Fish Barriers on Scottish Major Roads

Scottish Road Research Board

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Contents

1. Introduction

As part of an update to the River Basin Management Plans (RBMPs), the Scottish Environment Protection Agency (SEPA) is challenging authorities to mitigate fish barriers created by structures owned by public bodies. The Scottish Road Research Board (SRRB) Fish Barriers project aims to establish guidance for the assessment of existing Transport Scotland structures and to identify potential improvement measures that could be implemented.

The research aligns with the SRRB delivery priority to encourage innovation by seeking to understand the engineering properties of fish barriers found within the Scottish major road network and to propose a cost-effective programme of adaptation.

The objectives of this project are as follows:

- To identify high-level design options that improve fish migration across structures associated with road networks.
- To review the approach undertaken by other road authorities in the assessment and mitigation of fish barriers.
- To review existing processes within maintenance inspection regimes and contracts to ensure they take cognisance of fish passage.

This report will initially provide some background information on barriers to fish migration and innovative fish pass solutions, before detailing example projects undertaken by Jacobs. The site visit locations and methodology will be outlined in the following sections. Site visits were undertaken at several sites across Scotland and the findings from these will be detailed. The report will conclude with recommendations for structural improvements and for Transport Scotland's future contracts and maintenance inspection regimes.

2. Scotland's Approach to Fish Migration

2.1 River Basin Management Plans

The Water Framework Directive (WFD) required that Member States aim to achieve Good Ecological Status or Good Ecological Potential by 2015. In preparation for this the Scottish Environment Protection Agency (SEPA), the Environment and Heritage Service of Northern Ireland (EHSNI) and the Environment Agency (EA) undertook a programme of classification, the aim of which was to identify the current status of all river water bodies. Many of Scotland's river basin districts (covering its 3,169 rivers, lochs, wetlands and seas) are in a good or excellent condition, whereas others require improvement. 34% of water bodies are in less than good condition, which is due to several factors including: water quality, access for fish migration, physical condition, water flows or levels, and direct impacts from non-invasive species. The River Basin Management Plans in Scotland cover the actions to be taken by the Scottish Government, SEPA, responsible authorities and other public bodies in Scotland to improve the condition of the river basin districts. The plans are produced by SEPA every six years and outline the approach to protecting and improving Scotland's water environment. Scotland's third River Basin Management Plan will be finalised by December 2021.

SEPA have identified 238 weirs and dams, and 56 other man-made structures (such as culverts and bridge abutments), acting as barriers to fish migration. The location of the barriers is shown in Figure 1 (Buddendorf et al., 2019). SEPA aims to secure the removal of 145 barriers between 2015 and 2021, and a further 149 between 2021 and 2027. Public bodies are required to take action to ease barriers to fish migration at structures they own or maintain.

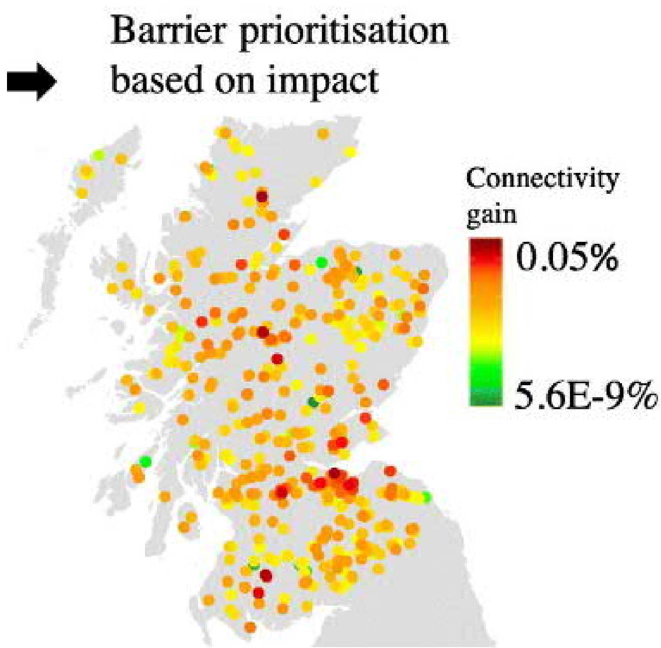


Figure 1. Location of the barriers to fish migration in Scotland, classified from high priority (red) to low priority (green).

Since 2009 SEPA have eased 41 barriers to fish passage, as shown in the table below, resulting in 1069km of habitat being made available to Scotland's migratory fish. The majority of this work has been carried out through the River Basin Management Plans and the Water Environment Fund.

Category	Licensing	WEF	SEPA Grand Total
Habitat freed up (km)	124	945	1069
No. of barriers eased	8	33	41

Table 1. SEPA barrier data 2009-present.

Fish passage was recognised as one of the three main priorities of the second River Basin Management Plan (RBMP), including the challenges faced by smolts in their downstream migration, particularly in relation to hydro schemes. SEPA is leading on work to remove or ease redundant barriers in rivers, utilising circa £5m of annual funding from the Scottish Government into the Water Environment Fund (WEF).

2.2 Benefits to Scotland

Scotland is renowned for its high-quality waters and fishing opportunities. There are important fisheries in Scotland for salmon, trout, grayling and species of coarse fish which are vital income sources, particularly in rural communities, and bring various other economic and social benefits to Scotland. Fishing is recognised as a recreational activity, promoting social inclusion, as well as a tourist attraction bringing employment opportunities to the people of Scotland (2,800 jobs are supported by coarse and game angling in Scotland, which equates to nearly £50 million in income). Removal of barriers to fish migration is necessary to increase the important fish populations in Scotland. Both Kanehl et al. (1997) and Burroughs et al. (2010) observed significant increases in native fish abundance within 4 to 5 years after dam removal along rivers in Wisconsin and Michigan, respectively.

Scotland’s three key overarching objectives are to:

1. Provide protection and enhancement of Scottish wild Atlantic salmon and the habitats they depend on.
2. Promote effective, evidence-based, wild Atlantic salmon fishery management through integrated data gathering, research and dissemination.
3. Maximise the environmental, economic and social benefits from sustainable wild salmon fisheries.

The benefits to Scotland of improved fish migration tie in to the Scottish Government’s five Strategic Objectives (which are related to Transport Scotland’s National Transport Strategy): to create a Scotland that is Wealthier and Fairer, Smarter, Healthier, Safer and Stronger and Greener. Removing or easing fish barriers can help to meet these objectives by:

- Increasing and sustaining employment;
- Increasing the capital value of Scottish freshwater fisheries resources;
- Improving the health of Scottish residents (fishing as a recreational activity can contribute to this);

- Educating and raising awareness of environmental issues and reconnecting people with rural areas;
- Promoting education about the importance of fisheries to Scotland's natural heritage;
- Protecting the environment and indigenous biodiversity.

3. Fish Migration in Existing Weirs, Flumes and Culverts

3.1 Ecology

Fish and other aquatic organisms rely on the physical habitats created by river processes. Migratory species such as Atlantic salmon (Salmo salar), sea trout (Salmo trutta), sea lamprey (Petromyzon marinus) and European eel (Anguilla anguilla) require a river corridor free of in-stream barriers to facilitate their migration between freshwater and the marine environment. Atlantic Salmon, for example, emerge as juveniles between March and early May and are common throughout Scotland's river systems. Juveniles live in crevices created by mixed substrates and forage in the calm water behind rocks in the river channel, before migrating to the marine environment as smolts. As adults, they return to the upper river catchment (often the same from which they originated) to spawn. Returning Atlantic salmon gradually move upstream, resting in pools prior to reaching spawning grounds, and use gravel substrates close to riffles to deposit their eggs in redds in late autumn and early winter. They will avoid areas that are predominantly silt or fine sand as this can block oxygen and increase egg mortality.

Another common fish found in Scottish rivers is trout. They follow one of two life history paths and either spend their lives in rivers (brown trout) or migrate to the marine environment as sea trout. Trout have similar habitat requirements to Atlantic salmon throughout all life stages, but generally spawn in finer gravel deposits. Resident brown trout prefer areas of low current speed and with a high level of vegetation cover or undercut embankments. Man-made barriers can prevent Atlantic salmon and trout from reaching critical upstream spawning sites and suitable juvenile habitats. They also hinder juvenile fish from migrating downstream, making them susceptible to attacks from predators.

3.2 Existing Weirs, Flumes and Culverts as Barriers

The 238 barriers (Weirs, Dams, and Culverts) noted earlier in Section 2.1 include a mix of physical structure types. Some of these are actively used by businesses to abstract water, while others are historic, with strong community attachment as part of the landscape, and many have been recognised as requiring conservation as historic structures. Developing measures to amend the physical structure (to remove the fish barrier and restore fish passage), while continuing to meet wider objectives, requires time to consider the range of options available. Each option has different costs, levels of effectiveness and maintenance requirements and each option has a different impact on flood risk, erosion risk, ecology, socioeconomics and cultural heritage.

Man-made structures that can hinder fish migration include weirs, dams and culverts.

Culverts

Culverts are used to allow a river channel to flow underneath civil engineering infrastructure. They take the place of the natural river channel and thus alter the flow characteristics and hinder natural river connectivity. As a result, culverts are known to contribute to a decline of fish populations.

Figure 2. Example culvert.

Figure 2. https://en.wikipedia.org/wiki/Culvert

Weirs

Weirs are often used in association with road infrastructure to manage river levels to suit the geometry of a crossing. They form an obvious barrier to the passage of water, and therefore fish.

All owners of weirs are required to have an authorisation, and many do. However, in parts of the country there are weirs that have been in place for a long time and many owners are unaware of the requirement for authorisation, and in some cases ownership is uncertain. As Scotland progressively takes action to address fish passage issues across the country, SEPA identifies the persons responsible for the weirs and ensures that they obtain the appropriate authorisation for the structure.

Figure 3. Example weir.
Figure 3. https://en.wikipedia.org/wiki/Weir

The Scottish Government accepts that there are circumstances where it would be unreasonable to expect owners to absorb the costs of undertaking improvement works and owners may apply for financial support from public funds through WEF. Those circumstances were set out in a Scottish Government Consultation.

Rectangular Channels and Flumes

Where the land that is available in a road improvement scheme to manage watercourses is constrained, it is common for river banks to be steepened and hardened, and for the width of the channel to be reduced. This can create fluming effects that accelerate water flows and create unsuitable conditions for fish passage.

Barriers to Fish Movement

There are several features of structures such as culverts, weirs, man-made rectangular channels, and flumes, that cause them to become a barrier to migratory fish. The first of these is the geometry (the cross section and gradient) within the structure, as this determines the water depth and water velocity in the watercourse. A physically constrained channel or culvert has restricted flow area available. This results in an increase in water velocity, often much higher than the flow velocities found in an equivalent natural river reach, and this can cause a fish barrier. In addition, during periods of low river flow, the water depth within a constrained structure could be well below the minimum required for fish passage.

Secondly, at the downstream outlet of any structural barrier there should be an adequate depth of water to allow fish to successfully gain access into, and through, the structure as they head upstream. The depth requirement will depend on the fish species in the channel. It is particularly important in flow conditions where the downstream invert of the structure is above the nearby river level (“perched” conditions). Structures can be perched due to poor design, construction, or unexpected downstream erosion. If perching is greater than 300mm, this alone provides a fish barrier, as it is too high for fish to navigate.

Thirdly, assuming downstream conditions are adequate, it will still be highly unlikely for fish to swim into an enclosed culvert that is excessively long. In the event that they do, a long man-made channel or culvert that does not provide any resting points may cause fish to become exhausted when attempting to swim upstream. As mitigation, rest areas may be required within a culvert or smooth channel of excessive length. Resting places are also important upstream and downstream of structures and can be created by placing large rocks or small weirs in the channel to produce pools and eddies.

There are many design options available to reduce or remove the barriers to fish passage caused by the structural features noted above. These will be discussed in the following section.

3.3 Design Options

The main objective of a fish pass is therefore to restore river connectivity and the hydraulic characteristics of a natural channel to allow for fish migration and healthy ecosystems. Fish passes are implemented to ease barriers to migratory fish and can vary in function and complexity. They are designed with consideration of numerous factors, including the characteristics of both the site and the fish species found at the site (their species; life stage; size range and migration period). Different fish species have different swimming abilities and thus, depending on the needs of the species using the fish pass, different geometries and hydraulic performance will be required in the design.

In the Environment Agency's Fish Pass Manual, fish passes (for all types of obstruction) have been divided into six broad categories, although variations of each can be found: Pool and Weir Passes; Rock-Ramp Passes; Baffled Passes; Fish Locks; Pre-Barrages and Bypass Channels. These are defined as follows:

- Baffled Passes – water is redirected down a rectangular channel by a series of 'baffles' placed within a sloping channel. This results in a continual dissipation of energy and controlled water velocities. The four main types of Baffle Passes are: Larinier Baffle Fish Pass, Plane Baffle Pass (Denil), Alaskan and Chevron. An example of a Larinier Baffle Fish Pass is shown in Figure 4.

Figure 4.

- Bypass Channels – resembles a fish-friendly channel running alongside the main watercourse, avoiding the structure by allowing fish to move around it rather than through it.

- Fish Locks – typically consist of a cylinder connecting two pools within the structure. The pools have a sluice gate that controls the operation.

- Pool & Weir Passes – consist of a number of pools which are organised as a series of steps and are separated by cross walls. Resting areas for migrating fish are provided to dissipate energy, either in large eddies or by turbulent mixing and a hydraulic jump. These passes can be used by the majority of fish species. An example Pool Pass is shown in Figure 5.

Figure 5.

- Pre-Barrages – a small weir that is placed downstream of the structure to cause water to back up and flood the downstream end of a potential obstruction, thus improving hydraulic conditions and acting to facilitate entry into and passage through a structure. An example of Pre-Barrages is shown in Figure 6.

Figure 6.

Figure 4 – 6. http://evidence.environment-agency.gov.uk/FCERM/en/SC060065/MeasuresList/M4/M4T1.aspx

- Rock-Ramp Passes – involve the direct integration of a ramp of bedrock or concrete-embedded boulders spanning the entire width of the obstruction. These are used extensively worldwide and often considered as the form of fish pass that best replicates natural rapids. An example Rock-Ramp Pass is shown in Figure 7.

Figure 7.

A fish pass is not defined in legislation, however for the purposes of this report a fish pass is defined as follows.

Any form of conduit, channel, lift, device, or structure which facilitates the free passage of migrating fish over, through or around any dam or obstruction, whether natural or man-made, in either an upstream or a downstream direction (as defined in Environment Agency Fish Pass Manual).

For the range of structures on the Trunk Road Network the three most cost-effective fish pass categories are Baffled Passes (particularly the Larinier Pass), Pre-Barrages, and Rock-Ramp Passes.

The choice of the appropriate fish pass for any obstruction requires careful consideration of the local conditions. For example, a well-designed and constructed Baffled Pass is effective in improving fish passage at locations where the channel gradient is steeper than fish can navigate, however they can have higher maintenance requirements due to the potential for sediment and debris blockage. Where this is an issue, the Larinier Type Baffle Pass or Rock-Ramp Pass may be appropriate due to their lower maintenance requirements.

At other locations Pre-Barrages (or weirs) may be an appropriate choice, as they can back up water within the culvert, increasing the water depth and reducing the water velocity to values that are passable for fish. They can also reduce or remove any drops that are present by increasing the water depth at the downstream outlet. A low flow notch should be included in any Pre-Barrage or weir design to provide flow concentration to allow fish passage during periods of low flow.

At locations where there is sufficient natural material in the area, Rock-Ramp Passes can be a cost-effective solution.

Lighting in Culverts

The most effective way to improve fish passage in long dark culverts is to restore the watercourse to open channel (known as ‘daylighting’). This can be achieved by entirely opening the culvert or, where road infrastructure must still pass over the channel, introducing a bridge.

There will be cases where this is not feasible and other solutions such as artificial lighting, potentially with a solar panel and battery, can be considered. The potential barrier effect created by the sharp contrast between light and dark at the entrance and exit of the culvert could be reduced by planting vegetation in these areas.

The evidence regarding the effect of light levels on fish passage through culverts is minimal and conflicted. Therefore, the focus should be on getting flow conditions correct, mimicking as closely as possible those in the natural channel.

3.4 International Innovation in Fish Pass Design

Fish Pass designs have been shared internationally with research in the USA, Europe and Australia leading the way. Fish pass innovation in the UK is level with the majority of European countries. However much has been learnt in the UK from early pioneering French designs. The Larinier Fish Pass is widely used in the UK due to its applicability to a variety of species and low maintenance requirements in comparison to other passes. Over the past two decades, a type of sloping brush-furnished fishway has become popular in several European countries, including England (e.g. on the River Medway). This multi-functional type of pass is not used solely for the migration of fish and eels but also by boats including canoes and kayaks, by vertebrates/invertebrates and for the harbouring of aquatic populations. The flexibility of the bristles ensures this type of pass is low maintenance.

Outside of Europe, expertise can be found in the United States and Canada (e.g. Alaskan fish passes), however these tend to be on a larger scale than those found in the UK. Culverts maintaining the natural river bed are recognised internationally as an effective alternative to enclosed artificial channels. Maintaining the natural flow characteristics can be achieved through use of a natural sediment substrate or a culvert with a similar width and gradient to the channel (Larinier, 2002). By keeping the natural flow characteristics, a structure can be constructed without compromising the passage of migratory fish.

Existing structures or potential new infrastructure designs can be assessed using Computational Fluid Dynamic (CFD) models. These models can evaluate structures in detail and analyse proposed fish pass structures, showing areas where velocities, water depths and gradient would prevent passage. A CFD model has been developed by Jacobs for an Environment Agency project looking at improving fish pass efficiency.

Whilst sharing knowledge internationally can be and has been successful, it should be noted that the indigenous species using a pass differ in each location. A solution in one location may therefore not be suitable in another as fish will differ in their swimming abilities and behaviours. General aspects of fish pass designs can be successfully used worldwide, however localised solutions with features appropriate to the indigenous fish are often preferred.

4. Previous Fish Pass Design at Jacobs

This section will detail three examples of projects undertaken by Jacobs involving fish pass design.

4.1 Ashford Water: Fordingbridge

The town of Fordingbridge in Hampshire is located adjacent to the River Avon and has a population of 5,500 (location shown in Figure 8). The town lies on the banks of the River Avon and its tributaries the Ashford Water, Sweatsford Water and Allen Brook. A flood defence scheme was constructed by the Environment Agency between 2005 and 2007.

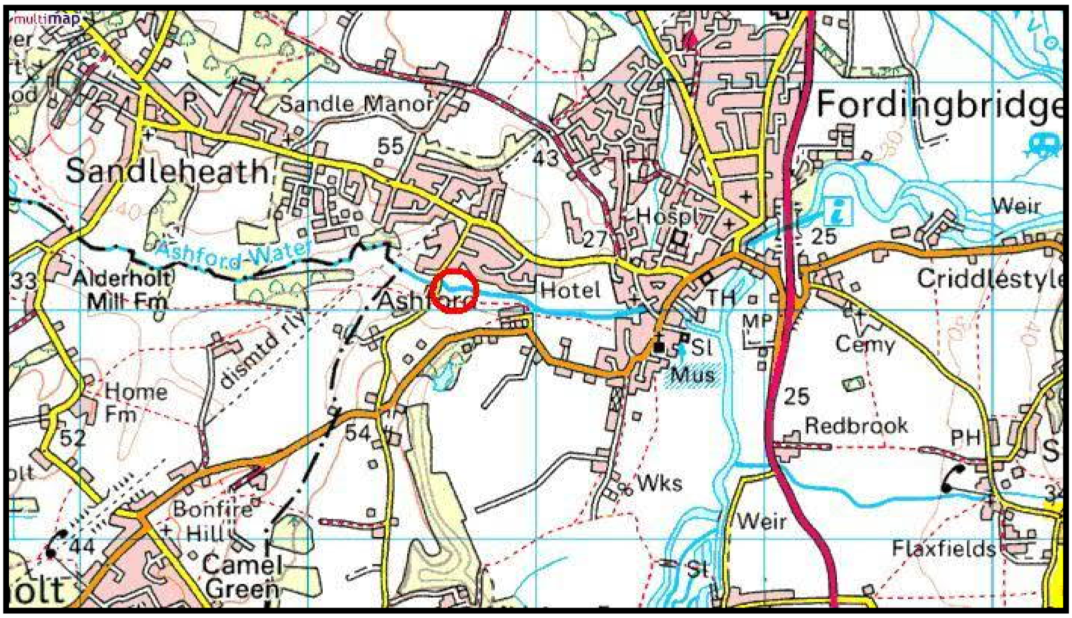


Figure 8. Location of the Bypass Channel Offtake Weir (circled in red).

The scheme provided new defence infrastructure on the River Avon and its tributaries throughout the town. This included flood defence walls and banks, drainage improvements, and the creation of a new flood relief channel to allow floodwaters in the Ashford Water to bypass the town and discharge back into the River Avon downstream of Fordingbridge. In addition to providing an economic flood defence solution for Fordingbridge, the bypass channel also provided 3km of new watercourse, forming new wetland habitat for BAP species and supporting the nearby River Avon SAC and SSSI.

The bifurcation of the Ashford Water is formed by a 15m long side weir spillway structure, which is formed from steel sheet piles, a concrete crest, and a downstream face (carrying water into the bypass channel) of Open-Stone Asphalt (OSA). The weir incorporates a small Larinier Baffle fish pass to enable upstream migration and movement of a range of coarse and game fish. The pass is unusually small (only 0.5m wide) due to concerns about maintaining adequate depths of flow in low flow conditions and the risk that large-scale fish stranding and predation could occur after periods of operation of the bypass channel. The type and geometry of the pass, together with the modelled hydraulic performance, was agreed with the English Environment Agency's fish pass panel prior to construction. The addition of the fish pass enabled environmental consenting approval of the flood defence scheme. A detailed plan and long section of the pass can be found in Figure 9.

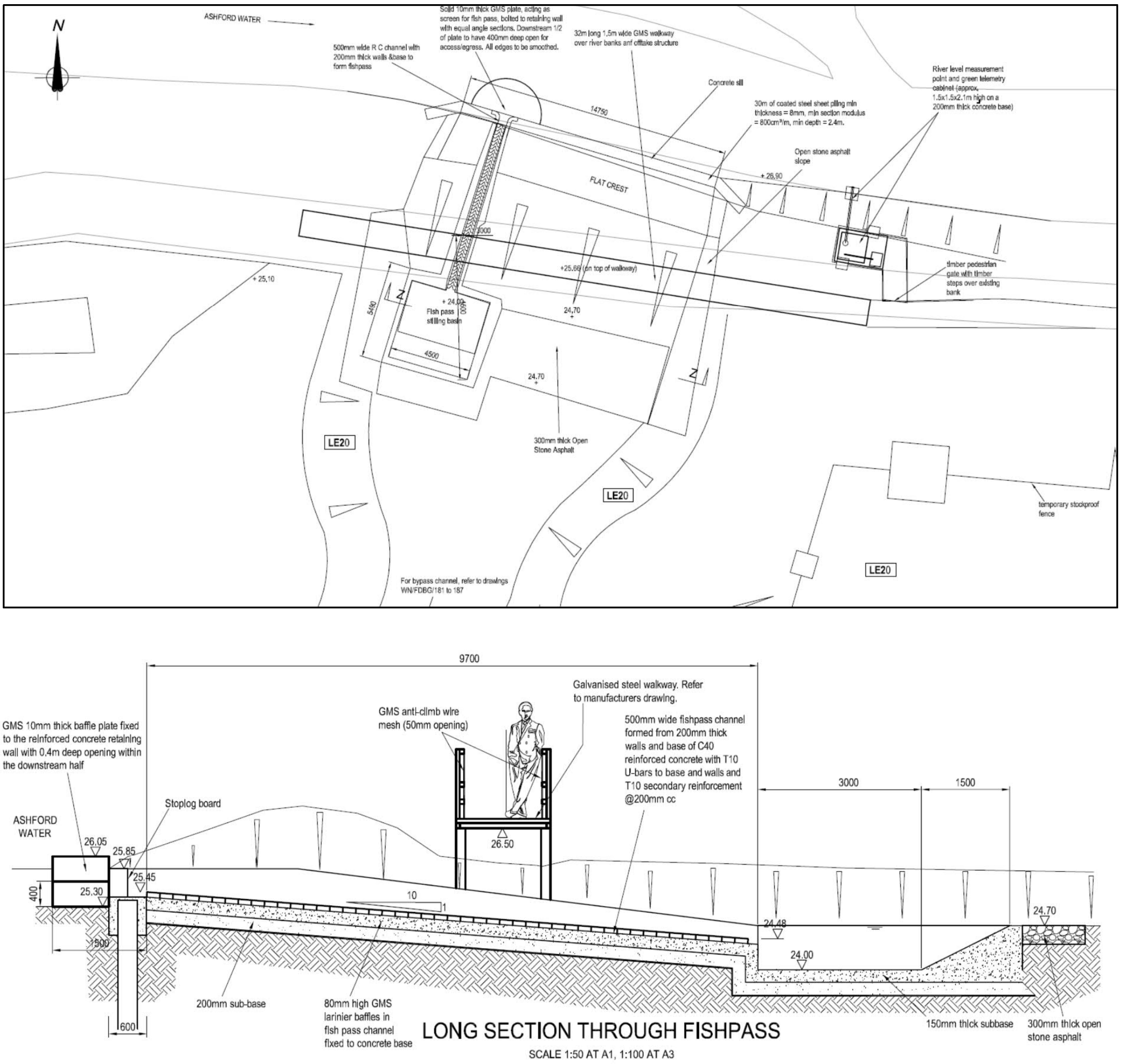


Figure 9. Top image shows the Detailed Plan and bottom image the Long Section.

The pass takes the form of a 10m long, 0.5m wide concrete lined channel, with galvanized steel baffles fixed to the floor of the channel, and a semi-circular inlet baffle at the upstream end to protect from debris whilst allowing fish to exist the pass into the Ashford Water. A diagram of the baffles is shown in Figure 10 and photographs can be found in Figure 11.

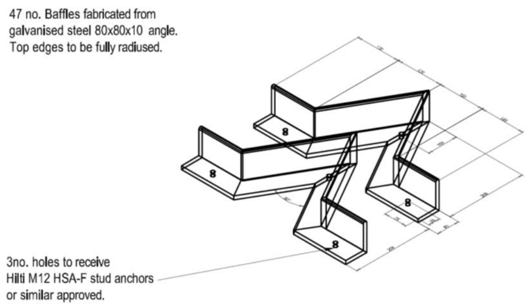


Figure 10. Diagram of baffles.

Figure 11. Photographs of the fish pass.

4.2 River Mole: Head Weir

Following previous obstructive weir abstraction refurbishment works by a partnership of local landowners, and closure of a nearby abstraction for a fish farm, an opportunity was identified by the West Country Rivers Trust to improve fish passage on the River Mole by removal of the existing weir and non-functional fish pass and replacement with a new Rock-Ramp style fish pass. The existing weir was an obstruction to fish passage, reducing the number of fish that can access the upper reaches of the River Mole to breed. The site location is shown in Figure 12.

Figure 12. Site location (circled in red).

The River Mole, together with its tributary, the River Bray, is an important sub-catchment of the River Taw, and provides the primary spawning and nursery area for brown trout and Atlantic salmon in the Taw catchment. There are no obstructions on the River Taw before its confluence with the River Mole, so that fish have free access to Head Weir, which forms the most downstream obstruction on the River Mole.

A Rock-Ramp style pass was selected due to the gentle gradients and natural flow conditions that this style of pass provide, the large available construction footprint, and availability of suitable rock material. The existing concrete faced crump weir and denil fish pass was completely removed and the river bed graded to create a 1 in 30 slope from the existing pool level downstream of the weir to approximately 60m upstream. A detailed plan and long section of the pass are provided in Figure 13.

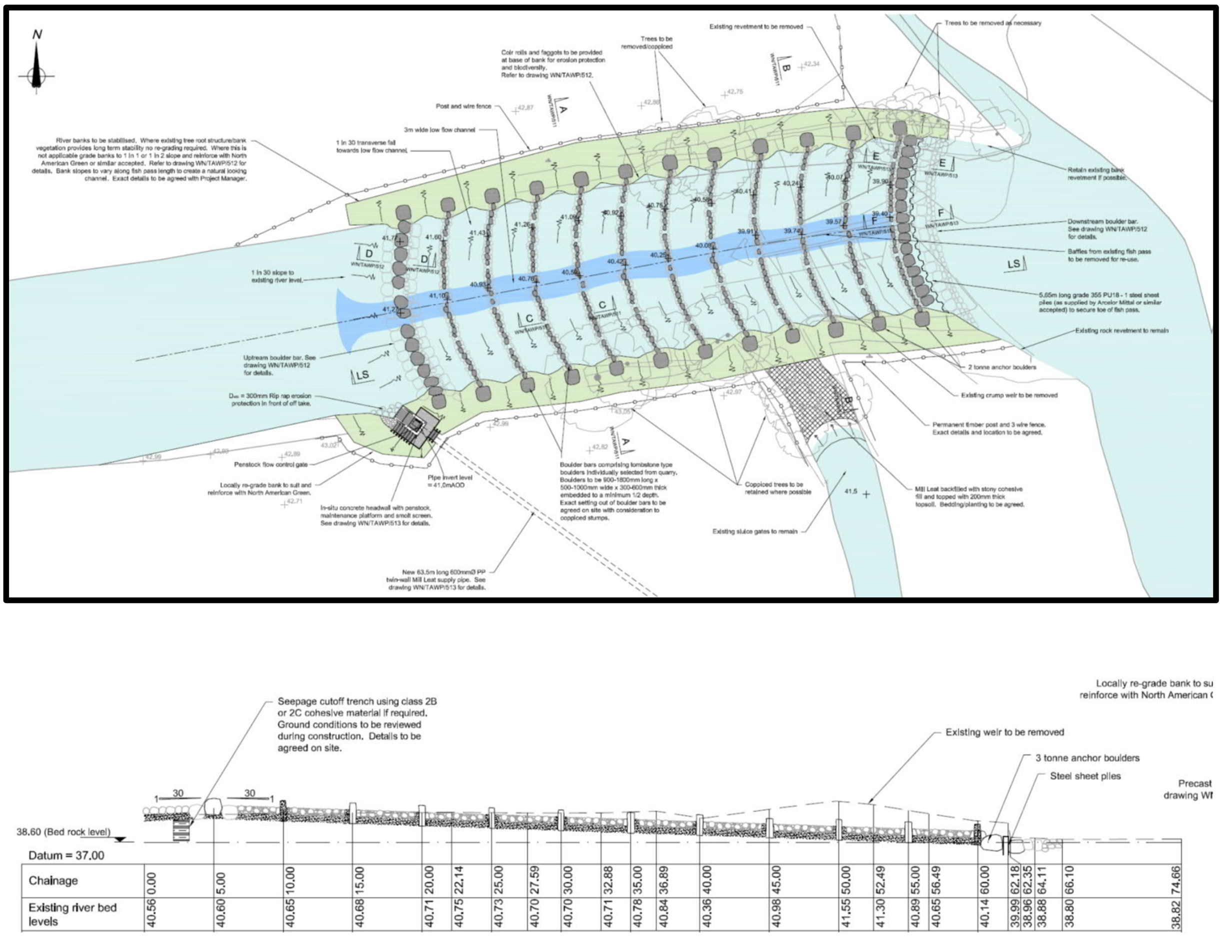


Figure 13. Top image shows the Detailed Plan and bottom image the Long Section.

Bars of embedded tombstone shaped boulders were placed perpendicular to the river flow at 5m centres with the boulders protruding around 500mm above bed level. The crest of the boulder bars gradually increases in level creating a stepped pool system. A low flow channel and gaps in the bars provides a diversity of flow with low flows concentrated in mid-stream. The rock bars are shown in Figure 14 below and a photograph of the finished pass is shown in Figure 15.

Figure 14. Diagram of the rock bars.

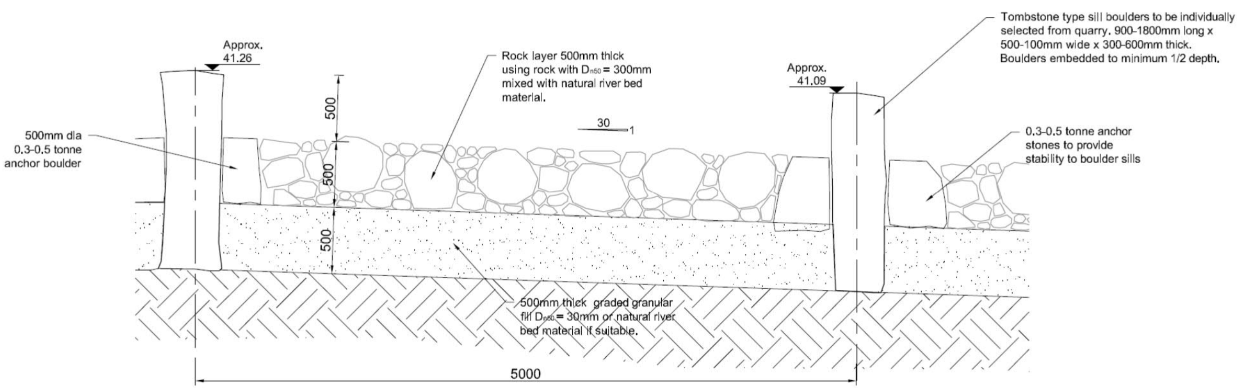


Figure 15. Photograph of the finished fish pass.

The River Mole scheme successfully reactivated 80km of river for migratory fish.

4.3 River Exe: Trews Weir

The Environment Agency have constructed a flood defence scheme in Exeter in partnership with Devon County Council and Exeter City Council to improve flood protection over the next 100 years. The Scheme includes improvements to existing conveyance channels and flood defences and the construction of new defences, which have increased the standard of flood protection to a 1% chance of flooding in any given year.

A key component to protection of Exeter's historic quayside has been the modifications to the Trews Flood Relief Channel and adjacent inlet weir, together with compensatory fish passage enhancements on both the main River Exe and the inlet weir. A location plan is shown in Figure 16.

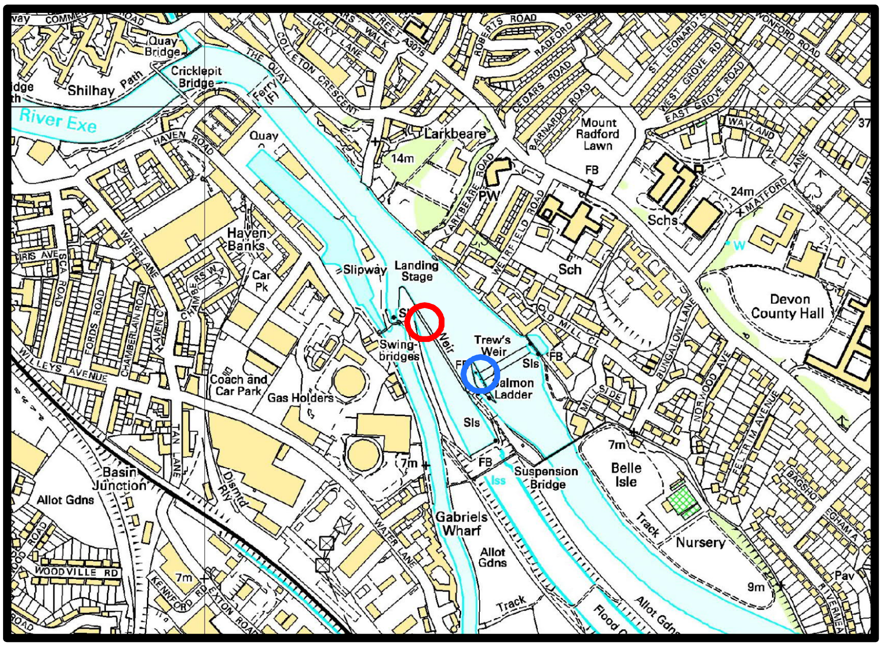
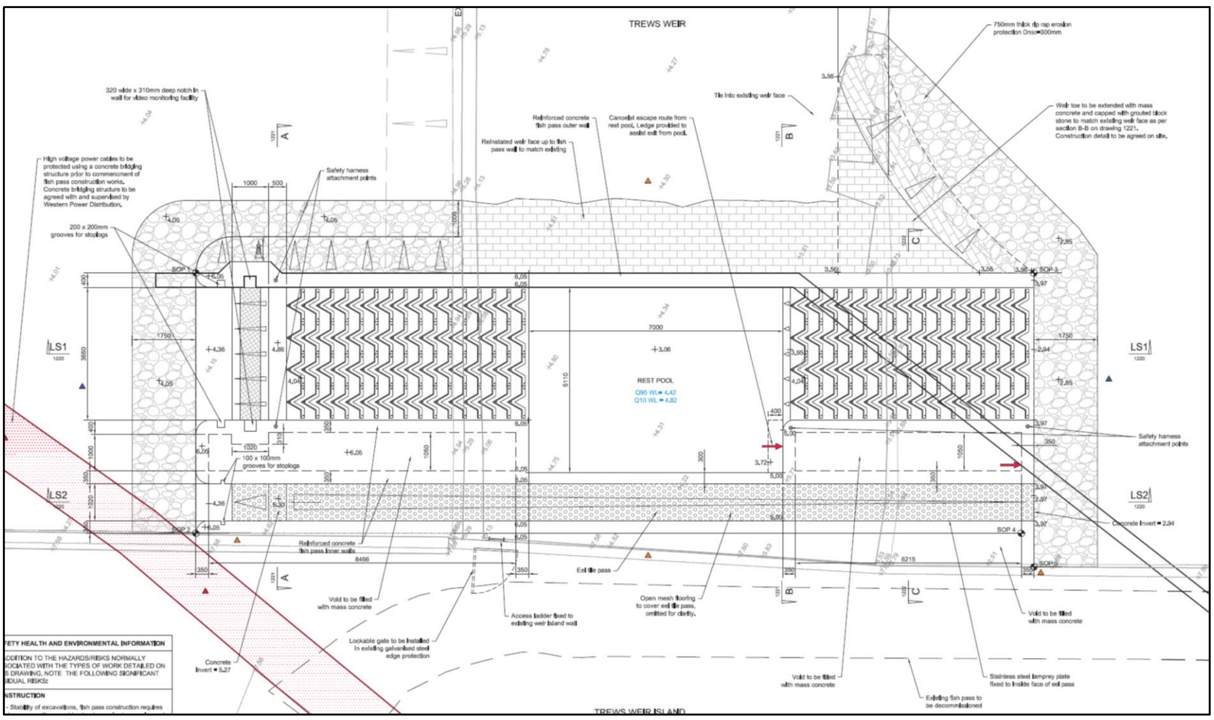


Figure 16. Location of the Side Spill Weir Fish Pass (circled in red) and the Trews Weir Fish Pass (circled in blue).

The main river is the primary migration route for Atlantic Salmon and Brown Trout, and a new 3.7m wide Larinier Baffle Fish Pass has been provided. To provide appropriate conditions for fish passage across this large weir, the pass incorporates a central rest pool and separate eel pass channel. The detailed plan and long section of the pass are shown below in Figure 17.



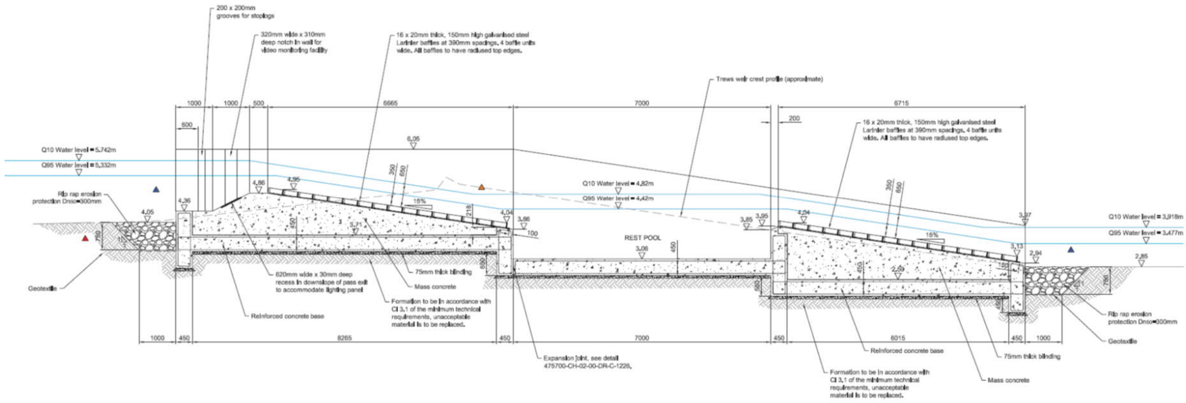


Figure 17. Detailed Plan (top) and Long Section (bottom).

A secondary Larinier Baffle Fish Pass has been provided in the side spill inlet weir to the Flood Relief Channel. To minimise construction costs and overall footprint, the pass was constructed in a galvanised steel channel. Again, to meet the technical requirements of the EA fish pass group, a central rest pool was constructed on an elevated platform midway along the pass. Photographs of the fish pass can be found in Figure 18.

Figure 18. Photographs of the fish pass.

5. Site Locations

The authors of this report worked closely with SEPA to identify eight representative fish barrier locations, near the Trunk Road network, to identify typical issues and possible solutions. These locations were chosen by reviewing the list of high priority fish barrier locations and assessing this to choose representative locations based on the following criteria:

- Extent of suitable upstream habitat;
- Size of catchment;
- Severity of blockage to fish migration.

This review identified eight locations (with some secondary barriers found in close proximity) for analysis. These locations were geographically spread across Scotland, including Aberdeen City, Aberdeenshire, the Highlands, and Dumfries. A summarised table of the chosen barrier locations is shown in Table 2. Site-specific preliminary data was collected at each site.

Fish Barrier Number	Local Authority	Location	Owner of Barrier
20689	Aberdeen City	River Don	Private
20690	Aberdeen City	River Don	Unknown
3176 (two other barriers nearby)	Aberdeenshire	Huntly	Transport Scotland
602	Highlands	North of Poolewe	Highland Council
1423	Dumfries and Galloway	Evan Water	Network Rail
1424	Dumfries and Galloway	Evan Water	Dumfries and Galloway Council
91	Dumfries and Galloway	Evan Water	Network Rail
21394	Dumfries and Galloway	Evan Water	Unknown

Table 2. Barrier locations and owners.

5.1 Aberdeen City

In Aberdeen City, there are two culverts on the Green Burn, which is a tributary of the River Don.

Fish Barrier 20689 (FB20689) and Fish Barrier 20690 (FB20690) are separated by around 60m of open water. They are located at NGR NJ 89360 10497 and NJ 89607 10511 respectively. FB20690 is upstream of FB20689 and is a 100m long round culvert that may be associated with the A947 road and/or the adjacent railway. FB20689 is a 120m long round culvert that discharges over an apron before a small drop into the River Don. It goes under the Stoneywood Mill car park. The location of the two barriers is shown in Figure 19.

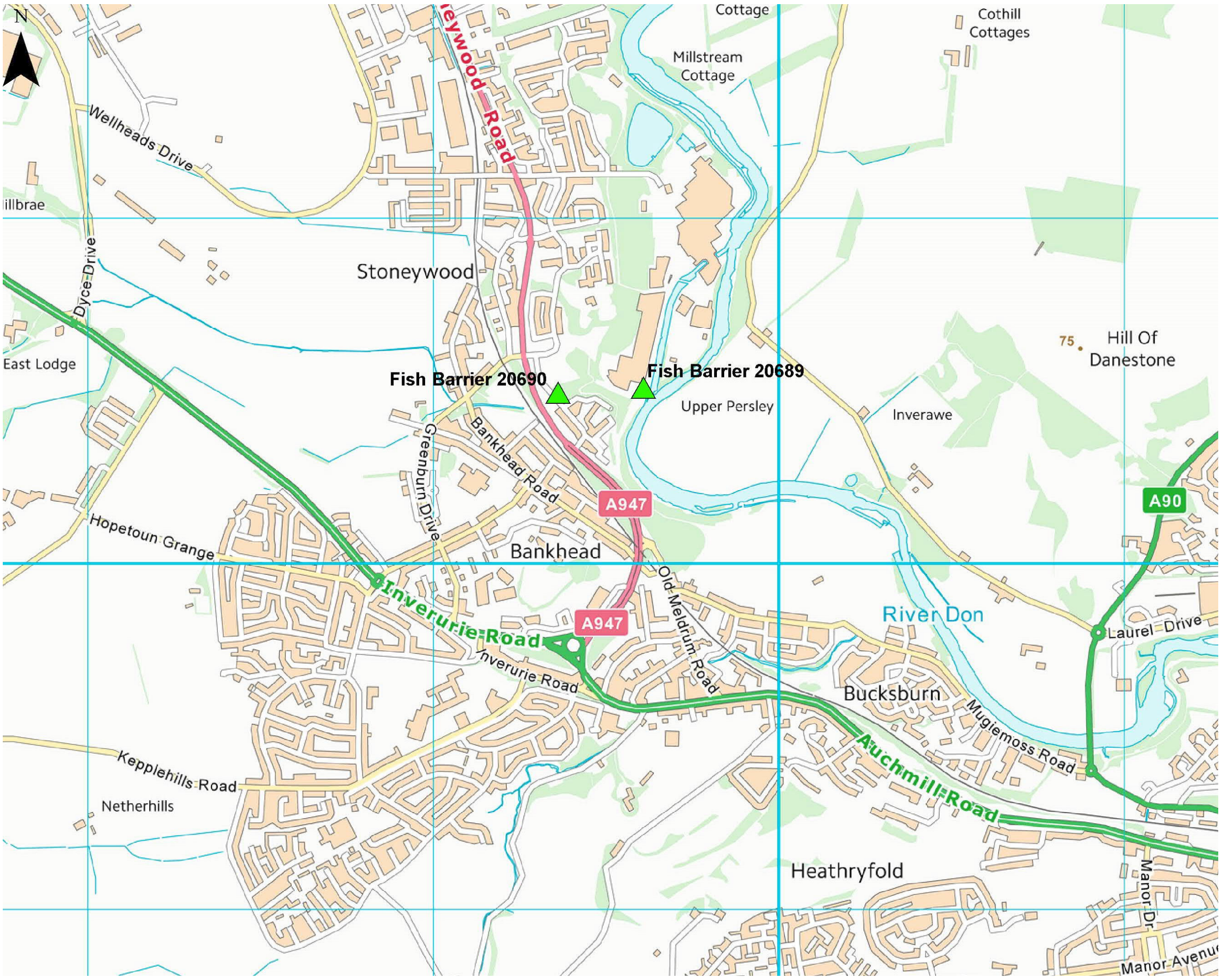


Figure 19. Location of FB20689 and FB20690.

5.2 Aberdeenshire

The main barrier which SEPA have identified in Aberdeenshire is Fish Barrier 3176 (FB3176), a culvert under the A96 road at NGR NJ 53677 93268. Following a site walkover conducted by a SEPA ecologist, two further impassable culverts have been discovered downstream of FB3176. The location of the three culverts is shown in Figure 20.

Culvert 2 is approximately 25m long and is found under an industrial site. A SEPA walkover established that it is possibly passable at medium flows. Culvert 3 is an approximately 70m long culvert located under the railway line. The same SEPA walkover found that it is impassable but potentially passable at higher flows.

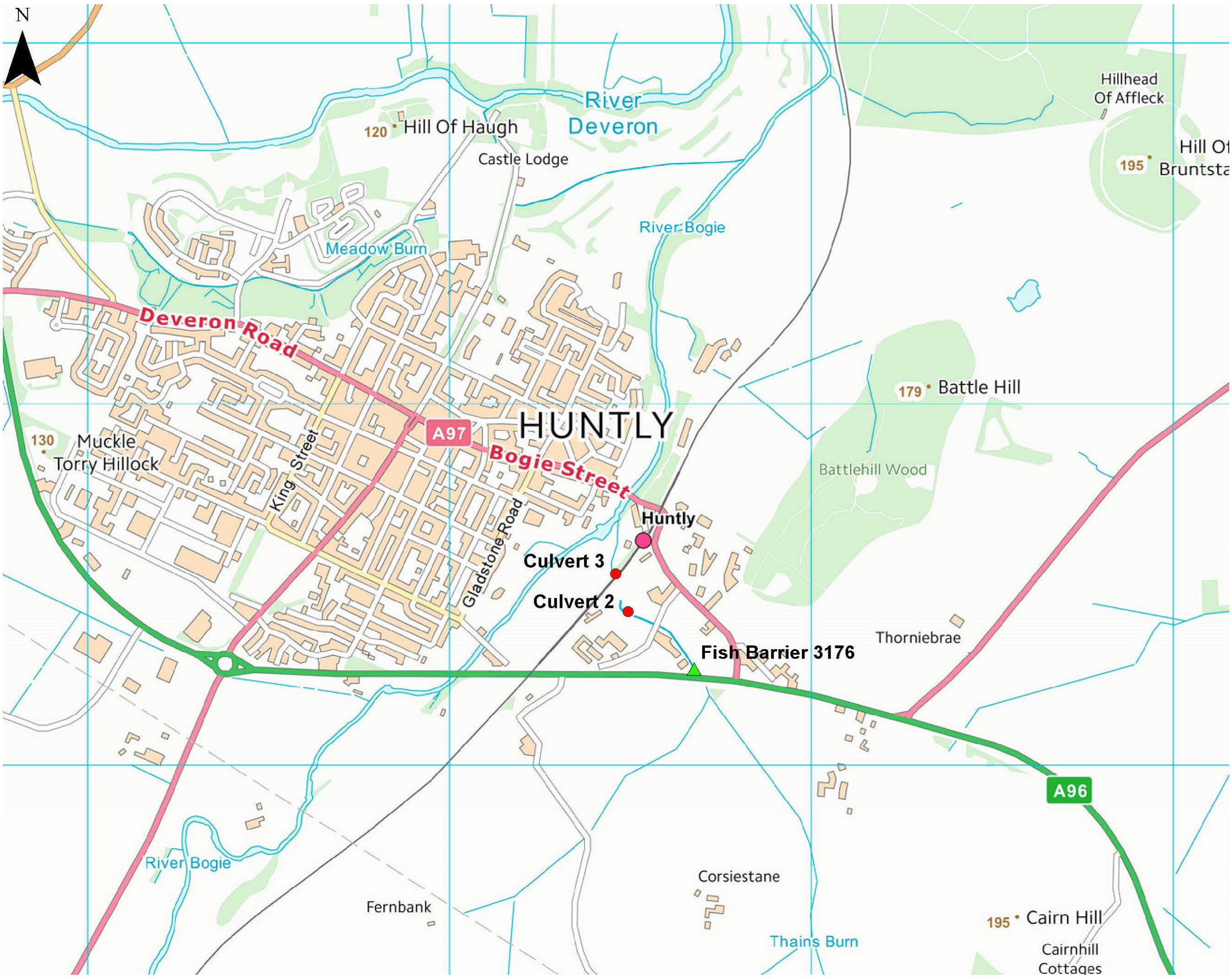


Figure 20. Location of FB3176 and two downstream culverts.

5.3 Highlands

Fish barrier 602 (FB602) is located in the Highland Council area approximately 1.5 hours North West of Inverness at NGR NG 9306 9029. The location of the barrier is provided in Figure 21. This is a five-pipe culvert that has been deemed impassable by SEPA.

Figure 21. Location of FB602.

5.4 Dumfries

There are four barriers found on the Evan Water in Dumfries and Galloway Council. These are Fish Barrier 1423 (FB1423), Fish Barrier 1424 (FB1424), Fish Barrier 21394 (FB21394) and Fish Barrier 91 (FB91). The location of each is shown in Figure 22.

FB1423 sits just off the main stem of the Cloffin Burn. The culvert is owned by Network Rail.

FB1424 is a culvert around 70m long under an all-purpose road and is owned by Dumfries and Galloway council.

Immediately downstream of FB1424 is FB21394. It is located under the bridge structure of the railway line. Baffles and a stepped channel are already placed within the culvert and it has been deemed passable in some conditions. Both FB1424 and FB21394 require inclusion in the site visit due to their close proximity.

Aqueduct FB91 is a 50m structure over the West Coast railway line owned by Network Rail. Having visited this site previously, SEPA state it is necessary to obtain input from Network Rail regarding this structure to determine whether it is technically feasible to make changes to the design.

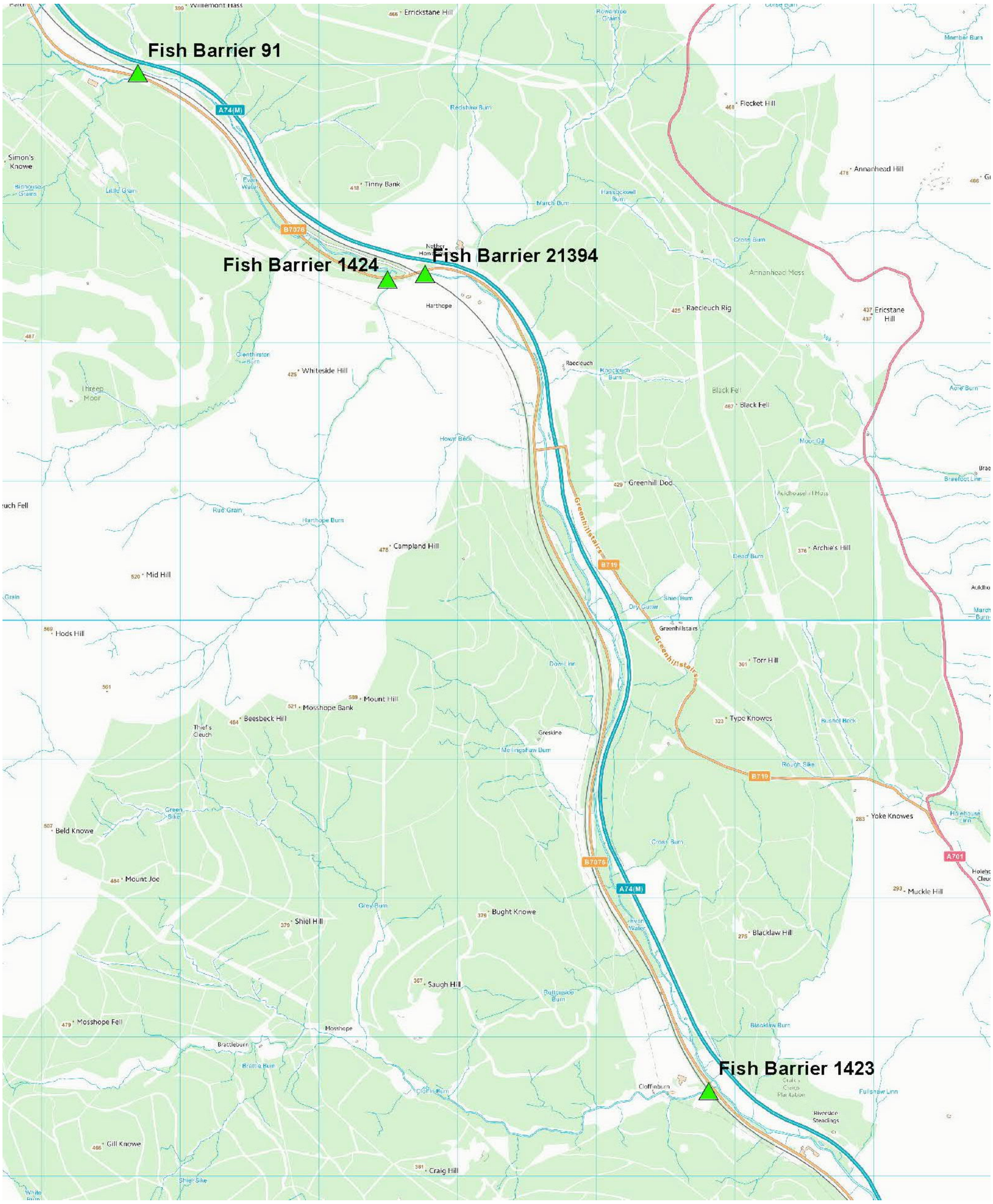


Figure 22. Location of FB1423, FB1424, FB21394 and FB91.

6. Checklist

Jacobs produced a checklist and scoring system, adapted from the SNIFFER (2010) guidance, that allow for rapid visual assessment of a structure on site. Consideration is given to the main aspects that may be inhibiting fish migration, such as the size of the drop and structure geometry. The checklist was successfully used during all of the site visits and used to assist with decision making for possible improvements. The full checklist is provided in Appendix A, with an extract shown below in Figure 23. The checklist and scoring system can be used by road authority maintenance staff to determine the ‘ease of fix’ for known fish barriers.

Check List

Section 1: Geometry

1. Name/reference of obstruction ______________________________
2. Type of obstruction (*tick all that apply*)
   - ☐ Weir
   - ☐ Culvert
   - ☐ Bridge (Ford or Bridge Footing)
   - ☐ Natural obstacle (e.g. debris, vegetation growth etc).
   - ☐ Other (specify) ______________________________
3. Width of obstruction ______________________________
4. Length of obstruction ______________________________
5. Gradient of obstruction ______________________________
6. Are there barriers within the obstruction e.g. debris, litter etc? Yes ☐ No ☐
7. Is a pre-barrage present? Yes ☐ No ☐
   If Yes, specify here it’s drop size, length and whether it is passable
   ____
   ____
   ____

Section 2: Velocity

To be passable, the velocity of water should be less than 1m/s. For visual assessments, describe the velocity as slow (passable) or fast (impassable).

8. Velocity of the water ______________________________

Section 3: Depth

To be passable, the depth of the water should be at least 150-200ml. For visual assessments, describe the depth as deep (passable) or shallow (impassable).

9. Water depth (consider within/over the obstruction, as well as upstream and downstream)
   ____
   ____

Figure 23. Extract showing example sections from the site check list.

The scoring system is placed at the bottom of the checklist with a request to score the culvert from 0.0 (low priority and passable) to 1.0 (high priority and impassable). The scoring system is shown in Figure 24.

Figure 24. The scoring system.

7. Findings

The main checklist findings from the site visit at each of the locations are summarised in Table 3, including a recommended solution and cost estimate. The benefit of removing each barrier is also provided in terms of length of reactivated river upstream (in metres), which was estimated using ArcGIS software and OS mapping. Further detail on the findings will be provided in the following sections.

Fish Barrier	Type	Width	Length	Velocity	Depth	Drop	Score	Recommended Solution	Estimated Cost	Benefit** (metres)
20689	Culvert	~1.5m	~100m	Fast	Shallow	Yes	1.0	Restore to open channel	£135,000	~2500m
20690	Culvert	~1.5m	~120m	Slow	Deep	No	1.0	Two possible solutions: 1) Open with bridge or 2) Artificial lighting & Pre-Barrage	1) £10m / 2) £100,000	~2500m
3176	Culvert	~2m	~50m	Fast	Shallow	No	1.0	Pre-Barrage	£50,000	~4500m
602	Culvert	~1.5m per pipe	~40m	Fast	Shallow	Yes	1.0	Two possible solutions: 1) Rock-Ramp Pass or 2) Larinier Baffle Fish Pass	£500,000	~3000m
1423	Culvert	~2m	~60m	Fast	Deep	No	1.0	Grates in carriageway	£200,000	~5000m
1424	Culvert	~2m	~50m	Fast	Shallow	No	1.0	Pre-Barrage	£50,000	~4000m
91	Aqueduct	~5m	~80m	Slow	Shallow	Yes	1.0	Raise crest height	£20,000	~4000m

Table 3. Summary of findings.

** Benefit of implementing solutions in terms of length of reactivated river upstream.

7.1 Aberdeen City

7.1.1 Fish Barriers 20689 and 20690

FB20689 and FB20690 are in close proximity to one another in Aberdeen City. Ownership of FB20689 is unknown. FB20690 is privately owned by Stoneywood Mill. The culvert runs under the car park of the mill (Figure 25) with an outlet into the River Don.

Figure 25. The sloping valley side leading down to the car park of Stoneywood Mill.

FB20689 is a long culvert lacking in light. Access to view the upstream inlet of the culvert was restricted by the factory boundary, however the water could be seen to be fast flowing. The downstream outlet features a drop into the River Don that is too high for fish to successfully navigate. The water flowing over this drop is extremely shallow, as is the pool downstream of the outlet, making it impassable to fish attempting to gain access (Figure 26).

Two options for improvement can be considered here. The first is to build a weir or Pre-Barrage downstream of the culvert outlet to increase the water depth in the downstream pool and throughout the culvert and to reduce the velocity. However, with such a long and dark culvert, it is still unlikely that this would attract fish.

Figure 26. The downstream outlet of FB20689.

The second option, which is preferred by SEPA, is to either divert the channel from the car park or to open the culvert from underneath the car park to introduce light. This would involve a major operation as a full diversion and restoration project. If the channel were to be diverted, it would be necessary to find a channel gradient suitable to the steep sloping land at the side of the channel. Given the length and lack of light in the culvert, diverting the channel or opening the culvert would be the recommended option. For both options, large rocks will be required upstream to produce eddies and provide a resting place for fish.

Permission would need to be given by the land owner to open or divert the culvert. SEPA have confirmed following the site visit that the car park is under used by the mill, and so the culvert could possibly be opened up. However, the mill has gone into administration and SEPA therefore cannot discuss major changes until a new owner has taken over or there is some clarity on the future of the mill (it could be redeveloped). There is no clear timeline but there is the potential for improvement.

Around 60m upstream of FB20689 is FB20690. This is an extremely long and dark culvert. The depth through the culvert looks adequate, whereas the river bed downstream of the culvert outlet is shallow and is only passable at high flows (Figure 27). Making this culvert passable could be a major highway project if the culvert is opened with a bridge to introduce light. Whilst this is the recommended solution, a cheaper alternative to be considered would be using artificial lighting, preferably with a solar panel and battery, along with a Pre-Barrage downstream.

Improvements should only be considered to FB20690 if it is confirmed that work is possible at FB20689, and vice versa. In cases such as this where a large amount of work would be involved to improve the structures, consultation is required with SEPA to determine if the upstream habitat is in good enough condition to merit the level of work.

Figure 27. The downstream outlet of FB20690.

7.2 Aberdeenshire

7.2.1 Fish Barrier 3176

SEPA originally only listed FB3176 as a high priority barrier to be considered in Aberdeenshire. Following a site walkover conducted by a SEPA ecologist, it was discovered that there were a further two culverts close by that were impassable. Therefore, all three will need to be considered in any improvements. FB3176 is owned by Transport Scotland, Culvert 2 has an unknown private owner and Culvert 3 is owned by Network Rail (it runs under a disused railway line).

FB3176 runs under the A96. The channel is shallow throughout the culvert with a very high velocity making it impassable to fish (Figure 28). The SEPA ecologist on site advised sea trout have been found in the channel.

Figure 28. View from the outlet facing upstream (FB3176).

A Pre-Barrage or small weir structure is required downstream of the culvert to back up water, thus reducing water velocity and increasing the depth throughout. A low flow notch should be included in the middle of the Pre-Barrage to concentrate flows and ensure passage in low flows. The channel upstream of the culvert is a suitable habitat (Figure 29).

Figure 29. Upstream channel at FB3176.

Downstream of FB3176 is another impassable culvert running under an industrial site (Figure 30). SEPA consider this to be possibly passable at medium flows. While the water in the culvert is relatively deep, a Pre-Barrage is required downstream to hold water depth throughout during low flows. Large rocks are required in the channel upstream of the inlet to create eddies.

Figure 30. The downstream outlet on the left and the upstream inlet on the right (Culvert 2).

A third culvert is found slightly further downstream which runs under a disused Network Rail line (Figure 31). The culvert is unattractive to fish due to its length and lack of light. Only the upstream inlet of the culvert could be viewed due to access issues, and large rocks are required here to create eddies. A Pre-Barrage may be necessary downstream, but it was not possible to confirm this.

Figure 31. Upstream inlet of Culvert 3.

7.3 Highlands

7.3.1 Fish Barrier 602

FB602 can be found North of Poolewe. It is a five-pipe culvert and weir running under the A832 road, managed and maintained by Highland Council (Figure 32). There is a lack of flow concentration with the channel flowing through all five pipes. The weir at the downstream outlet is large with an insufficient depth in the pools below. Due to the slope and lack of friction within the culvert pipes the water velocity is extremely high as it approaches the crest of the downstream weir, making fish passage impossible at this site.

Figure 32. Downstream outlet of FB602.

Water depth is greater on the left bank (facing downstream), and so flow should be concentrated to the culvert on this side of the channel. Stop logs can be placed in the remaining four culverts to create this concentration. However, this could result in a reduced capacity through the culverts and so the resulting flood risk must be considered. Another method of concentrating flows is to lower the base of the culvert inlet which could potentially damage the bottom of the culvert.

There are two options for improvement here. First is for a Larinier Baffle Fish Pass with a plunge pool in the left-hand bank culvert. Larinier fish passes have lower maintenance requirements than other types and have good flow attraction. The second option is to use natural material found in the surrounding area to create a Rock-Ramp Fish Pass downstream leading up to the culvert. The rock pools should be of significant size to allow dissipation of energy. Whilst this is a lower cost option, and is possible given the availability of material, it will involve moving a large amount of rock and may require some imported material. A natural Rock-Ramp Pass at this site is also at a high risk of being washed away during a large flood due to the steep gradient and high water velocity. For these reasons, the Larinier Baffle Fish Pass is recommended.

7.4 Dumfries

7.4.1 Fish Barrier 1423

FB1423 is a culvert owned by Network Rail. The culvert is narrow downstream and widens as it moves upstream (Figure 33 and Figure 34). The channel is deep throughout the culvert but is very fast flowing. The main issue with this culvert is the length and lack of light. SEPA had concerns that there may be an impassable waterfall upstream of the culvert. This was checked during the site visit by conducting a walkover, but no impassable features were found upstream. There was a large log blocking some flow upstream of the culvert in an area of private land, however this can be easily removed and should not impact the decision on whether improvements can be made to the culvert.

Figure 33. Upstream inlet of FB1423.

Figure 34. Downstream outlet of FB1423.

Due to the length of the culvert and lack of light, this would require either a bridge to open it up or a gap to be created between the carriageways by adding grates. The culvert also needs to be widened at the downstream outlet. Once this has been done, large rocks will be required upstream to produce eddies.

7.4.2 Fish Barriers 1424 and 21394

Whilst FB1424 has plenty of light, the channel flowing through is too shallow and has an excessive velocity (Figure 35). A Pre-Barrage with a low flow notch is required downstream to back up water, thus increasing the depth and reducing the velocity. Large rocks should also be placed upstream of the structure.

Figure 35. Downstream outlet of FB1424.

FB21394 has been deemed passable by SEPA and already has baffles within the culvert (Figure 36), which is likely to have been chosen as the solution here due to the steeper gradient. This barrier was included in the site visit to check the structural integrity. No modifications are required to FB21394. It should be noted, however, that there will be maintenance requirements at this site due to the potential for blockages in the baffles.

Figure 36. Downstream outlet of FB21394.

7.4.3 Fish Barrier 91

FB91 is an aqueduct over a National Rail line. There are currently a series of steps at the downstream end of the crossing over which the water depth is too shallow and channel slope too steep for migrating fish (Figure 37). The vertical sides to the channel prevent the formation of natural rest pools and eddies.

Figure 37. Series of steps downstream at FB91.

It is possible to work with the weir steps already in place by raising the height of the crests to create a deeper pool, allowing fish adequate depth for jumping. Low flow notches should be created in the middle of the crests to concentrate flow during low flows and to create eddies at either side. It should be noted that the walls surrounding the aqueduct are in poor condition (Figure 38) and may require structural support during any improvement works.

Figure 38. The surrounding walls of the aqueduct are in poor condition.

8. Contract and Maintenance

8.1 Contract

The overall policy framework for roads, including trunk roads, is set by the Scottish Government. Transport Scotland is responsible for the operation, improvement and continual maintenance of the network of trunk roads. This is delivered through separate contracts with operating companies (divided into four regional units and the Forth Road Bridge unit). A plan of the trunk road network in Scotland is shown in Figure 39.

The current 4G contracts do not specifically reference fish barriers. There are wider environmental legislation requirements within the contracts, placing responsibility with the operating companies to consider their removal and mitigation measures. Transport Scotland has a wider landscape policy, 'Fitting Landscapes'. This provides a high-level, flexible approach to sustainable design, management and maintenance. It aims to 'address the challenges of delivering and managing a transport network that offers a demonstrable contribution to national policy targets'.

8.2 Maintenance

The Road Asset Management Plan (RAMP) details the strategic maintenance of the trunk road network and how assets are protected and provided with the resources available. Ten agents in contract with Transport Scotland are responsible for the maintenance of each section of the Trunk Road Network. Transport Scotland Principal Structure Inspections take place every six years, with General Inspections every two years. During these inspections, the structural condition and any maintenance works required are determined. During future inspections, road authority maintenance staff can use the rapid assessment checklist and scoring system produced by Jacobs. Assuming both the upstream inlets and downstream outlets of each structure can be accessed, all of the information on the checklist can be obtained visually during a maintenance inspection. The scoring system can be used to prioritise improvements.

Figure 39. Plan of the trunk road network in Scotland.

9. Conclusions and Recommendations

9.1 Conclusions

With any road infrastructure there are several options for improving fish passage, including building small weirs and Pre-Barrages downstream of obstructions and installing Baffled Fish Passes. Consideration should always be given to the particular local flow characteristics and fish species at each site when determining the most effective solution. The rapid assessment checklist can be used to assess existing structures and to assist in selecting the most suitable solution for a given site.

9.2 Recommendations for Structural Improvements

The sites examined by this project offer a variety of examples and options for improvement.

Most of the structures assessed have inadequate water depth and high velocities, which can be improved by adding a small Pre-Barrage or weir downstream of the structures to increase depth and slow water velocity within the affected structures.

In cases where the gradient of the structure is steep, as was seen in the Highlands (FB602), a Larinier Baffle Fish Pass may be a more effective option. If baffles are chosen as the solution, more regular maintenance is required to manage the potential for debris blockage, although a Larinier Baffle Fish Pass has lower maintenance requirements than other types.

Structures that are exceptionally long will benefit from being opened up entirely, often via a bridge, to introduce daylight. This could involve major highway works. Before any works commence, discussions with SEPA should be held to determine the amount of suitable fish habitat that may exist upstream of each obstruction. Works will only be required where habitat size surpasses SEPA's threshold (generally 1.5km).

The obstructions may be located in close proximity to other impassable structures that have different owners or natural waterfall features. SEPA will consult with all owners in these cases as improvements must be made to all related obstructions in order to fully re-activate upstream habitats.

9.3 Recommendations for Maintenance Inspection Regimes and Contracts

Transport Scotland's 4G contracts have been reviewed by Jacobs and do not specifically reference fish barriers, although there are general references to environmental legislation. Jacobs recommends an ecological design guide be produced by Transport Scotland that covers the wider environment and all specific ecological concerns, not solely fish migration. SEPA have best practice guidance documents that can be linked to and referenced in the guide, including:

- 'WFD111 (2a) Coarse resolution rapid-assessment methodology to assess obstacles to fish migration': *a method for estimating the passability of an obstacle and for prioritising the removal or mitigation of man-made structures acting as a barrier to migration.*
- 'Managing River Habitats for Fisheries': *a best practice guide to managing river habitats for fisheries.*
- 'The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (CAR) – A Practical Guide': *all impoundments, weirs and dams require authorisation under this regulation. All culverts and bridges*

built after 1 April 2006 require authorisation under CAR. A CAR license is required before any barrier removal or easement engineering work can take place.

9.4 Next Steps

A pilot project could be run by Transport Scotland with focus on a simple example culvert. The example culvert should be large with a small drop and gentle gradient. A Pre-Barrage should be installed downstream across the entire width of the river, forming a 2-3m long rest pool immediately downstream of the culvert. It should include a 600mm wide, 200mm deep low flow notch to concentrate low flows and to attract fish to the entrance. The Pre-Barrage can be concrete and thus permanent, or driven timber boards and metal H piles can be used as a temporary and more flexible solution. The latter will allow for future changes in geometry to suit observed fish behaviour. Depending on the nature and grading of the river bed substrate, the piles can be either driven into the bed or the bed can be excavated and reformed around the placed piles. Upstream of the culvert, large boulders (volume approx 0.1m^3, weight approx 2.7 tonnes) should be placed in the watercourse and arranged to produce eddies. Alternatively, a partial weir can be constructed that will allow eddies to form behind it.

The location of a pilot project should be chosen on the basis that a simple solution can be implemented at the site. FB1424 in Dumfries, where the recommended solution is a Pre-Barrage with a low flow notch and the placement of rocks upstream, would be appropriate for a pilot project. The estimated cost of implementing the solution at this site is £50,000 and the implementation would result in approximately 4km of upstream habitat being reactivated.

If Transport Scotland decide to run a pilot project, or to begin any works on fish barrier removal or easement, the first step in the process would be to commission a design through a consultant or contractors. SEPA will likely partner in the project, and the Fisheries Trust in Scotland may also look to be involved. The Fisheries Trust may look to be included in any site visits to agree the designs and may monitor any works after completion.

10. Bilbliography

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Appendix A. Full Site Checklist

JACOBS

Site Visit Checklist

Subject

Client **Date**

Project

Prepared by **Phone No.**

Participants

Notes:

- *Agree a safety plan with every member of the site team prior to the site visit.*
- *Ensure photographs are taken of all structures/obstructions, including the surrounding area for context.*
- *When prompted below provide either a measurement or a best estimate from visual assessment of the structure/obstruction.*

Check List

Section 1: Geometry

1. Name/reference of obstruction ______________________________

2. Type of obstruction (*tick all that apply*)
   - ☐ Weir
   - ☐ Culvert
   - ☐ Bridge (Ford or Bridge Footing)
   - ☐ Natural obstacle (e.g. debris, vegetation growth etc).
   - ☐ Other (specify) ______________________________

3. Width of obstruction ______________________________
4. Length of obstruction ______________________________
5. Gradient of obstruction ______________________________

6. Are there barriers within the obstruction e.g. debris, litter etc? Yes ☐ No ☐

7. Is a Pre-Barrage present? Yes☐ No☐
   If Yes, specify here it's drop size, length and whether it is passable
   ____
   ____
   ____

Section 2: Velocity

To be passable, the velocity of water should be less than 1m/s. For visual assessments, describe the velocity as slow (passable) or fast (impassable).

8. Velocity of the water ______________________________

Section 3: Depth

To be passable, the depth of the water should be at least 150-200ml. For visual assessments, describe the depth as deep (passable) or shallow (impassable).

9. Water depth (consider within/over the obstruction, as well as upstream and downstream)
   ____
   ____

Section 4: Drop (Please use N/a if no drop)

To be passable, the drop should be less than 30cm (300mm). For visual assessments, describe the drop as small (passable) or large (impassable).

10. Size of the drop ____

11. Is the drop split up into a number of smaller drops? Yes ☐ No ☐
    If Yes, how many? ____

12. Are rest pools present? Yes ☐ No ☐
    If Yes, specify the number of rest pools and their size, and comment on their effectiveness at dissipating energy
    ____
    ____
    ____

Section 5: Concentration of Flow

Fish are attracted to areas of concentrated flow, as well as noise and aeration.

7. Is there a concentration of flow to one point? Yes ☐ No ☐

8. Are notches present? Yes ☐ No ☐
   If Yes, specify the number of notches and their size. Comment on their suitability for fish passage?
   ____
   ____
   ____

Section 6: Additional Comments

Section 7: Cross Section Sketch

Include here a cross section sketch, with any measured/estimated values.

Section 8: Score

Using the scoring system to the right, please provide a score for the structure from 0.0 to 1.0

Low Priority/Passable	0.0
Low Priority/Impassable	0.3
High Priority/Passable	0.6
High Priority/Impassable	1.0