Testing the Effectiveness of Fish Passage Solutions

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1   Introduction

Many of the migratory fish species in New Zealand appear to be declining in both abundance and distribution across their ranges (Goodman et al. 2014). Apart from the degradation of adult habitats, one of the most significant causes of the decline in freshwater fish populations in New Zealand is the construction of in-stream structures such as culverts, weirs and tide gates that prevent migratory fish from accessing critical upstream habitats. As such, remediation of migration barriers to restore longitudinal habitat connectivity and to re-establish fish populations is an integral component of river restoration.

In the Manawatu Region, a series of perched culverts and weirs that are preventing or restricting fish passage have been identified and prioritised for remediation. Significant investment is often required to retrofit structures to promote fish passage, and therefore it is important to ensure that solutions are likely to be effective in restoring passage for the target fish species. In this regard, any retrofit solution that is being installed to restore fish passage at barriers requires robust and repeatable testing to ensure it is fit for purpose prior to widespread installation.

This report describes methods suitable for evaluating the effectiveness of retrofit solutions for enhancing fish passage. These methods can be used to ensure that solutions are fit for purpose and fulfil objectives for improving upstream fish communities. This provides greater certainty for regional councils and other land owners that their investments are optimised and are effective. A case study is also presented of a site in the Manawatu Region where these methods have been applied. As trials to test the effectiveness of retrofits at two further sites in the Manawatu Region are planned for spring 2015, guidance and reference to applying methods at these sites is also provided.

2 Retrofitting structures for fish passage

Retrofitting existing in-stream structures is the most cost-effective means to restoring habitat connectivity for fish. However, to be effective at promoting fish passage, the retrofit implemented needs to account for fish behaviour, fish swimming ability, the receiving environment and the engineering constraints at each site. Each site's suitability for fish passage should be assessed according to the characteristics of the site and the type of fish passage problem that exists. As each potential barrier is different, and the species to be catered for are not always the same, passage solutions will tend to vary from site to site.

For streams prone to floods and erosion, such as many waterways in the Manawatu, back-filling the weir or culvert outlet with rock and cement to create a rock-ramp can effectively promote passage of both swimming and climbing fish species. This technique is advantageous for flashy dynamic streams as the solution is long lasting and retains a natural look against the surrounding landscape. Presently, rock-ramps have been retrofitted to perched culverts at two sites in Kara Stream (Figure 2-1), and these fishways are planned to be installed at several other sites in the Manawatu Region.

Figure 2-1:   Rock-ramps created to enhance passage of both swimming and climbing fish species in Kara Stream, Manawatu. A, Upper Kingston Road culvert before remediation. B, Upper Kingston Road culvert after remediation. C, Lower Kingston Road double culvert before remediation. D, Lower Kingston Road double culvert after remediation.

3   Monitoring the effectiveness of fish passage solutions

Even when best practice guidelines are followed, it is important to adopt a monitoring programme to ensure a retrofitted structure is fit for purpose and operating as designed. This is particularly important when retrofit solutions form only one component of an in-stream structure. For example, remediating a perched culvert with a rock-ramp will provide access for fish to the culvert outlet, but the culvert barrel itself may present a further migration barrier. Therefore, testing the effectiveness of each component of the in-stream structure, e.g., rock-ramp *and* culvert, will provide certainty as to whether fish are effectively passing the overall structure and consequently enhancing upstream fish communities.

There are two recommended monitoring approaches for evaluating fish passage success at an in-stream structure: a before-after-control-impact (BACI) survey, and an in-situ mark and recapture study. Both the objectives and timeframe of the fish passage remediation works will inform which monitoring approach is appropriate for a given site or solution. The main benefits and drawbacks of the two approaches are outlined in Table 3-1.

Table 3-1:   The main benefits and drawbacks of before-after-control-impact (BACI) and mark and recapture monitoring approaches.

Monitoring	Benefits	Drawbacks
BACI survey	Documents changes to fish communities upstream of the remediated structure	Can take several years to determine if the remediation is effective
	Minimises handling and stress to fish species	If the retrofit is unsuccessful in promoting fish passage no information is provided on which component of the remediated structure is still problematic
Mark & recapture study	Test different components of an in-stream structure independently and collectively	Fish are subjected to handling and stress which may affect passage success
	Immediate results on the effectiveness of the solution	Does not document changes in upstream fish communities

The following sections outline key aspects of these two methodologies.

4 BACI survey

Where the objective is to evaluate the effects of improved connectivity on upstream fish communities, the recommended long-term approach to monitoring would be to utilise a before-after-control-impact (BACI) survey design. This is where fishing surveys are undertaken both downstream (control) and upstream (impact) of the structure before and after remediation is carried out. A BACI survey coupled with mark and recapture trials would provide the most robust assessment of a fish passage retrofit.

4.1 Methodology

Fishing methods at the downstream and upstream sites should follow the National Freshwater Fish Sampling Protocols by Joy et al. (2013). However, there are two caveats to utilising the electric fishing protocol suggested by Joy et al. (2013):

Stop nets. The standardised electric-fishing protocol does not utilise stop nets at the start and end of the survey reach. Recent works by Crow and Jellyman (2014) have indicated that population estimates generated without stop net catches will underestimate fish abundance by 12-25% depending on the time of year. Therefore, utilising stop nets will provide a more accurate representation of the fish community at the survey sites.

Fish density assessment. The standardised electric-fishing protocol utilises a single pass, which is a semi-quantitative method. Therefore, the results generated are the relative abundance of fish species, which is not equivalent to fish density and can only be used for a relative comparison between sites. Multi-pass depletion fishing would need to be utilised to generate population estimates and fish densities, therefore allowing a quantitative comparison of fish communities before and after remediation of the passage barrier and improved detection of trends in populations over time. Should multi-pass depletion fishing be carried out, the recommended protocol is as follows:

- Utilise a 50 m reach at each site.
- Set stop nets should be used at the top and bottom of each reach.
- Carry out multiple electric-fishing passes until there is at least a 50% reduction in the catch of each fish species compared with the previous pass. Generally, three passes are the minimum necessary.
- Fish and habitat information (e.g., fish lengths, wetted stream widths) would still be collected as detailed in Joy et al. (2013), but with five 10 m sub-reaches assessed instead of ten reaches.

For three pass depletion fishing, population estimates for each species in the reach can then be calculated using the explicit approximation of the maximum likelihood formulae from Cowx (1983):

Population estimate $N_o = (6X^2 − 3XY − Y^2 + (Y \times \sqrt{(Y^2 + 6XY − 3X^2)})) / (18 \times (X-Y))$

Where $X = 2c_1 + c_2$ and $Y = c_1 + c_2 + c_3$ and c_n = the number of fish captured during n pass.

The density of each fish species in each section can then be calculated by dividing the population estimate by either the length of stream fished, to give the number of fish per linear metre of stream, or the stream area, to give the number of fish per metre square.

It should be noted that if a different electric-fishing method from that of Joy et al. (2013) is employed, it will provide more detailed information on fish communities in the survey stream, but these data will not be comparable to other areas where the standardised approach has been utilised e.g., for state of the environment monitoring.

4.2   Frequency and timing

As recruitment of diadromous fish species can show annual variation, and migrations of juveniles tend to be seasonal, it can take several years of monitoring to detect the change in biodiversity and fish abundance attributable to the remediation. At any given site, there is also considerable temporal variation in most fish species' abundances. To help account for this, we would recommend annual surveys of the upstream impact site in the same month each year until results are clear. Where possible it is recommended that surveys should be carried out between December and April inclusive (Joy et al. 2013). Use of quantitative multi-pass survey methods will further enhance the ability to detect real changes in fish numbers over time.

5   Mark & recapture study

A mark and recapture study would be recommended if a particular fish passage solution is to be installed across a range of sites, the effectiveness of the solution has not been demonstrated in practice, and/or if only one component of the structure is retrofitted and other unmodified aspects may still represent an impediment to migratory fish. For example, remediation of perched culverts commonly entails retrofitting a fish pass to the culvert outlet, yet the culvert barrel or transition from the fish pass to inside the culvert may still represent an impediment or barrier to certain fish species.

Because this type of study requires the stream to be barricaded at the top and bottom of the test reach, it is difficult to carry out in large non-wadable rivers and streams, or streams with high discharges and water velocities. For larger, high flow systems a BACI survey using nets and traps would be more applicable.

5.1   Target species

To ensure the fish pass is effective for all target species, mark and recapture trials should focus on the weakest species that requires passage. If passage of swimming fish is desirable, juvenile inanga are the benchmark species to use if present in the catchment. If passage of climbing fish is the objective, then juvenile redfin bullies are the least adept climbing species. If redfin bullies are not present in the catchment, then utilise juveniles of the weakest climbing galaxiid(s) present. Of the four diadromous galaxiids capable of climbing, their ability to surmount in-stream obstacles in ascending order would be: giant kokopu, shortjaw kokopu, banded kokopu, and koaro. As obtaining large numbers of identifiable shortjaw and giant kokopu whitebait is difficult and/or costly, either banded kokopu or koaro juveniles would be recommended.

5.2   Fish capture and maintenance

It is important to test the life-stage of the target species that reaches the in-stream obstacle. For example, the perched culvert on Kara Stream, Upper Kingston Road (described in the case study in Section 6), is more than 30 km from the sea. Therefore, inanga reaching these culverts will be pigmented, feeding fish (post-whitebait/juvenile) with stronger swimming abilities than fresh-run whitebait. In this regard, the site of capture for test fish should be representative of the test location. In the upcoming trials examining inanga passage past the culverts in Waterfall Creek and Kara Stream (Lower Kingston Road), using post-whitebait/juvenile fish as opposed to fresh run whitebait is recommended.

It is desirable to capture test fish using nets and traps rather than electric-fishing. This is to minimise the physiological damage to fish that is likely to influence passage performance.

To reduce stress and increase performance of the test fish, it is recommended to hold all fish in the stream they are to be tested in. This is because previous trials carried out by NIWA have indicated that fish held in a different water supply to that of the test system, display reduced upstream movement, which could relate to detectable changes in water quality. We recommend holding fish in purpose built live-bins that provide an adequate transfer of fresh aerated stream water (Figure 5-1). Bins should be secured in a pool that provides deep water without excessive water velocities (Figure 5-1). Ensure the lids are cable tied onto the bins otherwise whitebait can push their way out. Test fish should be held for at least 24 hours to habituate and recover from capture and handling prior to colouring in the dye solution. Although experimental releases should be timed with appropriate

weather and flow conditions, it is advisable to not hold fish for longer than a week before using in trials.

Figure 5-1: **Live-bins deployed in Kara Stream to maintain inanga for fish passage trials.** Inset shows close up of live-bin.

5.3 Fish marking procedure

Mark test fish by immersion in a solution of Rhodamine B or Bismarck Brown. By colouring fish in both dyes, it provides two replicates of test fish that can be trialled simultaneously, under the same environmental conditions. In the case study of the Upper Kingston culvert (Section 6), where next to no inanga were present in Kara Stream at the time of carrying out the mark and recapture trials, unmarked inanga could also be released as a third replicate. These fish also act as a control for the marked fish as they haven't had the additional stress of staining, and are not more visible to predators. Unmarked fish should only be used as test fish in situations where these fish are not naturally occurring in high numbers, and therefore cannot infiltrate the test reach and confound results. In upcoming trials examining inanga passage past the culverts in Waterfall Creek and Kara Stream (Lower Kingston Road), it would be appropriate to use unmarked inanga as a third replicate.

For each trial, utilise between 100 and 200 fish per replicate. However, if only low numbers of test fish are able to be reliably captured (i.e., such as banded kokopu whitebait) then using 30-50 fish per replicate will suffice.

To stain fish:

- In the shade adjacent to the stream, set up a separate bin containing 50 litres of stream water (to stain up to 500 fish) for each dye solution.

- To increase survival and buffer the solution, add aquarium salts (sold in pet shops to make salt water) to produce a salinity of c. 18-20‰.

- Add 10 g of Rhodamine B[1] (0.2 g/L) or 2.5 g Bismarck Brown[2] (0.05g/L). Wear gloves when handling both dyes. Refer to the MSDS for each compound to ensure safe practices are adhered to. Rhodamine B colours fish pink, and Bismarck brown colours fish orange (Figure 5-2).
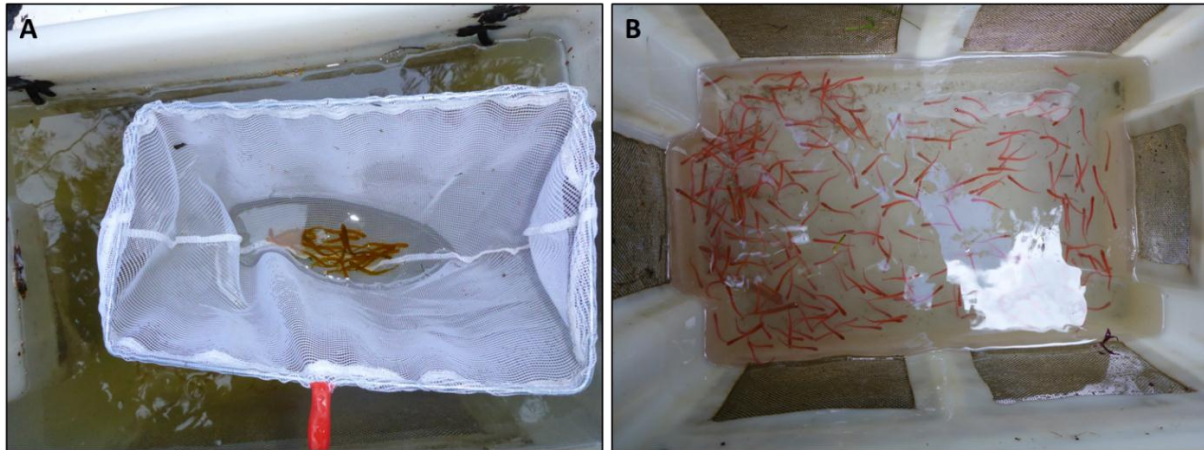
Figure 5-2: **Fish coloured orange with Bismarck Brown (A) and pink with Rhodamine B (B).**

- Aerate the solution well with a portable air supply system. This will require more than a small 3 or 6 volt battery powered air bubbler. Use a dive cylinder and adapted regulator or portable 12 volt air compressor unit.

- Determine the stream water temperature and add ice as necessary to the dye solutions to maintain the water at ambient stream temperature.

- For fish in Rhodamine B, remove after 2 hours, and for fish in Bismarck Brown, remove after 1 to 1.5 hours. Hold coloured fish overnight in live bins to recover before trials. After removing the fish, discard the waste solution onto the bank. Do not pour it into the stream.

- Wear gloves whilst removing fish, discarding waste solutions and cleaning bins and dip nets.

For each experimental trial, it is advisable to hold 10% of the marked fish in a live-bin as 'control' fish to verify mortality attributable to the colouring procedure.

5.4   Timing

A critical aspect of mark and recapture trials is timing. That is, carrying out the trials during base flow in the study stream, under a high pressure front that will limit rainfall and subsequent rises in stream discharge over the trial period. This is not only because the barricades and trap can get washed out, but also because fish species such as inanga may alter their behaviour during changing flow conditions, which will disrupt trial results.

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[1]http://www.sigmaaldrich.com/catalog/product/sigma/r6626?lang=en&region=NZ&gclid=Cj0KEQiAw PCjBRDZp9LWno3p7rEBEiQAGj3KJgIsyxGXuruPdLVT5O5k7MEP9-rFYmNe--7qRJcTBOIaAkMt8P8HAQ

[2] http://www.sigmaaldrich.com/catalog/product/sigma/15000?lang=en&region=NZ

5.5   Trial design

At some culverts, monitoring the effectiveness of the rock-ramp retrofits will require separating passage through the culvert from passage over the ramp. This ensures that the culvert itself is not an additional obstacle, and allows the effectiveness of the rock-ramp to be assessed independently of the culvert influence, as well as when paired with the secondary obstacle. This was particularly important in the case study at Upper Kingston Road, as the culvert had baffling installed that had not previously been field tested for passage of juvenile inanga. If a resting pool is present between the rock-ramp and the culvert outlet, this provides a means of easily separating the rock-ramp trials from the culvert trials (i.e., fish can be trapped in the pool and/or at the culvert inlet). For structures such as the Kara Stream culvert at Upper Kingston Road, the absence of a resting pool directly downstream of the culvert outlet makes separating each component challenging, and the recommended approach would be that carried out in September 2014:

- Examining fish passage through the culvert only.

- Examining fish passage over the entire structure; rock-ramp and culvert.

This will control for the culvert influence and allow the effectiveness of the ramp to be determined.

In some cases, multiple culvert barrels may be present in which case the trial design must be adapted. The recommended approach would be to test the two culverts and any associated retrofits collectively to determine what proportion of fish select, and successfully pass, each culvert. For these tests, a whitebait trap would need to be deployed at the inlet (upstream end) of each culvert.

5.5.1   Kara Stream – Lower Kingston Road

At the Kara Stream double culverts (Lower Kingston Road), two approaches could be utilised. The recommended approach would be that described above, to test the two culverts and rock-ramps collectively to determine what proportion of fish select, and successfully pass, the true right culvert with the higher flow and spat rope and baffles installed, compared with the true left culvert with lower flows and no baffling installed. As previously stated, for these tests, a whitebait trap would need to be deployed at the inlet of each culvert.

Alternatively, or additionally, passage through the true right culvert with the spat ropes and baffles could be tested independently. Here, a temporary pool would need to be created in the rock-ramp below the culvert outlet (Figure 5-3). Sandbags and/or rock (lined with mesh) can be used to form the pool boundaries. However, the pool should be kept shallow (20 – 40 cm) to prevent significant increases in the water level within the culvert. If deemed necessary, place one or two large boulders in the pool to ensure low velocity refuge areas are present. This approach will determine the effectiveness of the spat ropes and baffles in promoting inanga passage through the culvert, but will provide less information on how effective the whole system is in promoting inanga passage.

Figure 5-3: **Recommended area to create a temporary pool to facilitate testing inanga passage through the baffled culvert in Kara Stream at Lower Kingston Road.** Utilise sandbags and/or rocks to form the pool boundary.

5.5.2 Waterfall Creek

Because of the shallow water depth and larger width of Waterfall Creek, it will be difficult to effectively separate the culvert from the rock-ramp. Therefore, the box culvert and rock-ramp should initially be tested together. Results of the trials will inform if additional testing is necessary, as well as appropriate approaches.

5.6 Barricades

Install a barricade at the bottom of the test site to prevent fish escaping downstream or stream fish moving upstream. A seine net or whitebait mesh form suitable barriers (Figure 5-4). It is important to dig the bottom of the mesh into the substrate and cover with boulders to try and create a secure barrier. If possible, the top of the mesh can be secured to trees on the stream banks (Figure 5-4B), otherwise waratahs or stakes will need to be utilised (Figure 5-4C). Installing a second net downstream as a back-up is also advisable (Figure 5-4). The barrier should be installed below the pool at the base of the rock-ramps to provide fish with a low velocity area to rest before ascent. Note: each retrofit rock-ramp should have rock weirs installed downstream to create a pool at the base of the ramp (Figure 5-4B & C) to dissipate energy and prevent erosion.

Figure 5-4: **Downstream barricades installed in Kara Stream during the inanga passage trial.** A - C Barrier nets deployed during the rock-ramp trial. D, Barrier nets deployed for testing inanga passage through the culvert independently of the rock-ramp.

At the top end of the test site, a whitebait trap and barrier net also needs to be installed (Figure 5-5). Ensure the trap is weighted down to avoid any movement with increases in water flow.

Figure 5-5: **Whitebait trap installed at the culvert inlet in Kara Stream.**

At the double culvert on Kara Stream (Lower Kingston Road), a separate trap and whitebait mesh should be used at the inlet of each culvert.

At the box culvert in Waterfall Creek, the whitebait trap should be set at the margin of the culvert inlet where the main flow is located, with a seine net or whitebait mesh wing extending to the opposite stream margin.

5.7   Measurements

5.7.1   Flow

It is important to record the flow at the time of the trials. If the study stream does not have a water level recorder installed, a flow gauging can be carried out on each day the trials are being undertaken. A flow gauging will require:

- A current meter.

- A gauging rod.

- Tape measure.

If you are unfamiliar with flow gaugings, in-house hydrologists would be best placed to advise on gauging methodology and explain the operation of flow gauging equipment.

5.7.2   Water velocity

It is also advisable to measure the average velocity over each section of the in-stream structure (e.g., culvert and rock-ramp). This will help inform or predict potential problem areas for fish passage, as well as provide some comparative information between sites. The most commonly used method to calculate average water velocity is to time how long a float takes to travel a set distance. A mandarin or orange makes an excellent float as it's easy to see, can withstand knocking into rocks, and it floats almost submerged so the wind doesn't influence its movement.

For each site, measure the average water velocity inside the culvert separately from that over the rock-ramp. For sites containing double culverts, measure the average velocity in both culverts. On each trial day, undertake six orange/mandarin releases for each section of the structure (culvert and rock-ramp). This will provide an indication of variation both within and between trial days.

5.8   Trial length

As each fish pass and stream system is different, the appropriate trial length will be determined during the monitoring, but based on results from the Upper Kingston Road trial, it is recommended that fish are given 24 hours to pass the culvert independently, and up to 36 hours to pass the rock-ramp and culvert. The trap can be inspected after 12 and 24 hours to determine if extending the trial to 36 hours is warranted.

5.9   Methodology

- Initiate trials in the early morning. This may require the barricades to be installed the previous day.

- Prior to releasing the marked fish, electric-fish the test reach to remove any resident fish that could confound trial results. Utilise multi-pass fishing until no fish are captured.

- Release the marked fish at either the base of the rock-ramp or culvert (Figure 5-6).

Figure 5-6:   **Releasing marked inanga below the rock-ramp in Kara Stream, at Upper Kingston Road.**

- Check barrier nets periodically throughout the trial to ensure they remain functional. However, do not walk adjacent to the stream edge to prevent spooking the fish.

- At the conclusion of the trial (rock-ramp and culvert only) install a temporary stop net at the base of the culvert to prevent both upstream and downstream fish movement between the rock-ramp and the culvert.

- Empty the upstream trap into a bucket or fish bin to hold fish for processing.

- Electric-fish each component of the structure separately, in a downstream direction to collate unsuccessful fish. Use multi-pass fishing until no fish are collected over several passes. Start with the culvert barrel, then the rock-ramp, and lastly the pool below the rock-ramp. Keep fish collected from each section of the structure in a separate bucket.

- Anaesthetise fish in each bucket and record their length and colour. If time allows, record the length of every recaptured fish, otherwise ensure lengths are measured for at least 50 successful and 50 unsuccessful fish from each replicate (pink, orange and unmarked). This will determine if fish size influenced passage success over the in-stream structure. Carry out counts of the remaining fish where lengths are not measured.

6 Mark & recapture case study: Upper Kingston

6.1 Introduction

This case study describes the results of mark-recapture trials undertaken by NIWA and Horizons Regional Council at a culvert on Kara Stream, Manawatu, which has been retrofitted with a rock-ramp and culvert baffles. The trials were carried out in September 2014 and demonstrate the methodology described in Section 5. This case study helps to illustrate the practical limitations of applying the methodology, but also the valuable inferences that can be gained from the results.

6.2 Upper Kingston study description

During the remediation works, it was deemed unfeasible to build the rock-ramp on top of the existing culvert apron (Figure 6-1). As such, one aim during the mark and recapture trials was to determine if the apron presented a bottleneck for fish passage and therefore also required retrofitting (Figure 6-3). In addition, there was no documented field tests of the plastic baffles (0.18 m in height) installed at 1.24 m intervals along the length of the culvert barrel (Figure 6-2). Therefore, to ensure each component of the in-stream structure was effective at promoting inanga passage, the culvert was assessed independently from the rock-ramp. To achieve these aims, three mark and recapture trials with juvenile inanga were carried out between 15 and 19 September 2014:

Trial 1 - Rock-ramp + culvert: Examining fish passage over the rock-ramp, unmodified apron and through the culvert.

Figure 6-1: **Remediated culvert on Kara Stream, Upper Kingston Road.** Inset shows the unmodified culvert apron.

Examining fish passage through the culvert only.

Figure 6-2: **Culvert under Upper Kingston Road.** A, at low flow. B, at high flow.

Examining fish passage over the rock-ramp, modified apron and culvert.

Figure 6-3: **Culvert apron at Upper Kingston Road.** A, unmodified. B, modified using boulders as baffling elements.

Because of logistics in co-ordinating NIWA and Horizons staff for testing the effectiveness of the fish pass at Upper Kingston Road, these trials were carried out under sub-optimal flows. This unfortunately led to the final trial of the entire structure with the modified apron being washed out in rising flood water, but it does provide a good example of issues that can occur when undertaking mark and recapture experiments.

6.3 Control fish

For each of the three trials, inanga were marked in Rhodamine B and Bismarck Brown the day prior to release. After marking, between 30 and 50 fish of each colour were held as control fish. For all three sets of control fish, no mortality was observed after 48 hours. Inanga marked on the 15th September for the first trial, were held till the 19th September with no mortality recorded. This shows the marking procedure was not causing mortality in experimental fish.

6.4   Trial 1: Rock-ramp + culvert (24 h)

Three replicates containing 200 inanga (pink, orange and uncoloured (clear)) were released in the pool below the rock-ramp (see Figure 5-6). Each replicate was sequentially released at 30 minute intervals from 8:20am on 16th September 2014, and given 24 hours to pass the rock-ramp and culvert. For all three replicates, fish size ranged between 45 and 59 mm.

At the conclusion of the trial the proportion of fish that were recaptured in each section of the in-stream structure, missing and dead fish were relatively similar between marked (pink and orange) and uncoloured replicates (Figure 6-4). This indicates that the marking procedure did not unduly influence behaviour or passage ability compared to inanga that were not subjected to the marking procedure.

After 24 hours, no inanga had successfully passed the in-stream structure, and no inanga were found inside the culvert itself (Figure 6-4). Close to half of the inanga released were recaptured on the rock-ramp, in the pool below the rock-ramp, or below the first barrier net in the pools created by the rock weirs before the secondary stop net (Figure 6-4; see Figure 5-4B & C for stop net positioning).

However, around half of the test fish were missing with a small proportion found dead in the barrier net (Figure 6-4). As the trials were carried out at higher than base-flow conditions, it is likely that inanga were attempting to move downstream into quieter waters and were successful at passing the barrier nets. The small proportion of dead fish are most likely fish that succumbed to the cumulative stressors of capture, handling, and release into an area where they were vulnerable to damage or getting trapped by the barrier net when trying to move downstream.
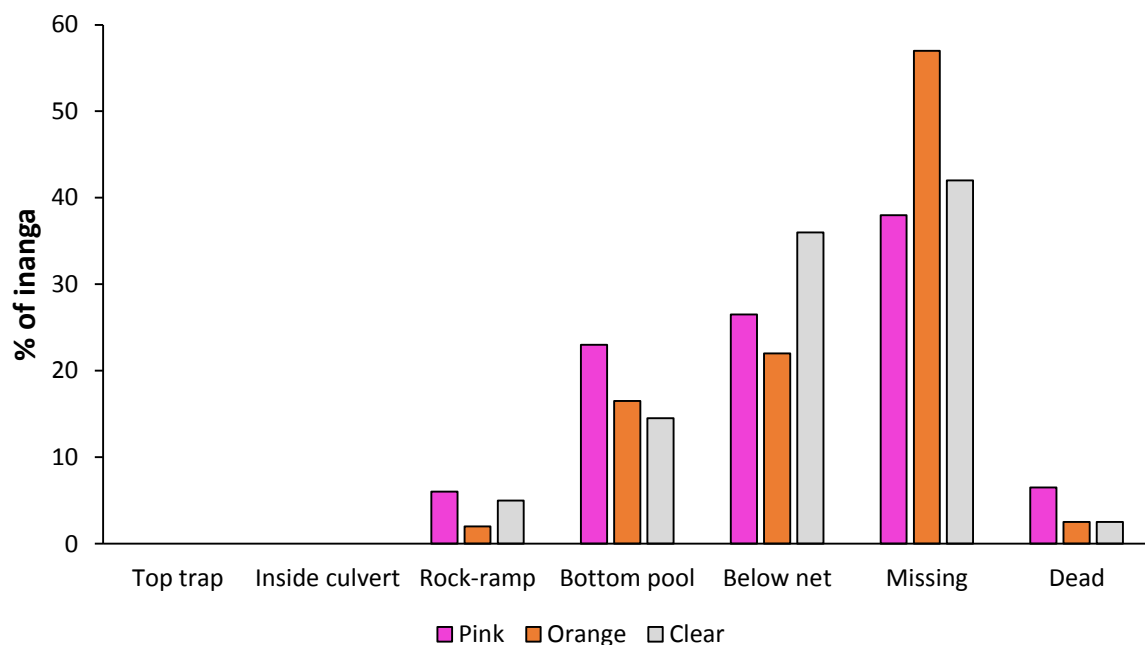
Figure 6-4:   Percentage of inanga successfully passing the rock-ramp and culvert, recaptured in different sections of the structure, and fish either unaccounted for or found dead after 24 hours. 'Bottom pool' represents inanga in the pool at the base of the rock-ramp. 'Below net' represents inanga captured in the pools above the second barrier net.

The high proportion of fish moving downstream during the trial could also have been influenced by the fact that they were unable to move upstream and pass the structure. No inanga passed the culvert apron, even though inanga were observed reaching the apron and resting on the apron margins (Figure 6-5). The average water velocity over the apron was considerably higher than that inside the culvert or over the rock-ramp (Table 6-1). On average, 50-70 mm inanga can burst swim at 1.5 m s^{-1} for 4 sec, and 2 m s^{-1} for 2 sec (Stevenson & Baker 2009). Therefore, at the trial flows, water velocity over the apron (>1.5 m s^{-1}; Table 6-1) would have been a limiting factor for juvenile inanga passage.

A further impediment for inanga is likely caused by the transition between the culvert apron and the baffling inside the culvert barrel, where a weir is formed immediately at the culvert outlet (Figure 6-6). Should inanga successfully burst swim over the apron, there is no low velocity water or rest area prior to the requirement to burst swim over the weir. Therefore, the cumulative effect of water velocity over the apron and the weir at the culvert outlet are, in my opinion, the key factors presently preventing inanga passage past the culvert. It should be noted, however, that species capable of climbing, such as banded and shortjaw kokopu, (that are also found in Kara Stream) will not be prevented from passing over the apron and into the culvert as the wetted margin is sufficient for promoting passage of these species.

Figure 6-5:   **Pink inanga resting on the culvert apron (red circle).**

Table 6-1: **The flow (m³ s⁻¹) of Kara Stream and the average water velocity (m s⁻¹) through the culvert, and over the apron and rock-ramp during each of the trial days.** The float used for calculating the average velocity (mandarin or stick) is also provided. For each day, the velocity given is the average of six replicates. - indicates measurements were not recorded that day. † The float over the rock-ramp needed to be changed from the mandarin because of issues with the mandarin getting stuck in the small pools on the ramp.

Date	Trial start	Flow (m³ s⁻¹)	Average water velocity (m s⁻¹)			
			Rock-ramp	Unmodified apron	Culvert	Modified apron
			Stick[†]	Mandarin	Mandarin	Mandarin
15 Sept		0.017	0.50	1.53	0.36	-
16 Sept	Rock-ramp + culvert	0.025	0.45	1.52	0.34	-
17 Sept	Culvert	0.019	-	-	0.43	-
18 Sept	Rock-ramp + mod apron + culvert	0.015	-	-	-	0.25
19 Sept		0.180	-	-	-	-
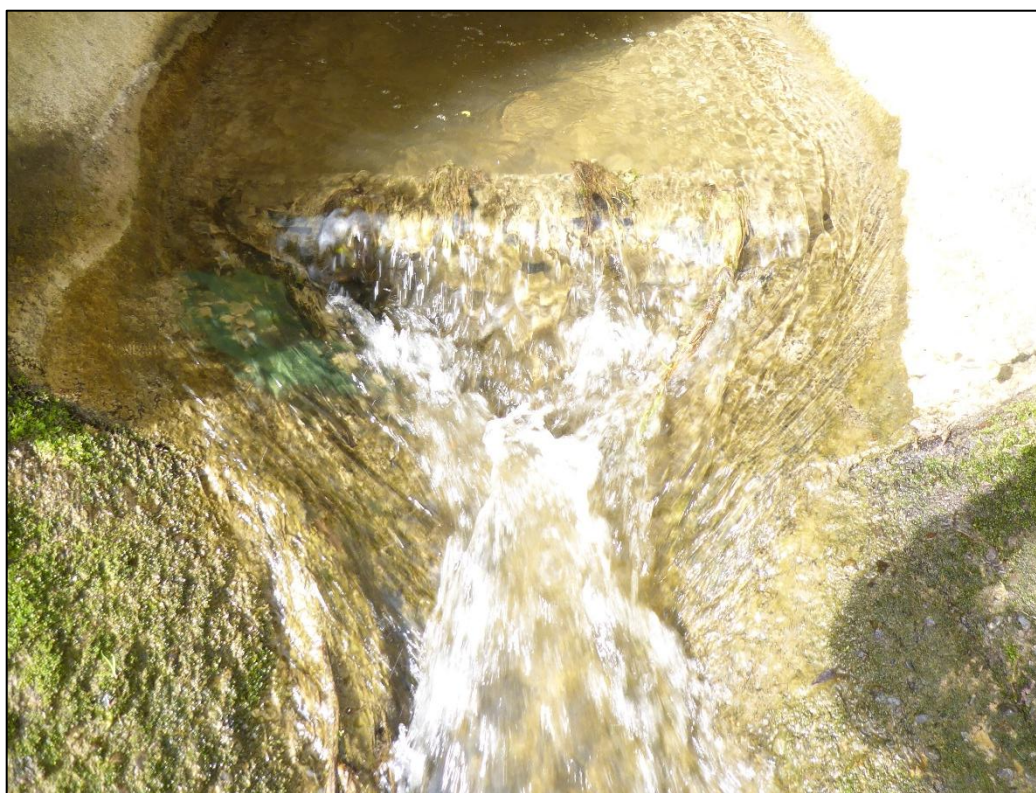
Figure 6-6: **Weir created by the baffle at the transition point between the culvert outlet and apron.**

6.5   Trial 2: Culvert only (20.5 h)

Three replicates of fish (198 pink inanga, 200 orange inanga and 179 uncoloured (clear) inanga) were released at 12:30 pm on 17th September 2014, and given 20.5 hours to pass the culvert. All fish were released into the pool formed between the first and second baffles inside the culvert barrel. For all three replicates, fish size ranged between 45 and 75 mm. These juvenile and post-juvenile inanga were captured further inland than those used in Trial 1 and are more representative of the size of inanga that would be reaching the culvert at Upper Kingston Road.

In line with Trial 1, at the conclusion of the trial, the proportion of fish that had passed the culvert or were still migrating within the culvert, and those unsuccessful, missing or dead fish were relatively similar between marked (pink and orange) and uncoloured replicates (Figure 6-7). These data again support the notion that the marking procedure did not unduly influence behaviour or passage ability compared to inanga that were not subjected to the marking procedure.

On average, 31% of inanga successfully passed the culvert after 20.5 hours, with 10% of fish still migrating upstream within the culvert barrel (Figure 6-7). In comparison, the trap was inspected after 5 hours with only a handful of inanga visible. This suggests that passage through the culvert was slow and therefore, inanga may need to be left for longer than 24 hours to accurately assess passage over the rock-ramp and culvert.

In contrast to Trial 1, the majority of inanga from each replicate were recaptured (Figure 6-7). Here, the barrier nets were more effective due to the smaller wetted width of the stream and the more uniform shape of the culvert and apron. However, around half of the fish released were found dead against the barrier net (Figure 6-7). The high death rate is most likely a result of carrying out the trials under higher, sub-optimal flows. Although the baffling inside the culvert creates a pool between the weirs, the pool is shallow (c. 18 cm), and under the trial flows, the pool was turbulent with areas of fast water velocities. It is likely that many of the smaller weaker fish encountered, and were unable to swim against, the fast water velocities and ended up getting swept into the barrier net. Once pinned against the mesh, the fast water velocities would make it difficult if not impossible for small fish to free themselves (Figure 6-8).

An examination of fish size successfully passing the culvert compared to those dead in the barrier net supports this notion (Figure 6-9). For the orange and clear inanga, those successfully passing the culvert were significantly larger than those found dead in the barrier net (P<0.05; Figure 6-9). Collectively, the pink inanga were significantly smaller than those in the clear and orange replicates (P<0.019), and although the larger of the pink fish were more successful at passing the culvert, the smaller variation in fish size within the cohort meant the difference was not significant (Figure 6-9).
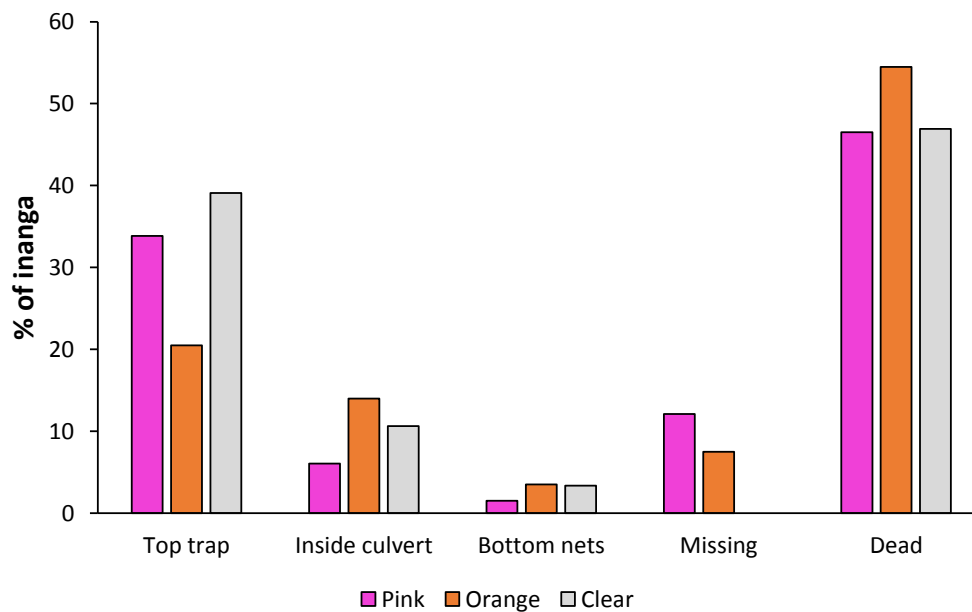
Figure 6-7: Percentage of inanga successfully passing the culvert, still migrating upstream inside the culvert, caught in the bottom barrier nets, and fish either unaccounted for or found dead after 20.5 hours.

The effect of fish size on passage success suggests the culvert baffles may be less effective for small inanga. However, the size effect may have been partially biased from carrying out the trial under higher flows. This is because smaller fish encountering the faster water velocities in the pool were more likely to be swept into the barrier net as opposed to an area of low velocity refuge. As such, these fish were less likely to be able to undertake repeated attempts at passage over the weir before incurring damage or death. At lower flows, it would be anticipated that the majority of inanga would have successfully passed the culvert as opposed to expiring against the barrier net.

Figure 6-8: Barrier net set upstream of the baffle at the culvert outlet.
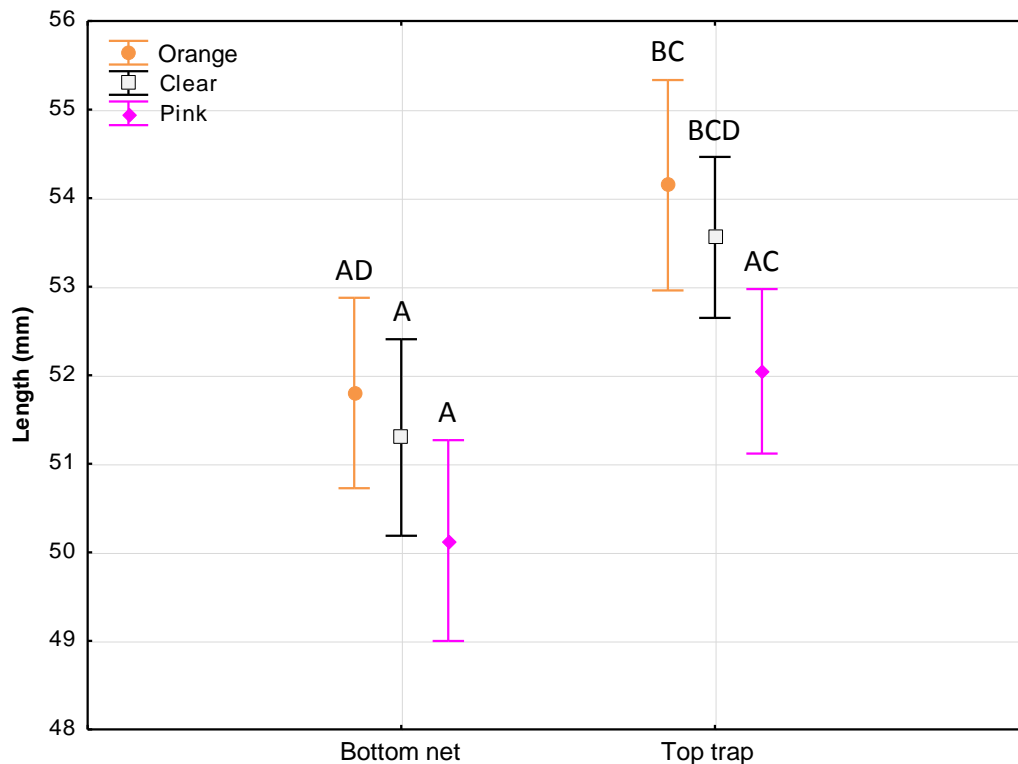
Figure 6-9: **Mean length (mm) of inanga successfully and unsuccessfully passing the culvert in 20.5 hours.** 'Bottom net' represents expired fish collected in the first barrier net at the culvert outlet. Error bars denote ±95% confidence intervals. Different letters signify significant differences between means (Factorial ANOVA & Tukey HSD test, $P<0.05$).

6.6   Trial 3: Rock-ramp + mod apron + culvert (12 h)

Three replicates of fish (199 pink inanga, 199 orange inanga and 143 uncoloured (clear) inanga) were released at 10:30 am on 18th September 2014. Fish sizes were similar to Trial 2, ranging from 45 to 75 mm. However, 20 large adult inanga (85 - 120 mm) that were captured with the juvenile inanga were also released for comparative purposes. Of these, 15 were uncoloured and 5 were coloured in Bismarck Brown.

Because of high rainfall and concerns over the integrity of the trap and barricades in rising flows, the top trap was checked after 12 hours to determine if the modified apron had promoted inanga passage. In total, 24 inanga had successfully passed the rock-ramp and culvert with the modified apron. Of these, 12 were from the smaller juvenile and post-juvenile fish (45 – 75 mm), and consisted of 6 pink fish (51 – 53 mm), 4 orange fish (51 – 74 mm) and 2 uncoloured fish (50 & 51 mm). Of the 20 large adult inanga released, 10 uncoloured inanga (85 – 110 mm) and 2 orange inanga (105 & 117 mm) successfully passed the structure in the 12 hour window.

Based on the slower movement of juvenile inanga in Trial 2, it was anticipated that fish may require 36 hours to pass the rock-ramp and the culvert in Trial 3. However, nature intervened and the flow of Kara Stream rose around tenfold overnight (Table 6-1). By 24 hours, the trap and barrier nets had been washed out and the trial had to be abandoned (Figure 6-10 & Figure 6-11 & Figure 6-12). It should be noted that the trial results suggest passage of adult inanga is considerably quicker than for smaller fish, as over 50% of the adult fish released had successfully passed the rock-ramp and culvert within 12 hours.

Although the flood waters prevented an accurate assessment of inanga passage past the rock-ramp and culvert with the baffled apron, the successful passage of both small (50 mm) and large (>85 mm) inanga recorded after 12 hours confirmed that the culvert apron is the key factor limiting swimming fish passage. Therefore retrofitting baffles to the apron is recommended to enhance fish passage past the culvert.

Figure 6-10:   Top trap during increasing flood waters at the conclusion of Trial 3.

Figure 6-11:   Flow through the culvert and over the rock-ramp at the conclusion of Trial 3.

Figure 6-12:   Bottom barricades at the conclusion of Trial 3.

6.7   Retrofit options for Upper Kingston culvert apron

Temporarily baffling the apron of the culvert with boulders reduced water velocities, increased the water depth and wetted width of the channel over the apron, and provided resting areas for fish. The results of Trial 3 indicated that the baffling was effective in promoting the passage of juvenile and adult inanga past the rock-ramp and into the culvert barrel.

Based on computational fluid dynamic modelling and field tests with inanga, staggered rows of rectangular spoiler baffles have been shown to be the most effective formation for promoting inanga passage through large (>0.8 m) culverts (Stevenson et al. 2006; Stevenson & Baker 2009). The spoiler baffles create a continuous low velocity zone along the base of the culvert (Figure 6-13). The comparatively close spacing of the spoilers create lower velocity areas as the bottom layer of water passes through the spoilers in a sinuous manner (Figure 6-13). In addition, low velocity resting zones are provided on the downstream end of the baffles (Figure 6-13) and also at the culvert margins to allow fish to recuperate after bouts of burst swimming. The size and shape of the spoiler baffle was important. For example, wedges with a sloped upstream face produced a turbulent flow behind them and were therefore not recommended, and rectangular baffles longer than 0.25 m were found to channel the water and create areas of increased velocities so were also not suitable (Stevenson et al. 2006; Stevenson & Baker 2009).

The installation of rectangular spoiler baffles (0.25 m length, 0.12 m width and 0.12 m height) to the culvert apron at Upper Kingston is the recommended approach to promote passage of juvenile inanga past the rock-ramp. Although the apron at Upper Kingston is less dished than a culvert barrel, the spoiler baffles will still provide a functional solution.

It is important that the spoiler baffles are fitted in a complex arrangement with staggered rows to force the flow to meander, as this is a key factor for reducing water velocities. The fact that baffles

are not placed in a continuous line allows fish to progress upstream between low velocity areas without having to negotiate the higher velocity flow above the baffles. Not having all the baffles submerged during base/low flows is advantageous as the partially submerged baffles on the apron margins can provide important resting areas for migrating fish.

The spacing of the baffles is also important as this will ensure that fish are able to use the resting areas created between rows of baffles. A spacing of 0.20 m between baffles will ensure that the resting areas provided are large enough to accommodate migratory fish up to 200 mm in size (which will include most indigenous adult fish) without compromising the passage of small fish.

Stevenson and Baker (2009) recommended using alternate rows of 3 and 4 baffles for culverts 1.3 m in diameter, and rows of 5 and 6 baffles for culverts of 2 m in diameter. It is recommended that alternate rows of 5 and 6 baffles be installed on the culvert apron at Upper Kingston because the apron has less curvature and therefore more wetted width than the 1.5 m culvert. This arrangement is supported by measurements taken after baffling the apron with boulders as the wetted width of the channel increased approximately three-fold to 1.6 m (Figure 6-14). The recommended configuration and spacing of the spoiler baffles is depicted in Figure 6-15. Each baffle should measure 0.25 m in length, 0.12 m in width and 0.12 m in height. Baffles should be secured to the apron using stainless steel anchor bolts (Figure 6-16).

It is recommended that the first row of baffles contains 5 spoilers and is set up against the culvert outlet. Either 4 or 5 rows of baffles will be able to be installed down the apron before reaching the top of the rock-ramp.
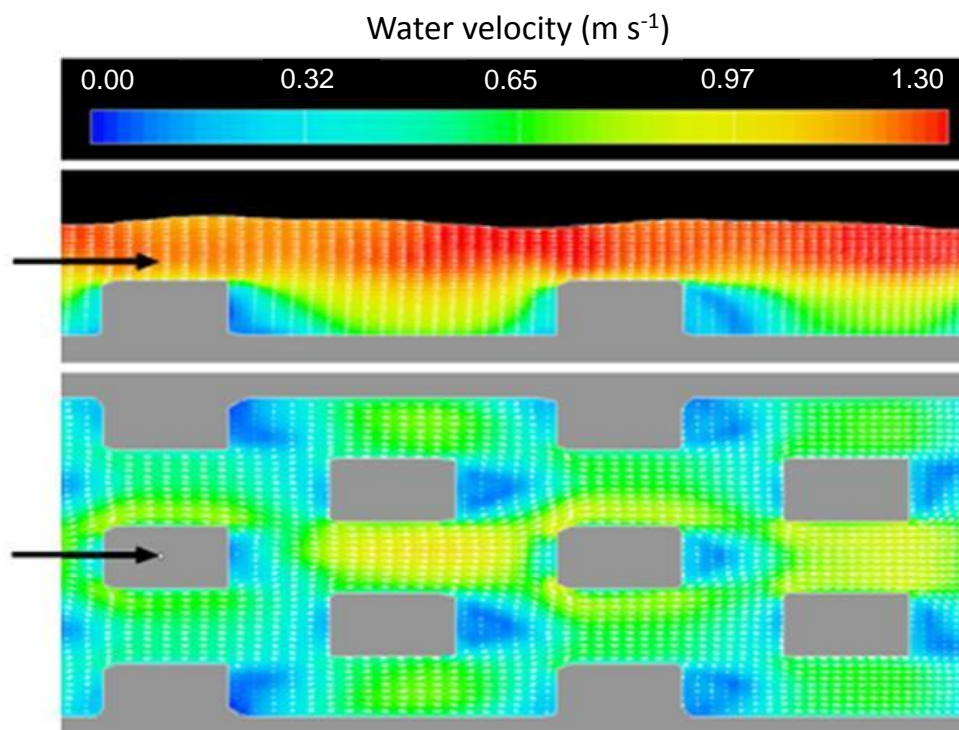
Water velocity (m s^{-1})

Figure 6-13:   Side view (top section of diagram) and plan view (bottom section of diagram) of modelled water velocities in a culvert fitted with alternating rows of rectangular spoiler blocks (0.25 m length, 0.12 m width and 0.12 m height), spaced 0.20 m apart at a flow of 0.11 m^3 s^{-1}. Arrows indicate the direction of flow. Culvert diameter = 1.35. The coloured band at the top of the figure gives the water velocity range (red = 1.30 m s^{-1}, blue = 0 m s^{-1}).
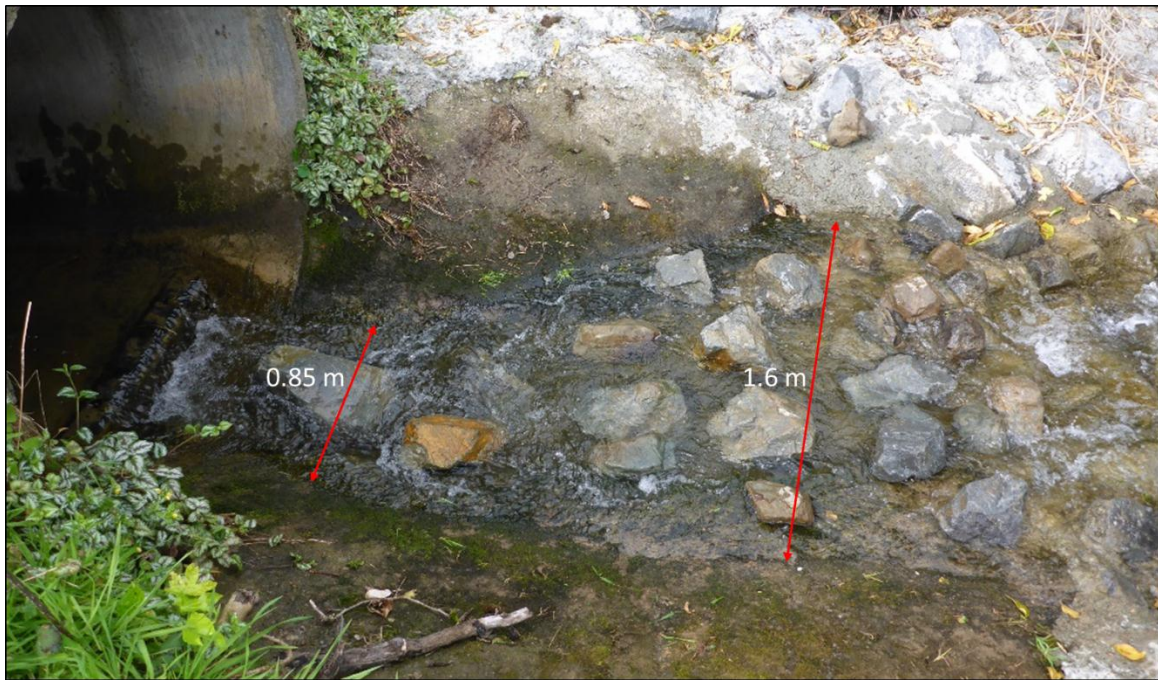
Figure 6-14: Wetted widths measured across the culvert apron after installing boulder baffles. Flow was approximately 0.015 m^3 s^{-1}.
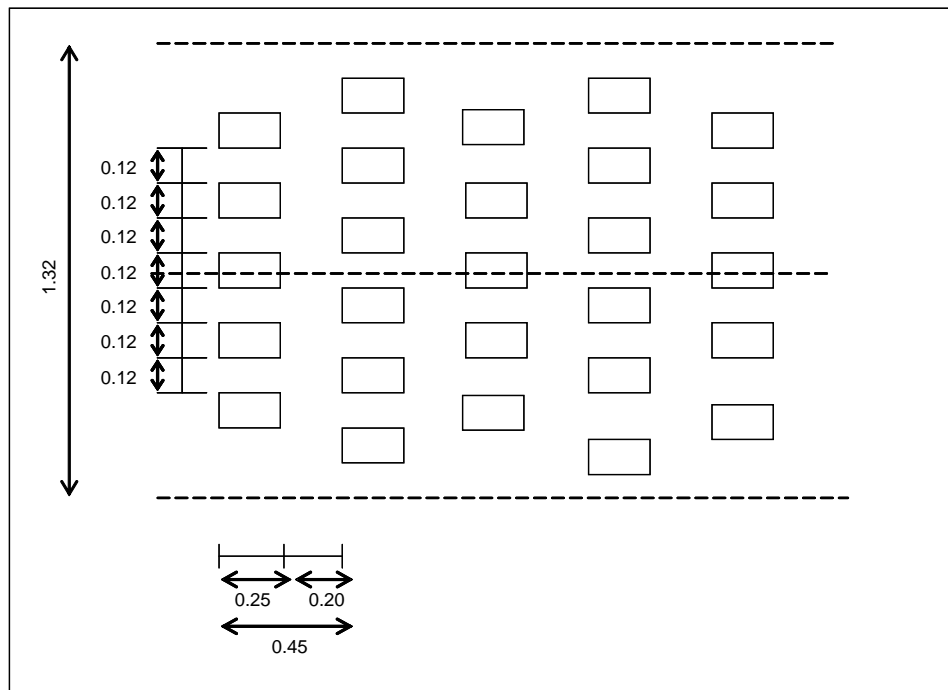
Figure 6-15: Plan view of spoiler baffle arrangement within a 1.35 m culvert. Rectangles represent wooden spoiler baffles (0.25 m length, 0.12 m width and 0.12 m height). Dotted lines signify the culvert edges where the array was installed to (1.32 m). Rows of baffles are staggered and alternate in rows of five and six spoilers. All dimensions are in metres.

Figure 6-16:   Wooden spoiler baffles (0.25 m length, 0.12 m width and 0.12 m height) installed in a 1.3 m diameter culvert.   Spoiler baffles are attached to the concrete with stainless steel bolts.

7 Conclusions and recommendations

Effective retrofit fish passes at low-head obstacles requires the transfer of scientific knowledge into practical engineering solutions. There are a wide range of innovative and cost-effective solutions being developed and implemented, but with little monitoring or testing to ensure that they meet best practice guidelines. The present case study at Upper Kingston has highlighted how bottlenecks to fish passage can still develop even when best practice guidelines are followed. It is therefore advisable to carry out robust testing of retrofit solutions to ensure they are fit for purpose prior to widespread installation. This will improve the confidence in the effectiveness of different solutions, and stakeholders will be more willing to invest in implementing solutions for restoring fish passage.

7.1 Recommendations for Upper Kingston

7.1.1 Maintenance

After retrofitting the culvert apron at Upper Kingston, it is advisable to monitor the baffles to ensure that waterborne debris or large bedload movements don't build up between the baffles. Both debris and sediment could reduce spoiler baffle efficacy by becoming trapped between spoilers and preventing water velocities from being reduced, as well as reducing the physical resting area available for fish. It is anticipated that any sediment deposition will be transient and removed in subsequent flood waters, however, stubborn debris may require occasional removal.

7.1.2 Monitoring

As Upper Kingston culvert has been used as a case-study for examining the effectiveness of rock-ramp retrofits in promoting passage of inanga, it provides an opportunity to fully document the success of the fish passage solution. The combined approach of BACI surveys and mark and recapture trials would provide the most comprehensive assessment of fish passage success. After retrofitting spoiler baffles to the culvert apron, carrying out a further mark and recapture trial to assess the effectiveness of the final solution is recommended. As electric-fishing surveys were carried out below and above the culvert prior to remediation, completion of the BACI surveys can then be undertaken to document changes to the fish community upstream of the remediated structure and therefore assess the effectiveness of the solution across a range of fish species. Ideally, electric-fishing surveys above and below the culvert should be carried out annually in January until changes to the upstream fish community are clear. If feasible, carrying out the first electric-fishing surveys upstream and downstream of the structure in January 2015, prior to retrofitting the apron, would provide additional information on fish passage success during spring/summer 2014/15.

If time or cost prohibits a complete monitoring approach, then carrying out electric-fishing surveys above and below the culvert in summer 2016 (after retrofitting the culvert apron) would be recommended as the minimum method for assessing the effectiveness of the final fish passage solution.

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Appendix A   Equipment for mark & recapture studies

1. Rhodamine B dye for 50 litres of water (0.2g/L) = 10g vials

2. Bismarck brown dye for 50 litres of water (0.05g/L) = 2.5g vials

3. Aquarium salts

4. Refractometer

5. Portable air compressor & car battery

6. Air lines and air stones with adjustable flow control

7. Thermometer

8. Electric-fishing machine including batteries, stop nets and dip nets

9. Extra live-bins for separating marked fish and control fish

10. 2 x large bins for marking fish (need to hold 50 litres each)

11. Buckets

12. Hand held dipnets

13. Waratahs/wooden stakes + sledgehammer

14. Shovel

15. Tool box

16. Cable ties

17. Seine nets or whitebait mesh for creating barricades

18. 2 x whitebait traps

19. Measuring board

20. Gloves

21. Mandarins or similar for velocity measurements

22. Tape measure

23. Flow gauging gear – current meter and gauging rod