	150.7615	2	Causeway	HL, D, V,	Box culvert with low flow cells	4.5
37	HAWK100	Upper HN, Gouburn Mulwaree	Mulwaree R	Currawang Rd	-33.9073	150.7626	2	Causeway	V, LF	Remove	9
38	HAWK069	Lower HN, Liverpool City	Kemps Ck	Gurner Rd	-33.9098	150.7965	3	Culvert - Pipe	S, D, V	Maintenance and reduce invert height	2
39	HAWK070	Lower HN, Liverpool City	Kemps Ck	Off Elizabeth Dve	-33.8810	150.7987	3	Culvert - Pipe	D, V	Box culvert with low flow cells	3.5
40	HAWK092	Upper HN, Gouburn Mulwaree	Tarlo R	Roslyn Rd	-34.6426	150.1099	2	Culvert - Box	D	Remove redundant part of causeway	7.5
41	HAWK038	Lower HN, Penrith City	Mulgoa Ck	Mulgoa Rd	-34.6510	150.2220	2	Culvert - Pipe	D, LF	Maintenance / Install low flow cells	3
42	HAWK058	Upper HN, City of Lithgow	Long Swamp Ck	Cullenbong Rd	-34.4786	150.1930	2	Causeway	HL, V	Box culvert with low flow cells	6
43	HAWK065	Upper HN, Blue Mountains City	Megalong Ck	Megalong Valley Rd	-34.5003	149.9872	2	Causeway	HL	Reduce invert height	1
44	HAWK086	Upper HN, Gouburn Mulwaree	Wollondilly R	Murrays Flat Rd	-34.6923	149.8574	2	Causeway	V	Remediate u/s weir / Box culvert with low flow cells	0.01
45	HAWK082	Upper HN, Upper Lachlan Shire	Bridgy Ck	Mt Hannibal Rd	-34.6290	149.9345	2	Causeway	D, V	Box culvert with low flow cells	2
46	HAWK056	Upper HN, City of Lithgow	Blackheath Ck	Private Rd off Mill Ck Rd	-34.7211	149.7959	2	Causeway	S, V	Increase cell size and roughen surface	3
47	HAWK066	Upper HN, Blue Mountains City	Megalong Ck	Private Dve off Nellies Glen Rd	-34.5964	149.7608	2	Causeway	D, V	Box culvert with low flow cells	4
48	HAWK057	Upper HN, City of Lithgow	Ganbenang Ck	Ganbenang Rd	-34.8565	149.6537	2	Causeway	D, V	Box culvert with low flow cells	6
49	HAWK044	Lower HN, Shire of Baulkham Hills	O'Haras Ck	Midden Valley Rd	-34.5429	150.5824	3	Culvert - Pipe	D, V	Remediate u/s weirs / Box culvert with low flow cells	6
50	HAWK067	Lower HN, Camden	Rileys Ck	Anthony Rd	-34.5264	150.5821	4	Causeway	HL, D, V	Reduce invert height and increase cell size	3

* HL = Headloss; V = Velocity barrier; LF = Low flow depth; S = Slope >1:20; D = Woody or sediment debris; L = Light.

Appendix F – Conceptual Diagrams of Fishways Employed in Australia

The following remediation options are primarily employed on structures not requiring vehicle access (e.g. weirs or infrastructure such as water delivery pipes). Information is presented here to provide a guide on alternative remediation options, and as a guide for native fish passage requirements (fish passage is optimal when there is a maximum slope of 1:20 – 1:30, an effective depth of water to allow adult fish to pass (>200mm), the absence of headloss >100mm, the absence of long distances of high, linear velocity water).

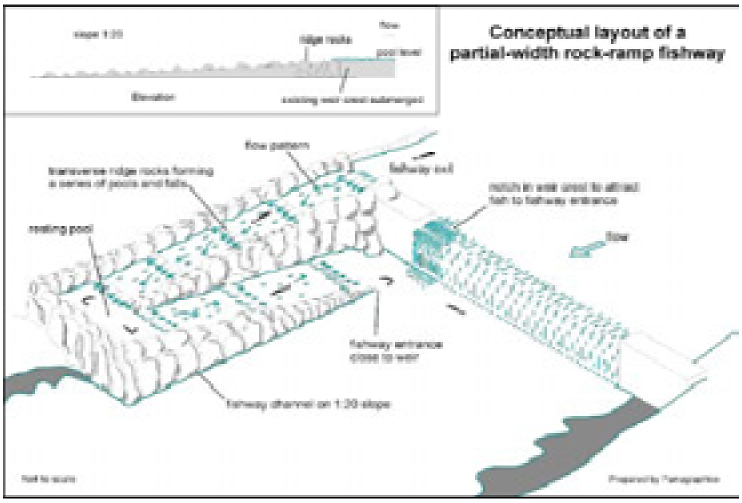
Rock ramp fishways

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.

Two variations of this form of fishway are employed in Australia – the partial width rock ramp fishway (below), and the full width rock ramp fishway. As the name implies, the partial width rock ramp fishway only extends part way across the width of a waterway, with water directed down a defined channel; whereas a full width rock ramp fishway extends the entire width of a waterway, with low flows being directed down a defined channel, and moving out from this channel as river flows increase.

In the Gloucester Shire Council LGA (Hunter/Central Rivers CMA), modified versions of the partial width rock ramp fishway have been employed at causeway road crossings, with the upstream exit of the fishway meeting the downstream edge of the road cap at a depression in the road surface. This modified fishway provides a means for fish to reach the road surface, but fish passage remains limited to rising flows when water depth across the road surface is increased.

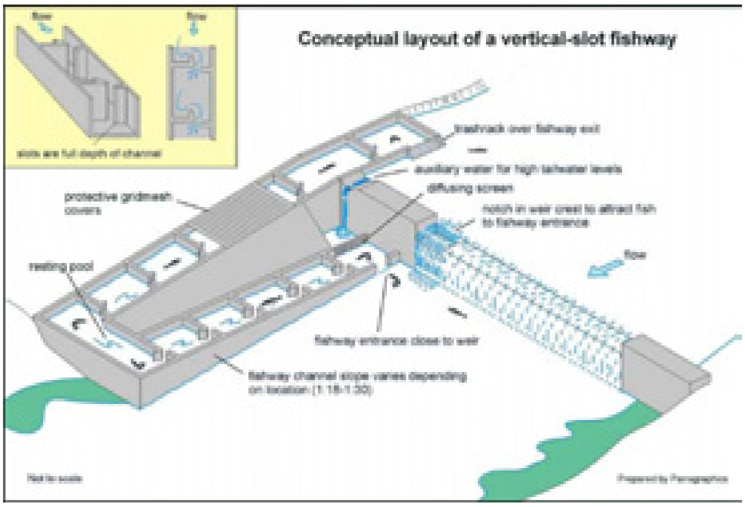


Vertical slot fishways

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.

Appendix F – Conceptual Diagrams of Fishways Employed in Australia

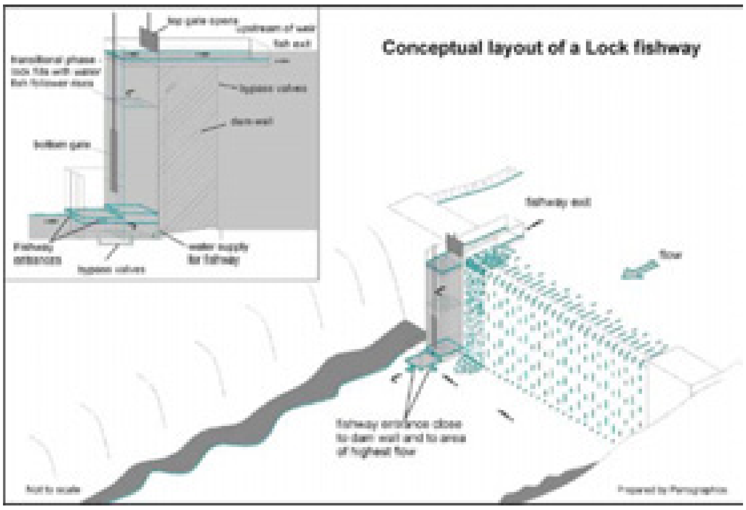
Vertical slot fishways have flexibility of operation over varying headwater and tailwater levels, as well as allowing fish to pass through the fishway at any depth. This type of fishway is more expensive than a rock ramp fishway, and requires larger volumes of water to operate.



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.

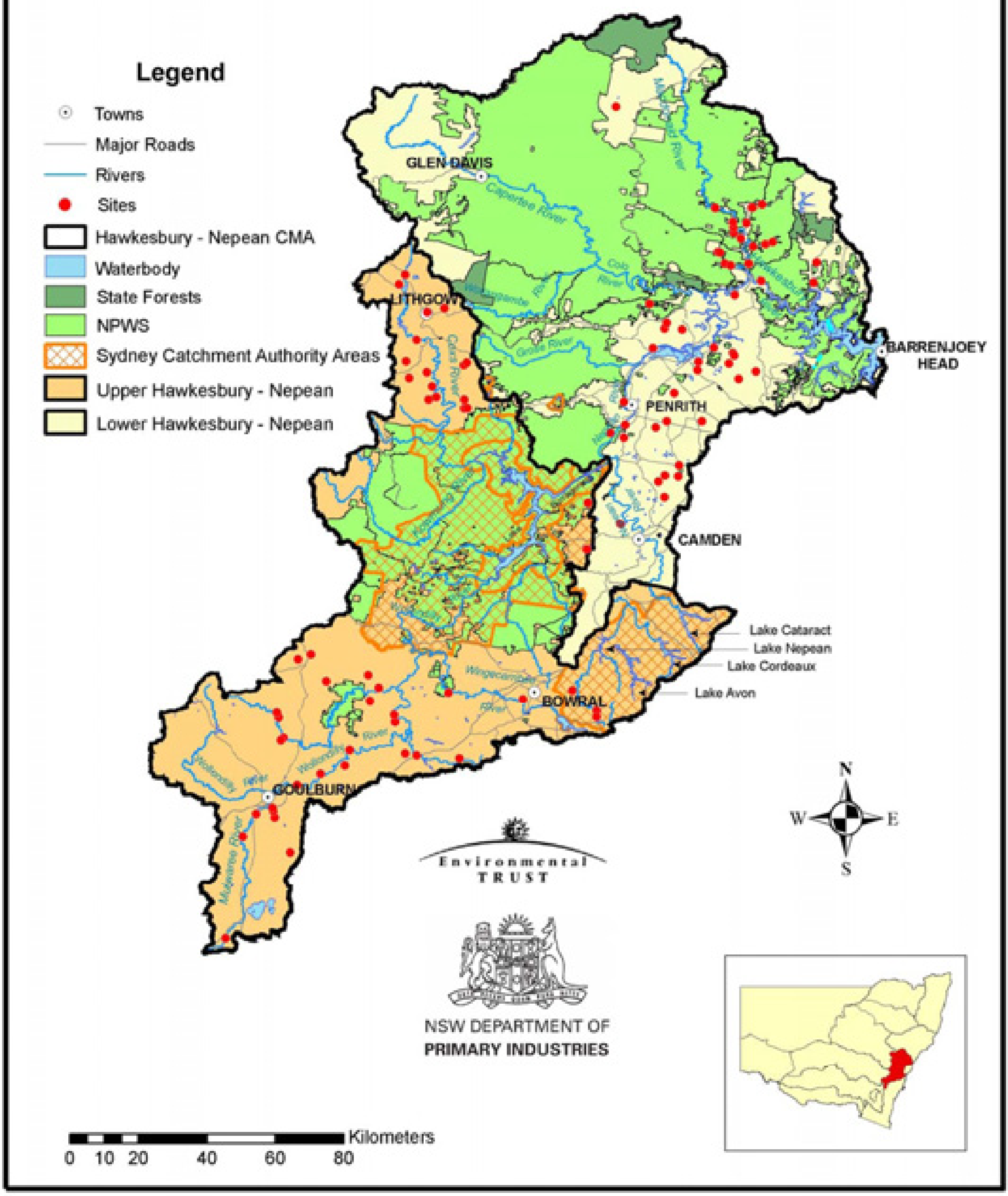
The first lock fishway in New South Wales waters was on the Murray River at Yarrawonga Weir, and has been shown to be effective in transporting fish over the 12m high weir. The Deelder fish lock (or Deelder fishway) is a variation of the lock fishway for use on lower barriers. This type of fishway is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



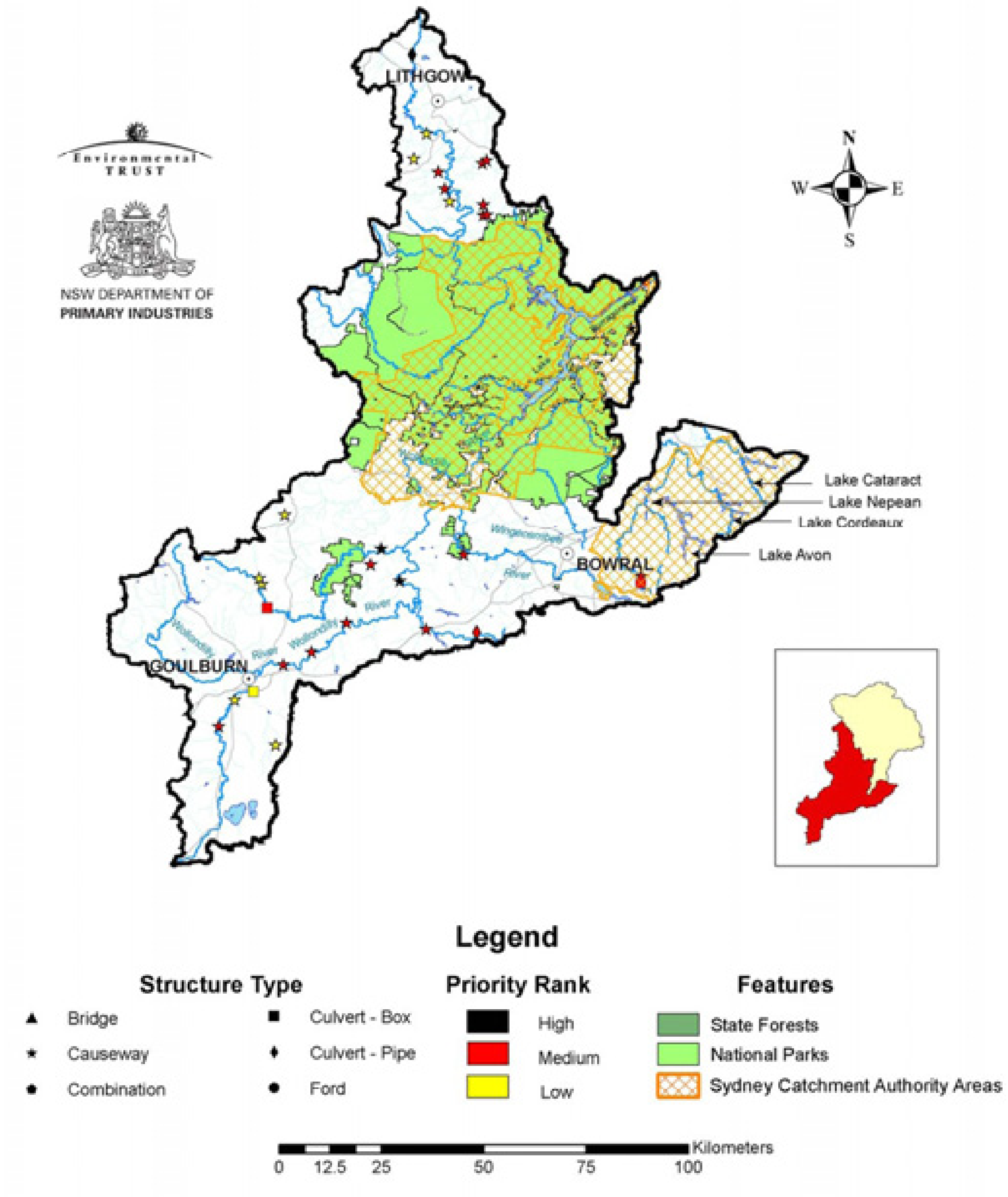
Reference:

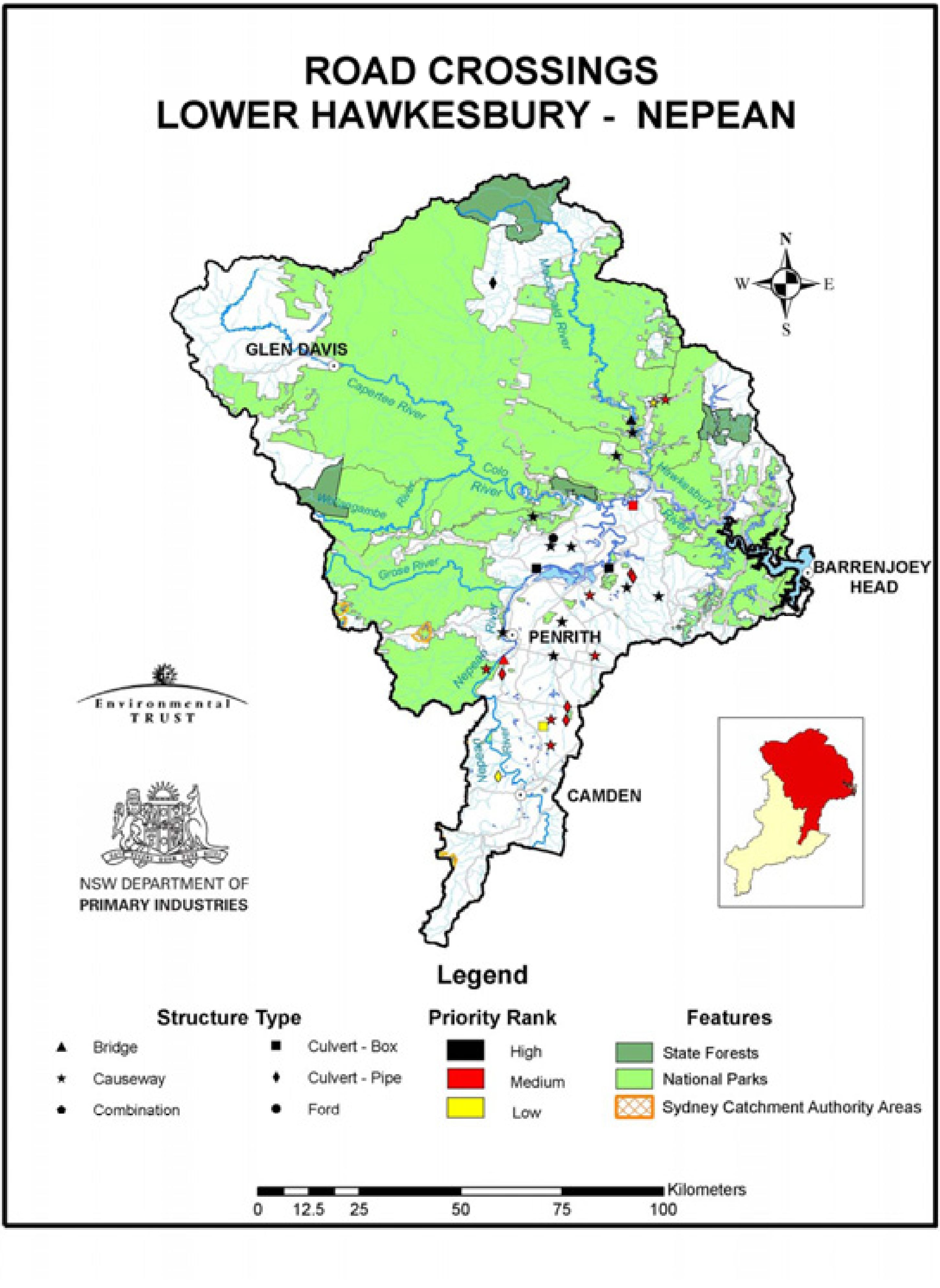
Thorncraft, G. and Harris, J.H. (2000) *Fish passage and fishways in NSW: A Status Report.* Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000.

HAWKESBURY - NEPEAN ROAD CROSSING SITES



ROAD CROSSINGS
UPPER HAWKESBURY - NEPEAN




ROAD CROSSINGS
LOWER HAWKESBURY - NEPEAN
GLEN DAVIS
Capertee River
Colo River
Wollangambe River
Grose River
Macdonald River
Hawkesbury River
Nepean River
BARRENJOEY HEAD
PENRITH
CAMDEN
N
S
E
W
Environmental TRUST
NSW DEPARTMENT OF PRIMARY INDUSTRIES
Legend
Structure Type
Bridge
Causeway
Combination
Culvert - Box
Culvert - Pipe
Ford
Priority Rank
High
Medium
Low
Features
State Forests
National Parks
Sydney Catchment Authority Areas
Kilometers
0
12.5
25
50
75
100

aquatic habitat rehabilitation

making more fish

...naturally