The feasibility of excluding alien redfin perch from Macquarie perch habitat in the Hawkesbury-Nepean Catchment

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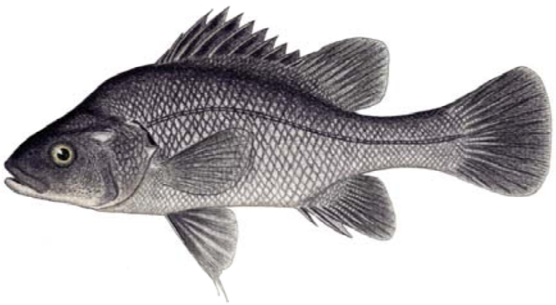

Threatened Macquarie perch

Alien redfin perch

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NON-TECHNICAL SUMMARY

HN 0507 B6D The feasibility of excluding alien redfin perch from Macquarie perch habitat in the Hawkesbury-Nepean Catchment.

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OBJECTIVES:

(1) Review the distribution, biology and conservation status of Macquarie perch in the Hawkesbury-Nepean catchment.
(2) Assess the techniques available for excluding redfin perch from Macquarie perch habitat in the Warragamba Dam study area.
(3) Determine the potential effects of an exclusion device on the local fish populations.
(4) Identify the most appropriate location within the study area for an exclusion device.
(5) Determine the approvals required to construct an exclusion device.

NON TECHNICAL SUMMARY:

This report assesses the feasibility of excluding alien (i.e., non-native) redfin perch (*Perca fluviatilis*) from a feeder tributary of Warragamba Dam (Lake Burragorang) in the Hawkesbury-Nepean catchment that supports threatened Macquarie perch (*Macquaria australasica*). Objectives included to review the distribution, biology and conservation status of Macquarie perch in the Hawkesbury-Nepean catchment; assess the techniques available for excluding redfin perch from Macquarie perch habitat within the Warragamba Dam study area; determine the potential effects of an exclusion device on the local fish populations; identify the most appropriate location within the study area for an exclusion device; and determine the approvals required to construct an exclusion device.

The Macquarie perch is a small to medium sized, freshwater fish that is listed as endangered under Commonwealth and NSW legislation. The species is native to the cooler middle-upper reaches of the Murray-Darling Basin and several eastern coastal streams including the Shoalhaven, Georges and Hawkesbury-Nepean River systems. It has a fragmented distribution within the latter coastal system and often occurs in low numbers. The species is secretive and largely nocturnal, taking refuge in cover such as rocky caves and under ledges during daylight hours. Macquarie perch are currently under threat from a wide range of processes including habitat degradation, flow regulation, pollution, and impacts from alien and translocated native species. Alien redfin perch are heavily implicated in the decline of Macquarie Perch through predation on young fish, competition for space and food, and the transfer of disease. Macquarie perch populations considered to be immediately threatened by the recent invasion of redfin perch into the Hawkesbury-Nepean catchment are those currently known to inhabit the feeder tributaries of Warragamba Dam, including Kanangra Creek and the Cox’s, Kowmung, Kedumba and Little Rivers. Intervention is required to prevent redfin perch from invading these tributaries.

Many of the techniques available for excluding redfin perch were not suitable for installation within the study area because of an inability to effectively exclude this species; a lack of

knowledge on their effectiveness; their potential effects on non-target species and the environment; the unavailability of electricity required to power behavioural modification devices; and the costs associated with constructing and maintaining some technologies. The most appropriate device was deemed to be a velocity barrier. This technique is considered 100% effective at excluding redfin perch and has been successfully used in Tasmania for this purpose, with design specifications available. It is also relative inexpensive to construct and maintain, and has relatively minor environmental impacts in comparison to some of the other techniques available.

Of the 17 fish species recorded in the Warragamba Dam study area, four gudgeons, Australian smelt and Macquarie perch were considered to be potentially impacted by an exclusion device such as an in-stream barrier. These impacts could be mitigated, however, by installing a velocity barrier designed specifically to exclude redfin perch while allowing other species of fish to pass. The device should be placed downstream of the known limits of the resident Macquarie perch population to reduce the risk of population fragmentation and disruption of in-stream movements.

Rucksack Ridge Ford on the Kedumba River was considered the most suitable of the eight sites assessed for the installation of a redfin perch exclusion device. Human-assisted introductions of redfin perch upstream of this site were considered unlikely given the remoteness of the surrounding catchment; fragmentation of the resident Macquarie perch population was unlikely; there was direct vehicle access; and the site had a range of geomorphological and hydrological features conducive to the effective exclusion of redfin perch and to the cost-effective construction, maintenance, and monitoring of an exclusion device. Given its location in the lower reaches of the Kedumba River, this site would also exclude redfin perch from much of the river, thereby maximising the size of the refuge habitat for Macquarie perch and limiting disruption of in-stream movements.

The Kedumba River occurs within the Blue Mountains National Park and drains part of the Sydney Catchment Authority (SCA) Warragamba Dam Catchment Area. Therefore, a Review of Environmental Factors (REF) relating to the installation of an exclusion device must be submitted to the NSW Department of Environment, Climate Change and Water (DECCW) and the SCA as part of the environmental impact assessment process. The final decision on site selection for a redfin perch exclusion device may be determined by the development approval process. If development consent is denied by DECCW, approval from the SCA to modify an existing SCA weir may be the only option available for allowing an exclusion device to be installed.

KEYWORDS:

Alien fish, threatened species, pest management, fish exclusion device, Hawkesbury-Nepean.

1. BACKGROUND

The Macquarie perch *Macquaria australasica* Cuvier is a small to medium sized, freshwater fish native to the cooler middle-upper reaches of the Murray-Darling Basin and several eastern coastal streams including the Shoalhaven, Georges and Hawkesbury-Nepean River systems. The species has declined in distribution and abundance during the last century due to habitat degradation (erosion leading to siltation of spawning sites, removal of snags, alteration of river flows, barriers to fish migration, water extraction), reduced water quality and altered water temperatures, overfishing, disease, and interactions with alien species including redfin perch (NSW DPI 2005). Consequently, it is listed as an endangered species under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, NSW *Fisheries Management Act 1994*, and ACT *Nature Conservation Act 1980*, as threatened under the Victorian *Flora and Fauna Guarantee Act 1988*, and as Data Deficient on the IUCN Red List. A growing body of scientific evidence suggests that Macquarie perch populations in coastal streams may be a distinct species to those in the Murray-Darling Basin (see Chapter 2). Based on this premise, each form of Macquarie perch would have smaller distributions and fewer remnant populations, and consequently would conceivably be more vulnerable to extinction than previously thought. The currently known distribution of eastern Macquarie perch in the Hawkesbury-Nepean catchment is given in Figure 1.

The redfin perch *Perca fluviatilis* Linnaeus, also known as European perch, Eurasian perch, and English perch, is a moderate-sized, freshwater fish native to Europe and Asia (Figure 2). The species was introduced into Australia in the 1860s as a sport and table fish, but has since been implicated in the decline of many native threatened and non-threatened fish (McDowall, 1996; Arthington and McKenzie, 1997; Morgan *et al*. 2002). Redfin perch are voracious predators of native fish and invertebrates, may destroy recreational fisheries in enclosed waters by building up large numbers of stunted fish and eliminating other species, and may devastate native fish populations through transmission of the Epizootic Haematopoietic Necrosis Virus (EHNV) (Lintermans 2007; Lintermans *et al.* 2007). In addition to the impacts of direct predation on macrofauna and the spread of disease, more cryptic impacts associated with resource competition may also occur. The predatory behaviours of schools of juvenile and adult redfin perch may alter the behaviour and resource utilisation of native prey (Shirley 2002; Closs *et al*. 2006), while large schools of larvae, juveniles and adult fish may cause cascading effects through heavy predation on the algal-grazing zooplankton communities (Shirley 2002; Matveev 2003; Hicks *et al*. 2007; McAllister 2007; Smith and Lester 2007). Redfin perch are heavily implicated in the decline of Macquarie Perch through predation on young fish, competition for space and food, and the transfer of EHNV to which Macquarie perch are highly susceptible (Langdon 1999; Arthington and McKenzie 1997; Morris *et al*. 2001).

Redfin perch were discovered by Industry & Investment NSW (I&I NSW; formerly the NSW Department of Primary Industries) in the Wollondilly River within the Hawkesbury-Nepean catchment in early 2006. Subsequent surveys in 2007 resulted in the capture of redfin perch from a further six localities in the Mulwaree, Wollondilly and Paddys Rivers (Figure 1). The species has also been recently recorded from the Wingecarribee River (T. Grant, University of NSW, pers. comm.). Redfin perch are expected to move downstream from these localities and invade Warragamba Dam. Once established in the dam, the species is likely to disperse up feeder tributaries inhabited by Macquarie perch (Figure 1). The recent introduction of redfin perch into the Hawkesbury-Nepean system poses a significant threat to the remnant Macquarie perch populations. Intervention is required to restrict the spread of redfin perch and to exclude them from tributaries occupied by Macquarie perch.

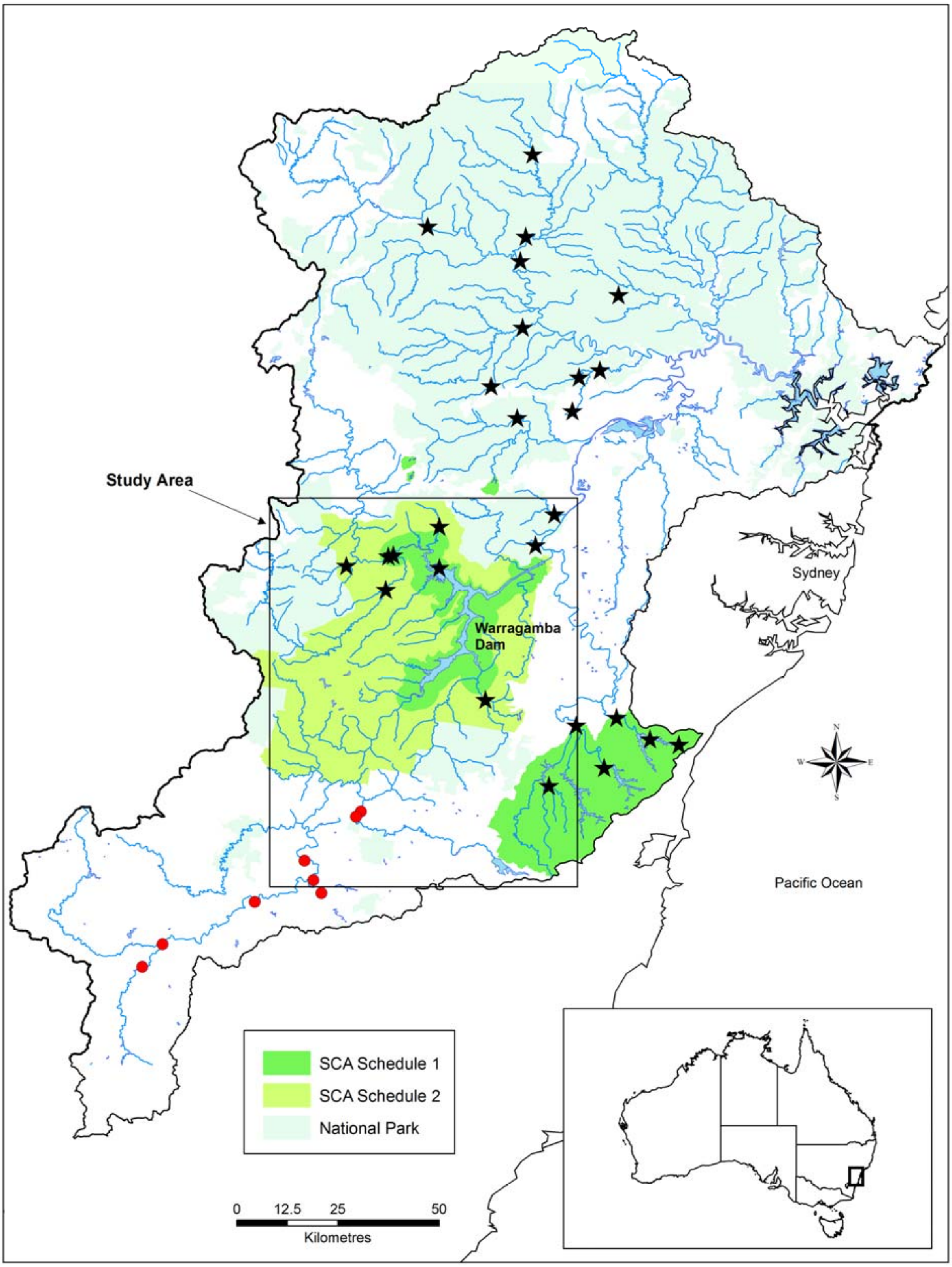

Figure 1. The Hawkesbury-Nepean catchment depicting the study area surrounding Warragamba Dam and the currently known distribution of redfin perch (red circles) and Macquarie perch (black stars). Refer to Figure 4 for a close up view of the study area. Fish distribution data are sourced from the I&I NSW Freshwater Fish Research Database.

Figure 2. Redfin perch *Perca fluviatilis* Linnaeus (© G. Schmida).

This report was commissioned by the Hawkesbury-Nepean Catchment Management Authority (HNCMA) to assess the feasibility of excluding alien (i.e., non-native) redfin perch (*Perca fluviatilis* Linnaeus) from a feeder tributary of Warragamba Dam (Lake Burragorang) that supports threatened Macquarie perch (*Macquaria australasica* Cuvier). As background to the project, a review of the distribution, biology and conservation status of Macquarie perch in the Hawkesbury-Nepean was initially undertaken. The feasibility of excluding redfin perch was then determined based on an assessment of the techniques available for preventing the upstream invasion of redfin perch into Macquarie perch habitat in the Warragamba Dam study area; the relative suitability of specific drainage systems in the study area for the installation of an exclusion device; and the potential impacts of an exclusion device on the local fish populations. Approvals required to construct and install an exclusion device in the most appropriate location were also determined.

2. MACQUARIE PERCH IN THE HAWKESBURY-NEPEAN CATCHMENT

Macquarie perch distributed east and west of the Great Dividing Range are conventionally considered to be a single species. A growing body of scientific evidence, however, now suggests that this mountain range physically separates what appears to be at least two species of Macquarie perch. Major morphological and genetic differences exist between fish in the western and eastern flowing streams, as well as significant genetic differences between some populations within these two groups (Dufty, 1986; Harris and Rowland, 1996; Faulks *et al*. 2009). The characteristic morphology and colour of 'eastern' and 'western' Macquarie perch inhabiting the Hawkesbury-Nepean catchment and Murray-Darling Basin, respectively, is shown in Figure 3. General characteristics shared by each form include a deep, laterally compressed body, a rounded tail, and a large white eye. However, the caudal peduncle is shorter and the dorsal head profile is straighter in the eastern form. Eastern fish are typically jet black when first sampled but soon take on a brown, green and/or yellow mottled appearance. They are also distinctly smaller than western fish with respective maximum recorded sizes of 253 mm (total length) and 0.29 kg (Industry & Investment [I&I] NSW Freshwater Fish Research Database) and 555 mm and 3.5 kg (Cadwallader and Rogan 1977; Lintermans 2007). Recent surveys for the eastern form in the Hawkesbury-Nepean catchment revealed that 60% of the sampled population were less than 130 mm TL, 90% were less than 190 mm TL, and no fish larger than 260 mm TL were recorded (I&I NSW Freshwater Fish Research Database). Western Macquarie perch have been translocated into the Shoalhaven and Hawkesbury-Nepean catchments early last century and genetic analysis suggests that the existing populations within the Mongarlowe River and Cataract Dam are descended from these translocated fish (Faulks *et al*. 2009).

Figure 3. The eastern (left) and western (right) form of Macquarie perch.

Recent surveys by I&I NSW have clarified the current distribution and conservation status of Macquarie perch within the Hawkesbury-Nepean catchment (Bruce *et al*. 2007). Macquarie perch were found to have a fragmented distribution and often occurred in low numbers. It was captured from 11 of the 25 sub-catchments surveyed, including five sub-catchments from which it had not been previously recorded. The species was sampled from 20 of the 48 water bodies sampled including from tributary streams of Warragamba Dam (Figures 1 and 4). The Macquarie perch was often one of the most common fish sampled at those sites found supporting the species. However, it had a fragmented and patchy distribution in the catchment and often occurred in low numbers. Although not included in surveys by Bruce *et al*. (2007), the Upper Nepean River subcatchment is also known to support the Macquarie perch (Figure 1; Knight and Creese 2008; Knight and Rodgers 2009; I&I NSW Freshwater Fish Research Database).

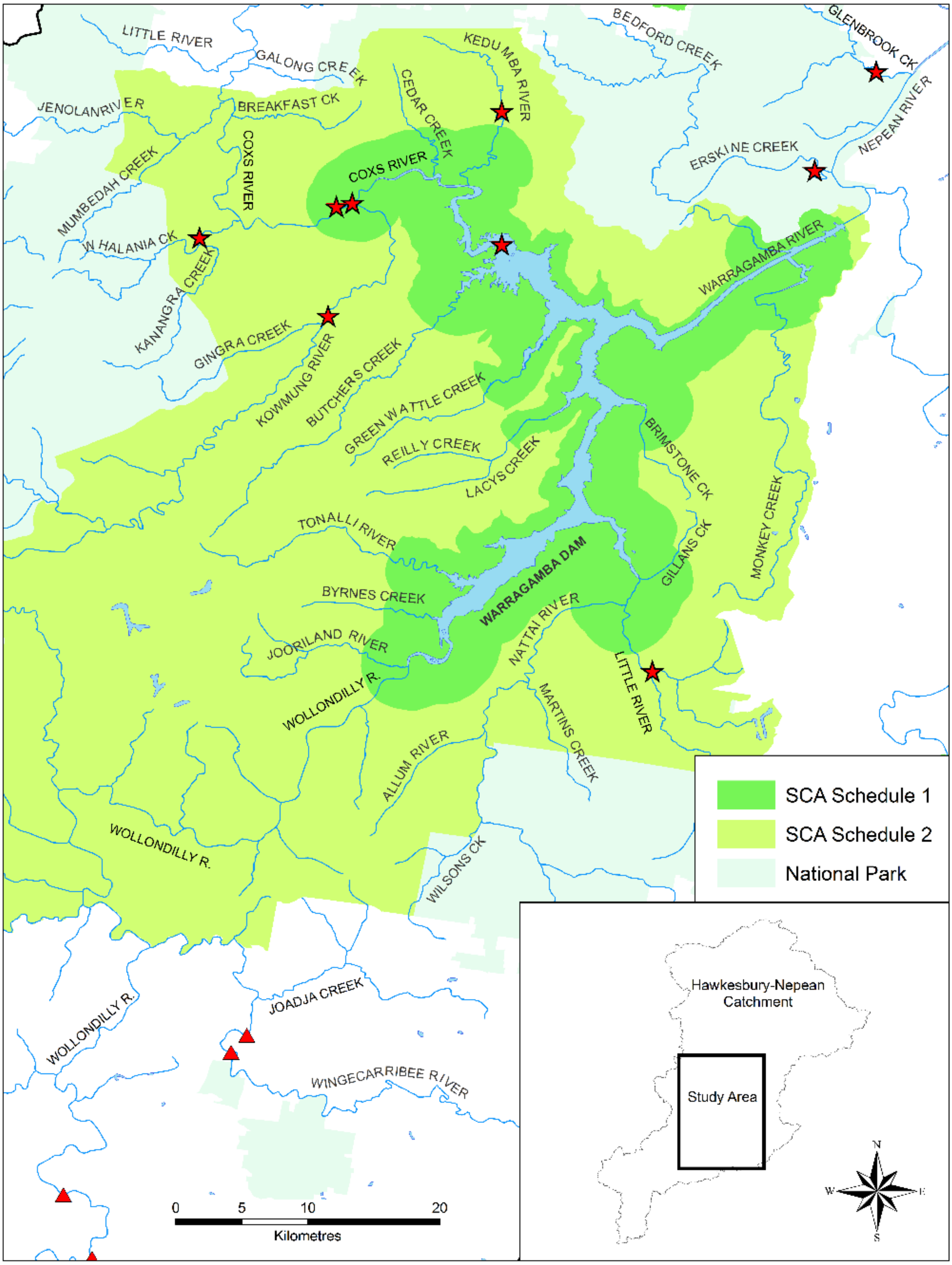

Figure 4. Currently known distribution of Macquarie perch (red stars) and redfin perch (red triangles) within the Warragamba Dam study area.

Preliminary analysis of habitat characteristics at sites where Macquarie perch were found suggested a strong day-time association between this species and complex rocky habitat (Bruce *et al*., 2007). A very high percentage of rock cover was present at nearly all sites where Macquarie perch were recorded (15 of the 20 sites had greater than 50% rock cover, and six of these sites had greater than 75% rock cover). These findings are in accordance with available information on the habitat associations of the western Macquarie perch, a secretive and largely nocturnal species that takes refuge in cover such as rocky caves and under ledges during daylight hours (Morris *et al*., 2001; NSW DPI 2005; Lintermans 2007). Hence, the abundance and complexity of available habitat is likely to be a major factor in the species' distribution. The typical habitat occupied by Macquarie perch in the Hawkesbury-Nepean catchment is shown in Figure 5.

Figure 5. Typical rocky habitat inhabited by Macquarie perch in Wheeny Creek (© I&I NSW).

Little biological information exists on Macquarie perch from eastern drainages, although they are distinctly smaller than western fish and appear to mature at a smaller size. Given the apparent biological differences between the two forms and different hydrological environments inhabited by each it is plausible that their ecology differs accordingly. Ripe females of 100 mm TL have been reported from the Hawkesbury and Shoalhaven river systems and ripe males as small as 80 mm TL have been captured in the Georges River (Dufty 1986; Morris *et al*. 2001; I&I NSW Freshwater Fish Research Database). Field observations of eastern fish in reproductive condition are sparse. In October 2008, running ripe males were found congregating in a shallow, riffle area at the tail end of a large pool in the Georges River. Despite intensive sampling no females were captured (ASFB 2008). This record, however, contrasts with observations of ripe females attempting to move upstream in the lower and middle reaches of the Kowmung River in May 2005 (A. Bruce, I&I NSW, pers. obs.) and of migrating fish congregating below Pheasants Nest weir in May 1993

(Sammut and Erskine 1995). This wide variation in observations between mid spring and late autumn may indicate that eastern Macquarie perch are opportunistic and take advantage of optimal environmental conditions (e.g., suitable river flows) to enhance spawning and recruitment success. However, many characteristics of the migrations of eastern Macquarie perch (e.g., environmental cues stimulating movement, timing, frequency, duration, and distance travelled) remain unclear. Eastern fish in captivity feed on a wide variety of small, aquatic and terrestrial insects (A. Bruce, I&I NSW, pers. obs.).

All sites recently found supporting Macquarie perch in the Hawkesbury Nepean system were in a relatively undisturbed condition (Bruce *et al*. 2007; Knight and Rodgers 2009). No fish have been found at sites in a moderate to degraded condition, re-enforcing the species' apparent sensitivity to in-stream habitat alteration. All but one location known to support eastern Macquarie perch occurs within National Parks estate. The inaccessibility of many of these locations and the added protection of the surrounding land implies that the local fish populations are generally free from threatening processes. However, even within these protected areas the species is threatened by in-stream barriers and river regulation, river cracking caused by underground longwall mining, sedimentation, recreational activities (e.g., fishing), riparian damage, degraded water quality from sewage treatment plants and stormwater discharge, blue-green algae outbreaks, and introduced plants and aquatic animals (e.g., willows, oriental weatherloach, European carp, redfin perch, translocated Murray cod, stocked Australian bass) (Bruce *et al*. 2007; Knight and Rodgers 2009). These threatening processes occur in many of the major arteries of the Hawkesbury-Nepean system such as the Wollondilly, Wingecarribee, Grose, Capertee, Wolgan, MacDonald, Nattai, Coxs, Nepean, and Kowmung Rivers. The emerging threats posed by human-induced climate change are also apparent. For example, low rainfall in recent years throughout much of the Hawkesbury-Nepean catchment has lead to very low to no flows and poor water quality in many streams and may have contributed to the patchy distribution and low abundances of the Macquarie perch populations (Bruce *et al*. 2007). The severity of this drought has been intrinsically linked to anthropogenic climate change (Karoly *et al*. 2003), which has recently been recognised as a significant threat to freshwater fishes (Matthews and Marsh-Matthews; 2003; Pusey *et al*. 2004; FSC 2009).

Macquarie perch populations considered to be immediately threatened by redfin perch in the Hawkesbury-Nepean catchment are those currently known to inhabit the feeder tributaries of Warragamba Dam, including Kanangra Creek and the Coxs, Kowmung, Kedumba and Little Rivers (Figure 4). Effective management is required to prevent redfin perch from dispersing from the dam upstream into these tributaries.

3. TECHNIQUES FOR EXCLUDING REDFIN PERCH FROM MACQUARIE PERCH HABITAT IN THE WARRAGAMBA DAM STUDY AREA

Preventing the establishment and spread of fish introduced from overseas is a key objective of pest species management. This is because once established, it is extremely difficult to eradicate a species or reduce its numbers (Braysher 2007). Strategies to prevent invasion by undesirable species are therefore crucially important, particularly in areas where they may have considerable environmental, economic or social impacts. One such strategy is to install an exclusion device (Koehn *et al*. 2000).

Fish exclusion devices aim to control the movements of migrating animals through physical intervention or modifying behaviour. Physical exclusion techniques physically block fish passage whereas behavioural technologies control fish movements by either deterring them from entering, or guiding them away from, specific areas. While physical barriers have a long history of use in fisheries management, behavioural technologies are relatively new and are largely in the experimental stages of research and development (Popper and Carlson 1998; Lavis *et al*. 2003). Exclusion devices can be used in combination with other control methods to maximise the success of a pest control programme (Patrick *et al*. 1985; Welton *et al*. 2002; Lavis *et al*. 2003).

With the possible exception of the European carp *Cyprinus carpio*, there is a paucity of information on effective, target specific strategies for preventing the spread and controlling the impacts of alien fish species in Australia (MacKenzie *et al*. 2000; Koehn and MacKenzie 2004; Wilson 2006). However, substantially more research has been done internationally, particularly in regards to suppressing the impacts of the sea lamprey *Petromyzon marinus*, a parasitic fish that has invaded the North American Great Lakes (Smith and Tibbles 1980; Vélez-Espino *et al*. 2008). In addition, technologies to modify the movement behaviour of fish have been developed throughout the Northern Hemisphere for a variety of reasons, including to improve the effectiveness of fishways to allow the upstream or downstream passage of fish (Lucas and Baras 2001); drive fish away from sources of mortality such as hazardous intakes associated with hydroelectric stations, nuclear power plants, and irrigation infrastructure or attract them to areas where they can pass an in-stream obstacle (e.g., Maes *et al*. 2004; Richards *et al*. 2007); and to guide fish towards census sites for scientific sampling (Welton *et al*. 2002). It is possible that physical and behavioural technologies could be adapted to exclude redfin perch from invading the feeder tributaries of Warragamba Dam.

A number of issues require consideration when selecting or implementing pest control techniques. These include target specificity, animal welfare, possible harm to non-target species and other secondary-effects (e.g., contamination of water), efficacy, cost-effectiveness, safety, and overall acceptability (West *et al*. 2007). Following a review of available exclusion techniques, a comparative analysis of these techniques in relation to the above issues is undertaken to identify the most appropriate method for impeding the upstream dispersal of redfin perch in the tributaries of the Warragamba Dam study area.

3.1. Physical exclusion

Physical exclusion techniques such as in-stream barriers and screens are a relatively common technique used to contain alien species, such as the sea lamprey in the North American Great Lakes. This species is presently targeted using an integrated approach which employs a variety of barriers in conjunction with poisons, migratory traps, and sterile males that are released to reduce the reproductive success of the population (Lavis *et al*. 2003; Sorensen and Stacey 2004). Natural barriers, modified natural falls and man-made barriers provide an alternative control method to the use of poisons by preventing, reducing, or eliminating access to spawning habitat in many of the 430 Great Lakes tributaries in which lampreys successfully spawn (Lavis *et al*. 2003).

Sea lamprey barrier designs typically incorporate a fixed-crest height and overhanging lip to maintain a low vertical drop of about 30 cm from headwater to tailwater, and fishways or jumping pools to aid in native fish migration. Alternative barrier designs include adjustable crest barriers, gradient field electrical barriers (classed as a behavioural barrier and discussed in the following section), velocity barriers, inflatable-crest barriers, and a combination of fixed-crest, lowhead and gradient field electrical barriers (Hunn and Youngs 1980; Porto *et al*. 1999; Lavis *et al*. 2003). In most of the alternative designs, the barrier is removed or deactivated after the lamprey migration, thereby allowing other fish species unimpeded movement in the stream during most of the year.

The most extensive investigation and deployment of physical exclusion techniques in Australia has been undertaken with the aim of controlling European carp. In Tasmania, barriers in the form of fish screens have been successfully deployed to prevent the spread of carp from Lake Crescent and Lake Sorell (IFC 1999; Koehn *et al*. 2000). A wire mesh barrier that funnelled carp into a trap has also been trialled in Barmah Lake on the Murray River in south-eastern Australia (Stuart and Jones 2002). The barrier prevented upstream migration of overwintering aggregations of carp from the main river channel during low to medium flows but became inundated at high flows of 7600 ML day^{-1}. Barrier devices have also been tested in the laboratory. Smith (2005) reported that a solid metal screen that extended approximately one-third of the way from the substrate to the water surface was completely successful in containing carp in laboratory experiments. Carp separation cages that exploit the jumping behaviour of carp have also been developed in the laboratory and successfully trialled on existing fishways (Stuart and Jones 2002; Smith 2005). These cages can be relatively inexpensive at less that $5000 each (Smith 2005), although cages have recently been installed costing in the order of $50,000 (B. Creese, I&I NSW, pers. comm.). As not all carp will jump when confronted with a fixed barrier, this method is more suited to reducing carp numbers rather than excluding the species from specific areas.

The effectiveness of increasing flow velocities in fishways to impede navigation by alien fish has also been investigated. Stuart and Jones (2002) found that young-of-the-year (YOY) carp possessed a swimming ability at least equal to many similar sized native fish. Therefore, water velocities to restrict YOY carp would also be highly likely to effectively block migration of small native fish (Stuart and Jones 2002). A velocity barrier, however, has been installed in Liawenee Canal in Tasmania that effectively prevents the upstream dispersal of trout and redfin perch (IFC 1999; Wisniewski 2006). This barrier consists of a concrete weir built on an existing rock bar. The weir has a downstream jump height of 1.6 metres to prevent trout from clearing the barrier and has a flow capacity of 24 m^{-3} S^{-1} (IFC 1999). The cost of constructing the velocity barrier in Liawenee Canal in 2002 was approximately $20,600 (Wisniewski 2006).

Importantly, the swimming ability of redfin perch and its implications for preventing their passage has been investigated in Tasmania by Davies (2000). Davies quantified the maximum sustained and burst swimming speeds of this species and compared these estimates to those for two native Galaxias species (*Galaxias maculatus* and *G. truttaceus*), the native congolli *(Pseudaphritis* urvillii), and the alien brown trout (*Salmo trutta*). Redfin perch had significantly lower mean maximum sustained (0.15 m S^{-1}; SD: 0.00) and burst swimming speeds (0.32 m S^{-1}; SD: 0.02) than the other species tested, indicating relatively weak swimming ability. These estimates were consistent for redfin perch across a wide size range (fork lengths of 82 to 221 mm, equivalent to a 15 fold range in weight). From these data, Davies (2000) calculated that water velocities of above 0.5 m S^{-1} would form a complete barrier to this species. It was recommended that barriers should be designed to ensure that these velocities are sustained over distances no shorter than 2 m, that flows are hydraulically smooth, and that there is an absence of hydraulic refuges for fish (e.g., bed roughness, backwaters, still-water zones). Longer structures of greater than 5 m would permit brown trout and some native fish to pass while still excluding redfin perch, provided that velocities were constrained between 0.3 and 0.4 m S^{-1}.

Elsewhere, the use of physical barriers to exclude alien fish has been applied in a relatively ad hoc fashion. In south-eastern Australia, culvert pipes, concrete weirs, log weirs, rock filled gabions, and natural falls enhanced with rocks and concrete have been used to a limited extent to prevent upstream movements of alien trout species (Lintermans 2000; Lintermans and Raadik 2003; Jackson *et al*. 2004). Fish screens have also been installed on dams in Queensland to prevent the invasion of introduced species as a result of inter-basin water transfers (Koehn and MacKenzie 2004). Numerous existing in-stream infrastructures may also inadvertently impede the dispersal of alien species. For example, Higham (2007) reported that water supply dams have prevented the upstream establishment of alien brown trout, carp and redfin perch in the Cotter River in the ACT.

3.2. Behavioural systems

Internationally, one of the most commonly utilised behavioural systems is the electrical barrier. This method involves the use of electrical current that is passed through the water column from an electrode array embedded into an underwater structure across the stream. Like physical barriers, electrical barriers have been used extensively in the sea lamprey control program (Swink 1999). However, the latter system offers an advantage over solid in-stream structures in that it does not affect the hydrological characteristics of a stream. Upstream electrical barrier systems use electric pulses to partially paralyse fish without causing physical injury. Pulsed direct current generators are controlled by computers to produce an ascending electrical field perpendicular to the stream flow sufficient to gradually reduce the ability of the fish to swim against the water flow (Smith-Root, Inc. 2008). Combined electrical and fixed-crest barriers have been developed that allow for a lower crest height and construction of barriers on streams with widely fluctuating flows (Swink 1999; Lavis *et al*. 2003). Electrical barrier systems can be expensive to install and operate, with Clarkson (2004) estimating construction and set-up costs for barriers in canals between 15 and 30 metres wide in the order of US$500,000 and average annual operation and maintenance costs (including labour, energy, and maintenance contracts) of between US$12,700 and $14,500.

A variety of other behavioural systems have been developed, including bubble curtains, artificial lighting arrays and underwater acoustic systems. A typical acoustic system consists of a signal generator which produces the required signal(s); power amplifiers which boost signal levels to the required output levels for the sound projector; and sound projectors which are used to create the underwater sound field (Lambert *et al*. 1997). To obtain a behavioural response, a fish must hear the sound and also react to it. Although fish will react to a sound if it is loud enough, it is more cost-effective to use a signal which the fish find irritating at relatively low pressure levels. Often, there are differences in response among fish species and species-specific signals have to be developed. These signals are usually in the range of 20 – 2000 Hz, and are within the audible range of humans. In addition, resident fish may become accustomed to a single signal, meaning a range of alternative signals may need to be developed and then released in sequence or at random (Lambert *et al*. 1997).

Fish detect sound via the lateral line and inner ear and their ability to sense sound pressure is dependent on the connection between these two systems. Relative to ‘hearing specialists’ such as various members of the carp (Cyprinidae) and herring (Clupeidae) families, redfin perch are regarded as only moderately sensitive to sound (Lambert *et al*. 1997) and are capable of responding to frequencies ranging from 0.3 to approximately 300 Hz (Karlsen 1992). Although they have a swimbladder, the connection between it and the inner ear is not as close as for hearing specialists. Acoustic deterrent systems therefore are considered to be less effective on redfin perch than on carp, for example, which have a close connection between the inner ear and swimbladder (Lambert *et al*. 1997). An acoustic system producing 20 to 600 Hz sound has been shown to significantly reduce the catch of redfin perch by 51.2% near a nuclear power station inlet in Belgium (Maes *et al*. 2004). Hence, while sound may deter many fish, complete exclusion using current technology is unlikely.

Bubble curtains produced from submerged pipes have been used for many years as a means of diverting fish from water intakes associated with power stations and other riverine infrastructure (Welton *et al*. 2002). Their effectiveness is questionable, however, with an increasing body of evidence from field studies showing that bubbles do not cause consistent avoidance behaviour (Sager *et al*. 2000; Lucas and Baras 2001). Bubble screens have been combined with acoustic systems to produce a more effective deterrent to migrating native fish (Welton *et al*. 2002) and alien fish (Pegg and Chick 2008). For example, the hybrid sound projector array 'BioAcoustic Fish Fence' has been trialled for its effectiveness in preventing alien bighead carp (a hearing specialist) from moving up the Illinois River towards Lake Michigan in North America (Pegg and Chick 2008). This system employs an air bubble curtain that contains a pneumatically generated sound signal creating a sound field repulsive to targeted fish species. The system was deemed successful with 95% of the 284 attempts by carp to cross the functional barrier repelled. According to Koster *et al*. (2002), both acoustic systems and bubble curtains are relatively expensive to install and operate. However, Popper (2002) and Welton *et al*. (2002) promoted them as 'cost-effective' devices that have been developed in an attempt to overcome the need for more elaborate and expensive exclusion technologies.

Light is promoted as another cost-effective means of repelling fish (Brown 2000). The greatest success has been achieved with strobe (flashing) lights, while mercury (constant) light appears to be less successful (Nemeth and Anderson 1992). As with acoustic deterrent systems, the effectiveness of the light stimulus appears to be species-specific, and may vary for a single species depending on the age of the fish and other physiological variables (Popper and Carlson 1998). In addition, effectiveness may vary with time of day, turbidity and lighting array. Strobe lights combined with bubble curtains as an exclusion barrier have been shown to increase avoidance in several fish species in North America (Patrick *et al*. 1985; Sager *et al*. 2000).

Both mercury and strobe lighting might be an effective deterrent to redfin perch. Continuous light has reportedly reduced night-time impingement of redfin perch in water intakes in Europe (Popper and Carlson 1998; Lucas and Baras 2001). In North America, Richards *et al*. (2007) found that the stress response and avoidance behaviour of yellow perch (*Perca flavescens*), a close relative of redfin perch, to high-frequency strobe lights was relatively high compared to four other fish taxa studied. These authors concluded that the yellow perch was very sensitive to this system. Avoidance of strobe lights by yellow perch has also been reported by Brown (2000) and Richards (2006). No studies were found which reported on the effectiveness of strobe lights in deterring redfin perch. However, given the results above, testing is warranted to determine the suitability of strobe and mercury lights as an exclusion method for redfin perch in Australian waters.

Chemical poisons have also been shown to exclude alien species from specific areas. This method has been primarily used to suppress the spawning migrations of sea lamprey in the Great Lakes of North America. Although most poisons are lethal to a wide variety of animals and are therefore inappropriate as an exclusion technique, the unique physiology of the ancient sea lamprey makes it susceptible to poisons that have little effect on teleost ('bony') fish (Sorenson and Stacey 2004). The compound 3-trifluoromethyl-4-nitrophenol (TFM) or a combination of TFM and 2'.5-dichloro-4'-nitrosalicylanilide (Bayer 73), commonly known as lampricides selectively kill sea lampreys with minimal environmental side effects. However, the application of lampricides constitutes only a temporary, restricted, and expensive method as the chemicals must be introduced into the environment at periodic intervals on a continuing basis to remove sea lampreys that enter the stream from the lakes to spawn after the stream has been treated (Smith and Tibbles 1980).

Poisons such as rotenone are available that are lethal to redfin perch (Meadows 1973). This chemical has been used to remove alien fish in Australia in conjunction with physical barriers to prevent reinvasion (Lintermans 2000; Lintermans and Raadik 2003) but its sole use as an exclusion technique is usually inappropriate as it affects most gill-breathing animals (Rayner and Creese 2006). No target-specific poisons exist for redfin perch and, given that the physiology of this species is typical of bony fish, it is unlikely that a selective poison like a lampricide can be developed.

Other chemicals such as pheromones (chemical signals that pass between individuals of the same species) are being investigated that may repel alien species away from specific areas (Sorenson and Stacey 2004). For example, repulsive odours such as pheromones released when fish are alarmed could supplement and increase the effectiveness of exclusion devices such as physical barriers. However, much research is still required to develop this method for use in alien fish management.

3.3. Comparison of exclusion devices

The use of physical and behavioural exclusion devices to prevent the upstream dispersal of redfin perch in the tributaries of Warragamba Dam was assessed in regards to a technology's ability to specifically target redfin perch; efficacy in excluding this species; effects on animal welfare, non-target species and the environment; cost-effectiveness; safety; and overall acceptability (West *et al*. 2007). The results of the assessment are summarised below in Tables 1a and 1b.

From reviewing Table 1a and 1b, it was concluded that many of the techniques available for excluding redfin perch were not suitable for installation within the study area. This was due primarily to an inability to or a lack of knowledge on their effectiveness to contain this species, lack of target specificity and a range of other environmental impacts, and the costs associated with constructing and maintaining some technologies (Tables 1a and 1b). In addition, behavioural control devices such as electrical barriers require a considerable power supply to operate, which is not readily available near the remote tributaries within the study area. Even if power could be supplied, an inherent risk with these systems is that loss of power or other system breakdowns may allow redfin perch to pass. Alternatively, a velocity barrier possessed many characteristics suitable for preventing the upstream dispersal of redfin perch (Table 1a). Importantly, this technique is considered 100% effective at excluding this species and has been successfully used in Tasmania for this purpose, with design specifications available. It is also relatively inexpensive to construct and maintain, and has relatively minor environmental impacts in comparison to other techniques such as conventional in-stream barriers and electric barriers, including the capacity to allow the passage of at least some native fish.

Potential also exists for behavioural systems such as strobe lights and acoustic systems to effectively exclude redfin perch (Table 1b). However, laboratory and field-based testing is required before the efficacy of these techniques to prevent upstream dispersal by redfin perch can be gauged. Testing and fine-tuning behavioural control devices should be based on a sound understanding of the behaviour of the target species in each place it is to be applied (Popper and Carlson 1998). Research is needed to fill such knowledge gaps for redfin perch in Australia (Lintermans *et al*. 2007).

Table 1a. The suitability of available physical exclusion devices for preventing the upstream dispersal of redfin perch in the tributaries of Warragamba Dam. Target specificity is defined as a device's ability to solely target redfin perch based on current knowledge. Information sourced from Hunn and Young (1980); Davies (2000); Stuart and Jones (2002); Lavis *et al*. (2003); Wisniewski (2006); Braysher (2007); West *et al*. (2007); D. Lavis (U.S. Fish and Wildlife Service, pers. comm.); and W. Swink (U. S. Geological Survey, pers. comm.).

Device	Advantages	Disadvantages
In-stream barriers	- Capable of effective exclusion during low to moderate flows - Minimal physical harm to target and non-target species - Moderately inexpensive to install - Minimal maintenance required - Relatively safe	- Reduced capacity to contain target species if breeched by high water flows (although effectiveness may increase if combined with an electric barrier) - Disrupts the movements of non-target species - Minor damage to soil and vegetative cover and increased turbidity during construction - Impoundments created immediately upstream and can modify flow regime - Impairment of the aesthetics of the exclusion site - Possibly unacceptable overall as fish passage disruption is a threat to native fish
Velocity barriers	- Target specific allowing at least some native fish to pass - Capable of 100% exclusion under a range of flow conditions - Minimal physical harm to target and non-target species - Minor effects on surrounding physical environment during operation - Moderately inexpensive to install - Minimal maintenance required - Overall acceptability likely as it is effective, target specific, and has relatively minor environmental impacts	- Potential to disrupt the movements of some non-target species - Minor damage to soil and vegetative cover and increased turbidity during construction - Flow velocities modified directly downstream - Increased flows across an in-stream structure may pose a safety issue - Impairment of the aesthetics of the exclusion site
Screens	- Capable of effective exclusion during low to moderate flows - Minimal effects on surrounding physical environment during operation - Relatively cheap to install across small tributaries - Relatively safe	- Reduced capacity to contain target species if breeched by high water flows - Disrupts the movements of non-target species - Potential physical harm to target and non-target species (e.g., fish caught in mesh) - Constant maintenance if waterborne debris loads are high - Impairment of the aesthetics of the exclusion site - Possibly unacceptable overall as fish passage disruption is a threat to native fish
Traps	- Moderately inexpensive to install - Relatively safe	- Non-target specific and unlikely to effectively exclude target species - Potential animal welfare issues associated with fish caught in traps dying - Requires the construction of supportive infrastructure (e.g., fishway) - Constant clearing of traps and disposal of trapped animals required - Impairment of the aesthetics of the exclusion site - Possibly unacceptable overall given that traps are non-target specific

Table 1b. The suitability of available behavioural exclusion devices for preventing the upstream dispersal of redfin perch in the tributaries of Warragamba Dam. Target specificity is defined as a device's ability to solely target redfin perch based on current knowledge. Information sourced from Lambert *et al*. (1997); Popper and Carlson (1998); Swink (1999); Brown (2000); Lucas and Baras (2001); Popper (2002); Welton *et al*. (2002); Koster *et al*. (2002); Lavis *et al*. (2003); Clarkson (2004); Maes *et al*. (2004); Braysher (2007); West *et al*. (2007); D. Lavis (U.S. Fish and Wildlife Service, pers. comm.); W. Swink (U. S. Geological Survey, pers. comm.); and D. Lambert (Fish Guidance Systems Ltd, U.K., pers. comm.).

Device	**Advantages**	**Disadvantages**
Electric barriers	- Capable of effective exclusion under a range of flow conditions - Minimal harm to target and non-target aquatic species - Minimal effects on surrounding physical environment during operation	- Potential for failure if system breaks down or power supply is lost - Disrupts the movements of non-target aquatic species - Minor damage to soil and vegetative cover and increased turbidity during construction - Expensive to construct and maintain - Requires a major power source to operate - Potentially harmful to terrestrial animals and humans - Impairment of the aesthetics of the exclusion site - Possibly unacceptable overall as fish passage disruption is a threat to native fish
Acoustic systems	- Minimal effects on surrounding physical environment during construction and operation - Relatively inexpensive to install and operate - Minimal impairment of the aesthetics of the exclusion site - Relatively safe	- Non-target specific and ability to effectively exclude target species is unlikely (research and development required) - Potentially harmful to target and non-target species (research and development required) - Requires a power source to operate - Potential for failure if system break down or power supply is lost - Overall acceptability unknown and is dependent on research and development
Bubble curtains	- Minimal harm to target and non-target species - Minimal effects on surrounding physical environment during construction and operation - Relatively inexpensive to install and operate - Minimal impairment of the aesthetics of the exclusion site - Relatively safe - Overall acceptability likely as potentially effective if used in conjunction with other techniques and has minimal environmental impacts	- Non-target specific and unlikely to effectively exclude target species (although effectiveness may increase if combined with other techniques) - Potential for failure if system break down or power supply is lost - Requires a power source to operate

Table 1b continued.

Device	**Advantages**	**Disadvantages**
Light	- Potentially effective at excluding target species (research and development required) - Minimal harm to target and non-target species - Minimal effects on surrounding physical environment during construction and operation - Relatively inexpensive to install - Relatively safe - Overall acceptability likely as it is potentially effective and has relatively minor environmental impacts (research and development required	- Target specificity unknown (research and development required) - Effectiveness to exclude target species may differ depending on background light levels, turbidity, etc. - Potential for failure if system break down or power supply is lost - Requires a power source to operate
Poisons	- Minimal effects on surrounding physical environment during application	- Currently non-target specific and ability to develop target-specific poisons is unlikely (extensive research and development required) - Harmful to target and non-target species - Expensive to maintain effectiveness as requires continual application - Potentially unsafe - Probably unacceptable overall given that poisons are typically non-target specific; may be more acceptable if a target-specific poison was developed
Pheromones	- Likely to not harm target and non-target species - Minimal effects on surrounding physical environment during application - Relatively safe - Overall acceptability likely if target-specific pheromones are developed and has relatively minor environmental impacts (research and development required	- Currently undeveloped, and target specificity and ability to effectively exclude target species is unknown (extensive research and development required) - May be expensive to maintain effectiveness as probably requires continual application

The use of exclusion devices should be considered in relation to the behavioural biology of the target species. The redfin perch is a non-migratory species that can complete its life cycle in small enclosed bodies of water (Morgan *et al*. 2005). Hence, unlike the temporary structures used to inhibit the seasonal spawning migrations of the sea lamprey (Lavis *et al*. 2003), a redfin perch velocity barrier would have to provide continual year-round exclusion to be effective. As with all exclusion devices, velocity barriers can cause the dispersion of alien species to other streams. Thus, consideration should be given to installing velocity barriers on all tributaries of Warragamba Dam inhabited by Macquarie perch to protect this threatened species from the significant threats posed by redfin perch. Careful consideration should also be given to containing redfin perch within the dam to protect downstream populations of Macquarie perch and other native aquatic animals. Behavioural deterrents such as strobe lights and perhaps acoustic systems show the most promise in this regard.

4. EFFECTS OF AN EXCLUSION DEVICE ON THE LOCAL FISH POPULATIONS

The installation of an in-stream device that excludes redfin perch from invading new waterways has the potential to act as a barrier to other aquatic biota, preventing them from moving freely within their environment. Fish, in particular, require passage to different habitats at different stages in their life cycle. Movement and migration patterns vary widely among species. Some species migrate seasonally over large distances within freshwaters or between marine, estuarine and freshwaters while others undertake more regular, smaller-scale within-stream movements. Regardless of the interval or spatial scale, such movements may be necessary for breeding, feeding, finding refuge or for fulfilling other important life requirements (Lucas and Baras 2001). In-stream barriers can disrupt these movement patterns thereby impeding access to important habitats, fragmenting populations and preventing the recolonisation of upstream areas experiencing localised species extinction due to other threats and impacts (Morris *et al*. 2001; Pusey *et al*. 2004). In-stream barriers are therefore considered a major threat to native fish as they can lead to reduced population sizes, the loss of genetic diversity and extinction (Lucas and Baras 2001).

A search of the I&I NSW Freshwater Fish Research Database revealed that 29 sites have been sampled in Warragamba Dam and its feeder tributaries between 1993 and 2007 (Figure 6). Seven large-bodied and 10 small-bodied freshwater species belonging to 10 families have been recorded in the study area during this period (Table 2). Eleven species are native to Australia and the remainder are alien species.

Of the native species recorded in the study area, the freshwater catfish and mountain galaxias are relatively sedentary, typically residing in the one locality (Table 2). Thus, an exclusion device is unlikely to have a major impact on these two species. Few diadromous (those fish which regularly migrate between freshwater and estuarine/marine habitats for the purposes of reproduction) or amphidromous (similar to diadromous but for purposes other than for reproduction) species have been recorded in the study area (Table 2). The notable absence of these types of fish (e.g., Australian bass *Macquaria novemaculeata*, sea mullet *Mugil cephalus*), which are relatively common throughout other reaches of the Hawkesbury-Nepean system including directly below Warragamba Dam (see Knight and Creese 2008), is likely a result of the major barrier to fish passage created by the dam wall. Those migratory species inhabiting the study area, including the longfinned eel, shortfinned eel and Cox's gudgeon, possess behaviours that allow them to negotiate major in-stream obstacles (Table 2). Consequently, there are no diadromous/amphidromous species known to occur in the study area that could be affected by a redfin perch exclusion device.

A number of native, small-bodied fish inhabit the study area including Australian smelt and four species of gudgeon. Although information is lacking on the movement patterns of some of these species, it is thought that they may all undertake mass migrations within freshwaters (Table 2). Of these, the empire gudgeon, firetailed gudgeon and dwarf flathead gudgeon were only recorded from a small number of widely dispersed sites (Table 2; Figure 6 and Appendix 1), indicative of a patchy distribution within the study area. Conversely, the Australian smelt and flathead gudgeon were the most widely distributed species recorded in the study area, being recorded from 19 (66%) and 15 (52%) of the 29 sites sampled (Table 2; Appendix 1). This is typical for smelt and gudgeons, which are relatively common and widespread throughout the freshwaters of south-eastern Australia and are not considered to be of conservation concern (McDowall 1996; Pusey *et al*. 2004; Lintermans 2007). It is possible that an exclusion device such as an in-stream barrier installed in one or more feeder tributaries of Warragamba Dam may fragment a small portion of the metapopulation of each species and impede access by these fish to upstream areas.

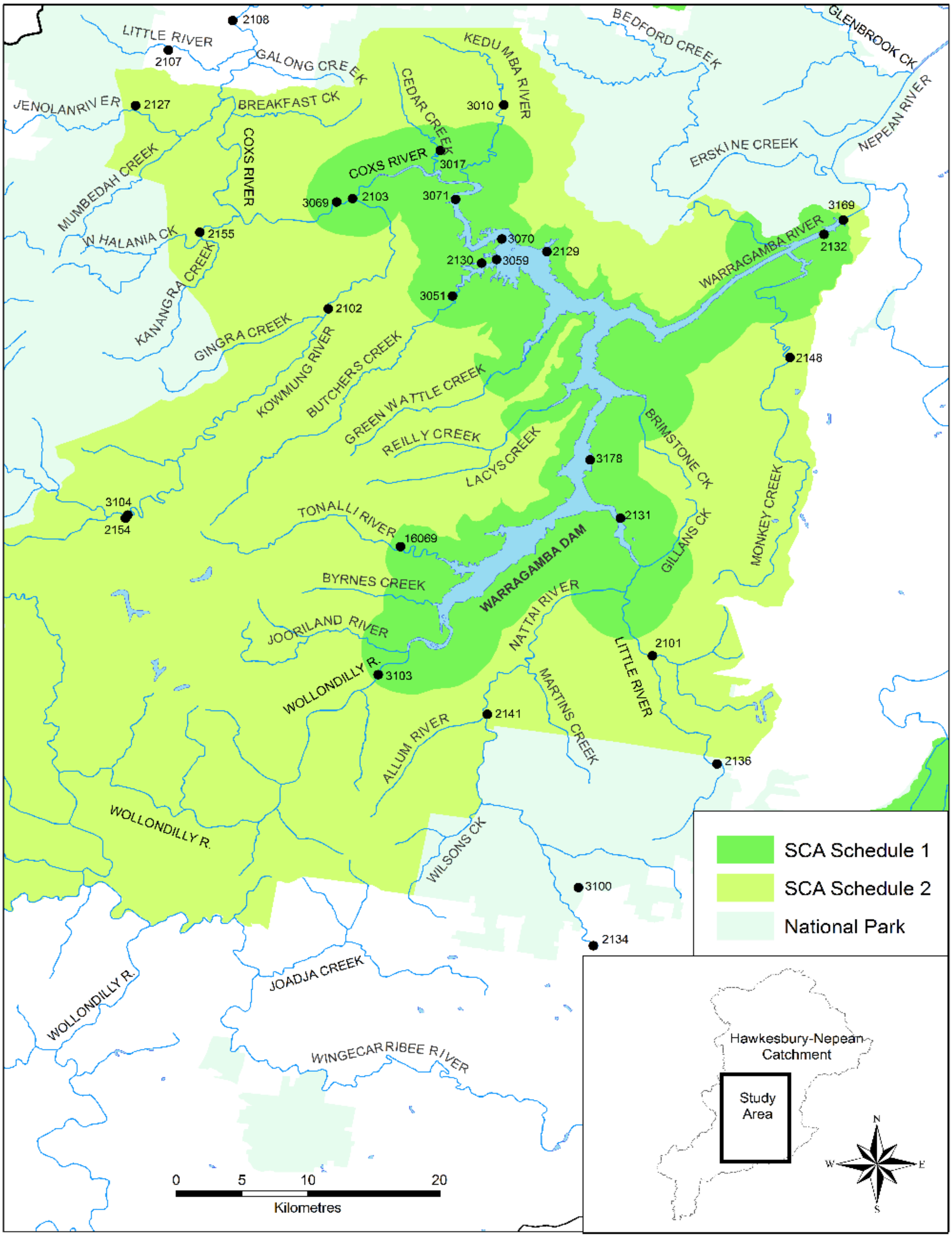

Figure 6. Location of I&I NSW survey sites (black circles) used to assess the fish species inhabiting Warragamba Dam and its feeder tributaries that may be affected by the installation of a redfin perch exclusion device.

Table 2. Fish species recorded in the Warragamba Dam catchment study area by I&I NSW between 1993 and 2007 and their associated movement behaviours. ***** = alien species introduced from overseas. Catch data sourced from the I&I NSW Freshwater Fish Research Database. Behavioural information sourced from Sammut and Erskine (1995); McDowall (1996); Pusey *et al*. (2004); Karolak (2006); Bruce *et al*. (2007); Lintermans (2007); and ASFB (2008).

Family	**Scientific name**	**Common name**	**No. sites**	**Body size**	**Movement behaviours**
Anguillidae	*Anguilla australis*	Shortfinned eel	8	Large	Migrates over large distances between the sea and fresh water; Access to estuarine areas is obligatory. Highly capable of negotiating barriers and moving over land to colonise new waterways.
	Anguilla reinhardtii	Longfinned eel	6	Large	As above.
Cobitidae	*Misgurnus anguillicaudatus*	Oriental weatherloach*	12	Small	Good dispersal abilities; Highly capable of negotiating barriers and moving over land to colonise new waterways; Continuing to spread throughout south-eastern Australia including the Hawkesbury-Nepean catchment.
Cyprinidae	*Carassius auratus*	Goldfish*	6	Large	Highly mobile; Adults and juveniles move up and downstream throughout the year. Continuing to spread throughout the Hawkesbury-Nepean catchment.
	Cyprinus carpio	Common carp*	4	Large	Highly mobile species moving up and downstream throughout the year.
Eleotridae	*Gobiomorphus coxii*	Cox's gudgeon	1	Small	Little information on movement patterns; Adults possibly spawn in freshwaters with larvae carried downstream to lowland rivers or estuaries and then migrating upstream later in life. Highly capable of negotiating barriers; Observed to leap out of the water to pass minor obstacles to movement.
	Hypseleotris compressa	Empire gudgeon	1	Small	Juveniles and adults undertake mass upstream migrations within fresh waters, and also between estuarine and freshwater reaches although access to estuarine areas is not obligatory; Smaller individuals apparently have difficulty ascending some fishways; Recorded to negotiate flows up to $1 m.sec^{-1}$ through some weirs; Tidal barrages and dams often exclude species from upstream reaches.
	Hypseleotris galii	Firetailed gudgeon	4	Small	Little information on movement patterns; May undertake mass upstream migrations within fresh waters during elevated discharges.
	Philypnodon grandiceps	Flathead gudgeon	15	Small	Little information on movement patterns; Juveniles may undertake mass upstream migrations between estuaries and freshwater during elevated discharges although access to estuarine areas is not obligatory.
	Philypnodon macrostomus	Dwarf flathead gudgeon	4	Small	No information on movement patterns; Possibly similar to *P. grandiceps*.

Table 2 continued.

Family	**Scientific name**	**Common name**	**No. sites**	**Body size**	**Movement behaviours**
Galaxiidae	*Galaxias olidus*	Mountain galaxias	6	Small	Non-migratory and have a small home range of around 19 metres.
Percichthyidae	*Macquaria australasica*	Macquarie perch	8	Small	Little information on the eastern form of Macquarie perch (i.e., east of the Great Dividing Range, see Chapter 2); Limited field observations suggest that migration within freshwaters does occur. Lake populations of the western form move upstream to riffles in the lower reaches of tributaries to spawn.
Plotosidae	*Tandanus tandanus*	Freshwater catfish	5	Large	Relatively sedentary species, typically remaining in the one locality; Have been recorded to move short distances during elevated discharges and to navigate through fishways on weirs and tidal barrages.
Poeciliidae	*Gambusia holbrooki*	Eastern gambusia*	8	Small	Non-migratory; Avoids fast flowing waters.
Retropinnidae	*Retropinna semoni*	Australian smelt	19	Small	Undertake mass migrations within fresh waters, and between estuaries and freshwater although access to estuarine areas is not obligatory; Apparent difficulty in ascending certain fishways on weirs and barrages.
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout*	10	Large	Move upstream often into small tributaries to spawn over gravel beds in flowing water; Large-scale migrations of spawning fish into estuaries observed.
	Salmo trutta	Brown trout*	11	Large	Move upstream often into small tributaries to spawn over gravel beds in flowing water.

Macquarie perch may also be affected by an exclusion device. In particular, a device located within a river reach inhabited by the species may cause population fragmentation and impede movement within the river. It is also possible that an in-stream barrier installed within the lower reaches of a feeder tributary of Warragamba Dam may impede the annual migration of lake populations which may move upstream to riffles in the lower reaches of these tributaries to spawn (Table 2). Little evidence exists, however, of Macquarie perch populations inhabiting the lentic waters of Warragamba Dam. Only one specimen has been recorded in the dam, at site 3070 (Figure 6 and Appendix 1). This is despite repeated, temporal sampling by I&I NSW at 10 dam sites (sites 2129 – 2132, 3051, 3059, 3070, 3071, 3169, 3178; Figure 6 and Appendix 1). Indeed, the dam is characterised by a lack of structural cover habitat such as rocky crevices and ledges typically utilised by Macquarie perch (Bruce *et al*. 2007). As site 3070 is located directly downstream of river reaches inhabited by the species it is possible that the sole individual sampled was a riverine vagrant.

Of the six alien species, the two trout species are considered of high recreational and economic value. Trout are, however, of little value in the localities inhabited by Macquarie perch in and around Warragamba Dam. Public access is restricted in these areas as they occur within SCA Schedule 1 and 2 lands. All six alien species are considered a threat to native fish populations (Arthington and McKenzie 1997; Koehn and MacKenzie 2004; West *et al*. 2007). An exclusion device that restricts the movements of alien species in addition to redfin perch may contribute further to the protection of Macquarie perch and assist in conserving other native fish populations in the study area.

In summary, of the 17 fish species recorded in the study area, four gudgeons, Australian smelt and Macquarie perch were considered to be potentially impacted by a redfin perch exclusion device. These impacts can be mitigated, however, by specifically designing an exclusion device that excludes redfin perch while still allowing the upstream passage of at least some native species (e.g., a velocity barrier; see Chapter 3). Any potential impacts to the local fish populations should also be viewed in light of the significant threat posed by redfin perch if this species is allowed to invade the habitats of Macquarie perch. In this regard, the installation of an exclusion device in one location is unlikely to have a significant species-level impact on the gudgeons and smelt as these species are widespread and relatively common and hence are not threatened with extinction. Careful consideration should be given to the placement of an exclusion device in relation to the localised distribution of Macquarie perch. Ideally, a device should be placed downstream of the known limits of a riverine population to reduce the risk of population fragmentation and disruption of in-stream movements.

5. LOCATION OF AN EXCLUSION DEVICE WITHIN THE STUDY AREA

5.1. Background and site assessment methodology

A field-based assessment was undertaken to assist in determining the most appropriate location for the installation of a redfin perch exclusion device within the study area. Field surveys were undertaken in September 2007 to access all potential riverine locations. A location was initially selected for assessment if it was situated in a river known to support Macquarie perch and was accessible by road; the latter being an important logistical consideration in the construction, maintenance and evaluation of an exclusion device. Using these criteria, a total of seven locations were selected within the study area, including one in the Nattai River below the Little River junction (site 1), three in the Little River (sites 2 – 4), two in the Kedumba River (sites 5 and 7), and one in the Cox’s River (site 6) (Figure 7). One site was assessed at each locality except for the lower reaches of the Kedumba River where two sites were assessed (sites 5a and 5b). Specific details regarding each site are given in Appendix 2.

Sites were compared based on a range of characteristics deemed to enhance the effectiveness of a device to prevent the upstream dispersal of redfin perch while also contributing to cost effective device construction, maintenance and monitoring. The criteria used to assess each site are provided in Table 3. Sites were scored against each criterion to assist in ranking their relative suitability. Higher scores for each criterion represented more desirable characteristics for exclusion device installation than lower scores. The rationale for adopting the assessment criteria is outlined below.

5.1.1. Exclusion site location

The location of a site is important when considering control methods such as exclusion devices (Wilson 2006). A redfin perch exclusion device should ideally be located downstream of the known limits of the resident Macquarie perch population to reduce the likelihood of population fragmentation and disruption of in-stream movements (see Chapter 4). Proximity to human settlement was also considered important as alien species are often illegally introduced into new areas through unintentional or deliberate human intervention (Lintermans 2004). Indeed, an exclusion device would offer little protection to Macquarie perch if redfin perch were introduced further upstream. Introductions are partially dependent on access and hence are conceivably less likely to occur in remote, isolated catchments than in catchments draining rural or urban areas.

5.1.2. Existing infrastructure

The presence of existing infrastructure was a key consideration in site selection for four reasons. First, the modification of an existing in-stream structure (e.g., a weir) owned by the Sydney Catchment Authority (SCA) to restrict the upstream dispersal of redfin perch may simplify the approval process required for device installation by negating the need to seek approval from the land holder (see Chapter 6). Second, modification of an existing in-stream structure may be more cost effective than the construction of a new in-stream structure. Third, existing road infrastructure allowing direct vehicle access to a site would greatly assist in the construction, maintenance and evaluation of an exclusion device. Fourth, the installation of a device at a site already disturbed by an existing in-stream structure and/or road crossing would conceivably have fewer environmental impacts than installation in an undisturbed location and thus may be more acceptable to the land owner and more readily meet the requirements of environmental impact assessment (see Chapter 6).

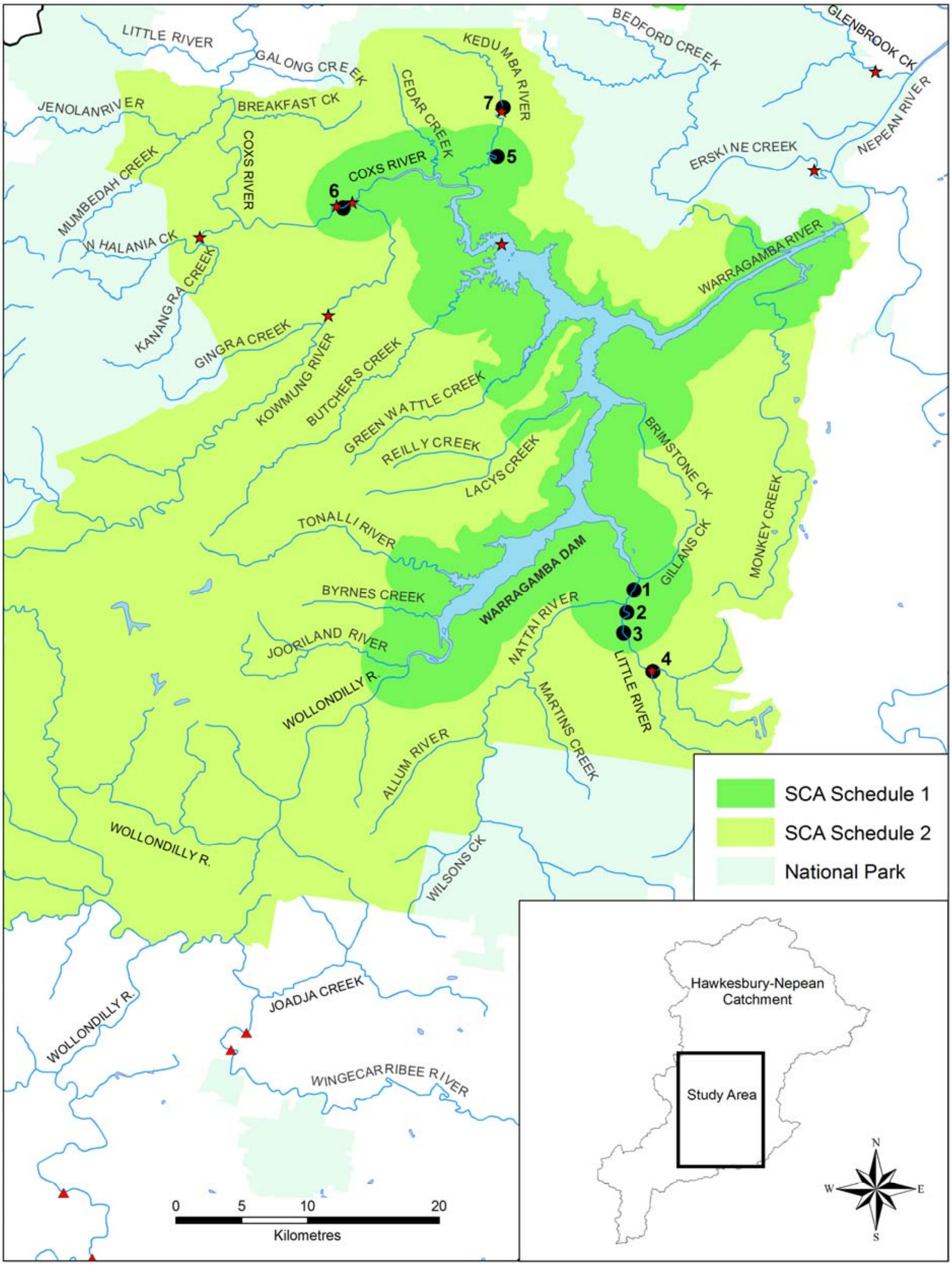

Figure 7. Locations of sites 1 – 7 (black circles) within the Warragamba Dam catchment study area investigated for their suitability for the installation of a redfin exclusion device. The currently known distributions of Macquarie perch (red stars) and redfin perch (red triangles) within the study area are also shown.

Table 3. Criteria used to score each survey site for its suitability for the installation of a redfin perch exclusion device. Higher scores represent more desirable characteristics for exclusion device installation than lower scores.

Criteria	**Score**
<u>Exclusion site location</u>	
Location in relation to Macquarie perch population	1 = downstream of known distribution
	0 = within known distribution
Risk of redfin perch introductions upstream	1 = unlikely
	0 = possible
<u>Existing infrastructure</u>	
Existing in-stream structure	2 = major structure
	1 = minor structure
	0 = no structure
Vehicle access	2 = directly to site
	1 = within 10 metres
	0 = greater than 10 metres
<u>River geomorphology</u>	
Flood bank width	Ranked relative to all sites accessed:
	2 = narrowest
	1 = intermediate
	0 = widest
Flood bank height/steepness	1 = high steep banks
	0 = low sloping banks
Substrate	1 = solid: bedrock, concrete
	0 = soft: gravel, sand, mud, etc
Water depth	1 = shallow riffle/run
	0 = deep pool/run
Water depth directly upstream	1 = shallow riffle/run
	0 = deep pool/run
Water depth directly downstream	1 = shallow riffle/run
	0 = deep pool/run
<u>Hydrology</u>	
Flow regime	Ranked relative to all sites accessed:
	2 = smallest
	1 = intermediate
	0 = largest
Stream flow gauges	1 = no fixed gauges present
	0 = fixed gauges present

5.1.3. *River geomorphology*

The geomorphology of the riverine site was considered critical in regards to the logistics of construction and to the ability of a device to effectively exclude redfin perch (Wilson 2006). For a device to be effective, it would need to block the passage of redfin perch upstream under a range of flow conditions including high flow events. To achieve this, the device would ideally be built up to the top of the flood banks. Thus, it would be logistically easier and more cost effective to construct a device in a narrow river section with steep flood banks than in a wide, gently sloping floodplain section. A shallow water depth and solid substrate would also assist in reducing the costs associated with construction. Concomitantly, the success of a device is likely to be enhanced if it is constructed in a shallow section of river. This is because a fish's ability to negotiate an in-stream structure is partially dependent on a sufficient depth of water to allow it room to gain momentum (i.e., sufficient burst swimming speed and sustained swimming speed) (Castro-Santos 2006). A lack of deep water directly upstream and downstream of a device may also prevent fish from resting and regaining energy before attempting to move upstream (Lintermans and Raadik 2003). It should be noted that all geomorphological measurements presented in Appendix 2 were taken under low flow conditions associated with a prolonged drought experienced throughout much of the Hawkesbury-Nepean catchment and Australia during 2007 and in previous years (Karoly *et al*. 2003; Bruce *et al*. 2007).

5.1.4. *Hydrology*

The flow regime of the river in which each site was located was another important consideration (Wilson 2006). Theoretically, an exclusion device is likely to be most effective in a river with a relatively small flow regime because the smaller the flow regime the less often would a device be drowned out by large flow events. Furthermore, the degree of engineering required to construct a structurally-sound device may be positively related to the size of the flow regime. Thus, a device built to withstand a relatively small flow regime may be simpler in design and cheaper and easier to construct than one built to withstand a relatively large regime. Assessment of the flow regime at each site was based on data provided by the SCA and discussions with relevant SCA staff. A summary of these data is provided in Appendix 3.

The installation of an exclusion device within a river section containing gauges used to monitor flow volumes entering Warragamba Dam was another important consideration highlighted by the SCA. A device such as a weir would presumably modify the river's flow regime resulting in the need to recalibrate gauges and develop new flow models. This would require an allocation of resources by the SCA and therefore needed to be considered when choosing the most appropriate site for an exclusion device.

5.2. Results and discussion

Of the eight sites assessed, site 5a in the Kedumba River at Rucksack Ridge Ford received the highest score, followed closely by site 7, which was located further upstream at the Kedumba Crossing (Table 4). Sites in the Kedumba River have an advantage over the other study sites in that the human-assisted introduction of redfin perch upstream of these sites is unlikely due to the surrounding catchment being largely isolated from urban or rural development. Other advantages of Rucksack Ridge Ford include that it is unlikely to fragment the resident Macquarie perch population as it is located downstream of the known distributional limits of the population, there is direct vehicle access and it had most of the desirable geomorphological and hydrological features (e.g., relatively narrow flood bank widths of approximately 20 metres; Appendix 2) (Figure 8). Kedumba Crossing also had a number of similar features to Rucksack Ridge Ford and had an additional advantage in that it had an existing, albeit minor, in-stream structure (Table 4; Figure 9) which may assist in development approval (see Chapter 6) and cost-effective device construction. However, this site also had two disadvantages including that it would fragment the resident Macquarie perch population and it contains an important gauging station regularly used by the SCA to monitor flows entering Warragamba Dam. For these reasons, Rucksack Ridge Ford is considered the more suitable location for the installation of an exclusion device. Given its location in the lower reaches of the Kedumba River, this site would also exclude redfin perch from much of the river, thereby maximising the size of the refuge for Macquarie perch and limiting disruption of in-stream movements. The final decision on site selection for a redfin perch exclusion device may be determined by the development approval process (see Chapter 6).

An undesirable feature of most sites including Rucksack Ridge Ford and Kedumba Crossing was the presence of a soft cobble, sand substrate into which extensive footings may have to be constructed to support an exclusion device. Exceptions included site 4 in the Little River which had an existing concrete causeway that could potentially provide solid footings (although the structural capacity of the causeway to adequately support an exclusion device is unknown) and site 6 in the Coxs River which had an existing concrete weir. The major disadvantage of these two sites was that the flood bank widths were greater than 60 metres (Appendix 2) which was considered too wide to feasibly install an exclusion device. The remaining sites had a range of undesirable characteristics that made them relatively unsuitable for the installation of an exclusion device (Table 4). Representative photos of Rucksack Ridge Ford and Kedumba Crossing are provided in Figures 8 and 9 below and of the remaining sites in Appendix 4.

Table 4. Assessment of each survey site for its suitability for the installation of a redfin perch exclusion device. Higher scores represent more desirable characteristics than lower scores for the installation of an exclusion device. Refer to Table 3 for details on the scoring of criteria and to Appendix 2 for details regarding each site.

	Site							
Criteria	**1**	**2**	**3**	**4**	**5**	**5b**	**6**	**7**
Exclusion site location								
Location in relation to Macquarie perch population	1	1	1	0	1	1	0	0
Risk of redfin perch introductions upstream	0	0	0	0	1	1	0	1
Existing infrastructure								
Existing in-stream structure	0	0	0	2	0	0	2	1
Vehicle access	0	2	1	2	2	0	2	2
River geomorphology								
Flood bank width	0	1	2	0	2	1	0	2
Flood bank height/steepness	0	0	1	0	1	1	0	1
Substrate	0	0	0	1	0	0	1	0
Water depth	1	1	0	1	1	1	1	1
Water depth directly upstream	1	1	0	0	1	1	0	1
Water depth directly downstream	1	1	0	1	1	1	0	1
Hydrology								
Flow regime	1	2	2	2	1	1	0	1
Stream flow calibrated using permanently fixed gauges	1	1	1	0	1	1	0	0
Total Score	6	10	8	9	12	9	6	11

Figure 8. Site 5a located at Rucksack Ridge Ford, Kedumba River.

Figure 9. Site 7 located at the Kedumba River Crossing.

6. APPROVALS REQUIRED TO CONSTRUCT AN EXCLUSION DEVICE

The NSW Department of Environment, Climate Change and Water (DECCW) is responsible for maintaining and developing the parks and reserve system and manages activities in the Kedumba River catchment in the Blue Mountains National Park in accordance with the *National Parks and Wildlife Act 1974*, the National Parks and Wildlife Regulation 2002, the *Wilderness Act 1987*, and sections 60 and 140 of the *Heritage Act 1977*. As part of this role, the DECCW is the determining authority that assesses the impacts of proposed activities within reserves. Assessment is carried out under Part 5 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) through a Review of Environmental Factors (REF) prepared by the proponent.

A REF is a document which identifies, scopes, and evaluates the impacts of an activity to:

- assist the determination of whether an activity should be approved taking into account, to the fullest extent possible, all matters affecting or likely to affect the environment (s 111 EP&A Act); and,
- determine whether the activity is likely to have a significant effect on the environment (a EIS is then required) or significantly affect threatened species, populations or ecological communities or their habitats (a SIS is then required).

Part of the REF process requires consultation to be undertaken to assist in the identification of impacts and to minimise disputes. In regards to the current proposal, consultation with the I&I NSW and DECCW is required as the proposed activity may impede fish passage and/or affect threatened species in the area. In undertaking consultation, the proponent must provide a sufficient level of information about the activity to allow the body or person being consulted to fully understand what is being proposed. This may include making available a copy of the draft REF, as well as engineering specifications and any other supporting information.

When there is more than one determining authority, an REF must be submitted to all determining authorities. As the Kedumba River drains part of the Sydney Catchment Authority (SCA) Warragamba Dam Catchment Area, a REF must be prepared for the proposed installation of a redfin perch exclusion device and submitted to both the DECCW and SCA. Under Clause 27 of the Drinking Water Catchments Regional Environmental Plan No 1, the SCA requires that an activity proposed to be carried out on land in the SCA hydrological catchment must include an assessment additional to a REF of whether the activity will have a neutral or beneficial effect on water quality (termed a NorBE).

A neutral or beneficial effect on water quality occurs when an activity:

- has no identifiable potential impact on water quality; or
- will contain any such impact on the site of the activity and prevent it from reaching any watercourse, water body or drainage depression on the site; or
- will transfer any such impact outside the site by treatment in a facility and disposal approved by a public authority (but only if the public authority is satisfied that water quality after treatment will be of the required standard).

The final decision on site selection for a redfin perch exclusion device may be determined by the development approval process. If development consent is given by the DECCW, Rucksack Ridge Ford is considered the most suitable location as an exclusion device at this location would not fragment the resident Macquarie perch population, whilst limiting disruption to in-stream movements and excluding redfin perch from much of the Kedumba River. If however, development consent in denied by the DECCW, approval from the SCA to modify an existing SCA weir may be the only option available allowing an exclusion device to be installed. This is because under the Sydney Catchment Authority Regulation 1980, there are exemptions that allow the SCA to modify and upgrade their existing weirs occurring on DECCW lands without the need to seek development consent (N. Abraham, SCA, pers. comm.). In this scenario, it is recommended that an exclusion device is installed at the Kedumba Crossing (site 7). This site has many of the desirable characteristics that are present at Rucksack Ridge Ford and, although it is located within the known distribution of the resident Macquarie perch population, a refuge would be provided for that part of population upstream of the device (see Chapter 5).

7. CONCLUSIONS AND RECOMMENDATIONS

A purpose-built velocity barrier to prevent the upstream dispersal of alien redfin perch is a relatively novel management approach in Australia. If installed, the barrier is likely to provide immediate protection for Macquarie perch from the threats posed by redfin perch. An adaptive management framework is recommended to assist in evaluating the success of the device and to mitigate any potential negative effects of the device on the local fish fauna. This would include the regular monitoring of the fish populations in the vicinity of the device. In particular, the survival, population abundance and recruitment success of the resident Macquarie perch population should be carefully assessed. Complementary surveys for redfin perch in the Wollondilly River and Warragamba Dam and its feeder tributaries would also provide valuable information on the distribution, abundance and spread of this pest and assist in evaluating the success of the exclusion device. Contingency plans should be developed to rescue the resident Macquarie perch population if the exclusion device is breached by redfin perch. Consideration should also be given to removing the exclusion device if it is breached or if it has a detrimental impact on the resident Macquarie perch population.

Monitoring the success of the exclusion device may also demonstrate the value of aquatic pest animal control to the management of native fish stocks, provide a method from which information on costs and problems of larger control programs could be identified, and encourage development and testing of improvements in existing control techniques and new technologies. These actions are urgently required to assist in effectively controlling the introduction, spread and impacts of alien fish.

As with all exclusion devices, velocity barriers can cause the dispersion of alien species to other streams. Thus, consideration should be given to installing velocity barriers on all tributaries of Warragamba Dam inhabited by Macquarie perch to protect this highly threatened species from the significant threats posed by redfin perch. Careful consideration should also be given to containing redfin perch within the dam to protect downstream populations of Macquarie perch and other native aquatic animals. Behavioural deterrents such as strobe lights and perhaps acoustic systems show the most promise in this regard.

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9. APPENDICES

Appendix 1. Fish species recorded in the Warragamba Dam study area by I&I NSW. Data sourced from the I&I NSW Freshwater Fish Research Database.

	I&I NSW Fisheries Sites																												
Common Name	2101	2102	2103	2107	2108	2127	2129	2130	2131	2132	2134	2136	2141	2148	2154	2155	3010	3017	3051	3059	3069	3070	3071	3100	3103	3104	3169	3178	16069
Short-finned eel			X	X			X	X		X							X	X								X			
Long-finned eel									X								X					X	X		X		X		
Oriental weatherloach	X	X	X		X								X		X	X		X			X				X			X	X
Goldfish			X		X									X					X			X						X	
Common carp							X	X	X	X																			
Cox's gudgeon																	X												
Empire gudgeon																									X				
Firetailed gudgeon								X	X	X												X							
Flathead gudgeon			X		X		X	X	X	X			X				X	X			X	X	X		X		X	X	
Dwarf flathead gudgeon										X							X	X							X				
Mountain galaxias				X							X	X		X			X							X					
Macquarie perch	X	X	X													X	X	X			X	X							
Freshwater catfish							X	X	X	X																	X		
Gambusia	X		X		X									X								X	X		X			X	
Australian smelt	X	X	X		X		X	X	X	X			X	X	X		X	X			X	X	X		X		X	X	
Rainbow trout						X										X	X	X	X	X	X				X	X	X		
Brown trout			X		X	X										X	X	X	X	X	X			X		X			

Appendix 2. Details of sites assessed in the Warragamba Dam catchment area for the installation of a redfin perch exclusion device. Datum is GDA94.

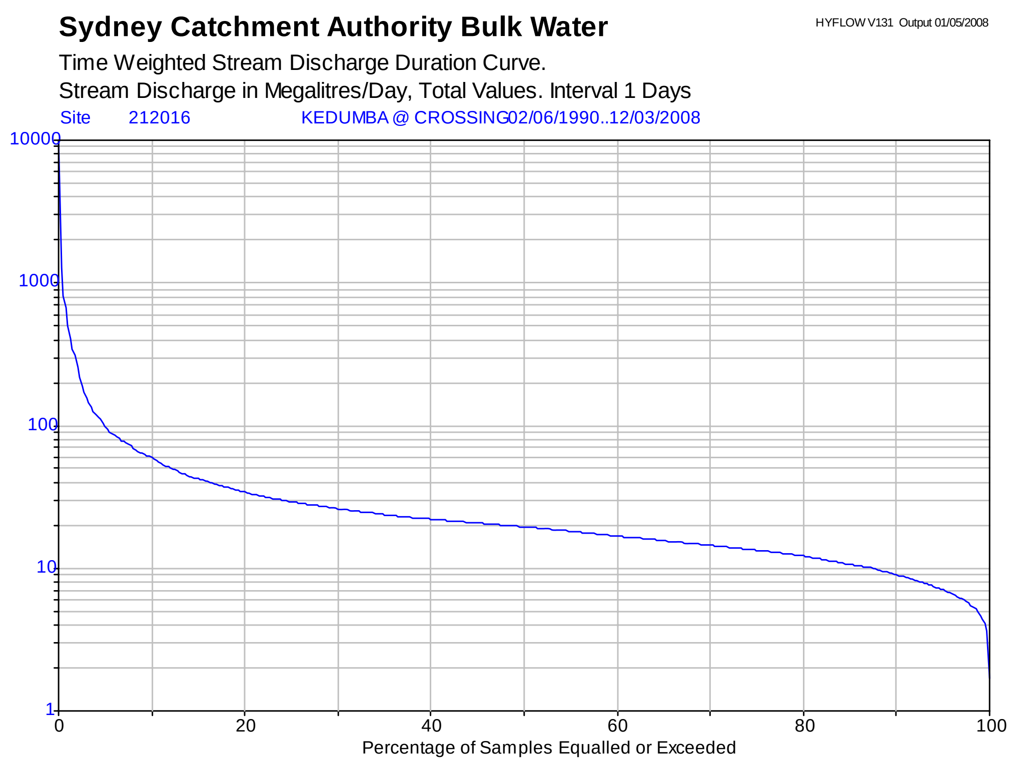
Site	Water body	Location	Road Access	Latitude	Longitude	1:25000 topo map	Wetted dimensions	Flood bank dimensions
1	Nattai River	Yerranderie Crossing	Sheehys Ck Rd	-34.13316	150.45273	Nattai	10m x 0.1m deep	60m x 4 m high
2	Little River	W4i track lower crossing	Off Sheehys Ck Rd	-34.14867	150.44788	Nattai	16m x 0.3 m deep	47m x 2-3m high
3	Little River	Between W4i track lower crossing and causeway	Off Sheehys Ck Rd	-34.16280	150.44583	Nattai	20m x 2m deep	20m x 5m high
4	Little River	W4i causeway	Off Sheehys Ck Rd	-34.18916	150.46565	Nattai	24m x 0.05m deep	>60 m x 2m high
5a	Kedumba River	Rucksack Ridge Ford	Kedumba Valley Rd	-33.83661	150.35939	Jamieson	12m x 0.5m deep	21m x 2.5m high
5b	Kedumba River	Rucksack Ridge Ford	Kedumba Valley Rd	50m upstream of site 5a		Jamieson	6m x 0.1m deep	30m x 2-3m high
6	Cox's River	Kelpie Point	Megalong Valley Rd	-33.87186	150.25446	Jamieson	26m x 0.05m deep	66m x 2-3m high
7	Kedumba River	Kedumba River Crossing	Kedumba Valley Rd	-33.80310	150.36357	Jamieson	20m x 0.4m deep	22m x 1.5m high

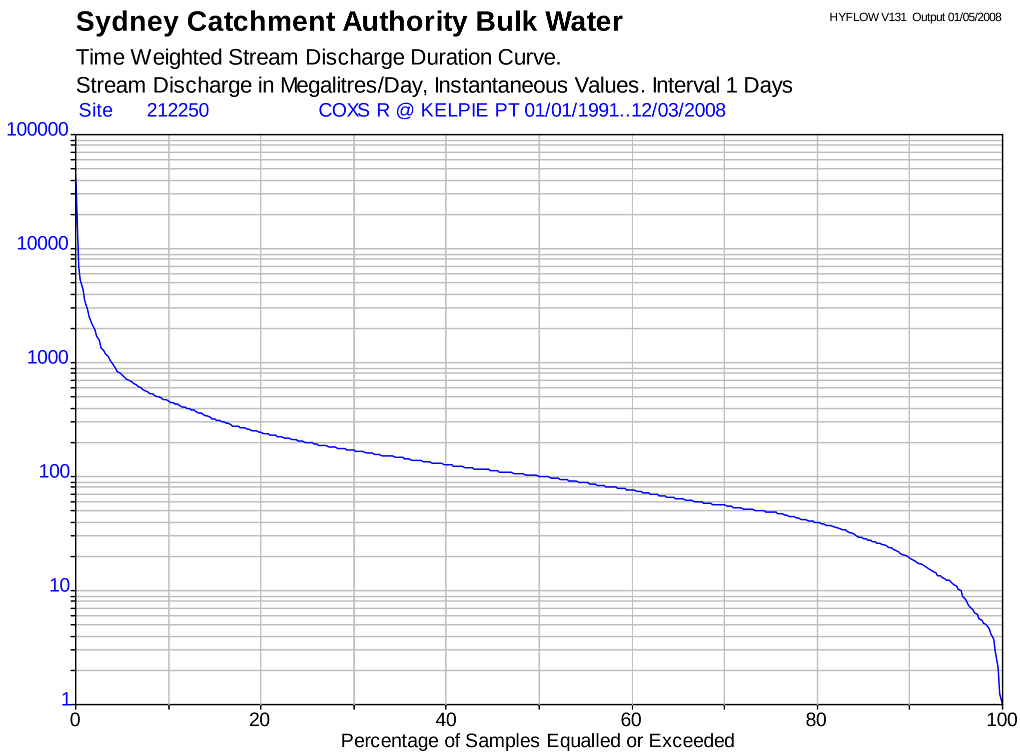
Appendix 3. Summary statistics for the flow regimes of the Kedumba, Cox's, Nattai, and Little Rivers. Statistics derived from flow data collected between 1/01/1990 and 11/03/2008 and from flow duration curves (see graphs below). Flow data and duration curves provided from the SCA.

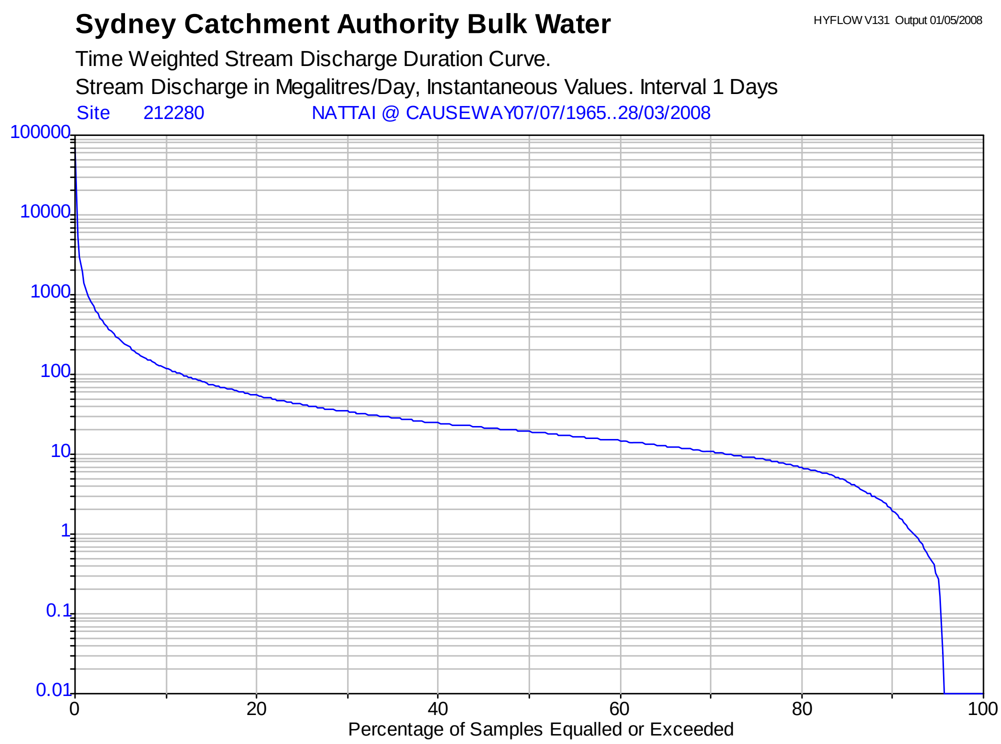
River[1]	Area (km^2)	Annual discharge (Ml x 10^{-3})				Discharge duration percentiles (ML. day^{-1})		
		Mean	S.E	Min	Max	20%	50%	80%
Kedumba River	81	13.8	1.99	6.6	19.9	32	20	12
Cox's River	1700	158.2	62.70	17.0	689.9	240	100	40
Nattai River	441	36.4	14.12	7.0	166.6	55	20	6
Little River	105	6.9	2.01	1.9	16.6	8	5.5	4

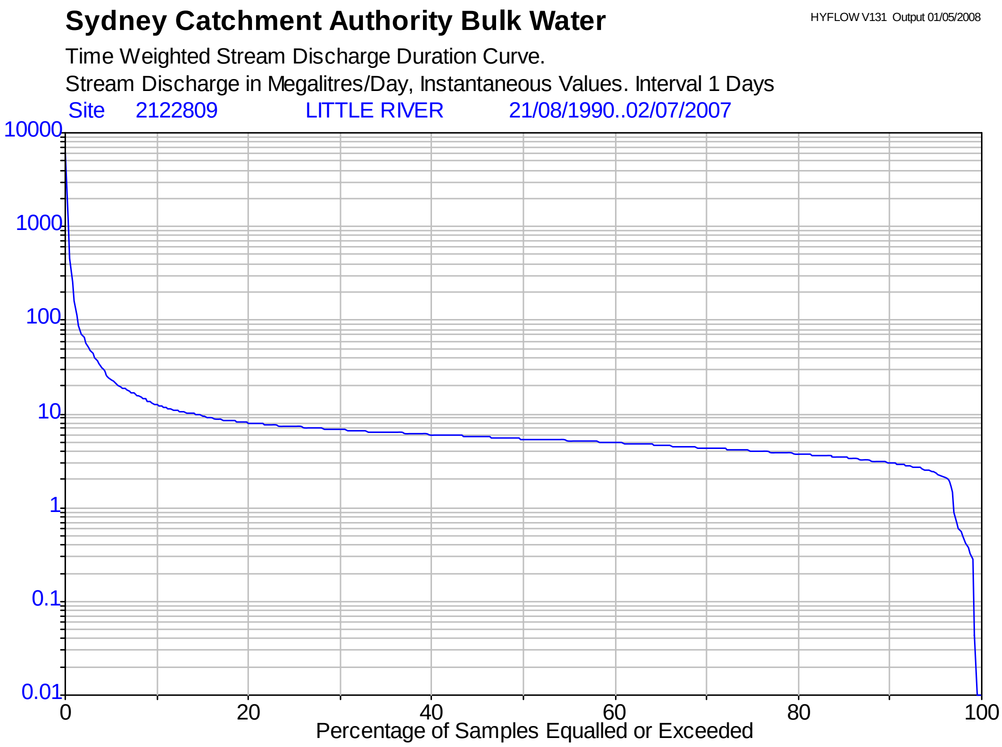
[1] Based on data from the following gauging stations: Kedumba River at Kedumba Crossing (Site 212016); Cox's River at Kelpie Point (Site 212250); Nattai River at the Causeway (Site 212280); Little River at Fireroad W4i (Site 2122809).

Flow duration curves for the Kedumba Crossing, Kelpie Point (Cox's River), Nattai Causeway, and Little River. Note the different scales on the y-axes. Source: Sydney Catchment Authority, May 2008.




Sydney Catchment Authority Bulk Water
HYFLOW V131 Output 01/05/2008
Time Weighted Stream Discharge Duration Curve.
Stream Discharge in Megalitres/Day, Instantaneous Values. Interval 1 Days
Site 212250 COXS R @ KELPIE PT 01/01/1991..12/03/2008
100000
10000
1000
100
10
1
0
20
40
60
80
100
Percentage of Samples Equalled or Exceeded


Sydney Catchment Authority Bulk Water
HYFLOW V131 Output 01/05/2008
Time Weighted Stream Discharge Duration Curve.
Stream Discharge in Megalitres/Day, Instantaneous Values. Interval 1 Days
Site 212280 NATTAI @ CAUSEWAY07/07/1965..28/03/2008
100000
10000
1000
100
10
1
0.1
0.01
0
20
40
60
80
100
Percentage of Samples Equalled or Exceeded


Sydney Catchment Authority Bulk Water
HYFLOW V131 Output 01/05/2008
Time Weighted Stream Discharge Duration Curve.
Stream Discharge in Megalitres/Day, Instantaneous Values. Interval 1 Days
Site 2122809 LITTLE RIVER 21/08/1990..02/07/2007
10000
1000
100
10
1
0.1
0.01
0
20
40
60
80
100
Percentage of Samples Equalled or Exceeded

Appendix 4. Photographs of sites surveyed between the 25 – 27th September 2007 that were determined to be unsuitable for the installation of a redfin perch exclusion device.

Site 1 at Yerranderie Crossing, Nattai River.

Site 2 at the W4I track lower crossing, Little River.

Site 3 between the W4I track lower crossing and causeway, Little River.

Site 4 at the W4I causeway, Little River.

Site 5b, approximately 50 metres upstream of Rucksack Ridge Ford, Kedumba River.

Site 6 at Kelpie Point, Cox's River.

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