Fish & Game
NEW ZEALAND

6 July 2018

Greg Martin
Arrowsmith Law Limited
163 West Street
ASHBURTON 7700

Dear Mr Martin

We respond to your requests for information and documentation as follows:

1. The product of the testing of the fish screen of Rangitata Water Limited ("RWL")

We **attach** the report of that testing entitled "A trial of the effectiveness of a permeable rock bund for excluding fish at the Rangitata Water Limited intake" dated July 2018.

2. Whether RWL has made any financial contribution to the costs of this testing programme

RWL contributed to materials and construction for fish traps, labour of 2 RWL personnel over the course of the trial, and supporting machine costs over the course of the trial. RWL has not otherwise made payment to Central South Island Fish and Game for the testing of the rock bund.

3. Confirmation as to whether the product of the testing has been provided to RWL

The report attached and referred to at (1) above has been provided to RWL.

4. Adam Daniel's review of the Acton Fish Screen trial

We **attach** a copy of an email received from Adam Daniel on 16 December 2016.

Yours faithfully

J P Graybill
Chief Executive

Statutory managers of freshwater sports fish, game birds and their habitats

Central South Island Region

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A trial of the effectiveness of a permeable rock bund for excluding fish at the Rangitata Water Limited intake

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July 2018

1. Introduction

Rangitata Water Limited (RWL) operate a large irrigation intake on the south bank of the Rangitata River approximately 500m upstream from the Arundel Bridge on SH72. The scheme is consented to take up to 20 m^3/s from the Rangitata River when flows exceed 110 m^3/s as measured at the Environment Canterbury flow recording site at Klondyke approximately 20km upstream.

Water is diverted from a natural braid of the Rangitata River into a channel that has a number of high flow return exits to the river before entering the intake where water passes along the face of an "S" shaped permeable rock bund. The bund is approximately 600m long and 15m wide at the base and composed of boulders ranging in diameter from approximately 200mm to 400mm. In normal operating conditions the bund is approximately 4m wide at water surface level and about 1.5m of bund is exposed above the water level. Automatic gates within the scheme regulate water flow along the river side of the bund and through the bund into the scheme. Water not taken into the scheme stays on the river side of the bund and is bypassed back to the Rangitata River. The bypass flow is typically 4 m^3/s to 8 m^3/s.

A rock bund structure is considered to be a behavioural barrier for brown trout and Chinook salmon. Juvenile salmonids are believed to avoid dark holes and fissures most probably because of the association with predators that may occupy those spaces. If salmonid behaviour is to stay away from the rock bund then they are more likely to be bypassed back to the river than pass through the bund provided water velocities allow for that path and a bypass channel exists.

Reported incidents of juvenile salmon within the RWL scheme downstream of the rock bund from 2015 prompted the owner of the scheme to ask Central South Island Fish and Game (CSIFG) to investigate the effectiveness of the rock bund. End of season pumping of drop structures, syphons and ponds by the scheme's staff in 2015 and 2016 had confirmed the presence of salmon up to two years of age within the scheme. These captures do not identify the population of salmon that came into the vicinity of the bund, that is, came into the area of influence of the scheme intake. Nor do they identify the population of salmon that may have been present within the scheme over the salmon migration season. To be able to estimate the efficiency of the bund from capture of a sample of wild salmon within the scheme, the total numbers of both the number of fish in the vicinity of the scheme and the number within the scheme need to be known for the migration season.

To obtain an estimate of bund efficiency based on wild salmon presence and capture is a significant undertaking. CSIFG completed a similar exercise in the Rangitata Diversion Race (RDR) in the 1998/99 irrigation season to estimate the number of salmon diverted from the Rangitata River by the 30 m^3/s scheme intake. This required random sampling of 130 sites within the scheme using 8 traps fished for almost 4,000 hours over 7 months and sampled 4.5 million cubic meters of scheme water.

An adaptation of this survey technique is to release a known number of test fish upstream of the diversion structure and recapture them at key downstream sites to identify the efficiency of the fish diversion structure. Recapture of test fish in the bypass is an indication of fish successfully returned to the river, while those recaptured within the scheme are an indication of fish passing through the diversion structure and not returned to the river. This was the technique used for the RWL trial.

2. Aim

To estimate the fish diversion efficiency of the RWL permeable rock bund for hatchery-origin juvenile salmon of 120mm to 180mm length and assess the general exclusion of wild salmonids and native fish from entering the RWL scheme.

3. Field Method

In the absence of large numbers of downstream migrating wild juvenile salmon, this trial required releases of known numbers of identifiable hatchery-origin juvenile salmon at various sites within and outside the RWL intake and permeable rock bund. Released fish were recaptured in traps at other sites to identify likely behaviour of the fish in reaction to the permeable rock bund and to ultimately identify a fish diversion efficiency.

Previous experience using inclined-plane fish traps to monitor juvenile salmon passage at a variety of irrigation scheme intakes in Canterbury has shown that existing traps could sample flows of between 0.2 m^3/s and 1.4 m^3/s provided the source water was not from a river in flood.

The RWL scheme is consented to take high flow water from the Rangitata River and store it for later distribution. In normal operation it takes up to 20 m^3/s into the scheme when the Rangitata River at Klondyke is between 110 m^3/s and 130m^3/s and bypasses an additional 4 m^3/s to 8 m^3/s back to the river. At these flows the river is at least in a state of fresh or more often in flood and can be discoloured and carrying significant debris.

To test the capability of existing traps under normal RWL scheme operating conditions the largest trap, capable of passing 1.4m^3/s, was installed in the scheme main race on 27 March 2017 following prediction that rainfall in the Rangitata headwaters earlier that day would cause the river to rise and RWL would be able to take 20m^3/s into the scheme. By 10pm that night the scheme was taking 20m^3/s and the fish trap sampling approximately 1.38 m^3/s or 6.9% of that flow, required continuous cleaning to maintain it in operating condition. This meant that continuous monitoring of multiple traps for up to 10 days under normal operating flows for the RWL scheme exceeded the capabilities of equipment and manpower to maintain. An alternative strategy was needed.

RWL operate a water swap agreement with neighbouring RDR irrigation scheme that allows the unused allocation of one scheme to be utilised by the other if the donor scheme agrees. RDR resource consents provide for the taking of Rangitata River water when the flow in the Rangitata at Klondyke is greater than 20m^3/s such that 20m^3/s may be taken by RDR in flows up to 40m^3/s at Klondyke, and above that there is a 1:1 sharing of flows up to a maximum of 33m^3/s abstraction. Rangitata River flows at Klondyke less than 70m^3/s are generally clear and suspended debris should be much less than in flows over 110m^3/s.

RWL approached RDR to identify any opportunities when RDR would not be taking their full allocation to enable RWL to take water in the clearer river flow range, below 110m^3/s at Klondyke. RDR responded that their intake would be shut down for maintenance from 3 May until 17 May 2017. Constraints on RWL using this water for the monitoring programme were that there was a 14-day window of availability and RWL needed to find sufficient storage within their scheme for any water taken. RWL advised that if they operated their intake flow in the range of 10m^3/s to 13m^3/s starting on 7 May they would be able to maintain that for approximately eight days and at the same time provide bypass and other flows at sampling sites around the intake.

Four sites were identified for trap placement (Figure 1). These covered all possible downstream avenues for fish passage, and required monitoring for fish movements:

River – The small flow of water that provided a safety overflow back to the river for water that did not enter the scheme intake. Wild and released salmon and other fish could potentially take this route back to the Rangitata River before encountering the rock bund or by swimming back upstream from the intake. Flow in this channel was likely to be around 0.7m^3/s. At the trapping site the channel was about 4m wide and the trap covered 0.98m of this width or about one-quarter of the channel width.

Bypass – The main return route back to the river for fish successfully retained on the river side of the rock bund. Once in the return channel juvenile salmon would not be able to swim back upstream to the scheme intake due to a velocity barrier in the bypass channel culvert producing velocities in the order of 6m/s. Flow in this channel was likely to be around $3m^3/s$. At the trapping site the channel was about 12.5m wide and the trap covered 2.0m of this width or about one-sixth of the channel width.

Pond 1 – The intake to Pond 1 within the scheme. This site could contain a proportion of fish that may have passed through the bund and entered the scheme. Flow in this channel was likely to be around $2m^3/s$. At the trapping site the channel was about 7.5m wide and the trap covered 1.47m of this width or about one-fifth of the channel width.

Main Race – The main channel within the scheme downstream of the Pond 1 offtake. This site could contain a proportion of the fish that may have passed through the bund and entered the scheme minus the proportion diverted into Pond 1. Flow in this channel was likely to be around $10m^3/s$. At the trapping site the channel was about 29m wide and the trap covered 1.95m of this width or about one-fifteenth of the channel width.

Pond 1 and Main Race Trap sites provided two samples of the same water, both sampled the Main Race downstream from the permeable rock bund.

The location of trap sites and salmon release sites around the RWL intake and Main Race are shown in Figure 1. Site locations and flows are indicative only and not to scale. Photographs of each trap and trap site are provided in Appendix 1.

The reason for trapping four sites was to record the passage of released fish in the different routes fish could take through and past the RWL intake. The main salmon release would be of approximately 8,500 fish about 100m upstream of the intake and these fish would have several options available to them:

i. Released fish could avoid the RWL intake by passing down the River channel where a proportion would be caught in the River Trap.
ii. Released fish could turn into the RWL intake and not pass through the rock bund. They would exit the scheme through the Bypass where a proportion would be caught in the Bypass Trap on their way back to the Rangitata River.
iii. Released fish could pass through the rock bund and be taken into the Main Race, where a proportion could be caught in the Pond 1 and Main Race Traps. The efficiency of the rock bund at diverting fish back to the Rangitata River would be the sum of fish successfully diverted back to the river in the River and Bypass channels divided by the sum of fish estimated to have passed down the River, Bypass, Pond 1, and Main Race channels.

At each of the four RWL trapping sites, each trap sampled a different proportion of channel width and channel flow and it was expected these proportions could change in response to the natural changes in Rangitata River flow over the course of the trial. Flow relationships between trap sites could also change if scheme control gates were altered. Changes in flow conditions at all trap sites were monitored by measurement of channel widths and gauging of trap and channel flows at least twice a day, generally morning and evening.

Four inclined-plane fish traps constructed of 3.2mm aperture stainless mesh were installed at the River, Bypass, Pond 1, and Main Race sites between 1800hs on 7 May and 0800hs 8 May 2017. Traps were monitored continuously at one- to five-hour intervals depending on debris accumulation until their removal between 1130hs and 1500hs on 14 May.

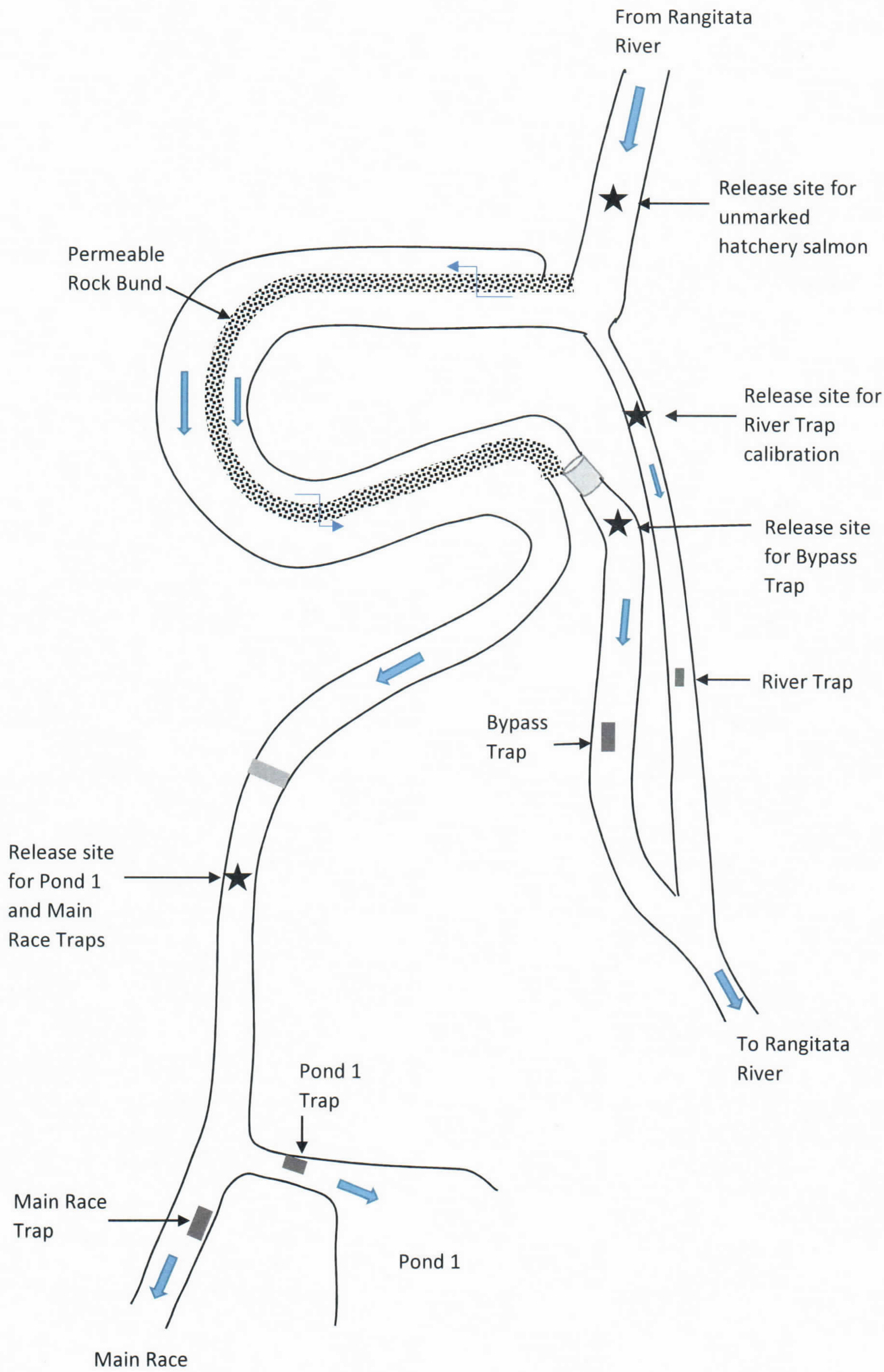


Figure 1. Flow distribution and location of inclined-plane fish traps and salmon release sites around the intake of the RWL scheme. Not to scale.

River and Bypass traps were run overnight on 7/8 May to identify any background native fish and salmonid movements around the RWL intake prior to release of any hatchery-origin juvenile salmon. First releases of marked fish for calibration of each trap were made between 1130hs and 1720hs on 8 May, followed by the main release upstream of the intake between 1550hs and 1745hs on 9 May (Table 1). The final calibration release of marked fish was completed between 1219hs and 1250hs on 11 May. Where possible, releases were made into the centre of the receiving channel. The main upstream release required use of a release tank moored mid-river in which fish were first acclimatised after transfer from the hatchery. These fish were released late in the day to more closely reflect timing of wild juvenile salmon migration.

Table 1. Release sites, timing, number of fish and marking type for hatchery-origin salmon released during trap calibration and rock bund trials in the RWL scheme.

Date	Time	Site	Distance	Number	Fin Clip	Purpose
8 May	1130	Bypass	60m abv trap	1,044	Adipose	Calibration
	1150	River	150m abv trap	1,013	Adipose	Calibration
	1720	MR + Pond 1	600m abv traps	918	Adipose	Calibration
9 May	1550 -1745	Above Intake	100m abv	8,519	None	Main upstm release
11 May	1219	Bypass	60m abv trap	495	Left Pelvic	Calibration
	1230	River	90m abv trap	529	Left Pelvic	Calibration
	1250	MR + Pond 1	130m abv traps	592	Left Pelvic	Calibration

For each of the calibration releases a different batch fin clip was used. Fin clipping had been completed 12 days prior to release and all hatchery fish used were taken from the same raceway. A sample of these were measured to identify the length distribution of test fish. Release sites for each trap-specific calibration were sufficiently separated to minimise any mixing of fish with those from other sites that were released at the same time. The second calibration release on 11 May was made at the same sites as those for the first calibration release and required use of a different mark to enable separate identification of these fish. The main release 50m upstream from the intake, was of hatchery fish that were not fin clipped or marked in any way. CSIFG staff consider experience gained during RDR trapping where wild and fin-clipped hatchery fish were present, enabled visual separation of wild and hatchery fish based on size, condition factor and colour. Hatchery fish were identified as being longer and fatter on average than wild fish, and wild fish were uniformly silver and bright in colouration where hatchery fish were darker.

In addition to moving downstream from the release sites through the four channels where there were fish traps, released salmon could avoid detection by: remaining near the release sites; or they could swim upstream; or they could move downstream and actively avoid capture in the fish traps. To identify any released fish that chose not to move downstream, at the end of the trial the River and Bypass channels were drained and electric fished. It was not possible to confirm if any released salmon moved upstream from the main release site or the river release site or the main race release site however results from similar trapping programmes in the RDR confirmed that released fish moved downstream, they did so quite soon after release - usually within 5 days and there did not appear to be evidence of trap avoidance. More than 45 long-term (>7 days) and short-term (<5 days) release and recapture trials completed at the RDR intake between 2008 and 2016 found that greater than 90% of all hatchery-origin juvenile salmon released in the RDR race moved downstream. In these trials salmon were released between 100m and 1,200m upstream of the trap and were recaptured within 105hrs of release. In these RDR trials the fish capture trap operated continuously so any long-term residency and late downstream movement by released fish would have been detected.

On 14 May when scheme storage ponds were close to full, Pond 1 and Main Race flows were significantly reduced, and River and Bypass channel flows were increased. This extended the trial for a further night by ensuring flows in the scheme were able to be retained in the last 3% of pond storage. The changed regime also provided a flush down the River and Bypass channels to encourage any remaining released salmon present upstream of the traps to move downstream over the final night.

4. Statistical Method

Let p_S denote the probability that a salmon in the upstream vicinity of trap S is captured in the trap, during the period when the trap is active. This capture probability will be the combination of a number of biological and practical processes (e.g., fraction of flow sampled and salmon movement), which is largely immaterial provided that all salmon in the population of interest are potentially exposed to the trapping effort.

For the calibration releases of N_S salmon, the number captured (x_S) could be modelled with the binomial distribution. That is, x_S is considered a random value from a binomial distribution with size N_S and probability p.

For the main release, let ψ_S be the probability that a salmon released above the intake moves to the vicinity of trap S. Once there, the probability of capture is assumed to be the same as that for the salmon in the calibration trials, i.e., p_S. Therefore, the probability of a salmon from the main release being captured at site S is $\psi_S p_S$. Note that as the salmon must move through one of the three pathways (assuming downstream movement only), then $\psi_{Bypass} + \psi_{River} + \psi_{Race}$ must equal 1, hence two of the ψ parameters can be estimated and the other calculated by subtraction. Here, ψ_{Bypass} was selected to be calculated by subtraction (i.e., $\psi_{Bypass} = 1 - \psi_{River} - \psi_{Race}$.

Furthermore, there are only four possible observation types for a salmon in the main release:

1. captured in the Bypass channel trap.
2. captured in the River channel trap.
3. captured in the Main Race/Pond 1 traps.
4. not captured anywhere.

This final outcome includes all other options aside from being captured in one of the traps, including moving to the vicinity of the trap and not getting caught or not moving downstream past the trap. As there is a discrete number of possible outcomes, the number of salmon observed to have each outcome can be modelled with a multinomial distribution. The probability of each outcome can be defined as:

1. $\pi_{Bypass} = (1 - \psi_{River} - \psi_{Race})p_{Bypass}$
2. $\pi_{River} = \psi_{River}p_{River}$
3. $\pi_{Race} = \psi_{Race}p_{Race}$
4. $\pi_{Other} = 1 - \pi_{Bypass} - \pi_{River} - \pi_{Race}$

where these probabilities sum to 1.

Importantly, the capture probability is assumed to be the same for the salmon in both the main release and calibration releases, which allows the movement probabilities (ψ's) to be estimated for the salmon in the main release.

In summary, there are therefore five parameters to estimate (Table 2) where ψ_{Race} is the measure of rock bund effectiveness. The number of released salmon that may have passed through the rock bund can therefore be estimated as the product of the number released and the estimate of ψ_{Race}.

Table 2. Parameters used to analyse release and capture data from trial of hatchery-origin juvenile salmon.

Parameter	Description
p_{Bypass}	Probability a salmon in the Bypass channel trap site is captured
p_{River}	Probability a salmon in the River channel trap site is captured
p_{Race}	Probability a salmon in the Main Race/Pond 1 trap site is captured
ψ_{River}	Probability a salmon moves from main release site to River channel trap site
ψ_{Race}	Probability a salmon moves from main release site to Main Race/Pond 1 trap site

Parameters were estimated using maximum likelihood methods, based on the properties of the main- and calibration-release data (i.e., multinomial and binomial random variables, respectively). While there are shared parameters between the two data types, the observations are assumed to be independent in all other respects. 95% confidence intervals were calculated based upon the profile-likelihood approach as the values of some parameters were expected to be close to zero. The analysis was conducted in the software R with custom-written code.

5. Results

5.1 Trapping Effort

All inclined-plane traps were operated continuously and without interruption. River and Bypass traps operated from 1800hs on 7 May to 1230hs on 15 May. Pond 1 and Main Race Traps operated from 0800hs on 8 May to 1500hs on 15 May. River and Bypass traps fished overnight on 7/8 May prior to release of any hatchery-origin salmon to assess movement of wild salmon and other fish.

5.2 River, Channel and Trap Flows

Over the 7 May to 15 May trapping period Rangitata River flow at Klondyke steadily receded from $57.5m^3/s$ to $49.5m^3/s$ except for a period of 20 hours starting at about 2200hs on 11 May when the river rose by about $5m^3/s$ and then returned to a steady decline.

As Rangitata River flows receded over the course of the trials, RWL managed the distribution of the take to try to maintain stable flows in the River and Bypass channels. The reduction in the intake flow as the Rangitata River receded was borne by reduced flows into Pond 1 and the Main Race (Figure 2).

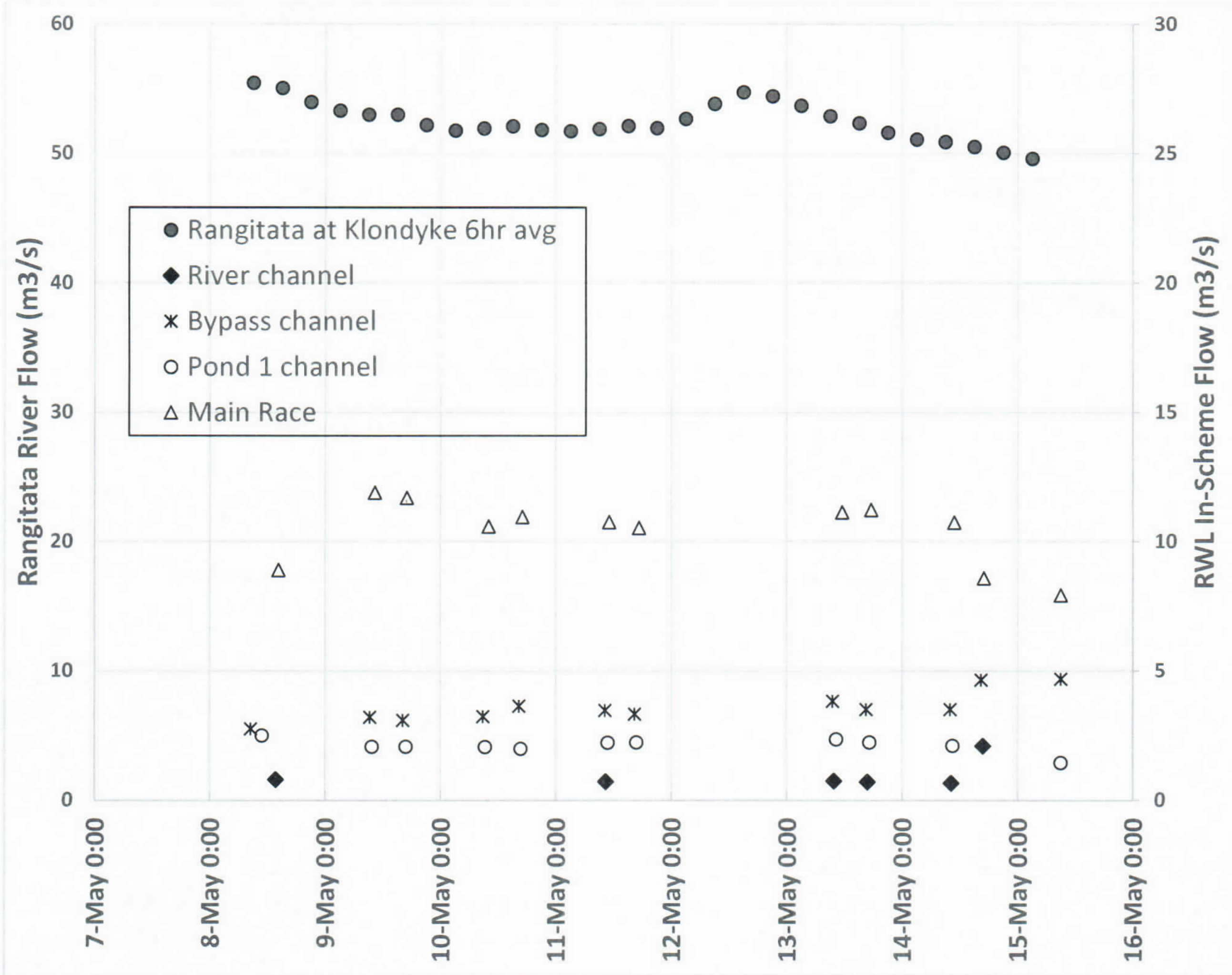


Figure 2. Rangitata River flow at Klondyke (left vertical axis) and spot flows in four channels within the RWL scheme (right vertical axis) during fish trapping operations from 8 to 15 May 2017.

A total of 62 channel- and trap-flow gaugings were completed between 8 May and 15 May. The River Trap sampled the highest average proportion of the flow present in its channel and the Main Race Trap sampled the lowest average proportion of flow present in its channel (Table 3).

Changes in flow in the channels and changes in the proportion sampled by traps were unlikely to be significant factors impacting on low and variable trap catches.

Table 3. Total channel flow and proportion of channel flow passing through each trap for the controlled flow period of 8-14 May and the flush flow period 14/15 May.

Site	Date		Channel flow (l/s)	Trap flow (l/s)	Trap flow as proportion of channel flow
River	8-14 May	Minimum	663	106	
	8-14 May	Maximum	743	136	
	8-14 May	Average (n=16)	710	118	16.6%
	14/15 May	n=5	2,100	449	21.4%
Bypass	8-14 May	Minimum	2,763	409	
	8-14 May	Maximum	3,822	556	
	8-14 May	Average (n=11)	3,358	486	14.5%
	14/15 May	n=3	4,687	763	16.3%
Pond 1	8-14 May	Minimum	1,961	269	
	8-14 May	Maximum	2,354	404	
	8-14 May	Average (n=11)	2,187	326	14.9%
	14/15 May	n=2	1,449	226	15.6%
Main Race	8-14 May	Minimum	8,905	421	
	8-14 May	Maximum	11,893	499	
	8-14 May	Average (n=13)	10,839	456	4.2%
	14/15 May	n=3	7,928	275	3.5%

5.3 Catch of Salmon from Calibration Releases

The first releases between 1130hs and 1720hs on 8 May totalled 2,975 adipose-clipped hatchery-origin salmon across three sites, for calibrating trap recapture efficiency for all four traps. The second calibration release was a total of 1,616 left-pelvic-clipped hatchery-origin salmon at the same sites between 1219hs and 1250h on 11 May. All hatchery-origin salmon were taken from the same raceway and a random sample of 63 fish averaged 151mm with a range of 118mm to 176mm.

At all trap sites the first recaptures appeared in the traps within an hour of their release and 50% of the total catch for each trap was taken between 0.16 hr and 17.3 hr after release. The proportion of fish recaptured was uniformly low at less than 2 fish per 100 released with the best result being an average of 1.71 fish per 100 released averaged across the two calibration releases for the River Trap. The poorest recapture rate was an average of 0.52 fish per 100 released across the two calibration releases for the Bypass Trap. Pond 1 and Main Race Trap sites were two sampling points on the same body of water. Overall efficiency of fish capture on this water body, the Main Race, was estimated from the sum of the efficiencies of each site and each release. Overall capture efficiency for the Pond 1 and Main Race traps was 1.32 fish per 100 fish released (Table 4). The full record of trap operation and catch by species and time for each trap including residual fish recapture is provided in Appendix 2.

At the end of the trial when flows were shut down recovery of released fish that remained downstream of the release sites but upstream of the trap sites was possible in the River and Bypass channels. These fish were considered to have not come into contact with the traps and were removed from calculation of trap efficiency. Results of residual fish capture are presented in Section 5.6. Main Race sites could not be dewatered.

Table 4. Number of fish released, number remaining above the trap until completion of the trial, number recaptured and trap calibration for two trials at each trap site. NS = not sampled.

	Release			Residual above trap	Trap recaptures		
Site	Type	Date	Number		Number	Proportion recaps	Last recapture
River	Calibration 1	8 May	1,013	15	18	1.80%	0720hs 14 May
	Calibration 2	11 May	529	5	8	1.53%	1935hs 11 May
	Combined		1,542	20	26	1.71%	
Bypass	Calibration 1	8 May	1,044	12	7	0.68%	0715hs 14 May
	Calibration 2	11 May	495	2	1	0.20%	1930hs 11 May
	Combined		1,539	14	8	0.52%	
Pond 1	Calibration 1	8 May	918	NS	3	0.33%	2130hs 8 May
	Calibration 2	11 May	592	NS	0		
Main Race	Calibration 1	8 May	918	NS	13	1.42%	2100hs 13 May
	Calibration 2	11 May	592	NS	4	0.68%	1000hs 13 May
Pond 1 + Main Race combined			1,510	NS	20	1.32%	

The first calibration releases produced recapture results well below the expected level given the uniform physical conditions at each trap site and placement of the traps across the uniform weir crest. At the River and Bypass sites the traps covered approximately one-quarter and one-sixth of respective channel width and sampled approximately one-sixth and one-seventh of the flow in the channels, respectively. It was expected that traps would catch approximately the same proportion of released fish as channel width and flow sampled. Recaptures in the order of 200 fish in the River Trap and 160 fish in the Bypass Trap were expected compared to actual catches of 26 and 8 fish, respectively.

Recapture rates from calibration releases for the Pond 1 and Main Race traps were also lower than expected. Combined, these traps covered about one-tenth of the width of their channels and sampled about one-sixteenth of the flow in the Main Race. Calibration releases totalling 1,510 fish immediately above the traps should have produced trap captures of around 100 to 150 fish. Trapping yielded only 20 salmon.

Following uniformly low recapture rates from the first calibration release, observers were stationed at the River and Bypass trap sites during the second calibration release to record released fish behaviour in relation to the weirs and trap entrances. No released salmon in the Bypass channel were observed interacting with the weir or trap in the first hour after release. At the River Trap site, three separate interactions were observed in the first hour after release. In one of these a school of six salmon swam down to the weir then returned back upstream. The other two observations were of individual salmon that took evasive action to avoid being swept over the weir, however both failed, with one being washed downstream past the trap and one being washed into the trap. The fish caught in the trap had been released five minutes earlier approximately 90m above the trap.

5.4 Catch of Salmon from Main Trial Releases

The main release of 8,519 unmarked hatchery salmon into the Rangitata River channel approximately 100m upstream of the RWL intake was completed in three batches between 1550hs and 1745hs on 9 May. During the remaining 141.25 hours of trapping between their release and removal of traps, 55 of these fish were recaptured (Table 5).

Table 5. Recapture of unmarked hatchery-origin salmon in the River and Bypass return traps and within the RWL scheme at Pond 1 and Main Race Traps, from the main trial release of 8,519 fish upstream of the RWL intake between 1550hs and 1745hs on 9 May.

	Recapture of unmarked hatchery origin salmon			
Site	**Number**	**Proportion recaptured**	**Last recapture**	**Trap removed**
River	14	0.16%	0720hs 14 May	1100hs 15 May
Bypass	41	0.48%	2000hs 14 May	1230hs 15 May
Pond 1	0			1500hs 15 May
Main race	0			1500hs 15 May

All fish recaptured from the main trial release above the scheme were found in the River and Bypass traps and none were captured within the scheme. Approximately 25% of recaptured fish did not enter the scheme and were caught in the River Trap while the remaining 75% entered the scheme intake and negotiated passage past the permeable rock bund to remain in the channel that would have returned them to the Rangitata River if the Bypass Trap had not intercepted them.

On the night of 14/15 May flow in the River channel was increased 3-fold and flow in the Bypass channel was increased by approximately 40% to provide a flush in flows prior to the end of the trial scheduled for the following morning. It was considered that the increased flow might encourage any released salmon that had taken up temporary residency upstream, to move downstream and become subject to capture in traps. Two hatchery-origin unmarked salmon were caught in the Bypass Trap overnight, a catch comparable to that of the previous night. No hatchery-origin salmon were caught in the River Trap overnight on 14/15 May and for the two sites the high flows did not appear to produce elevated catch rates of hatchery-origin salmon.

5.5 Catch of Other Fish

During overnight trapping on 7/8 May of the River and Bypass channels prior to release of any hatchery fish, four juvenile wild salmon were caught in the Bypass Trap between 0315hs and 0650hs on 8 May and 28 torrentfish were captured, all in the Bypass Trap. No other fish were caught that night. The capture of wild salmon was a feature of fish catch in the Bypass Trap with a further 15 being caught at this trap and only one other being caught at the River Trap (Table 6). No wild salmon, brown trout or native fish were captured in the Pond 1 or Main Race traps.

Table 6. Trap catch of wild salmon, brown trout and native fish (torrentfish and bluegilled bully) at the River and Bypass sites on the 7/8 May and at River, Bypass, Pond 1 and Main Race sites from 8 May to 15 May.

Site	Wild salmon	Brown trout	Torrentfish	Bluegilled bully
River 7/8 May	0	0	0	0
River 8-15 May	1	6	2	0
Bypass 7/8 May	4	0	28	0
Bypass 8-15 May	15	12	16	1
Pond 1 8-15 May	0	0	0	0
Main Race 8-15 May	0	0	0	0
Total	20	18	46	1

All wild salmon were measured for length and averaged 112mm with a range of 80mm to 136mm. No wild salmon were caught within the RWL scheme in Pond 1 and Main Race traps.

Between 2000 and 2004 inclined-plane trapping for juvenile salmon from the Rangitata River in the Cracroft intake for the Ashburton District Council stockwater system identified that maintenance of river bed structures by earthmoving machinery to ensure flow to intake structures can result in immediate downstream movement of torrentfish. It is likely the high catch of torrentfish in the Bypass Trap overnight on 7/8 May compared to catches on other nights was related to disturbance by river works completed on 7 May to provide controlled flow to the RWL intake for the trapping programme.

The third most common fish caught behind salmon and torrentfish was brown trout. Eighteen juvenile brown trout of between 107mm and 190mm were caught in the River and Bypass channels. No brown trout or native fish were caught in traps within the scheme.

The high flow flush overnight on 14/15 May in the River and Bypass channels may have encouraged fish other than hatchery-origin salmon to move downstream or increased their likelihood of being caught in the traps. The overnight catch in the Bypass Trap of 4 wild salmon, 4 brown trout, 4 torrentfish and 1 bluegilled bully, was higher for each of these species than for any of the previous five nights. The bluegilled bully was the only one caught during the trial. The Bypass Trap also caught two unmarked hatchery-origin fish from the release above the intake and this was the equal lowest overnight catch at this site in the five nights since fish were released. The overnight catch in the River Trap was 1 wild salmon and this was the only wild salmon caught at this site during the trial. So while the overnight flush flow appeared to encourage wild salmon, trout and native fish to move downstream it did not encourage trial hatchery-origin salmon to move.

5.6 Sampling of Residual Channels at Conclusion of Trial

Shutdown of the RWL scheme on the morning of 15 May at the completion of the trial trapping provided an opportunity to estimate the number of hatchery-origin salmon that remained near the River and Bypass release sites and were not caught in the downstream traps. The within-scheme, Pond 1 and Main Race, sites could not be dewatered to assess residual fish numbers as they were at their water holding capacity.

Multiple-pass electric fishing of the River and Bypass residual channels above the traps after shutdown captured 27 adipose fin-clipped, 7 left pelvic fin-clipped and 28 unmarked hatchery-origin salmon in total with 31 in each channel (Table 7). No wild salmon or bluegilled bullies were caught.

Table 7. Fish captured by electric fishing in residual River and Bypass channels downstream of release sites and upstream of traps on completion of trapping.

Site	Hatchery-origin salmon			Brown trout	Torrentfish	Canterbury galaxias
	Adipose	Left Pelvic	Unmarked			
River	15	5	11	12		
Bypass	12	2	17	7	13	1
Total	27	7	28	19	13	1

5.7 Analysis

A summary of the data used in the analysis is given in Table 8. The number of salmon caught in the Main Race and Pond 1 traps have been combined, as have the number of salmon captured from the first and second calibration releases. This assumes that sufficient time has elapsed such that the same fraction of salmon from each release cohort has been exposed to capture by the trap, once in the vicinity of the trap (for those from the main release).

Table 8. Summary of release and capture data used in analysis to determine effectiveness of rock bund.

Release	Outcome	Number
Main	Captured in Bypass trap	41
	Captured in River trap	14
	Captured in Main Race traps	0
	Not captured	8464
	Total Released	**8519**
Calibration	Captured in Bypass trap	8
	Not captured in Bypass trap	1531
	Total released	**1539**
	Captured in River trap	26
	Not captured in River trap	1516
	Total released	**1542**
	Captured in Main Race traps	20
	Not captured in Main Race traps	1490
	Total released	**1510**

The estimated capture probability is smallest in the Bypass channel (0.005; Table 9), and largest in the River channel (0.017). If there were hatchery-origin juvenile salmon in the vicinity of the traps in the main race, the probability of capture is estimated to be 0.013, which equates to expecting 13 to be captured for every 1000 salmon nearby. There is a very low estimated probability of salmon moving from the main release site, through the rock bund, and into the trap sites on the Main Race/Pond 1 intake, with the upper bound of the 95% CI slightly above 0. Essentially all salmon are estimated to have moved through the River and Bypass (in particular) channels. Note that while the point estimates of the ψ parameters should sum to 1, it should not be expected that the confidence intervals necessarily will. The number of salmon from the main release estimated to have moved through the Bypass channel, residual channel and Main Race is therefore 7690 (95% CI: 6972-8096), 829 (423-1547) and 0 (0-151), respectively.

Table 9. Parameter estimates and lower and upper bounds of 95% profile-likelihood confidence intervals. ψ_{Bypass} was not estimated directly and was calculated as $1 - \psi_{River} - \psi_{Race}$

	Estimate	**Lower**	**Upper**
p_{Bypass}	0.005	0.004	0.007
p_{River}	0.017	0.011	0.024
p_{Race}	0.013	0.008	0.020
ψ_{Bypass}	0.903	0.818	0.950
ψ_{River}	0.097	0.050	0.182
ψ_{Race}	0.000	0.000	0.018

6. Discussion

On 9 May, 8,519 unmarked hatchery-origin salmon were released above the RWL intake and their passage through or around the intake and permeable rock bund fish diversion structure was monitored by recapture at four inclined-plane fish traps at key sites. Up to mid-afternoon on 15 May none of those fish were recaptured in either of the traps downstream of the permeable rock bund, that is, inside the RWL scheme. All 56 unmarked hatchery-origin salmon recaptured in the River and Bypass traps were in channels that gave fish access back to the Rangitata River.

The 41 recaptures of unmarked hatchery-origin salmon in the Bypass trap all entered the RWL intake and were caught on the river side of the permeable bund confirming they had entered the intake and had not irreversibly passed through the bund.

The River Trap yielded 15 unmarked hatchery-origin salmon that had not entered the scheme intake or if they did they swam back out and then down the River channel towards the Rangitata River.

A key assumption of the analysis is that the hatchery-origin juvenile salmon will only move downstream once released. Significant upstream movement will create a bias in the estimates. It is also assumed that all salmon have moved downstream from the release site near the main intake of the irrigation scheme. Estimates will also be biased if a substantial number of salmon have remained near the intake, although the estimates of the number that have moved through each area will be proportional to the number that actually dispersed from the release site.

The analysis presented does not use the data from the electric fishing of the residual Bypass and River channels, which gives an indication of what proportion of salmon had not passed the traps by the conclusion of the trial. Alternative analyses were attempted to incorporate this information, and the associated probability of movement past the traps, but such analyses were unsuccessful, primarily due to the paucity of the data. However, from the perspective of estimating the probability of capturing a salmon that is in the vicinity of the trap, it is not necessary to account for those salmon that have not moved past the trap. The capture probability, p_S, implicitly accounts for this movement given that the number of salmon available to be trapped from the calibration releases is known. This should not create a bias provided that at each trapping site, the proportion of salmon that have moved past the trap from each cohort is similar (once they arrive at the trapping site).

Using the binomial and multinomial distributions to account for the number of salmon observed to be captured assumes that salmon move and are captured independently of other salmon. If salmon are not behaving independently then the assumed distributions will not be entirely appropriate with the consequence being that the precision of the estimated may be overstated (i.e., confidence intervals are too narrow). Our ability to assess the reasonableness of this assumption is limited due to the nature and quantity of data available, although if salmon were not behaving independently, then it might be expected that there are pulses in the number of salmon caught (aside from the pulse caused by the general downstream movement following release). Typically, only a few salmon were caught at a time which is what would be expected with independent behaviour.

There were no recaptures downstream of the permeable rock bund of any of the 8,519 unmarked-hatchery salmon released above the scheme intake as part of the main release. The 95% confidence interval for estimated catch of unmarked-hatchery fish within the scheme ranges from 0 to 151. Based on this trial and the analysis applied to it, it is unlikely that the rock bund was less than 98.0% efficient at preventing test fish from passing through the bund and entering the scheme.

The significant flow of the RWL scheme and the comparatively small proportion of it that could be trapped required a large number of test fish to be released in order for catch rates to be numerically significant. It would have been desirable to capture and use downstream migrating juvenile wild salmon, but they could not be caught in sufficient numbers to be used as test fish. Large numbers of juvenile salmon were available from a nearby fish hatchery however these fish were larger than wild salmon of the same age, they were not naturally migrating downstream at the time of the trial, and their behaviour in response to river conditions, the rock bund, and fish traps may be different from wild salmon. By using hatchery-origin salmon the assumption was that their behaviour was the same as wild fish. As the permeable rock bund is a behavioural barrier, behavioural differences between wild and hatchery test fish in reaction to the bund could have a bearing on estimated efficiency of the bund.

Along with possible behavioural differences between wild and hatchery salmon, the different habitats in which they have reared could influence their reaction to natural river habitat and the permeable rock bund. Fish size could also affect the physical reaction to the bund. Salmon fry and fingerlings of 35mm to 80mm will be the most common wild salmon migrating downstream in the Rangitata River. These fish have slower swimming speeds and less endurance for avoiding sustained high velocity flows than larger salmon, and they are likely to be physically able to pass through a greater number of smaller spaces in a rock bund wall. This means salmon smaller than those used in these trials may be more at risk of passing through a rock bund either by choice or by fate.

During the trial the RWL scheme was operating at 50% to 65% of its normal capability and the Rangitata River was running clear. These features may also affect salmon behaviour around the permeable bund and may create differences from their behaviour had the scheme been operating normally and intake flows were higher and more turbid.

All 20 of the Rangitata River wild salmon caught during the trapping programme were taken in the channels returning fish to the river and none were caught inside the scheme. One was caught in the River Trap and 19 in the Bypass Trap. Applying the known trap catch calibration results from the hatchery-origin release and recapture rates, to wild salmon, it is estimated that approximately 3,700 wild salmon passed down the River and Bypass channels during the trial and 95% were in the Bypass channel. The magnitude of the wild salmon catch was similar to that experienced during recent RDR trapping in autumn to monitor the effectiveness of the Bio-acoustic Fish Fence (BAFF). Combined, these studies could indicate downstream migration in the Rangitata River of about 1,000 wild salmon of 100mm to 150mm length per night in stable flows up to about $60m^3/s$ from February through to June.

During the sampling there were no observations of released salmon being able to escape once inside the traps. Average water velocities in the mouths of traps ranged from 0.87 m/s to 1.26 m/s and combined with the short reaction time fish would have to avoid capture, should have been sufficient to prevent escape. In the Bypass channel calibration fish were confined between a 6m/s velocity barrier upstream of the release site and the weir and trap site downstream. These fish could only take up residence or move downstream into the trap or past the trap. Of 1,539 marked salmon released above the trap 99.5% left the site by avoiding capture in the trap. Our expectation based on previous experience and the proportion of channel width and flow that was trapped, was that at least 10% of released fish should have been caught by the trap. The implication is that hatchery-origin salmon used at this site, and accordingly all sites, were able to avoid capture. This avoidance clearly affected the strength of conclusions able to be made about the ability of the permeable rock bund to ensure salmon do not enter the RWL scheme. The most positive outcome from this trial was that none of the 8,519 hatchery-origin salmon released above the scheme intake were recaptured by in-scheme traps placed in Pond 1 and Main Race channels.

7. Conclusions

Seven calibration releases, four before and three after the main release, were made using marked hatchery-origin salmon of average length 151mm. Inclined-plane traps were placed at four sites around the RWL scheme being two upstream of the permeable rock bund returning fish back to the Rangitata River and two downstream of the permeable rock bund, to assess fish numbers entering the irrigation scheme. All calibration trials produced low recapture rates at the four trapping sites.

There were no captures downstream of the permeable rock bund of any unmarked hatchery salmon from the 8,519 fish released above the scheme intake. Likewise, there were no captures in traps downstream of the rock bund of any of the 3,700 wild salmon estimated to have been present above the scheme intake during the trial. No trout or native fish species were caught downstream of the bund. Wild salmon, brown trout, and two native fish species, torrentfish and bluegilled bully, were caught in low numbers outside the scheme in the two traps on channels flowing back to the river. Of the 20 wild salmon captured outside the scheme, 19 were captured in the Bypass Trap. Wild salmon caught in this trap would have been required to first have encountered the rock bund and been diverted into the Bypass channel. The only other wild salmon caught was in the River Trap and it was unlikely to have encountered the permeable rock bund. From these results it can be concluded that during the trial some 12,000 juvenile salmon, made up of 8,519 hatchery-origin salmon, and an estimated 3,700 wild salmon, were in close proximity to the scheme intake, yet none were captured in traps inside the RWL scheme.

Information on the probability of capturing a salmon on an inclined-plane fish trap was estimated from calibration releases of salmon upstream of the traps. The number of salmon estimated to have moved from the main release site to the vicinity of each trapping site was estimated from the number of salmon from the main release caught at each trap site, in combination with the estimated capture probabilities.

It is estimated that the number of salmon that moved from the main intake release site to the trapping sites was:

- Bypass channel: 7690 (95% CI: 6972-8096).
- River channel: 829 (95% CI: 423-1547).
- Main race/Pond 1: 0 (95% CI: 0-151).

The 95% confidence interval for estimated catch of unmarked-hatchery fish within the scheme ranges from 0 to 151. Based on this trial and the analysis applied to it, it is unlikely that less than 98.0% ((8,519-151)/8,519) of unmarked hatchery salmon released above the scheme intake and coming in contact with the bund along the Bypass channel, were prevented from irreversibly passing through the bund and entering the scheme

Key assumptions in this analysis are that there was only downstream movement of juvenile salmon; sufficient time elapsed so that a similar proportion of salmon from each release had the opportunity to pass through the trapping sites, once they reached them; and salmon move and are captured independently of other salmon. There is insufficient data to asses this final key assumption.

Fish behaviour and/or trap conditions that resulted in released salmon avoiding capture in the traps were consistent across all sites and releases. The most likely reason for the low capture numbers was some form of trap avoidance. The best evidence for this came from the release of 1,539 marked salmon directly upstream of the Bypass Trap. These fish could only move downstream yet only 8 fish were captured in the trap and a further 14 were recovered by electric fishing at the end of the trial from the Bypass channel between the velocity barrier and the trap site.

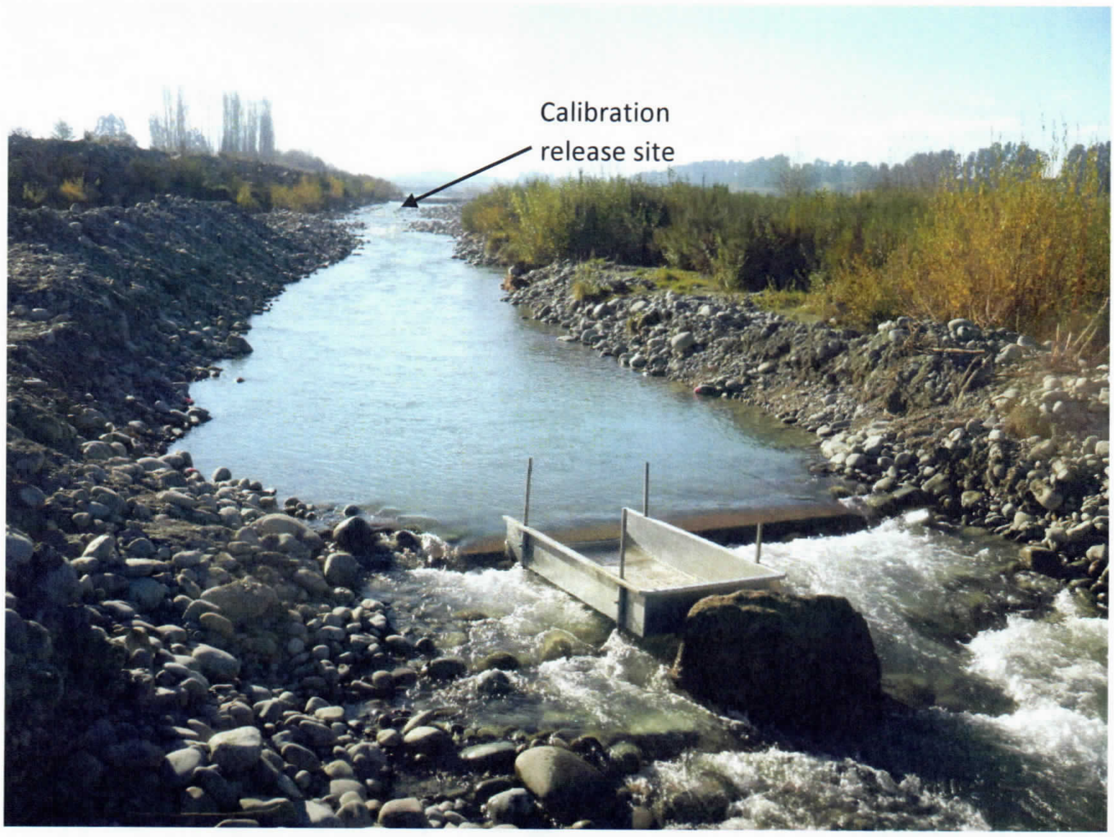
These conclusions apply to the movements of 118mm to 176mm hatchery-origin salmon and a smaller number of 80mm to 136mm wild salmon in relation to river flow and abstraction conditions around and through the RWL permeable rock bund during 8-15 May 2017.

8. Acknowledgements

Thank you to RWL management for enabling the trial to take place when there was no legal requirement for them to do so, and for building one of the large fish traps at short notice. Thanks also to RWL employees Rowan Clarke and Chris Hendry for their assistance with site development, trap placement and trap checks. Thank you to the Riparian Support Trust and its volunteers for making valuable hatchery fish available and for providing enthusiastic volunteers for trap monitoring.

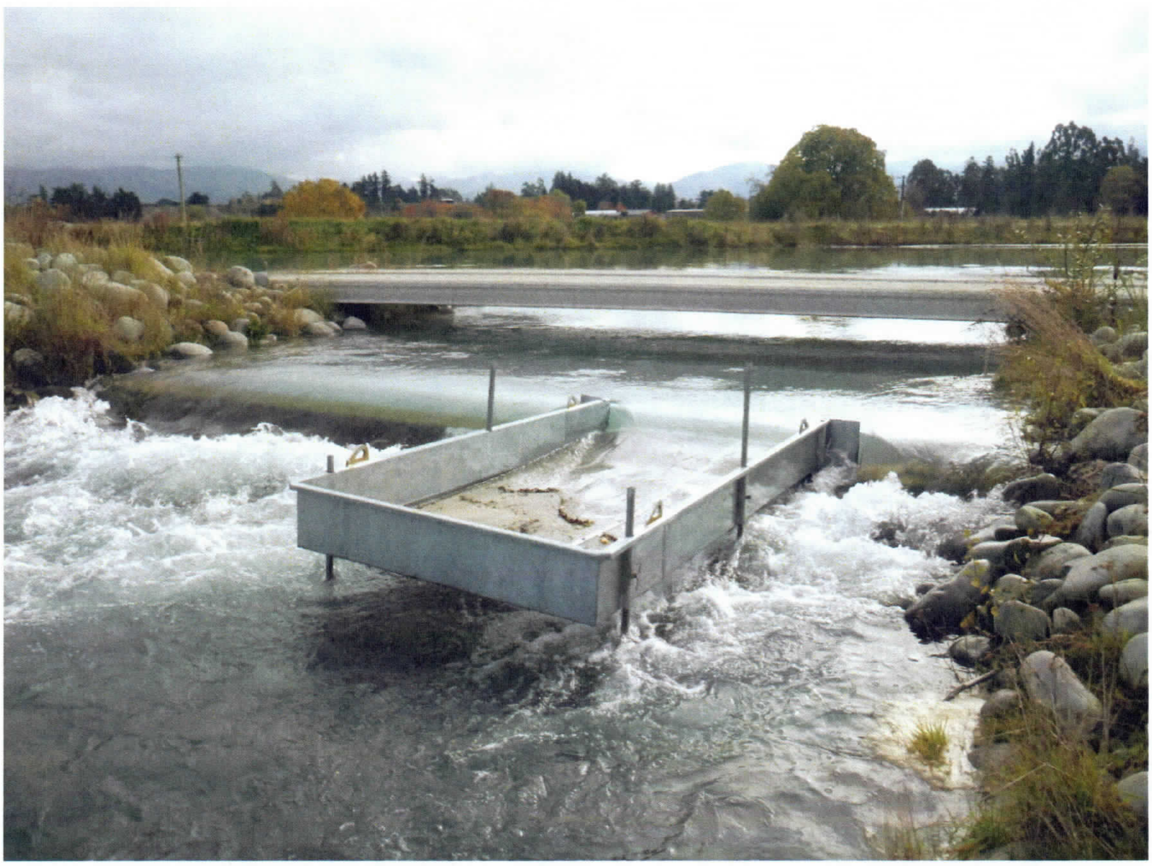
The recognition by Canterbury Regional Council of the importance of the trial by their agreement to river works required to establish channels and trap sites, is acknowledged.

River Trap

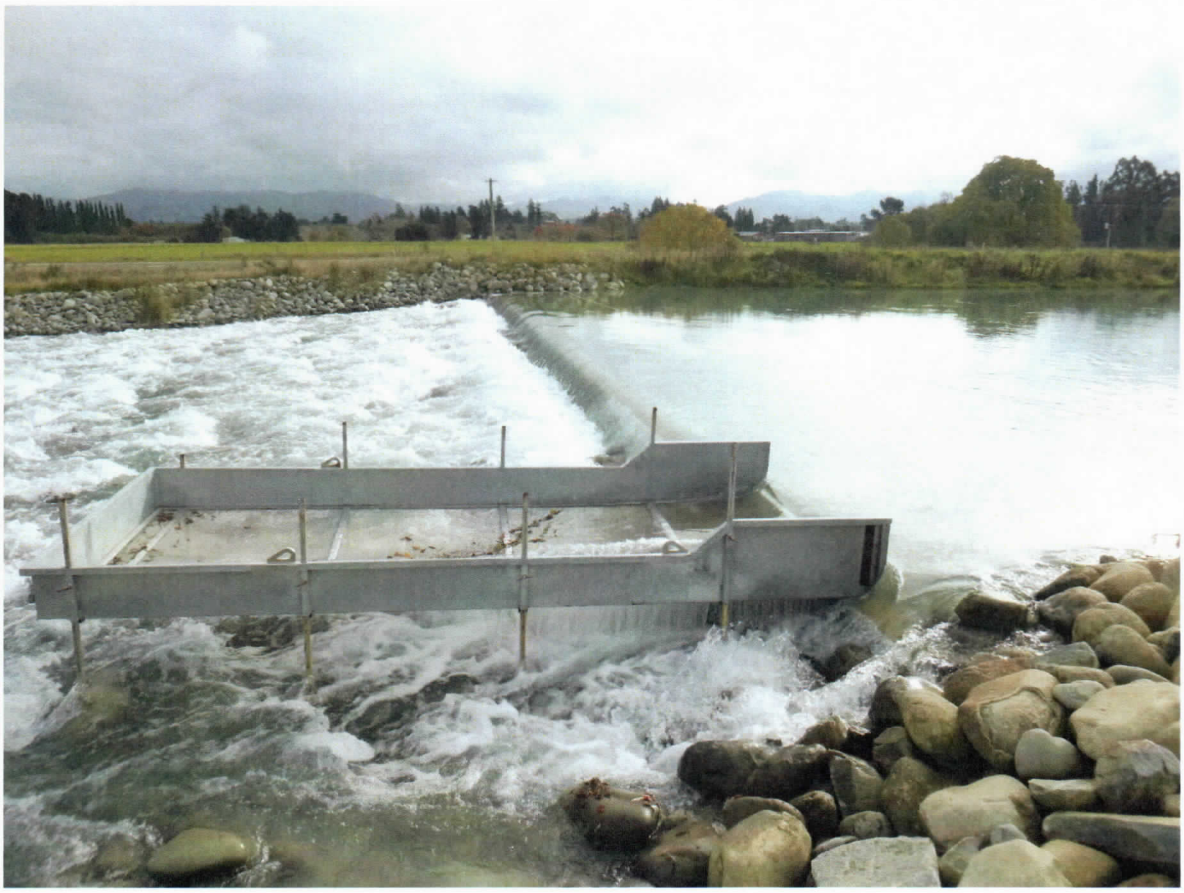


Bypass Trap

Pond 1 Trap



Main Race Trap



Trap and residual channel fish catch

APPENDIX 2

River Trap

Date	Time	AR	LP	Hatchery no clip	Wild	BT	Torrent	Bl Gill	Action
7-May	1815								Installed
	1915								
	2020								
	2230								
	2310								
8-May	0325								
	0655								
	0840								
	1150								1013 AR fish released imm. upstream
	1400								
	1705								
	2055	2				1			
	2300	3							
9-May	0510	5				1	1		
	0730	2				1			
	1205								
	1605								
	1550 to 1745								8519 hatchery fish released, not clipped
	1845	4							
	2005								
	2215								
10-May	0350								
	0725								
	1005								
	1400								
	1820			1					
	2300			2			1		
11-May	0330								
	0740			1					
	1115								
	1230								529 LP fish released imm. upstream
	1235		1						
	1355		1						
	1520		1						
	1735								
	1935		5	1					
	2100								
12-May	0330			1					
	0800								
	1130								
	1620								
	2200								
13-May	0235								
	0800			3					
	1205								
	1620								
	1940	1		3		1			
	2240			1					
14-May	0240								
	0720	1		1		2			
	1010								
	1530								
	2005								
	2235								
15-May	0330								
	0800				1				
	1100								water turned off
Total trap catch		18	8	14	1	6	2	0	
Residual Catch		15	5	11	0	12	0	0	
Total site catch		33	13	25	1		2	0	

J Couper, Fish and Game

From: Adam Daniel <ADaniel@awfg.org.nz>
Sent: Friday, 16 December 2016 1:22 PM
To: J Couper, Fish and Game
Subject: RE: Acton screen testing

Jay,

I had some free time last night and took a look at the "fish screen" and I had some serious concerns as follows:

1. The proposed device is a fish guidance structure not a fish screen as the gap size will allow fish to enter the weir and to be impinged within the structure.
2. This design has not been proven to be an effective fish guidance device. The test on the Acton Intake was flawed for the following reasons:
    a. Due to the blow out of the fish trap during the Acton Intake study the test should have been redone because "calculating the proportion of the total catch from the bypass trap compared to the intake trap" excludes all the moralities that occur from being impinged in the rock weir. Impingement is the fundamental issue with this design due to uneven gap spacing that will allow fish in and certainly have high and low velocity points along the weir face that are known to attract fish.
    b. Over 60% of the test fish (3585 of 5950 released) were not accounted for so the test was invalid and should be repeated and preferably with a subset of radio telemetry fish. Once a Fish Bypass Efficiency (FPE) is worked out for the structure a radio telemetry sample size could be derived to properly test the structure and determine the fate of fish rather than assuming that all of the fish that disappear have been successfully guided.
    c. Fish were detected in the intake channel in the test proving fish are attracted into the weir and making it very likely that some fish have been impinged in the weir.
    d. The volume and head difference at the Acton site are far less than proposed for the RDR site.
3. The design of the proposed structure is flawed presumably because it was engineered to fit in an existing pool. An effective fish guidance device should have a laminar flow along the face to prevent fish from being attracted to changes in velocity or aggregating near the structure to lower the probability of being entrapped in the weir. The design looks like it was forced into an existing pond rather than being a straight line to smooth the flow along the weir and guide fish. Past research on guidance structures has shown that fish are attracted to any change in velocity along the structure, the bend in the middle of the weir will create an eddy that will hold fish along the face greatly increasing the chances of being entrained. Similarly the addition of the pipes near the downstream end of the structure will likely increase the attraction flow into the weir increasing mortality. The structure should be redesigned to include adequate space to make a strait weir to promote a laminar flow, have gates to control the head differential and should include water level gauges to monitor head differential.
4. There is no means of removing debris from this structure without fully dewatering and it will clog creating high and low velocity point's attracting fish that could be entrained in the structure in areas with increased flow into the weir.

If this structure is consented I would make sure there is strict Bypass Efficiency (FPE) requirements in the consent based on field tests with repercussions written into the consent as the previous test was not sufficient in my view to give assurance this structure is not going to kill fish. A rotating fish screen or farmers screen would be far safer options with higher reliability in terms of maintaining the water take for the irrigation scheme.

I am happy to answer any questions as I am sure you will have some.

Adam Daniel, PhD
Fisheries Manager
Fish & Game New Zealand
Auckland/Waikato Region