Design of a fish barrier to prevent exotic fish entry into the Rotopiko/Serpentine lakes: issues, options and optimal designs

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David Rowe
Tracie Dean-Speirs

Prepared for

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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Reviewed by: Approved for release by

Dr Cindy Baker Mary de Winton

Formatting checked

A. Bartley

Executive Summary

Lake restoration and the conservation of aquatic biodiversity requires the reduction, control or eradication of pest fish in lakes and their inlet streams. However, management of these fish will only be possible where re-entry via the outlet stream can be blocked. Barriers are therefore required on the outlet streams of lakes to prevent continued upstream colonisation by pest fish.

This is particularly important for lowland lakes in the Waikato River catchment because koi carp, catfish, perch, rudd, tench, goldfish and gambusia are now widespread within the river and are affecting the water quality and biota of most lowland lakes. An exception is provided by the Serpentine lakes which still contain a relatively intact, native macrophyte flora and, compared with all other lakes, have a higher water quality. They provide a good example of the former status of most peat lakes within the Waikato River catchment and in this sense are useful reference lakes to guide the restoration of the more modified peat lakes. However, the Serpentine lakes now contain rudd and catfish which pose a threat to water quality, macrophytes and hence to lake health. On-going management of the pest fish in these lakes by the Department of Conservation and in particular, the possibility of eradication, is dependent on the installation of a barrier that prevents re-colonisation by such species from downstream sources, such as Lake Rotomanuka. The Department therefore commissioned this study to identify fish barrier designs suitable for lowland streams and specifically to assist in the selection of an optimal barrier design for the Serpentine lakes.

This report identifies the range of low-head barrier options used overseas in lowland streams to restrict fish access to lakes. It discusses the general advantages and disadvantages of such barriers and therefore provides a basis for selecting the best barrier options for the Serpentine lakes. The report identifies the unique geographical features of the Serpentine lakes outlet that will influence the selection of barrier options and it provides an indication of the issues and options concerning barrier selection, installation and management. It then identifies the five best options and presents the main advantages and disadvantages of each as a basis for a multi-departmental workshop to establish future directions and information needs related to settling on a barrier design for the Serpentine lakes.

1. Introduction

Restoration of lowland lakes in the Waikato region will, in many cases, require the removal or reduction of exotic fish and the construction of barriers to prevent their re-entry from the Waikato River. As these lakes are all low-lying, there is usually little hydrological head available for the construction of fish barriers and many are in peat bogs which create problems for the long-term stability of solid structures. In addition, the region was once a large interconnected flood-plain for the river and future climate change can be expected to increase flood flows and flooding to the point where low-head barriers may be compromised. These geographic features of the lowland lakes place a number of constraints on the design and maintenance of fish barriers. As a consequence, the Department of Conservation (DOC) is seeking advice on the issues and options facing the construction and operation of fish barriers for the Waikato lakes. In particular, the Department requires advice on the design of a barrier to prevent exotic fish re-entering the Serpentine Lake complex after they are removed.

The Serpentine lakes still contain an abundant native aquatic flora and compared with other lakes in the lower Waikato have a high level of water quality (de Winton et al. 2007). As such, they are relatively intact ecosystems within the lower Waikato region, and among the many peat lakes present, they are arguably the least modified. Apart from their biodiversity values, they are also useful as reference sites for gauging the status and restoration potential of other lakes.

This aside, an exotic herbivorous fish rudd (*Scardinius erythyrophthalamus*) is present in the Serpentine lakes and as it is herbivorous it poses a threat to the long term stability of the native macrophytes. Brown bullhead catfish (*Ameiurus nebulosus*) and goldfish (*Carassius auratus*) are also present and Rowe (2007) has shown that these exotic fish, including rudd, can collectively reduce the water clarity of lakes by accelerating the processes of eutrophication. The lakes have therefore been identified by regional management agencies (DOC, Environment Waikato, Waipa District Council) as priority sites for management and this necessitates a reduction or removal of these exotic fish species.

Reduction of rudd through netting is now included as an on-going, long-term management operation (Neilson et al. 2004) and, in the future, this may extend to eradication of all exotic fish using rotenone. However, this could only be contemplated if re-entry via the lakes outlet was prevented by a barrier. Rudd and tench have been eradicated from a small (2 ha) New Zealand lake using rotenone (Rowe & Champion 1994) and Shaw & Studholme (2001) eradicated gambusia and koi carp from small ponds using a formulation of rotenone powder. However, the feasibility of creating a barrier to upstream movement of exotic fish at the Serpentine lakes outlet is yet to be determined.

A range of barrier technologies for fish have been developed over the past 100 years to exclude freshwater fish from penetrating upstream and from occupying habitats where they can establish breeding populations. Some of these barriers are intentional and others are not. For example, large dams constructed for hydro-electric power generation or to create reservoirs for town water supply created unintentional barriers to the upstream migrations of many fish such as salmonids and eels. Dams clearly provide effective physical barriers to upstream fish movement but are only suitable as intentional barriers where large hydrological heads are present. They are not suitable for low-head sites. The construction of unintentional fish barriers in low-head sites is generally related to the installation of weirs and road culverts. This problem has generated much research over the past 50 years to develop retrofits and other technologies for restoring fish passage. Only recently, with the increasing concern over biosecurity and biodiversity has attention turned to the creation of fish barriers in rivers and streams to prevent the spread of pest fish species.

In the USA, this was spear-headed by an upsurge in demand for low-head fish barriers to prevent the upstream movement of introduced trout into small North American streams where they reduce the populations of rare and endangered salmonids. More recently, barriers have been installed in low-head sites to prevent the movement of common carp into North American wetlands because the carp reduce aquatic vegetation and compromise habitat for waterfowl. The most recent application of such barrier technology is in the headwaters of the Mississippi-Missouri where a US$9.1 million barrier is being constructed in the ship canal connecting the river to the Great Lakes. This barrier is required to prevent the movement of bighead and silver carp from the river to the lakes, while allowing continued access by shipping.

In New Zealand, barriers to prevent the upstream movement of trout have been developed and installed in several South Island streams to protect rare galaxiids from brown trout (Allibone 2000; Chadderton 2003). More recently barriers have been designed and used in a few streams in central North Island lakes to protect lacustrine koaro populations from predation by and competition from rainbow trout (Rowe & Konui 2007; Rowe & Smith 2008).

The lessons learned from such applications are relevant to the problem of designing a fish barrier to prevent exotic fish access to the Serpentine lakes. However, the unique features and characteristics of the Serpentine site also need to be examined to determine which of the many low-head barrier options that have been tried overseas is most suitable. This report therefore attempts to define the problem of exotic fish re-entry to the Serpentine lakes, collates relevant information on the site, describes the range of barrier technologies available, and recommends the best barrier designs with reference to effectiveness as well as site characteristics and potential costs. Although an optimal barrier design is a key object, there are a number of other issues that could affect its functioning and which may either enhance or negate its purpose. These related issues are also discussed and the potential management actions needed to prevent exotic fish re-entry to the Serpentine lakes complex are identified for inclusion within an overall exotic fish exclusion plan.

2. Issues related to preventing exotic fish entry to the Serpentine lakes

2.1 Species to consider

Although prevention of rudd entry to the Serpentine lakes is the main goal of a fish barrier, future changes in land and water use mean that other exotic fish species present in the Waikato catchment could also gain access to the lakes and so need to be considered. In particular, koi carp are herbivorous and, if they could enter these lakes, could reproduce and severely damage the aquatic plant community. Perch (*Perca fluviatilis*), brown bullhead catfish, tench (*Tinca tinca*) and goldfish are not obligate herbivores, so would not damage the plant community directly. However, because their natural predators are lacking in New Zealand lakes, they can produce very large populations and they have all been collectively implicated in water transparency decline and increased eutrophication in lakes (Rowe 2007). They could therefore limit plant community depth by reducing light penetration and by increasing hypolimnetic de-oxygenation. Under such conditions, plant growth is limited to shallower and shallower depths until the lake flips into algal domination. The collective impact of the non-herbivorous fish on aquatic plant communities is therefore indirect. As these exotic fish species are all present in the Waikato River, they could eventually move upstream and enter the Serpentine lakes. Therefore, any barrier needs to take their swimming, climbing and jumping abilities into account. Of the species not already present in the Serpentine lakes, koi carp are likely to be the best swimmers (and jumpers) and their ability to penetrate upstream will be exceeded only by that of brown and/or rainbow trout. Juvenile koi carp have ascended the new outlet for Lake Waikare (Boubee et al. 2004) and adults are capable of jumping small barriers (up to at least 50 cm high) in streams (Stuart et al. 2006). Little is known about the ability of the brown bullhead catfish, tench, goldfish or perch to penetrate upstream, but they are unlikely to have the same abilities as koi carp or trout. A barrier to prevent upstream movement of all these species therefore needs to account for the leaping ability of koi carp to prevent this species and other exotic fish from entering the Serpentine lakes. Trout are not known to affect water quality in lakes and prevention of their upstream movement is not considered important in the context of these lake’s conservation.

New freshwater fish species continue to be introduced to New Zealand (Fig. 1) and species not yet present in the Waikato River catchment may occur there in the future. Such species could include a range of small (<10 cm long), cool-water, aquarium fish. For example, golden orfe (*Leuciscus idus*) has been recorded in Auckland waters, the gudgeon (*Gobio gobio*) were found reproducing in a large pond but have since been eradicated and a dead plecostomid catfish was recovered from a Bay of Plenty River in 2008. Larger species not present in New Zealand but which may be illegally introduced in the future include the oriental weatherloach (*Misgurnus anguillicaudatus*), which has recently established breeding populations in both New South Wales and Victoria, and snakeheads (*Channa* sp) and the Asian swamp eel (*Monopterus albus*) now established in northern waters in the USA. Introductions of these and other species may occur in the future, but they are not known to leap, climb, or cope with high water velocities to the same extent as koi carp or trout.

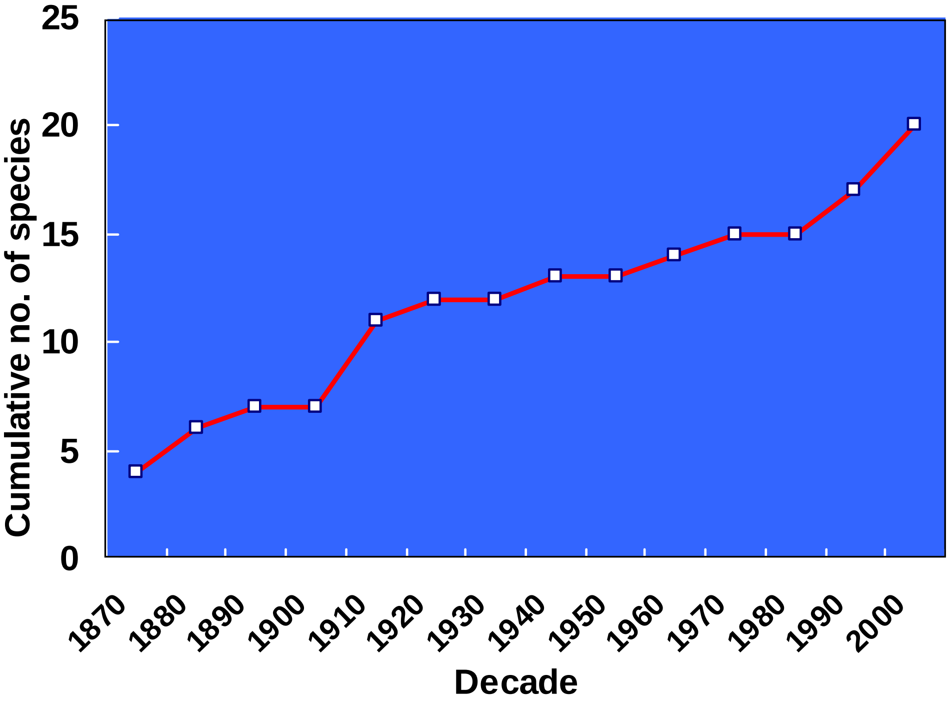

Figure 1: Decadal rate of increase in the introduction of exotic fish species to New Zealand over the past 150 years.

Although silver carp (*Hypopthalmichthys molotrix*) is present in New Zealand, it is not present in the Waikato River. However, it has a reputation as a fast-swimming fish and is a good jumper. Its ability to jump and swim is likely to exceed that of koi carp as well as trout and salmon. If released widely into ponds within the Waikato catchment some silver carp could be expected to eventually escape into the Waikato River. At present, this fish is not expected to reproduce in the Waikato River because of its highly specific spawning requirements, similar to those of grass carp (*Ctenopharyngodon idella*). However, recent reports from Japan, USA and Uzbekistan indicate that silver carp are proliferating in rivers where grass carp do not. This may indicate that silver carp can reproduce more easily in rivers where grass carp cannot. If so, then silver carp could conceivably reproduce in the Waikato River. Ideally, the barrier should also be capable of withstanding the ability of this species to penetrate upstream. It is arguably, the species with the greatest ability to surmount a low-head barrier and if the barrier were constructed to prevent its upstream movement, it would prevent the movement of all other species of concern.

2.2 Fish swimming and leaping abilities

Exclusion of fish with the ability to jump small falls depends on the maximum height and distance which the species can jump. The jump height of silver carp has not been reported (to my knowledge), but observations of jumping behaviour when disturbed in rivers indicates a height of more than 1.5 m, but less than 2.0 m over a distance of 2 m. However, this does not mean that the barrier must be >1.5 m high as there are other ways of limiting upstream access by jumping fish. The height and distance which a fish can jump depends on their size as well as on the size of the pool immediately below the barrier. Deeper and larger pools provide more space for large fish to gain maximum swimming speed before leaping out of the water. In general, larger fish can jump to greater heights because they swim faster than smaller fish and exit velocities at the water surface are greater. The jumping ability of fish is therefore dependant on the presence of deep water in front of a fall. It follows that dams or weirs with shallow aprons below them that restrict water depth would be more effective barriers than weirs or dams with large pools at their bases. This aspect of fish leaping behaviour underpins the design of many low-head barriers constructed to limit the upstream movement of trout in the USA. It may also prove to be a useful component of fall-based barriers designed to restrict the upstream movement of other fish.

Other key components of fish swimming behaviour that will have an important bearing on barrier design are water velocity and water depth in the stream channel. Maximum swimming speeds for some native fish have been determined (Mitchell 1989; Stevenson & Baker 2009) and these studies indicate that the distance over which the maximum speed can be sustained is an equally important factor influencing fish passage through fast flowing chutes. It will also be important for any fish barrier design based on high water velocities. Some data on the maximum swimming speeds of fish such as trout, koi (or common) carp and silver carp are no doubt available in the scientific literature, which may need to be reviewed if barrier designs for the Serpentine lakes are to be based on high water velocity. However, published data on the minimum length of stream channel over which such swimming speeds can be maintained can be expected to be meagre.

An adequate water depth is also a key factor influencing the ability of fish to swim upstream. In general, a greater water depth is required for larger fish, apart from species such as eels and species with flattened body forms (e.g., flounders, rays).

Juvenile fish can cope with a lower water depth than adults and the juveniles of carp, trout and silver carp would probably require a water depth of at least 20 mm. A water depth of 10 mm or less, especially coupled with a high water velocity (e.g., > 0.2 m/s), would in all likelihood create a barrier to their upstream movement. However, there are unlikely to be many useful data in the literature on these factors at present and such data would be needed should a barrier design need to be based on restricting the upstream swimming ability of juveniles.

Data on the swimming requirements of exotic fish are required to determine the minimum water depths, maximum water velocity/distances, and minimum fall heights that will impede the upstream movements of adult and juvenile fish, such as koi carp and possibly silver carp.

2.3 Vectors for fish introductions

The ability of a fish barrier to prevent upstream movements of exotic fish into the Serpentine lakes assumes that such fish can only access these lakes via a natural or man-made waterway. However, waterway barriers would be of little use if the main vector for spread involved overland transport by human vectors. For example, catfish have probably been accidentally transported overland between many North Island waterways by eel fishermen’s fyke nets and/or in boat trailers. Gambusia and other small fish may also have been transported between waterways in this way and the juveniles of rudd and other exotic species could also be introduced by such means. This issue needs to be considered in the overall context of pest fish management.

An aquatic barrier is not sufficient in itself and management of lake use will need to address other land-based vectors for fish transfer such as boat bilge-water, trailers, nets.

Inadvertent fish introductions may also occur from fish populations in ornamental ponds site further upstream in the lakes’ catchment. Furthermore, some aquarists who do not wish to see unwanted fish die are guilty of releasing exotic species into natural waterways, and some religious groups practice the release of live fish into natural waters. A major vector for fish transfer in the northern hemisphere is the use of small live fish as baits by anglers. At present, this is not permitted by the Auckland-Waikato Fish and Game Council, but bait fishing is permitted by other Fish and Game Councils in other parts of New Zealand.

Signage and public education will be needed as a complement to other restrictions designed to prevent fish introductions.

2.4 Native fish passage

A barrier constructed to stop the ingress of exotic fish species may restrict the free passage of native diadromous fish species. Fish surveys of the lake have indicated that it contains both species of indigenous eel (*Anguilla dieffenbachii* and *A. australis*) as well as lacustrine populations of the common bully (*Gobiomorphus cotidianus*) and smelt (*Retropinna retropinna*). Historically, the fish fauna may have included species with good to moderate climbing abilities (e.g., banded kokopu, *Galaxias fasciatus*, and giant kokopu, *Galaxias argenteus*). However, the upstream passage of species such as inanga (*Galaxias maculatus*) and grey mullet (*Mugil cephalus*) will have probably been restricted naturally by the small fall, chutes, and high water velocities just above the confluence of Mystery Creek with the Waikato River. Of the species now present, only eels require passage into and out of the lake to maintain their life history, as the bully and smelt populations are lacustrine. Smelt were introduced into Lake Rotomanuka to provide a forage fish for trout (pers. comm., Dr. J.A.T. Boubée) and fish from this stock may have moved upstream to colonise the Serpentine lakes. Both these smelt populations can be expected to differ genetically from riverine stocks and it will be important to determine the degree of genetic difference in order to identify their status as evolutionary significant units (ESUs). Mitchell et al. (1993) found distinct differences in vertebral and gill-raker counts between stocks from Rotomanuka and from the Waikato River indicating that the Rotomanuka population was lacustrine. They also found electrophoretic differences in polymorphic enzymes suggesting some genetic divergence, but further studies (e.g., mRNA) are required to confirm this and indicate the provenance of these fish.

The immigration of elvers is relatively easy to maintain as they can climb wetted vertical faces that are impossible for other juvenile fish to climb, or a catch and transfer operation can be maintained. The technologies to allow their passage are now relatively well developed. However, the downstream emigration of the large and fecund adult eels to spawning grounds at the sea could be impeded by barriers based on screens. The downstream passage of adult eels needs to be considered where possible, but is not regarded by DOC as a factor that should limit or constrain the fish barrier design for the Serpentine lakes. This aside, an eel pass for the emigration of adult eels has been provided in several nature reserves in New Zealand that are completely surrounded by predator-proof, mesh barriers (e.g., Karori, Opouahi, Mangatautari). An adult eel pass has also been installed in the screens installed across the outlet stream of several lakes to prevent the emigration of grass carp (e.g., Lake

Tutira, Lake Rotootuauru). These downstream passes are based on large diameter PVC tubes with U-bends (Fig. 2) that allow large eels to move through them, but not other fish. The functionality of these designs is yet to be determined, but provides some scope for dealing with adult eel passage in the future.

Existing designs for allowing adult eel passage through low head barriers may be adaptable to the Serpentine lakes outlet barrier.

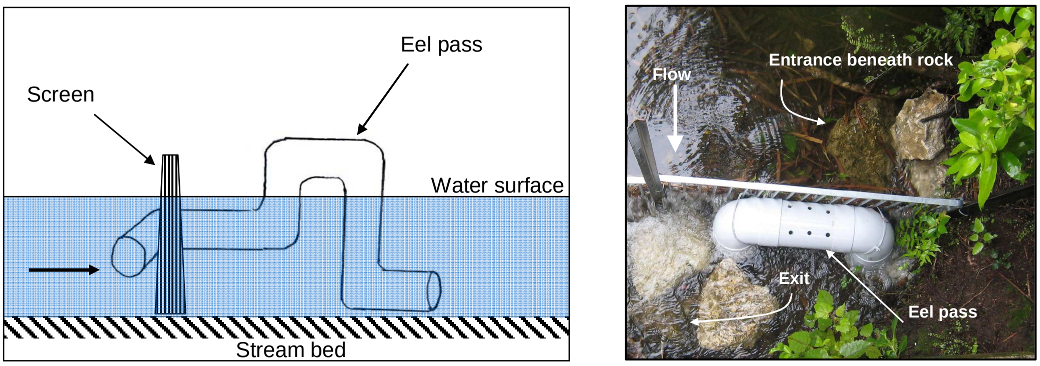

Figure 2: Downstream pass design for adult migrant eels at fish barriers.

2.5 Climate change implications

Another longer-term issue that has an important bearing on the design of a fish barrier is climate change and the probable future increase in rainfall intensity (IPCC 2007). Unprecedented increases in rainfall can be expected to raise the water levels in the lakes as well as flood the surrounding, relatively flat, pastureland. Major concerns for the biosecurity of the lake related to flooding will be; (a) washout or undermining of any barrier structure, (b) overtopping of the lake edge at its lowest point with the creation of an alternative outlet channel, and (c) flooding that raises water levels below the lake to a point where they either overtop its banks or allow fish access over the barrier. Although the size of future floods is unknown, the risk of larger than normal floods needs to be incorporated into the barrier design as far as possible.

2.6 Permitting and consents

The Resource Management Act (RMA) 1991 and the Freshwater Fisheries Regulations (FFR) 1983 (Part VI) provide the legal framework for managing fish passage in New Zealand. Regional Councils and the Department of Conservation are responsible for implementing the RMA and FFR, respectively, in a co-ordinated manner[1]. In some situations, DOC utilises its advocacy role[2] to engage in RMA processes and thereby fulfil its fish passage obligations.

The Freshwater Fisheries Regulations (1983) were designed to protect native and valued freshwater fish species and, as basic premise, require the maintenance of fish passage at 'any diversion or dam in any natural river, stream or water'. Whilst not specifically designed to prevent fish passage, there is some scope within the regulations for the Director-General of Conservation to apply some discretion in their application.

- Whilst the regulations apply to every dam and diversion structure in any natural river, stream or water, regulation 41(2)(a) specifically excludes 'Any…structure erected and used solely for the purpose of holding fish in accordance with the provisions of the Act, or these regulations'. This regulation provides some scope for constructing barriers to exclude certain fish, however it may be subject to interpretation within the wider ambit of the Act.

- In respect of culverts and fords, regulation 42(1) provides that the Director-General may provide written approval for a person to impede the passage of fish by constructing a culvert or ford in any natural river, stream or water. Any such authorisation may incorporate such conditions as the Director-General considers appropriate

- Under Regulation 43, anyone proposing to build a dam or diversion structure is required to apply for approval under, or dispensation from the requirements of the FFR regulations, and the Director-General may require any dams or diversion structures[3] to include a fish facility. Regulation 44 governs the requirements for a fish facility, and regulation 44(2) provides for the Director-General to specify what is required to enable fish to pass **or stop the passage of fish** – including

    a) the type, general dimensions, and general design of any fish pass to be utilised:

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[1] As confirmed by the Environment Court declaration

[2] Under s.53(3)(d) of the Conservation Act 1987 the Director-General of Conservation is required to advocate the conservation of aquatic life and freshwater fisheries generally

[3] this requirement does not apply to any structures subject to a water right issued under the provisions of the Water and Soil Conservation Act 1967 prior to 1 January 1984.

b) the type, general dimensions, general design, and placement of any fish screen utilised.

Subject to the Resource Management Act 1991, regulation 44(3) provides that the Director-General may also specify:

(a) the type and placement of any water intake to be utilised where fish screens are not required;

(b) the flow of water through any fish pass and the periods of the day and year when the pass must be operational;

(c) the volume, velocity, and placement of additional water to attract migrating fish to any fish pass;

(d) the type and scope of any remedial works in connection with any fish screen or fish pass to enable fish to approach the structure or to be returned to the normal course of the water channel;

(e) the volume or relative proportion of water that shall remain downstream of any dam or diversion structure and the period of day or year that such water flows shall be provided.

Some legal analysis of the Freshwater Fishery Regulations 1983 is required to confirm which authorisations are required for the construction of a fish barrier at this site. This is needed to meet any legal challenge from groups supporting the presence of exotic fish.

3. Site characteristics (geographic advantages and limitations)

The Serpentine lakes complex is located near the top of the Mystery Creek catchment (Fig. 3). The drainage network conveys water down to the confluence of Mystery Creek with the Waikato River just above Hamilton City. Fish records for this catchment are sparse (Fig. 3) and indicate that eels, common bullies, smelt and mudfish are the only native species present, with four exotic fish present in the lakes (Table 1).

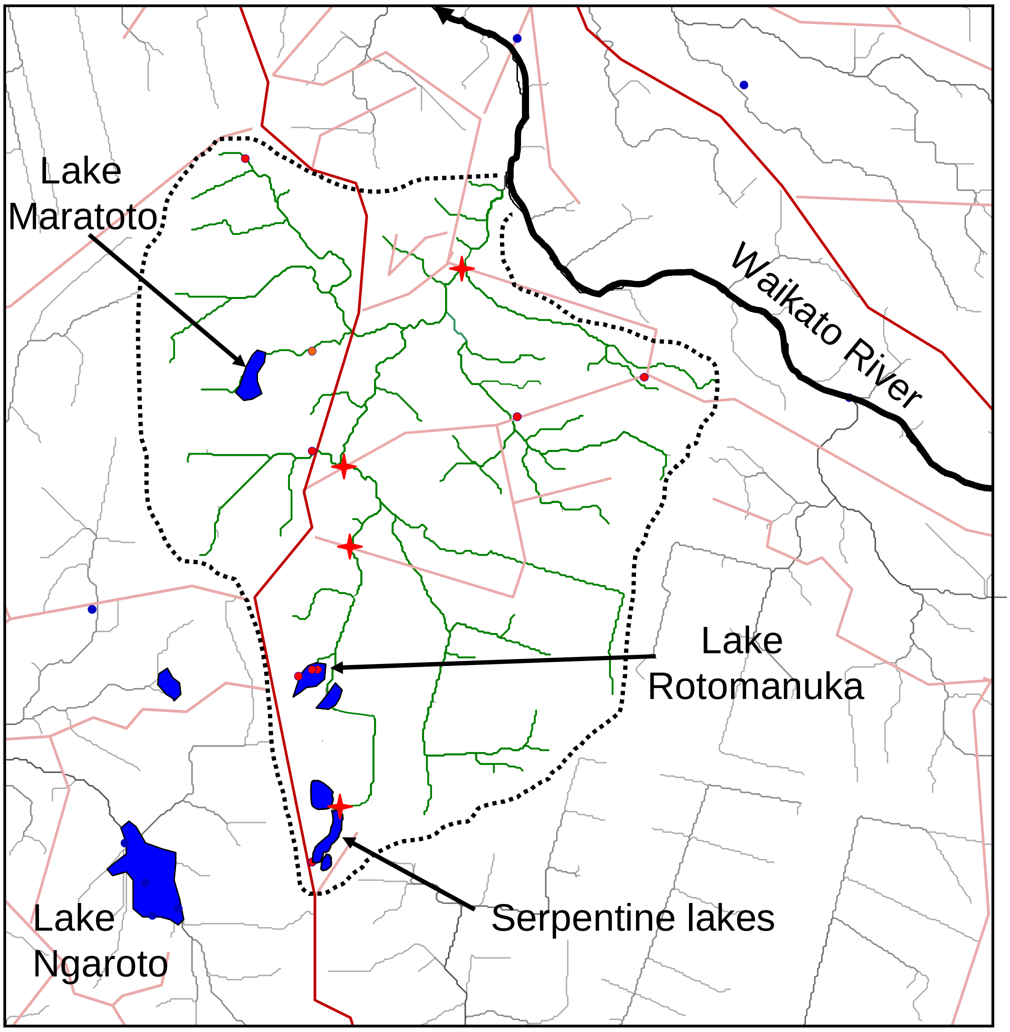

Figure 3: Mystery Creek catchment (dashed line) including lakes (blue) and waterways (green). Red dots indicate fish records in the NZ Freshwater Fish database, red stars indicate culverts between the Serpentine lakes and the Waikato River.

Table 1: Presence of fish species within the riverine and lacustrine components of the Mystery Creek catchment as recorded in the New Zealand Freshwater Fish database to date.

Common name	Scientific name	Mystery Creek	Serpentine	Rotomanuka	Maratoto
Longfin eel	*Anguilla dieffenbachii*	Present	Present	Present	
Shortfin eel	*Anguilla australis*	Present	Present	Present	
Common bully	*Gobiomorphus cotidianus*		Present	Present	
Smelt	*Retropinna retropinna*		Present	Present	
Black mudfish	*Neochanna diversus*	Present			
Catfish	*Ameiurus nebulosus*		Present	Present	
Rudd	*Scardinius erythrophthalamus*		Present	Present	
Goldfish	*Carassius auratus*		Present	Present	
Gambusia	*Gambusia affinis*				

The absence of any records for inanga in this catchment, coupled with their presence in the Waikato River above Mystery Creek and in other adjacent catchments (e.g., Mangapiko Stream), may reflect the inadequate sampling in Mystery Creek to date but could also indicate the presence of barriers to this species just above its confluence with the Waikato River. A small fall and chute are believed to occur in the stream just above its confluence with the Waikato River. In addition, the waterway from the Serpentine lakes down to the Waikato River is crossed by three roads (West Road, Kaipaki Road, and Mystery Creek Road) and the culverts under these roads may also create barriers to the upstream movement of fish other than eels. If so, these barriers should be maintained or enhanced to ensure that exotic species present in the main stem of the Waikato River cannot enter the catchment. This would provide added security to a barrier below the Serpentine lakes.

There is a need to identify the extent to which existing barriers (e.g., natural falls, road culverts) in the Mystery Creek catchment exclude the upstream movement of fish, especially exotic species.

The Mystery Creek catchment contains three groups of lakes; the Serpentine lakes complex, the Rotomanuka lakes, and Lake Maratoto (Fig. 3). Rudd, goldfish and catfish are breeding in Lake Rotomanuka (and possibly Maratoto as well, although there are no current data on fish in this lake). These stocks will provide a continued source of recruits to colonise Mystery Creek and hence will create a perpetual source of these fish in the Creek that could potentially swim upstream and enter the Serpentine lakes. Thus, barriers will be needed between the Lake Serpentine outlet and the drain connecting it to the outlet from Lake Rotomanuka.

The primary landuse in the Mystery Creek catchment at present is dairy farming and the topography is generally flat and undulating (Fig. 4).

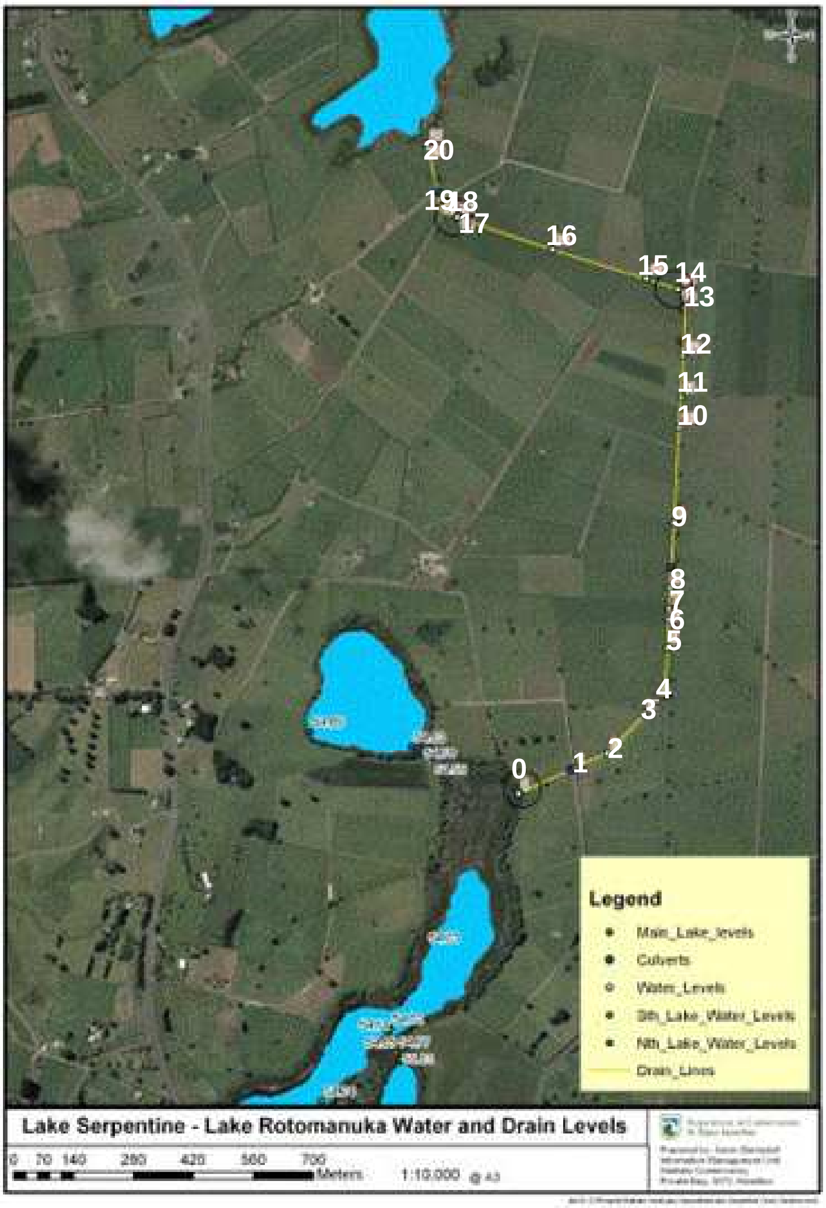

Figure 4: Aerial photograph (courtesy of DOC) showing the three Serpentine lakes (south) and Lake Rotomanuka (north) and the location of the farm drain (yellow line) channelling water from the Serpentine lakes outlet to Rotomanuka. (The white numbers refer to sites where the level of the drain bed and water surface were measured - see Fig 7).

Historically, this land will have been part of the Moantuatua peat-bog, which has since been drained to provide pasture. The outlet from the Serpentine lakes is now a relatively straight and gently sloping drain that heads north-east from the lake outlet (Site 0) before heading north. Approximately 2,500 m below the lake outlet (at Site

14), the drain heads west and enters Lake Rotomanuka (Figs. 4, 7). The section of drain to Lake Rotomanuka is relatively new as it formerly continued north at Site 14.

The drain is incised and steep sided but shows little sign of erosion, or of problems with aquatic weed growth (Fig. 5A). There was no indication that it had been mechanically cleaned of weed infestations in the past (e.g., by drag-liner or excavator), probably because the water level is generally low and the problem species are not present. Cattle access is prevented by the electrified fence on both sides. Bank vegetation on the true right side had been chemically treated. The drain leads to a culvert under the farm track (Fig. 5B) at Site 1 in Fig. 4 before joining the main drain that heads north.

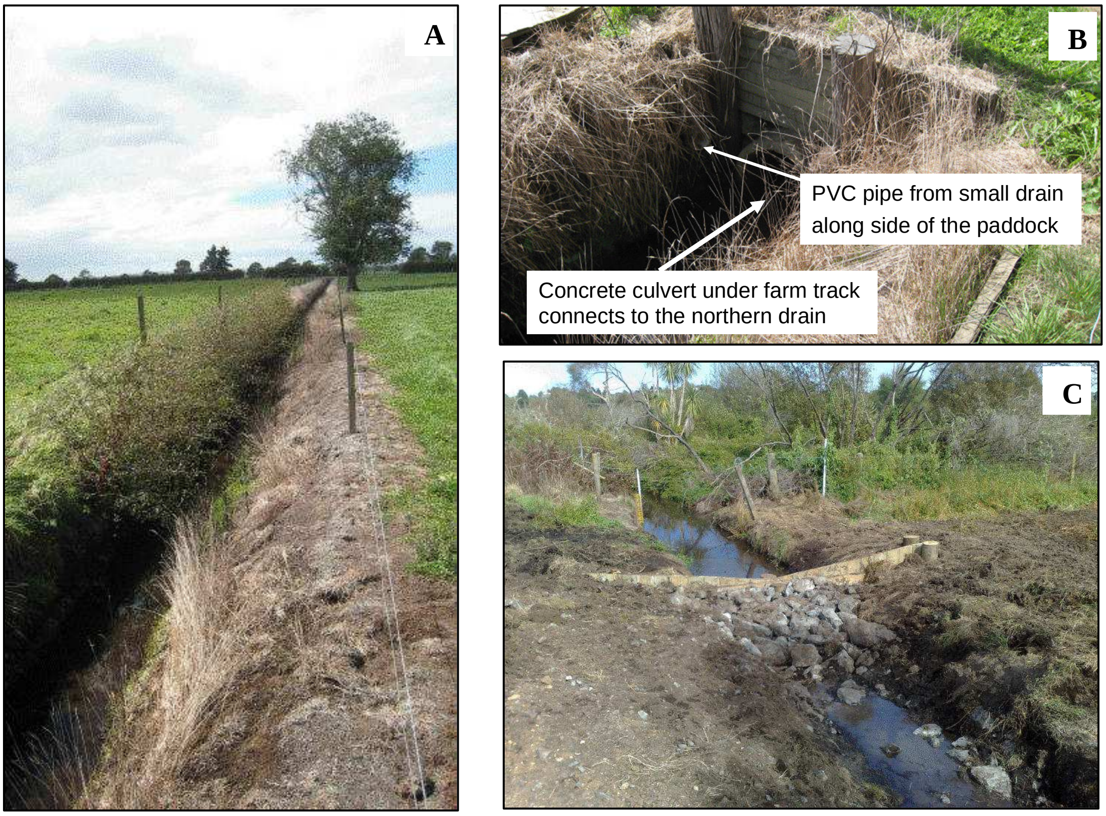

Figure 5: Photographs of; (a) the drain immediately below the Serpentine lakes outlet, (b) the first culvert below the outlet and (c) the new weir at the lake outlet (courtesy of Michael Lake, DOC).

A wooden weir has now been constructed across the outlet stream close to Site 0 to maintain the height of the lake (Fig. 5C). This is a horizontal log weir with a v-notch. At present, the rocks placed below the weir (Fig. 5C) mean that the potential vertical height of 0.5 m between the weir and drain water surface is reduced to about 5cm. The rocks spread the potential 0.5 m drop over a 1-2 m length of drain. The interstices of these rocks will eventually become clogged with silt and provide a roughened, sloping ramp down to the drain water level. It is unlikely, that a simple weir structure such as this will keep exotic fish out as juveniles may well swim up the ramp, and when water levels in the drain rise (i.e., during floods), adult carp could easily jump this short and low barrier.

Environment Waikato has determined the recent variation in water level heights of the Serpentine lakes (Fig. 6). Lake water heights have varied between 54.65 m to 55.45 m above sea level (Motoriki datum) and the weir is designed to maintain the lake level at just over 54.9 m. There will therefore be no surface outflow from the lake when water levels are below 54.9 m. However, lake levels have reached 55.4 m in the past and so can be expected to reach and surpass this level in the future.

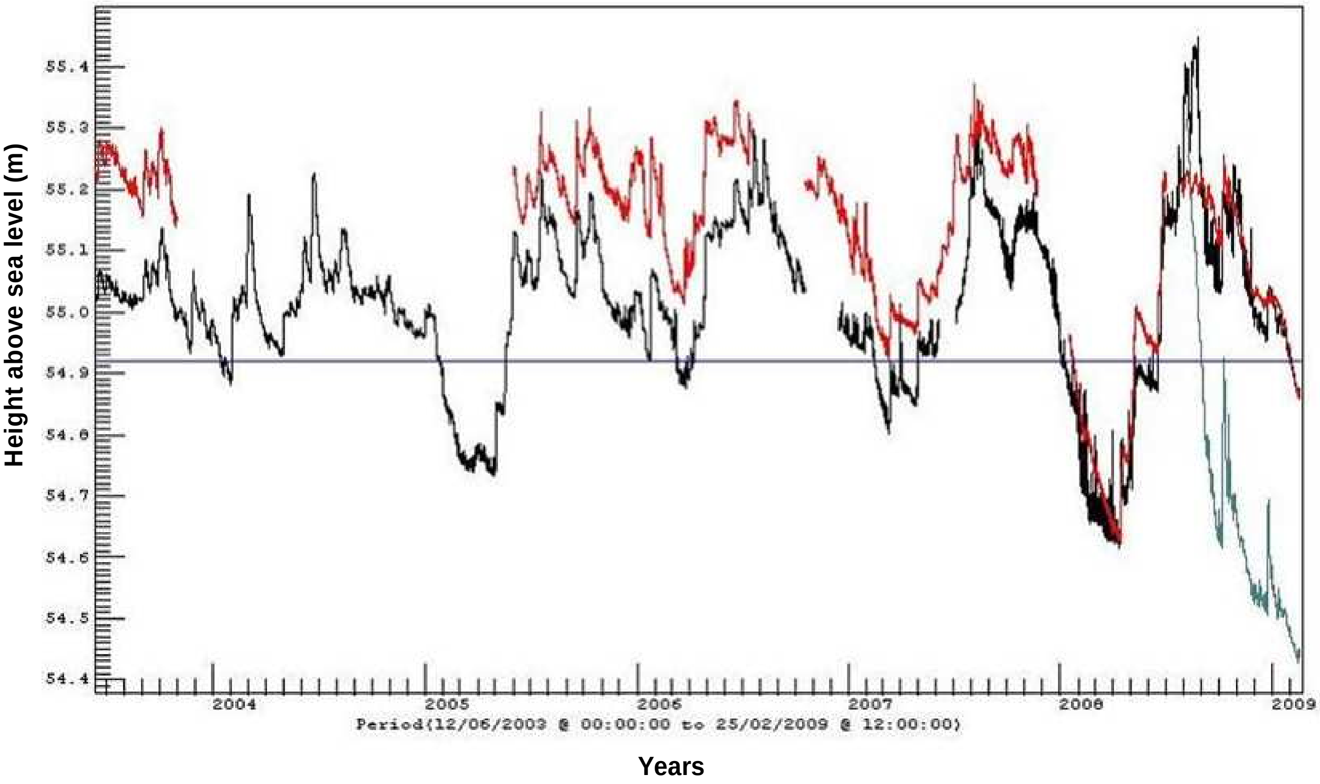

Figure 6: Changes in water levels in the Serpentine lakes since 2004 (courtesy of Environment Waikato). Horizontal line at 54.92 m indicates the height of the current weir. The red line is for the northern lake surface, the black line is for the southern lake surface and the green line is the water level at the lake's outlet.

Environment Waikato surveyed the height of the drain bed and its water level between the weir and Lake Rotomanuka (Fig. 7). The maximum height of the drain bed above sea level was 54.0 m (between sites 0 and 2 in Fig. 4) and the total drop in altitude between the Serpentine outlet and the Rotomanuka Stream confluence was close to 3.4 m. This drop occurred over 2 kilometers. There was a relatively short and sharp drop (of approx. 80 cm) in the channel bed between Sites 2 and 6 (Fig. 7) and another (of approx. 90 cm) between Sites 18 and 19 just before the confluence. Weirs are present in the drain at Sites 13 and 18 to maintain water levels (e.g., during times of drought), or to prevent scouring and deepening (Fig. 7).

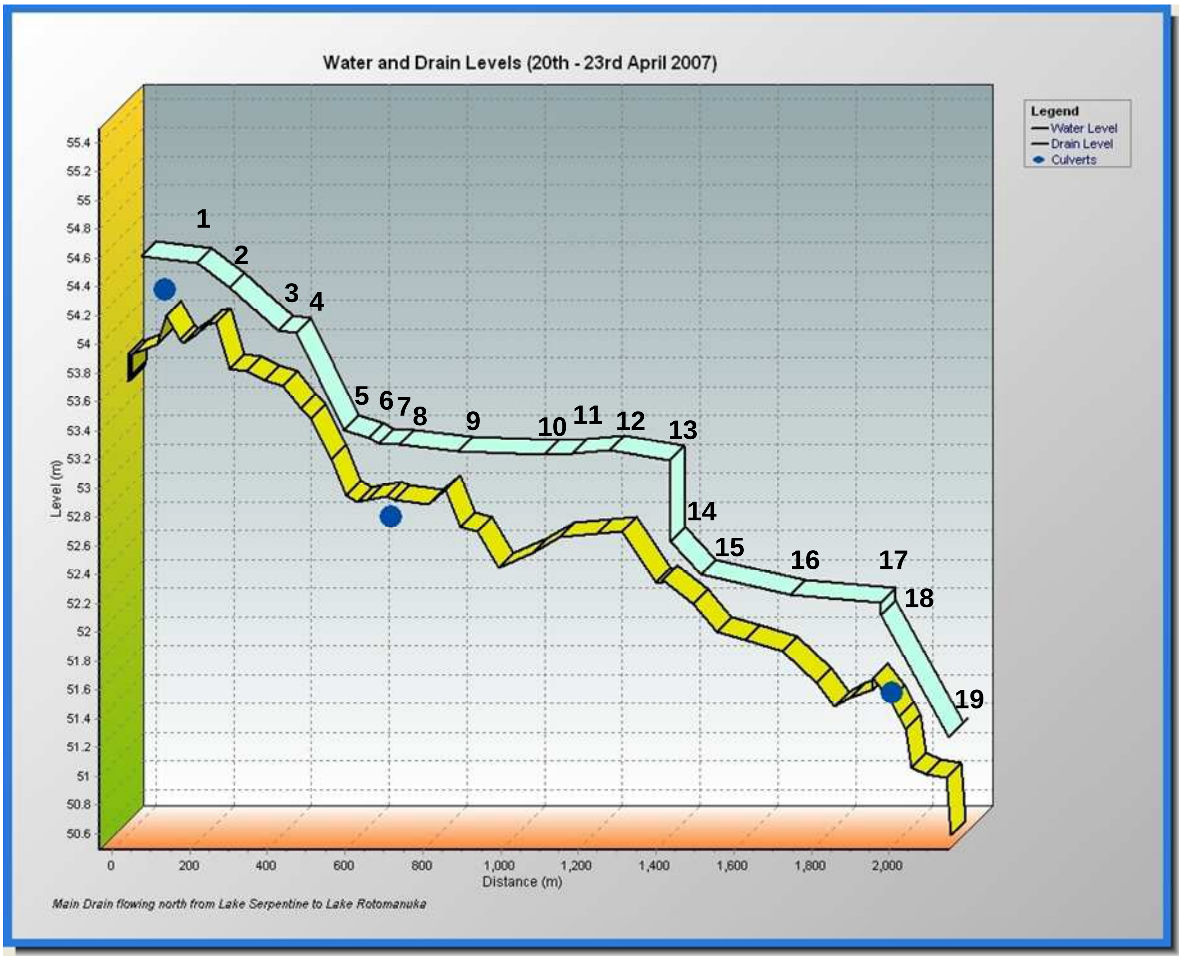

Figure 7: The drain bed and surface water levels between the Serpentine lakes outlet (Site 1 in Fig. 4) and Lake Rotomanuka (Site 19), 20-23 April 2007 (courtesy Environment Waikato). The yellow line is the bed of the drain and the green line is its water surface.

The vertical distance from the top of the weir (site 0) to the current bed of the drain below it will be close to 0.9 m, and to the water level in the drain (when it was surveyed) will be close to 0.5 m. However, water levels in the drain immediately below the weir can be expected to change over time depending on flow rates and on ground water levels. Variations in the height of the vertical drop can therefore be expected to vary accordingly. As there are no data on variations in water levels in the drain, variations in the height of the vertical drop are unknown but will not be greater than 0.9 m at present.

Data on water levels in the outlet drain just below the weir are required to indicate the extent of seasonal variation and the maximum flood height.

Water depths in the drain immediately below the weir site were relatively low when the drain survey was carried out and ranged from 0.2 to 0.5 m. A reduction in the water level in the drain would increase the vertical drop between the top of the weir and the surface water in the drain. For example, if the surface water level in the drain was reduced by 0.2 m, the vertical drop would increase from 0.5 to 0.7 m. This could be achieved by levelling the drain bed between sites 0 and 2 and by repositioning the culvert which currently acts to maintain water levels in the outlet drain. If the bed of the drain was excavated to a greater depth and so that it sloped regularly down to site 4, the drop in water level would be even greater. Such changes in channel morphology could increase the distance between the top of the weir and the surface water level in the drain to 1.0 m, with a water depth of 0.2 m. The potential changes in head (i.e., the vertical distance between the top of the weir and the water surface in the drain immediately below it) that could be achieved by various channel works are summarised in Table 2. It should be noted that changes in drain morphology that reduce water levels may reduce the peat and decrease pasture production in summer.

Table 2: Effects of changes in channel shape on the head height (vertical distance between the top of the weir and the water surface in the drain immediately below it).

Potential changes to the drain channel	Head height (m)*	Drain water depth (m)
• No change	0.5	0.4
• Channel widening, plus repositioning of the culvert and flattening of channel bottom between site 0 and 2	0.7	0.2
• As above, plus channel bed excavation and grading down to site 4	1.0	0.2

*These figures are based on the Department of Conservation's synoptic survey of drain water levels and do not take into account any seasonal changes in water levels in the drain.

The current lake margins are low lying and the presence of these lakes in what was once a peat wetland, means that heavy and prolonged rainfall could potentially result in flooding, with water levels in the surrounding land rising and overtopping the banks of the lake. This would allow exotic fish present in the drainage network below the lakes to enter them. Climate change implies an increased frequency and intensity of high rainfall events which mean that historic flood heights may need to be raised upwards. LIDAR data obtained by Environment Waikato needs to be analysed to indicate the height of the lake edge at its lowest point (i.e., where water would exit the lake in a major flood if the current outlet became blocked). This will allow calculation of the lake-edge height above the maximum flood level in adjoining pasture, as well as the height above the current weir. To avoid the risk of widespread flooding inundating the lakes and resulting in the ingress of exotic fish from downstream sources, the lowest-lying lake edge may need to be raised to exceed the maximum expected flood height for the surrounding land, or avert the risk of the lake flooding. Severe flooding also raises the issue of water levels in the lakes exceeding the weir height and then spilling over the lake edge at the lowest point where they could then cut a new channel down to the drain network. Raising the lowest-lying lake edge would also help prevent this risk.

The lowest-lying lake edge may need to be raised to exceed the maximum expected flood height for the surrounding land and the possibility of lake flooding.

4. Barrier types

The range of barriers commonly used to restrict upstream fish passage at low-head sites (Table 3) are discussed below to provide an indication of the types suitable for a range of sites in the Waikato River catchment. Some may be more applicable to the Serpentine lakes outlet than to other sites and these are listed and discussed further in chapter 6.

Table 3: Types of barrier used to prevent the upstream migration of fish at low-head sites in rivers and streams.

Behavioural barriers	Physical barriers
1. Electric	1. Dams (prevent all upstream movement)
2. High and low frequency sound, sonar	2. Shallow-water chutes (prevents swimming)
3. Air-bubble curtains	3. Fast-water chutes (prevent swimming)
4. Chemical (pH, salinity, temperature)	4. Falls (prevent leaping)
5. Light (absence/presence, strobes)	5. Screens (exclude fish over a given size)
	6. Overhanging lips (prevents climbing)
	7. Combinations of above

4.1 Behavioural barriers

Barriers that prevent the upstream movement of fish can be divided into two main types: behavioural and physical barriers. Behavioural barriers include bubble screens, acoustic barriers (both low frequency sound & sonar), electrical barriers, barriers based on strobe lights, and chemical barriers. They all work on the basis that fish will avoid visual, acoustic or physiological stimuli that exceed some, generally species specific, threshold. They also assume that all fish (for a given species) are equally affected by the deterrent. Whereas behavioural barriers have proved useful for guiding fish away from water intakes or reducing their abundance around intakes, they do not deter all fish or all life stages of fish. Because it would only take a few mixed-sex fish to create a breeding population in the Serpentine lakes, deterrent-type behavioural barriers would not achieve the prime purpose of preventing population re-establishment.

Of the range of technologies that have proved useful, sound and electricity are the most promising. Sound has been used to prevent fish from entering power station intakes (Ross et al. 1993) and electrical barriers have reduced the upstream migration of fish (Verrill et al. 1995; Stokstad 2003). The most recent application of electric barrier technology is the electrification of a section of a ship canal in the USA to prevent silver carp and big head carp from entering the Great Lakes via the canal that links these lakes to the Mississippi-Missouri River system via the Illinois River (www.epa.gov/glnpo/invasive/asiancarps). When the first barrier (prototype) in this canal was tested, 1 out of 100 acoustically tagged carp was found to have passed through it, presumably utilising the turbulence created by a vessel's propeller wash, or by finding a part of the hull where the electrical field was nullified, or by being stunned and then transported by a protrusion on the ship's hull to the end of the electrified reach, where it recovered. The second barrier is designed to avoid such breaches of the barrier but is yet to be proved. Whereas, back-up generator-based power may assure continued electrification of this barrier, there is a danger of electrocution to terrestrial animals (including humans) and there will be collateral damage to non-target fish species. A risk that will need to be carefully managed is that some juvenile fish may avoid the electrical field by hiding in the ballast water intake structures on a ship's hull. Low frequency active sonar may also prove useful but is experimental.

None of the behavioural barriers are likely to be suitable for the lowland Waikato lakes as they are either too expensive and/or their reliability cannot be guaranteed at present.

4.2 Physical barriers

Physical barriers depend on the abilities of the fish to swim, jump or climb and so are much more reliable for excluding upstream migrants. Physical barriers are created by high water velocities (chutes), or by falls, weirs, culverts, and screens.

4.2.1 High velocity chutes

High velocity chutes have been used at low-head sites to exclude salmonid upstream movements and generally require the construction of a long, narrow, sloping channel or the damming of water above a natural channel to provide a minimum length of stream over which high velocities are maintained (e.g., Fig. 8).

Such barriers require a constant high flow of water to create the desired velocity. Because a high flow of water is not always guaranteed, and instream debris can block the chutes at times, velocity chutes are only rarely used and only where the site is amenable (e.g., spring-fed streams).

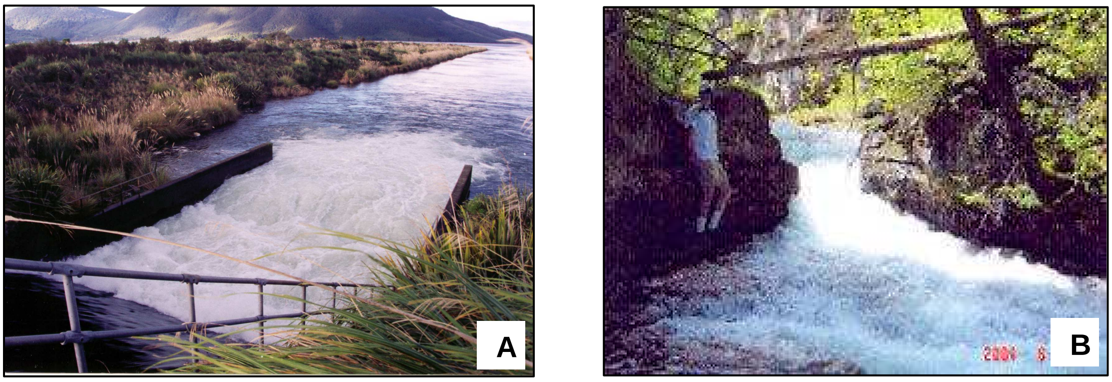

Figure 8: Chute of high velocity water designed to prevent the upstream movement of salmonids. (A) Inclined concrete ramp in the Wairehu canal. (B) Chute constructed by damming water behind the natural rock gorge from: www.wildfish.montana.edu/projects/barrier/browse.asp.

4.2.2 Falls and weirs

Small waterfalls, dams and weirs with vertical heights as low as 2 m can also prevent the upstream movement of fast-swimming and high-jumping fish such as salmonids, but do not restrict climbing species such as elvers and certain galaxiid species. For example the relatively small fall in Figure 9 provides an un-passable barrier to trout but not to juvenile koaro. Trout can attempt a jump at this site because of the deep pool below the fall, but it is still too high for them to surpass the rim of the fall.

Figure 9: Natural fall into the Wairehu Stream, Turangi, that prevents the upstream movement of rainbow trout.

Weirs are commonly used to create small falls and to exclude trout. In the USA, designs have encompassed linked metal piles (Fig. 10A), horizontal logs keyed into the bank (Fig. 10B), and the placement of rock-filled gabions with splash pads to avoid erosion and to limit fish jump heights (Fig. 10C). Gabion bags have also been used to create selective barriers. When filled with large as against small rocks, water flow occurs through the interstices allows the upstream movement of small fish but not large ones (e.g., Bulow et al. 1988). In effect, such selective barriers operate in the same ways as screens (see Section 4.8), except that there is less control over the size of the interstices and so some uncertainty as to what size of fish can access them.

Figure 10: Different ways of constructing weirs at low head sites; (A) interlocked metal sheets (i.e., coffer dam) rammed vertically into the substrate, (B) log or wooden planks laid across the stream channel, (C) rock-filled gabion bags with the spill height and splash pad designed to prevent upstream passage of salmonids. (Photos are from www.wildfish.montana.edu/projects/barrier/browse.asp).

4.2.3 Culverts

Culverts can also provide effective barriers to the upstream movement of fish and a perched culvert with a 1.0 m fall (e.g., Fig. 11) would provide a more effective barrier than a weir of the same height. An additional advantage with culverts is that the shallow, laminar flow through their length can act as an additional barrier by increasing water velocity (depending on the culvert slope) while decreasing water depth. However, culverts can be compromised by blockages or by increases in flow that exceed their design criteria.

Figure 11: Perched culvert creating a small fall into a deep pool

4.2.4 Culverts and weirs

Culverts can also be placed in weirs to add to the effectiveness of the weir as a barrier, and several culverts can be installed at different heights to allow for large changes in flow (Fig. 12). Culvert diameter is generally a function of expected flood flows and the MfE provide standard methods for determining culvert size (see Stevenson & Baker 2009). Culverts may also be square bottomed as against circular, thereby minimising water depth compared with a circular design. Culverts may be placed near the bottom of the weir to drain water from near the lake bed (e.g., hypolimnetic intakes), or they can be placed at varying distances up the weir to ensure a fall is provided (e.g., Fig. 12).

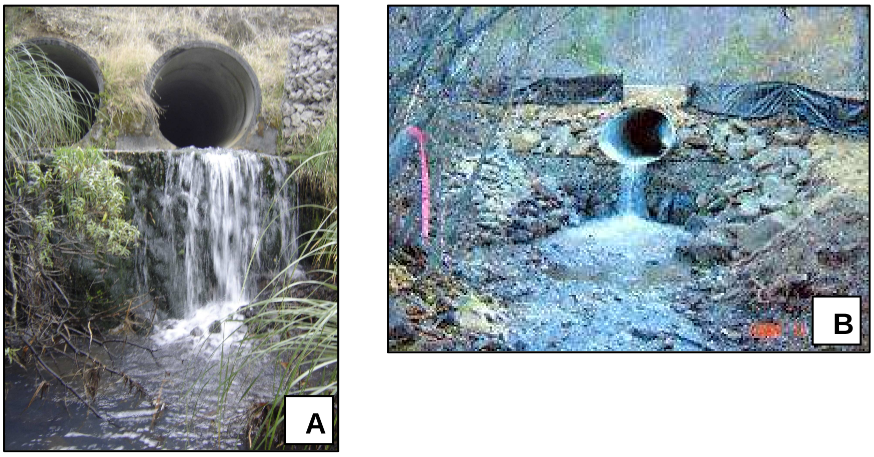

Figure 12: (A) double barrelled concrete culvert with a shallow water apron and fall created by gabion bags provides a major barrier to most fish including trout. (B) metal culvert inserted through the wall of a rock and earth weir

In general, culverts do not protrude far downstream from weirs because this would result in stress and lead to cracks and breakage. However, culverts associated with weirs could be extended further downstream to obtain a greater head if they can be properly supported.

4.2.5 Standpipes and wells

Lake outlets may be blocked by weirs and the outlet then replaced with a standpipe or well (Fig. 13). Water only leaves the lake via the well and its steep sides and height can provide an effective barrier to the upstream movement of swimming and jumping fish. Screening of the well inlet is generally required to prevent both floating material from blocking the entrance and fish or waterfowl from falling into it. The main limitations with a well is that the entrance may become blocked, resulting in water levels in the lake or pond rising and spilling over the top of the weir. Partial blockages in the culvert at the base of the well may result in flow constriction and water backing up the well. This could enable fish to swim up the well and into the lake.

Figure 13: A well or stand-pipe provides the outlet to a small pond created by a weir and maintains a constant water level in it. The well entrance can be screened to prevent waterfowl or debris from falling into the well. A horizontal culvert at the base of the well ducts water under the pond and away to the nearest water course.

4.2.6 Pumped outlets

Many lowland drains in New Zealand are gated to prevent water loss and use high-volume, submerged electrical pumps that are activated when water levels in the drain exceed a pre-determined water level to remove water. Such systems also create barriers to fish movement, albeit unintended, and these pumps have proved reliable over time and provide another way of conveying large amounts of water over weirs. However, pump intakes can become blocked with flood debris and flood conditions may occasionally overwhelm the capacity of the pump(s) resulting in water backing up in the drain and overflowing the flood gate.

Self-cleaning screens (Fig. 14) overcome the problem of intake blockage. They can be placed near the surface or the bed of the water body. Electric pumps suck water through the screen and rotating, electric-powered brushes keep the screens free of debris. The Johnson-style, cylindrical T-bar screen (Fig 14A) is commonly used for water intakes either in midwater or near the water surface. The cone screen was developed to abstract water from the bottom of ponds and reservoirs.

ISI Intake Screens, Inc.

Since 1996

Revolutionary Cleaning Technology

Cylinder Screen with External and Internal Brush System

(Patent No. 7,347,933)

- Strong, Innovative, Proven Technology using Wedgewire Screen
- Protects Downstream Equipment
- Minimizes Headloss and Clogging *Even* with Fine-Mesh Openings
- Complies with Regulatory Criteria

FEATURES:

- Powerful brushing *OUTSIDE* and *INSIDE* prevents biofouling and debris plugging
- Wedgewire screen designed for fish protection, filtration, and hydraulic loads
- Cylinder gives large screen surface area (small footprint)
- Easy retrieval on track system allows for easy inspection
- Even flow distribution for optimal cleaning and fish protection
- Hydraulic rotation is powerful, fully adjustable, and requires minimal power input
- Marine-duty hydraulic motor rotates screen for cleaning in *BOTH* Directions
- Custom-built systems available in cylinder diameters from 24 to 96 inches
- Remote monitoring and control systems available — SCADA interface
- *Design services and installation assistance available*

ISI Intake Screens, Inc.

Since 1996

ISI Cone Screen

for Shallow Problematic Intakes

(Patent Nos. 5,851,087 and 6,089,790)

- Rotating Brush Arms Keep Screen and Base Free of Silt and Debris Build-up
- External Brushing is a Durable and Proven Technology
- Minimizes Headloss and Clogging *Even* with Fine-Mesh Openings
- Complies with Regulatory Criteria

FEATURES:

- Powerful brushing action and brush rake prevents biofouling and debris plugging
- Wedgewire screen designed for fish protection, filtration, and hydraulic loads
- Cone provides large screen area in shallow water applications (small footprint)
- Internal baffle distributes flow evenly across the screen surface
- Easy installation and removal
- Marine-duty hydraulic motor rotates brushes in BOTH directions
- Hydraulic system requires minimal input power — brush system can operate on standard line voltage, solar power, or propeller-drive
- Base diameters from 5.5 to 12 feet — adaptable to concrete or steel base structure
- Remote monitoring and control system—SCADA interface
- *Design services and installation assistance available*

Figure 14: Self-cleaning screens for water intakes based on electric pumps (see www.intakescreensinc.com).

Electric pumps with self-cleaning screens could overcome potential problems with blocked intakes, but are also limited in that power supply may be interrupted resulting in water levels increasing and spilling over the weir. Impingement of fish on the intake screen can also be a problem if water velocities at the screen face exceed the ability of fish to swim. This is generally overcome by increasing the total area of screen, but the mechanical, self-cleaning mechanism places a limit on this. Other screen intake designs use bursts of compressed air inside the screen (Fig. 15) to force debris out of the screens pores.

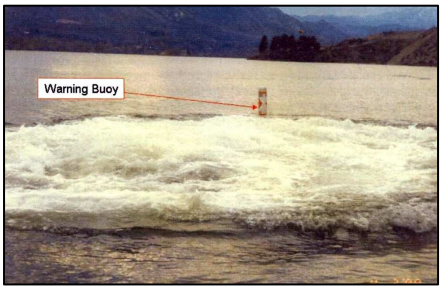

Figure 15: Surface disturbance caused by an air burst cleaning of a cylindrical screen (from U.S. Department of the Interior 2006).

4.2.7 Passive screens

Vertical or horizontal screens with bars or mesh are the other main method of restricting the upstream movement of fish (Fig. 16). Screens are generally inserted into either road culverts or into weirs and the bar spacing is set to exclude fish of a given head-width (i.e., the distance between the outer edges of their opercula). Such screens are problematic in that the bar spacing needs to be small enough to exclude most fish, especially juveniles, and this results in debris accumulation and blockages on the screen face requiring constant clearing and maintenance to avoid water damming up behind the screen and overtopping it. Another potential problem with screens is that they can act as barriers to the upstream migration of native fish and create reaches where high fish densities occur and where predators can readily prey on the fish.

Figure 16: Vertical bar screen to prevent fish emigration from a lake.

One way of overcoming the problem of debris accumulation in screens is the Coanda screen (Fig.17, http://www.coandaintakes.com/Coanda_video.html). This sloping screen is placed in the stream bed so that water drains over and through its bars, with debris being washed over the screen at times of high flow. Coanda screens are therefore well suited to small streams with low-heads. Water falling through the screen meshes drops into a well below and is then ducted to the side of the screen structure and back into the stream channel. This screen design is generally used for in-line water intakes but could be used as a fish barrier provided there is always a drop from the screen to the water surface in the well. The screen prevents fish from jumping up and the screen and its slope prevent fish from swimming upstream. Main limitations are the need to keep the well area free of debris and silt, and flooding which could result in the structure becoming totally submerged.

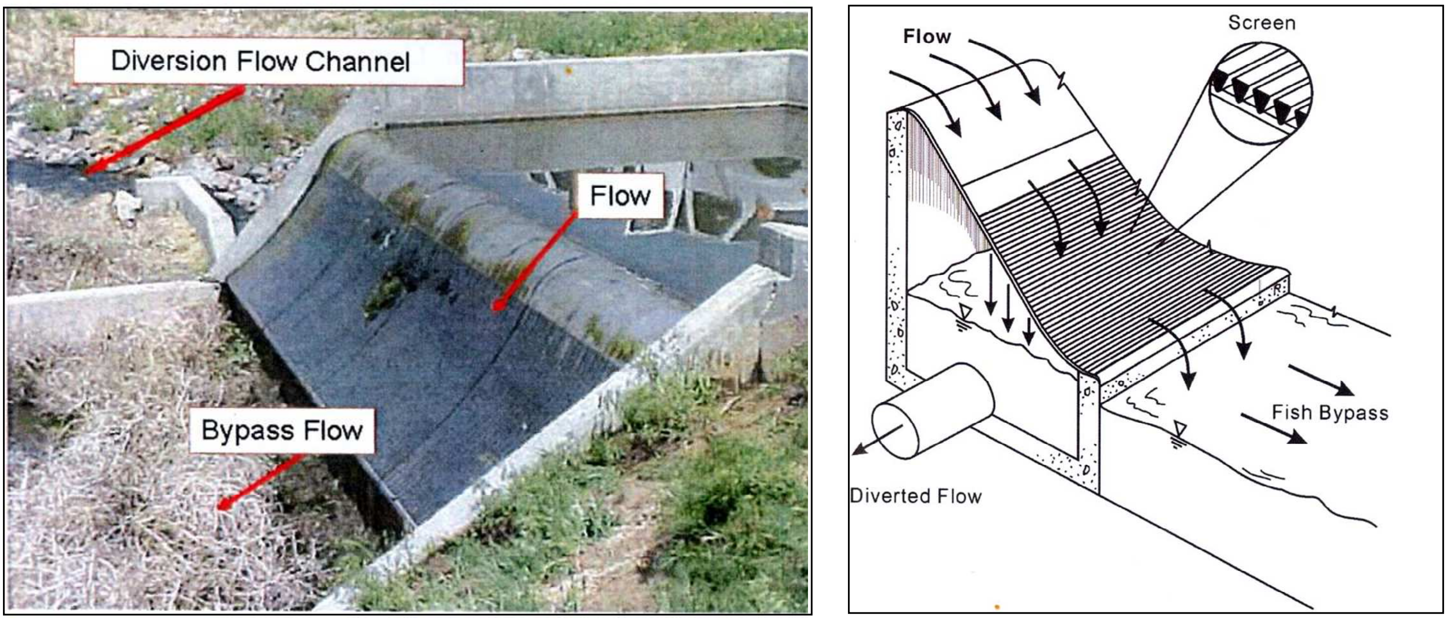

Figure 17. Example and design of a Coanda screen. Screens are constructed of wedge wire with 1-2 mm spaces (from U.S. Department of the Interior 2006).

4.2.8 Self-cleaning screens

The problem of screen blockage can be overcome by self-cleaning screens. These are either vertical travelling screens (Fig. 18A) or cylindrical drum screens (Fig. 18B). Both are placed in a square box or channel constructed in the waterway. Such screens are made of stainless steel with the screens being made of wedge-wire, woven wire or perforated metal sheets. The screens need to be large enough to allow the water to pass freely through the meshes and fine enough to prevent fish access. Both types sit partly in and partly out of the channel (65-85% submergence is required for drum screens) while rotating in the same direction as the stream flow. These screens generally need to be powered by an electric engine, but paddle wheel driven types are possible (Fig. 19).

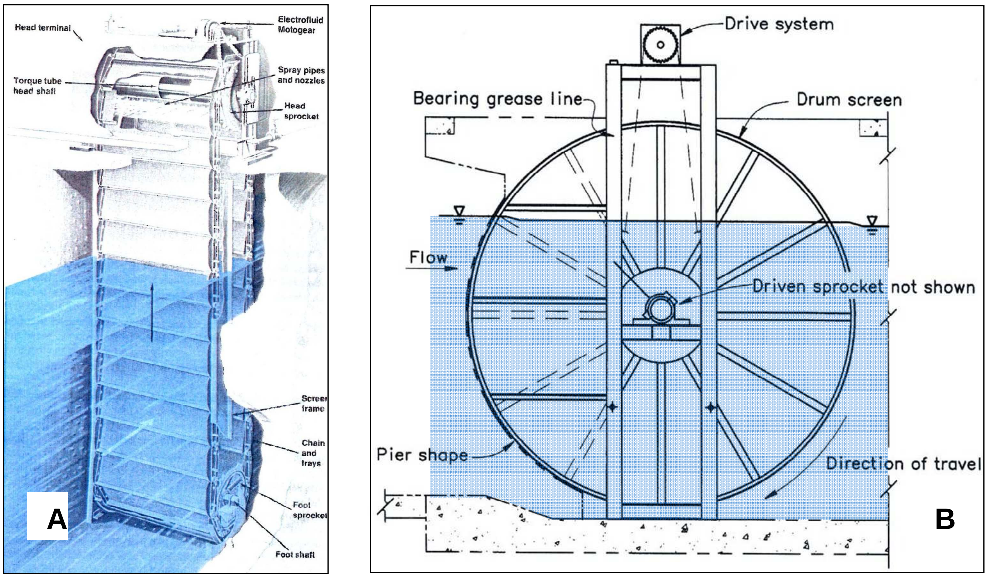

Figure 18: Self-cleaning screens: (A) Vertical travelling screen (B) cross section of a revolving drum screen (from U.S. Department of the Interior 2006).

Figure 19: Self-cleaning revolving drum screen powered by an upstream paddle wheel (from U.S. Department of the Interior 2006).

Any debris that accumulates on the upstream face of the screen is picked up by baffles and conveyed to the downstream side where it falls into the channel and is washed away. Such screens need to be sited in a close-fitting rectangular channel made of wood or concrete so that no erosion of the channel occurs and fish cannot move upstream either beneath, above or around the side of the screen at all flows. Brushes (Fig. 20) are used to seal the edges and prevent fish from moving beneath or around the edge of the screens.

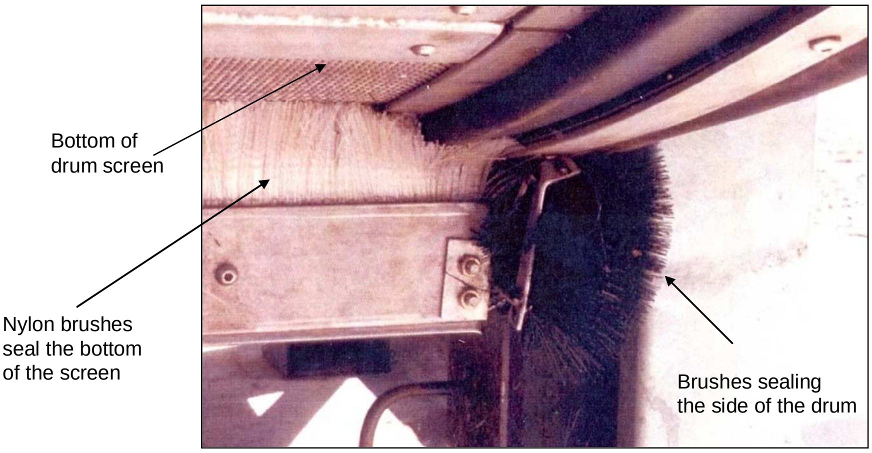

Figure 20: Use of brushes to seal the edges and sides of a revolving drum screens (from U.S. Department of the Interior 2006).

4.2.9 Protruding (anti-jump) bar screens

Screens that protrude out from the crest of a weir may also be used in conjunction with falls or weirs and aprons to deter jumping fish (Fig. 21, 22). Such screens are flat and consist of a series of bars that are aligned with the flow such that water falls through the spaces between the bars and most of the debris that accumulates is washed over them at times of high flow. Protruding, anti-jump screens are constructed to protrude well out beyond the fall and prevent fish from jumping over the fall at such times.

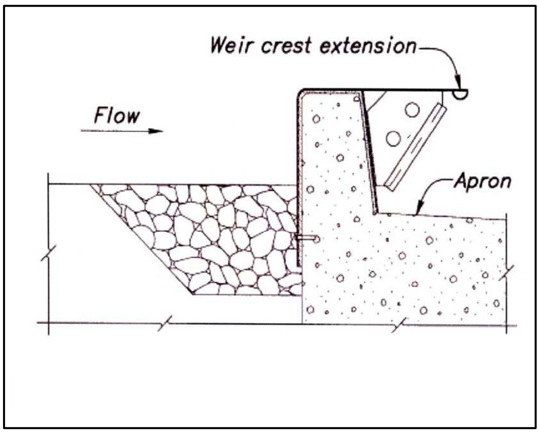

Figure 21: Basic design of a weir with a shallow apron and protruding bars to prevent fish jumping (from U.S. Department of the Interior 2006).

Figure 22: Examples of low-head protruding bar screens designed to prevent fish from jumping the crest of the weir. Such screens also act as trash barriers (cleared during flood flows) and provide a length of de-watered channel which is a further deterrent to fish upstream movement (photos courtesy of Nicole Hansel-Welch, Minnesota Department of Natural Resources).

5. Issues related to barrier construction and integrity

Whatever design is finally agreed upon, resource consents will be required to construct and operate the barrier. If publically notified, the application for consents could meet resistance from some individuals or community groups for various as yet unknown reasons some of which maybe related to future implications (e.g., use of rotenone, constraints on lake use including fishing, concerns over access to water for irrigation etc.). It will be important to consult widely to ensure that support is obtained. Any serious objectors can be expected to query the fundamental reason(s) for the barrier and these will need to be formally scrutinised and carefully justified to ensure they are viable.

Resource consents will be required and mean that widespread consultation may be required along with a strong case to support the construction of a barrier.

Once constructed, the integrity of a fish barrier will depend on a number of factors irrespective of the specific design selected to best suit a particular site. Such factors include sabotage or vandalism, lack of maintenance, breakdown from wear and tear, blockage of the water intake, blockage of the water outlet and power failure if the barrier is dependent on a power supply. Avoidance of problems related to these factors will require specific planning and monitoring.

Construction of barriers on private land or at places where access is required over private land will require permission from the current owner and some form of longer-term protection (e.g., via covenants).

Covenants would be needed for structures on private land to ensure new owners were bound to leave them in place and to maintain access to them.

The possibility of vandalism and the need to protect any aggregations of native fish (eels) that may assemble below the barrier will require the site of the barrier, or the inlet and outlet to be protected.

To maintain the security of the barrier, public access to the inlet and/or outlet may need to be protected by a gated fence.

In addition, a routine (e.g., monthly) inspection regime will be needed to detect any emerging problems with the barrier's function as well as to ensure that water intakes or outlets are cleared of debris. Initially, incident monitoring (e.g., after heavy rainfalls) would also be required to ensure any unforeseen problems are detected early and dealt with. In addition, long-term changes in the water levels of the lake and/or the outlet stream, slow sinking of the barrier structure (in the peat), or land subsidence (e.g., following flooding, after prolonged drought, or from an earthquake) may also compromise its function. The possibility of such long term factors compromising the barrier needs to be managed by a longer term (e.g., annual) monitoring programme attuned to structural (as against routine maintenance) issues.

A management plan to define monitoring requirements for the barrier and to identify appropriate management actions in the event of any problems that arise will need to be prepared.

Any changes in the shape of the existing drain channel (either width and/or depth) should not compromise the integrity of the weir, the drain, or significantly reduce ground water levels in adjacent pastureland. A civil engineering report would be required to confirm this and/or to evaluate the possibility of installing a sealed (e.g., concrete-lined) channel to avoid such problems.

Widening of the drain below the weir coupled with a levelling and deepening of the drain bed between site 0 and site 4 (see Figs. 4 & 7) would reduce the water level in the drain and provide a greater vertical drop between the top of the weir and the water level in the drain. Such works would require an engineering report to ensure they are sustainable.

The presence of culverts and weirs in the drain reflects the current use of the land (pasture) and adjacent land owners may require future changes to the existing drainage channels or may wish to construct new ones to both maintain soil water levels in summer and to reduce them following heavy rainfall events. Future uses of the lake or drain water (e.g., for irrigation or water supply) may also result in the creation of more ponds in the catchment.

Any future applications for consents to use the water in the lakes or drains will need to be examined to ensure the consents do not compromise the fish barrier.

The presence of exotic weeds results in periodic drain blockage in other drainage areas in the Waikato and results in the use of drag-liners to clear them. Such future changes in drain maintenance could affect water levels in the outlet from Lake Serpentine and compromise attempts to prevent exotic fish entering the lake. In addition, local land owners may plant the riparian margins of the drain and the resultant vegetation may restrict access to the drains and/or compromise their function. Any drain management that could raise water levels would need to be avoided and it may be possible to secure this by agreement with adjacent land owners. In the long term, shading with appropriate riparian trees planted more than 2 m from the side of the channel would allow for the development of a relatively wide and weed-free drain with the only concern being blockage by wood debris from falling trees.

Agreements may be required with land-owners to ensure that the drains continue to function properly and are maintained to achieve restrictions on fish passage as well as to ensure removal of rainfall runoff and the maintenance of soil water levels.

Barrier designs that use a culvert to remove water from behind a weir and carry it downstream will also reduce water supply to a length of outlet drain. This could reduce aquatic habitat and the continuity of flow in the drain especially during drought conditions, and this may restrict passage by eels. Conversely, water levels may be maintained via drainage through the underlying peat. Water soaking through peat has a low pH and when large amounts enter drains where water levels are already low (e.g., following a rainfall event in summer), the pH can drop to levels where fish life is affected. Low pH had resulted in fish kills in other Waikato drainage systems and such conditions could occur in a length of drain where water flow from the lakes is reduced.

6. Identification of best barrier option(s) for the Serpentine lakes

Barriers that cannot stop all exotic fish from entering the Serpentine lakes via the outlet drain have to be excluded as they cannot meet the criteria of preventing re-population. This criteria therefore excludes all deterrent barriers as they only deter most fish not all.

High velocity chutes are also excluded because their effectiveness is related to the maintenance of a high water flow and this would not be possible at the Serpentine lakes outlet.

Most stationary screen-based barriers are also unsuitable as the opercular body width for juvenile fish with moderate swimming abilities (i.e., 20-30 mm long fish), such as juvenile koi carp, is likely to be over 3 mm. In other words, the spaces between bars would need to be 3 mm or less and this would result in the screen becoming blocked too easily. Larger spacing between bars would reduce the risk of blockage, but small fish would be able to pass upstream.

Screen types that could be suitable in the Lake Serpentine drain situation are:

- Self-cleaning revolving drum screens with a very fine mesh. (e.g., 1-3 mm spacing).
- Coanda style screens.

Both these options would require the construction of a rectangular (concrete or wood) channel within the drain but because they don’t rely on a large head-height could potentially be overwhelmed during flood flows.

Revolving drum screens require a constant supply of electricity and because they involve moving parts are more prone to malfunction. If installed below the weir a revolving drum screen would exclude all but the smallest fish (larvae and fry) but these would not be able to jump the small head height at the weir (0.5 m).

A Coanda type screen could be installed close to the face of the current weir to replace the rocks that buttress it and to utilise the existing 0.5 m head. Or it could be sited further downstream. Its screen will prevent large fish from jumping over the barrier and the small fall through the meshes will prevent small fish from swimming upstream. Advantages include the relatively low construction, maintenance and running costs. However, during flood flows, or if the screen becomes blocked with fine debris, water can be expected to flow across the screen into the drain. Provided this overflow is shallow, fast, and extends over a reasonable distance, a chute would be created and would deter the upstream passage of many fish. However, it is difficult to determine the extent to which flood flows and screen blockage may combine to "restore" flow over a Coanda stream and so allow larger fish to swim upstream. This is its major weakness. If it was sited where a small head below its downstream face occurred, guaranteeing a small fall, anti-jump bars and a shallow apron could be installed to prevent fish from leaping this barrier.

Other barrier options suitable for the Lake Serpentine outlet stream include:

- Weirs
- Dams
- Culverts

The fall created by a weir or a culvert can provide a total barrier so long as the fall is high enough and flood flows do not reduce it. The current V-notch weir on the Serpentine lakes outlet only allows a maximum head height of around 5 cm to the rocks piled at its base at present. Removal of the rocks stacked below this weir could increase the head height to around 0.5 m, but even this is too low unless an apron is created at the base of the weir and an anti-jump screen is placed on the crest of the weir to prevent fish jumping (Fig. 23A).

If the drain bed below the weir was deepened a greater head height could be obtained (Fig. 23B). This could increase the drop over the weir to approximately 1.0 m. Concurrent widening of the drain bed would result in a shallower depth of water and, provided an apron was installed below the weir, this too would prevent fish jumping over the weir.

Although a 1.0 height does not meet the 1.5 m criteria for jumping fish, the inclusion of a shallow apron below the weir, coupled with protruding anti-jump bars over the intake channel, would effectively prevent large fish jumping, while still providing a 1.0 fall to deter upstream passage of all smaller fish. This option would require the creation of a solid (e.g., wood, concrete, fibreglass) rectangular channel within the drain and the drain works would probably need to extend 200-300 m downstream and involve re-positioning of the culvert across the farm track.

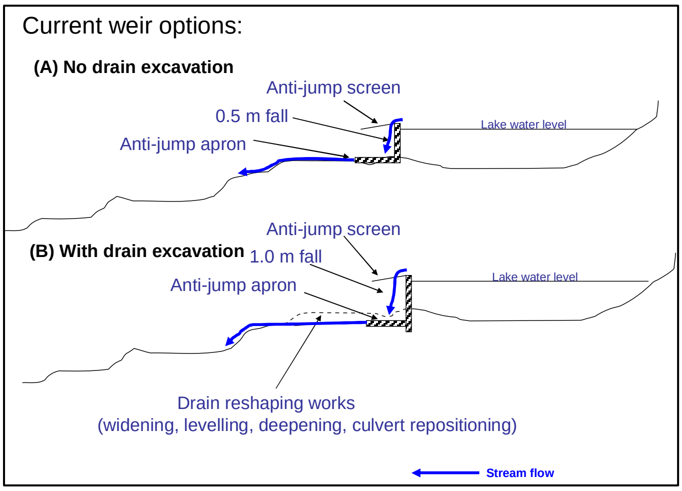

Figure 23: Fish barrier options based on a simple weir structure at the site of the current weir; (A) with no change to the current drainage channel, and (B) with drain deepening and widening for 200-300 m and culvert repositioning.

Other barrier designs that would be potentially suitable involve the creation of a higher weir with water being ducted out of the lake and water levels in the lake controlled by either a stand-pipe intake or a pumped intake. A standpipe would provide an effective barrier to upstream migrant fish (especially if it was over 1. 5 m high). However, this would require the installation of a culvert (connected to the standpipe) beneath the lake bed to a point down stream (Fig. 24). The standpipe would be more straightforward to construct if it was square and incorporated into the back of a new, more robust and higher weir at the site of the existing weir.

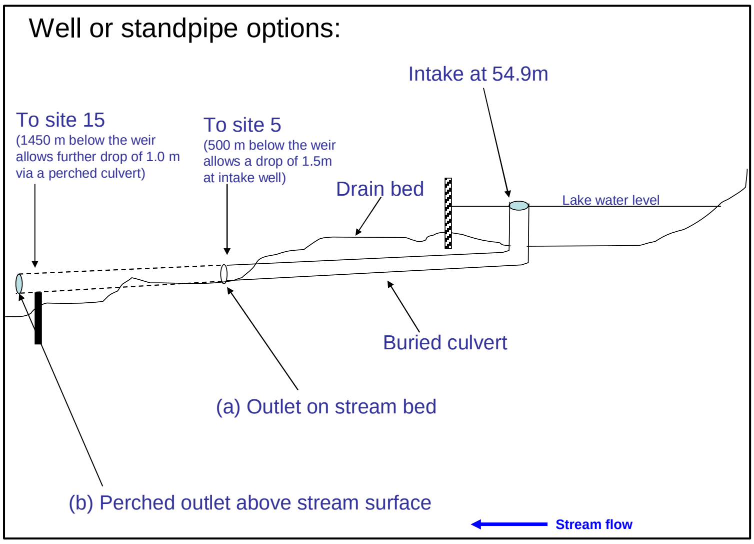

Figure 24: Fish barrier option based on a higher weir and a standpipe outlet to control water level and create a fish barrier**.**

A drop of 1.5 m in the standpipe could be achieved by laying the culvert underground to Site 5 in Figure 4. The installation of a culvert below ground might pose problems because of its length and the peaty nature of the soil. A civil engineering report would therefore be needed to fully evaluate the feasibility of this option.

Avoidance of hydrological and excavation issues could be achieved with a pumped outlet. A pumped outlet would also create an effective barrier to fish, but presents difficulties in terms of running costs. The technology for pumping water out of ponds, lakes and drainage ditches is now sufficiently advanced to be feasible but involves running costs and the risk of breakdown or overload. Water intakes to pumps are readily positioned, screened and cleaned whereas the outlet can also be positioned in such a way as to prevent upstream movement by fish and to minimise erosion. Pumped outlets are based on a constant flow and a switching mechanism would be needed to turn the pump on and off at predetermined lake water heights. This adds further potential for failure and the intermittent flow could result in a section of drain being de-watered when the pump is off. Conversely, when water inflow to the lake exceeds the pumps capacity, lake levels will rise and there is a danger of the water flooding over the weir. This may not be a major issue if the weir is higher and hence the fall is over 1.5 m, or if the weir is fitted with a shallow apron and protruding bars to minimise fish jumping.

Avoidance of hydrological and excavation issues could also be achieved using an overland culvert (round or square) from the top of the weir to a point downstream in the drain where a greater head and hence a higher fall from the perched culvert can be obtained (Fig. 25). The length of culvert required (e.g., c. 1.5k to Site 15) would in itself create a barrier to the upstream movement of fish, but the main barrier would be the fall height of up to 1.5 m gained at the outlet. This could only be achieved by raising the culvert above ground. An above-ground culvert would prevent movement by stock and vehicles across the land and so is unlikely to be acceptable. A culvert that follows the stream channel would not prevent cross-ground movement but it could not be linear (i.e., increased risk of blockage at bends), would need to be supported in much of the channel so as to maintain a gradual slope (difficult in peat), and would result in a substantial length of the drain becoming dewatered (implications for maintaining eel passage).

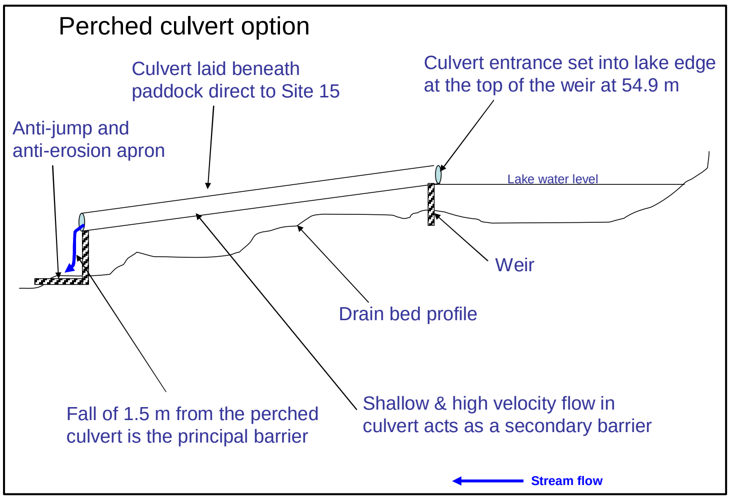

Figure 25: An overland culvert from the weir to Site 15 (see Fig. 4) would allow a fall from a perched culvert of 1.5 m.

The five generic barrier types noted above appear to be the most promising options for the Lake Serpentine outlet. The main advantages and disadvantages of each type are listed in Table 4.

The barrier would ideally be located close to the lake outlet (e.g., on DOC land) to obtain maximum head height and to avoid issues related to property ownership and land use. However, it could also be sited further downstream. The installation of a barrier at the outlet, or further downstream, should not preclude the installation of other barriers even further downstream.

None of the options above has been field tested and so there is a level of uncertainty associated with each of them. Whereas some testing could be carried out in flume tanks, there will still be a degree of uncertainty related to site characteristics. This could be reduced by the installation of secondary barriers further downstream at sites where other small weirs provide potential sites for fish barriers in the drain and/or where culverts occur.

Table 4: Barrier options for the Serpentine Lakes complex with main advantages and disadvantages (NB. See specific sections on each barrier type above for further information on generic design and advantages/disadvantages).

No.	Barrier type	Main advantages	Main disadvantages	Further information requirements
1	Current weir with a square notch, a one metre fall to a solid apron limiting water depth, and a protruding anti-jump screen extending from the crest of the weir over the apron for 1.5 m. The square notch would need to be large enough to cope with flood flows from the lake.	• Simplest to construct • Low maintenance • Likely to be cheapest option • No running costs • Easy to incorporate upstream passage for elvers	• Low head height if drain water level was increased by floods or drain blockage • Flood outflows from lake exceeding weir notch capacity • Drain bed widening, deepening and culvert repositioning required • Drainage works require land owner consent • Adult eel passage difficult to construct	• Civil engineering report on drain work feasibility • Maximum flood water height in the drain needs to be determined • Costing by civil engineer
2	Coanda screen installed at the current weir site, with a 1.5 m sloping screen at a 15º slope, a solid footing to restrict pool formation and of a sufficient width to cope with flood flows.	• Relatively simple to make and install • Low maintenance • No running costs • Easy to incorporate upstream passage for elvers	• Has a lower head height than option 1 in the event of floods and drain blockage • Requires some drain bed reshaping for installation • Adult eel passage not an issue.	
3	Revolving, self-cleaning drum screen with wedge wire screen and 1-3 mm gaps.	• High maintenance • Copes with very low head and water levels • Little change to current drain channel required • Elver passage possible	• Costly to construct • High operational costs • Requires electric power • Vulnerable if flood flows result in water levels overtopping the drum • Seal failure a risk • Repairs require removal from channel • Would require a fish pass for migrant adult eels	• Confirmation of gap distance to exclude juvenile fish (i.e., TL <2 cm)

No.	Barrier type	Main advantages	Main disadvantages	Further information requirements
4	Higher weir with stand-pipe water intake ducted to the drain	• Provides higher level of security than options 1-3 • Low maintenance • No running costs • Elver passage possible	• Installation of standpipe and culverts below the lake could be problematic • Expensive to install • Alternative outlet for adult eels may be required	• Civil engineering advice on feasibility in peat.
5	Higher weir with a pumped outlet	• Highest level of security • A residual flow would be required to maintain elver passage over the dam • Low maintenance	• High running costs • Requires electric power • Blockage of intake would result in lake water rise • Providing adult eel passage will be difficult.	

7. References

Allibone, R. (2000). Fish population and fish passage monitoring for Orokonui Creek, Otago. *Conservation Science Notes No. 304*. Department of Conservations, Wellington.

Boubée, J.A.T.; Wilding, T.; Baker, C.; Smith, J. (2004). Lake Waikare fish pass monitoring 2003-2004. NIWA Client Report HAM2004-142.

Chadderton, L. (2003). Management of invasive freshwater fish: striking the right balance. *In* Managing Invasive Freshwater Fish in New Zealand. Proceeding of a workshop hosted by the Department of Conservation 10-12 May 2002, Hamilton. Department of Conservation, Wellington.

De Winton, M.; Champion, P.; Baker, C. (2007). Management Action Plan for the Serpentine Lakes. NIWA Client Report HAM 2006-150. 51 p

IPCC (2007). Climate Change 2007 Mitigation of climate change. Fourth assessment report of the IPCC.

Mitchell, C.P. (1989). Swimming performances of some native freshwater fishes. *New Zealand Journal of Marine and Freshwater Research 23*: 181-187.

Mitchell, C.P.; Smith, P.J.; Northcote, T.G. (1993). Genetic differentiation among populations of New Zealand common smelt *Retropinna retropinna* (Richardson) from the Waikato basin. *New Zealand Journal of Marine and Freshwater Research 27*: 249-255.

Neilson, K.; Kelleher, R.; Barnes, G.; Speirs, D.; Kelly, J. (2004). Use of fine-mesh monofilament gill nets for the removal of rudd (*Scardinius erythrophthalmus*) from a small lake complex in Waikato, New Zealand. *New Zealand Journal of Marine and Freshwater Research 38*: 525-539.

Ross, Q.E.; Dunning, D.J.; Thorne, R.; Menezes, J.K.; Tiller, G.W.; Watson, J.K. (1993). Response of alewives to high frequency sound at a power plant intake on Lake Ontario. *North American Journal of Fisheries Management 13*: 291-303.

Rowe, D.K; Champion, P.D. (1994). Biomanipulation of plants and fish to restore Lake Parkinson: a case study and its implications. Pp. 53-65. In *Restoration of Aquatic Ecosystems*. (ed.) Collier, K.J. Department of Conservation, New Zealand.

Rowe, D.K. (2007). Exotic fish introductions and the decline of water clarity in small North Island, New Zealand lakes: a multi-species problem. *Hydrobiologia 583:* 345-358.

Rowe, D.K.; Smith, J.P. (2008). Do koaro need a helping hand in the Rotorua lakes? *Water & Atmosphere 16(3)*: 10-11.

Rowe, D.K.; Konui (2007). Enhancement of koaro (*Galaxias brevipinnis*) in the streams of central North Island lakes. 1 - Lake Rotoaira. NIWA Client Report No. HAM2007-046.

Shaw, T.; Studholme, B. (2001). Koi carp and gambusia. Survey for and eradication of Gambusia (*Gambusia affinis*) and koi carp (*Cypinus carpio*) populations in the Nelson region 2000-2001. Department of Conservation Occasional Publication No. 52.

Stokstad, E. (2003). Can well-timed jolts keep out unwanted exotic fish? *Science 301 (5630):* 157-159.

Stuart, I.; Williams, A.; McKenzie J.; Holt, T. (2006). Managing a migratory pest species: a selective trap for common carp. *North American Journal of Fisheries Management 26:* 888-893.

Stevenson, C.; Baker, C. (2009). Fish Passage Guidelines for the Auckland Region - 2009. Auckland Regional Council Technical Publication No.

United States Department of the Interior (2006). Fish protection at water diversions a guide for planning and designing fish exclusion facilities. Water Resources Technical Publication.

Verrill, D.D.; Berry, C.R. Jr. (1995). Effectiveness of an electrical barrier and lake drawdown for reducing common carp and bigmouth buffalo abundances. *North American Journal of Fisheries Management 15*: 137-141.

www.epa.gov/glnpo/invasive/asiancarps.

8. Appendix 1: Relevant Overseas Experience

Ducks Unlimited (DU) has a “Living Lakes” initiative which seeks to protect and restore a series of shallow lake complexes and floodplain wetlands from Southern Iowa through Northern Minnesota. The objective of this program is to protect and restore habitats for waterfowl. In many situations this involves the installation of water level control structures and the protection of water quality and aquatic vegetation to improve habitat for waterfowl. In order to protect aquatic vegetation and water quality a number of lakes have had their outlets modified (including fish barrier installation) to help prevent harmful species (like carp) from entering them.

These projects are particularly relevant to the Serpentine lakes complex as they involve shallow lake complexes and involve similar issues. The main focuses of DU’s work are the Prairie Pothole Lakes in Minnesota. To date work has been carried out on Lake Maria, Lake Christina, Frank Lake, Simon Lake, and Geneva Lake.

At Geneva Lake (1875 acres), Ducks Unlimited engineers designed and installed **a variable crest outlet structure and fish barrier** in 2007. This structure was used for a temporary draw down in preparation for a rotenone operation that was also conducted to remove undesirable fish.

At Lake Maria (425 acres), work has involved installation of an **electric fish barrier** (in a road culvert that separates two lakes) and an electric pump that will be used to induce a drawdown to rejuvenate the lake’s aquatic plants and invertebrates. Carp, black bullhead, and fathead minnows are the target nuisance species for this project.

At Lake Christina, DU’s involvement has included an aerial application of rotenone, followed by the **design and installation of fish barriers** between Lakes Ina and Anka and at Nycklemoe Slough to prevent fish from re-entering Lake Christina. This work has taken place since 2003. The next phases include assessing the feasibility of a permanent pump structure that would allow periodic drawdowns and to work with Lake Christina property owners to help protect undeveloped shorelines.

At Frank Lake DU have installed two new water siphons and a **temporary fish barrier grate** on the outlet of the lake. The water siphons are lowering lake levels faster and to a greater depth than would naturally occur due to a dam on the outlet of the lake. It is hoped that the draw down will reduce populations of rough fish (incl. black bullheads and fathead minnows), and the fish barrier will prevent fish from re-entering the lake.

At Simon Lake (620 acres), DU have installed **high-velocity, tube fish barriers** on the outlet to limit undesirable species of fish, such as carp, from entering the lake. The high-velocity, tube fish barrier uses an outlet culvert with enough length and slope (approximately four feet of drop) to create such high water velocities that fish cannot navigate up the tube and into the lake. This was considered to be the best low maintenance option for the site.

See www.ducks.org/conservation/initiative84.aspx for more background information on this initiative. The key contacts for this work are Jon Schneider (Manager, Conservation Programs Minnesota) jschneider@ducks.org, Josh Kavanagh (Regional Biologist, Minnesota) jschneider@ducks.org.

Frank Lake screen.

Simon Lake high velocity tube barrier.

Lakes with modified outlet structures to create fish barriers

There are a number of references to other lakes that have had outlet barriers constructed to exclude invasive freshwater fish. These include:

The Clearwater River Watershed District (Minnesota, USA) installed 3 carp barriers at the Cedar chain of lakes (at 2 lake outlets and 1 wetland outlet). The engineering assessment for this project is available on the internet www.crwd.org/projects/index.html. This is part of a larger restoration project that aims to improve the water quality of the Clearwater River Chain of Lakes which also involves commercial rough fish harvesting, planting buffers at tile intakes, diverting inflow through a constructed treatment basin with a filter. The annual summary of this work is available at http://www.crwd.org/Documents/2008%20CRWD%20Brochure.pdf. More detailed publications relating to each stage are available at http://www.crwd.org/publications/index.html.

Restoration plans have been developed for Clear Lake/Ventura Marsh (Iowa, USA) by the US Army Corps of Engineers. Construction of a fish barrier to prohibit movement of adult carp from the marsh into the lake is a key component of the plan. See www.clearproject.net/marsh.html.

In 2005 Ducks Unlimited and DNR installed a fish barrier to prevent carp and bullheads from entering Smith Lake from downstream. This work has been carried out as part of a larger habitat restoration project for the lake (see http://www.herald-journal.com/archives/2008/stories/smithlake-dnr.html). Smith Lake is a 330-acre shallow basin located in Wright County Road, Minnesota. The average depth is 4 feet, with a maximum depth of 5.8 feet. Shallow Lakes Program Supervisor Nicole Hansel-Welch, 1601 Minnesota Driver, Brainerd, MN 56401 (email nicole.hansel-welch@dnr.state.mn.us).

Ducks Unlimited is also working with DNR on a program of work to restore Diamond lake, which is a 143 acre shallow prairie lake situated in Iowa. The restoration plan includes construction of a lake outlet structure which will also include the placement of a fish barrier downstream of the outlet. This is expected to take place in 2007. See http://www.iowadnr.gov/water/lakerestoration/index.html.

The Shell Rock River Watershed District is a state agency focused on improving water quality in the district – including its lakes (www.shellrock.org/about.htm). It has a programme of projects to improve water quality that include developing rough fish barriers for a number of its lakes (e.g., Lake Chapeau, Pickeral, Fountain, Goose lakes). http://www.shellrock.org/pdfs/projectlist07_08.pdf. On March 18, 2009 funding was approved to install fish barriers at 3 places in the Shell Rock River Watershed – along Fountain Lake. It would appear that at least one of these barriers is likely to feature an electric barrier.

In-river barriers to protect threatened salmonids

The majority of fish barriers have been constructed in US river situations to extend the habitats of threatened salmonid species. Peter Brown and Alexander Zale of Montana State University have reviewed the information available on these barriers from 2003-2005 and concluded that the falls barrier was the most common type of barrier used to exclude non-native fish from river reaches. They identified knowledge gaps as the major limitation in achieving effectiveness. In particular, managers lacked information in relation to the jumping performance of wild fish, knowledge of proper barrier siting, and effective barrier designs that can accommodate both high and low discharge.

As part of their work, Peter Brown (pbrown@montana.edu) and Alexander Zale (zale@montana.edu) have established a database of fish barrier designs based on information supplied from an online survey. The results of these surveys are available at http://wildfish.montana.edu/projects/barrier/default.asp. Their work assessing barrier designs and effectiveness ends in 2009.