REDUCING THE IMPACT OF ROAD CROSSINGS ON AQUATIC HABITAT IN COASTAL WATERWAYS – HUNTER/CENTRAL RIVERS, NSW

REPORT TO THE NEW SOUTH WALES ENVIRONMENTAL TRUST

NSW DEPARTMENT OF
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Cover photo: Locketts Crossing Causeway with excessive headloss over Coolongolook River on Locketts Crossing Road (Lower North Coast subregion, Pt Stephens/Wallis Lake 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 Hunter/Central Rivers region included assessment of over 2,100 waterway crossings, with some of the primary findings including:

- 427 crossings identified as obstructions to fish passage throughout the Hunter/Central Rivers CMA region.
- 363 of these were recommended for remediation including:
    - 168 in the Lower North Coast subregion;
    - 177 in the Hunter subregion; and
    - 18 in the Central Coast subregion.
- The greatest number of obstructions to fish passage were identified within the Greater Taree City Council area (86 sites), Gloucester Shire (71 sites), Upper Hunter Shire (69 sites), and Singleton Shire (65 sites) Councils.
- Causeways were the most common type of fish passage obstruction in the Hunter/Central Rivers (70% of obstructions assessed).
- Pipe culvert crossings and box culvert crossings were also found to prevent fish passage (both being 10% of obstructions assessed) – all other structures types totalled 10% of barriers observed.
- Of structures recommended for remediation, over ¾ were causeways (76%), followed by pipe culverts (11%), and box culverts (6%) – all other structures totalled 7% of barriers recommended for action.

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 81 high priority structures identified – 47 of these (58%) being located in the Lower North Coast subregion.

Gloucester Shire and Greater Taree Councils had the greatest number of high priority sites (18 sites each), followed by Singleton Shire Council (12 sites).

The majority of high priority sites (93%) were causeways, with over half of these located in the Lower North Coast subregion (46 sites or 61%).

Eight high priority structures (causeways) were identified as being obsolete and therefore could easily be removed to remediated fish passage.

Overall, 11 sites were considered fish passage obstructions at least partly due to the presence of debris or sediment, with maintenance of these sites likely to improve fish passage prior to remediation works on the structure itself.

Overall recommendations for structure remediation include:

- 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

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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, Sarah McGirr, and Charlotte Grove. Maps were produced by Ben Maddox.

The Hunter/Central Rivers Catchment Management Authority, State Forests (Department of Primary Industries), Department of Environment and Conservation and local Councils provided advice and assistance toward the project.

CONTENTS

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 Hunter/Central Rivers Catchment Management Authority (HCRCMA), providing results of the study relevant to the Hunter/Central Rivers region. Results for the Northern Rivers, Hawkesbury-Nepean, Sydney Metropolitan, and Southern Rivers CMA regions road audit work 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 HCRCMA region.

The primary objectives and outcomes of the project were to:

- Identify and assess the impacts of road crossings on aquatic habitat within the HCRCMA;
- 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 HCRCMA region; and
- Increase awareness of the importance of fish passage and aquatic habitat management for road management authorities and the broader community.

1.1 Study area

This report outlines the project results for the HCRCMA region. The region includes all coastal (eastern) draining waterways from just north of Taree down to the coastal waterways of the Central Coast and Gosford in the south; and from Newcastle in the east to the Merriwa Plateau and Great Dividing Range in the west.

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

1) Lower North Coast subregion;
2) Hunter subregion; and the
3) Central Coast 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). In NSW, of the 55 native freshwater species, 32 are known to be migratory, requiring free passage to sustain populations (Thorncraft and Harris, 2000). 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 migratory movement 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 behavior 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 (refer Photos 1-12). '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. 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, causing increased sedimentation. An indirect

[1] See Section 7 for References

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.

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 incorporate 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 flooding, 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 thus were not included in the road crossing audit or prioritisation.

Photo 1. Causeway with high invert (headloss) and shallow water depth (Manning River, Lower North Coast subregion)

Photo 2. Pipe culvert with high invert (headloss) (Black Ck, Hunter subregion)

Photo 3. Piped crossing with inadequate sized pipes, and high invert (headloss) (Morans Ck, Central Coast subregion)

Photo 4. Bridge with scouring on downstream side creating headloss (Berrico Ck, Lower North Coast subregion)

Photo 5. Box culvert with high invert (headloss) and shallow water depth (Kerriki Ck, Lower North Coast subregion)

Photo 6. Low box culvert with steep apron (Wollombi Ck, Hunter subregion)

Photo 7. Combination structure (causeway used as low bridge base), high invert (headloss) and shallow water depth
(Firefly Ck, Lower North Coast subregion)

Photo 8. Combination structure (causeway used as low bridge base), high invert (headloss) and shallow water depth
(Belbora Ck, Lower North Coast subregion)

Photo 9. Ford with high invert (headloss)
(Berrico Ck, Lower North Coast subregion)

Photo 10. Pipe culvert with high water velocities
(Crawford R, Hunter subregion)

Photo 11. Ford crossing with high invert (headloss) and increased sediment loading
(Bullen Bullen Ck, Lower North Coast subregion)

Photo 12. Pipe culvert with excessive reed growth
(Wollumbi Ck, Hunter 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 that 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 (Gehrke 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 Hunter/Central Rivers region (see Sections 3 and 4). Other impacts (as listed above) were considered as part of the assessment process.

2.4 Waterways of the Hunter/Central Rivers region

The Hunter/Central Rivers Catchment Management Authority (CMA) region covers an area of approximately 36,000 square kilometers (sqkm). It is bounded in the west by the Great Dividing Range and Merriwa Plateau, and seaward to three nautical miles in the east. The CMA area supports a population of nearly one million people (HCRCMA, 2004), creating pressure on natural resources through direct use (such as extraction industries and farming), pollution activities (such as sewage treatment and disposal), and tourism.

The region extends from just north of Taree to Woy Woy and Brisbane Waters in the south. For reporting purposes three geographic zones (or subregions) have been identified to highlight catchment and sub-catchment issues and priorities. These are the:

- Lower North Coast subregion;
- Hunter subregion; and the
- Central Coast subregion.

Map 1 details the extent of these subregions within the Hunter/Central Rivers CMA region.

Lower North Coast subregion

The Lower North Coast subregion extends along the east coast from just north of Taree to just south of the township of Salt Ash between Nelson Bay and Newcastle, and comprises the catchments of the Manning, Myall, and Karuah Rivers, and Wallis Lake. This subregion has a total area of just less than 12,700sqkm (Lower North Coast Catchment Management Board 2003).

The Lower North Coast subregion forms part of the North Coast Bioregion, and includes the Port Stephens – Great Lakes Marine Park, and Myall Lakes Ramsar wetlands (DEC, 2004; DEC, 2006c; MPA, 2006). Established to conserve marine biological diversity and marine habitats, the Marine Park covers approximately 97,200 hectares (97.2sqkm) and extends from Cape Hawke (just south of Forster) in the north to Birubi Beach in the south (just south of Tomaree National Park boundary). The Marine Park also includes Port Stephens estuary, Karuah and Myall Rivers to their tidal limits, the Myall Lakes system, and Smiths Lake.

This subregion takes in nine local government authorities (LGAs) or parts thereof including Dungog Shire, Gloucester Shire, Great Lakes, Greater Taree City, Pt Macquarie-Hastings (part), Liverpool Plains Shire (part), Port Stephens (part), Upper Hunter Shire (part), and Walcha (part).

The major regional centres in this subregion are Taree (over 16,000 people), and Tuncurry/Forster (over 17,000 people), with smaller townships present throughout the subregion (Great Lakes Council, 2001). The region is very popular with tourists, with the population of regional centres swelling during peak periods (summer and school holidays).

The coastline is characterised by three main estuarine lake systems: Wallis Lake, Smiths Lake; the interconnected Myall Lake, Boolambayate Lake, and Bombah Broadwater; and Port Stephens (an embayment forming the mouth of the Myall and Karuah River systems). These estuarine lakes are fed by the main rivers within this subregion, with the Manning River being the only major river system that does not drain into one of these lakes. The estuarine systems support mangrove forests, seagrass meadows, diverse and abundant fish stocks, and attract large numbers of migratory birds. The majority of these estuaries also have viable recreational and commercial fisheries including finfish, and oyster farming.

The Myall Lakes system (including Myall Lake, Boolambayate Lake, and Bombah Broadwater) form the estuarine section of Myall River and is protected by the Myall Lakes National Park. Wallis Lake forms the estuarine section of the Wallamba, Wang Wauk, Coolongolook, and Wallingat Rivers and is protected by Wallingat, and Booti Booti National Parks, and Wallis Island Nature Reserve.

The Manning River catchment is the largest catchment in the Lower North Coast subregion covering an area of approximately 8,200sqkm. Major tributaries include Dingo Creek, Barnard, Nowendoc, Barrington, and Gloucester Rivers. The headwaters of the Manning River tributaries Myall, Barnard, Gloucester and Barrington Rivers are afforded some degree of protection through the presence of National Parks and State Forests in the highlands such as Woko and Barrington

Tops National Parks (Barrington Tops National Park forms part of the Central Eastern Rainforests Reserve World Heritage Area); Monkeycot and Bretti Nature Reserves; Giro, Mernot, and Barrington Tops State Forests. The remainder of the catchment mostly comprises freehold land with varying landuses including grazing, dairying and hobby farming.

The Karuah River is the second largest catchment within the Lower North Coast subregion (approximately 2,000sqkm), and, like the Manning River tributaries, has its headwaters protected to some extent through the presence of Barrington Tops National Park and Chichester State Forest.

Previous reports have recorded up to approximately 100 weirs, dams or tidal barriers other than road crossings within this area (Thorncraft and Harris, 2000; NSW Fisheries, 2002c). This number is in all likelihood much larger, due to the presence of other unlicensed structures on these waterways and road crossings, which have not previously been identified.

Hunter subregion

The Hunter subregion encompasses all the Hunter River and its tributaries and has a total area of approximately 22,000sqkm (Hunter Catchment Management Trust, 2003). As this subregion is based around a single river catchment, it has very little coastal area, with the majority of the subregion located inland.

The Hunter subregion falls across the border of both the North Coast Bioregion and the Sydney Basin Bioregions (DEC, 2004). The headwaters for the Hunter River and its tributaries the Williams, Allyn, Paterson, and Isis Rivers that run along the north eastern boundary of this subregion fall within the North Coast Bioregion. The rest of the Hunter River and its tributaries fall within the Sydney Basin Bioregion.

The region includes the major regional city of Newcastle, and several smaller townships such as Aberdeen, Branxton, Cessnock, Dungog, Kurri Kurri, Maitland, Muswellbrook, Raymond Terrace, Scone, and Singleton. The Hunter catchment is home to over 350,000 people, with over 137,000 residents in Newcastle region alone (Australian Bureau of Statistics, 2001; Hunter Catchment Management Trust, 2003).

The subregion takes in the nine local government authorities of Cessnock City, Dungog Shire, Maitland City, Mid-Western Regional, Muswellbrook Shire, Newcastle City, Port Stephens (part), Singleton Shire, and Upper Hunter Shire (part).

The main industries present within the Hunter subregion include agriculture (grazing, dairy, vineyards, hobby farms), and mining, with the Hunter River estuary supporting a general estuary fishery, and one of four estuary prawn fisheries (NSW Fisheries, 2003b; 2003c). Mining in this subregion has lead to subsidence districts along the mainstem of the Hunter River in an area beginning just west of Singleton to north of Muswellbrook, and extending west to Wybong Creek, which has the potential to disrupt flows within the Hunter and its tributaries.

The major tributaries of the Hunter River include the Wollombi (1,882sqkm), Goulburn (1,620sqkm), Williams (1,283sqkm), Pages (1,189sqkm), and Merriwa Rivers (969sqkm). The headwaters of the Hunter, and Williams Rivers both begin in or near Barington Tops in the north east of the subregion. The headwaters of the Williams, Allyn and Paterson Rivers are located in Barrington Tops National Park, and Chichester and Masseys State Forests, thereby protecting water quality in the formative sections of the waterways. This is in contrast to the majority of the Hunter River, which is out of reserve, with only a few minor headwater tributaries being located in Barrington Tops National Park (part of the Central Eastern Rainforests Reserve World Heritage Area).

Of the other major tributaries, the Pages and Merriwa Rivers are also predominantly out of reserve, whilst the mainstem of the Goulburn River (and some of its tributaries) and the Wollombi River catchment, which flow to the Hunter from the west (Goulburn) and south (Wollombi) are well protected through the presence of Goulburn River, Wollemi and Yengo National Parks; and Pokolbin, Corrabare and Watagan State Forests. Parts of these headwaters also fall within the Greater Blue Mountains World Heritage Area.

The Hunter River estuary supports extensive stands of mangroves and saltmarsh, and some *Ruppia* sp. sea grass meadows. Within the Hunter River estuary lie two wetland areas that have been designated Ramsar wetlands – together known as the "Hunter Estuary Wetlands" in recognition of their importance as habitat for migratory shorebirds, and rarity of vegetation complex type within the Sydney Basin Bioregion.

Over 300 weirs, dams, regulating structures or tidal barriers other than road crossings within this area have been identified in previous reports, and have the potential to impact fish movement within the catchment (Thorncraft and Harris, 2000; NSW Fisheries, 2002b). This number is in all likelihood much larger, due to the presence of other unlicensed structures on these waterways and road crossings, which have not previously been identified. Major dams within the Hunter subregion include Glenbawn, Glennies Creek, Lostock, Chichester, Liddel and Grahamstown dams (NSW Fisheries, 2002b), and form major barriers to fish passage on the waterways where they occur.

Central Coast subregion

The Central Coast subregion is the smallest of the three within the Hunter/Central Rivers CMA region (total area of approximately 1,600sqkm), and extends along the coast from the southern outskirts of Newcastle in the north to Brisbane Water in the south. This subregion is within the Sydney Basin Bioregion (DEC, 2004), and comprises the catchments of the estuarine lake systems of Lake Macquarie, Tuggerah Lakes, and Brisbane Water.

The subregion takes in the three local government authorities of Gosford City, Lake Macquarie City, and Wyong Shire, and includes the towns of Gosford, Wyong, Corranbong, Kilcare, Morisset, Terrigal, The Entrance, Swansea, and Woy Woy, all of which are focussed on the coastal and lake systems. The population of the Central Coast subregion is over 480,000 people, with this number greatly increased during school holidays and weekends (CCCMB, 2003).

Despite the population pressures on this subregion, approximately 58% of the Central Coast remains vegetated. The main industries for the region include mining, power generation, agriculture, forestry, and tourism related service industries (CCCMB, 2003).

The largest catchment within the Central Coast subregion is Tuggerah Lakes (approximately 809sqkm), which includes the major tributaries of Wyong River (approximately 250sqkm), Ourimbah Creek (approximately 150sqkm), and Jilliby Jilliby Creek (approximately 100sqkm). Much of the headwaters of these creeks, and several of their tributaries are within Watagans National Park; Olney, Wyong, and Ourimbah State Forests; or Jilliby State Conservation Reserve, and are therefore protected from development and have minimal pressures on their catchments.

The second largest catchment within the Central Coast subregion is Lake Macquarie (777sqkm), which has several small creek tributaries, the headwaters of some being located within State Forests (Heaton, Awaba, Watagan and Olney), and Watagans National Park.

The estuarine systems of Lake Macquarie, Tuggerah Lake, and Brisbane Water support mangrove forests, seagrass meadows, and saltmarsh communities which, as with the coastal lakes of the Lower North Coast subregion, provide habitat for diverse and abundant fish stocks, and attract large numbers of migratory birds. All these estuaries have viable recreational fisheries, with Tuggerah Lakes, Brisbane Water, and the smaller Wamberal, Terrigal, Avoca, and Cockrone Lakes also having a commercial estuary general fishery that allows the taking of finfish, shellfish, squid, octopus and beach worms (NSW Fisheries 2003c).

Previous reports have recorded up to approximately 69 weirs, dams or tidal barriers other than road crossings within this area (Thorncraft and Harris, 2000; NSW Fisheries, 2002a). This number is in all likelihood much larger, due to the presence of other unlicensed structures on these waterways and road crossings, which have not previously been identified.

Map 1. Hunter/Central Rivers CMA subregions.

2.5 Aquatic biodiversity in the Hunter/Central Rivers region

The aquatic habitats of the Hunter/Central Rivers region comprise freshwater, estuarine and marine environments. From montane streams to lowland floodplain wetlands and coastal lagoons, the extensive range of aquatic habitats supports a diverse assemblage of aquatic species including over 52 finfish species that inhabit freshwater and/or estuarine systems for at least part of their lives (refer Appendix A). The region supports an array of aquatic invertebrates including insects, prawns, crayfish and freshwater mussels, with the northern distribution of the threatened Adams emerald dragonfly (*Archaeophya adamsi*) potentially occurring within waterways of the Central Coast and southern Hunter subregions.

Estuaries within the North Coast Bioregion (within the Lower North Coast subregion) are characterised by mangrove communities and saltmarsh species, with freshwater margins dominated by swamp oak (*Casuarina glauca*) and paperbark (*Melaleuca quinquenervia*). Alluvial flats are occupied by flooded gum (*Eucalyptus grandis*) (DEC, 2004). Estuaries in the Sydney Basin Bioregion (remainder of the Hunter/Central Rivers area) are similar to those in the North Coast Bioregion, but with common reed (*Phragmites australis*) dividing swamp oak and salt marsh communities, and with dynamic boundaries to all these communities due to modern geomorphic processes. Riparian vegetation in this part of the Sydney Basin Bioregion is dominated by river oak (*Casuarina cunninghamiana*) and River red gum (*Eucalyptus camaldulensis*) (DEC, 2004).

The Hunter/Central Rivers region includes key protected estuarine and marine species such as the threatened Black cod (*Epinephelus daemelii*), Weedy seadragon (*Phyllopteryx taeniolatus*), and Estuary cod (*Epinephelus coioides*). It also potentially has remnant populations of the endangered estuary inhabiting Green sawfish (*Pristis zijsron*)[2], although the most recent confirmed record for this species is in 1972 from the Clarence River on the north coast of NSW.

58 species of frog are found in the region including five endangered species (Green and golden bell frog, Giant barred frog, Stuttering frog, Booroolong frog, and the Tusked frog population from Nandewar and New England Tablelands Bioregions [from the upper reaches of a tributary to the Manning River]), and eight vulnerable species (Davies' Tree Frog, Green-thighed Frog, Giant Burrowing Frog, Glandular Frog, Littlejohn's Tree Frog, Red-crowned Toadlet, Sphagnum Frog, and Wallum Froglet) (DEC, 2006b). The introduced invasive Cane toad (*Bufo marinus*) has been recorded from the near Taree in northern part of the Hunter Central Rivers region (DEC, 2006b), and could further increase pressure on native species through predation and competition for food and resources.

Many reptiles are also found in wetlands within the region including skinks, snakes, water dragons and two species of freshwater turtle (the common Eastern long-necked turtle, *Chelodina longicollis*; and a single record of the Brisbane River short-necked turtle, *Emydura macquarii signata*, from the upper Hunter River). In addition, Platypus (*Ornithorhynchus anatinus*), Water rats (*Hydromys chrysogaster*), and Swamp rats (*Rattus lutreolus*) - mammals specialised for freshwater aquatic habitats - can be found in and around many waterways within the region (DEC, 2006b).

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

Many freshwater and estuarine habitats are essential for conserving aquatic biodiversity and have been listed as Endangered Ecological Communities[3] (EECs) in recognition of their rarity, vulnerability and their importance as both aquatic and terrestrial habitat. These include river and floodplain communities in the Hunter/Central Rivers such as: Coastal saltmarsh, Freshwater wetlands on coastal floodplains, Hunter lowland redgum forest, Kurri sand swamp woodland, Montane peatlands and swamps, Coastal floodplains, Swamp oak floodplain forest, and Swamp Sclerophyll forest on coastal floodplains. Within the lower Hunter River, and potentially within other waterways of the Hunter/Central Rivers, an endangered submerged aquatic plant species

[2] Listed under the NSW *Threatened Species Conservation Act* 1995.
[3] Listed under the NSW *Threatened Species Conservation Act* 1995.

has been found. This small plant, *Zannichellia palustris*, grows in fresh or slightly saline stationary or slowly flowing water, and dies back every summer (DEC, 2006a).

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 artificial structures being erected. For example, the EEC freshwater wetlands on coastal floodplains have markedly reduced in size and distribution due to clearing and modification, with less than 66% remaining (3,500ha in the mid 1990s) within the Hunter Central Rivers region (DEC, 2006a).

In order to conserve some of these fragmented and stressed communities, several areas within the Hunter/Central rivers region have been placed within reserves or provided with protective legislation. For example, the Myall Lakes system in the Lower North Coast subregion is both within the Myall Lakes National Park, and is listed as a Wetland of International Importance under the 1971 Ramsar Convention in recognition of its importance to migratory waterfowl, its diversity of vegetation, and as a very good example of a coastal barrier lagoon system (DEC, 2006c). Within the Hunter subregion, the Hunter Estuary Wetlands, comprising two wetland areas: those within the Kooragang Nature Reserve, and the “Shortland Wetlands”, are also listed under the Ramsar convention due to their uniqueness, and as refuge to migratory birds (DEC, 2006c).

As with legislative protective measures, aquatic habitat rehabilitation, and in particular reinstating stream connectivity, is essential for maintaining aquatic biodiversity and protecting the integrity of rivers, lakes and wetlands in coastal NSW that are both inside and out of the reserve systems. 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 *et al.* (1996); Pethebridge *et al*. (1998); and Thorncraft and Harris (2000). 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 crossings sites identified through the following desktop assessments:

a) Assessment of 1:25,000 topographic maps for the Hunter/Central Rivers 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).

Over 2,100 sites were initially identified for assessment in the Hunter/Central Rivers region, although sites within marginal habitat (ephemeral streams, headwaters or upland swamps) were removed from this initial list.

Fieldwork in the Hunter/Central Rivers region was conducted from April 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) were also determined.

Location details (GPS readings or map grid references) were also recorded and digital photographs taken for each site. All data recorded in the road crossing audit was downloaded into the 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 is still in use).

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

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 summing all four criteria. The prioritisation process was applied to all road crossings within the Hunter/Central Rivers 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, and trends and priorities for subregions and LGAs.

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 sheer number of road crossings in the Hunter/Central Rivers 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 in this study in coastal draining waterways of NSW were causeways and pipe culverts, with box culverts and fords also commonly acting as barriers to fish passage.

4.2 Types of road crossing obstructions in the Hunter/Central Rivers region

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

Over 2,100 sites were visited in the Hunter/Central Rivers region. Of these, a total of 427 road crossings were identified as obstructions to fish passage, with 363 structures recommended for remediation (refer Appendix F – Map 2).

Several types of road crossings were assessed in the study including causeways, fords, pipe culverts, box culverts and bridges. Several sites identified had combination designs – for example, low wood bridges placed on top of causeways. Within the Hunter/Central Rivers region, the most common road crossing barriers identified were causeways (70% of all structures identified), with box culverts and pipe culverts being the next most common barrier types (each being 10% of all barriers respectively) – refer Figure 1.

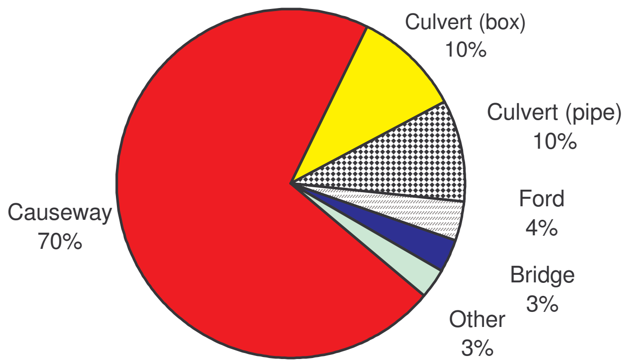

Figure 1. Structure types identified as fish passage barriers in the Hunter/Central Rivers region.

Of the structures with recommended remediation actions, 76% of sites were causeways (276 sites), 11% were pipe culverts (40 sites), and 6% were box culverts (23 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 Hunter/Central Rivers region. The remaining structure types (fords, bridges, and "other" together comprised 6% of all sites (24 sites).

Causeways, pipe culverts, and fords 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 act as fish passage barriers than other structure types due to the formation of sheet flow across causeways (lack of flow depth); the presence of high, linear, water velocities through pipes; and the creation of a waterfall effect on the downstream side of a causeway and a pipe culvert if the pipe is set incorrectly (above bed level). It is for these reasons that a greater number of causeways and pipe culverts were identified as fish passage barriers than other structures within the Hunter/Central Rivers.

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 fish 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 each of the four subregions.

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

	Central Coast subregion		*Hunter subregion*		*Lower North Coast*		*TOTAL*	
Fish Passage Obstructions	Tot+	RR*	Tot+	RR*	Tot+	RR*	Tot+	RR*
Causeway	5	5	153	126	146	145	304	276
Ford	1	1	9	3	5	4	15	8
Culvert (box)	11	6	27	15	4	2	42	23
Culvert (pipe)	6	6	32	32	3	2	41	40
Bridge	6	0	2	1	5	5	16	9
Combination structure/other	0	0	0	0	12	10	9	7
TOTAL	**29**	**18**	**223**	**177**	**175**	**168**	**427**	**363**

+ 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 reflected the size of the subregion. The Hunter subregion covers the largest area within the Hunter/Central Rivers region (approximately 21,452sqkm), and has the greatest number of structures both identified as fish passage barriers, and recommended for remediation (223 and 177 structures respectively). Only a couple of these structures were located on the mainstem of the Hunter River, or its major tributary - the Goulburn River; with nearly all problem sites located on the smaller tributaries to both of these rivers, and in the mid to upper reaches of these waterways. In these locations, causeways and pipe culverts are likely to dominate structure type, due to their lesser cost, and ease of construction.

Within the Hunter subregion, the major barrier types identified were causeways, followed by pipe and box culverts. A similar trend was present for those sites recommended for remediation, although causeways (126 sites) were four times more common than pipe culverts (32 sites), and eight and a half times more problematic than box culverts (15 sites).

The Central Coast subregion (1,603sqkm) is nearly 14 times smaller than the Hunter subregion, and has approximately eight times fewer sites identified (29 sites), with nearly ten times fewer sites recommended for remediation than the Hunter subregion (18 sites). Waterways within this subregion are generally smaller in length than those in the Hunter and Lower North Coast subregions, due to the catchment size. Despite the smaller size of the waterways, it is likely that there is a greater requirement for road crossings to remain dry for the majority of the time within this subregion due to the populous nature of the catchment. This may therefore have lead to the use of a greater number of box culverts, which may have been installed incorrectly, and led to larger number of these structures forming problems within this subregion.

Within the Central Coast subregion, the major barrier types identified were box culverts (11 sites), with pipe culverts (6 sites), bridges (6 sites), and causeways (5 sites) also relatively common. When structures were recommended for remediation, problem structures were spread evenly between these types, with 6 box culverts and 6 pipe culverts recommended for action, followed by 5 causeways. No bridges were recommended for action within this subregion.

The Lower North Coast subregion (12,664sqkm) is half the size of the Hunter subregion, and nearly eight times larger than the Central Coast subregion. Despite being half its size, the Lower North Coast subregion was found to have a comparable number of barriers identified and recommended for action as the Hunter subregion (175 and 168 structures respectively), indicating it is comparably more affected by faulty road crossings than the Hunter.

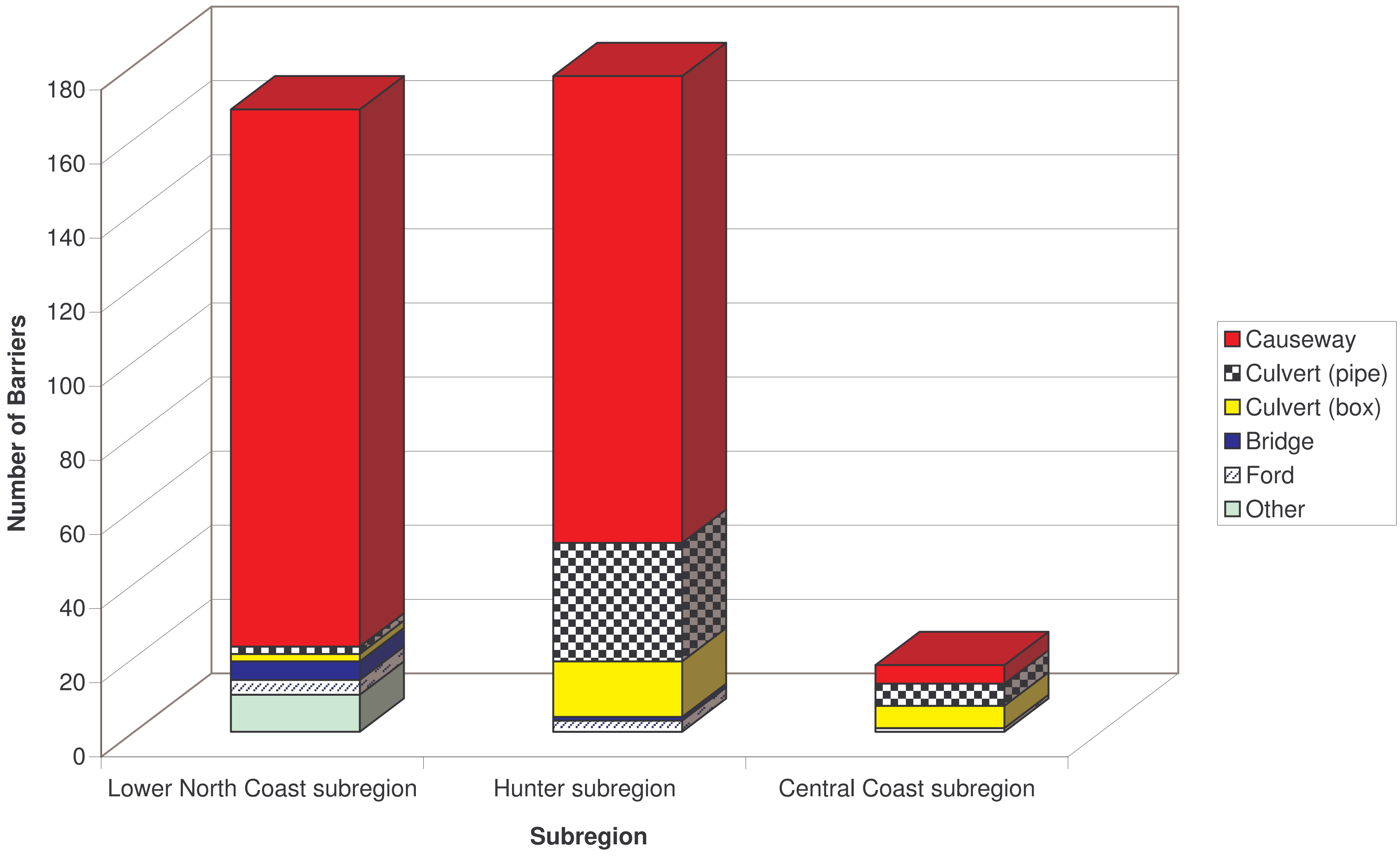

Figure 2. Fish passage obstructions with recommended remedial actions in Hunter/Central Rivers CMA subregions.

As with the Hunter, causeways were also the most prevalent fish passage barrier in the Lower North Coast subregion (146 sites identified, 145 recommended for remedial action), with all other structures types totalling less than ten sites each. Of the remaining structure types, “combination structures” (low wood bridges built over a causeway base), and bridges with a concrete base, were the most common barrier type (10 and 5 structures respectively recommended for action).

4.4 Summary of road crossing results by LGA

This project assessed over 2,100 road crossing sites across the 21 LGAs that comprise the Hunter/Central Rivers CMA region (nearly 36,000sqkm). From the sites assessed, 427 were identified as fish passage obstructions. Seven local government authorities were found to have no fish passage obstructions recorded (Hawkesbury City, Liverpool Plains Shire, Newcastle City, Port Macquarie-Hastings, Tamworth Regional, Walcha, and Warrumbungle Shire). In addition, many structures were deemed to have a negligible impact on fish movement, leaving 363 structures identified as requiring some form of remedial action.

Table 2 outlines the percentage area of each LGA within the Hunter/Central Rivers CMA region, the number of sites identified as obstructions in each, and the number of sites recommended for remediation.

Table 2. Waterway crossing assessments by LGA - Hunter/Central Rivers 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
Cessnock City	1,585	4.41	30	22
Dungog Shire	2,249	6.26	28	25
Gloucester Shire	2,949	8.21	71	70
Gosford City	270	0.75	2	2
Great Lakes	3,371	9.38	18	17
Greater Taree City	3,336	9.28	86	81
Hawkesbury City	0.17	0.00	0	0
Lake Macquarie City	750	2.09	18	14
Liverpool Plains Shire	14	0.04	0	0
Maitland City	392	1.09	3	2
Mid-Western Regional	2,309	6.43	5	4
Muswellbrook Shire	3,404	9.48	20	13
Newcastle City	215	0.60	0	0
Port Macquarie-Hastings	109	0.30	0	0
Port Stephens	972	2.70	2	2
Singleton Shire	3,430	9.55	65	52
Tamworth Regional	343	0.95	0	0
Upper Hunter Shire	7,976	22.20	69	56
Walcha	1,432	3.96	0	0
Warrumbungle Shire	3	0.01	0	0
Wyong Shire	824	2.29	10	3
TOTAL	**35,933.17**	**100%**	**427**	**363**

The greatest number of obstructions to fish passage were identified within the Greater Taree City Council area (86 sites), followed by Gloucester Shire (71 sites), Upper Hunter Shire (69 sites), and Singleton Shire (65 sites) local government authorities.

The number of barriers identified within these LGAs is likely to partly reflect the size of each LGA, with the aforementioned LGAs being within the top six LGAs by size, but also the nature of the catchments within these LGAs. Upper Hunter Shire Council has the largest council area within the Hunter/Central Rivers CMA region (7,975sqkm or 22.2%). This is over double the size of Singleton Shire LGA, which is the next largest (3,430sqkm or 9.55%), and has a comparable area to Muswellbrook Shire, Great Lakes, Greater Taree City, and Gloucester Shire LGAs within the Hunter/Central Rivers CMA region.

When looking at the number of structures identified as obstructions within each LGA, and comparing them with structure type, the total number of obstructions within an LGA are driven by the presence of causeways. All top four local government authorities mentioned above have far greater number of causeways than any other structure type within their LGA. This trend is also true for Dungog Shire, Great Lakes, and Muswellbrook Shire Councils.

Within the Hunter/Central Rivers area, there are a large number of small waterways present, with even the larger waterways often being shallow in nature. In these smaller and shallower waterways, causeways and pipe culverts are cheaper to construct, and are therefore likely to be more commonplace. As discussed earlier, they are also more likely to form fish passage barriers than other structure types, resulting in a greater number of problem sites being identified within the above LGAs.

As shown in Figure 3, the greatest number of sites recommended for remedial action were also within the Greater Taree City LGA (81 sites), again followed by Gloucester Shire (70 sites), Upper Hunter Shire (56 sites), and Singleton Shire (52 sites) local government areas. The total number of structures identified as requiring remediation was also driven by the presence of causeways within these LGAs.

The lowest number of sites identified as fish passage barriers (2 sites each) and recommended for remediation action were within Gosford City and Port Stephens LGAs, which together comprise 1,242sqkm (3.45%) of the Hunter/Central Rivers CMA area. Other LGAs with low numbers of structures identified as fish passage barriers were Maitland City (3 sites), Mid-Western Regional (5 sites), and Wyong Shire (10 sites). The number of sites within these LGAs that were recommended for remedial action followed the following order: Gosford City, Port Stephens, Maitland City (all 2 sites), Wyong Shire (3 sites), and Mid-Western Regional (4 sites). All these LGAs cover small areas within the Hunter/Central Rivers region as a whole, except Mid-Western Regional Council, which covers an area of approximately 2,309sqkm. A reason for this LGA having so few obstructions and therefore so few requiring remediation may be due to the presence of large areas of National Parks (Golburn River and Wollomi) within this LGA, which would reduce potential human impacts on waterways within the area.

A range of remediation options have been suggested for fish passage barrier sites identified in this study 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.

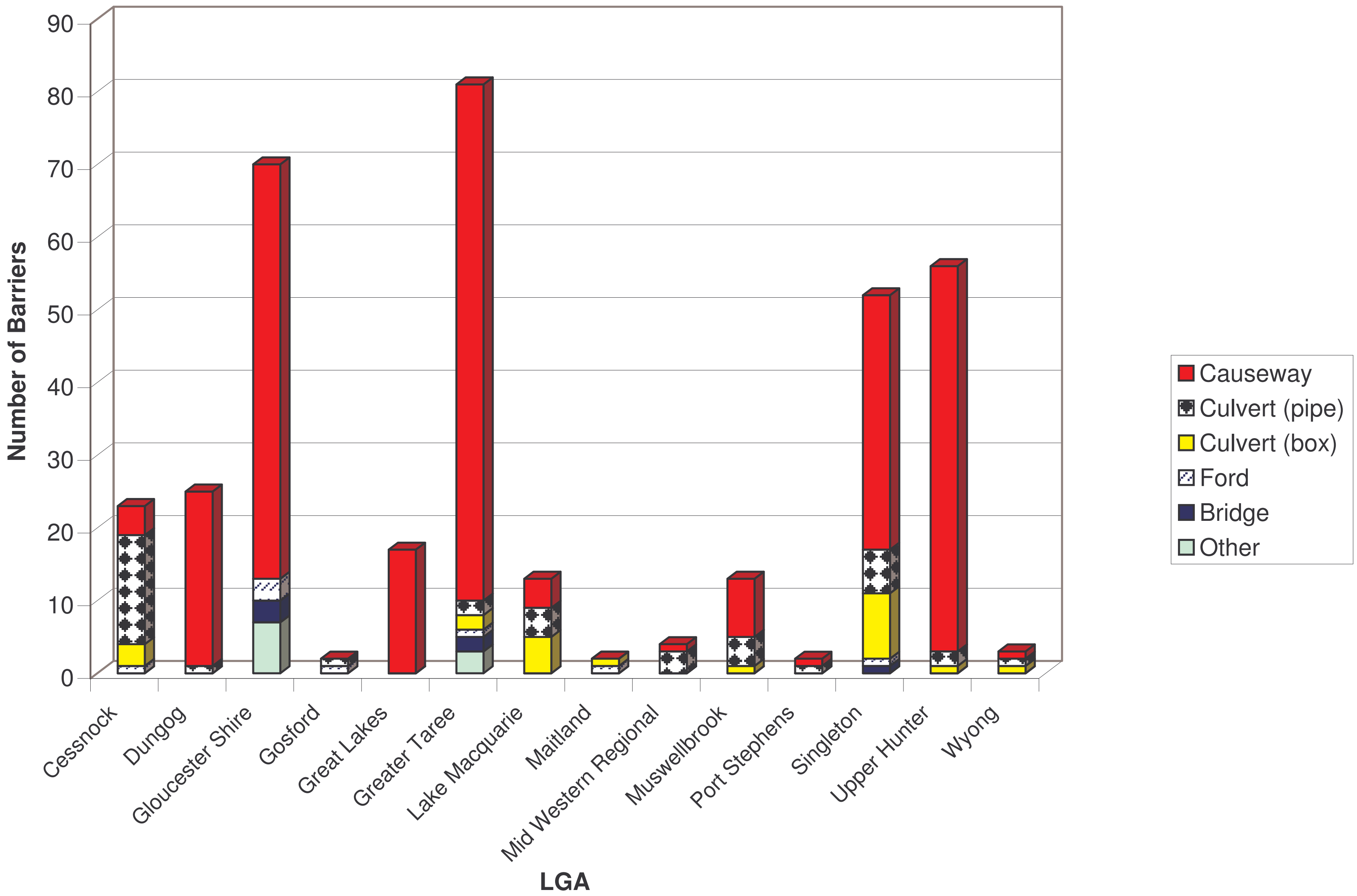

Figure 3. Actioned structure types identified as fish passage barriers in the Hunter/Central Rivers region by local government authority (LGA).

4.5 Hunter/Central Rivers road crossing remediation priorities by subregion

Setting goals and targets for aquatic habitat rehabilitation in the Hunter/Central Rivers 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 Hunter/Central Rivers.

This section of the report presents the major findings of this study on a subregion and local government area basis, highlighting regional priorities for fish passage remediation.

All 363 instream structures that were recommended for remediation were determined as either 'high', 'medium' or 'low' priority sites according to an objective prioritisation process (refer to Appendix F: Subregion Maps 3-5). This process resulted in 81 sites being determined as high priority and 110 sites as medium priority (Table 3): all other sites (172 sites) were regarded as having lesser importance with regard to fish passage in the Hunter/Central Rivers 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 owners maintenance schedules and remediated when possible.

Table 3. High and medium priority sites – Hunter/Central Rivers subregions

Subregion	High Priority	Medium Priority
Central Coast	3	8
Hunter	31	51
Lower North Coast	47	51
TOTAL	**81**	**110**

As shown in Table 3, the majority of high priority sites were found in the Lower North Coast subregion. Medium priority sites were evenly distributed between the Hunter and Lower North Coast subregions.

Of the high priority sites, 24 (30%) were located in lower part of the catchment, close to (or within) the vicinity of tidal influence. Nearly all of the remaining sites were in the middle part of the catchment (56 sites or 69%), with only one high priority site located in the upper section.

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 and anadromous[4] 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. In addition, in the lower part of a catchment, there is likely to be a lesser number of barriers located downstream of a problematic site, therefore increasing the importance of remediating that site. Of the high priority sites, 34 (42%) were the lowest barrier within the system, whilst 32 sites (40%) had only one or two barriers downstream of the site.

Within the Hunter/Central Rivers CMA region, no rare or threatened freshwater aquatic species are known to occur. Historically the endangered Oxleyan pygmy perch (*Nannoperca oxleyana*) is thought to have occurred within NSW from Tweed Heads to the waterways of the Manning estuary; whilst the Federally listed threatened Australian grayling (*Prototroctes maraena*) may have been found within Brisbane Water, Ourimbah Creek, Wyong River, and the Tuggerah Lake systems. Presently there are no current records of either species within the Hunter/Central Rivers region, but there are recent records of Australian grayling from the Hawkesbury River and its tributaries.

[4] *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.

The Australian grayling migrates as part of its life cycle – being an amphidromous[5] species (juveniles return upstream to freshwater habitats after being swept downstream as larvae). One reason for the decline of the Australian grayling is thought to be 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. With continued remediation of structures that are acting as fish passage barriers, combined with riparian and instream habitat restoration, it is possible that the Australian grayling population(s) within the Hawkesbury River will again recolonise the waterways within the Central Coast subregion.

Throughout the Hunter/Central Rivers region, the vast majority of high priority structures (96%) were found outside of protected areas and on rural land or other landuse. The three remaining high priority sites were all within State Forest Reserve. Of the medium priority sites, again 97% were located outside of protected areas, with only one site each located in a National Park, State Forest, and a regional reserve. This indicates that nearly all high and medium priority structures are present on property managed by local Council or private landholders.

4.6 Hunter/Central Rivers road crossing remediation priorities by LGA

When viewing the spread of high and medium priority sites by LGA (Table 4), it can be seen that the greatest number of high priority sites were located within the Gloucester Shire, and Greater Taree Council areas (18 sites each), followed by Singleton Shire Council area (12 sites).

These three LGAs are located within the mid-lower reaches of the Manning and Hunter Rivers, where structures located within waterways of good quality habitat are likely to have a greater impact on migratory fish species than those located higher in the catchment, and hence are likely to become a higher priority for remediation.

Table 4. High and medium priority sites – LGAs in the Hunter/Central Rivers region

Local Government Authority (LGA)	High Priority	Medium Priority
Cessnock City	2	7
Dungog Shire	8	14
Gloucester Shire	18	23
Gosford City	0	1
Great Lakes	11	5
Greater Taree City	18	23
Lake Macquarie City	2	7
Maitland City	0	2
Muswellbrook Shire	3	3
Port Stephens	1	1
Singleton Shire	12	6
Upper Hunter Shire	5	18
Wyong Shire	1	0
TOTAL	**81**	**110**

The greatest number of medium priority sites were also located in Gloucester Shire and Greater Taree Councils (23 sites each), with the Upper Hunter Council and Dungog Shire Councils also having a large number of sites (18 and 14 medium priority sites respectively).

No high or medium priority sites were recorded from Mid-Western Regional LGA (sites within this LGA were regarded as low priority sites).

Appendix D lists the all high priority sites for the Hunter/Central Rivers region, with a subset below.

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

4.7 Hunter/Central Rivers road crossing remediation options and top priority sites

Table 5 outlines the top 20 priority sites within the Hunter/Central Rivers region and their recommended management actions.

Of the high priority sites identified in Hunter/Central Rivers region, nearly all of the high and medium priority structures were found to be causeways (75 high priority [93%], 88 medium [80%] priority structures), with only 4 pipe culverts and 2 box culverts considered high priority sites. The remaining medium priority structure types all numbered less than 7 structures each (7 box culverts, 6 pipe culverts, 6 fords, 3 bridges, and 2 combination structures [low wood bridge over a causeway]).

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 likely only to be a problem for causeway structures where water moves across the surface of the structure. A headloss barrier can occur for all structure types due to the lack of low flow sections or cells within a structure, or the formation of scour pools on the downstream side of the structure (thus increasing headloss). Velocity barriers can occur within pipe or box 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 5. Top 20 priority sites – Hunter/Central Rivers region

Rank	Crossing ID	Waterway/ Subcatchment	Structure Type	Road Name	Recommendation
1	HUNT408	Coolongolook River	Causeway	Locketts Crossing Rd	Bridge / box culvert with multiple low flow cells
2	HUNT276	Manning River	Causeway	Private Road off Walcha Rd	Box culvert with multiple low flow cells
3	HUNT172	Cromarty Creek	Causeway	Private Road off Lemon Grove Rd	Bridge / box culvert with multiple low flow cells
4	HUNT396	Cooplacurripa River	Causeway	Private Road off Nowendoc Rd	Clear sediment / Box culvert with low flow cell
5	HUNT233	Telegherry River	Causeway	Moores Creek Rd	Box culvert with low flow cell
6	HUNT415	Wang Wauk River	Causeway	Smedleys Cutting Rd	Box culvert with low flow cell
7	HUNT407	Wallamba River	Causeway	Clarksons Crossing Rd	Remove / partial width rock ramp fishway
8	HUNT268	Bowman River	Causeway	Bowman Farm Rd	Bridge / remove apron and install box culvert with multiple low flow cells
9	HUNT403	Wallamba River	Causeway	Wellers Lane	Box culvert with multiple low flow cells
10	HUNT275	Manning River	Causeway	Private Road off Walcha Rd	Bridge / remove apron and install box culvert with multiple low flow cells
11	HUNT381	Paterson River	Causeway	Private Road off Cross Keys Rd	Box culvert with multiple low flow cells
12	HUNT380	Paterson River	Causeway	Cross Keys Rd	Box culvert with multiple low flow cells or rock ramp fishway
13	HUNT223	Tumbledown Creek	Causeway	Private Road off Langlands Rd	Investigate removal / Install more cells (with low flow cell)
14	HUNT416	Paterson River	Causeway	Private Road following Paterson R upstream of Lostock Dam	Box culvert with multiple low flow cells
15	HUNT038	Dingo Creek	Causeway	Unnamed Road off Robinson Rd	Box culvert with low flow cell
16	HUNT278	Manning River	Causeway	Curricabark Rd	Remove
17	HUNT402	Wallamba River	Causeway	Dargavilles Rd	Remove apron and install box culvert with multiple low flow cells / rock ramp fishway
18	HUNT299	Wallamba River	Causeway	Barrys Rd	Bridge / box culvert with multiple low flow cells
19	HUNT022	Dora Creek	Causeway	Kemp Lane	Box culvert with low flow cell
20	HUNT200	Pages River	Causeway	Brushy Hill Rd	Box culvert with multiple low flow cells (structure faulty), remove upstream sediment accumulation

Of the high priority sites identified within this study, 8 sites were determined to be obsolete structures. Obsolete structures are potentially remediated more easily than structures that are still required, as they can simply be removed – often for minimal cost. 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. As part of the "demonstration site" component of this project, "Clarksons Crossing" (7th highest priority site) is being investigated for removal, and consultation with upstream landholders occurring to determine if removal of the structure will have an adverse or positive effect. Further details on demonstration sites can be found in a companion report ("*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*").

Overall (regardless of priority), 11 sites were considered fish passage obstructions at least partly due to the presence of debris (sediment build up, or plant material including large woody debris). Of these, 2 were high priority sites, whilst 4 were medium priority. In addition, 7 sites overall were a fish passage barrier at low flows due to the presence of logs placed perpendicular to the waterway. All sites causing an obstruction due to sediment, plant debris build up, or presence of logs could therefore be remediated relatively easily and cost effectively within a short time frame.

This is in contrast to 17 high priority structures identified that require more major works (and thus a significant financial contribution) to provide for fish passage. Such recommendations include the installation of a partial width rock ramp fishway, construction of a bridge, installation of multiple box culverts with low flow cells, and increasing the number of cells on structures of greater than 10m wide.

Sixty four of the high priority structures within the Hunter/Central Rivers require replacement of or complete removal of smaller structures (<10m wide). Generally works recommended for these structures include the installation of box culverts with low flow cells, increasing the number of cells, and lowering the invert of the existing structure.

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 indunated. 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*").

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 have been remediated by Gloucester Shire Council through the construction of modified partial width rock ramp fishways adjacent the crossings (Figure 5 and Appendix E). 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.

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*").

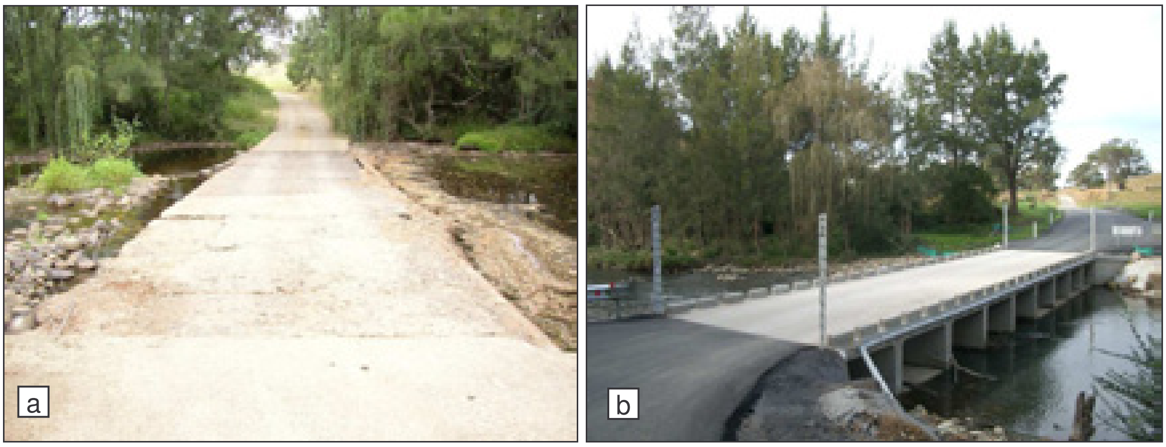

Figure 4. Dixons Crossing causeway (Karuah River) prior to (a), and following (b) remediation – note three central low flow cells.

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).

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

For sites where a road crossing is causing large amounts of sediment input, sealing of road approaches, installation of drainage diversion works, and construction of sediment control basins can limit or stop sediment input into a waterway. As part of the demonstration site component of this project, sites in the Southern Rivers CMA (Wapengo Lakes Road, Wapengo Lake), and Hawkesbury-Nepean CMA (Goodmans Ford, Wollondilly River) have been sealed, drainage diversion works installed, and sediment control basins constructed to limit sediment input into the adjacent waterways. Further information 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 Hunter/Central Rivers NSW. The following summary 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 Hunter/Central Rivers 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 sheer number of structures in the Hunter/Central Rivers 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 should 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) provides 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 8 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 approvals requirements in relation to road crossing construction, modification and maintenance in NSW can be found in:

- *Policy and Guidelines for Fish-Friendly Waterway Crossings* (NSW Fisheries, 2003a); 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 Hunter/Central Rivers 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 Hunter-Central Rivers CMA 2006*) and includes data on road crossing location information, environmental data, recommended remediation action, and photo library. 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 Hunter/Central Rivers CMA, local Government, other structure owners, and NSW DPI Fisheries (Conservation and Aquaculture) 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 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.

7. REFERENCES

Allen G.R., Midgley, S.H. and Allen M. (2002). *Field Guide to the Freshwater Fishes of Australia*. Western Australian Museum, Perth, WA.

Australian Bureau of Statistics (2001). Census of Population and Housing. Australian Bureau of Statistics, Canberra, ACT.

Baumgartner. L (In prep). *The Effects of Weirs on Fish Movements in the Murray-Darling Basin*. PhD thesis, University of Canberra, Canberra, ACT.

Big R Manufacturing LLC (2004). Super·Cor®. Website: http://www.bigrmfg.com/products/structuralplate/supercor.html, Accessed May 2006.

Central Coast Catchment Management Board [CCCMB] (2003). Integrated Catchment Management Plan for the Central Coast 2002. Department of Land and Water Conservation, Sydney, NSW.

Fairfull, S. and Witheridge, G. (2003). *Why do fish need to cross the road? Fish passage requirements for waterway crossings.* NSW Fisheries, Cronulla, NSW.

Farabi H., James R. and McCormack R.J. (2004). Mitigating the effects of forests roads on water quality by managing hydrological connections. *Proceedings of the 4th Australian Stream Management Conference*. October 2004, Launceston, Tasmania.

Gehrke, P.C., and Harris, J.H. (2001). Regional-scale effects of flow regulation on lowland riverine fish communities in New South Wales, Australia. *Regulated Rivers Research and Management*: 17, 369–391.

Great Lakes Council (2001). Great Lakes Population 2001 Census Summary Information. Community Services Branch, Great Lakes Council, Forster, NSW.

Hunter Catchment Management Trust (2003). Integrated Catchment Management Plan for the Hunter Catchment 2002. Department of Land and Water Conservation, Sydney, NSW.

Hunter/Central Rivers Catchment Management Authority [HCRCMA] (2004). NSW Hunter/Central Rivers Catchment Management Authority website. Website: http://www.hcr.cma.nsw.gov.au/, Accessed March 2006.

Lower North Coast Catchment Management Board [LNCCMB] (2003). Integrated Catchment Management Plan for the Lower North Coast 2002. Department of Land and Water Conservation, Sydney, NSW.

McDowall, R.M (1996). *Freshwater Fishes of South-eastern Australia*. Reed Books, Sydney, NSW.

NSW Department of Environment and Conservation [DEC] (2004). Bioregions of NSW, biodiversity, conservation, history. Website: http://www.nationalparks.nsw.gov.au/npws.nsf/Content/bioregions, Accessed April 2006.

NSW Department of Environment and Conservation [DEC] (2006a). Threatened species website. Website: www.threatenedspecies.environment.nsw.gov.au, Accessed April 2006.

NSW Department of Environment and Conservation [DEC] (2006b). National Parks and Wildlife Service Atlas of Wildlife. Website: http://wildlifeatlas.nationalparks.nsw.gov.au/wildlifeatlas/watlas.jsp, Accessed April 2006.

NSW Department of Environment and Conservation [DEC] (2006c). National Parks and Wildlife Service Ramsar sites in NSW. Website: http://www.nationalparks.nsw.gov.au/npws.nsf/Content/nsw_ramsar_sites, Accessed April 2006.

NSW Department of Primary Industries (2005). *Threatened Species in NSW, Green sawfish, Pristis zijsron*. Primefact Series Primefact 7, NSW Department of Primary Industries, Pt Stephens, NSW.

NSW Fisheries (1999). *Policy and Guidelines for Aquatic Habitat Management and Fish Conservation*. NSW Fisheries, Cronulla, NSW.

NSW Fisheries (2002a). *Initial Weir Review – Central Coast Catchment*. Report for the State Weir Review Committee. NSW Fisheries, Ballina, NSW.

NSW Fisheries (2002b). *Initial Weir Review – Hunter Catchment*. Report for the State Weir Review Committee. NSW Fisheries, Ballina, NSW.

NSW Fisheries (2002c). *Initial Weir Review – Lower North Coast Region*. Report for the State Weir Review Committee. NSW Fisheries, Ballina, NSW.

NSW Fisheries (2002d). *Threatened Species in NSW, Black cod, Epinephelus daemelii.* Fishnote Series NSWF1070. NSW Fisheries, Pt Stephens, NSW.

NSW Fisheries (2003a). *Policy and Guidelines for Fish Friendly Waterway Crossings*. Fishnote Series NSWF1181. NSW Fisheries, Cronulla NSW.

NSW Fisheries (2003b). *Fishery Management Strategy for the Estuary Prawn Trawl Fishery*. NSW Fisheries, Cronulla NSW.

NSW Fisheries (2003c). *Fishery Management Strategy for the Estuary General Fishery*. NSW Fisheries, Cronulla NSW.

NSW Marine Parks Authority [MPA] (2006). Port Stephens-Great Lakes Marine Park. Website: http://www.mpa.nsw.gov.au/psglmp/psglmp.htm, Accessed April 2006.

Pethebridge, R., Lugg, A., and Harris, J. (1998). *Obstructions to Fish Passage in New South Wales South Coast Streams*. Final Report Series 4. Cooperative Research Centre for Freshwater Ecology. NSW Fisheries, Cronulla, NSW.

Richmond Valley Council (2006). The Doolan Deck Modular Bridge and Decking Solution. Website: http://www.richmondvalley.nsw.gov.au/doolandeck/index.html, Accessed May 2006.

Rutherfurd, I.D., Jerie, K., and Marsh, N. (2001). *A Rehabilitation Manual for Australian Streams*. Land and Water Resources Research and Development Corporation and Cooperative Research Centre for Catchment Hydrology: Canberra, ACT.

Takken I., Croke J., Mockler S., Hairsine P. and Lane P. (2004). Delivery of sediment from forest roads to streams: A function of hydrologic connectivity. *Proceedings of the 4th Australian Stream Management Conference*. October 2004, Launceston, Tasmania.

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. Canberra, ACT

Warren Jr, M. and Pardew M.G. (1998). Road crossings as barriers to small-stream fish movement. *Transactions of the American Fisheries Society*. 127: 637-644.

Williams, R.J., Watford, F.A. and M.A. Taylor (1996). *A Summary of Aspects of FRDC Project 94/041 "Restoration of Estuarine Fisheries Habitat" Relevant to Tidal Obstructions in New South Wales Estuaries.* NSW Fisheries Research Institute, Cronulla, NSW.

Witheridge, G. (2002). *Fish passage requirements for waterway crossings – Engineering Guidelines.* Catchment and Creeks Pty Ltd, Brisbane.

Yearsley G.K., Last P.R., and Ward R.D. (2001). *Australian Seafood Handbook – Domestic Species*. CSIRO Marine Research and Fisheries Research and Development Corporation, Hobart, Tasmania.

8. APPENDICES

Table 7. Freshwater and estuarine finfish of the Hunter/Central Rivers region, NSW

Scientific Name	Common Names	Status	Migration[6] and habitat
Acanthopagrus australis	Yellowfin bream Silver bream	Common	Amphidromous; coastal marine; estuaries and inshore reefs.
Afurcagobius tamarensis	Tamar River goby	Common	Estuaries, coastal lakes and lower freshwater river reaches.
Aldrichetta forsteri	Yellow-eye mullet	Common	Marine and estuarine; brackish coastal lakes and lower freshwater reaches.
Ambassis marianus	Estuary perchlet Glass perchlet	Common	Local migration; brackish mangrove estuaries and tidal creeks.
Amniataba percoides	Banded grunter	**EXOTIC; NSW NOXIOUS LISTING**	Freshwater habitats – in Clarence River, has potential to spread to the Hunter/Central region.
Amoya bifrenatus	Bridled goby	Common	Estuarine and marine waters.
Anguillia australis	Short-finned eel	Common	Catadromous; coastal rivers and wetlands.
Anguilla reinhardtii	Long-finned eel	Common	Catadromous; coastal rivers.
Arrhamphus sclerolepis	Snub-nosed garfish	Common	Coastal bays and brackish estuaries.
Arius graeffei	Freshwater fork-tailed catfish	Common, although only occasional in Hunter/Central region	Can complete life cycle in freshwater, estuarine and marine populations are anadromous.
Atherinosoma microstoma	Smallmouthed hardyhead	Common	Unknown migration pattern; coastal estuarine and fresh waters.
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.
Hippichthys penicillus	Steep-nosed pipefish	Common	Mangrove estuaries, lower reaches of freshwater streams.
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 klunzingeri	Western carp gudgeon	Common	Freshwater; around aquatic vegetation in slow moving rivers, lakes or wetlands.

[6] 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 and estuarine finfish of the Hunter/Central Rivers region, NSW

Scientific Name	Common Names	Status	Migration[6] and habitat
Gerres subfasciatus	Silver biddy	Common	Marine estuaries and bays, brackish coastal rivers and lakes.
Leiopotherapon unicolor	Spangled perch	Common	Amphidromous; freshwater, although wide salinity tolerance; flowing streams, wetlands, lakes, dams, bores.
Liza argentea	Flat-tail mullet	Common	Estuaries and sea beaches.
Lutjanus argentimaculatus	Mangrove Jack	Common	Estuaries and tidal river reaches.
Macquaria colonorum	Estuary perch	Uncertain	Amphidromous; estuarine areas in coastal rivers and lakes.
Macquaria novemaculeata	Australian bass	Uncertain	Catadromous; Coastal rivers up to 600m altitude.
Megalops cyprinoids	Oxeye herring	Common	Amphidromous; marine and estuarine, juveniles and small adults frequent freshwater reaches.
Monodactylus argenteus	Diamondfish Silver batfish	Common	Bays, mangrove estuaries, tidal creeks and lower reaches of freshwater streams.
Mugil cephalus	Striped mullet Sea 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 elongatus	Sand mullet	Common	Amphidromous as juveniles; estuaries and brackish waters in lower river reaches.
Myxus pertardi	Freshwater mullet	Common	Catadromous; prefers deep pools of slow flowing rivers, adults spawn in estuaries and sea.
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.
Platycephalus fuscus	Dusky flathead	Common	Amphidromous; marine and estuarine waters.
Potamalosa richmondia	Freshwater herring	Not common but not considered under threat	Catadromous; estuaries and coastal fresh water rivers.
Pristis zijsron	Green sawfish	**NSW THREATENED SPECIES (*ENDANGERED*)**	Inshore marine and estuaries; last confirmed sighting in 1972 from Clarence River (natural distribution to Jervis Bay NSW).
Pseudogobius sp 9	Blue-spot goby	Common	Sheltered estuaries and coastal lakes.
Pseudomugil signifer	Pacific blue-eye	Common	Amphidromous; eastern draining freshwater catchments.
Redigobius macrostoma	Largemouth goby	Common	Amphidromous; estuaries, coastal rivers and some freshwater streams.
Retropinna semoni	Australian smelt	Common	Potamodromous; Inland and coastal freshwater.
Rhabdosargus sarba	Tarwhine	Common	Coastal waters, often entering estuaries.
Salvelinus fontinalis	Brook Char	**EXOTIC**	Restricted to cool-cold waters, restocking sustains populations in Tasmania, NSW, SA.
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.
Tandanus tandanus	Eel tail catfish	Common (eastern draining form)	Translocated from western species in most of Hunter/Central region; native subspecies in the Manning R and waterways north of this.
Terapon jarbua	Crescent Perch	Common	Marine, but also penetrating estuaries and lower river reaches.
Valamugil georgii	Fantail mullet	Common	Amphidromous; estuarine and marine, young entering freshwater.

Sources: McDowall (1996), Thorncraft and Harris (2000), Yearsley *et al.* (2001), Allen *et al.* (2002), NSW Fisheries (2202d), and NSW DPI (2005).

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:** ____________________________

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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 NSW Department of Primary Industries Fisheries (Conservation and Aquaculture) applies a basic 'CLASS' system to assign aquatic habitat values to waterways. Table 8 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 Hunter/Central Rivers CMA region.

Table 8. 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 9.

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 9. 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 behavioral 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 (eg 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 (eg 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

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 (>/= 4^{th} 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 Hunter/Central Rivers CMA

Table 10. High priority fish passage obstructions in Hunter/Central Rivers 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	HUNT408	Lower North Coast, Great Lakes	Coolongolook R	Locketts Crossing Rd	-32.2306	152.3276	1	Causeway	HL,LF	Bridge / box culvert with multiple low flow cells	23.0
2	HUNT276	Lower North Coast, Gloucester Shire	Manning R	Private Rd off Walcha Rd	-31.8346	151.8874	1	Causeway	HL,V,LF	Box culvert with multiple low flow cells	3.0
3	HUNT172	Lower North Coast, Great Lakes	Cromarty Ck	Private Rd off Lemon Grove Rd	-32.5080	151.9572	1	Causeway	HL,LF	Bridge / box culvert with multiple low flow cells	6.0
4	HUNT396	Lower North Coast, Greater Taree City	Cooplacurripa R	Private Rd off Nowendoc Rd	-31.6841	151.9924	1	Causeway	D,V	Clear sediment / Box culvert with low flow cell	50.0
5	HUNT233	Lower North Coast, Great Lakes	Telegherry R	Moores Creek Rd	-32.2157	151.8103	1	Causeway	HL,V	Box culvert with low flow cell	23.0
6	HUNT415	Lower North Coast, Great Lakes	Wallamba R	Clarksons Crossing Rd	-32.1063	152.3722	1	Causeway	HL	Remove / modified partial width rock ramp fishway	3.0
7	HUNT407	Lower North Coast, Greater Taree City	Wang Wauk R	Smedleys Cutting Rd	-32.2043	152.2193	1	Causeway	LF	Box culvert with low flow cell	6.0
8	HUNT268	Lower North Coast, Gloucester Shire	Bowman R	Bowman Farm Rd	-31.9243	151.9221	1	Causeway	HL,LF	Bridge / remove apron and install box culvert with multiple low flow cells	24.0
9	HUNT403	Lower North Coast, Greater Taree City	Wallamba R	Wellers Lane	-32.1156	152.3311	1	Causeway	HL,D	Box culvert with multiple low flow cells	29.0
10	HUNT275	Lower North Coast, Gloucester Shire	Manning R	Private Rd off Walcha Rd	-31.8497	151.8870	1	Causeway	HL	Bridge / remove apron and install box culvert with multiple low flow cells	16.0
11	HUNT381	Hunter, Dungog Shire	Paterson R	Private Rd off Cross Keys Rd	-32.3645	151.4814	1	Causeway	HL,LF	Box culvert with multiple low flow cells	10.0
12	HUNT380	Hunter, Dungog Shire	Paterson R	Cross Keys Rd	-32.3647	151.5041	1	Causeway	HL,LF	Box culvert with multiple low flow cells or modified partial width rock ramp fishway	4.0
13	HUNT223	Hunter, Port Stephens	Tumbledown Ck	Private Rd off Langlands Rd	-32.6153	151.7464	1	Causeway	D,V	Investigate removal / Install more cells (with low flow cell)	21.0
14	HUNT416	Hunter, Dungog Shire	Paterson R	Private Rd following Paterson R upstream of Lostock Dam	-32.2246	151.3863	1	Causeway	HL,LF	Box culvert with multiple low flow cells	27.0

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

Appendix D – High Priority Sites in the Hunter/Central Rivers CMA

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
15	HUNT038	Lower North Coast, Greater Taree City	Dingo Ck	Unnamed Rd off Robinson Rd	-31.79916	152.3277	2	Causeway	HL,V	Box culvert with low flow cell	18.0
16	HUNT278	Lower North Coast, Gloucester Shire	Manning R	Curricabark Rd	-31.8240	151.8132	1	Causeway	HL	Remove	3.0
17	HUNT402	Lower North Coast, Greater Taree	Wallamba R	Dargavilles Rd	-32.1048	152.3547	1	Causeway	HL,D,LF	Remove apron and install box culvert with multiple low flow cells / modified partial width rock ramp fishway	3.0
18	HUNT299	Lower North Coast, Greater Taree	Wallamba R	Barrys Rd	-32.0999	152.2415	1	Causeway	HL,LF	Bridge / box culvert with multiple low flow cells	18.0
19	HUNT022	Central Coast, Lake Macquarie City	Dora Ck	Kemp Lane	-33.0575	151.4158	3	Causeway	HL,V,LF	Box culvert with low flow cell	5.0
20	HUNT200	Hunter, Upper Hunter Shire	Pages R	Brushy Hill Rd	-32.0797	150.9503	1	Causeway	HL	Box culvert with multiple low flow cells (structure faulty), remove upstream sediment accumulation	125.0
21	HUNT277	Lower North Coast, Gloucester Shire	Barnard R	Bretti Trail	-31.7913	151.9148	1	Causeway	LF	Box culvert with multiple low flow cells	110.0
22	HUNT279	Lower North Coast, Gloucester Shire	Manning R	Curricabark Rd	-31.8077	151.7951	1	Causeway	HL,LF	Box culvert with multiple low flow cells	40.0
23	HUNT371	Hunter, Dungog Shire	Williams R	Private Rd off Salisbury Rd	-32.2276	151.5735	1	Causeway	HL	Box culvert with multiple low flow cells / modified partial width rock ramp fishway	27.0
24	HUNT377	Hunter, Dungog Shire	Allyn R	Private Rd off Allyn River Rd	-32.2512	151.5043	1	Causeway	HL	Box culvert with multiple low flow cells / modified partial width rock ramp fishway	15.0
25	HUNT378	Hunter, Dungog Shire	Allyn R	Private Rd off Allyn River Rd	-32.3401	151.5238	1	Causeway	HL,LF	Box culvert with multiple low flow cell / modified partial width rock ramp fishway (left side)	13.0
26	HUNT370	Lower North Coast, Great Lakes	Telegherry R	Middle Rd	-32.2231	151.7421	1	Causeway	HL,LF	Box culvert with multiple low flow cells / modified partial width rock ramp fishway	13.0
27	HUNT090	Lower North Coast, Greater Taree City	Woolshed Ck	Wheril Flat Rd	-31.8625	152.1757	2	Causeway	HL,LF	Box culvert with low flow cell	10.0
28	HUNT129	Central Coast, Lake Macquarie City	Cockle Ck	The Weir Rd	-32.9368	151.5990	1	Causeway	HL	Box culvert with multiple low flow cells	2.5

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

Appendix D – High Priority Sites in the Hunter/Central Rivers CMA

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
29	HUNT379	Hunter, Dungog Shire	Allyn R	Cross Keys Rd	-32.3516	151.5236	1	Causeway	HL,LF	Box culvert with multiple low flow cells / modified partial width rock ramp fishway	2.0
30	HUNT330	Hunter, Upper Hunter Shire	Isis R	Waverly Rd	-31.9667	151.0346	1	Causeway	HL	Remove	16.0
31	HUNT239	Lower North Coast, Gloucester Shire	Gloucester	Bucketts Rd	-32.0542	151.9150	1	Causeway	HL,LF	Bridge / box culvert with multiple low flow cells	2.0
32	HUNT394	Lower North Coast, Greater Taree City	Rowleys R	Private Rd off Cells River Rd	-31.5662	152.0660	1	Causeway	HL	Box culvert with multiple low flow cells / modified partial width rock ramp fishway	4.0
33	HUNT150	Hunter, Singleton Shire	Fal Brook	Carrowbrook Rd	-32.3898	151.2187	2	Causeway	S,V,LF	Bridge / box culvert with multiple low flow cells, remove downstream apron	6.0
34	HUNT143	Hunter, Singleton Shire	Glendon Brook	Mitchells Flat Rd	-32.5563	151.2899	2	Causeway	HL,LF	Box culvert with low flow cell	56.0
35	HUNT235	Lower North Coast, Great Lakes	Sugarloaf Ck	Private Rd off Unnamed Rd off The Bucketts Way	-32.2678	151.9019	2	Causeway	HL	Box culvert with multiple low flow cells	12.0
36	HUNT141	Hunter, Singleton Shire	Lambs Valley Ck	Private Rd off Lambs Valley Creek Rd	-32.5819	151.4580	2	Causeway	D,V,HL	Box culvert with multiple low flow cells	20.0
37	HUNT398	Lower North Coast, Greater Taree City	Burrell Ck	Private Rd off Gloucester Rd	-31.9415	152.2961	3	Causeway	HL,LF	Box culvert with low flow cell	16.0
38	HUNT232	Lower North Coast, Great Lakes	Karuah R	Cherry Tree Rd	-32.2570	151.8483	1	Causeway	V	Lower invert levels in cells and/or install flow retardants in cells	15.0
39	HUNT365	Hunter, Muswellbrook Shire	Wybong Ck	Ridgelands Rd	-32.2553	150.6233	2	Causeway	HL,LF	Box culvert with multiple low flow cells	30.0
40	HUNT359	Hunter, Muswellbrook Shire	Baerami Ck	Baerami Creek Rd	-32.6348	150.3685	2	Causeway	HL,S,LF	Box culvert with multiple low flow cells, remove apron	15.0
41	HUNT409	Lower North Coast, Great Lakes	Curreeki Ck	Private Rd off Curreeki Rd	-32.2311	152.3049	2	Causeway	HL,LF	Box culvert with low flow cell	20.0
42	HUNT165	Hunter, Singleton Shire	Reedy Ck	Reedy Creek Rd	-32.4869	151.3328	2	Causeway	HL,LF	Remove	6.0

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

Appendix D – High Priority Sites in the Hunter/Central Rivers CMA

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
43	HUNT035	Lower North Coast, Greater Taree City	Cedar Party Ck	Private Rd off Cedar Party Creek Rd	-31.76861	152.3638	2	Causeway	HL,V	Bridge / box culvert with multiple low flow cells / modified partial width rock ramp fishway	2.0
44	HUNT242	Lower North Coast, Gloucester Shire	Barrington R	Barrington West Rd	-32.0382	151.8712	1	Causeway	HL,LF	Bridge / box culvert with multiple low flow cells	170.0
45	HUNT238	Lower North Coast, Gloucester Shire	Gloucester R	Barrington West Rd	-32.0610	151.8782	1	Causeway	HL,LF	Bridge / box culvert with multiple low flow cells	20.0
46	HUNT241	Lower North Coast, Gloucester Shire	Gloucester R	Faulkland Rd	-32.0612	151.8810	1	Causeway	HL,LF	Bridge / box culvert with multiple low flow cells	0.3
47	HUNT267	Lower North Coast, Gloucester Shire	Gloucester R	Gloucester River Rd	-32.0560	151.7131	1	Causeway	HL,LF	Box culvert with multiple low flow cells, remove apron	25.0
48	HUNT395	Lower North Coast, Greater Taree City	Rowleys R	Cells River Rd	-31.5409	152.0569	1	Causeway	V,LF	Box culvert with multiple low flow cells	13.0
49	HUNT202	Hunter, Singleton Shire	Foy Brook	Upper Hebden Rd	-32.3534	151.0343	2	Culvert - Box	HL,LF	Box culvert with multiple low flow cells	5.0
50	HUNT164	Hunter, Singleton Shire	Reedy Ck	Reedy Creek Rd	-32.5049	151.3302	2	Causeway	HL,LF	Remove	3.0
51	HUNT309	Lower North Coast, Greater Taree City	Coandoormakh Ck	Private Rd off Unknown Rd	-32.0839	152.3636	2	Causeway	HL,LF	Box culvert with low flow cell	7.0
52	HUNT029	Hunter, Cessnock City	Swamp Ck	Horton Rd	-32.7983	151.4819	3	Culvert - Pipe	V,LF	Box culvert with low flow cell	8.0
53	HUNT146	Hunter, Singleton Shire	Goorangoola Ck	Dawsons Hill Rd	-32.4066	151.1802	1	Causeway	S,LF	Bridge / box culvert with multiple low flow cells	5.0
54	HUNT133	Hunter, Singleton Shire	Black Ck	Private Rd off New England Highway	-32.6495	151.3372	2	Culvert - Pipe	HL	Box culvert with multiple low flow cells	30.0
55	HUNT236	Lower North Coast, Great Lakes	Mammy Johnson R	Tereel Rd	-32.2436	151.9756	2	Causeway	LF	Box culvert as low flow cell (reset existing cell level)	30.0
56	HUNT175	Hunter, Muswellbrook Shire	Martindale Ck	Martindale Rd	-32.5172	150.7026	2	Causeway	HL	Box culvert with multiple low flow cells	17.0
57	HUNT073	Lower North Coast, Gloucester Shire	Belbora Ck	Belbora Creek Rd	-31.9016	152.1290	2	Causeway	HL	Remove	3.0

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

Appendix D – High Priority Sites in the Hunter/Central Rivers CMA

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
58	HUNT184	Hunter, Upper Hunter Shire	Hunter R	Glenbawn Dam Rd	-32.1363	150.9609	1	Causeway	HL	Bridge / box culvert with multiple low flow cells	2.0
59	HUNT262	Lower North Coast, Gloucester Shire	Gloucester R	Gloucester River Rd	-32.0595	151.7402	1	Causeway	HL,LF	Bridge / box culvert with multiple low flow cells	0.3
60	HUNT410	Lower North Coast, Great Lakes	Curreeki Ck	Private Rd off Curreeki Rd	-32.2287	152.3029	3	Causeway	HL,LF	Box culvert with low flow cell	20.0
61	HUNT099	Lower North Coast, Greater Taree City	Dingo Ck	Gunyah Rd	-31.7180	152.2926	2	Causeway	HL,S	Bridge / box culvert with multiple low flow cells	7.0
62	HUNT284	Lower North Coast, Gloucester Shire	Bowman R	Upper Bowman Rd	-31.9473	151.8045	2	Causeway	HL,LF	Remove	3.5
63	HUNT287	Lower North Coast, Gloucester Shire	Bowman R	Upper Bowman Rd	-31.9356	151.8181	2	Causeway	HL	Remove	1.0
64	HUNT285	Lower North Coast, Gloucester Shire	Bowman R	Upper Bowman Rd	-31.9446	151.8064	2	Causeway	HL,LF	Remove	1.0
65	HUNT134	Hunter, Cessnock City	Black Ck	Old North Rd	-32.7123	151.3226	2	Culvert - Pipe	HL,V	Bridge / box culvert with multiple low flow cells	18.0
66	HUNT391	Lower North Coast, Greater Taree City	Kerriki Ck	Kerriki Forest Rd	-31.6991	152.0651	3	Culvert - Box	HL,LF	Reset box culvert / low cost modified partial width rock ramp fishway	12.0
67	HUNT037	Lower North Coast, Greater Taree City	Mooral Ck	Private Rd off Little Back Creek Rd	-31.75583	152.3230	2	Causeway	HL,D,LF	Bridge / box culvert with multiple low flow cells, clear large log downstream	1.5
68	HUNT145	Hunter, Singleton Shire	Brandy Ck	Dawsons Hill Rd	-32.4141	151.1959	3	Causeway	HL,LF	Box culvert with multiple low flow cells and remove downstream apron	1.0
69	HUNT140	Hunter, Singleton Shire	Lambs Valley Ck	Private Rd off Lambs Valley Creek Rd	-32.5744	151.4614	2	Causeway	HL,D	Box culvert with multiple low flow cells	19.0
70	HUNT369	Hunter, Dungog Shire	Carowiry Ck	Private Rd off Carowiry Creek Rd	-32.3326	151.8010	3	Causeway	HL,LF	Box culvert with low flow cell	12.0
71	HUNT036	Lower North Coast, Greater Taree	Cedar Party Ck	Leaches Rd	-31.75638	152.36	3	Causeway	HL,V,LF	Box culvert with low flow cell	4.0
72	HUNT401	Lower North Coast, Greater Taree	Koorainghat Ck	Half Chain Rd	-31.9700	152.5003	3	Causeway	LF	Box culvert with low flow cell	10.0
73	HUNT230	Lower North Coast, Great Lakes	Booral Ck	Conger Rd	-32.4731	152.0006	3	Causeway	D,LF	Box culvert with low flow cell	5.0

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

Appendix D – High Priority Sites in the Hunter/Central Rivers CMA

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
74	HUNT003	Central Coast, Wyong Shire	Canada Drop Down Ck	Almdale Creek Rd	-33.33	151.3702	3	Causeway	HL,D,V	Remove debris / install box culvert	1.5
75	HUNT329	Hunter, Upper Hunter Shire	Isis R	Private Rd off Waverly Rd	-31.8758	151.0738	1	Causeway	D,V	Clear debris	25.0
76	HUNT148	Hunter, Singleton Shire	Goorangoola Ck	Dawsons Hill Rd	-32.3872	151.1761	1	Causeway	HL,LF	Remove	3.0
77	HUNT266	Lower North Coast, Gloucester Shire	Gloucester R	Gloucester River Rd	-32.0625	151.7220	1	Causeway	HL,LF	Improve modified partial width rock ramp fishway/ remove apron and install box culvert with low flow cell	1.0
78	HUNT332	Hunter, Upper Hunter Shire	Dart Brook	Thompsons Creek Rd	-31.9846	150.7584	2	Causeway	HL,LF	Remove / box culvert with low flow cell	20.0
79	HUNT125	Hunter, Singleton Shire	Crawford R	Crawford Rd	-32.4380	151.1325	2	Culvert - Pipe	V	Box culverts with low flow cell	16.0
80	HUNT286	Lower North Coast, Gloucester Shire	Bowman R	Upper Bowman Rd	-31.9430	151.8126	2	Causeway	HL,LF	Remove	1.0
81	HUNT308	Lower North Coast, Greater Taree City	Pipeclay Ck	Pipeclay Creek Rd	-32.0741	152.3993	3	Causeway	HL,LF	Box culvert with low flow cell	0.8

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

Appendix E – Conceptual Diagrams of Fishways Employed in Australia

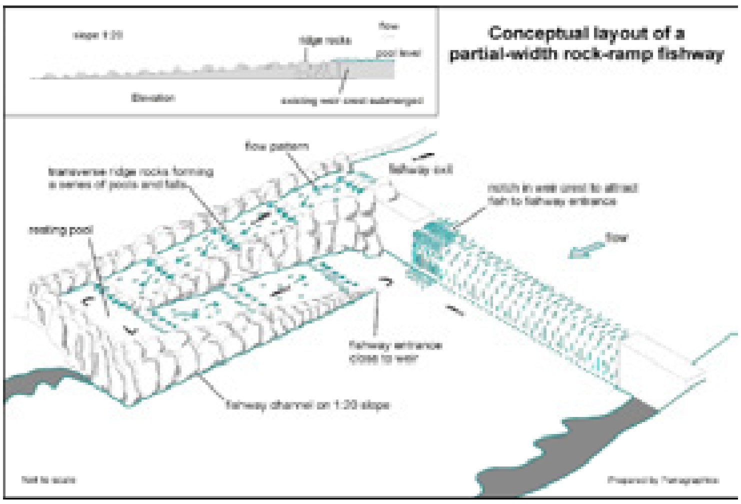
The following remediation options are primarily employed on structures not requiring vehicle access (e.g. weirs or infrastructure such as water delivery pipes). Information is presented here to provide a guide on alternative remediation options, and as a guide for native fish passage requirements (fish 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.

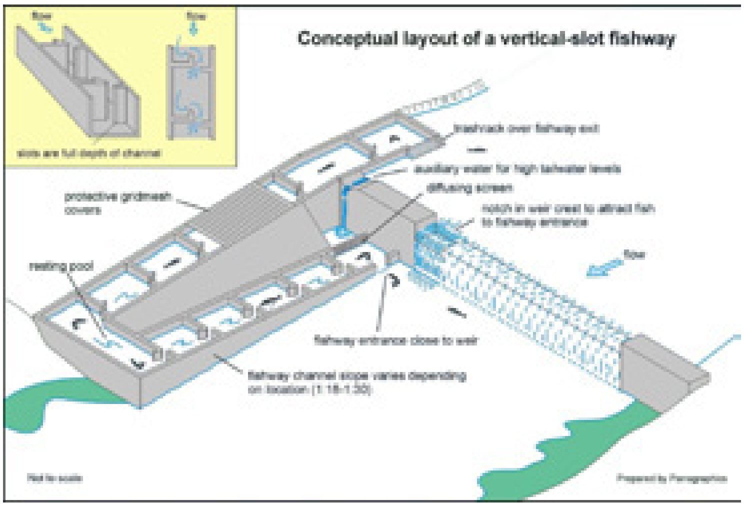
Two variations of this form of fishway are employed in Australia – the partial width rock ramp fishway (below), and the full width rock ramp fishway. As the name implies, the partial width rock ramp fishway only extends part way across the width of a waterway, with water directed down a defined channel; 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.

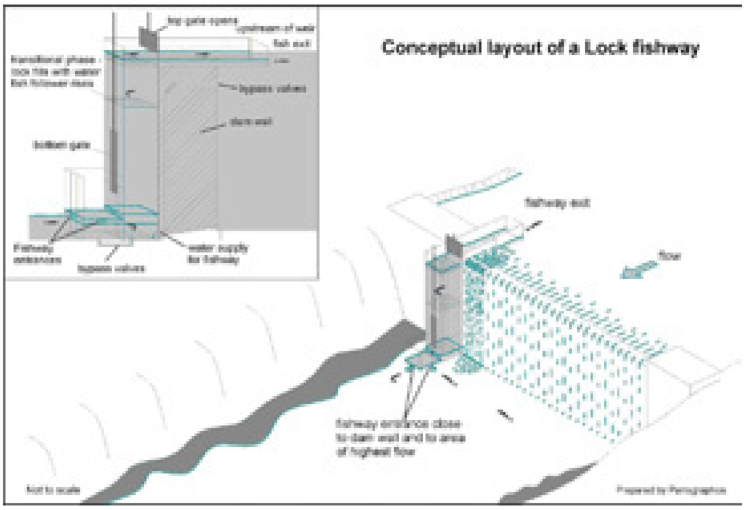
Vertical slot fishways have flexibility of operation over varying headwater and tailwater levels, as well as allowing fish to pass through the fishway at any depth. This type of fishway is more expensive than a rock ramp fishway, and requires larger volumes of water to operate.



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.

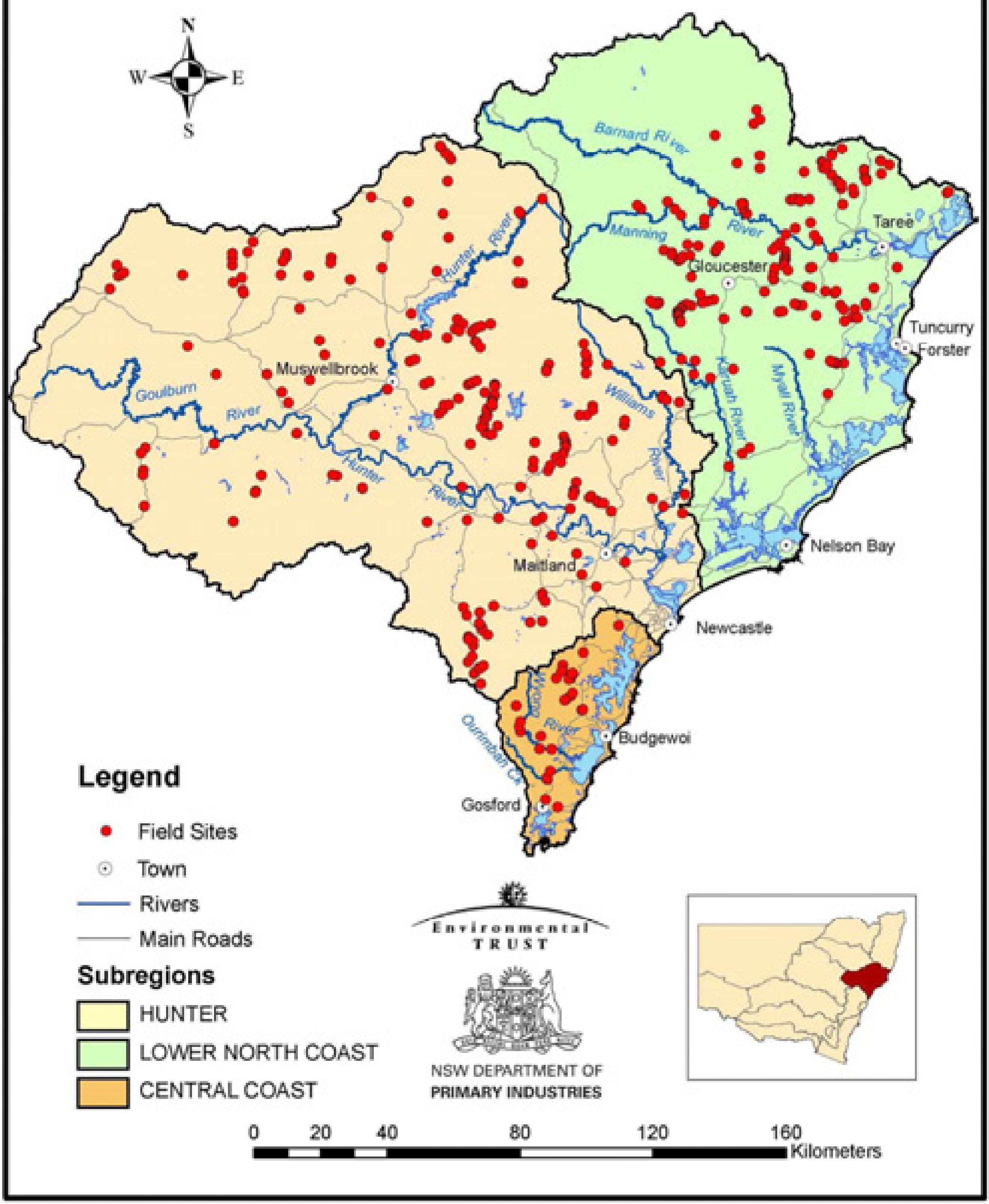
The first lock fishway in New South Wales waters was on the Murray River at Yarrawonga Weir, and has been shown to be effective in transporting fish over the 12m high weir. The Deelder fish lock (or Deelder fishway) is a variation of the lock fishway for use on lower barriers. This type of fishway is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

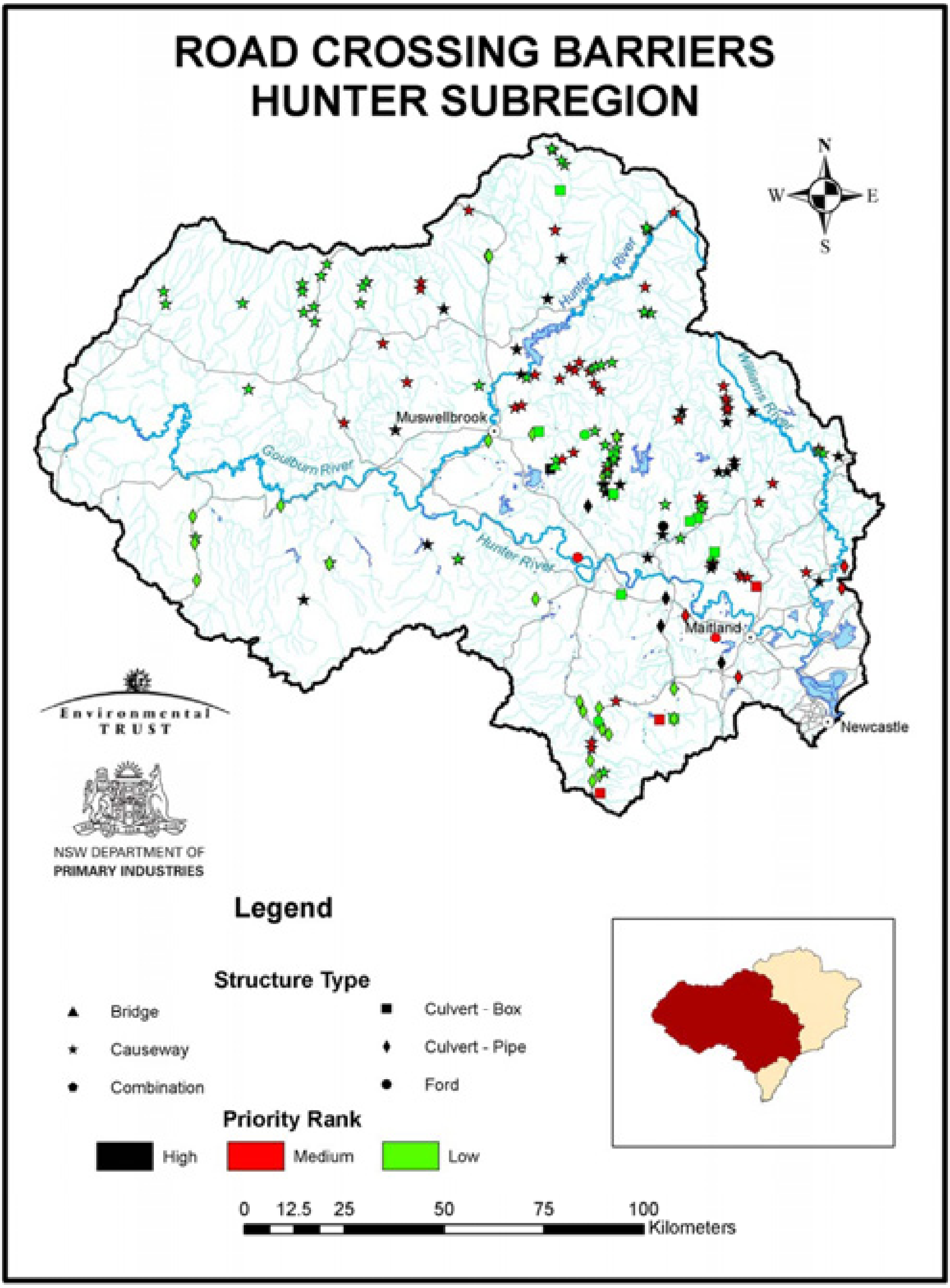


Reference:

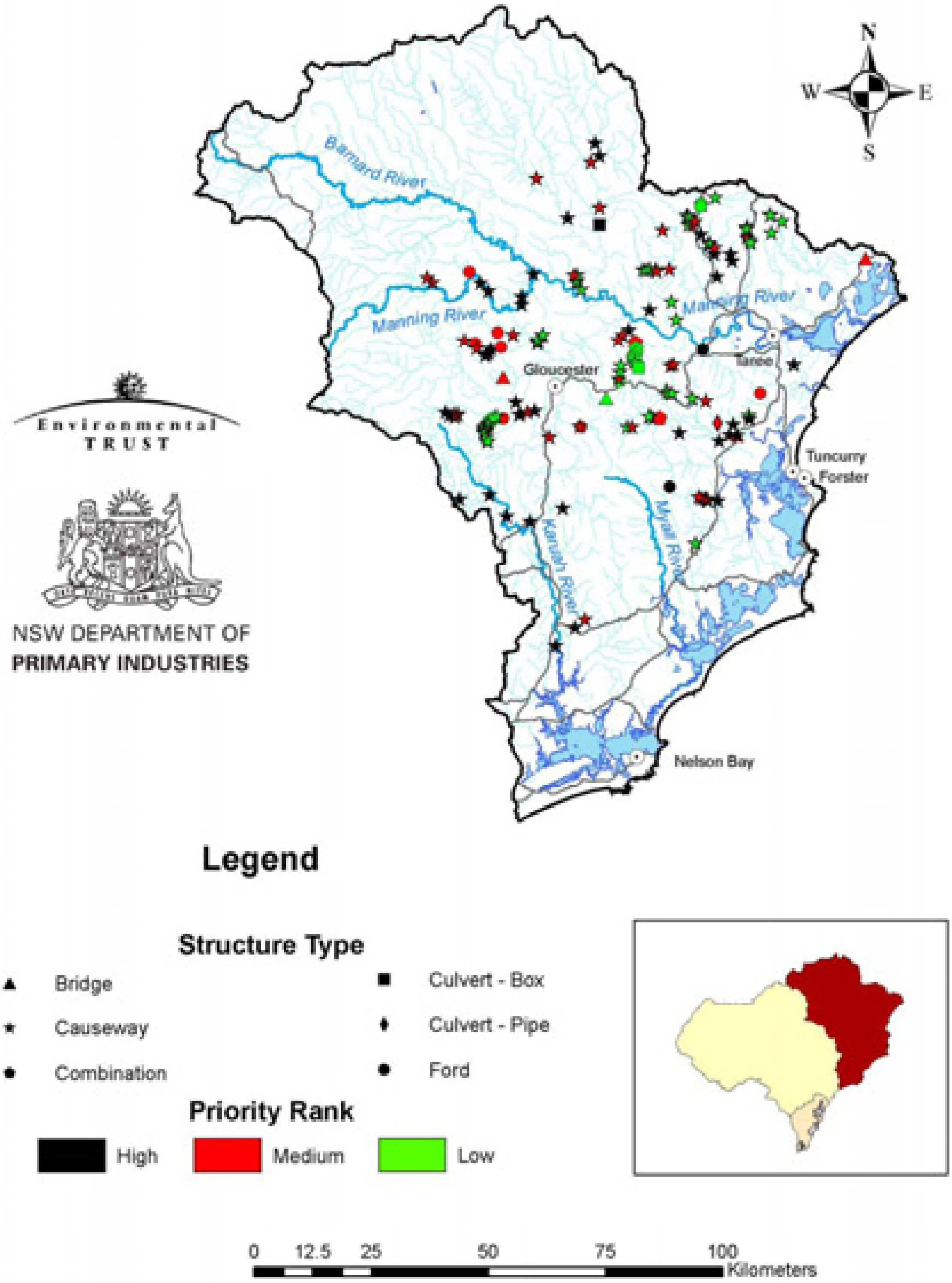
Thorncraft, G. and Harris, J.H. (2000) *Fish passage and fishways in NSW: A Status Report.* Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000.

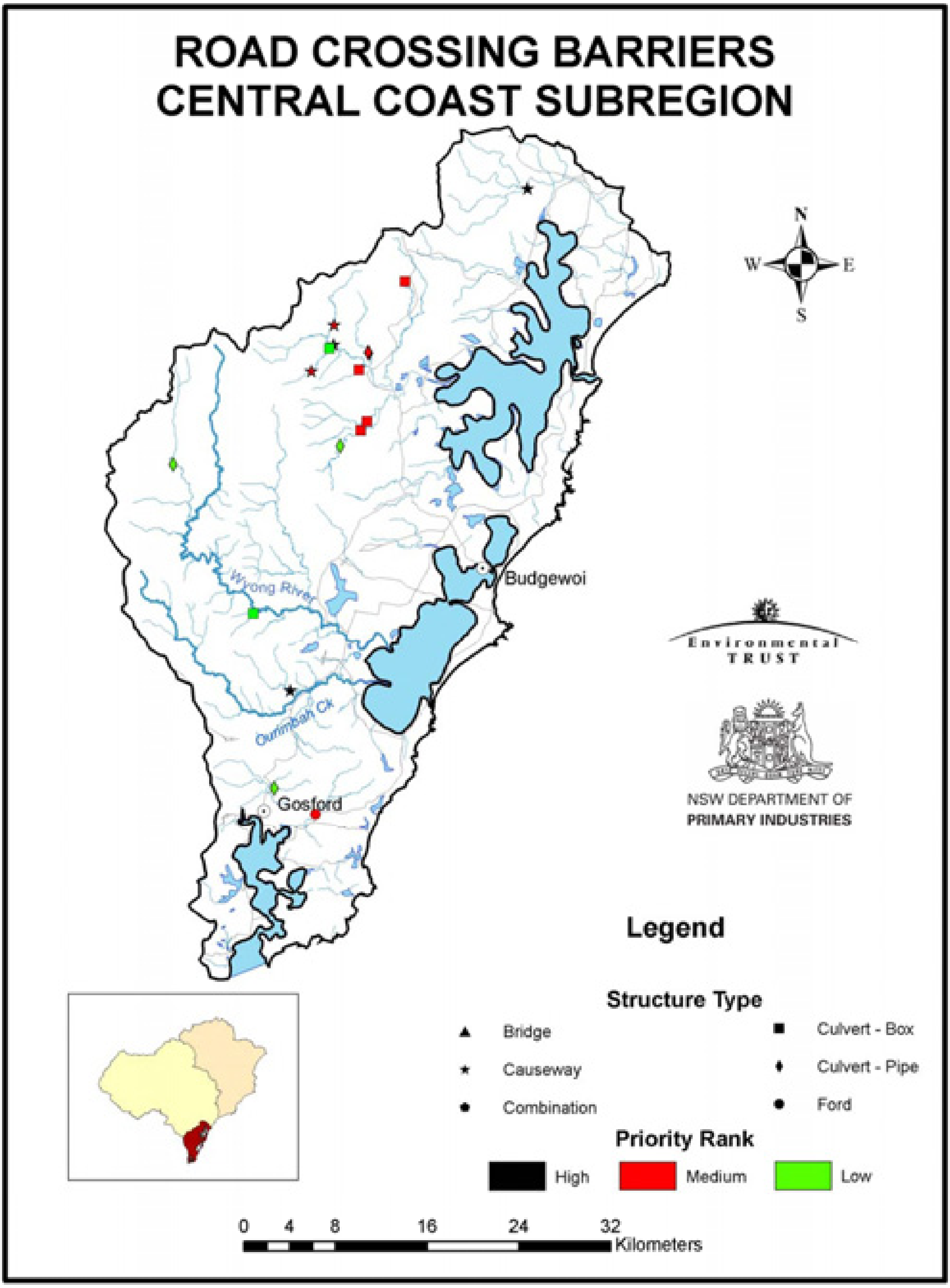
HUNTER/CENTRAL RIVERS FIELD SITES




ROAD CROSSING BARRIERS
HUNTER SUBREGION
N
W
E
S
Hunter River
Williams River
Goulburn River
Muswellbrook
Maitland
Newcastle
Environmental
TRUST
NSW DEPARTMENT OF
PRIMARY INDUSTRIES
Legend
Structure Type
Bridge
Causeway
Combination
Culvert - Box
Culvert - Pipe
Ford
Priority Rank
High
Medium
Low
0
12.5
25
50
75
100
Kilometers

ROAD CROSSING BARRIERS
LOWER NORTH COAST SUBREGION




ROAD CROSSING BARRIERS
CENTRAL COAST SUBREGION
N
W
E
S
Wyong River
Ourimbah Ck
Budgewoi
Gosford
Environmental
TRUST
NSW DEPARTMENT OF
PRIMARY INDUSTRIES
Legend
Structure Type
Bridge
Causeway
Combination
Culvert - Box
Culvert - Pipe
Ford
Priority Rank
High
Medium
Low
0
4
8
16
24
32
Kilometers

aquatic habitat rehabilitation

making more fish

...naturally