Rangitata Diversion Race Management Limited

Review of Bio-acoustic Fish Fence Effectiveness

prepared for RDRML by

Ryder Consulting

March 2010

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Cover photo: RDR Bio-acoustic Fish Fence, photo provided by Ben Curry, RDRML.

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Table of Contents

1. Introduction

1.1 Background

The Rangitata Diversion Race (RDR) is a 67km long canal that carries a maximum of 30.7m^3s^{-1} of water from an intake on the Rangitata River to the Rakaia River, crossing the Canterbury Plains in a northeasterly direction. Along its way the RDR supplies water to two power stations (Highbank and Montalto) and three irrigation schemes (Hopkinson 1997).

The intake to the RDR is unscreened and therefore fish, including downstream migrating Chinook salmon (*Oncorhynchus tshawytscha*) fry, are diverted along with water from the Rangitata River into the RDR. It is estimated that in the 1998/99 irrigation season that about 200,000 salmon smolt from the Rangitata River were entrained to the RDR (Hamish Stevens, Fish and Game Officer, December 2007). It has been suggested that juvenile salmon entering the RDR may comprise 5-25% of Rangitata River migrants (Unwin *et al.* 2005). Rangitata Diversion Race Management Limited (RDRML) therefore sought a method of screening juvenile salmon from the RDR, thereby allowing them to return to the Rangitata River.

The RDR carries a large volume of water, which is often silt laden, and the invasive algae Didymo (*Didymosphenia geminata*) is also present in the canal. Under these conditions a traditional mesh fish screen would quickly become blocked and ineffective. After evaluating alternative screening options a bio-acoustic fish fence (BAFF, Fish Guidance Systems, Southampton, United Kingdom) was installed in the RDR approximately 2km downstream of the intake in June 2007. However, due to a number of issues affecting its operation, the BAFF was not considered commissioned until August 2008. The BAFF consists of a combination of low-medium frequency sound and an air bubble curtain that concentrates the sound. This acts to repel fish travelling down the RDR, instead directing them towards a bypass that returns to the Rangitata River. As the BAFF is not a physical screen as such, algae does not clog it, although regular maintenance is required to ensure silt does not block the air bubble jets. The RDR BAFF is the first of its type in Australasia, although similar acoustic bubble curtains have been used to screen fish in Europe, North America and the United Kingdom with varying success depending on the species and site (reviews in, DWA Topics 2006, O'Keeffe and Turnpenny 2005, United States Department of the Interior Bureau of Reclamation 2006, Welton *et al.* 2000).

Canterbury Regional Council consent CRC051180 authorises the discharge of water and associated sediment to the Rangitata River from a fish bypass channel associated with the RDR BAFF. Condition 7 of that consent has the following requirements:

(a) Within 18 months of the commencement of this consent, the consent holder shall implement a monitoring programme to determine how effective the fish bypass is in diverting salmon smolt, unharmed, back to a main braid of the Rangitata River.

(b) The monitoring programme shall be carried out for the duration of this consent.

(c) A copy of the monitoring programme shall be provided to the Canterbury Regional Council, Attention RMA Compliance & Enforcement Section, and Fish & Game New Zealand - Central South Island, not less than 20 working days prior to its implementation.

(d) Within three years of the commencement of this consent, and at five yearly intervals thereafter, the consent holder shall provide the Canterbury Regional Council, Attention RMA Compliance & Enforcement Section, and Fish & Game New Zealand - Central South Island with a report prepared by a suitably qualified and experienced person such as a freshwater fisheries scientist, which details how effective the fish bypass is in diverting salmon smolt, unharmed, back to a main braid of the Rangitata River, and makes recommendations as to how the effectiveness of fish bypass may be improved.

(e) Within 20 working days of the provision of every report prepared in accordance with clause (d), the consent holder shall advise the Canterbury Regional Council, Attention RMA Compliance & Enforcement Section, and Fish & Game New Zealand - Central South Island what actions will be taken to implement any recommendations made to improve the effectiveness of the fish bypass, and when those actions will be completed by.

1.2 Report objectives

RDRML engaged Ryder Consulting Limited to undertake a review of the effectiveness of the RDR BAFF in fulfillment of consent condition 7(d).

2. Monitoring of BAFF effectiveness

2.1 Mark-recapture monitoring

The data contained in the following paragraphs has been drawn from a summary of the mark-recapture monitoring trials provided to Ryder Consulting by Mark Webb (Fish and Game). These trials form a part of condition 7(a) of consent CRC051180.

Releases of marked salmon have been undertaken on several occasions since the installation of the RDR BAFF to test its effectiveness. Salmon are released upstream of the BAFF and a trap located in the bypass back to the Rangitata River, known as the BAFF trap (Figure 1, 'C') allows the number of marked salmon that are diverted by the BAFF to be estimated. Downstream of the BAFF there is a second trap, known as the ADC trap (Figure 1, 'F'), which allows the number of marked salmon that pass through the BAFF to be estimated. The efficiency of both these traps to retain fish and therefore record the number of fish diverted or not by the BAFF has been tested using marked fish released within the bypass channel leading to each of these traps (Figure 1, 'B' and 'E').

Between 68-94% of marked salmon released within the bypass channel immediately upstream of the BAFF trap were captured in the BAFF trap during these trials. The percentage of salmon captured varied depending on the time that had elapsed since release. In all three trials at least 40% of salmon were captured within 30 minutes of release, however it took up to 44 hours (range approximately 9-44 hours) for 80% of the marked salmon to be captured.

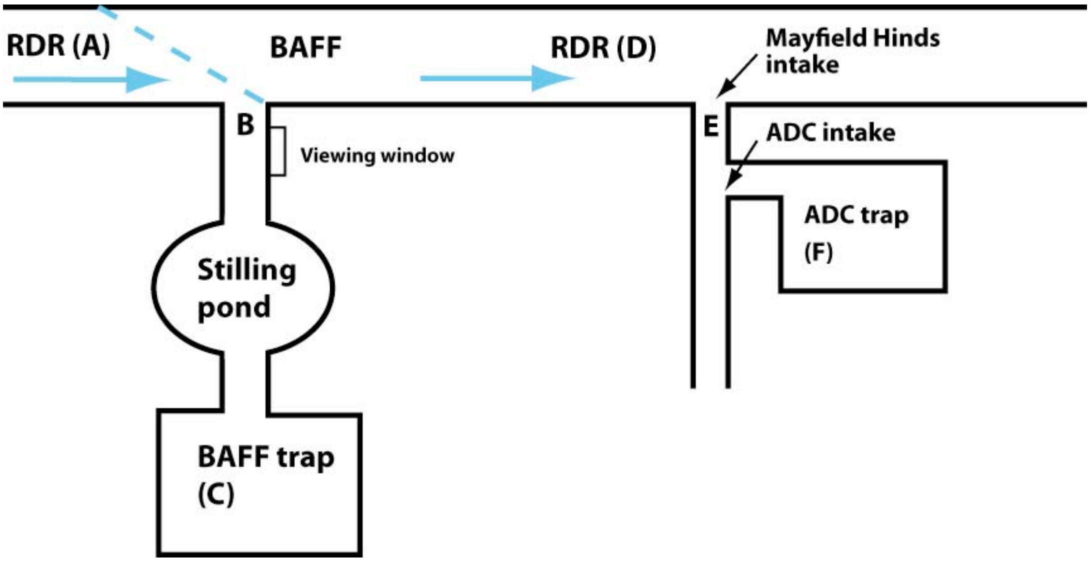
The ADC trap captured 100% of released salmon in the one trial of its effectiveness. Within 15 minutes of release 71% of salmon were captured and after approximately one hour 80% of salmon had been captured. It took approximately 24 hours however for 100% of the salmon to be captured.

The effectiveness of the ADC trap to capture salmon released into the RDR above the intake to the ADC trap (Figure 1, 'D') has also been tested on five occasions. The release location varied from 400m to 1500m upstream of the ADC trap. Capture rates varied from 0.027% after seven hours for salmon released 1500m upstream to 1.26% after approximately two hours for salmon released 400m upstream. The average capture rate over the five trials was 0.32%.

The above monitoring indicates that the BAFF trap is only reasonably effective in capturing fish released at the trap intake. At least 40% of fish have been shown to be captured within 30 minutes, however several days of monitoring are required to achieve capture rates of 80%. The duration of time required for some fish to reach the trap is surprising and may be due to the presence of the stilling pond between the intake to the BAFF trap and the trap itself (Figure 1). The ADC trap is more effective at capturing fish once they enter the trap intake, however it appears that on average only 0.32% of fish travelling down the RDR will enter the intake to the ADC trap.

In 2008 the effectiveness of the BAFF to divert salmon was estimated by releasing marked salmon upstream of the BAFF and counting the number of fish captured in the BAFF and ADC traps. In October and November 2008 526 and 3371 dyed salmon, respectively, were released 1.5km upstream of the BAFF. In October, only 1.3% (7 fish) of the fish released had been captured in the BAFF trap within 137 hours, with 3 fish captured downstream of the BAFF in the ADC trap. Approximately seven hours elapsed between the time when the fish were released and when the first fish was captured in the BAFF trap. In November, only 0.89% (30 fish) of the fish released were captured in the BAFF trap after 20 hours. Five fish were captured in the ADC trap.

Monitoring undertaken in 2008 therefore indicated that the effectiveness of the BAFF was low. However, the effectiveness of the BAFF and ADC traps in determining whether or not fish have been diverted or not is only moderate at best and requires a long period of monitoring following release. An alternative method of monitoring was therefore sought by RDRML.



Key to diagram:
RDR (A) flow and/or salmon in RDR above BAFF
Bypass channel from BAFF to Stilling pond (B)
BAFF Trap (C) flow and/or salmon diverted by BAFF
RDR (D) flow and/or salmon remaining in RDR below BAFF
ADC intake channel from RDR to ADC (E)
ADC Trap (F) flow/salmon diverted from the RDR below the BAFF as an index of fish remaining in RDR below the BAFF

Figure 1 *Schematic diagram of the RDR BAFF and associated monitoring traps. Provided by Mark Webb, Fish and Game.*

2.2 Dual-Frequency Identification Sonar (DIDSON) monitoring

The Cawthron Institute was engaged to undertake a Dual-Frequency Identification Sonar (DIDSON) monitoring trial of juvenile salmon in the RDR in order to determine the effectiveness of the BAFF (Quarterman 2009). DIDSON provides near video quality images for inspection and identification of objects underwater, including in turbid conditions, such as those found in the RDR. The objectives of this monitoring were to assess the effectiveness of the DIDSON camera to detect juvenile salmon passage and behaviour in relation to the BAFF, and if the DIDSON camera was deemed to be effective, therefore assess the effectiveness of the BAFF for deflecting juvenile salmon (Quarterman 2009).

In order to test the effectiveness of the DIDSON camera to detect juvenile salmon releases of marked (dyed) hatchery reared salmon (length 35-50mm, average length calculated from a sample of 61 fish was 44mm) were made to the RDR 20-30m upstream of the BAFF (Quarterman 2009). During these releases the DIDSON camera monitored the water column on the true right side immediately upstream of the BAFF. Four hundred salmon were released in total (two groups of 200), from the true right followed by the true left side of the race (Quarterman 2009).

Approximately 2.5 hours after the first salmon release the DIDSON camera was moved to a point immediately downstream of the BAFF in order to detect any salmon that had passed through the BAFF, and therefore assess its effectiveness (Quarterman 2009). Following this, two further groups of marked salmon, each containing approximately 2300 individuals, were released approximately 500m upstream of the BAFF (Quarterman 2009).

The releases of the hatchery reared salmon took place on the 22 September 2009 from 1130 to 1412 hours (Quarterman 2009). Following the last salmon release DIDSON camera monitoring immediately downstream of the BAFF took place for 18.5 hours (Quarterman 2009) (i.e. until 0845 hours on the 23 September).

Only 10 of the 400 hundred juvenile salmon in the first two releases were detected by the DIDSON camera monitoring immediately upstream of the BAFF for approximately 2.5 hours after the release (Quarterman 2009). Visuals observations made from the bank recorded four of the released salmon being " ... *washed downstream just below the surface.*" (Quarterman 2009). This suggests that these salmon were not in control of their movement. However, one of these four fish did enter the diversion race bypass trap (Quarterman 2009). The remainder of these four fish were swept through the BAFF (Quarterman 2009).

DIDSON camera monitoring upstream of the BAFF does not appear to have been very effective in detecting juvenile salmon following the initial two releases, with only 10 of the 400 released salmon detected.

About 45 minutes prior to the first release of the hatchery reared salmon (i.e. at approximately 1045 hours) the DIDSON camera did however detect approximately 150 'natural run' salmon (Quarterman 2009). Forty-three percent of these natural run salmon went towards the bypass trap, either by active movement or by being washed there, and the remaining 55% went through the BAFF (Quarterman 2009). There is no information available on the length of these fish so it is not possible to determine if fish length was a factor in successful diversion to the bypass.

DIDSON camera monitoring, downstream of the BAFF for 18.5 hours after the second two releases of a total of 4600 hatchery salmon, detected a total of 5211 small fish that had passed through the BAFF (Quarterman 2009). It is not possible to tell from the DIDSON monitoring how many of these salmon were from the hatchery release or from natural runs. However, Quarterman (2009) assumed that the proportion of hatchery released salmon caught in the bypass trap in relation to the total catch could be used to estimate the ratio of hatchery released salmon compared to natural run salmon in those detected by the DIDSON (Quarterman 2009). This relies on several assumptions, including that salmon behaviour is not affected by marking (whether or not this is a fair assumption is discussed in more detail below).

Of the 225 salmon caught in the bypass trap 204 (91%) were hatchery reared fish (Quarterman 2009). Assuming a similar ratio for the DIDSON monitoring, then 4742 of the 5211 fish observed by the DIDSON were hatchery reared fish (the remainder assumed to be natural run fish) (Quarterman 2009). If the 204 hatchery reared fish caught in the bypass trap are added to this then 4946 of the hatchery reared salmon released are accounted for. As this total exceeds 4600 (the number of salmon released in the final two releases), some of the salmon from the first two releases must be included in this total, and this reasoning was adopted by Quarterman (2009). However, if this reasoning is correct, this then raises the question of what juvenile salmon, released in the first two releases, were doing in the one to two hours that elapsed between their release within 20-30m of the BAFF and their detection by the DIDSON downstream of the BAFF. A possible explanation is that these fish were actively avoiding the BAFF but did not find the bypass and eventually became exhausted and were swept through the BAFF. This is speculation, however it does indicate that more detailed information on salmon behaviour in relation to the BAFF is required to determine if juvenile salmon are in fact actively avoiding the BAFF but failing to enter the bypass.

Regardless of whether the 5211 fish detected by the DIDSON as passing through the BAFF were hatchery released or natural run salmon, Quarterman (2009) concluded that as only 225 salmon were caught in the bypass trap over the monitoring period, an indication of the effectiveness of the BAFF to deflect juvenile salmon from the race to the bypass trap is approximately 4%. It should also be noted here though that Quarterman (2009) observed an efficiency of approximately 43% for salmon in the natural run, prior to any hatchery reared salmon releases.

This is perhaps an appropriate point to comment on possible differences in the behaviour of the hatchery reared salmon releases and natural run salmon in the RDR encountering the BAFF, which may provide an explanation for the reduction in the effectiveness of the BAFF observed when hatchery reared salmon were introduced. The hatchery reared salmon were transported to the RDR and dyed prior to their release. The salmon are marked by immersion in neutral red dye for one hour at a concentration of 1:40,000 (pers. comm. Mark Webb, Fish and Game). Trials of the survival of dyed salmon had previously been undertaken to determine the optimum immersion time in order to maximise survival while retaining the ability to differentiate between dyed and un-dyed fish. A dye concentration of 1:40,000 with immersion of one hour was found to be optimal. The mortality rates (percent) of dyed salmon under these conditions are shown in Table 1. Mortality rate varied markedly between the two trials, with 53% mortality reported after 193 hours (8 days) on the first trial and no mortality after the same period in the second trial.

Table 1 *Mortality rates (percent) of salmon dyed by immersion in neutral red dye for one hour at a concentration of 1:40,000. Data provided by Mark Webb, Fish and Game.*

Time elapsed since dyeing (hours)	23 September 2008 (70 salmon, 30-50mm)	14 September 2009 (25 salmon, 34-55mm)
169	0	0
193	53	0
238	-	4
259	-	16
282	-	28
337	100	-
362		48

The dyed hatchery reared salmon are exposed to stress that is likely to alter their behaviour relative to natural run salmon. Hatchery reared salmon are likely to be exposed to slower water velocities during their development than natural run salmon and may not have had sufficient opportunity to acclimatize to water velocities in the RDR (which range from approximately 0.5-0.8ms^{-1} at flows of 15-30m^3s^{-1}) before they encountered the BAFF (being released 20-500m upstream). This, in addition to probably being weakened from the dyeing and transportation process, may mean that they did not have the strength to actively swim to avoid the BAFF. In a hatchery the swimming behaviour of small salmon would be aimed at maintaining their position, rather than actively swimming downstream. If the hatchery reared fish tried to maintain their position in the uniform high water velocities found in the RDR they would eventually become exhausted and be swept downstream to the BAFF, even a momentarily drop in swimming performance is likely to result in them being swept downstream. In contrast, natural run salmon entering the RDR though the Rangitata River intake are more likely to be actively migrating downstream and therefore not attempt to maintain their position upstream of the BAFF for sustained periods. These factors suggest that the use of hatchery reared salmon to test the effectiveness of the RDR BAFF may have resulted in its efficiency being underestimated. This scenario is supported by the observed greater effectiveness of the BAFF in deflecting a small group comprised of only natural run salmon.

Available data on the length of salmon caught at the BAFF and ADC traps during the DIDSON trial was analysed in order to determine if the effectiveness of the BAFF varied depending on fish length. On average the length of hatchery salmon caught in the BAFF trap during the DIDSON trial was 48mm (208 fish), only two hatchery reared salmon were caught in the ADC trap downstream of the BAFF during the trial, they were 38 and 47mm long. The average length of wild salmon caught in the BAFF trap was 46mm (46 fish). Sixteen wild fish (average length of 39mm) were also caught downstream of the BAFF in the ADC trap. This small sample indicates that the average length of the hatchery reared and wild fish is similar, however as the number of fish caught in the ADC trap is small it is not possible to make any conclusion relating to BAFF effectiveness and fish length.

During the salmon migration season RDRML staff undertake daily measurements of the number and length of fish caught in the BAFF and ADC traps. This data is summarized monthly for the periods August 2008-March 2009 and September 2009-January 2010 in Tables 2 and 3. Comparing mean and median lengths and length range of fish caught in the BAFF and ADC traps each month there does not appear to be any evidence of a size difference between fish in the two traps. Comparison of the number of fish caught in the BAFF trap between the 2008/2009 and 2009/2010 season indicates that slightly more fish were caught per day in the 2009/2010 season. A total of 2074 fish were caught over approximately 152 days in 2008/2009 (14 fish per day), while 2098 fish were caught over approximately 122 days in 2009/2010 (17 fish per day). The difference is minor and likely to be due to natural variation in the number of smolt entering the RDR in addition to differences in the monitoring periods between seasons.

Table 2 *Lengths (mm) of wild salmonids (less than 20cm long) caught in the RDR BAFF and ADC traps from August 2008 to March 2009. Data provided by Ben Curry, RDRML.*

Date	Number of fish caught	Number of fish measured	Mean length	Median length	Minimum length	Maximum length
BAFF trap						
3-31 August 2008	642	441	39	35	14	125
1-30 September 2008	471	205	42	36	27	126
1-30 October 2008	536	510	55	55	21	86
2-23 November 2008	341	291	63	62	19	96
14-21 January 2009	28	25	74	74	63	95
12-26 February 2009	18	18	84	81	70	98
1-22 March 2009	38	38	93	92	68	111
ADC trap						
6-31 August 2008	63	63	36	35	30	100
1-30 September 2008	78	76	38	35	30	129
1-30 October 2008	148	117	40	35	29	85
2-23 November 2008	133	94	59	60	32	100
14-21 January 2009	23	15	84	83	70	100
21-26 February 2009	6	6	87	90	75	98
1-22 March 2009	5	5	97	95	95	100

Table 3 *Lengths (mm) of wild salmonids (less than 20cm long) caught in the RDR BAFF and ADC traps from September 2009 to January 2010. Data for the 14 September and 23-30 September have been excluded as releases of marked hatchery fish took place during this time. Data provided by Ben Curry, RDRML.*

Date	Number of fish caught	Number of fish measured	Mean length	Median length	Minimum length	Maximum length
BAFF trap						
8-22 September 2009	244	217	44	42	28	121
1-31 October 2009	775	555	57	56	31	150
1-30 November 2009	612	565	64	62	38	100
1-31 December 2009	365	194	70	69	45	96
15-31 January 2010	102	79	84	84	25	100
ADC trap						
8-22 September 2009	91	75	36	34	31	57
1-31 October 2009	94	86	58	58	32	165
1-30 November 2009	84	80	59	58	33	92
1-31 December 2009	23	22	73	72	50	105
15-31 January 2010	4	3	122	85	85	195

A feature of the DIDSON analysis software allows the determination of what point on the BAFF the majority of the fish passed through, which may indicate a weakness in the BAFF or alternatively simply reflect the channel section with the highest water velocity (Quarterman 2009). By far the majority of the fish (51%) passed through the BAFF at a point 3-4m from the true right bank (Quarterman 2009). The next highest percentage of fish (11%) was detected at points approximately 1.75-3m or 10.25-12m from the true right bank (Quarterman 2009). As the BAFF had been checked and cleaned immediately prior to the DISON trial there is no obvious reason to suspect that there was a weakness in any section of the BAFF. There is unfortunately no information available on water velocities at points across the BAFF during the DIDSON trial. However, the fact that 51% of the salmon detected passed through a 1m section of the BAFF does suggest that that section differed from other sections in some way.

Welton *et al.* (2002) studied the effectiveness of a BAFF to deflect Atlantic salmon (*Salmo salar*) smolt into a bypass in a river in the United Kingdom (River Frome). In their study Welton *et al.* (2002) used 235 replicates, each of four hours duration, which ran continuously through the April/May smolt run (Northern Hemisphere). It was found that the efficiency of the BAFF was higher at night, with 73% of smolts deflected in comparison to 32% during the day. Welton *et al.* (2002) considered that smolt behaviour was likely to be the main reason for the difference, with smolts using visual cues during the day to identify gaps in the bubble curtain that they could pass through. These gaps would be less visible at night (Welton *et al.* 2002). This raises the possibility that covering the BAFF to reduce light levels during the day may increase its effectiveness (Welton *et al.* 2002). An analysis of data provide by Aaron Quarterman on the time of day that each salmon was observed to pass through the BAFF during the DIDSON trial does indicate a slight difference in the number of salmon passing through the BAFF during the day compared to the night, with salmon passing through the BAFF at a rate of 236 fish per hour during the night (defined as the hours between sunset and sunrise) and at rate of 297 fish per hour during the day. However, a trial designed specifically to test this question would need to be undertaken to confirm if any significant difference actually exists.

Welton *et al.* (2002) also observed that the smolts appeared reluctant to enter a darkened tunnel used for monitoring (Fluvarium) in his study. It is possible that juvenile Chinook salmon exhibit the same behaviour as juvenile Atlantic salmon and therefore may be reluctant to enter the RDR bypass to the Rangitata River, which has a darkened entrance. However, again this is only speculation and would need to be confirmed through a targeted study.

During the RDR DIDSON monitoring Quarterman (2009) observed the presence of what is assumed to be a large trout (length 55cm) feeding within 15cm upstream of the BAFF. Quarterman (2009) concludes that this indicates that the acoustic signal and bubbles of the BAFF do not deter adult salmonids. This appears to be true for this individual, however, previous studies of bio-acoustic screens has found that resident fish may become habituated to the presence of sound (Mark Bowen, United States Bureau of Reclamation, http://science.calwater.ca.gov/publications/sci_news_1209_bubble.html, Schilt 2007, O'Keeffe and Turnpenny 2005). This appears to be especially true for predatory resident fish, which gain a benefit from feeding in the area where smaller fish are congregating. As the juvenile salmon are actively migrating downstream when they enter the RDR their exposure to the BAFF is novel and therefore habituation is unlikely to be a factor in their response.

3. Conclusions and recommendations

It should be noted that since the installation of the BAFF, RDRML have undertaken several modifications to improve its effectiveness (Ben Curry, RDRML, pers. comm.). In 2008 the angle of the BAFF was altered (with Fish and Game assistance) to introduce a bend into the last five sections (i.e. closest to the bypass). In 2009 several downstream shrouds were removed from the BAFF units in an effort to decrease the area where sand can collect and block the BAFF bubble jets. The entrance into the bypass was also redesigned to decrease the eddy effect and increase the velocity through the slide gate. Further modifications are planned in September 2010 to raise the BAFF units on 20-30mm pedestals to allow sand to flow underneath. Attempts have therefore been made by RDRML to improve BAFF effectiveness. It is not possible to determine what effect these modifications have had, but it is likely that the modifications to reduce the potential for sand to block the bubble jets are beneficial to BAFF operation.

This review has identified several possibilities as to why the effectiveness of the BAFF is lower than expected, and trials can be designed to test each of these.

The DIDSON camera trial has indicated that the DIDSON is effective in monitoring juvenile salmon passing through the RDR BAFF, however the use of dyed hatchery reared salmon to test the effectiveness of the BAFF may have lead to an underestimation of its effectiveness due to possible differences in the behaviour of dyed hatchery reared and natural run salmon. Marking of the salmon is necessary to allow estimation of how many salmon are diverted by the BAFF, and there are few other options for marking such small fish (although fin clipping may be possible), however if natural run salmon rather than hatchery salmon could be used in the trials that would remove some of the possible behavioural differences.

Monitoring has indicated that the BAFF trap is only reasonably effective in capturing fish; trials have shown that although at least 40% of fish are captured within 30 minutes, several days of monitoring are required to achieve capture rates of 80%. This should be borne in mind when using this trap to monitor BAFF effectiveness. Alternatively, other options for counting the number of fish diverted to the BAFF bypass should be investigated.

The behaviour of salmon as they approach the BAFF and bypass can be monitored in more detail to determine if salmon are actively avoiding the BAFF but then failing to find or enter the bypass and eventually tiring and being swept through the BAFF. This behavioural monitoring should be possible using the DIDSON camera. Collecting information on how many fish enter the BAFF bypass when the BAFF is not operating would also indicate if salmon are simply being swept into the BAFF trap rather than actively entering it.

To clarify if water velocities in the RDR are related to BAFF effectiveness it is recommended that water velocities in front of the BAFF are measured during further trials. If possible, monitoring should also be undertaken during periods of reduced flow in the RDR when approach velocities to the BAFF will be reduced.

DIDSON monitoring can be used to determine if the number of salmon passing through the BAFF varies between day and night. If less salmon are found to pass through the BAFF at night, covering the BAFF in order to reduce light levels could be trialled to determine if this increases its effectiveness.

This review has identified that there are a number of uncertainties associated with the monitoring of the RDR BAFF that has been undertaken to date. In turn, this raises uncertainty in determining the effectiveness of the BAFF. It is therefore recommended that further trials, as described above, are undertaken before recommending any further major changes to fish screening within the RDR.

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