A trial of the effectiveness of a permeable rock bund for excluding fish at the Acton intake, Canterbury

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Authors/Contributors:
M. Bonnett

For any information regarding this report please contact:

Marty Bonnett
Scientist
Freshwater Ecology
+64-3-348 8987
marty.bonnett@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
10 Kyle Street
Riccarton
Christchurch 8011
PO Box 8602, Riccarton
Christchurch 8440
New Zealand

Phone +64-3-348 8987
Fax +64-3-348 5548

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Reviewed by

Paul Sagar

Approved for release by

Helen Rouse

Executive summary

Fish exclusion structures ("fish screens") are present on many irrigation intakes in Canterbury, and have three core fishery functions:

- To prevent fish from becoming entrained within the irrigation system.
- To prevent or minimise exposure of fish to physical harm or predation near the intake.
- To safely divert or "bypass" fish to the river downstream of the intake.

In addition, screens on intakes perform an important operational function by preventing or minimising the intrusion into the irrigation scheme of objects that may otherwise interfere with pumps and other infrastructure.

Although fish exclusion structures have been incorporated into some intakes for many years, there has been uncertainty around their effectiveness. This study was commissioned to measure the effectiveness of a permeable bund as a fish exclusion device, and was conducted at the Acton Irrigation Scheme intake on the southern bank of the Rakaia River near the Rakaia township, Canterbury.

This is a large intake (maximum rate of abstraction 2.6 $m^3 sec^{-1}$ for irrigation and 0.7 $m^3 sec^{-1}$ for stockwater) which utilises a permeable rock bund between the supply and intake channels.

Fish traps were installed in the intake channel and in the bypass channel and c. 6000 hatchery-reared juvenile Chinook salmon were released upstream of the bund. Comparison of catches of trial fish (and other "wild" fish) between the two traps demonstrated how fish were diverted past the bund, and the proportion of fish diverted provides a simple measure of screen effectiveness. Overall the bund was very good at excluding juvenile Chinook salmon, as 95.2% were diverted into the bypass channel back to the Rakaia River. Of the small number of salmon that did get trapped at the intake, 46% of these were small (< 40 mm long) suggesting the bund is less effective at screening and diverting these smaller salmon. The bund was effective at screening and diverting torrentfish (97.5% diverted). However it was much less effective at excluding bluegill bullies (36.4% diverted).

Observations of the bypass channel also show that flow in the bypass decreases along its 1.4 km length, and there may be insufficient flow to transport fish safely back to a braid of the Rakaia River. Two suggestions for improving the performance and effectiveness of the Acton intake screen are made.

1 Introduction

Irrigation and stock water intakes from New Zealand rivers are required by regulatory agencies (Regional Councils, Fish & Game Councils, and the Department of Conservation) to have fish exclusion devices. These devices, routinely referred to as "fish screens", have several core functions: to prevent fish from becoming entrained within the irrigation system; to prevent or minimise exposure of fish to increased risk of physical harm or predation near the intake; and to safely divert or "bypass" fish back into the river downstream of the intake. Although there is concern for a range of fish species, the issues in Canterbury have mainly concentrated on the risks to Chinook salmon (*Oncorhynchus tshawytscha*). This species is notably susceptible, because small juvenile salmon migrate down braided rivers in the region during spring and summer, with the strong possibility of encountering screens on operating irrigation intakes. Chinook salmon have become the "key" species for fish exclusion because fish screens that effectively exclude a high proportion of juvenile salmon will in all likelihood exclude a high proportion of other species.

In recent years, the requirement for excluding fish at intakes has been of concern for both abstracters of water and the regulatory agencies, as problems have arisen over the design and effectiveness of fish screens. Jamieson et al. (2007) developed good practice guidelines for designing and operating fish screens at irrigation intakes, and recommended suitable screen apertures, water velocities, and fish diversion measures. However, the guidelines were based on theoretical information, mostly derived for overseas situations and overseas fish species, with little or no practical validation of the guidelines in New Zealand. Therefore it was not clearly established if fish screens do, in fact, effectively exclude fish, irrespective of whether or not the structure has been designed and operated according to the guidelines.

The Canterbury fish exclusion working party (comprising representatives of the Department of Conservation, Environment Canterbury, Fish & Game NZ, Irrigation NZ, and NIWA), identified the need to properly validate the guidelines by practical testing, and has undertaken effectiveness trials of several intakes in the Canterbury region. The previous trials have assessed the exclusion performance of:

1. a rotary drum screen, using hatchery-reared juvenile salmon and rainbow trout released upstream (Bonnett 2012a)
2. an "Andar" flat screen, using hatchery-reared juvenile salmon and rainbow trout released upstream (Bonnett 2012b)
3. an infiltration gallery, using hatchery-reared juvenile salmon released upstream (Bonnett 2013)

This report discusses the latest trial of fish exclusion performance at an intake facility that uses a permeable rock bund as a fish screen. As in previous trials, the main objective was to assess the overall effectiveness of the facilities by monitoring the fate of live fish at the site when the intake was operating. Using this approach, the effectiveness was measured from the proportion of fish which encountered the intake and were successfully (i.e. safely) transferred back into the river of origin. This gave practical insight as to how well the fish exclusion mechanisms performed and whether they fulfilled their core functions. A further objective of the trials was to provide information that may assist in the design of future structures at intakes.

To compare the structures performance against criteria suggested in Jamieson et al. (2007), individual elements of effectiveness were measured or assessed (where applicable) as follows:

1. **Site location**: was the intake and associated fish exclusion structure installed at, or as close as practical to, the point of water diversion from the main stem of the river?

2. **Screen apertures**: were the apertures in the screen small enough to prevent fish from penetrating the screen and becoming entrained (trapped) in the irrigation system?

3. **Approach velocity**: was the water velocity onto and through the structure (the approach velocity) slow enough so that fish could escape the structure by swimming against the flow?

4. **Sweep velocity**: were fish diverted away from the structure by a flow moving across the structure and toward a diversion?

5. **Bypass and connectivity**: did fish locate and use a bypass, and was the bypass connected to the river for fish to return safely?

6. **Operation and maintenance**: was the facility operated and/or maintained in a manner that ensured its effectiveness at excluding fish?

2 Methods

2.1 Site location

The Acton Irrigation Scheme intake is situated on the southern bank of the Rakaia River, close to the township of Rakaia, c. 1 km downstream of the SH1 Bridge. Water is diverted from an active braid of the river and is passed along a permeable rock-bund; the bund is c.120 m long, c. 3 m wide at the base, and composed of rocks and boulders from c. 100 mm to 500 mm in diameter (Figures 2-1 and 2-2).

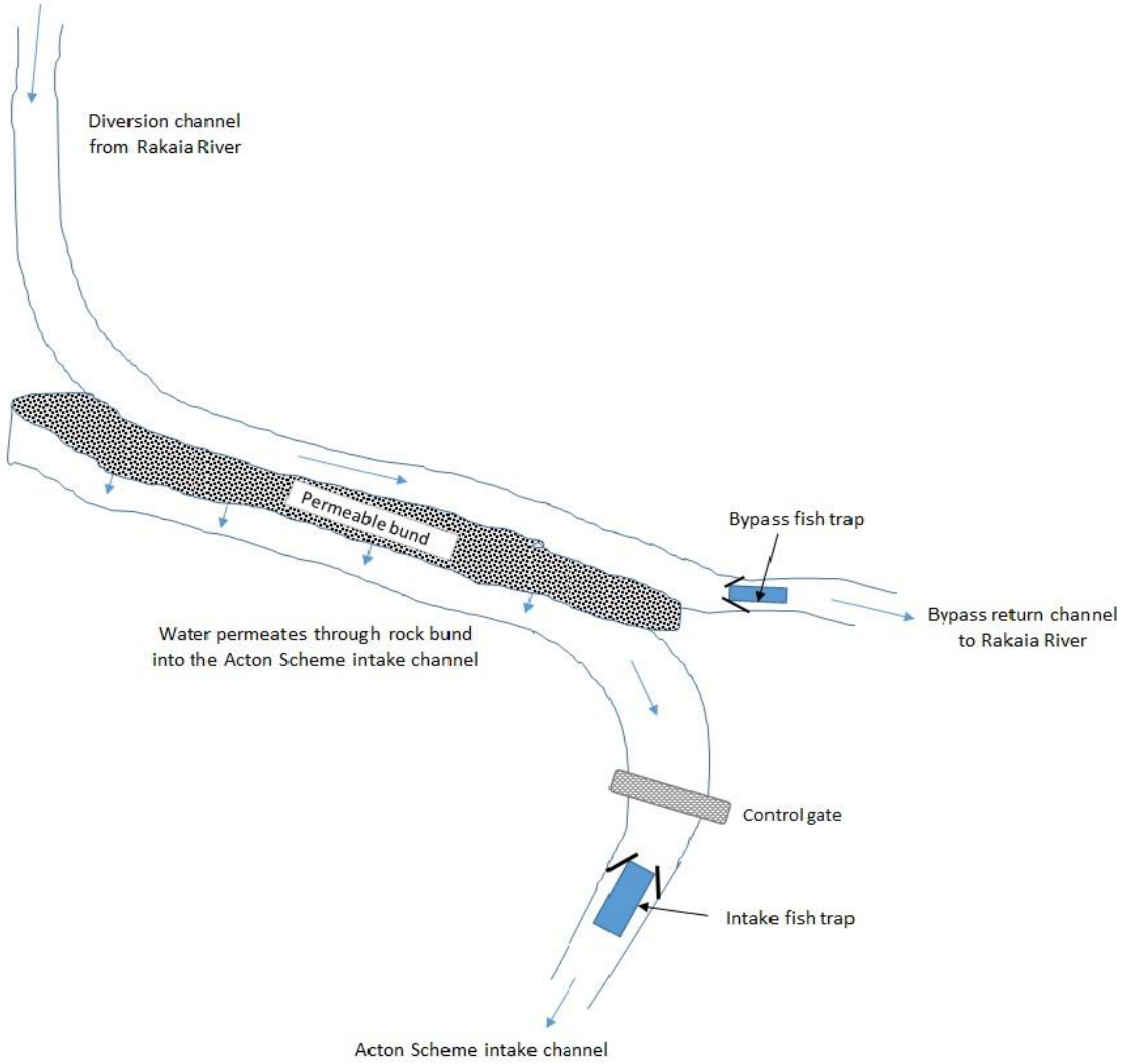

Figure 2-1: Sketch of the layout of the Acton Irrigation Scheme intake.

Figure 2-2: The permeable rock bund at the Acton intake, photographed looking upstream and with low water levels. The diversion channel supplying water can be seen the right of the photograph, and the scheme intake channel to the left.

The scheme is consented to allow diversion of up to 6 m^3sec^{-1} of water from the Rakaia into a primary channel in the river bed, and to discharge up to 4.3 m^3sec^{-1} back to the river. The channel leading to the screen can have a maximum diversion of 4.3 m^3sec^{-1}, comprising:

- 0.7 m^3sec^{-1}stock-water supply year-round into the Acton scheme channel
- 2.6 m^3sec^{-1}maximum irrigation water supply
- 1.0 m^3sec^{-1} year-round into the bypass channel back to the river

The bypass channel back to the Rakaia River is c. 1.4 km in length.

2.2 Trial methods

Fish traps were installed on the intake channel and bypass channel (Figures 2-3 and 2-4 respectively) during the afternoon of 21 October 2013. The traps were not able to cope with the full volume of water in the channels, so for this trial the facility was operated at a lesser flow than normal, but with the same bypass: scheme ratio of 1:2.6. The intake and bypass channels were gauged immediately after the fish trial.

The traps were operated for about 6 hours before 5950 hatchery-reared juvenile Chinook salmon were released into the supply channel c. 200 m upstream of the bund. Operation of the traps continued until the morning of 23 October 2013. The traps were inspected regularly throughout this time, and the numbers of all fish of all species caught in the traps were recorded. Samples of fish caught in the traps were measured to the nearest millimetre, as were samples of the hatchery-reared salmon used in the trial, and wild salmon sampled by electrofishing in the Rakaia River nearby.

The section of the intake channel between the permeable bund and the intake fish trap (c. 240 m^2) was electrofished prior to the traps being operated, and again at the conclusion of the trial. Water depths and velocities were measured in the intake and bypass channels.

Figure 2-3: The fish trap on the scheme intake channel.

Figure 2-4: The fish trap on the bypass channel. The permeable rock bund can be seen in the background, and upstream of the trap.

3 Results

3.1 Catches

The traps on the intake and bypass channels were operated from the afternoon of 21 October 2013 through to the morning of 23 October 2013; during this time both traps were monitored and cleared every few hours, with the exception of the bypass trap which was washed out by high flows on the night of the 21st, and could not be re-instated until early the next morning. A total 3,532 fish were collected in the traps, and Table 3-1 summarises the installation times, catch by species, and catch times, times of installation.

Table 3-1: Installation time and catch of fish, by species, in the intake and bypass traps during the trial on the Acton Intake, 21-23 October 2013.

		intake trap								bypass trap							
	Species	chinook	torrent-	bluegill	common	unid.	unid.	rainbow	shortfin	chinook	torrent-	bluegill	common	upland	brown	rainbow	shortfin
Date	Time (h)	salmon	fish	bully	bully	galaxiid	bully	trout	eel	salmon	fish	bully	bully	bully	trout	trout	eel
21-Oct	1345																
	1400									5							
	1430				2												
	1500												1	1			
	1530					1				1					2		
	1600														1		
	1630				1								1				
	1715	1															
	1740																
	1815	5,950 hatchery salmon released 200 m above intake															
	1900									145	1						
	1620																
	2030									482							
	2115									washed out							
	2140	6							1								
	2240	6		1		2											
22-Oct	0230	2		8													
	0700	5		3			1										
	0710									reinstated							
	0830									179	1	1			1		
	0930	2															
	1000	1								133	2	2	1		1		
	1200	1								116	3	4				2	
	1400				2					60		1			1	3	
	1600	1								51							
	1805						1			71		4					
	2000	5		6						240	4	28	2				
	2210	14		6													
	2230									212	1	3	1		1		
23-Oct	0100	12		5					1								
	0130									82	3	7	1				
	0345	17		19	1				1								
	0410									66		23	1				
	700	47	4	232	1												
	0730									310	31	15					1
	0930	11	6	135	1			1		82	341	143			4		
Totals		131	10	415	8	3	2	1	3	2235	387	231	8	1	11	5	1

The effectiveness of the permeable bund as a fish screen was determined by calculating the proportion of the total catch from the bypass trap compared to the intake trap. Three species of fish were caught in substantial numbers during the trial; Chinook salmon, torrentfish (*Cheimarrichthys fosteri*), and bluegill bully (*Gobiomorphus hubbsi*), and estimates of the effectiveness of the bund for these species are presented in Table 3-2. Two estimates are presented for each species; the first uses total numbers caught, and the second uses total numbers caught in the traps only when both traps were operating (i.e. ignoring catches in the intake trap when the bypass trap was not operating).

Table 3-2: Screen effectiveness for salmon, torrentfish, and bluegill bullies at the Acton Intake during the trial, as a percentage of the total catch in the bypass trap. Adjusted estimates exclude catches from the intake trap during the period when the bypass trap was not operating.

	Total catch			Catch adjusted for trap wash-out		
Species	catch in bypass trap	catch in intake trap	Screen effectiveness (%)	catch in bypass trap	catch in intake trap	Screen effectiveness (%)
Chinook salmon	2235	131	94.5	2235	112	95.2
Torrentfish	387	10	97.5	387	10	97.5
Bluegill bully	231	415	35.8	231	403	36.4

3.1.1 Fish size

Table 3-3 presents the numbers of fish of each species measured in samples from the traps, from the hatchery sample, and from electrofishing in the intake channel and the Rakaia River. There are sufficient length data for Chinook salmon and for bluegill bullies for comparisons between sites.

3.1.2 Size of Chinook salmon

Comparison of the lengths of Chinook salmon sampled from the wild, in the traps, and from the hatchery sample demonstrated that it was not possible to distinguish completely wild fish from hatchery-reared fish used in the trial, because although many wild fish were clearly smaller than the hatchery sample, there was considerable “overlap” in fish lengths from different sites. However, of the salmon caught in the intake trap, a high proportion were small (46% were < 40 mm in length, compared to only 12% from the bypass trap), which indicates that the permeable bund is less effective as a screen for small (wild) fish.

3.1.3 Size of bluegill bullies

There was little difference between the lengths of measured bluegill bullies caught in the intake and bypass traps (Figure 3-2), and so nothing to suggest that the permeable bund is size-selective for this species.

3.1.4 Other species present during the trial

Some trout, eels, common bullies, upland bullies and unidentified galaxiids (probably *Galaxias vulgaris*, the Canterbury river galaxias) were caught during the trial (Table 3-1), but catches of these species were modest. A total of 52 common bullies and 4 upland bullies were caught by electrofishing and removed from the scheme intake channel upstream of the trap (an area of c. 240 m^2) prior to the commencement of the trial, but no fish were caught in this same area after the trial was completed.

Table 3-3: Numbers of fish measured by species and location/method.

Species	Chinook salmon	Torrentfish	Bluegill bully	Upland bully	Common bully	Unidentified bully	Shortfin eel	Unidentified galaxiid	Brown trout	Rainbow trout
Location/method										
Bypass trap	246	39	64	1	8		1		11	5
Intake trap	57	4	66	0	8	2	2	3		1
Hatchery sample	170									
Electrofishing										
Intake channel before trial	1			4	52					
Rakaia River	32									

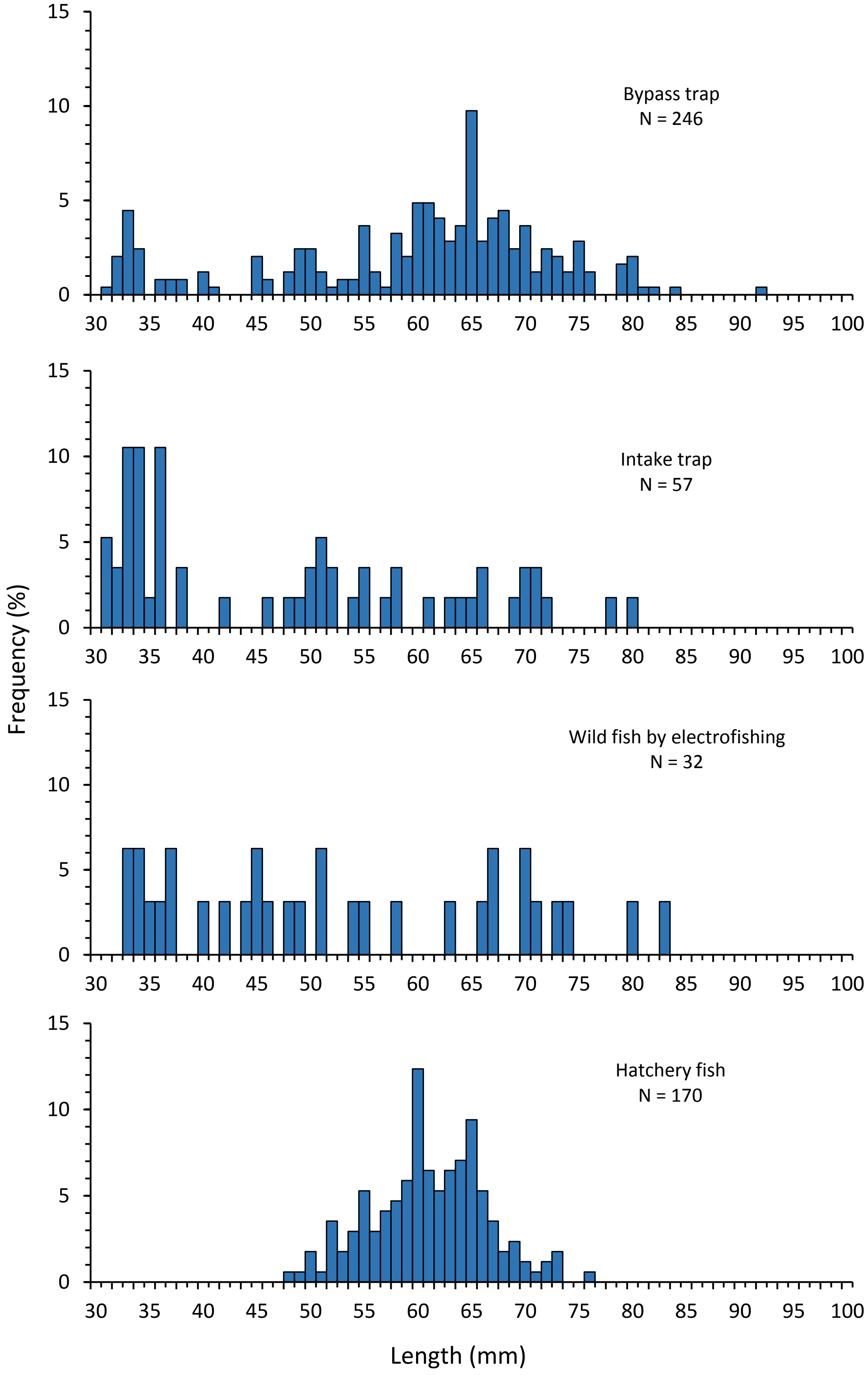

Figure 3-1: Lengths of measured samples of Chinook salmon from the bypass trap, the intake trap, from electrofishing in the Rakaia River, and from a sample of the hatchery-reared fish released in the trial.

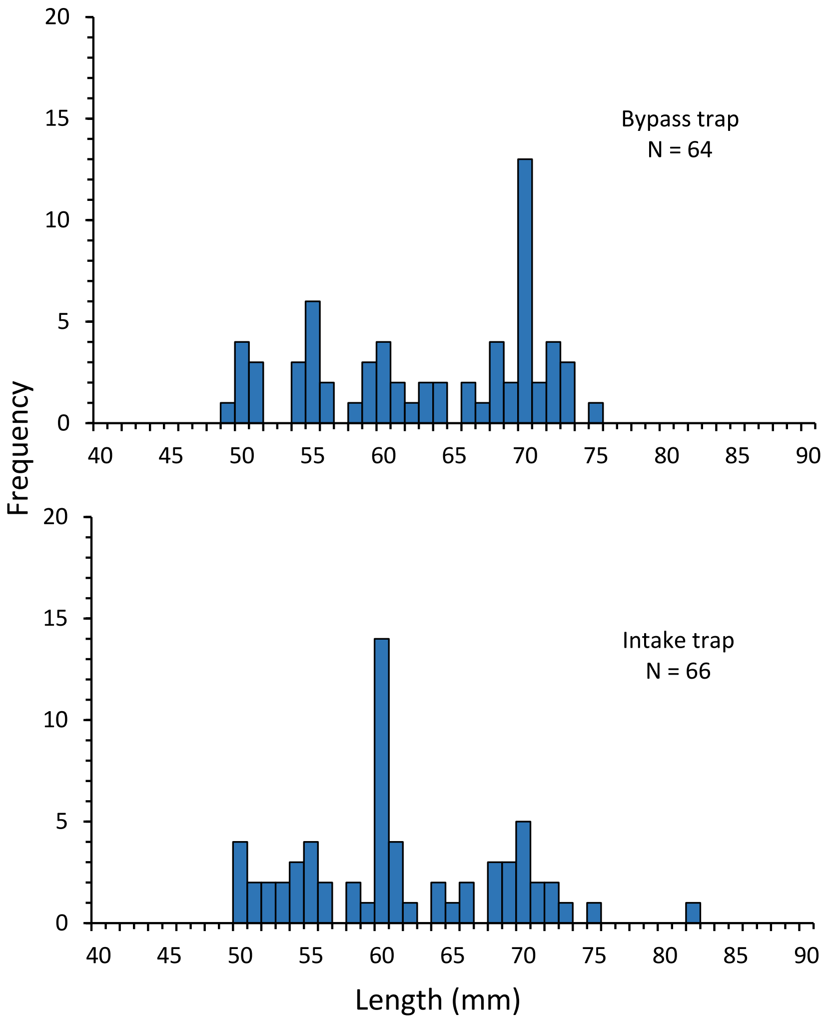

Figure 3-2: Lengths of measured samples of bluegill bullies from the bypass trap and the intake trap.

3.2 Flows and water velocities

The Rakaia River ranged from c. 300 m^3s^{-1} at the start of the trial, rose to c. 950 m^3s^{-1} during the afternoon/evening of the 22nd October, then receded to c. 450 m^3s^{-1} at the end of the trial (Figure 3-3). The Acton intake is c. 50 km downstream of the Rakaia River gauging site at Fighting Hill, and flows in the vicinity of the intake will “lag” the upper river by several hours.

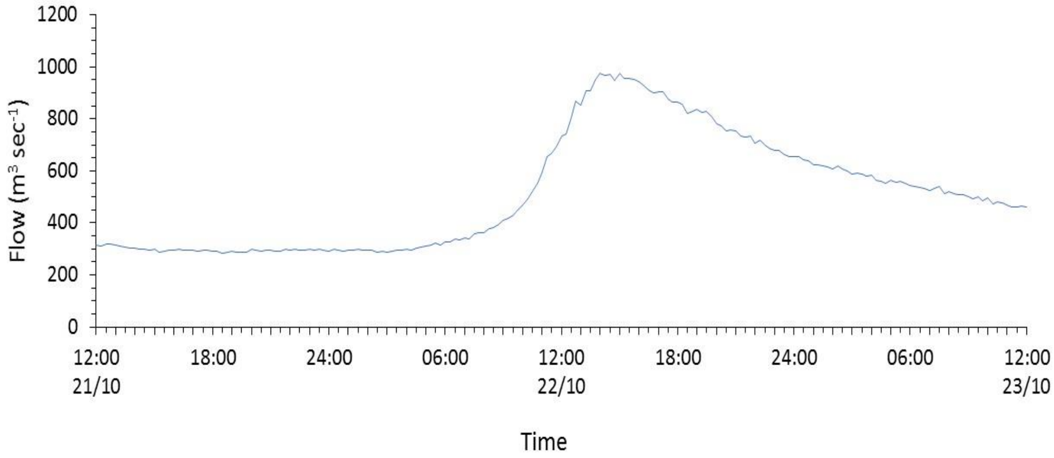

Figure 3-3: Flows in the Rakaia River during the trial (NIWA data; recorded at NIWA's Fighting Hill gauging station c. 50 km upstream of the Acton Intake).

3.3 Water depths and velocities near the permeable bund

Water depth, water velocity, and discharge (flow) information from the intake and bypass channels adjacent to the permeable bund was derived from flow gauging the channels on 23 October 2013 (Table 3-4).

Table 3-4: Water depth, water velocity, and channel discharge (flow) in the intake and bypass channel adjacent to the permeable bund. Gauged 23 October 2013.

	Depth (m)		Water velocity (m sec-1)			Discharge (flow) in m^3sec^{-1}
	max	mean	min	max	mean	
Intake channel	0.83	0.57	0.17	0.33	0.26	0.816
Bypass channel	0.67	0.49	0.05	0.34	0.19	0.371

4 Discussion

4.1 Performance against guideline criteria

The fish-exclusion performance of the Acton Irrigation Scheme intake is compared to the six guideline criteria (as outlined in Jamieson et al. 2007 and listed in section 1 above) in the sections below. These guidelines were developed for traditional mesh–based fish screens, and are harder to reconcile for a permeable rock bund. In this trial the measurement of aperture size and approach velocity were not practical, and for this report a combination of estimates and assessments are used.

4.1.1 Site location

The Acton intake is located on the edge of the Rakaia River bed, with water being diverted into the facility via a channel that is maintained through the bed substrates. It is as close as practical to the point of water diversion from large channels of the river.

4.1.2 Aperture size

An inherent property of an effective fish screen is that any mesh aperture is sufficiently small to prevent fish penetrating the screen. The Acton bund is not mesh, but comprised of a wall of gravel and boulders, and the size of the apertures between the gravel and boulders will be highly variable – conceivably anything from less than 1mm up to more than 100 mm in diameter. However, the bund does not comprise a single layer of gravel and boulders with apertures between – it is several metres wide and there is a succession of apertures of varying sizes.

4.1.3 Approach velocity

Approach velocity is the term used to describe the speed of water immediately upstream of a fish exclusion structure. It is important that the approach velocity is low enough to allow fish to swim upstream against the flow, and so escape from the screen. If a fish cannot sustain a swimming speed greater than the approach velocity it will become exhausted while trying to escape, and for mesh screens the fish will then either penetrate or become (fatally) impinged on the screen. The sustained swimming speed of a fish is proportional to its length, i.e. larger fish can maintain a higher speed. The "rule of thumb" for fish screens is that water approach velocities at a screen should be no greater than four times the body length of the fish each second (Clay 1995) – so for the smallest salmon in this trial (which were about 30 mm long), the approach velocity should be no greater than 120 mm per second (or 0.12 m sec^{-1}). It was not practical to measure approach velocities during this trial, and while the bund provided high fish-screening effectiveness overall for Chinook salmon and torrentfish (94.5% and 97.5% respectively), the lower effectiveness for salmon < 40 mm in length suggests that approach velocity is higher than ideal. This may have been exacerbated during the trial by the bund being partly blocked by the accumulation of silt which decreased the effective area of the bund.

4.1.4 Observations regarding aperture size and approach velocity criteria

For the permeable bund tested in this trial, it was not practical to measure aperture size or approach velocity. The bund achieved a high effectiveness overall for Chinook salmon, which suggests that that the combination of aperture size and water velocities is probably close to the recommended guidelines. The continual build-up of river silt within the bund further suggests that water velocities through the bund are quite low. However, it appears that the facility is less effective for smaller (wild) salmon; this is consistent with the expectation that smaller fish are more vulnerable to being drawn through the bund than larger fish, as they can more easily penetrate small apertures and are less powerful swimmers.

The apparent reduced effectiveness of the bund for smaller salmon is of concern, as most of the wild salmon migrating downstream in the Rakaia River during August, September, and October will be < 50mm in length (Hopkins & Unwin 1987; Unwin 1986). In other words, for the first two months of the irrigation season, the bund may be less effective at screening salmon from the Rakaia River than in later months. From about November, the salmon moving downstream will have been hatched for some time, and most will have grown to >50 mm in length, and so be less vulnerable to being drawn through the intake.

Furthermore, although the guidelines are based on standards for Chinook salmon as the "benchmark" species, they are also intended to protect many other fish species in our rivers. Thus if the gallery is not completely effective for small salmon it may not be effective for other small fish, including some native species that are regarded as threatened.

The occurrence of substantial numbers of torrentfish and bluegill bullies during the trial was entirely unexpected, and is also of some concern. Although both species are known to be relatively common in the lower Rakaia River, both are diadromous species that migrate from the sea as tiny juveniles, and migrate gradually upstream as they grow. There are no reports of either species making substantial downstream migrations en masse. It has been suggested that sexually-maturing adult torrentfish migrate downstream to spawn in rivers such as the Rakaia (Scrimgouer & Eldon 1989), but the presence of torrentfish as small as 47 mm long indicate that this was not a spawning migration. No bluegill bullies, and only one torrentfish (in the bypass trap), were caught before the bypass trap washed out because of greater water flow – in other words, these fish were presumably moving downstream (or being moved downstream) by flooding of their habitat in the river.

4.1.5 Sweep velocity

The term "sweep velocity" refers to the velocity of water sweeping across a screen (i.e. at right angles to the approach velocity). Sweep velocities should be greater than approach velocities, in order to sweep fish away from the screen and into a bypass system. Water velocity in the Acton bypass (supply) channel ranged from 0.05 msec^{-1} to 0.34 msec^{-1}, with an average of 0.19 msec^{-1}; while this is mostly greater than the recommended approach velocity, higher sweep velocities might improve the overall effectiveness of fish screening.

4.1.6 Bypass provision and connection

A survey of the bypass channel, to its return into a side-braid of the Rakaia River, was conducted by Hamish Stevens of central South Island Fish & Game shortly after the trials were concluded. Although there was substantial flow in the bypass return channel near the intake facility, it was greatly reduced by the time it had travelled 1.4 km to the main River (Figure 4-1). There are concerns that if the Rakaia River changes course then there is a risk that the bypass return channel may be substantially lengthened, and subsequently become a "dead end" for fish. Ideally the bypass return channel should be as short as possible to prevent this.

Figure 4-1: Bypass channel returning water to a braid of the Rakaia River, c. 1.4 km from the Acton intake. Note that the flow in the channel here is greatly reduced from the 1.0 m^3sec^{-1} bypass flow requirement.

4.1.7 Operation and maintenance

The Acton facility has few moving parts or structures apart from flow-control gates and a concrete weir to maintain water height in the bypass/supply channel. The main operational issue is the build-up of river silt in the permeable bund; this occurs from the base upwards, and shrinks the effective screen area.

Periodic maintenance is required to remove built-up silt and consists of using an excavator to clear the accumulated silt, algae and debris from amongst the rocks. To clear the silt and debris the water take is slowed to approximately 0.8 m^3sec^{-1} and the rock bund is systematically deconstructed, washed, and reconstructed. Typically the screen may be cleaned 3 – 4 times during the irrigation season.

4.2 Overall performance/effectiveness

The overall measure of screen effectiveness is simply the proportion of fish encountering the screen which are returned to the river of origin. The trials demonstrated that the permeable bund at the Acton intake was very effective for Chinook salmon (95.2%) and torrentfish (97.5%), and not very effective for bluegill bullies (36.4%). Comparison of the length frequency of Chinook salmon caught in the two traps clearly indicated that small (<40mm) salmon were more vulnerable to being drawn through the permeable bund than larger fish.

That so few fish passed into the intake channel leads to the conclusion fish were not drawn through the permeable bund because water velocities through the bund were mostly less than the recommended maximum of 0.12 m sec $^{-1}$. The Acton bund provides a surface area of c. 330 m^2 for a maximum take of 3.3 m^3sec^{-1}, which equates to 100 m^2 of surface per 1.0 m^3sec^{-1} of take. This is considerably greater than that observed at the Selwyn District Council infiltration gallery intake near Te Pirita (Bonnett 2013), where the surface area above the galleries was 45 m^2 for a maximum take of 1.4 of 3.3 m^3sec^{-1} (32 m^2 of surface per 1.0 m^3sec^{-1} of take). Although having a larger bund or gallery costs more to construct and maintain, it has the advantage of needing less frequent maintenance because it will take longer for river-silt to build up and block the interstices between the rocks.

4.3 How might the screen effectiveness be improved?

There are at least two ways that the performance and effectiveness of the Acton intake screen might be improved:

1. The general effectiveness of the screen indicates that aperture size and approach velocity in the permeable bund are probably close to the recommended level. However, it is difficult to say how these features might be improved apart from ensuring that regular maintenance is undertaken to remove the accumulation of silt within the bund. Measurements indicate that sweep velocities may only just exceed recommended values. Higher water velocities in the bypass/supply channel would most likely improve the performance of the facility, and might be achieved by narrowing the channel, even by adding substrate to the upstream (bypass channel) side of the bund.

2. Ensuring the bypass/return channel is well connected to the Rakaia River at all times is probably the most important factor for excluding fish at the facility – the bypass channel needs to be maintained to provide quick passage back to the river for all fish, and thereby minimise the risks from predation, desiccation and changes in water quality in the channel.

5 Acknowledgements

Thanks to Mark Webb and Hamish Stevens of Central South Island Fish & Game for putting in some long hours getting the field work done in testing conditions, and to Fish & Game for providing the fish for this trial. This research was funded by MAF Sustainable Farming Fund, and the trails were made possible by the efforts of Paul Reese and the “fish screen team” including Nick Dunn, Sjaan Bowie, Dave West and Adrian Meredith. Many thanks to the Acton Irrigation Scheme for making the facility available for this trial, and Kevin Birchler-Stockdill for his assistance.

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