Trial of fish screen effectiveness at Mead irrigation intake, Canterbury.

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Executive summary

Fish screens are present on many irrigation intakes in Canterbury, and have three core fishery functions:

1. To prevent fish from becoming entrained within the irrigation system.
2. To prevent or minimise exposure of fish to physical harm or predation near the intake.
3. To safely divert or “bypass” fish back into the river downstream of the intake.

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

Although screens have been operating on some intakes for many years, there has been uncertainty around their effectiveness. This study was commissioned to measure the effectiveness of the fish screen at the Mead intake, situated near the northern bank of the Rakaia River in Canterbury. The trials were designed to observe how juvenile fish were screened and diverted from the Mead intake, and to assess how the screen performed its functions. The trials comprised releasing hatchery-reared Chinook salmon and rainbow trout just upstream of the screen structure, and then monitoring their fate (i.e., their location) after they encountered the screen.

Screen effectiveness overall was very poor, as at the time of the trial, no fish would have been returned to the Rakaia River because the bypass channel was a “dead end”. Effectiveness might be improved to around 50-60% (depending on size of fish) if the bypass channel was connected to the Rakaia River. Further improvements to effectiveness would require substantial changes to the construction and operation of the screen. Reasons for the poor effectiveness of the screens, and six suggestions to improve effectiveness, are discussed. It is suggested that:

1. The bypass channel is reconnected to the Rakaia River.
2. The screen mesh on the drum is replaces with mesh of smaller aperture.
3. The seals below and on the sides of the drum are made operative.
4. The bypass channel opening is moved closer to the screen.
5. Changes are made to the facility to reduce water velocity through the screen.
6. Consideration be given to installing baffles or shelter for fish upstream of the screen.

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1 Introduction

Irrigation and stock water intakes from New Zealand rivers are required by regulatory agencies (Regional Councils, Fish & Game Councils, and the Department of Conservation) to have fish screens. Screens have three core functions: to prevent fish from becoming entrained within the irrigation system; to prevent or minimise exposure of fish to increased risk of physical harm or predation near the intake; and to safely divert or “bypass” fish back into the river downstream of the intake. Although there is concern for a range of fish species, the issues in Canterbury have mainly concentrated on the risks to juvenile Chinook salmon. This species is susceptible to potential effects from irrigation intakes because small juvenile salmon migrate down braided rivers in the region during spring and summer, with the strong possibility of encountering screens on operating irrigation intakes.

In recent years, the requirement for fish screens at intakes has caused considerable problems for both abstracters of water and the regulatory agencies, as consents for some proposed or existing intakes have been contested on a case-by-case basis, at considerable expense and sometimes to the exasperation of all parties. The problems have mostly arisen over issues around the design and effectiveness of fish screens. Jamieson et al. (2007) developed guidelines for good practice for designing and operating fish screens at irrigation intakes, and recommended suitable screen apertures, water velocities, and fish diversion measures. However, the guidelines are based on theoretical information, mostly derived for overseas situations and fish species, and there has been little or no practical validation of the guidelines in New Zealand. Therefore it has yet to be clearly established if fish screens do, in fact, effectively screen fish in New Zealand, irrespective of whether or not the screen has been designed and operated according to the guidelines.

This report describes the first of a series of trials at fish screens on irrigation intakes in the Canterbury region. The objective of these trials was to test the effectiveness of screens, using live fish at an operating screening facility. Observing how fish react, and monitoring their fate, will give practical insight as to how well the fish screen performs, and whether it fulfils its core functions Individual elements of fish screen effectiveness were assessed against the following five guideline criteria outlined in Jamieson et al. (2007).

- **Screen apertures**: were fish prevented from penetrating the screen and becoming entrained (trapped) in the irrigation system?
- **Approach velocity**: was the water velocity onto and through the screen (the approach velocity) low enough so that fish could escape the screen by swimming upstream against the flow?
- **Sweep velocity**: were fish diverted away from the upstream side of the screen by a flow moving across the screen and toward a diversion?
- **Bypass**: did fish locate and use a bypass, and did the bypass return fish safely to the river?
- **Operation and maintenance**: was the screen operated and/or maintained in a manner that ensured its effectiveness as a screen?

An overall assessment of effectiveness of the screen facility is based simply on the proportion of fish which encounter the intake and are successfully (i.e., safely) transferred back into the river of origin. The conclusion of this report includes discussion on methods to improve screen effectiveness where appropriate.

2 Methods

2.1 Site description

The Mead irrigation screen is located on an irrigation raceway near the northern bank of the Rakaia River, Canterbury, about 500 m upstream of the SH1 bridge at NZTM: 1522482E 5157341N. Water is diverted from the Rakaia River, and flows down a raceway to a rotating drum screen which is 1.2 m in diameter and covered in stainless steel mesh with apertures c. 5mm wide. The drum is set within a formed concrete section of raceway c. 2 m wide by c. 15 m long, with the drum being fixed in place close to the downstream end, so that the mesh on the drum is at a right angle to the flow of water down the race. There is a bypass channel on the true right (TR) side of the concrete wall c.3.2 m upstream of the face of the drum. The bypass consists of a vertical slot in the concrete wall, with an opening c 0.12 m wide that provides a flow of water into an open, gravel- bottomed channel that moves in a roughly southerly direction towards the Rakaia River (Figures 2-1 to 2-3).

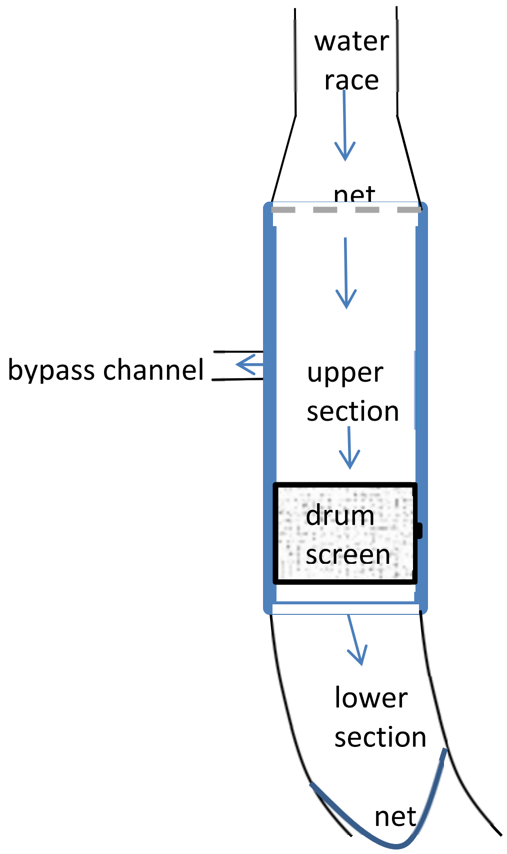

Figure 2-1: Sketch plan (not to scale) of the Mead intake screen. Concrete structure denoted by thick blue lines; water flow by blue arrows.

Figure 2-2: A view of the Mead screen facility, without water flowing. Looking upstream from behind the drum screen; the opening to the bypass channel is visible centre left**.**

Figure 2-3: Close up of the opening to the bypass channel. Flow into the bypass is controlled by the movable “guillotine” gate, which is at a typical setting during operation**.**

During the trials the flow of water through the screen was estimated by gauging to be between 363 and 406 litres per second (see section 4-1). Just upstream of the screen the water was c. 0.46 m deep, and average water velocity approaching the screen ("approach velocity") was c. 0.45 $m \cdot sec^{-1}$.

2.2 Operating trials

Two separate trials were undertaken on successive days. For both trials, a fine mesh net was positioned on the trash-rack upstream of the concreted section of raceway to isolate the area upstream of the drum. This prevented trial fish from escaping upstream, and also prevented wild fish from moving downstream into the trial area. The netted-off area between the trash rack and the drum is referred to as the upper section. A net was also placed across the race c. 28 m downstream of the drum to collect any trial fish that moved downstream through or past the drum; this area is referred to as the lower section. Before both trials the upper and lower sections were electrofished to remove resident "wild" fish and/or any fish remaining from a previous trial.

For each trial 1,000 juvenile hatchery-reared fish were released into the upper section of raceway upstream of the drum (nb. fish were used only once). Each release of fish comprised 500 juvenile rainbow trout (c. 25 to 35 mm in length) and 500 juvenile Chinook salmon (c. 60 to 80mm in length).

2.2.1 Trial 1: 13 & 14 December

For this trial, the bypass gate was closed, so that there was no fish bypass. Following the release of fish into the upper section, fish behaviour was observed, and fish were collected on the drum screen and in the downstream net. Fish were released at 1605 h, at this time the water in the race was clear and warm (probably > 20^{o}C). On the 14 December, remaining fish were collected separately from the nets, and by electric fishing, from both the upper and lower sections

2.2.2 Trial 2: 14 & 15 December

For this trial, the bypass gate was opened so that a bypass was available to fish. A net was placed across the bypass channel 3.7 m downstream of the opening. The upper and lower sections had been electrofished at the conclusion of trial 1, and further electrofishing of the bypass channel was conducted before trial 2 commenced (electrofishing was done to remove any wild fish and any fish remaining from the previous days trial). 500 juvenile trout and 500 juvenile Chinook salmon were released into the raceway upstream of the drum at 1415; at this time the water in the race was cool and so discoloured that no fish behaviour could be observed. On the 15 December, the water supply through the race was stopped, and remaining fish were collected from the nets and by electric fishing from all sections of the raceway, including the bypass channel.

3 Results

3.1 Water velocities and flow

During the trials, water depths and velocities were measured just upstream of the screen so that the approach velocity (i.e., the velocity of water approaching and passing through the screen) could be calculated (Table 3-1). Four measurements were taken at each 0.5 m interval across the channel: water depth; water velocity near the surface, water velocity near the bottom, and water velocity at 60% of the depth. The last measurement, at 60% of the depth, is commonly used to represent the average velocity of the entire water column. During trial 2, water depths and velocities were also measured in the bypass channel.

Table 3-1: Water depths and velocities immediately upstream of the screen during trials 1 and 2, and in the bypass channel (trial 2 only).

Trial	Distance from TL	Water depth (m)	Water velocity near bottom ($msec^{-1}$)	Water velocity near surface ($msec^{-1}$)	Water velocity at 60% depth ($msec^{-1}$)
1	0	0.47	0.14	0.28	0.35
	0.5	0.465	0.36	0.5	0.5
	1	0.46	0.4	0.54	0.49
	1.5	0.46	0.42	0.5	0.48
	2	0.455	0.12	0.37	0.38
	mean	0.462	0.29	0.44	0.44
2	0	0.475	0.17	0.39	0.34
	0.5	0.475	0.31	0.48	0.41
	1	0.47	0.38	0.51	0.45
	1.5	0.475	0.38	0.5	0.48
	2	0.48	0.21	0.35	0.23
	mean	0.475	0.29	0.45	0.38
2					
bypass	0	0.345	0.07	0.05	0.08
	0.25	0.345	0	1.31	0
	0.5	0.345	0.12	0	0
	mean	0.345	0.06	0.45	0.03

The amount of water passing through the 2 m wide channel immediately upstream of the screen was estimated using mean water depth and mean water velocity at 60% depth. For trial 1 the flow (discharge) through the screen was estimated to be 0.406 $m^{-3}sec^{-1}$ (i.e., 406 litres per second); for trial 2 the flow (discharge) through the screen was estimated to be 0.363 $m^{-3}sec^{-1}$ (i.e., 363 litres per second). The flow down the bypass channel during trial 2 was estimated at 0.005 $m^{-3}sec^{-1}$ (i.e., 5 litres per second), however this estimate may be quite inaccurate, as the gauging was performed in a small channel where flow was clearly not uniform (water velocities ranged widely from 0 to 1.31 $m \cdot sec^{-1}$).

3.2 Numbers of fish recovered

The numbers of fish that were released and subsequently recovered during and after each trial are summarised in Table 3-2.

Table 3-2: Numbers of fish in the trials. Numbers of fish (by species) released in each trial, and numbers and percentage recovered.

Trial	Species	No. released	No. and (%) recovered
Trial 1	Chinook salmon	500	135 (27.0%)
	Rainbow trout	500	0 (0%)
Trial 2	Chinook salmon	500	200 (40.0%)
	Rainbow trout	500	58 (11.6%)
All	Chinook salmon	1,000	335 (33.5%)
	Rainbow trout	1,000	58 (5.8%)

3.3 Location (fate) of fish recovered

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. Numbers of fish (by species) released in each trial, and numbers and percentage recovered.

Trial	Location recovered	No (and %) of fish 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)

3.4 Size of fish recovered

Not all of the fish that were recovered could be subsequently measured, however a summary of length measured in each location is presented in Table 3-4.

Table 3-4: Size of fish recovered. Length (in mm) of fish recovered by location and by trial.

Species	Location	Trial	n	Mean length (mm)	Std. deviation
Chinook salmon					
	Dead on screen	1	30	71.8	7.85
	Lower section	1	26	93.8	5.69
	Lower section	2	35	67.8	8.57
	Upper section	1	13	83.5	14.32
	Upper section	2	28	66.3	8.57
	Bypass	2	29	66.1	8.87
Rainbow trout					
	Lower section	2	29	30.3	2.8
	Upper section	2	1	26	-
	Bypass	2	12	27.3	2.1

3.5 Observations

3.5.1 Trial 1

Within a few minutes of being released into the top section, Chinook salmon were observed just upstream of the screen, where they attempted to hold station by swimming against the flow. Many of these salmon soon became exhausted and were held side-on to the screen by the current, and then died (Figure 3-1). Some of the dead fish were recovered by hand, others remained on the screen as it rotated, and were subsequently transferred to the downstream section.

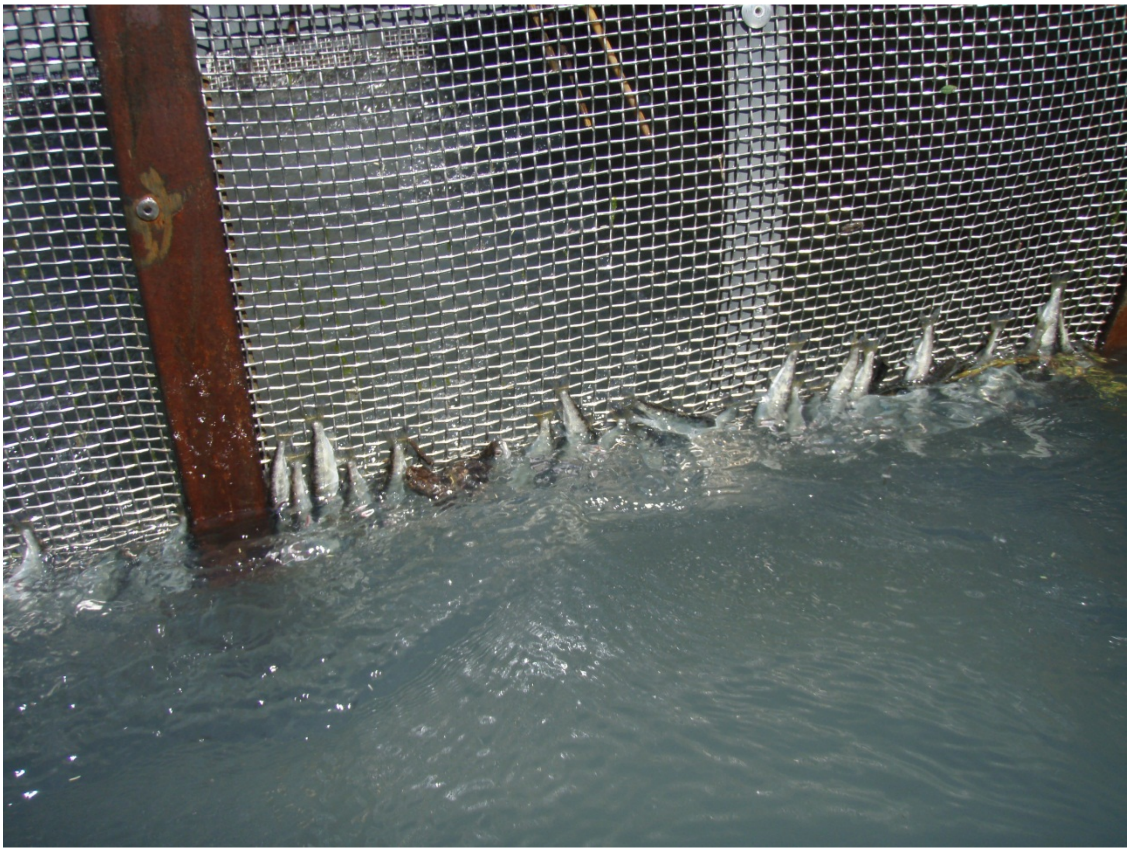

Figure 3-1**: Chinook salmon trapped on the upstream side of the drum screen.**

Of the 135 Chinook salmon that were recovered at the completion of the trial, 13 (9.6%) were in the top section, 94 (69.6%) were found dead on the screen, and 28 (20.7%) were downstream of the screen. Many rainbow trout were observed moving downstream of the screen (i.e., they had either penetrated or avoided the screen), but were not subsequently found in the downstream net or collected by electrofishing. No rainbow trout were recovered from this trial.

3.5.2 Trial 2

Few observations of fish were made, as the water was discoloured. Of the 200 Chinook salmon recovered, 126 (63%) were recovered in the bypass channel. A further 28 (14%) had remained in the top section and 46 (23%) had moved downstream through or around the screen into the bottom section.

Of the 58 rainbow trout recovered during this trial, 28 (48%) were recovered from the bypass channel, 1 (2%) had remained in the top section, and 29 (50%) had moved downstream through or around the screen into the bottom section.

No dead fish were observed on the screen drum during this trial, but the turbidity of the water did not allow observations of fish behaviour in the water.

4 Discussion

4.1 Screen performance against guideline criteria

The performance of the Mead screen was compared to five guideline criteria as outlined in Jamieson et al. (2007).

4.1.1 Aperture (mesh) size

An inherent property of an effective fish screen is that the screen mesh is of sufficiently small aperture to prevent fish penetrating the screen. The rotary drum on the Mead intake screen is of mesh that is c. 5 mm side-of-square, which is about twice the size required to prevent the passage of small (30 mm long) salmon and trout.

During both trials rainbow trout and Chinook salmon were observed or caught downstream of the drum screen soon after being released upstream; the trout were mostly around 30 mm long and were thus small enough to have penetrated the screen. However it was not possible to determine if the rainbow trout that moved downstream of the screen had done so by penetrating the mesh, or had moved round the screen via gaps in the seals. The Chinook salmon, which were roughly twice the size of the rainbow trout, were too large to penetrate the screen. This leads to the inevitable conclusion that the fish were able to avoid the screen by swimming under it or around it, probably because the seals on the bottom and sides of the drum were not functioning properly. During Trial 2, when the water was turbid, sticks and debris in the header race were also observed to be washed downstream of the drum, which supports the notion that the seals were not working properly.

4.1.2 Approach velocity

Approach velocity is the term used to describe the speed of water immediately upstream of a screen. It is important that the approach velocity is low enough to allow fish to swim upstream against the flow, and escape from the screen. If a fish cannot sustain a swimming speed greater than the approach velocity it will become exhausted while trying to escape, and them become (fatally) impinged on the screen. A fish's sustained swimming speed is proportional to its length, i.e., larger fish can maintain a higher speed. The "rule of thumb" is that water approach velocities at a screen should be no greater than four times the body length of the fish each second (Clay 1995). For the rainbow trout used in these trials, which were about 30 mm long, the approach velocity should have been no greater than 120 mm per second (or 0.12 $msec^{-1}$). Similarly for the Chinook salmon used (about 80 mm long) the approach velocity should be no greater than 0.32 $msec^{-1}$.

It is clear that approach velocity at the Mead screen (average 0.38 to 0.44 $msec^{-1}$) during the trials was too high, even for the larger Chinook salmon. This is corroborated by the observation during Trial 1 of Chinook salmon swimming in front of the screen for some time before becoming exhausted then dying on the screen. The exhaustion and subsequent death of these fish was very likely to have been partly associated with the high water temperature during trial 1, and possibly also by insufficient acclimatisation of the trial fish before release, as both of these factors influence a fishes swimming performance (Farrell 2007; Griffiths and Alderdice 1972). However, the fact remains that the water approach velocity was much greater (roughly three times) than that recommended for small salmon and trout.

4.1.3 Sweep velocity

The term "sweep velocity" refers to the velocity of water sweeping across the screen (i.e., at right angles to the flow of water through the screen). Sweep velocities should be greater than approach velocities, in order to sweep fish from upstream of the screen into a bypass system. There was no apparent "sweeping" flow across the Mead intake screen, as the bypass entrance was 3.2 m upstream of the screen.

4.1.4 Bypass provision and connection

Although the bypass entrance was too far upstream to provide a sweeping flow of water across the screen, some fish managed to find the bypass and utilise it. In trial 2 about two-thirds of the Chinook salmon and half the rainbow trout utilised the bypass. While this shows that bypasses can work, it is unfortunate that fish entering the bypass channel were unlikely to be returned to the Rakaia River – the bypass channel from the Mead intake diverts fish to a second raceway and screen, and the bypass channel from the second screen disperses amongst an area of willows without providing connection to the main river.

4.1.5 Screen operation and maintenance

The screen facility appeared to be well operated and maintained, and the mesh on the drum was in good condition. However in both trials more than 20% of Chinook salmon found their way past the screen – they were too large to have penetrated the mesh, and therefore must have found their way past the seals on the sides or bottom of the drum. This was corroborated by the observation of sticks and debris moving past the drum during trial 2.

4.2 Overall performance/effectiveness

The overall measure of screen effectiveness is simply the proportion of fish encountering the screen which are returned to the river of origin. The trials demonstrated that the Mead intake screen was ineffective at the time of the trial, as no fish would have been returned to the Rakaia River because the bypass channel was a "dead end". Effectiveness might be improved to around 50-60% (depending on size of fish) if the bypass channel was connected to the Rakaia River; further improvements to effectiveness would require substantial changes to the construction and operation of the screen as outlined in the following section.

4.3 How might effectiveness be improved?

There are six ways that the performance of the Mead screen might be improved:

1. The single most effective improvement is obvious: ensure that the bypass channel returns fish to the Rakaia River with minimal harm. This is probably mainly a maintenance issue, with connections between the river and bypass channels needing to be maintained. However, returning fish to another raceway and subjecting them to another screening process does risk cumulative loss. Without a return connection to the river of origin, improving any other aspects of the screen's performance is pointless.

2. Replace the existing mesh on the drum with mesh of smaller aperture (2.5 mm or 3 mm). This will prevent small fish (e.g., 30 to 40 mm long trout and salmon) penetrating the screen and becoming entrained (lost) in the irrigation system.

3. Ensure the seals on the bottom and edges of the drum screen are effective and operating
4. Ensure the bypass channel opening is adjacent to the screen, so as to create a sweeping flow across the screen and thus to sweep fish into the bypass. This should ensure that a greater proportion of fish are diverted into the bypass. The existing bypass opening is 3.2 m upstream of the screen so that there is little chance of fish being passively swept into the bypass. Ideally the entrance to the bypass should be full height (i.e., from the base of the raceway to the water surface) and open at the surface (i.e., not enclosed); this is important as some fish, notably juvenile salmon and trout, are known to avoid closed bypass structures such as pipes.
5. Reduce the water velocity through the screen (i.e., reduce the approach velocity). A substantial reduction is required, as a velocity of more than 0.4 $m \cdot sec^{-1}$ is about three times too fast. Reduction of approach velocity could be achieved by either reducing the volume of the irrigation take (to about a third of what was taken during the trials), or by increasing the surface area of the screen. The most practical way of increasing the surface area is probably by increasing the depth of water in the structure. Using finer mesh screen material will increase the water depth slightly; however substantial increases in depth will probably require the use of “dam boards” placed downstream of the screen. Unfortunately this may require the concrete work all around the screen structure to be raised considerably in height to contain the increase in water depth.
6. Including baffles or other small structures upstream of the drum may cause turbulence and thus provide some “shelter” for fish in created areas of slower flows. However without any other improvements being made to screen performance, this approach may only serve to delay the inevitable demise of fish. It is also likely that installing baffles and/or shelter would cause some operational problems, as debris and leaves would accumulate around them.

5 Acknowledgements

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