Findings from field investigations of six fish screens at irrigation intakes

Prepared for Irrigation NZ

May 2014

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NIWA Client Report No:	CHC2014-045
Report date:	May 2014
NIWA Project:	INZI13501

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Executive summary

Irrigation and stockwater intakes from rivers in Canterbury are required to exclude, or "screen", fish that might otherwise become entrained within the irrigation system and be lost. Guidelines for the design and operation of fish exclusion devices ("fish screens") have been developed, and these recommend screen apertures, water velocities, and other fish diversion measures (Jamieson et al. 2007). In order to assess the suitability of the guideline specifications for fish screens, field tests of six operating fish screens were reviewed. The screens tested represented the most common types of screens already installed in the Canterbury region and did not include "end of pipe" solutions.

Information from each of the investigations was reviewed to assess the validity of seven criteria outlined in "*Fish screening: good practice guidelines for Canterbury*" (Jamieson et al. 2007, hereafter the 2007 Guidelines): site location; screen apertures; approach velocity; sweep velocity; bypass provision; bypass connectivity; operation and maintenance.

Not all the criteria could be quantified during the tests, and therefore these trials were not a specific test of the individual criteria but a test of the effectiveness of each screen, whilst gaining information on the key criteria.

None of the six screens tested met all the criteria from the good practice guidelines, and none of the screens excluded all fish. From the tests conducted, the most critical features for effective fish screening were the provision, design and connection of suitable bypass facilities, and the correct fitting, maintenance and operation of screens.

There are presently no criteria specifying the quantity or proportion of water that should flow through a bypass; as this is an important factor that affects both sweep velocity and connectivity, some guidelines need to be developed. The investigations showed that, overall, the guidelines are appropriate for protection of fish communities in our rivers.

Trials conducted on intakes that utilised infiltration galleries or permeable rock bunds to screen fish demonstrated that these types of screen provide effective (close to 100%) exclusion of juvenile salmon, however they are less effective for very small salmon and trout and some native fish.

Fishing in the vicinity of the intake screens provided some information on which species of fish inhabit these areas and which may be at risk – either from becoming entrained within the irrigation schemes or by predation near screens. It is recommended that further research on the life cycles, distribution, migratory habits, swimming ability, and size of native fish in New Zealand rivers is undertaken to ensure that the 2007 guidelines are appropriate for native fish.

1 Introduction

Most freshwater fish species need free access to and from the sea, and/or within freshwater habitats. If fish are trapped within irrigation or stock water systems, they are essentially lost from the fishery. For some freshwater fish this could have disastrous results, especially for highly valued fisheries (e.g., salmon, whitebait, eels, lamprey), nationally threatened species (e.g., bluegilled bully, torrentfish, upland longjaw galaxias) and locally restricted species (e.g., kokopu species, Canterbury galaxias).

Irrigation and stock water intakes from New Zealand rivers therefore should be designed to ensure fish are excluded. Protecting freshwater fish habitat and managing fish passage are key functions managed by a number of agencies under legislation (e.g., regional councils, Department of Conservation). Fish exclusion devices are routinely referred to as "fish screens", and they have several core functions:

- to prevent fish from becoming entrained within the irrigation or stock water systems;
- to prevent or minimise exposure of fish to increased risk of physical harm or predation near the intake;
- to safely divert fish away from intake systems, and/or "bypass" fish back into the river downstream of the intake; and
- to protect irrigation infrastructure.

In recent years, the requirement for excluding fish at intakes has been of increasing 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 (hereafter the 2007 Guidelines) for designing and operating fish screens at irrigation intakes, and recommended a series of specifications including suitable screen apertures, water velocities, and fish diversion measures. However, it had never been clearly established if current fish screens do, in fact, effectively exclude fish, irrespective of whether or not the structure had been designed and operated according to the guidelines.

Juvenile Chinook salmon and rainbow trout have usually been used as the test indicator species for fish exclusion, predominately because they are at risk of being injured by contacting screens and/or being trapped within irrigation systems during migration phases, and because large numbers of appropriately-sized fish were readily available to use in trials. Many of the exclusion requirements for Chinook salmon are similar to that of other sports and native fish (Bejakovich 2006; Charteris & Hamblett 2006). There are some significant behavioural differences between salmonids and many native species, particularly as many native fish are cryptic and benthic, predominately occupying habitats near the bottom of the water column and within the substrate, while sports fish actively swim in the upper part of the water column. Native fish also differ from sports fish in activity patterns at different times of the day/night. These differences in behaviour patterns may be very important in determining screen design effectiveness.

The Canterbury fish exclusion working party (comprising representatives of the Department of Conservation, Environment Canterbury, Fish and Game NZ, Irrigation NZ, and NIWA), identified the need to both validate the 2007 guidelines by practical testing, and examine novel screening systems that do not relate directly to all guideline criteria. This report summarises what has been learnt to date from effectiveness trials at fish screens on a selection of irrigation intakes. The trials have assessed the exclusion performance of:

1. The North Otago Irrigation Company (NOIC) permeable rock bund, at Borton's Pond, Waitaki River, using dye-marked juvenile Chinook salmon enclosed in a small area upstream of the bund (Sykes et al. 2010).
2. The Levels Plain irrigation intake on the Opihi River, a vertical flat plate screen with travelling brushes, using a "DIDSON" acoustic camera and nets to observe hatchery-reared salmonids released upstream (Hay and Quarterman 2011).
3. The Mead intake on the Rakaia River, a rotary drum screen, using hatchery-reared juvenile salmon and rainbow trout released upstream (Bonnett 2012a).
4. The Totara Valley intake, Opihi River, an "ANDAR" flat screen with travelling brushes (also referred to as the "Didymo screen"), using hatchery-reared juvenile salmon and rainbow trout released upstream (Bonnett 2012b).
5. The Selwyn District Council (SDC) stockwater intake on the Rakaia River, an infiltration gallery, using hatchery-reared juvenile salmon released upstream of the gallery (Bonnett 2013a).
6. The Acton intake, lower Rakaia River, a permeable rock bund, using hatchery-reared juvenile salmon released upstream (Bonnett 2013b).

The objectives of trials at fish screens 1 and 2 (above) were mainly to observe and assess the behaviour of hatchery-reared juvenile salmonids when encountering a permeable bund or flat-plate screen. The main objective of trials at locations 3,4,5 and 6 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 as the proportion of fish which encountered the intake and were successfully (i.e., safely) transferred back into the bypass channel. This indicated how well the fish exclusion mechanisms performed, and whether they fulfilled their core functions. Where practical, aperture size, approach velocity and sweep velocity were measured to determine whether the facilities met the 2007 Guideline criteria, and to provide information that may assist in the design of future structures at intakes. In addition to controlled releases of fish into water intakes, electrofishing was undertaken, where possible, at intake and bypass locations to discover which species used the area and were entrained under normal operating conditions.

In order 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.

- **Site location**: was the intake and associated fish screen installed at, or as close as practical to, the point of water diversion from the main stem of the river?
- **Screen apertures**: were the apertures in the screen small enough to physically prevent fish from penetrating the screen and becoming entrained (trapped) in the irrigation system? The 2007 Guidelines recommend a bar gap of 2 mm or mesh/plate aperture size of 3 mm.

- **Approach velocity**: was the water velocity onto and through the screen (the approach velocity) low enough so that fish could escape by swimming upstream against the flow? The 2007 Guidelines recommend approach velocities of no more than 0.12 m/sec.
- **Sweep velocity**: were fish diverted away from the screen by a flow moving across the screen and toward a diversion? The 2007 Guidelines recommend a sweep velocity greater than the approach velocity.
- **Bypass provision:** was a bypass provided, and were fish able to locate and use it?
- **Bypass connectivity**: was the bypass connected to the river for fish to return safely?
- **Operation and maintenance**: was the facility constructed, operated and/or maintained in a manner that ensured its effectiveness at excluding fish 24 hours a day?

2 Methods

Two approaches were used to summarise information for this report.Firstly, each of the six previous studies is briefly summarised. Where appropriate, each screen is assessed against the recommended specifications in the 2007 Guidelines.

- Was the screen at, or as close as practical to, the point of water diversion from the river?
- Was the screen constructed with screening material of aperture size 3 mm or less?
- Was the approach velocity low enough (0.12 m/sec or less) to allow fish to escape?
- Was the sweep velocity equal to or greater than the approach velocity?
- Was there an effective bypass present and positioned to allow fish to escape or avoid the screen?
- Was the bypass connected back to the river, and could it return fish safely to an actively flowing section of the river of origin?
- Was the screen effectively constructed, maintained, and operated?

Secondly, information from all the studies was used to review the relative importance of each of the seven criteria listed above, along with any other pertinent features or observations.

3 Results of trials at intake screens

3.1 North Otago Irrigation Company (NOIC) bund

This study was conducted in October 2009 by NIWA (Sykes et al. 2010), and investigated the effectiveness of the 80 m long rock bund constructed by the North Otago Irrigation company (NOIC) for excluding fish. The bund has been constructed and modified several times, resulting in the present structure across the entrance of the NOIC canal in Borton's pond on the south bank of the Waitaki River (Figures 3-1 and 3-2). Water from the pond flows through the bund and into a canal and pumping station, but only when one, or both, of the pumps is operating.

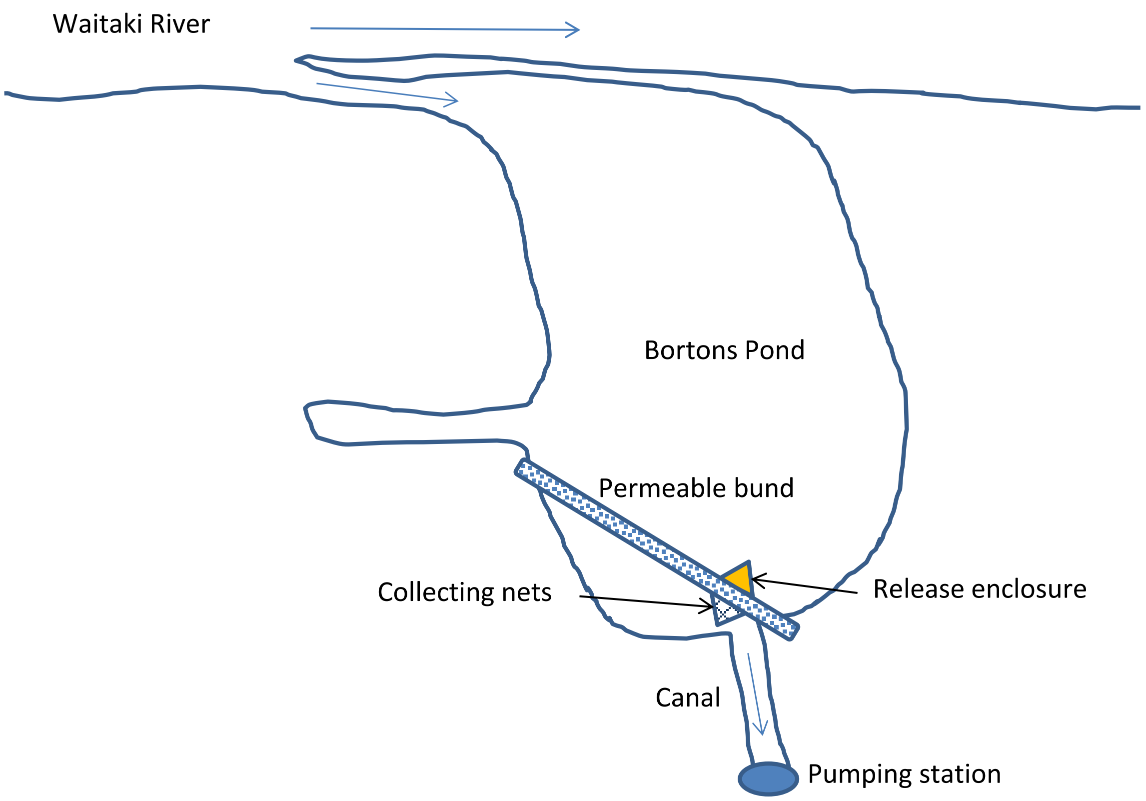

Figure 3-1: Sketch of the trial set-up at the NOIC intake on Borton's Pond.

Testing the effectiveness of the bund was carried out using hatchery-reared Chinook salmon ranging in length from 39 to 59 mm. The experimental fish were dye-marked, so that they could be distinguished from wild fish that were also present. The dye marked fish were placed in a net enclosure upstream of a portion of the rock bund, and fish penetrating the bund were observed and captured on the downstream side of the bund.

Two trials were carried out, coinciding with the operation periods of one of the pumps downstream from the bund (i.e. when water was flowing through, at an approach velocity estimated at 0.10 $msec^{-1}$). Approximately 1000 Chinook salmon were used for each trial, and only one dyed fish of 55mm length (from the first trial) was recorded in the nets downstream of the bund. The result indicated that the barrier was >95% effective in screening out juvenile hatchery salmon of 39-60mm.

Figure 3-2: The NOIC bund. Dye marked salmon were placed in the enclosure seen to the right of the bund; any fish that passed through the bund was collected from nets placed downstream, seen on the left.

3.1.1 Findings and conclusions from the NOIC trial

The main conclusion from this investigation was that juvenile salmon did not readily penetrate through the rock bund. It should be noted, however, that the trials undertaken for this investigation were probably constrained by the following factors:

- The trials were each of short duration (less than one hour) to coincide with pump operation.
- They were undertaken during daylight, whereas salmon migration downstream is more likely to occur during darkness.
- They were conducted when only one of the two pumps was operating; had both pumps been operating, a substantially greater approach velocity would have occurred.
- Relatively large (39 to 59mm long), hatchery-reared fish were used; wild fish encountering the bund during the trial period would generally be smaller (c. 30 mm to 50 mm).

The performance of the NOIC bund is summarised in Table 3-1.

Table 3-1: Summary of performance of NOIC bund with respect to guideline criteria.

Criteria	Assessment	Comments
Site location	Ok	Pond adjacent to mainstem of Waitaki River
Screen aperture size	Not measured	Range of rock sizes used to form bund
Approach velocity	Not measured	Estimated at c. 0.10 m/sec
Sweep velocity	Not measured	Less than 0.10 m/sec
Bypass provision	Not assessed	
Bypass connection	Not assessed	
Operation and maintenance	Not assessed	

Conclusion: The trial was a limited test to determine whether juvenile salmon would penetrate the bund; the trial did not assess performance or effectiveness of the bund with respect to the guideline criteria.

3.2 Levels Plain intake

This trial used DIDSON sonar equipment to monitor fish screen efficacy and fish behaviour in front of the Levels Plain Irrigation Scheme water intake on the Opihi River, South Canterbury, during December 2010 (Figures 3-3 and 3.4). Although no published report was produced from the trial, the following is summarised from a letter sent to Irrigation New Zealand (Hay and Quarterman 2011) and unpublished notes with summaries of electrofishing and netting results (DOC 2011). Electrofishing was undertaken in the water intake canal downstream and upstream of the screens when water levels were lowered before and after the fish being released.

Longfin eel, torrentfish, upland bully, common bully and brown trout were captured downstream (area 2) and upland bully captured upstream (area 1) of the flat screens in the intake canal prior to the trial, and represent the species entrained into and through the water intake under natural operating conditions. A range of sizes were caught, including large eels and trout, confirming that some large fish would be predating on fish that accumulate within the screen area.

Chinook salmon smolt (c. 1300 of 90 -120 mm long) and rainbow trout fry (c. 1400 of 25-30 mm long) were released. After the experiments, nets were checked and a few rainbow trout were found to have penetrated the screen, possibly through the one panel of 5 mm mesh (the other 14 panels were of 3mm mesh) or under the gap found at the bottom of the flat screen.

3.2.1 Findings and conclusions from the Levels Plain intake trials

- The DIDSON was not effective for monitoring fish of ~30 mm in length, as these fish could not be distinguished individually, although possible shoals could be seen.
- Salmon smolt of about 110 mm in length appeared to be most active around dawn (~05:00-06:30) in both experiments.
- When the fish bypass was blocked (i.e. there was no exit available) the salmon smolt spent much of their time apparently drift feeding, as well as moving about area 1 in shoals. It could not be determined what the small rainbow trout were doing.

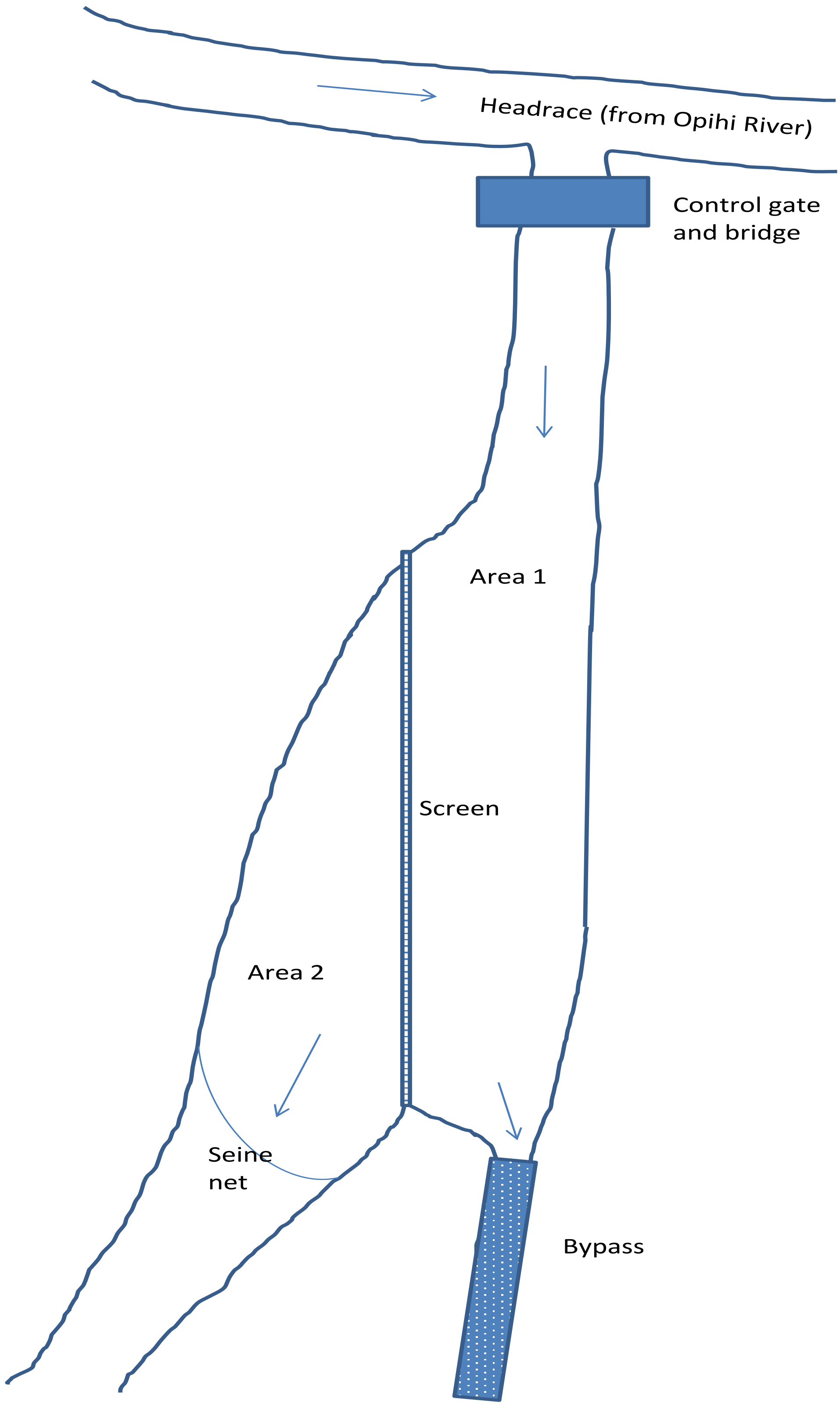

Figure 3-3: Sketch of the trial set-up at the Levels Plain intake screen.

Figure 3-4: The Levels Plain intake screen. Water moving downstream (towards camera) passes through the screen panels and into the scheme intake channel behind the screens. The entrance to the bypass is under the vegetation at the bottom left. The stakes near the screen support the DIDSON camera used for the trials.

- When the fish bypass was open there was less activity overall. Some fish did exit via the bypass, but they often made exploratory forays into the bypass several times before remaining in it, suggesting that the bypass velocity was insufficient to ensure fish were flushed back to the Opihi River.
- After the trial, a few rainbow trout were found entrained in the scheme race.

The performance of the Levels Plain intake screen is summarised in Table 3-2.

Table 3-2: Summary of performance of the Levels Plain intake screen with respect to guideline criteria.

Criteria	Assessment	Comments
Site location	Poor	c. 750 m from Opihi River, via a water race and through several structures
Screen aperture size	Ok	17 screen panels of 3 mm mesh; one of 5 mm mesh
Approach velocity	Not met	Ranged from 0.19 to 0.39 m/sec
Sweep velocity	Met	Mostly met - ranged from 0.25 and 0.54 m/sec
Bypass provision	Yes	Into enclosed pipe.
Bypass connection	Yes	To Opihi River.
Operation and maintenance	Ok	5 mm mesh panel was a temporary repair. Screen brushes may have caused fish impingement. Gap found under flat screen

Conclusion. The trial was primarily focused on DIDSON use to monitor the behaviour of fish. This fish exclusion design, if maintained well, would be effective to exclude both native and sports fish. The screen would be improved and more effective if:

- the location was not as far away from the active channel
- screen aperture was all 3 mm
- no gap existed under the flat screen panels
- approach velocity was decreased, sweep velocity increased
- the bypass entrance was open-topped, rather than enclosed.

3.3 Mead intake, rotary drum screen

This study took place at the Mead irrigation intake, situated c. 1 km upstream of the SH1 Bridge on the northern bank of the Rakaia River in Canterbury, during December 2011 (Bonnett 2012a).

The trials comprised releasing hatchery-reared Chinook salmon and rainbow trout upstream of the screen structure, and then monitoring their fate (i.e. their location) after they encountered the screen. The screen at the Mead intake (Figures 3-5 and 3-6) is a rotating drum type, 2 m wide by 1.2 m in diameter; and is covered in stainless steel mesh with apertures c. 5 mm wide. The drum is mounted in a rectangular concrete channel, with a vertical-slot fish bypass channel situated on one side c. 3.2 m upstream of the screen. At the time of the trial c. 0.4 m^3 /sec of water was passing through the screen.

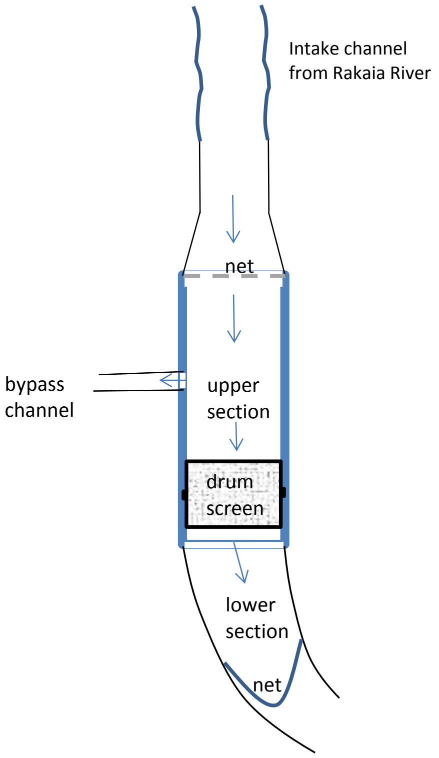

Figure 3-5: Sketch of the trial set-up at the Mead intake screen.

Figure 3-6: A view of the rotary drum at the Mead intake, looking upstream and without water flowing. The entrance to the fish bypass can be seen on the left side of the concrete channel.

Two trials were undertaken on successive days; before each trial, nets were placed upstream and downstream of the drum, and the area was electrofished to remove wild fish and any fish remaining from a previous trial. For each trial, hatchery-reared fish (500 juvenile rainbow trout c. 25 to 35 mm in length, and 500 juvenile Chinook salmon c. 60 to 80 mm in length) were released upstream of the rotary drum. For the first trial the bypass channel was kept closed, whereas for the second trial it was kept open and with a catch-net across the width of the bypass channel.

3.3.1 Results

For both trials the numbers and proportions of fish recovered upstream and downstream of the screen, and in the bypass channel (trial 2 only) are summarised in Table 3-3.

Table 3-3: Numbers and location of fish recovered in trials at the Mead Intake. Numbers of fish (by species) released in each trial, and numbers and percentage recovered.

		No (and %) of fish recovered	
Trial	**Location recovered**	**Chinook salmon**	**rainbow trout**
Trial 1	Bottom section (downstream of screen)	28 (20.7)	0 (0)
	Dead on screen	94 (69.6)	0 (0)
	Top section (upstream of screen)	13 (9.6)	0 (0)
Trial 2	Bottom section (downstream of screen)	46 (23)	29 (50)
	In bypass channel	126 (63)	28 (48.3)
	Top section (upstream of screen)	28 (14)	1 (1.7)

3.3.2 Findings and conclusions from the Mead intake trials

Overall, the performance of the Mead intake was very poor, as the trial indicated that no fish encountering the screen would be bypassed back into the Rakaia River. Most of the criteria outlined in the 2007 Guidelines were not met, as follows:

- The water approach velocity was too high; measurements taken upstream of the drum indicated that mean approach velocity was > 0.4 m/sec, more than three times that recommended (0.12 m/sec). Even the relatively large (80 mm long) Chinook salmon used in the trials could not sustain prolonged swimming against this flow.
- There was little or no sweep velocity across the screen, so that fish were not swept or guided into a bypass.
- At 5 mm, the mesh in the drum was too big to exclude small fish. The recommended size is 3 mm.
- The screen was apparently poorly maintained and/or operated; debris such as small sticks were seen to pass the drum and be washed downstream, presumably because the seals on the sides and bottom of the drum were not operative. This also allowed some fish to pass the screen.
- The position of the bypass was poor; it was 3.2 m upstream of the drum – a bypass entrance closer to the drum would be more effective. (An alternative bypass slot has since been constructed close to the screen edge).
- The bypass channel was also not well maintained, and did not return bypassed fish back to the Rakaia River.
- Electric fishing of the site before the trial commenced showed that torrentfish, lamprey and bullies were also present in the concrete channel and downstream; these had been entrained into the scheme under normal operating conditions.

The performance of the Mead intake screen is summarised in Table 3-4.

Table 3-4: Summary of performance of Mead intake screen with respect to guideline criteria.

Criteria	Assessment	Comments
Site location	Poor	c. 1 km from Rakaia River; situated in secondary intake channel
Screen aperture size	Poor	5 mm mesh
Approach velocity	Very poor	> 0.4 m/sec
Sweep velocity	Very poor	No sweep velocity detected.
Bypass provision	Poor	3.2 m upstream of screen; poor location exacerbated by low sweep velocity
Bypass connection	Very poor	Not connected
Operation and maintenance	Poor	Gaps around drum; bypass channel not maintained

Conclusions. Inadequate design; poorly maintained and operated. Would be improved by:

- Modification of intake channel to shorten/amalgamate primary and secondary channels, and multiple screens in close proximity.
- Decreasing the approach velocity; this could be achieved by modifying the structure to increase the area of the screen in the water; e.g., by deepening the water in the concrete channel.
- Reposition the bypass entrance closer to the screen, and increase bypass flow in order to improve sweep effect.
- Connecting bypass channel to active channel of the Rakaia River.
- Better maintenance.

3.4 Totara Valley Intake

This study took place at the Totara Valley Scheme intake, situated close to the southern bank of the Opihi River in South Canterbury, during late January and early February 2012 (Bonnett 2012b). This type of screen is commonly referred to as an ANDAR screen, because it has been manufactured by ANDAR Holdings in Timaru, and are promoted as being effective for maintaining intake flow in Didymo-effected waterways. The screen utilises two flat layers of stainless steel perforated plate material set on an inclined angle in the water; the plate screens are kept clean by constantly moving brushes and rubber “squeegees”. Leaves and debris cleaned off the screen are transported to the top of the screen and deposited on the bank, or a “trash rack” above the screen. This facility uses water diverted from the southern edge of the Opihi River to supply a head pool c. 150 m from the river edge. The ANDAR screen is situated on one side of the head pool, and on the other side of the pool there is a bypass comprising a length of plastic pipe draining a small flow of water through a gravel bank and into a small return channel back to the Opihi River (Figures 3-7 to 3-9).

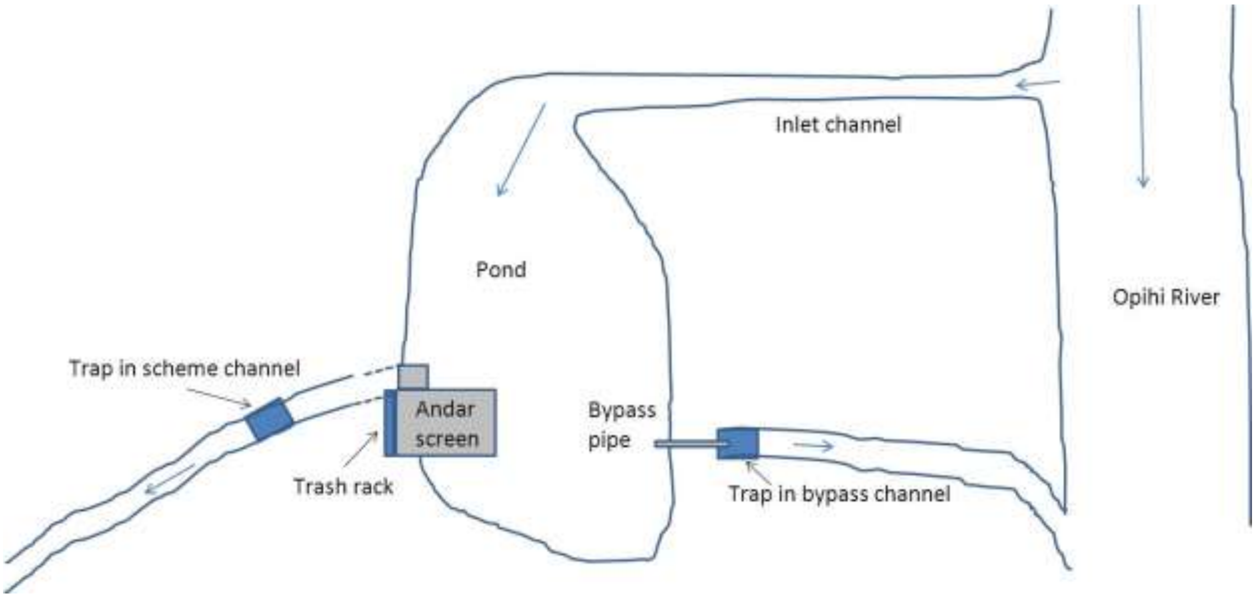

Figure 3-7: Sketch of the trial set-up at the Totara Valley intake screen.

Figure 3-8: The ANDAR screen, on one side of the head pond. Water flows from the pond, through the screen and down into a channel behind the screen (adjacent to the parked vehicle).

Figure 3-9: The bypass entrance; a pipe through the gravel bank opposite the screen. Water flows through the pipe into a small open channel that returns water to the Opihi River.

A single trial was conducted at this facility, using fish traps placed downstream of the scheme intake (i.e. fishing water that had passed through the screen) and downstream of the bypass pipe. During the trial the flow of water through the screen and into the irrigation scheme was estimated to be 0.486 m^3/sec (486 litres per second), and the flow through the bypass pipe was about 0.001 m^3/sec (1 litre per second).

3.4.1 Results

No wild salmon or trout were caught in the traps before the commencement of the trial. One thousand Chinook salmon, and 1000 rainbow trout were released for this trial; recovery in the traps and trash racks totalled 388 (38.8%) salmon and 330 rainbow trout (33.0%) (Table 3-5).

Table 3-5: Numbers, and in brackets percentage, of hatchery (trial) fish recovered by site.

Site (fate)	Chinook salmon	Rainbow trout
Scheme trap	244 (24.4)	40 (4.0)
Bypass trap	0 (0.0)	14 (1.4)
Trash rack	144 (14.4)	276 (27.6)
All combined	388 (38.8)	330 (33.0)

One pertinent observation made during the trial was that the rubber flange around the ANDAR screen appeared to fit poorly in places; it is likely that a substantial flow of water was passing around the screen at any such spot where the flange was not sealing properly. Such a flow of water may have "attracted" fish in the vicinity, and may have been sufficient to draw fish down and into the scheme.

3.4.2 Findings and conclusions from the Totara Valley intake trial

Overall, the performance of the Totara valley intake screen was very poor; none of the Chinook salmon, and only 14 (1.4%) of the rainbow trout used in the trial utilised the bypass channel back to the Opihi River. Substantial numbers of trial fish were drawn into the scheme, or were removed by the screen cleaning mechanism and ended up in the trash on the bank.

Before the trial, electric fishing of the intake channel showed that it contained upland bullies, common bullies, brown trout and eels.

The performance of the Totara Valley intake screen is summarised in Table 3-6.

Table 3-6: Summary of performance of the Totara Valley intake screen with respect to guideline criteria.

Criteria	Assessment	Performance
Site location	Good	c. 150m from Opihi River
Screen aperture size	Good	3 mm
Approach velocity	Fair	Estimated at c. 0.15 m/sec .
Sweep velocity	Poor	No apparent sweep velocity
Bypass provision	Poor	Bypass provided, but unsuitably small, poor design, poor location, and low flow.
Bypass connection	Poor	Connected but insufficient flow for proper operation
Operation and maintenance	Poor	Rubber flange at base not fitted; fish lost in trash.

Conclusions: Overall performance was poor. The ANDAR screen design is potentially effective, and improvements could be achieved by:

- Modifying brushes and squeegees by staggering and providing an escape gap to prevent fish being trapped on the brushes and transported onto the trash screen.
- Improving the bypass performance by having the entrance closer to the screen and using an entrance that it is open-topped.
- Increasing the bypass flow; this would help to create a sweeping flow toward the bypass, and also provide a better connection for returning fish to the Opihi River.
- Improving the maintenance of the facility, especially improving the fit of the rubber flange near the base of the screen.

3.5 Selwyn District Council (SDC) intake

This study took place at the Selwyn District Council (SDC) stockwater intake, situated on the northern bank of the Rakaia River near Te Pirita, in September 2012 (Bonnett 2013a) At this site, water is diverted from a braid of the Rakaia River, and flows down an inlet channel that is c. 1800 m long into a head pond c. 1 ha in size (Figures 3-10 and 3-11), which also supplies the Grasslands scheme (c. 0.5 m^3/sec but not operating during this trial). Three control structures can be used to regulate flows into and from the pool:

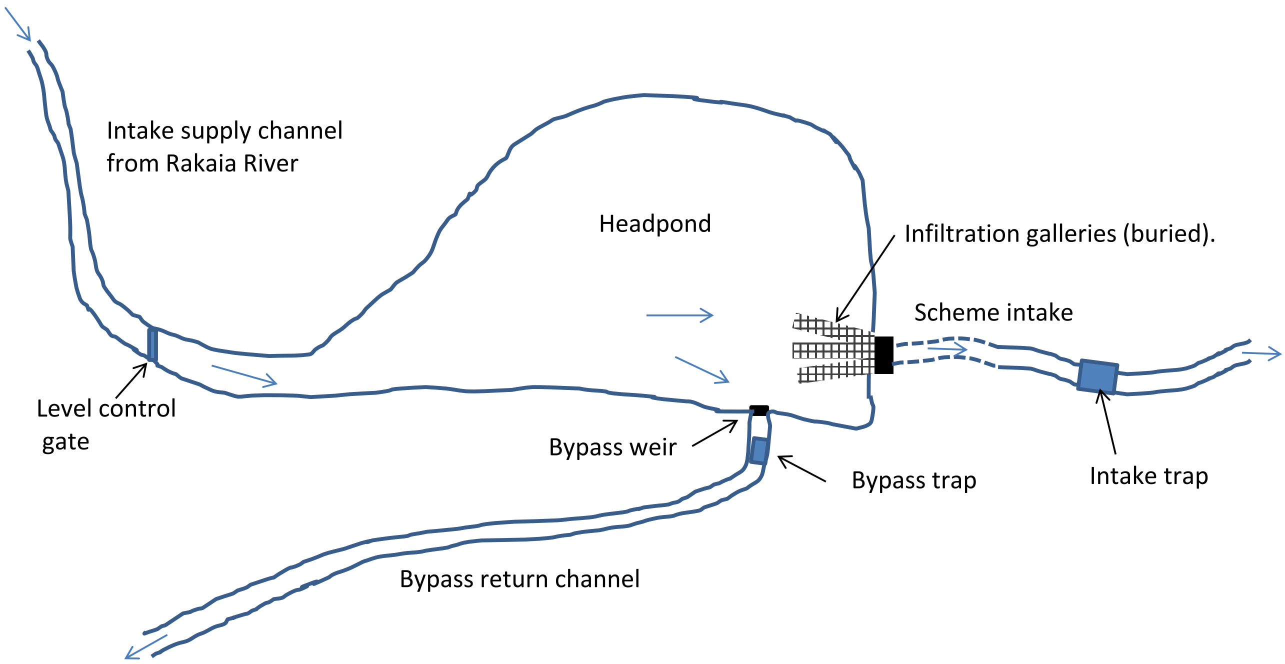

Figure 3-10:Sketch of the trial set-up at the SDC intake.

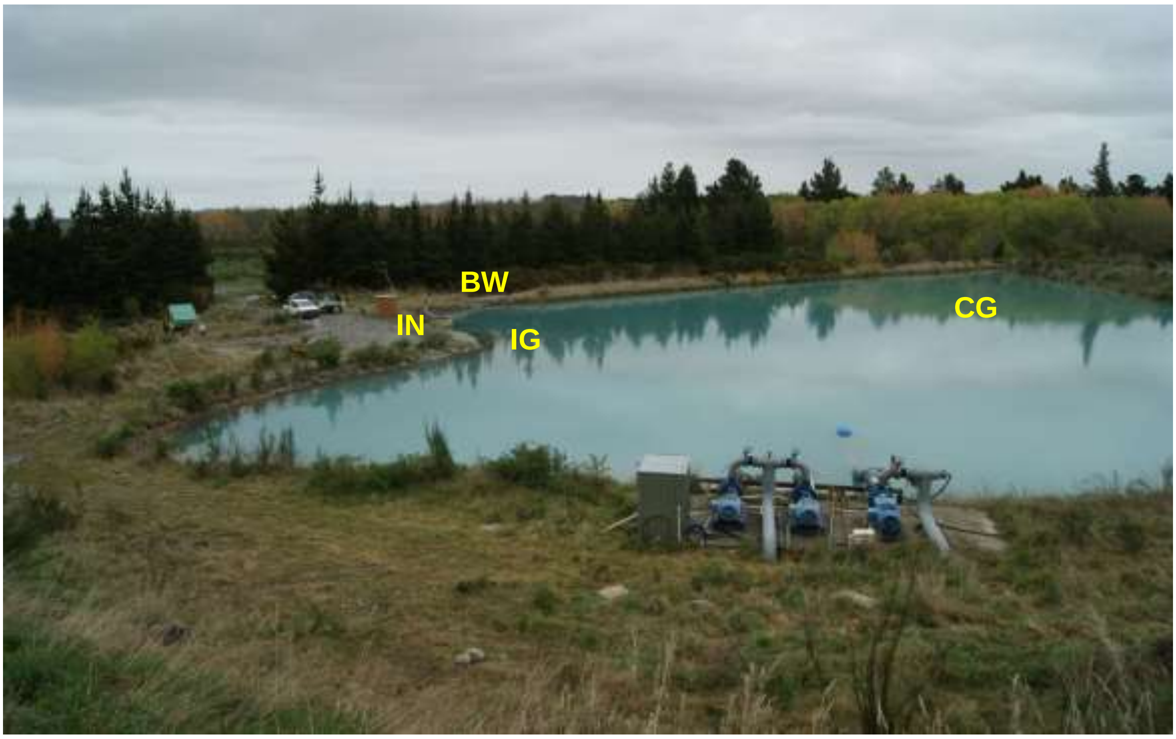

Figure 3-11:The SDC head pond. The infiltration galleries (IG) and SDC intake (IN) are situated near the vehicle seen on the left, and the bypass weir (BW) is on the edge of the pond to the right of the vehicle. In the foreground are the pumps for the Grasslands intake (not operating during this trial), and on the far right of the head pond is the control gate (CG) for water from the Rakaia River.

- A manually-operated gate between the inlet channel and the head pond, which can be used to regulate water flow into the head pond.
- A weir (adjustable using wooden "washboards") between the head pond and the bypass channel, which can be used to maintain the water level in the head pond and regulate water flow down the bypass channel. Water flowing down the bypass channel returns to a braid of the Rakaia River more than 5 km downstream.
- A remote-controlled gate structure is used to regulate the flow of water from the head pond through the infiltration gallery into the scheme intake.

The infiltration gallery comprises a layer of cobbles and small boulders (about 0.5 to 1 m deep) on top of buried galleries ("open pipes"). There are three gallery pipes, each 25 m long and made of steel mesh; the mesh has openings of 25 mm apertures. Water filters down through the cobbles and boulders into the galleries, and – when the remote-controlled gate is opened – flows into the scheme intake channel. During the trial 1.4 m^3/sec was flowing into the scheme.

Two traps were installed for this trial: The "intake" trap was installed c. 70 m downstream of the infiltration gallery, and the "bypass" trap immediately downstream of the bypass outlet control. These traps were installed before any trial fish were released, and monitored for 24 hours to determine the number of wild (i.e. non-hatchery) salmon and native fish species passing through the screen or bypass.

For the trial, 30,000 hatchery-reared juvenile Chinook salmon were released into the head pond near the intake channel control structure. After the release of trial fish, the scheme trap and bypass trap were monitored for the succeeding two days, and the numbers of fish caught in the traps was recorded at regular intervals. At the conclusion of the trial, water flow through the traps was again stopped, and electrofishing conducted in the vicinity of the traps; i.e. between bypass outlet control and the bypass trap site, and in the channel between the infiltration gallery control structure and the scheme trap.

Pre-fishing found longfinned eels, upland bullies, and brown trout in the intake channel, and brown trout, upland bully, longfinned eel, and juvenile Chinook salmon in the bypass. Adult lamprey were observed within the bypass weir structure. The presence of fish in the intake confirms some fish had been entrained into the intake under normal operating. Fish in the bypass indicated that fish were able to find and use the bypass.

The Rakaia River carries a significant amount of fine suspended sediment that settles out in intake ponds. This requires the screen to be cleaned annually or biannually depending on river condition. Cleaning involves draining the pond, using earth moving equipment to remove the gallery material so that silt can be removed to a dumping ground and then reinstating the gallery to the consistent design state with new or cleaned cobbles and boulders.

3.5.1 Findings and conclusions from the SDC trial

The SDC intake was very effective at excluding the trial fish. Of the 30,000 juvenile salmon released, a total of 6,293 (21%) were recovered over the following 47 hours; 79 (1.3%) in the scheme trap, and 6214 (98.7%) in the bypass trap. This indicates that the SDC intake was 98.7% effective as a fish exclusion structure. The capture of some (smaller) wild Chinook salmon during the trial indicated that the screen may be slightly less effective (93%) for such fish.

The fate of almost 24,000 hatchery salmon was unknown: some were seen in the head pond at the conclusion of the trial, and although some may have been eaten by predators (birds, trout, eels), or died in the head pond, it is assumed that most would eventually move downstream. This trial was undertaken with the adjacent grasslands water take not operating; at times when both schemes are operating it is possible that the bypass is less effective because of reduced flows and an additional attractant flow over to the grasslands intake.

The performance of the SDC intake screen is summarised in Table 3-7.

Table 3-7: Summary of performance of SDC intake galleries screen with respect to guideline criteria.

Criteria	Assessment	Performance
Site location	Poor	c. 1.8 km from Rakaia River.
Screen aperture size	Not assessed	Rock substrate over galleries
Approach velocity	Not measured	Rock substrate over galleries
Sweep velocity	Not measured	Rock substrate over galleries
Bypass provision	Good	Substantial bypass adjacent to intake
Bypass connection	Poor	Connected, but very long bypass channel and potentially flow lost
Operation and maintenance	Good	Rock substrates replaced every c. 2 yearly intervals, depending on conditions, bypass structure good, bypass channel poor.

Conclusions. Performed well for test fish. The effectiveness of this type of screen may be compromised by silt build-up; thus the construction, maintenance and replacement of screen substrates is critical. Approach velocity, sweep velocity, and aperture size were not able to be measured (as the screen consisted of a layer of cobbles and boulders) and were not 100% effective at preventing entrainment.

Improvements could be achieved by:

- Fish salvage when the intake is drawn down to remove silt and replace boulders and cobbles, as fish are being entrained into the pond, intake and bypass.
- Modifying the bypass channel to make the return to the Rakaia River shorter and more direct.

3.6 Acton Intake

This study took place at the Acton Irrigation Scheme intake on the southern bank of the Rakaia River, near the Rakaia township, Canterbury (Bonnett 2013b). This is a large intake (maximum rate of abstraction 3.3 m^3/sec) which utilises a permeable rock bund between the supply and intake channels. Water is diverted from an active braid of the Rakaia River and is passed along the bund, which is c. 100 m long, c. 3 m wide at the base and <0.5 m wide at water level, and composed of rocks and boulders from c. 100 mm to 500 mm in diameter (Figures 3-12 and 3-13). Some water passes through the bund into the intake channel, while the remainder is bypassed down the supply channel / bypass channel.

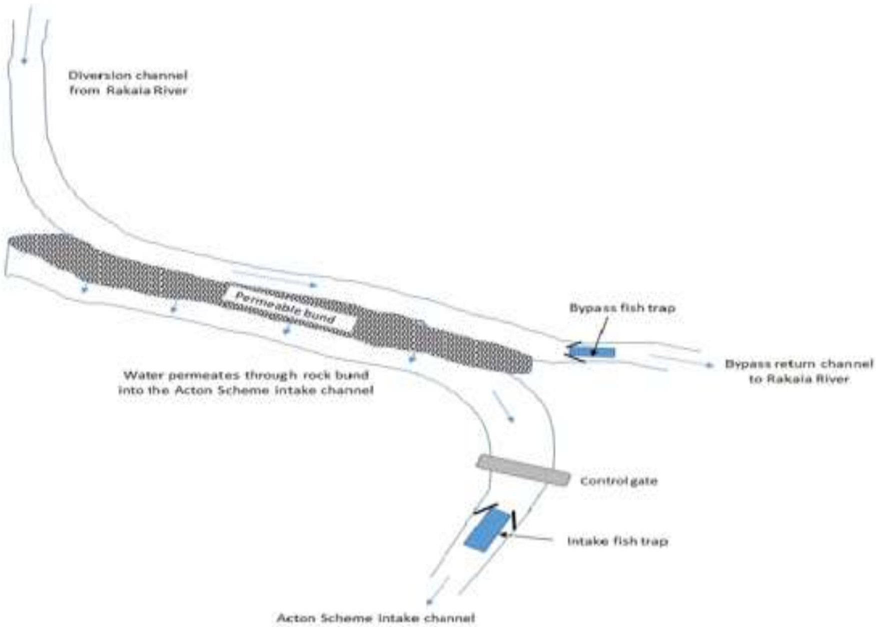

Figure 3-12:Sketch of the trial set-up at the Acton intake.

Figure 3-13:The permeable rock bund at the Acton intake, photographed looking upstream and with low supply channel water levels and scheme not operating (dewatered). The diversion channel supplying water can be seen to the right of the photograph, and the scheme intake channel to the left.

Fish traps were installed on the intake channel and bypass channel and 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 for about 40 hours – the traps were inspected regularly throughout this time, and the numbers of all fish of all species caught in the traps were recorded.

3.6.1 Results

In addition to Chinook salmon trial fish, substantial numbers of torrentfish and bluegill bullies were caught during this trial. The trap on the bypass channel was washed out for a few hours by high flows during the trial, and catch data for this period is not included for the estimates of effectiveness (Table 3-8).

Table 3-8: Catch of fish in the bypass and intake traps, and effectiveness of screening for the three main species observed.

Species	Catch in bypass trap	Catch in intake trap	Screen effectiveness (%)
Chinook salmon	2235	112	95.2
Torrentfish	387	10	97.5
Bluegill bully	231	403	36.4

3.6.2 Findings and conclusions from the Acton trial

The trials demonstrated that the permeable bund at the Acton intake was effective for Chinook salmon (95.2%) and torrentfish (97.5%), and ineffective for bluegill bullies (36.4%). Comparison of the length frequency of Chinook salmon caught in the two traps clearly indicated that small (<40 mm) salmon were more vulnerable to passing through the permeable bund than larger fish.

The capture of torrentfish and bluegill bullies coincided with an increased flow in the Rakaia River. Both species of fish are migratory and relatively common in the river, and normally progress steadily upstream as they grow; however a few of the fish were encountered in the traps during periods of normal flow in the river. The greater numbers caught during the period of high river flow indicates that these fish had been displaced from upstream of the intake by flooding, or may have been migrating downstream as part of their lifecycle. Many bluegill bullies penetrated through the bund, whereas only a few torrentfish did so; this is probably because bluegill bullies favour the sheltered crevice habitat created by the bund more than torrentfish. In surveys of the Rangitata River, Bonnett (1986) described the habitat in which bluegill bullies were often found as “the boulders making up steep banks in deep, fast-flowing runs”. Once within the bund, a high proportion of the bluegill bullies were presumably “drawn through” into the intake channel.

The maintenance of this bund consists of periodic de-silting by deconstructing, flushing and then reconstructing again. This occurs two to three times per season depending on river conditions. Silt, leaves and other debris become trapped in the gaps affecting the screen performance and water flow.

The performance of the Acton intake is summarised in Table 3-9.

Table 3-9: Summary of performance of the Acton intake permeable bund with respect to guideline criteria.

Criteria	Assessment	Performance
Site location	Poor	c. 1 km from Rakaia River
Screen aperture size	Not assessed	Rock substrate in bund
Approach velocity	Not measured	Rock substrate in bund
Sweep velocity	Not measured	Probably good, as velocity in supply/bypass channel was c. 0.19 m/sec
Bypass provision	Good	Supply channel becomes large bypass at bund
Bypass connection	Ok	Connected, but long bypass channel which supplies a further intake
Operation and maintenance	Ok	Bund needs to be rebuilt often to counter silt build-up

Conclusions. Effective for preventing entrainment of juvenile salmon and torrentfish, poor for bluegill bullies. The frequency and timing of "rebuilding" the bund is of concern, as at these times the screen is not operating and fish may be entrained into the scheme. Improvements could be achieved by:

- Making a more direct (shorter) bypass route to the main river.
- Screening additional intakes from the supply channel.
- Considering turning the scheme off during peak flows during key migration periods for at risk species e.g., bluegill bully.
- Considering whether fish salvage is required when undertaking maintenance of bund.

4 Discussion

Six trials of fish exclusion at various irrigation intakes were summarised in the previous sections (3.1 to 3.6). This section reviews each of the criteria specified by the 2007 Guidelines (Jamieson et al. 2007) with respect to what has been learnt from all the trials.

4.1 Site location

The main site location issue is whether the intake and its associated fish exclusion structure is installed at, or as close as practical to, the point of water diversion from the main stem of the river. This is an important factor in minimising environmental effects, but has to be balanced with the need to protect the structure from flood events. Having the intake and screen close to the edge of the river, or even within the river, minimises the exposure of fish to risks that may occur within intake channels and bypass systems; risks that include loss from predatory fish and birds establishing in the intake, desiccation when flows are reduced, and mechanical damage when fish are transported through or over flow-control structures. Furthermore, water that is diverted through an intake bypass system is water that is not available to maintain in-river ecological and recreational values; this is especially so in small rivers, where the diversion of water for fishes might require a significant proportion of the river flow.

None of the intakes investigated during these studies was positioned in-river, and they ranged from close to the river for the Totara Valley intake (c. 150 m from the Opihi River), to distant for the SDC intake (where the intake channel was c. 1.8 km long). They either utilised an intake settling pond or an offtake from an actively flowing race.

Overall, site location is a very relevant criterion identified in the 2007 Guidelines, as a good site location will promote good design attributes, particularly with respect to the length of intake, potential for fish entrapment and predation, and effectiveness of bypass channels.

4.1.1 Site location and cumulative losses at intakes

Another important aspect of site location is the potential for cumulative losses when fish moving through a river system encounter a series of intakes; although each of the intakes may be effective at excluding most fish, the small loss of fish at each intake in succession may result in a significantly large cumulative total loss. To illustrate this, Table 4-1 outlines the cumulative loss when fish successively encounter a series of intake screens (of various effectiveness) as they move through the river. In an extreme case, if fish encounter a series of three screens that are each only 50% effective (i.e., half of the fish are lost at each screen), the total cumulative loss is 87%, and only 13% of the fish remain (Table 4.1, 50% column). So the series of three screens is equivalent to one screen operating at only 13% effectiveness.

Even in a situation where fish encounter a succession of intakes of relatively high effectiveness (e.g., 95%), after encountering five such intakes only 77% of the fish remain; cumulative loss is 23%, or the equivalent of one screen operating at 77% effectiveness (Table 4.1, 95% column).

These figures illustrate that loss is cumulative, and that both the effectiveness of each screen, and the number of such screens encountered in succession, have a bearing on the overall loss in a river. Thus the location of intakes and effective fish screens is particularly relevant in rivers where there are multiple intakes, particularly in situations where several intakes are supplied by one diversion channel.

Table 4-1: Combined screening effectiveness of fish screens, illustrating potential cumulative loss of fish as they are exposed to a succession of screens. The numbers represent total percentage effectiveness (survival) of fish, rounded to the nearest whole number; reading down the columns illustrates how total effectiveness decreases with the number of screens in succession. Figures in shaded cells are examples referred to in the text.

		Effectiveness (efficiency) of individual fish screens.										
		10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	99%
No. of screens in succession	1	10	20	30	40	50	60	70	80	90	95	99
	2	1	4	9	16	25	36	49	64	81	90	98
	3	0	1	3	6	13	22	34	51	73	86	97
	4	0	0	1	3	6	13	24	41	66	82	96
	5	0	0	0	1	3	8	17	33	59	77	95

Overall, it is much more effective from a fish-screening perspective to have one effective screen on a diversion at or near the near the source river, rather than to subject fish to a succession of screened intakes off the diversion channel.

4.2 Screen apertures

Apertures in the screening material/matrix not only need to be small enough to prevent fish from penetrating the screen and becoming entrained in the irrigation system, but also need to be small enough to prevent fish becoming stuck or “gilled” in the aperture. For this reason the maximum aperture size (3 mm side-of-square or 2 mm bar width) recommended in the 2007 Guidelines is based on the head size of juvenile salmon and trout, as well as suggested apertures for the size of native fish by Charteris and Hamblett (2006).

The investigation of the Mead Intake screen indicated that 5 mm aperture mesh on the rotary drum was small enough to exclude Chinook salmon of about 80 mm in length, but not small enough to exclude juvenile rainbow trout of about 30 mm in length. However, this was not a legitimate test of aperture size, as the trial was probably compromised by ineffective sealing between the mesh-covered drum and the concrete surfaces of the channel that allowed the passage of fish.

The Levels Plain scheme utilised 18 screen panels; 17 with 3 mm mesh, and one with 5 mm mesh. Some of the small (c. 30 mm long) rainbow trout used in the trial penetrated through the screen, however it could not be established whether these had penetrated the mesh or moved through small gaps underneath the screens. The larger (c. 110 mm) Chinook salmon in the trial were not observed to penetrate the screen.

The inner flat-plate screen at the Totara Valley Scheme intake had apertures of 3 mm diameter; this was probably effective at preventing the passage of fish through the screen, however this test was also compromised by ineffective sealing around the screen (it was thought that the rubber gasket between the metal screens and the concrete base provided an unscreened route for water and fish).

Aperture size was not able to be measured for the trials at the NOIC, SDC, and Acton intakes, as these screens comprised mixtures of various gravels and boulders.

The maximum aperture size (3 mm side-of-square or 2 mm bar width) recommended in the (2007) Guidelines was not conclusively tested by these trials, but otherwise remains appropriate for conventional mesh or plate screens, as it will prevent the passage of most juvenile salmonids and native fish.

4.3 Approach velocity

The term "approach velocity" refers to the speed of water onto and through the screen; the Guidelines outline the need for approach velocity to be low enough for fish to escape the screen by swimming upstream against the flow. Although there are several factors affecting the swimming speed that fish can maintain, the most critical is the size of the fish; the "rule of thumb" is that a fish can maintain an active swimming speed of four times its length every second (Clay 1995). So fish of 30 mm in length can maintain a swimming speed of (4 x 30) = 120 mm per second, or 0.12 m sec^{-1} for short periods of time.

At the Levels Plain intake screen, measured approach velocity ranged from 0.312 to 0.536 m sec^{-1}, with an average of 0.436 m sec^{-1}. At the Mead intake, the mean approach velocity was greater than 0.4 m sec^{-1}. These velocities are 3 or 4 times greater than recommended, and fish less than 100 mm in length would be unable to sustain a sufficient swimming speed to escape. This was corroborated by observations of many 80 mm long Chinook salmon becoming exhausted and becoming impinged against the screen of the Mead intake. This observation was made when water temperature was also so high as to detrimentally affect the fishes swimming ability; however these were relatively large fish, and it is highly unlikely that fish of 30 to 50 mm in length could escape upstream against a flow of 0.4 m sec^{-1} at any water temperature.

Approach velocity was not measured at the Totara Valley intake screen, but was estimated from gauged flow and known dimensions of the screen to have been c. 0.15 m sec^{-1}. This is slightly greater than the recommended approach velocity, but was probably low enough to allow the short term escape of most sports fish used in the trial.

It was not practical to measure or estimate the approach velocity of water moving down or through the infiltration galleries or bunds at the SDC or Acton intakes, however, the performance of the screens for hatchery-reared salmon used in these trials (> 95 % effectiveness) suggests water velocities were mostly close to the recommended Guidelines. At the SDC intake, the surface area above the galleries was c. 45 m^2 for a maximum take of 1.4 m^3sec^{-1}, which equates to 32 m^2 surface area per 1.0 m^3sec^{-1} of take. The Acton rock bund provides a surface area of c. 330 m^2 for a maximum take of 3.3 $m^3sec\text{-}^1$, which equates to 100 m^2 of surface per 1.0 m^3sec^{-1} of take. It must be noted that both infiltration gallery and rock bund screens are subject to the deposition of silt amongst the substrates during operation; this will reduce the effective open area of the screen and increase water velocities through the screen, and regular maintenance to remove the silt is required.

Measured approach velocities of 0.4 m/s caused significant impingement on at least one tested screen. It is concluded that the maximum approach velocity (0.12 m sec^{-1}) recommended in the 2007 Guidelines by Jamieson et al. (2007) is appropriate for fish screens at intakes, as it will allow small (30 mm long) fish to escape from the screen.

4.4 Sweep velocity

The term “sweep velocity” refers to the speed of water across the face of a screen (i.e. at right-angles to the approach velocity) to promote the transport of fish toward a bypass. The sweep velocity across a screen should be at least as fast as the approach velocity, and preferably even faster.

Sweep velocity was not measured at the trial of the Levels Plain intake, however it was probably somewhere between 0.2 and 0.55 m sec^{-1} (based on measurements made by ECan in 2005 and 2006). If this was the case then the sweep velocity could be considered as barely acceptable, being both below and similar to the approach velocity at the site (0.312 to 0.536 m sec^{-1}).

It was not possible to discern or measure any sweep velocity across the screens at either the Mead intake or Totara Valley intake trials. At both sites the bypass was some distance from the screen, and the flow of water down the bypass was insufficient to provide a sweeping flow. At the Mead intake the bypass was 3.2 m upstream of the screen, and had a flow of about 0.005 m^3sec^{-1} (about 0.8% of the 0.406 m^3sec^{-1} flow through the screen); at the Totara Valley intake, the bypass was more than 10 m away from the screen and had a flow of about 0.001 m^3sec^{-1} (about 0.2% of the 0.486 m^3sec^{-1} flow through the screen). The absence of a sweep velocity at the Mead installation contributed to fish entrapment, exhaustion and death.

It was not practical to measure sweep velocity at the SDC intake site, and there was no discernable sweep velocity towards the bypass channel entrance (more than 10 m away).

From the SDC trial, and to a lesser extent the Totara valley trial, it may be deduced that a sweep velocity per se is unnecessary, and all that is required is a bypass flow to transport fish back to the river of origin. However, without a sweep flow “guiding” fish into the bypass, fish may accumulate upstream of the screen and risk long term exercise stress or mortality, predation, effects of poor water quality, damage associated with screen cleaning brushes etc., and lack of food.

So overall, while there was no consistent evidence that the requirement for sweep velocity across a fish screen should be a mandatory guideline, in most situations having a flow of water to sweep fish away from an intake, and towards a bypass, should enhance the overall effectiveness of a screen and minimise stress and mortality for salmonids and native fish.

4.5 Bypass provision

There are several aspects of fish bypass design and operation which are important for excluding fish from intakes:

- A bypass has to be provided if fish are removed from the main body of the river; excluding fish from an intake is pointless if the fish are not returned to the source river.
- Fish need to be able to “find” the bypass; this is best achieved by having the bypass close to the screen/intake, and with a substantial amount of water flowing across the screen and into the bypass. A sweep flow across a screen should help to “guide” fish naturally into a bypass.
- For salmon and trout, it is important that the bypass entrance is a well-lit or open-topped channel, as many fish will avoid pipes, small culverts and dark entrances.

- A bypass should include a "non-return" function, so that once a fish is drawn into the bypass it cannot return to the screen. Fish can be prevented from swimming upstream through the bypass by areas of fast-flowing water, or by having the bypass flow "free-falling" into a pool (as occurs at a perched culvert).

In the six investigations of screens at intakes, the bypasses provided ranged from being unsuitably small, poorly sited, and poorly designed, as at the Totara Valley and Mead intakes, to large channels, as at the SDC and Acton intakes.

The 2007 Guidelines for bypass provision by Jamieson et al. (2007) are appropriate for fish screens at intakes. The bypass is probably the most critical feature for fish screening at intakes; even if all other guideline criteria are met, the screen won't be effective unless the screened fish are safely and promptly bypassed back to the river.

4.6 Bypass connectivity

A bypass on an intake needs to return fish back to the river of origin promptly and safely; this requires that the bypass channel:

- Is connected to the river.
- Has sufficient flow to maintain water quality (water temperature, dissolved oxygen) and to ensure that fish are not subjected to desiccation.
- Isas short and direct as possible, to minimise the risk of predation by birds, trout and eels.

Only the Levels Plain intake appeared to have suitable connectivity with the river of origin; other intakes ranged from "not connected at all" to "connected but with a very long bypass channel".

In conclusion, the 2007Guidelines for bypass connectivity by Jamieson et al. (2007) are appropriate for fish screens at intakes; the intake screen won't be effective unless the screened fish are quickly and safely returned to the river.

4.7 Operation and maintenance

The series of trials in Canterbury have shown that poor construction, maintenance, and operation of fish screen facilities undoubtedly greatly reduced their effectiveness at excluding fish. For example:

- At the Mead intake, many fish either penetrated the 5 mm mesh on the rotary drum screen or passed around the screen because the seals on the side and bottom of the screen were not operating correctly. Fish that utilised the bypass were not successfully returned to the river of origin, because the bypass channel had not been maintained.
- At the Totara Valley intake, many fish passed into the scheme intake, probably by utilising gaps between the rubber flange and the concrete base. Other fish were lost because they were swept onto the bank as 'trash' above the screen by the moving brushes and screens. The bypass channel was operating with a very small flow, and was unlikely to return fish safely to the river of origin.

- At the SDC intake, the bypass channel had a good flow of water during the trial, but the channel was not properly maintained and meandered across the flood plain of the Rakaia River for about 5 km before joining a braid of the river. This would have exposed fish to risks from desiccation, changes in water quality, and predation by birds. Risks would be exacerbated if – at some times - less water flowed in the bypass channel.
- At the Acton intake, the bypass channel was too long, and much of the flow was dissipated before it returned to the Rakaia River. As for the SDC intake, this would probably have exposed fish to risks from desiccation, changes in water quality, and predation.

In conclusion, the operation and maintenance of the screens investigated was mostly poor, especially with respect to the maintenance of bypass channel connectivity; the criteria as recommended in the Guidelines by Jamieson et al. (2007) are appropriate for fish screens at intakes.

4.7.1 Consideration of sediment build-up

Many of the irrigation and stockwater intakes in Canterbury use water from rivers with high sediment loads, and the deposition of sediment within or near many intake screens is a significant operational and maintenance issue. This is particularly so for infiltration galleries and permeable rock bunds, where the deposition of silt amongst the substrates which form the screen may greatly reduce the permeability of the screen.

One design approach is to incorporate settling ponds upstream of the screen to allow some sediment to settle out prior to contact with the screen. Settling ponds, however, also “hold” fish; not only are fish kept away from the river, but they may be exposed to sub-optimal conditions (poorer water quality, less food) and to increased risk of predation (by birds, eels, and large trout).Settling ponds may also provide good conditions for nuisance growths of weeds and algae.

Sediment usually has to be periodically removed from settling ponds; this may require drainage of the pond and the use of earth-moving machinery and/or deconstruction and subsequent reconstruction of the layer of cobbles and boulders forming the screen. Similarly, the build-up of sediment within permeable bunds may require the bunds to be deconstructed and reconstructed.

Overall, sediment build-up in infiltration galleries and permeable bunds may require frequent and substantial maintenance to maintain screen performance, reduce outages, and avoid issues with consistent reconstruction.

5 Conclusions and recommendations

The investigations of fish screens at six operating intakes in Canterbury have shown that:

- The (2007) Guidelines are appropriate for excluding juvenile salmon and trout from intakes in our rivers. This acknowledges that these fish are pelagic, schooling fish that avoid dark crevice environments. The design criteria for salmonids are therefore well established.
- At conventional intake screens (e.g., flat screens, rotary drums) the 2007 Guidelines are also appropriate for most native fish. Trials conducted on intakes that utilised "behavioural" barriers (e.g., infiltration galleries, permeable bunds) to screen fish demonstrated that these types of screen effectively exclude most juvenile salmon, but are less effective for very small salmon/trout and ineffective for some native fish. It is recommended that further information on responses of native fish to fish exclusion criteria are investigated, and the life cycles, distribution, migratory habits, swimming ability, and size of native fish in New Zealand rivers is made available, and/or commissioned to ensure that design considerations, and the 2007 Guidelines, are entirely appropriate for protecting native fish communities also.
- The provision, design and connection of suitable bypass facilities are probably the most critical features of an effective fish screen; in simple terms, a bypass without a screen will be more effective than a screen without a bypass. The minimum quantity of water required to provide and maintain an effective bypass has not been determined, and there is no rule of thumb specifying the bypass flow as some proportion of total flow into an intake. Such a rule would be difficult to establish, simply because conditions will vary from site to site; all the work to date underlines the importance of bypasses, and emphasises the need to have as much water as possible flowing through a bypass in order to create a sweep velocity, move fish promptly away from the screen, and maintain a good channel to return fish to the river of origin.
- The operating trials on fish screens clearly demonstrated that careful construction/implementation, maintenance, and operation of screens are also critical for achieving effective fish screening. Several of the intake screens tested were poorly operated and maintained – if they had been better operated (e.g., better seals on the rotary drum screen; better fit of the ANDAR screen onto its base) these trials would have been more conclusive and meaningful.
- Lessons learnt through these trials should be considered when designing new fish screens at intakes; novel designs need adequate monitoring to ensure intakes are effectively meeting exclusion targets. Based on the conclusions from section 4, it is recommended that:

    a. The location of the intake screen is as close as practical to the point of take, to limit water abstracted and fish diverted away from the main stem. Amalgamation of takes should be undertaken wherever possible to avoid cumulative losses and ensure physical and cost effectiveness of screens.

b. Careful construction and maintenance is critical, and further impetus needs to be put on requiring consent holders to maintain the design accepted in consent (monitoring).

c. When establishing new intakes it is useful to identify ecological values in the area, and determine the risks at the proposed location before confirming the screen design.

6 Acknowledgements

This research was funded by MAF Sustainable Farming Fund, and the work is mostly the result of the efforts of the Canterbury fish exclusion working party: Paul Reese (Irrigation New Zealand), Mark Webb and Hamish Stevens (Central South Island Fish and Game Council), Nicolas Dunn, Dave West, and Sjaan Bowie (Department of Conservation), Mary Beech, Patrick Lees, and Adrian Meredith (Environment Canterbury). Many thanks also to the irrigators and landowners for making their facilities available for trials, as well as for their local knowledge and much valuable information on intake operation and maintenance.

Report availability:

All reports are available on the Irrigation NZ website http://www.irrigationnz.co.nz/.

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