AECOM

Horseshoe Falls Fish Pass

Design Report

Natural Resources Wales

Project number: 60672359

02/11/2022

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Quality information

Prepared by	Checked by	Verified by	Approved by
Massimiliano Fini Water Scientist	Mark Biesta Principal Engineer	Adrian Hill Principal Engineer	Mark Biesta Principal Engineer
Thomas Adams Engineer	Gill Wright Principal Aquatic Ecologist		

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Prepared for:

Natural Resources Wales

Prepared by:

AECOM Limited
1 New York Street
Manchester M1 4HD
United Kingdom

T: +44 161 601 1700
aecom.com

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1. Introduction

1.1 Background

The River Dee has a high conservation value being designated as two separate Sites of Special Scientific Interest (SSSIs) which are defined by the national boundary between England and Wales. The River Dee (England) SSSI is in England and the Afon Dyfrdwy (River Dee) SSSI is in Wales. The River Dee is the largest river in North Wales and together with Bala Lake (Afon Dyfrdwy a Llyn Tegid) is designated as a Special Area of Conservation (SAC). Atlantic salmon (*Salmo salar*), listed under Annex II of the EC Habitats Directive (92/43/EEC), are a primary reason for selection of the site. Annex II species present as a qualifying feature include sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*), brook lamprey (*Lampetra planeri*) and bullhead (*Cottus gobio*). Other species of conservational interest include sea/brown trout (*Salmo trutta*) and European eel (*Anguilla anguilla*). However, the Dee is significantly regulated, with three upstream reservoirs supplying potable water, historically modified banks and floodplains and fourteen weirs considered to impact fish passage. Consequently, some protected species and habitats have been categorised as unfavourable-bad or unfavourable-inadequate.

The LIFEDeeRiver project (LIFE18 NAT/UK/000743) aims to take a catchment-based approach to restore natural processes, features and habitats over a 55 km or more stretch of the SAC, contributing towards implementation of the Habitats Directive, Water Framework Directive (WFD) and other national and EU policies.

1.2 Horseshoe Falls Weir

Horseshoe Falls Weir is one of six weirs where fish passage solutions are being developed. The site is situated on the River Dee in Denbighshire, north east Wales, approximately 2.3 km north west of Llangollen town centre. The site comprises a weir spanning the majority of the width of the River Dee, falling short from the eastern bank to allow for the navigation of the Shropshire Union Canal Llangollen Branch. The weir forms part of Pontcysyllte Aquaduct and Canal World Heritage Site, while also lying within a SAC and SSSI.

The weir is a large horseshoe-shaped structure around 145 m long, forming a vertical drop in water of approximately 1.5 – 2 m high. The site lies approximately 85 m above ordnance datum (AOD). AECOM (2021) prepared an outline design for a close-to-nature fish bypass channel on the right-hand bank (Figure 1 and Figure 2). The left- and right-hand banks are defined by their respective directions when looking in a downstream-direction down the river. The aim of this project is to develop the design to a detailed design for construction.

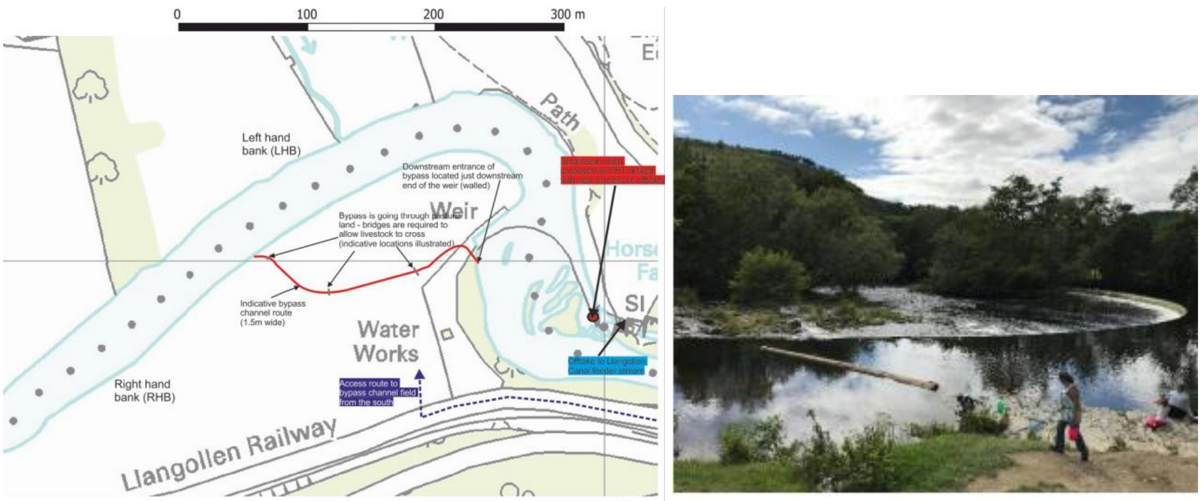

Figure 1. Horseshoe Falls Weir fish passage outline design overview and weir view from upstream (Left-Hand Bank)

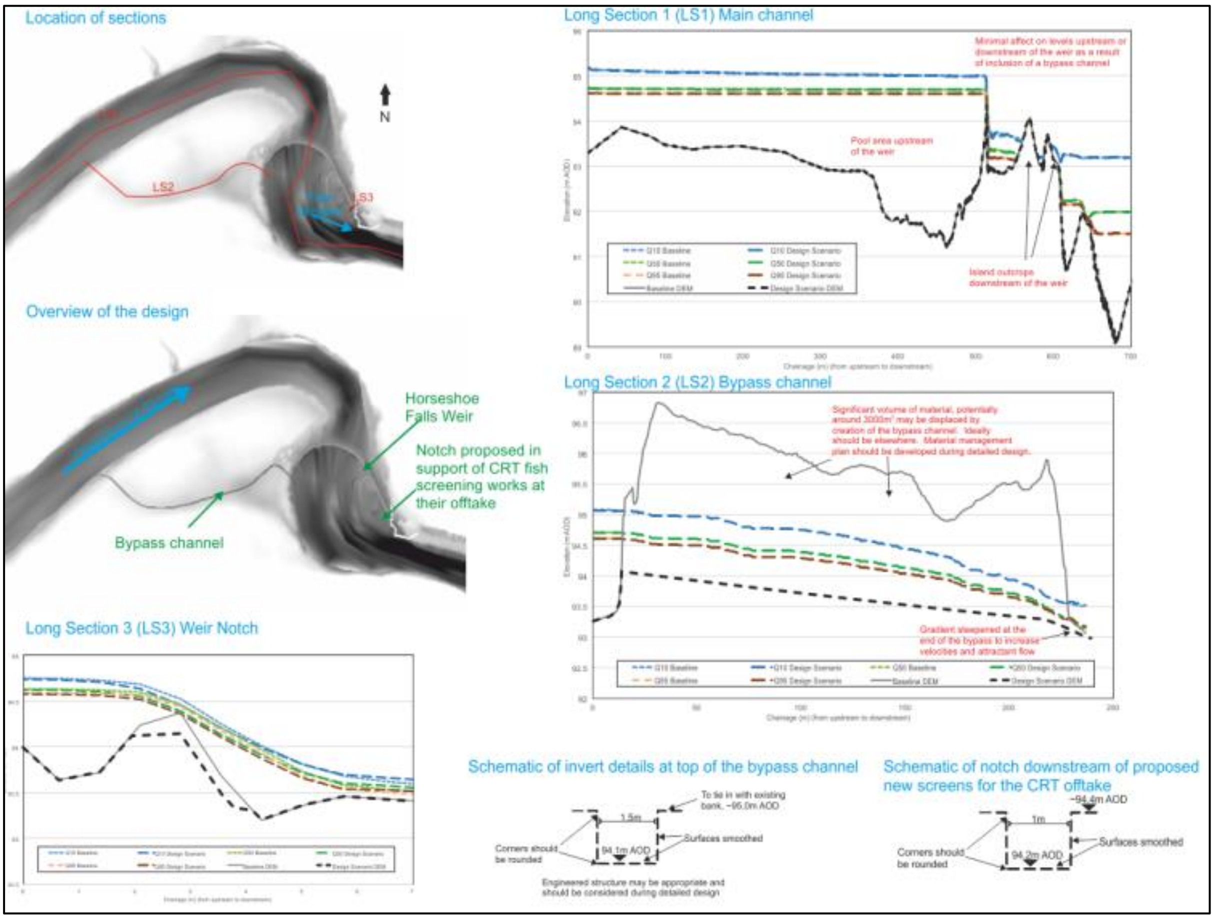

Figure 2. Horseshoe Falls Weir outline design (long section and channel sections showing baseline and design scenario and other design details)

1.3 Scope

Natural Resources Wales commissioned AECOM to develop a detailed design for a fish bypass channel at the weir. The scope included the following and the outcomes are presented in this report:

- Further services investigations
- Ground Investigation specification and supervision
- Hydraulic design including hydromorphology and fish passage
- Engineering design
- Production of a construction package including drawings, specification and CDM Pre-Construction Information

The following are aspects of the project were undertaken by NRW where required:

- Planning application
- Stakeholder consultation
- Ecology
- Heritage
- Landscape (including landscape design)
- Others e.g. Habitat Regulations Assessment, Water Framework Directive assessment

1.4 Report Structure

This report sets out the approach taken for the detailed design of the fish pass. The structure of this document is as follows:

1. Available information
2. Detailed design criteria and considerations
3. Hydrology and modelling
4. Initial design decisions
5. Detailed design
6. Design performance
7. Construction considerations
8. Maintenance
9. Summary and recommendations
10. References
11. Appendices

2. Available Information

2.1 Summary

Table 2-1 below shows the information provided to, and obtained by, AECOM for the purposes of this project.

Table 2-1. Available information

Title	Source / author	Date / version	Description
GS-8425412 Fast-track Utility Search Report	Emapsite	05 January 2022	Utility search results
SP20251	Groundsure Utilities	23 April 2022	Utility search results
LA-075-006 Horseshoe Falls Weir Principal Inspection Report	Arcadis	October 2018	Summary of weir inspection
019-LDN-APM-ZZ-RP-002 Horseshoe Falls Screening	APEM Ltd	03 March 2020	Site visit report and engineering assessment
P00003875 UU Horseshoe Falls Eels Regulations Intake Screening	APEM Ltd	September 2020	Assessment of the risk to eels posed by United Utilities intake
DEE01_HORS_LS+LP	Storm Geomatics	19 October 2020	Long sections along the River Dee
DEE01_HORS_XS	Storm Geomatics	19 October 2020	Cross sections across the River Dee
60672359_River Dee Fish Pass DD_HF_Options Appraisal	AECOM	11 March 2022	Horseshoe Falls Bypass Options Appraisal
DDD Project Onset Plan_26-11-21	AECOM	November 2021	Project Plan at Project Onset
60627686_LIFEDeeRiver_Restoration_of_Freshwater_Features_Horseshoe Falls	AECOM	March 2021	Assessment of preferred options and determination of recommended option for improving longitudinal connectivity for fish
Horseshoe Falls LiDAR	Natural Resources Wales		
Dee Stock Assessment Programme Angler Report 2019	Natural Resources Wales	March 2020	Assessment of fish stock
OS_MasterMap_Topography Layer_739499_957466_OS_Mastermap	Ordnance Survey	November 2021	Background Mapping
HORSE_TOPO	Storm Geomatics	October 2020	Topographic survey of area around right-hand weir abutment
River Dee Geophysical Investigation	AECOM	28 November 2021	Buried utility detection and geophysical survey summary including at Horseshoe Falls

2.2 Site Walkover

2.2.1 General

The site was initially visited by AECOM on 16th July 2020 prior to the outline design work. Additional site visits occurred on 7th December 2021 and 8th February 2022 in order to inform the detailed design of the fish pass bypass channel. The final site visit (8th February 2022) was carried out by water resources and fish pass design specialists from AECOM.

The weather on the day was overcast with occasional drizzle, with the previous two weeks being characterised by frequent and light rainfall events. According to the rainfall recorded at the NRW rainfall station of Penygwely[1], during the two weeks prior to the site visit, 9 days had less than 0.5mm of rainfall and on only 3 days more than 5mm were accumulated with a peak of 11.6mm on 6th February 2022. Assuming the flow levels measured at the NRW gauging station of Dee at Manley Hall were representative of the flows at Horseshoe Falls weir, a flow corresponding to H15 (level statistic)[2] was estimated to occur on the day of the final site visit.

The right bank of the River Dee (upstream of Horseshoe Fall weir) was accessed via vehicle until SJ 19634 43210 through a single carriageway road (Plate 2-1 and Plate 2-2) which then continues along a fenced grazing field on the right-hand bank (floodplain) of River Dee (Plate 2-3 and Plate 2-4). At this point the site was accessed via the public footpath access (Plate 2-3). It was believed that an access track through this grazing field would potentially be the easiest access to the site during eventual construction works although an access ramp and a temporary disruption of the fence (along access road) should be required (and to be reinstated at work completion). The area appeared to be frequently used by sheep and likely by other livestock (Plate 2-5). This highlights the requirement for fencing around the final site to avoid cattle poaching. From the access point to the field, a fence runs along a disused pumping station (Plate 2-6 and Plate 2-7) through to a retaining wall on the right-bank of the weir (Plate 2-8, Plate 2-9 and Plate 2-10). At SJ 19493 43337, near the weir wingwall, infrastructure related to the disused pumping station is present. Plate 2-10 shows a metallic platform (presumably used for access / inspection of the abstraction point), fencing (continuation of the above mentioned fence) and a concrete manhole structure for water utility access. For additional information related to the presence of a raw water pipe at this location see section 2.3 and 6.8.

The surrounding area is relatively flat with an evident paleo-channel (Plate 2-7 and Plate 2-11) running from the right-hand bank of the River Dee through to the true right edge of Horseshoe Falls weir. An intermittent line of trees is present along the River Dee where the upstream end of the bypass channel was envisaged to be located (see section 6.1), approximately at SJ 19392 43382 (Plate 2-12, Plate 2-13 and Plate 2-14). Therefore, tree clearance may be required during construction with some of these potentially to be re-instated at completion of work. Refer to section 6 for detailed information on the bypass channel alignment. The right-hand bank of the River Dee at SJ 19392 43382 presents a natural slope varying from 1 in 2 to 1 in 3, with some jagged segments due to erosion. At the end of the works, some of the material excavated during construction could be used to support some of these vulnerable areas and improve appearance.

[1] Accessed at https://rivers-and-seas.naturalresources.wales/Station/1145?parameterType=2
[2] Assuming this to be equivalent to Q15 (flow statistic)

Plate 2-1 Access road to River Dee right-hand bank (looking towards main road)

Plate 2-2 Access road to River Dee right-hand bank (looking towards site)

Plate 2-3 Public access to River Dee floodplain (red arrow in the background)

Plate 2-4 Overview of access road and public footpath access (red arrow)

Plate 2-5 Grazing land on right-hand bank of River Dee (upstream of Horseshoe Falls weir)

Plate 2-6 Disused pumping station and fence

Plate 2-7 Panoramic view of River Dee floodplain

Plate 2-8 Access fencing to right-hand side of Horseshoe Falls weir (location of downstream end of bypass channel)

Plate 2-9 Fencing (looking from weir wingwall on right-hand side of weir)

Plate 2-10 Panoramic view near Horseshoe Falls weir (downstream end of bypass channel)

	
Plate 2-11 Visible paleo-channel on River Dee true right floodplain	**Plate 2-12 Line of trees along River Dee right-hand bank (looking upstream)**
	
Plate 2-13 Line of trees along River Dee right-hand bank (looking downstream)	**Plate 2-14 Line of trees along River Dee right-hand bank (looking downstream)**

2.2.2 Geomorphology

Geomorphology specialists from AECOM visited the site on 16th-17th July 2020 prior to the outline design work. Refer to the outline design report (AECOM, 2021) for geomorphology assessment and audit information. The site was re-visited on 14th December 2021 to inform the detailed design of the fish bypass channel. As a result, it was concluded that geomorphological risks for the project have been assessed as low throughout baseline, optioneering (section 5), outline design, and detailed design, due to the bedrock typology of the local River Dee. The natural bedrock outcrops forming the Horseshoe Falls weir mean the river has no significant vulnerability to scour or to any localised changes in flow patterns that would be brought about by the fish pass.

2.3 Services

During the outline design, utilities record drawings indicated that an underground power cable and a raw water pipe cross the proposed path of the bypass channel. An extract of the outline design drawing showing these features is shown in Figure 3.

Additionally, a geophysical survey was undertaken prior to detailed design, which included an Electomagnetic Location (EML) survey to detect underground services using electromagnetism, and a Ground Penetrating Radar (GPR) survey to map subsurface non-conductive services at the site and complement the EML. The geophysical survey results showed the location of both the power cable and the water pipes, as well as approximate depths in places, although these could not be reliably defined for all of the length of the services.

The raw water pipe is associated with a river abstraction immediately upstream of the weir and connects to a pumping station just south of the proposed bypass channel. Its alignment crosses the path of the proposed open channel, as will the manhole in the system, and will therefore require diversion or removal for the fish pass channel to be constructed. NRW consulted with Hafren Dyfrdwy who own the pumping station site and confirmed that the site is no longer operational and the pipe can be removed.

Scottish Power Energy Networks (SPEN) have been consulted on the diversion of the low voltage cable whose alignment cuts through that of the proposed channel. The depth of the cable shown in the geophysical survey shows that the cable is 1.02m below ground level at a location to the south of the fish pass, but the depth at the fish pass crossing was not defined. Given ground levels are similar at the fish pass crossing and the nearest location where the depth of the cable is provided, it is assumed that the depth of the cable at the fish pass crossing is also approximately 1 m. This means that the construction of the fish pass channel requires the diversion or removal of the electricity cable. A sketch with a plan of the area and a section along the cable, showing the approximate depths of the cable, read from the geophysical survey, and the width of the channel under which it would be required to be diverted, was sent to SPEN, who questioned whether the supply was still required as the Pumping Station was disused. This feedback was passed back to the client, who agreed that the supply is no longer required. Further consultation is required with SPEN on the process of removing the cable at the location of the fish pass.

The utility search report and the geophysical survey reports can both be found in Appendix A.

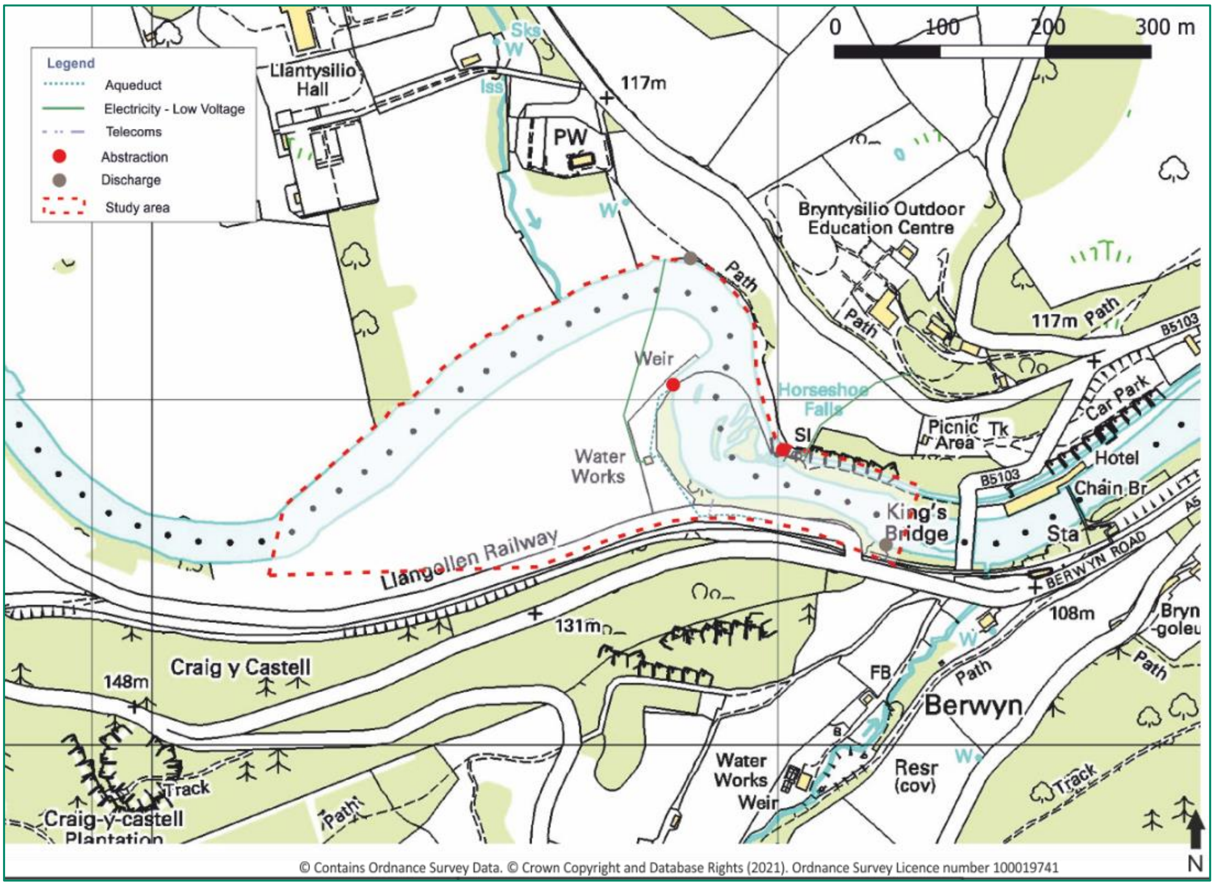

Figure 3. Outline design utilities drawing extract

2.4 Ground Investigation

Ground Investigation (GI) was undertaken on the site to obtain an understanding of the overall ground conditions, both geological and hydrogeological. The outputs of the GI were used to derive geotechnical and geo-environmental parameters for the site which were used to determine design constraints, such as maximum slopes that can be used. Further detail can be found within the AECOM *Ground Investigation Report*. The investigation comprised of the following:

Boreholes:

- 3 No. Rotary Open Holed/Cored Boreholes
- 11 No. Windowless Sampled Boreholes

In situ testing

- 41 No. Standard Penetration Tests typically at 1 – 1.5m intervals
- 72 No. Photo-Ionisation Detector (PID) headspace tests on selected soil samples

Instrumentation

- Installation of 3 No. 50mm HDPE groundwater / ground gas monitoring wells

Groundwater Monitoring

- 1 No. round of groundwater monitoring post site works
- 1 No. round of groundwater sampling post site works

The ground beneath the site was found to be granular alluvium underlying topsoil, described as very loose to loose consisting of gravelly sand or sometimes sandy gravel. Below or in the absence of alluvium, river terrace deposits were found, consisting of medium dense to very dense sandy gravel or gravelly sand with low to medium cobble content. Elwy Formation bedrock was encountered beneath the site.

The geotechnical risks identified within the GIR were:

- Unrecorded made ground and contamination
- Damage to existing services
- Instability of excavations
- Groundwater level
- Contamination from construction activities
- Unforeseen ground conditions
- Uncertainty of rockhead levels.

These were considered to be tolerable with appropriate mitigation to be applied through the design and construction process. One key point highlighted was the presence of loose sandy deposits which would require removal and replacement with a more stable fill material if found to be present in the side slopes of the open channel. Due to changes in the proposed alignment of the fish pass which occurred after ground investigation works had taken place (refer to Section 5.1 of this report), it should be noted that borehole locations are not positioned directly on the proposed fish pass alignment and thus the ground below the fish pass may differ.

3. Design Criteria and Considerations

3.1 Project Aims

The aim of the project is to improve fish passage up the River Dee at Horseshoe Falls weir. The weir currently presents a barrier for fish migrating upstream. Target fish species the fish pass should provide for are shown in Section 3.3.2. This should be achieved in a way that is visually sympathetic to Horseshoe Falls weir and its wider environs, which are part of a World Heritage Site. The design should have low embodied carbon while maintaining its integrity for its design life, and include for resilience to flood risk events and climate change up to a 1 in 100 year flood event plus climate change allowance, while not increasing flood risk downstream. This is to be achieved with no negative impact to the local ecology or environment.

3.2 Consent

NRW is leading on discussions with the local authority in relation to requirement for planning consent and World Heritage Site Consent. At the time of writing, no planning application has been made in relation to the works. A Flood Risk Activity Permit (FRAP) will be required for the works.

3.3 Design Criteria for Fish Passage

3.3.1 Target Species

Bypass design should aim to accommodate Atlantic salmon, brown/sea trout, lamprey spp, European eel and bullhead across the flow range Q95[3]-Q10.

3.3.2 Depths and Velocities

A minimum water depth of 0.30 m in the open channel and culvert is required to facilitate passage for all target species and life stages (Table 3-1).

Table 3-1 Fish passage requirements to inform open channel and culvert design (Armstrong et al., 2010)

Species	Min depth (m)	Sustained swimming speed* (m/s)	Burst swimming speed* (m/s)
Atlantic salmon	0.30	1.75	2.50
Brown trout 25-50 cm	0.15	1.25	1.60
Brown trout <25 cm	0.10	0.80	1.25
European eel 70 cm	0.10	0.58	1.26
European eel 10 cm	0.10	0.09	1.01
Elver 6-9 cm	-	0.30	0.35 - 0.60
Bullhead	0.10	0.61	0.90

* Salmonid speeds achievable at 5°C

Total length of the open channel and culvert combined will be approximately 128m. Best practice guidance recommends that maximum cross-sectional velocities do not exceed sustained swimming speeds over distances <30m.

3.3.3 Attraction Flow

Best practice guidance suggests a minimum target discharge of 5% Annual Daily Flow (ADF) for fish attraction to a route of passage, however, the guidance also notes that there can be no prescriptive definition of discharge requirements and that these will be dependent on site specific factors (Armstrong et al., 2010).

[3] Q95 is the flow exceeded 95% of the time

3.3.4 Fish Pass Entrance and Exit

The entrance and exit of the culvert should be designed not to discourage fish from entering (e.g. light / dark interface). The flow at the entrance of the fish pass inlet (downstream end) should be fast enough to create some degree of turbulence to attract fish away from the weir structure, however target velocities per species and life stage should be met.

The bypass inlet level is to be determined based on allowable water levels upstream of the weir.

3.4 Maintenance

NRW are to take responsibility of operation and maintenance of the culvert post construction. The fish pass should be designed to reduce maintenance as far as practicable. A debris / security screen risk assessment should be undertaken to assess whether the inclusion of a screen is necessary. Decisions should be made to protect any features of the fish pass channel from users of the land, including livestock. If any regular maintenance should still be required post construction, the design should enable this to be done in a safe and uncomplicated manner.

While it is thought that no geomorphological or sediment design considerations are necessary, due to the position and angle of the upstream hydraulic intake, any sedimentation within the fish pass or open channel should be avoided.

3.5 Fish Monitoring

The design should incorporate provision for fish monitoring equipment to be included at the upstream end of the culvert, specifically the installation of Passive Integrated Transponder antennae circumventing the culvert / channel at two locations to track movement of tagged fish through the fish pass. It is understood the client is in discussion with the provider of this equipment. Full details of design requirements are not known at the time of writing this report and no specific measures have been included in the design for the equipment at this stage.

The exact location of the antennae remains under discussion. However, the antennae require placement away from ferrous materials (such as steel rebar >1m away from the antennae) and mains electricity. GRP rebar is a possible replacement for steel at the location of the antennae if the final location demands it, however the use of this would need to be discussed with the headwall or culvert manufacturer. The antennae can be built either within the structure, or attached via fixings which is less robust but easier to maintain.

3.6 Design Life, Resilience and Flood Risk

A design life of 120 years was adopted for structural components of the fish pass. Whilst concrete, for example, can be designed to a given design life, the working life of channel materials is dictated by the ability of the channel to withstand flood flow conditions. The timing of a flood event of a given magnitude cannot be determined and it is therefore not possible to design for a flood that would not be exceeded during the design life of the scheme. The approach taken has been to design for a relatively extreme flood event – the 1% Annual Exceedance Probability (AEP)[4]. This has a 70% chance of being exceeded in the next 120 years[5] assuming there is no change in flood frequency (the changing climate is increasing the frequency of severe weather events). Designing for a more severe flood is technically possible but would reduce the aesthetic appeal of the channel due to the need for more robust bed and bank protection, as well as costing more and potentially compromising fish passage due to increased interstitial flow. Whilst there is a notional 70% chance of the 1% AEP design flood being exceeded over a 120 year period, exceedance of the design event does not necessarily imply failure as a number of safety factors are included. The following mitigating factors apply:

- An allowance was made for climate change in modelling the 1% AEP flood. This represents a more extreme scenario in present day terms and would result in a more resilient channel.
- The selection of materials (such as stones, rock mattress and geotextile) has been conservative, both in terms of design parameters and the choice of grading (section 6).
- The materials include a variety of stone sizes, so there would be stones greater than the design size which would help to provide stability for other rocks.
- Over time the river would be likely to make small adjustments to the channel making it more stable by rolling unstable stones to a more stable orientation and consolidating substrates.
- Failure would be unlikely to be catastrophic unless design parameters are grossly exceeded. Localised movement of stones would be a more likely consequence of a flood, and this could be inconsequential or require minor repair works.

The construction of the fish pass should not increase flood risk elsewhere in the catchment.

3.7 Llangollen Canal Abstraction

On the left-hand side of the channel there is an inlet directly into the Llangollen canal which operates by gravity. The canal abstraction requires water levels upstream of the weir to be maintained within the existing range. They bypass channel must not significantly lower the water levels in the primary river channel.

3.8 Sustainability

The design should minimise whole life carbon and take a sustainable approach to use of raw materials. Where possible, site-won material should be reused and waste should be minimised.

3.9 Safety

The design will include a full H&S audit (including construction, operational and public safety). Safety in Design principles will be utilised to ensure a safe, buildable design delivered in accordance with the CDM Regulations 2015. The design should minimise risks to the public and maintenance personnel.

3.10 Land Use

The land on the right-hand bank of the river at Horseshoe Falls weir appears to be farmland and is presumably used for pasture. NRW has liaised with the landowner during the design process and provided feedback regarding the landowner’s preferences. The landowner would prefer that the footprint of the fish pass is minimise to reduce the loss of available land for grazing. They were also

[4] Annual Exceedance Probability (AEP) refers to the chance that a flood of a particular size is experienced or exceeded during any year. In this report we use a probability value expressed as a percentage to quantify this. For example a 1% AEP equates to a 1 in 100 chance of the flood being experienced or exceeded in a year. Similarly the 50% AEP equates to a 1 in 2 chance of the flood being experienced or exceeded in a year

[5] Assuming the formula Exceedance probability = $1 – (1-p)^n$ with p being the annual exceedance probability and n the design life.

concerned that the fish pass could attract the public onto their land. It is required that access for people, vehicles and livestock be maintained to the piece of land in the bend in the river which may otherwise be cut off by the construction of the fish pass.

A redundant pumping station previously used for canal abstraction is located on the right-hand riverbank approximately 70m southwest of the weir. This pumping station has connecting rising mains and electricity supply. The pumping station building should not be altered. Any alterations/diversions to the connected infrastructure should be agreed with Hafren Dyfrdwy.

Access to the proposed site will likely be from minor road that connects to the A5 a short distance to the west of Berwyn Railway Station. This access will also require a temporary track to be created through the field on the right-hand riverbank. This access will need to be negotiated with the landowner. A potential area for a site compound should be identified.

The route should be designed to minimise encroachment on Hafren Dyfrdwy land.

3.11 Amenity

The river is used by kayakers and people are known to swim in the pool upstream of the weir. The site is used for fishing but is not publically accessible. The fish pass should be designed to discourage members of the public from accessing it. The fish pass should not create any new or increased risks to river users.

3.12 Heritage and Landscape

There are several (12) designated heritage sites within 500m of Horseshoe Falls weir, including the weir structure itself (AECOM (2021) LIFEDeeRiver Restoration of Freshwater Features. LIFE18 NAT/UK/000743 Appendix D, Cultural Heritage Desk-based Assessment). The Pontcysyllte Aqueduct and Canal is registered as a world heritage site although the aqueduct itself is approximately 7.5km to the east of the horseshow falls weir. The canal inlet is adjacent to the weir structure and therefore the water levels in the River Dee at this location are critical to the continuing function of the Pontcysyllte Aqueduct and Canal. Horseshoe Falls weir is located within the “essential setting buffer zone” of the world heritage site. Existing landscape value should be maintained. Works must be sympathetic to this setting and minimal alterations to the landscape should be aimed for. Any visual impact on the surroundings caused by the fish pass should be in keeping with existing land use and appearances.

The proposed works will alter the site, although they will not directly impact any of the identified assets. There is a risk of impacting unidentified archaeology. NRW is responsible for considering heritage aspects and AECOM have not been made aware of any other additional heritage requirements relating to design or construction.

The weir has been assessed as being in a fair condition. It is still serviceable and unlikely to fail in the short to medium term (10-20 years). Additional loading or forces should not be applied to the weir, including during construction, to ensure damage to the weir is avoided.

3.13 Ecology

The design of the fish pass is to minimise any impacts on the subsequently mentioned flora and fauna present on the site. A Preliminary Ecological Appraisal (PEA) was undertaken (AECOM (2021) LIFEDeeRiver Restoration of Freshwater Features, LIFE18 NAT/UK/000743 Appendix C PEA), which identified, categorised and appraised all habitats within and adjacent to the Site, and advised of potential ecological constraints and opportunities, including requirements for surveys and mitigation.

The purpose of the scheme is to improve the aquatic ecological conditions of the River Dee. A number of protected and environmentally important species have been identified within the River Dee including Atlantic salmon, sea/brown trout, sea, river and brook lamprey, European eel and bullhead ,. The River Dee and Bala Lake are recognised as an internationally important river and lake system which provide a key habitat for these species, with the Site located within a SAC and SSSI. This habitat and the species therein must be protected both by the scheme and during the construction phase. In addition to protected fish species it is believed that the River Dee in this location provides a habitat for otters (*Lutra lutra*). The construction method of the fish pass must not create unacceptable risk to aquatic species.

The principal benefit intended from the scheme is to facilitate fish passage through a bypass channel on the right-hand bank.

Broadleaved woodland of high ecological value is present near the site. This woodland is to be protected during works where practicable. Tree removal is to be minimised.

Due to the presence of broadleaved woodland it is likely that mammal and bird species will be present in the vicinity of the site. These may include species such as bats and badgers, the presence, or absence, of which should be confirmed through ecological surveys. Disturbance of habitat should be minimised.

Invasive Non-Native Species (INNS) have been identified close to the Horseshoe Falls Weir. Himalayan balsam (*Impatiens glandulifera*), montbretia (*Crocosmia sp*.), butterfly bush (*Buddleia davidii*) and potentially *Cotoneaster sp.* have been identified in the woodland on the right bank of the river downstream of the weir. Additionally, records of American signal crayfish identify that it is likely that this INNS is present in the River Dee. . Where possible, the design should seek to avoid the disturbance and potential spread of INNS. NRW is responsible for any further ecological requirements associated with INNS.

3.14 Contamination

There are no known existing contamination issues associated with the land or River Dee that would affect the design of the fish pass. The results of any land contamination tests are to be taken into account within the design. Tier 2 human health and controlled waters risk assessments have been undertaken as part of the ground investigation works comparing soil and water samples taken during the investigation to Generic Assessment Criteria (GAC) and Water Target Values (WTVs) respectively.

No exceedances of the GAC were encountered and risks to human health are considered to be low. It is envisaged that risks can be handled with normal mitigation measures and procedures can be applied in accordance with the construction design management regulations and confined space regulations.

In groundwater the majority of compounds were not detected above the level of detection (LOD). Exceedances of the WTV were limited to Zinc in a single sample. This is not considered to represent gross contamination.

In leachate samples, the WTV for selected PAHs' anthracene and fluoranthene, copper, lead, and zinc were exceeded in a number of locations. However, due to the low concentrations encountered, low threshold WTVs and consideration of the conservative method for the leachate tests which involves shaking of samples, it is expected that these do not represent gross contamination.

It is expected that the proposed development can be progressed safely provided that:

- Appropriate measures are taken to control the spread and/or run-off of fines and sediments the River Dee during construction and in the design of the proposed development;
- Groundwater is appropriately tested, treated and/or disposed of if it is extracted during dewatering observations;
- Where practical materials are reinstated in their natural state and location to prevent vertical leaching of contaminants if present.

The design should allow for the fish pass to be constructed without unacceptable risks of pollution of the environment.

4. Hydrology and Modelling

4.1 Hydrology

The River Dee flow is measured by NRW at four gauges. Table 4-1 shows the catchment area and grid reference for each gauging station, in order from upstream to downstream, along the river. Pertinent flow statistics were also calculated at each gauging station.

Table 4-1 Catchment information from National River Flow Archive (NRFA) at gauging stations

River and location	NGR [6]	Catchment area (km^2)	Flow (m^3/s)		
			Q_{10}	Q_{50}	Q_{95}
Dee at Bala	SH942357	262	29.8	7.9	2.5
Dee at Manley Hall	SJ348415	1,013	70.5	19.5	8.5
Dee at Ironbirdge	SJ417600	1,674	95.0	22.8	9.7
Dee at Chester Suspension Bridge	SJ410659	1,817	91.0	18.5	4.9

Horseshoe Falls weir is located at SJ 19541 43352 and has a catchment size of 752.7 km^2. The weir site was considered to be reasonably close to the Manley Hall flow gauge (see Table 4-1) and so typical flows at Horseshoe Falls weir (Q95 to Q10) were estimated using catchment areas ratio as a scaling factor. These are summarised in Table 4-2. These values were then used to prime the hydraulic model.

In agreement with NRW, return periods and flood flows were estimated with WINFAP 4 (FEH statistical method) whilst the ReFH2 method was implemented to derive flood hydrograph shapes for hydraulic modelling input. Flood peaks for '50% AEP' and '1% AEP + climate change allowance' event hydrographs are shown in Table 4-2 below.

Further details on the above are available in the outline design report (AECOM, 2021).

Table 4-2. Flow estimates at Horseshoe Falls Weir

Flow type	Flow description	Flow (m^3/s)
Typical flows*	Q99	5.6
	Q95	6.3
	Q70	8.6
	Q50	15
	Q30	26
	Q15	42
	Q10	52
	Q5	69
Flood flows	50% AEP	191
	1% AEP + climate change allowance**	519

** These were the Q95 (low flow) to Q5 (high flow). The Q95 or 5th percentile flow is the flow exceeded 95% of the time and is a typical dry summer flow, whereas the Q5 or 95th percentile flow is defined as the flow exceeded 5% of the time and therefore representing a spate flow.*

*** Climate Change (CC) allowances account for the potential future change in peak river flow*

[6] National Grid Reference

4.2 Model Overview

4.2.1 Introduction

This section summarises the methodology and the results of the modelling work used to inform the detailed design of the fish bypass channel. The software used to perform river hydraulic simulations was TUFLOW

4.2.1.1 Ground Model

A baseline ground model was constructed combining LiDAR and topographic survey data available at the site. Additional details and information about how the baseline ground model was built are available in section 4.1.8 of the outline design report (AECOM, 2021).

4.2.1.2 Hydraulic Model Simulations

Baseline hydraulic model simulations of typical flow scenarios (Q95, Q50 and Q10) and flood flows (50% AEP and 1% AEP + 30%CC) were performed in TUFLOW and detailed in section 4.2.1.2 of the outline design report. Detailed design simulations are carried out to inform detailed design and compared with the baseline results as shown in section 4.2.3.2.

4.2.2 Outline Design

4.2.2.1 Ground Model

During the outline design phase and following optioneering, a nature-like bypass channel was considered the preferable option compared to other technical fish pass solutions. A ground model was built and included a bypass channel with a length of 220 m with a drop in level between top and bottom of bypass of 1.6 m (representing a gradient of 0.72%). The channel width was set to approximately 1.5 m. For additional details, refer to section 4.2.1.3 of the outline design report (AECOM, 2021).

4.2.2.2 Hydraulic Model Simulations

Hydraulic model simulations were run for typical flow scenarios (Q95, Q50 and Q10) and flood flows. The results are summarised in section 4.2.1.3 of the outline design report. The final arrangement of the outline design bypass channel would convey 2.5%, 3.3% and 7.3% of ADF under Q95, Q50 and Q10 scenarios, respectively.

4.2.3 Detailed Design

4.2.3.1 Ground Model

The final footprint of the bypass channel used to support the modelling resulted from further development after the outline design phase (section 5.1). The ground model built was set up with the following main characteristics (from upstream to downstream):

- Although not a part of the ground model itself, a concrete box culvert was modelled in the upstream end of the bypass channel as a result of the optioneering work. The culvert would extend for approximately ~67 m starting from an upstream invert level of 94.1 m AOD and a downstream end invert level of 93.8 m AOD. The resulting culvert gradient was 0.44%. This was kept low compared to the downstream open-channel length to control the flow regime and velocities. Ideally the flow would be outlet controlled (or subcritical) during typical flow scenarios (Q95 to Q10) to avoid undesirable turbulence.

- The open-channel reach (downstream of the culvert) was modelled as a channel ~65 m long, with a base channel width of 1.5 m and side slopes at a gradient of 1V:4H. The first ~45m of the open-channel (‘0.8% slope’ reach) was assigned with a 0.80% channel invert gradient (from 93.8 m to 93.45 m AOD), whereas the last 20 m (‘1% slope’ reach) of channel was given a gradient of 1.00% (from 93.45 m to 93.25m AOD, tying into the downstream riverbed).

4.2.3.2 Hydraulic Model Simulations

Hydraulic model simulations were run for typical flow scenarios and flood flows (refer to Table 4-2). The results obtained in terms of velocity and depth have been compared with baseline scenario and included in Figure 4 to Figure 7. The final model results presented below, in terms of velocity and depth, were used to refine the detailed design of both culvert and open-channel reaches.

4.2.3.3 Hydraulic Model Results

The 2D modelling results obtained show that velocities along the open-channel reach of the fish bypass channel are lower along the ‘0.8% slope’ reach and tend to increase in the ‘1% slope’ reach with peaks above 1.5 m/s (Figure). This should help enhance the attraction flow in the area immediately downstream of the bypass channel without impairing fish capability to migrate upstream (for this reason the ‘1% slope’ length was kept relatively short compared to the overall length of the channel to allow smaller fish to cover the distance using burst swimming if required).

Results show that velocities along the open-channel reach, especially near bends and close to the downstream end, were estimated to be locally above average at all tested flow events (apart from 1% AEP where velocities are expected to reduce due to overland water flowing in and out the channel footprint). Consequently, scour protection was expected to be required, such as in the form of rock mattress or boulders in keeping with the bedrock and boulder morphology of the river. Indeed, the 50% AEP showed the highest localised peak velocity of 2.9 m/s (see also Table 4-5), which was used for sediment sizing along the main channel.

A review of the modelled volumes flowing through the bypass channel showed that the discharge constituted 2.35%, 3.14% and 6.28% of ADF under Q95, Q50 and Q10 scenarios, respectively.

At flood flows (Figure 5 and Figure 7), the extent of the 1% AEP + CC flood event appeared to be unchanged with respect to the baseline scenario.

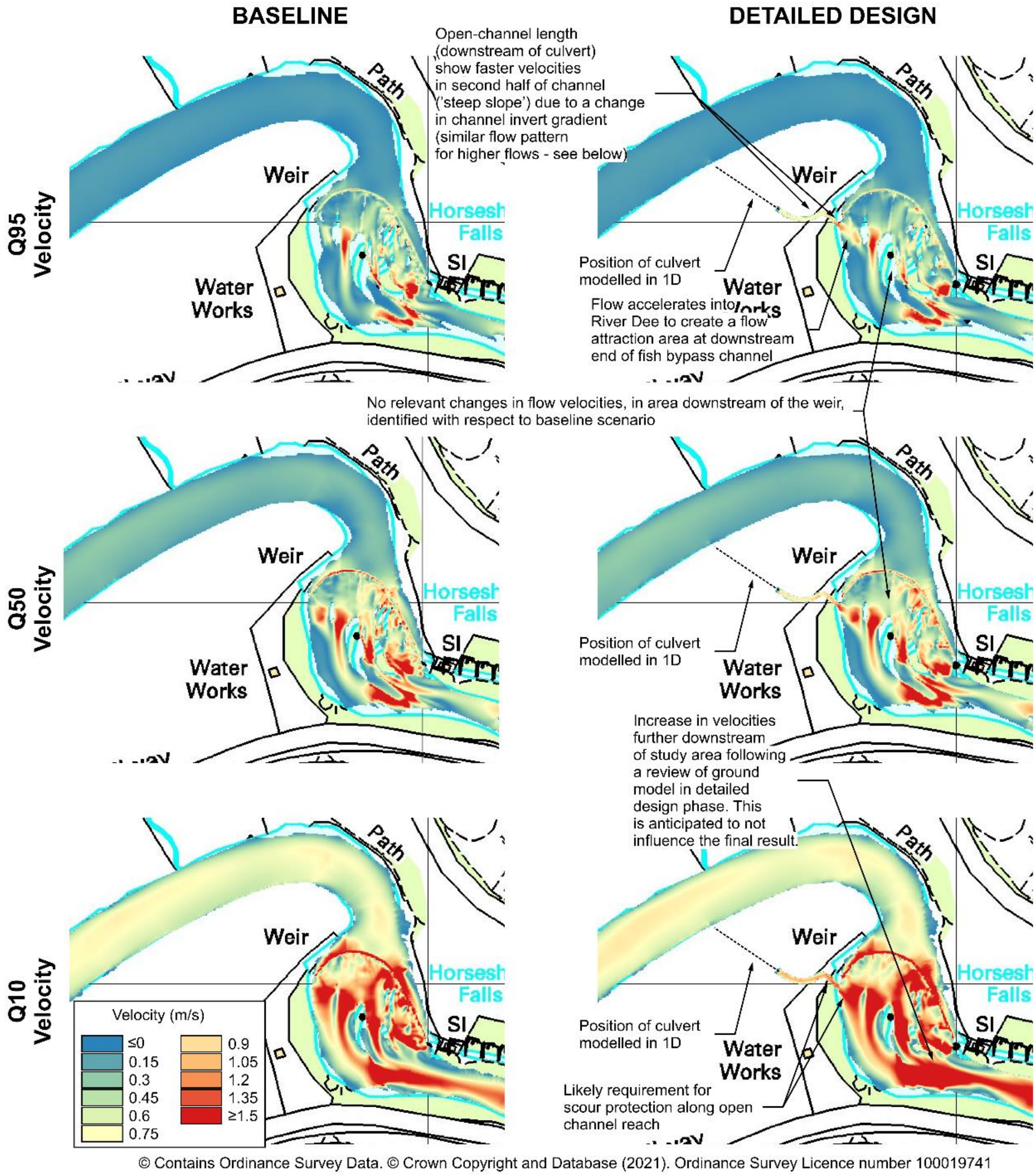

Figure 4 Modelled velocity results for typical flow scenarios under the baseline (left) and detailed design (right)

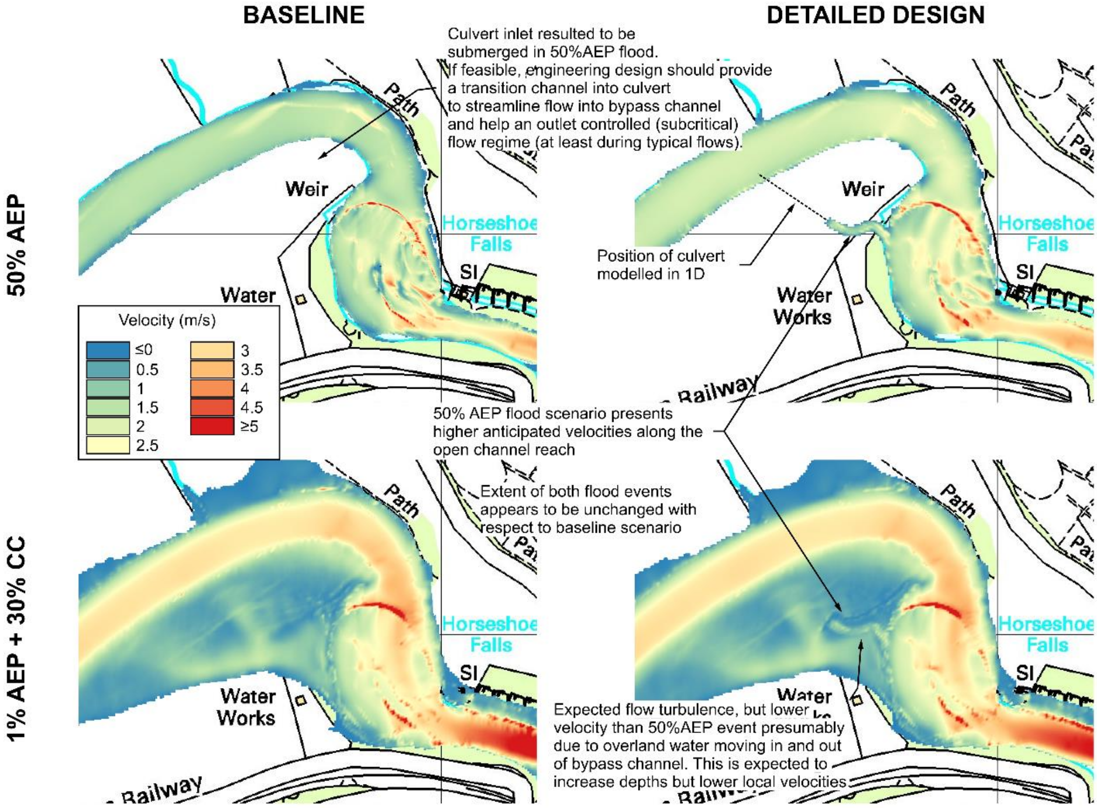

Figure 5 Modelled velocity results for flood flow scenarios under the baseline (left) and detailed design (right)

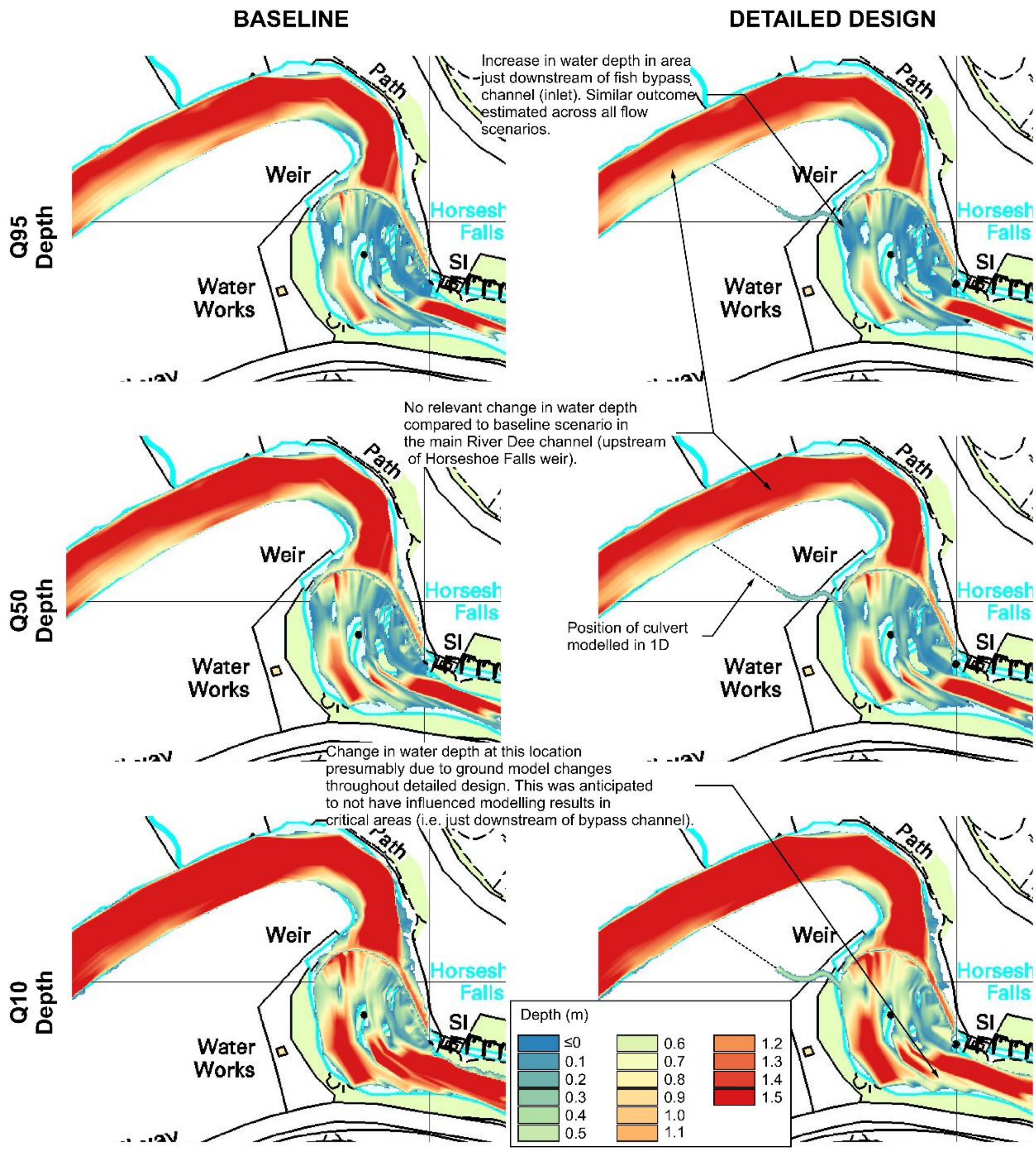

Figure 6 Modelled depth results for typical flow scenarios under the baseline (left) and detailed design (right)

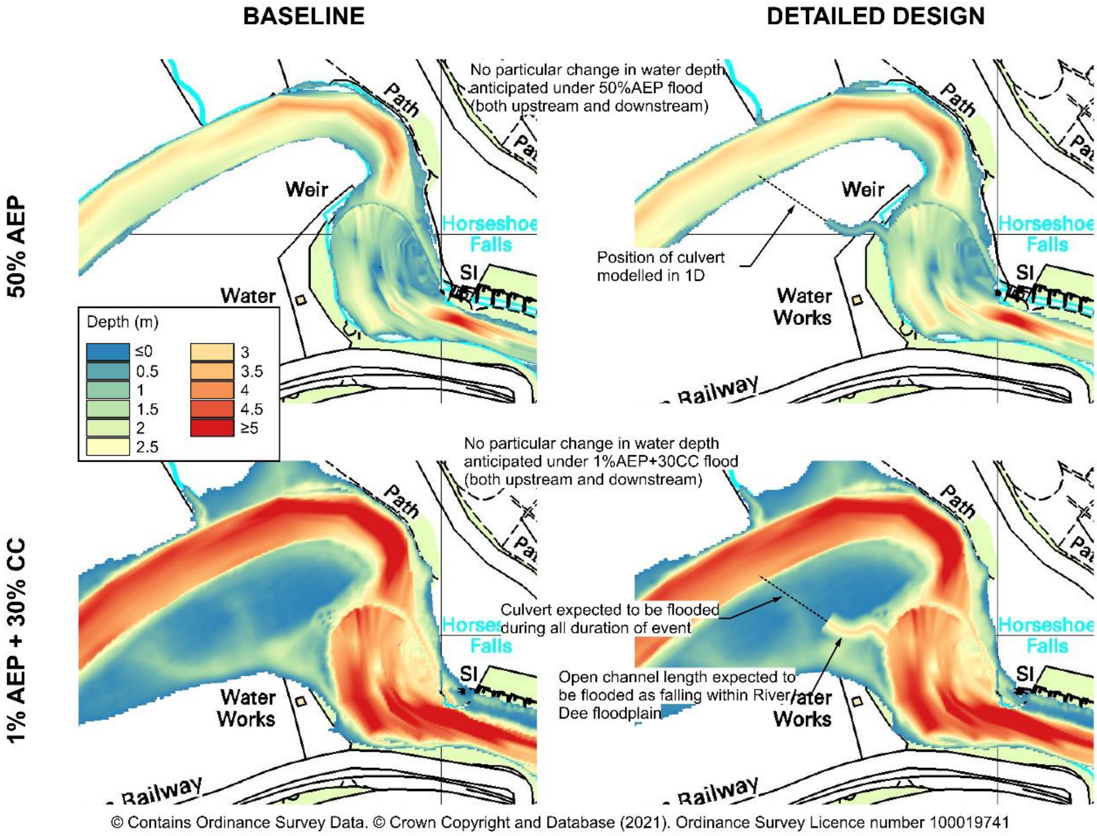

Figure 7 Modelled depth results for flood flow scenarios under the baseline (left) and detailed design (right)

Following the introduction of the bypass channel, water depths upstream of the weir structure were shown to be unchanged at all flows (Figure 6 and Figure 7). Water level data under the detailed design modelling scenario was extracted at a sample area upstream of Horseshoe Falls weir (Figure 8 and Table 4-3) and compared with baseline results.

Table 4-3 Mean water level (WL) upstream of Horseshoe Falls weir (areal statistics)

Flow scenario	Baseline mean WL (m AOD)	Detailed Design mean WL(m AOD)
Q95	94.6	94.6
Q50	94.7	94.7
Q10	95.0	95.0
50% AEP	95.5	95.5
1% AEP + CC	96.8	96.8

The results in Table 4-3 showed that the fish bypass channel would not impact the canal abstraction present on the left-hand bank of the weir structure.

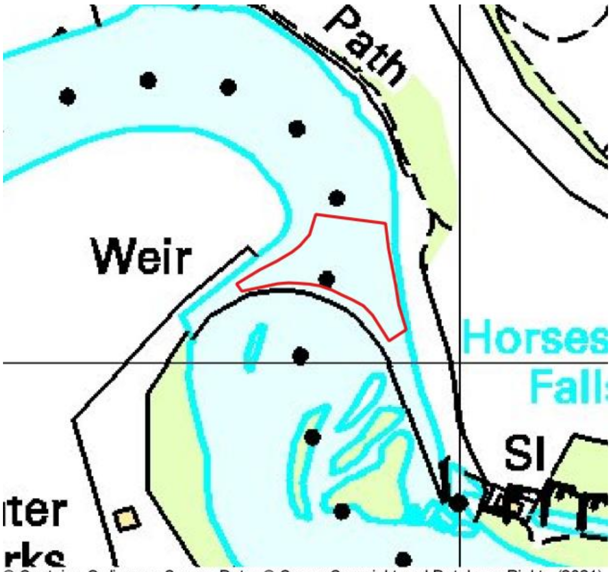

Figure 8 Sample area for areal statistics upstream of Horseshoe Falls weir

Additional hydraulic modelling was carried out to test the potential effect of spreading surplus excavated material within the paleochannels. The results are shown in Figure 9 below. Small differences in water levels away from the material placement locations appear to be caused by minor changes made to the underlying detailed design ground model to improve the reliability of model results for the detailed design scenario. The effects of the material placement appear to be localised to the location of the material placement itself, without significant wider impacts on water levels in the wider floodplain.

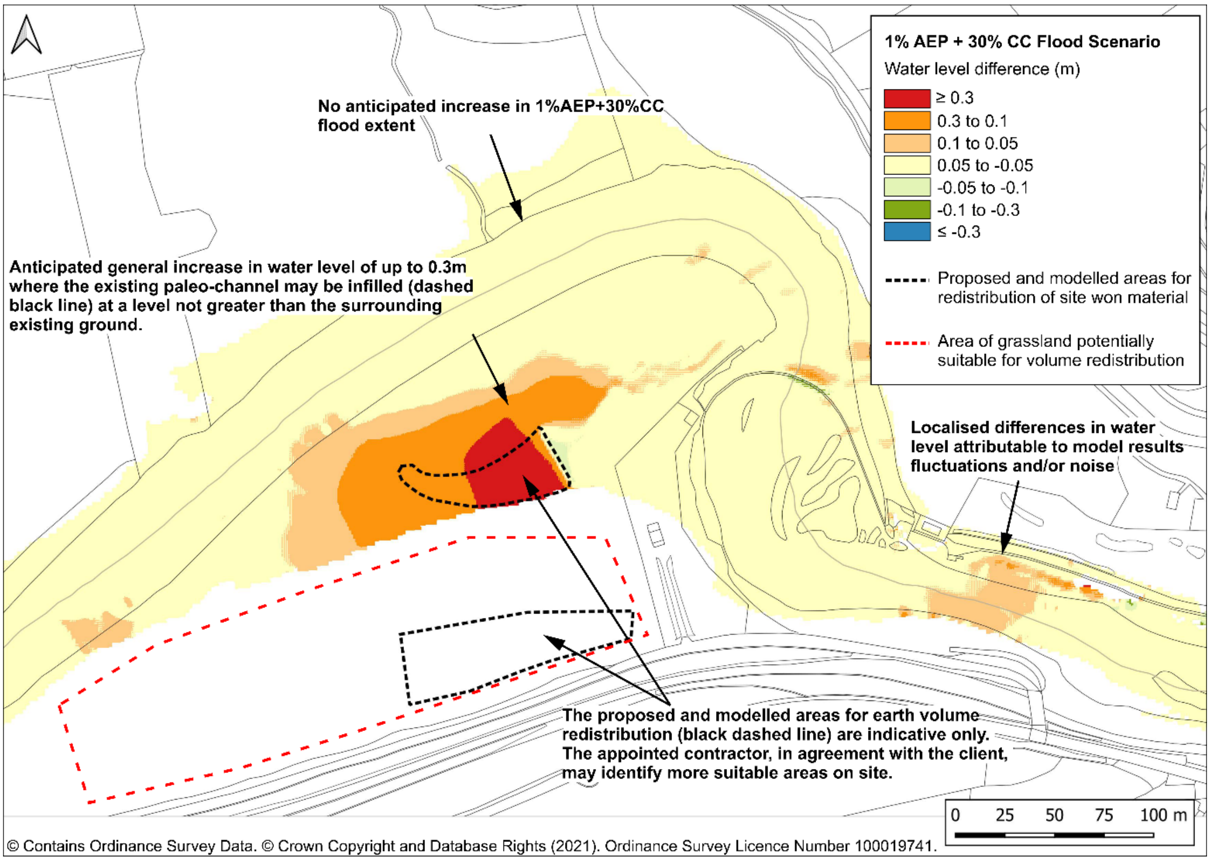

Figure 9 Effects on water levels as a result of proposed reuse of surplus excavated material

4.2.3.4 Sensitivity Testing

Sensitivity testing was performed on the Manning's roughness coefficient applied to the study reach in order to gain further confidence in the results and identify fluctuations potentially occurring in real life scenarios. The model was primed with a roughness coefficient of 0.035 (including main channel, bypass culvert and bypass open-channel reach) and sensitivity testing was carried out by running the model with an increased roughness (+20%) and reduced roughness (-20%). The flow scenario considered in the sensitivity test was Q10 which represents a high spate flow. After a review of the modelling results obtained, the following aspects were identified:

- Generally, depths appeared more sensitive to roughness change where water is shallower. For instance, in the area just downstream of the bypass channel, an increased roughness would cause an average increase in depth of 11% whereas a decreased roughness would result in an average decrease in depth of 7% (as measured along the centre of the bypass channel).
- Near the offtake of the bypass channel (upstream end, near NGR: SJ 19390 43377), where depths in the Dee were modelled to be approximately 1.6 m (with a roughness coefficient of 0.035), depths would show a 2% increase following a 20% increase in roughness (and vice versa).
- Just upstream of the weir, where depths in the River Dee are approximately 3.6 m, a slight change (+/-1%) was identified.
- Along the open-channel reach of the bypass channel, changes in roughness caused a change of +/-3% (as measured along the centre of the channel).

4.2.3.5 Key water depth and velocity outputs

As mentioned in section 4.2.3.1, the culvert was modelled as a 1D element in TUFLOW. The results were reviewed in terms of expected maximum velocities, modelled flow regime and estimated water depth at inlet and outlet locations during all modelled flow scenarios (typical and flood flows). The results obtained for Q95 to Q10 were reviewed against the requirements for fish passage.

Depth and velocity for the open-channel reach (downstream of the culvert) were reviewed for both the '0.8% slope' (extending approximately ~42 m from the downstream end of the culvert at a gradient 0.8% or 1 in 126) and '1% slope' (last ~20 m of bypass channel at a gradient of 1.0% or 1 in 100). Mean depth is the average depth across the middle of the channel (1.5m width). It should be noted that the hydraulic model does not take account of interstitial flow within the culvert or channel substrate. The results obtained are shown in Table 4-5 and Table and further discussed in relation to fish passage in section 7.1.

Table 4-4 Mean modelled flow depth and velocity in culvert

Flow scenario	Velocity (m/s)	Culvert inlet depth (m)	Culvert outlet depth (m)	Estimated flow regime
Q95	0.89	0.48	0.34	Subcritical (or outlet controlled)
Q50	1.00	0.58	0.40	Subcritical (or outlet controlled)
Q10	1.30	0.91	0.61	Subcritical (or outlet controlled)
50% AEP	2.78	1.8 (inlet submerged at 1.2m)	0.82	Various
1% AEP + CC	1.63	3.3 (inlet submerged at 1.2m)	2.85 (outlet submerged at 1.2m)	Various

Table 4-5 Mean modelled depth and velocity along open-channel reach

Flow	Category	0.8% slope		1% slope	
		Mean velocity (m/s)	Mean depth (m)	Mean velocity (m/s)	Mean depth (m)
Q95	Wetted channel	0.64	0.19	0.86	0.15
Q95	Middle of channel*	0.99	0.41	1.58	0.28
Q50	Wetted channel	0.71	0.21	0.93	0.17
Q50	Middle of channel*	1.39	0.45	1.60	0.32
Q10	Wetted channel	0.85	0.29	1.00	0.27
Q10	Middle of channel*	1.41	0.61	1.82	0.48
50%AEP	Wetted channel	1.20	0.62	1.49	0.81
50%AEP	Middle of channel*	2.26	1.00	2.90	1.29
1%AEP+30CC	Wetted channel	0.87	2.73	1.20	2.93
1%AEP+30CC	Middle of channel*	1.44	3.13	1.98	3.42

*1.5m width

Velocities were greatest at the downstream entrance to the open channel. Mean cross-section velocities at the bypass entrance ranged from 0.8 - 1.2 m/s for all flow scenarios (Q10, Q50, Q95).

Velocity was also used to inform the detailed design of the channel including the sediment size and any requirement for additional scour protection in areas with potentially high shear stress such as downstream of the culvert outlet and at the downstream end of the bypass channel where the flow accelerates into the River Dee.

Due to limited detailed topographic survey in the River Dee at the downstream end of the proposed fish pass channel, there is uncertainty regarding exact river bed levels and consequently uncertainty in water depths shown in the hydraulic model. Site inspections have confirmed areas of deeper water in this location, although there are also areas of coarse sediment that create shallower pools. See Figure 10 and Figure 11.

The Q95 and Q50 water levels shown on drawing 60672359-ACM-XX-XX-DR-CE-200021 indicate particularly shallow flow, however this does not represent the diversity in flow conditions that would be expected exist in this location. Furthermore, there is a potential requirement to adjust the channel position due to the presence of the wall adjacent to the weir (see section 6.4). This could result in the channel being moved to a position of shallower or deeper water. The design is therefore based on tying into the existing river bed level; the site supervisor would need to determine whether the depth of water at that location is adequate. If required, a small amount of excavation to remove deposited gravels and cobbles would likely be sufficient.

Figure 10 Water depth along riverbank in the vicinity of proposed channel (deeper areas)

Figure 11 Water depth along riverbank in the vicinity of proposed channel (shallower areas)

5. Initial Design Decisions

5.1 Channel Alignment and Inclusion of Culvert

Prior to detailed design commencing, an options appraisal was undertaken to determine the alignment and construction of the fish pass. Three fish pass alignments were considered, as shown in Figure 12:

- Long palaeochannel alignment (follows the major palaeochannel directly).
- Short palaeochannel alignment (follows a minor palaeochannel, resulting in a reduced channel length vs the long palaeochannel alignment)
- Direct alignment (shortest route to bypass the weir)

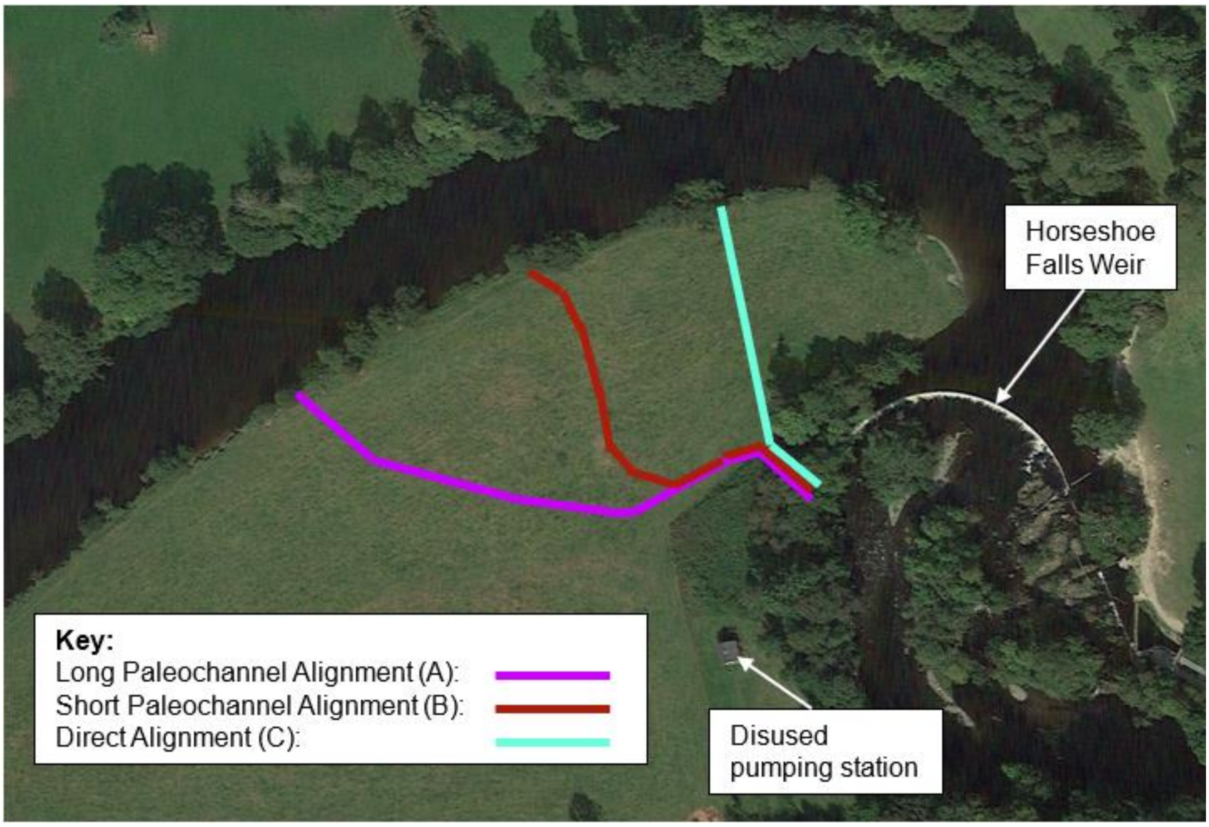

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Figure 12 Fish Pass Alignment Options

The three primary methods of construction considered were:

- Fully culverted channel
- Partially culverted channel
- Fully open channel

Each combination of options was assessed against a number of criteria: fisheries benefit; heritage impact; economic performance; environmental performance, and safety. Further detail of the assessment of the options can be found in the *Horseshoe Falls Options Appraisal Technical Note* (AECOM, 2022).

Options including the open channels were also investigated for varying side slopes and retaining wall options, in order to reduce the amount of earth that would require removal.

The option chosen by NRW to be taken forward was a part-culverted, part-open channel with 1 in 4 slopes following the short palaeochannel alignment. This is shown in Figure 13 below. The reasoning behind this decision is as follows.

Having an open channel is preferable to a culvert from a fish passage perspective as fish can be reluctant to swim through culverts. CIRIA C786 states that due to the uniformity of a culvert in terms of slope, cross section and roughness, culverts can also present undesirable properties for fish migration due to flow velocities being too high with nowhere for fish to rest unless features for this purpose are designed in. The guidance also states that there are suggestions that a dark culvert can pose a potential behavioural obstacle to fish migration, although this is not conclusive. Culverts also present a blockage risk and safety hazard if designed incorrectly, and can be higher in monetary and carbon cost. However, the site is visually sensitive, and a culvert would be much less visually intrusive than an open channel as it is underground. A culvert would also result in less land-take required for the construction of the fish pass which is preferable to the current landowner. As a result, a partially closed channel was selected as the preferable option to take forward in order to achieve good suitability for fish passage with a sensitively deigned culvert while at the same time reducing the visual impact and amount of land required.

The short palaeochannel alignment was chosen as this reduces the amount of excavation required significantly compared to the longer palaeochannel alignment, saving significant cost and earthworks requiring removal, while reducing the maximum excavation depth when compared to the direct alignment due to lower ground levels. Additionally, the channel is longer compared to the direct alignment leading to a slacker average slope and reduced velocities, improving fish passage suitability.

1 in 4 side slopes for the open channel were preferable compared to the other options: steeper slopes up to 1 in 2 or retaining walls for part or all of the length of open channel. The ground conditions are not suitable for slopes steeper than 1 in 4 without further stabilisation works, while also presenting increased safety hazards (particularly in the case of retaining walls) and more difficult conditions for maintenance. While slacker side slopes result in greater land-take area, this was deemed not to be excessive for the landowner when a culvert is utilised for part of the fish pass length.

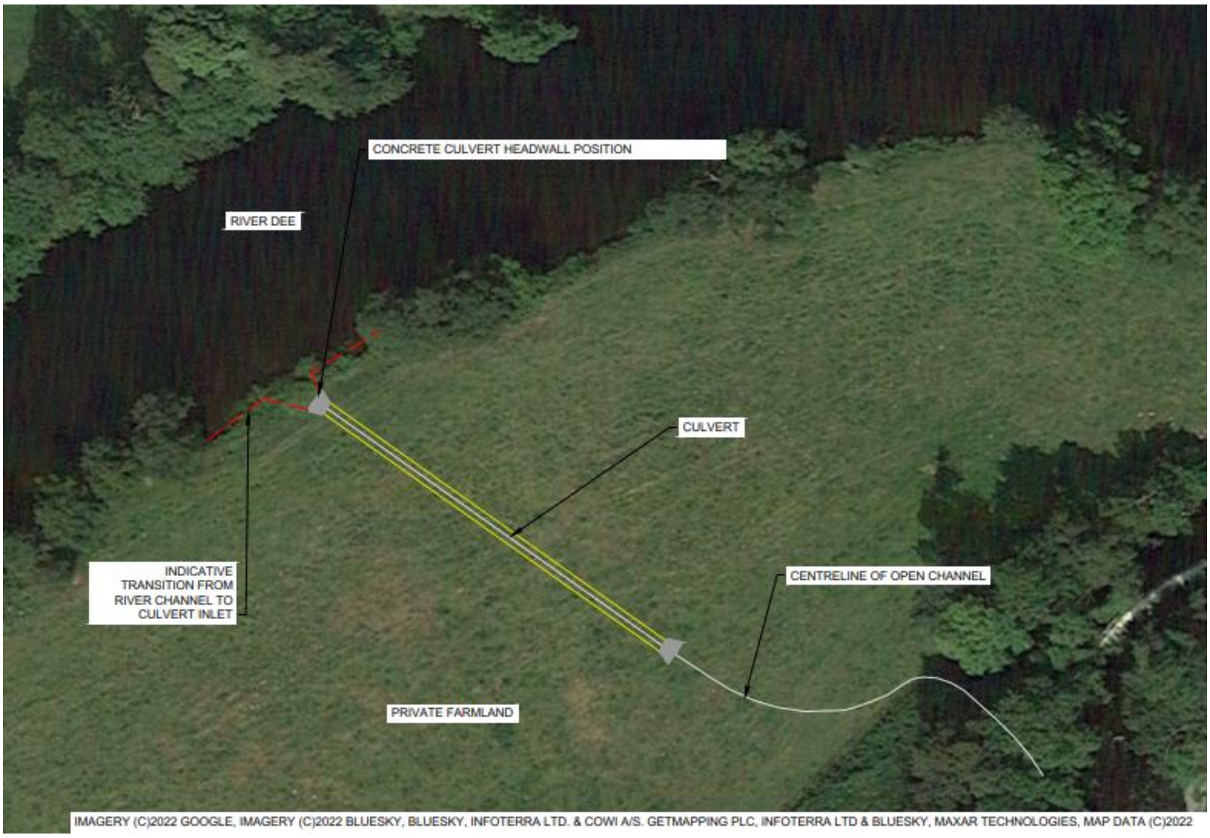

Figure 13 Preferred Option

5.2 Debris / Security Screen

The need for a debris / security screen was reviewed in line with the guidance provided in CIRIA C786 *Culvert Screen and Outfall Manual*. There is a presumption against screening unless the need for one can be confirmed. The scoring system in Appendix A2, *Initial need assessment for a security screen,* was used to provide a numerical assessment of whether any screen is required, with the proposed culver assessed against criteria that relate to the safety of the culvert: rate of rise of water levels in the watercourse in flood, length of culvert barrel, flow conditions in the culvert barrel, the possibility of someone being trapped inside the culvert and the degree of accessibility to the culvert entry/exit. The outcome from the assessment was that neither a debris nor security screen is required, as the culvert is straight with consistent slope and cross section, flow through is rapid (>1 m/s), and there are minimal obstructions within the culvert that could cause anything to become trapped.

This decision was further reviewed in light of the difficulty of cleaning the culvert if required. Consideration was given to providing a coarse debris screen within the river channel to deflect any debris away from the culvert inlet. It was considered that any large pieces of debris would likely be carried past the inlet due to the dominant flow direction in the main river channel, and any smaller debris entering the culvert would simply be washed through. CIRIA C786 states that if "flow through the culvert barrel in front will be rapid (velocity greater than 1 m/s and no intermediate piers or service crossings)", this is a mitigating factor. Flow velocity through the culvert during a 50% AEP flood event is 2.7 m/s, and is therefore considered a mitigating factor in the scoring. It was thought that the installation of a coarse screen could actually create a feature requiring frequent maintenance, with the associated hazards. Although it is accepted that if debris were to accumulate inside the culvert this would be difficult to remove, the likelihood of this occurring was considered to be low. The approach was discussed and agreed with NRW and it was confirmed that confined spaces trained personnel would be available for maintenance if required.

Space was left between the stop logs and back of the headwall (refer to Section 6.2), to ensure adequate ventilation of the culvert during confined space entry for maintenance. The outcome of the C786 Screen Risk Assessment was a score of 26, well below the score of 41 at which a coarse debris screen is considered. Even excluding the flow velocity within the culvert as a mitigating factor, the score remains below 41.

5.3 Flows

The culvert geometry was tested as part of the modelling (section 4) with the aim of conveying a suitable amount of water through the bypass channel in accordance with best practice guidance (the EA Fish Pass Manual) (Armstrong et al., 2010). The manual suggests a minimum target discharge of 5% of ADF for fish attraction to a route of passage, however, the guidance also notes that there can be no prescriptive definition of discharge requirements and that these will be dependent on site specific factors. Horseshoe Falls Weir is reported to be flow sensitive primarily due to abstraction requirements (AECOM, 2021). The flow entering the channel is dictated by the invert level of the substrate within the culvert (94.07 mAOD) and the width of the culvert (1.8 m). The hydraulic model indicated a flow of 0.55 m^3/s at Q95, 0.74 m^3/s at Q50 and 1.47 m^3/s at Q10 would enter the fish pass. These correspond to 2.35%, 3.14% and 6.28% of the River Dee ADF, respectively; these values align with those determined and agreed with NRW during the outline design phase. Armstrong et al. (2010) also outlines French guidelines for larger (>100 m^3/s) watercourses, where fishway discharges of 1% - 5% of the competing flow at the obstruction are recommended during the migration period (Larinier, 1992). Table 5-1 provides a comparison between the flow expected to be conveyed through the bypass and the flow within the River Dee main channel. The range of estimated discharge percentages through the bypass channel at Q95, Q50 and Q10 indicated that flows should be ≥ 1% - 5% of the competing flow at the Weir during key migratory periods for the range of target species.

Table 5-1 Modelled flow entering bypass channel vs flow within the River Dee

Flow scenario	Flow in River Dee main channel (m^3/s)	Estimated discharge through bypass channel in m^3/s (% of corresponding River Dee flow)
Q95	6.3	0.55 (8.7%)
Q50	15	0.74 (5.1%)
Q10	52	1.47 (2.8%)

6. Detailed Design

6.1 Channel Alignment and Culvert Position

As part of the detailed design process, some adjustments were made to the alignment and profile of the fish pass culvert and open channel. The culvert was rotated slightly so that there is a less acute angle from the main river channel into the fish pass inlet, smoothing flow and reducing turbulence in this location. Additionally, the slope of the channel was adjusted so that the downstream end of the channel is steeper to achieve a higher velocity entering the river, in order to attract fish into the channel and away from the weir at the river.

6.2 Upstream Channel Interface with River

To prevent the chance of scour at the interface of the existing riverbank and the inlet headwall of the culvert, the inlet headwall has been set back from the riverbank by approximately 4 m. A short inlet channel will connect the river to the culvert inlet, maintaining the width of the headwall, and with side slops profiled to the headwall and the existing ground and riverbank. The channel side slopes have been designed at a 1 in 3 slope for the majority of the channel length (as opposed to 1 in 4 in the downstream channel) in order to reduce the excavation extent in this area to reduce the visual impact of the channel but become steeper as the channel is profiled into the steeper existing riverbank. To ensure slope stability, class 1A/6N/6P engineering fill will be placed around the headwall where slopes are locally steeper to match the wingwalls. At locations where the slope is steepened to 1 in 3, and the slope height is greater than 1.8m the permeability of the soils should be proven to be a minimum of $5x10^{-5}$ m/s by in situ testing. For further information refer to the *Horseshoe Falls Geotechnical Design Report.*

Rock mattresses are placed on the bed of the inlet channel, continuing up the side slopes to Q10 water level for scour protection, with permanent turf reinforcement erosion control matting above Q10 level to the top of the channel and behind the headwall. Salix rock mattresses and Salix $Vmax^3$ C350 matting, have both been specified for their resistance to water velocities in excess of the 1% AEP + 30% CC flood event. The turf reinforcing erosion control matting is placed above Q10 level to provide erosion protection while also supporting vegetation growth above the waterline. A 100 mm thick layer of site-won topsoil is placed below the geotextile and seeded with CESWI grass seed mixture 2, or similar. This grass seed mix is suitable for application in wet areas such as riverbank locations and provides slow-growing grass with a low maintenance requirement.

The bed substrate installed in the culvert (refer to Section 6.3) is extended through the inlet headwall on top of the headwall base. Fittings have been specified within the headwall for the installation of stop logs to prevent flow entering the culvert for maintenance purposes. The stop logs are fitted approximately 540 mm from the back of the headwall to provide ventilation of the culvert when the stop logs are in place. A 400 mm deep concrete plinth spanning the width of the headwall underneath the stop logs has been designed so that a good seal with the bottom stoplog can be achieved, preventing leakage of river water into the culvert during maintenance.

The client has requested for provision for fish monitoring equipment to be included at the upstream end of the culvert, specifically the installation of Passive Integrated Transponder antennae circumventing the culvert / channel at two locations to track movement of tagged fish through the fish pass. Further design is required to enable this, and no specific measures have been included in the design for the equipment at this stage.

For further detailed information on the upstream channel interface with the river, including the culvert inlet headwall details, refer to AECOM drawing No. 60672359-ACM-XX-XX-DR-CE-200012.

6.3 Culvert

After the decision was made to construct a culvert for part of the fish pass length (refer to Section 5.1), an optioneering assessment was undertaken to determine the most suitable culvert type in terms of material. Three culvert options were assessed: a concrete box culvert, an open steel arch, and a circular HDPE pipe. They were each assessed against the following criteria: size, achievable cover, fish passage, design life, maintenance, visual appearance, constructability, embodied carbon, cost and ease of fish counter integration. Due to simpler design and construction methods, along with lower visual impact on the landscape, a long design life with lower maintenance requirements, and the potential to integrate fish counter requirements at the production stage, it was considered that the option of a concrete box culvert would offer a suitable solution. The open steel arch provided little benefit in carbon savings due to requirements for concrete foundations and collars. The HDPE presented potential savings in cost and embodied carbon, however the lower design life of 50 years would reduce these savings in the long term, while increasing the earthworks cut requirements and the associated safety implications, as well as worse hydraulic results in terms of fish passage as a result of a lower roughness value on the culvert sides.

A precast reinforced concrete rectangular box culvert was therefore specified with an internal width of 1800 mm and height of 1500 mm. The culvert is 59.4 m in length and has a slope of 1 in 220. This results in the culvert maintaining flow velocities that make it accessible for fish to swim its length successfully.

The culvert is founded on a 300 mm thick layer of Class 6N/6P granular fill to level any irregularities along the bottom of the trench and ensure uniform support under the full extent of the culvert.

To maintain flow diversity and create a more natural riverbed, a 300 mm thick layer of substrate lines the bed of the culvert. A minimum boulder size was calculated to resist flows up to a 1% AEP + 30% CC flood event, however the resulting minimum stone size d_{50} of 805 mm is impractical to use in the culvert. As a result, it was investigated whether it would be possible to use a smaller size of loose stone. However, there is no reliable replenishment of lost material washed out from the culvert, and it would be hazardous and difficult to maintain. Therefore, it was decided that the culvert substrate needed to be permanent. 300 to 400 mm diameter boulders will be embedded in a 150 mm thick layer of concrete to prevent them being washed downstream. A 100 mm thick layer of angular gravel, including some larger cobbles, will fill the gaps in the boulders. The tops of the boulders will be left exposed to leave an uneven bed profile, creating areas of slower flow and turbulence. Figure 14 shows the culvert substrate in cross section.

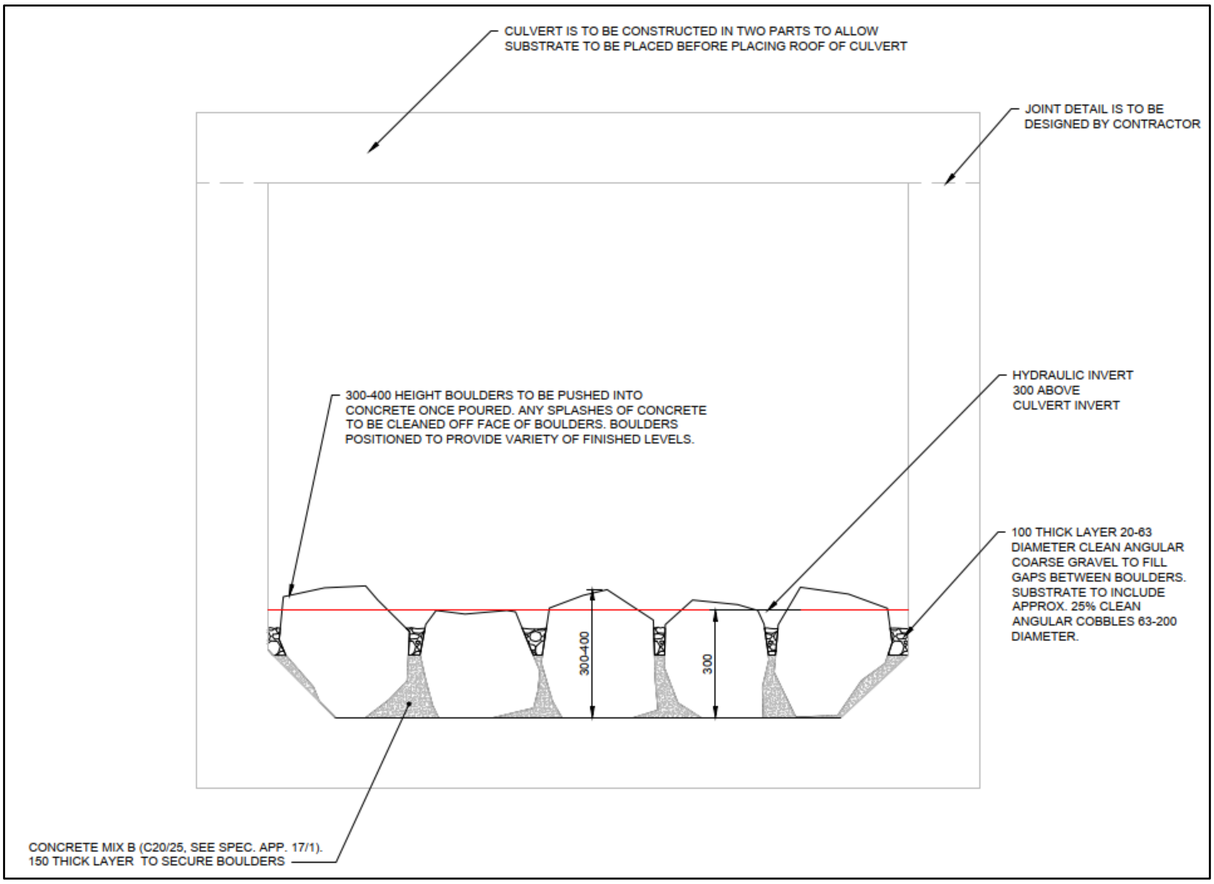

Figure 14 Culvert Cross Section

The global stability of the culvert in an uplift scenario was assessed in accordance with Eurocode 7 and found to be satisfactory. Structural design of the culvert and wingwalls will be undertaken by the pre-cast manufacturer. Box culvert manufacturers were contacted to request what tolerances are specified for differential settlement at culvert joints. While no specific figure was provided, Shay Murtagh Precast Ltd stated that the maximum differential settlement that the joint detail for culverts could accommodate is much greater than the differential settlement that would effectively correspond to the failure of the EN 1997 based Design Bearing Resistance checks. The stability of the culvert against bearing failure has been analysed, with the percentage utilisation of bearing resistance found to be less than 5%. Refer to the *Horseshoe Falls Geotechnical Design Report* for further details.

An additional settlement analysis on the culvert was undertaken as a sense check, checking the total settlement of the culvert against an assumed maximum allowable limit of 20 mm (1% differential settlement for a 2 m long box culvert section). The total settlement of the culvert was found to be approximately 15 mm, within the allowable limits. The culvert specification requires that the culvert design is able to accommodate this differential settlement. Refer to the *Horseshoe Falls Geotechnical Design Report* for further details.

Reinforced concrete headwalls with angled wingwalls were specified at both the upstream and downstream ends of the culvert. As these are lighter than the culvert, bearing and settlement are considered less critical compared to the culvert and therefore no separate analysis was undertaken. However, the stability of the headwalls against sliding and overturning was verified. Refer to the *Horseshoe Falls Geotechnical Design Report* for further details.

To improve constructability, the culvert design is based on a two-part structure, comprising a U-shaped channel with a separate roof slab. This would allow the full length of U-channels to be constructed, followed by machine placement of substrate from above and finally fixing the roof slab onto the channel walls. A box culvert option is also possible, but this would require substrate to be installed on a unit-by-unit basis. That would potentially be more time consuming and may involve increased risk.

It is intended that the material excavated from the trench to enable placement of the box culvert units is reinstated around and above the culvert up to existing ground level should it meet the requirements of a suitable Class 4 material. Excess material will be spread over the adjacent field in specified locations. Hydraulic modelling indicated that the placement of material as specified is unlikely to affect flood risk elsewhere (refer to section 4.2.3.3). Refer to Section 7.4 for further details on the use of excess material.

As at the culvert inlet headwall as described in Section 6.2, the bed substrate installed in the culvert (refer to Section 6.3) is extended through the outlet headwall on top of the headwall base. Timber post and rail fencing to meet *MCWH Volume 3 Section 1 Detail H15* is provided on top of and down the sides of the headwall to reduce the risk of a fall from height.

6.4 Open Channel

The open channel section of the fish pass connects the culvert outfall to the River Dee immediately downstream of the Horseshoe Falls weir. For the majority of its length the trapezoidal channel consists of a 1500 mm wide base, with side slopes at 1 in 4 up to the existing ground level. The global stability of the channel side slopes has been assessed with a combined seepage and slope stability analysis. For further information refer to *Horseshoe Falls Geotechnical Design Report.*

The upstream extent of the open channel has a slope of 1 in 126. This changes to a slope of 1 in 100 approximately 52 m downstream of the start of the channel, in order to provide an appropriate attraction velocity for fish at the outfall to the River Dee.

The channel base is locally widened at the upstream end to match the width of the headwall to create a smooth transition from culvert to channel. The channel slopes are steepened around the headwall, up to a 1 in 3 slope behind the headwall and up to a 1 in 1 slope where the slope matches that of the wing wall. The backfill to the headwall will be Class 6N/6P to ensure slope stability. For further information refer to the *Horseshoe Falls Geotechnical Design Report.*

The bed substrate installed in the culvert (refer to Section 6.3) is extended through the outlet headwall on top of the headwall base. Immediately downstream of the culvert outlet headwall, the channel bed is formed of rock mattresses, which also extend up the banks to the approximate Q10 level. The rock mattress extends this far up the channel because this is the height of channel bank that is regularly wetted, in which vegetation may find it difficult to establish itself and result in bare earth. Rock mattresses have been selected to line the bed in this location due to the excessive stone sizes that would otherwise be required. When calculated in accordance with the guidance in *CIRIA C683 The Rock Manual* – a d_{50} value of 805mm was found to be the required stone size. Salix rock mattresses are suitable for applications with flow velocities up to 8 m/s and are only 0.3 m in depth, so they (or equal approved mattresses) were deemed suitable for use immediately downstream of the culvert outlet where flow is of a higher velocity (2.7 m/s mean flow) and more turbulent than further down the channel while reducing excavation depth and simplifying constructability. The rock mattress extends 12 m downstream of the headwall, two times the average channel top width which was judged to be a conservative length in which the flow will have stabilised after the transition from culvert to open channel. This meets the guidance provided within *CIRIA C742*, in which it is recommended that the minimum length of scour protection is 5 times the head difference across the structure. From visual analysis of the shear stress and velocity profiles in the channel from the hydraulic modelling results, it certainly appears that the flow has stabilised from the transition to the open channel by this point.

Downstream of the rock mattresses, the bed material changes to a double layer of HMA40/200 angular stones placed in tightly packed layers, with the voids in the lower layer filled with selected site-won material and the upper voids filled with 20 to 63 mm diameter clean angular coarse gravel and cobbles. The boulders are to be left protruding above the upper gravel layer to leave an uneven surface to promote flow diversity. The stones were sized in accordance with *CIRIA C683 The Rock Manual* – a d_{50} value of 422 mm was calculated for the required stone size for the steeper downstream section which was deemed critical due to the higher velocity. This value for the stone size aligned with an armourstone mass grading of HMA40/200 in accordance with *BS EN 13383-1:2013*. While the minimum mass value of M_{50min} of 101 kg falls slightly below the 122 kg required by the calculation, considering the conservative nature of the calculation, this was deemed to be acceptable. Furthermore, the average M_{50} is 125 kg which exceeds the required size. D_{n50} (equivalent cube length), based on a stone mass of 125 kg would be 368 mm, giving a d_{50} (sieve size) of approximately 450 mm. The stone size shown on the drawings is based on this value. Changes in stone density or the final grading have the possibility to slightly alter these dimensions and may require formation levels to be adjusted from that shown on the drawings.

The rock mattresses and loose boulders will be placed on non-woven geotextile (GEOfabrics HPS11 or equal approved). This was specified in accordance with *GEOfabrics Ltd Design Guidance* and *CIRIA C742 Manual on Scour at Bridges and Other Hydraulic Structures*, to assess the geotextile against permeability, filtration, and resistance to damage during installation. The large loose boulders were assumed as critical to be assessed against, due to their heavier weight and increased likelihood of being dropped from height versus the rock mattress. Maximising permeability of the geotextile should drive selection once the minimum criteria in other areas have been satisfied.

The banks of the channel above a depth of 450 mm (approximate Q_{10} level) will have a 150 mm thick layer of topsoil with permanent erosion control matting (Salix VMAX^3 C350 permanent turf reinforcement matting or equal approved) placed on top to enable vegetation to establish without being damaged and washed away during flood events. This geotextile has a maximum permissible unvegetated shear stress of 153 Pa and velocity of 3.45 m/s – exceeding the maximum values expected in the channel up to a 1% AEP +30% CC flood event. It is to be seeded with CESWI grass seed mixture 2, or similar. This is suitable for application in wet areas such as riverbank locations and provides slow-growing grass with a low maintenance requirement.

An existing concrete abutment is located at the western end of the weir. The purpose of this wall and the actions applied onto it, as well as its depth and extent below the ground surface, are not known. There is therefore a possibility that any excavation adjacent to the wall could destabilise it with unknown consequences. Prior to starting works it must be investigated the depth of the wall so that an exclusion zone adjacent to the wall can be applied. Visual guidance to the extent of this exclusion zone can be seen on AECOM drawing 60672359-ACM-XX-XX-DR_CE-200023. The exclusion zone is to extend at a 45° angle from the found base of the wall towards the channel to the existing ground surface, as this is the potential zone of ground supporting the wall, with an additional 1 m buffer applied horizontally away from the wall. This angle is based on presumed geotechnical data which requires verification on site. Refer to *Horseshoe Falls Geotechnical Design Report.* Any works, permanent or temporary, may only take place outside of this zone.

6.5 Downstream Channel Interface with River

The downstream end of the channel discharges to the River Dee immediately downstream of the right-hand end of Horseshoe Falls weir. The fish pass channel is steeper in this location to provide sufficient attraction velocity for fish, while the main river channel also poses a risk to erosion of the banks at the connection between the two channels. Therefore, further erosion protection is provided in this location.

Rock mattresses are used to line the fish pass channel bed for the final 12 m of channel, extending up to 450 mm above the channel bed on the right bank and to the top of the channel on the left bank. The rock mattresses wrap around the exposed edge on the left bank of the fish pass channel, which is exposed to the main river channel flows and at risk of erosion if left unprotected, and continue up the full width of the existing riverbank upstream of the fish pass until the existing weir abutment is reached. Downstream of the fish pass channel, the rock mattresses are to extend along the bank until the end of the tie-in works between the fish pass and the riverbank.

Rock mattresses have been specified as opposed to loose stone in this location due to the impractical size of loose stone that would be required. The stones were sized in accordance with *CIRIA C683 The Rock Manual* – a d_{50} value of 1109 mm was calculated, which, as a double layer of stones is recommended, would require an excessive amount of excavation in this location. Rock mattresses are 300 mm thick and only a single layer is required, while they can also have a grass-reinforcing geotextile laid over the top which can be seeded for a more natural and less visually intrusive appearance. Placing of rock mattresses within the exclusion zone of the existing weir abutment is to be avoided (refer to Section 6.4), as excavation of the existing ground would be required to do this. Erosion in this area is unlikely to affect the performance of the fish pass channel. Permanent erosion control matting (Salix VMAX^3 C350 permanent turf reinforcement matting or equal approved) will be placed above the rock mattresses on the right bank of the fish pass and extend up to the top of the channel, while on the left bank it will also extend from Q10 level to the top of the bank but here will be covering the rock mattresses. The matting is to extend to the existing weir abutment and will be seeded with CESWI grass seed mixture 2, or similar, as in other areas of the site.

The rock mattresses will extend beyond the end of the fish pass channel into the main river channel for 2 m. This is in accordance with falling apron approach defined in *CIRIA C742 Section 6.5.3.7* and will ensure that the rock mattress will follow the shape of any developing scour hole, ensuring the channel is not undermined.

Adjacent to the weir abutment is an existing tree on the river bank. The tree should be retained if possible, and the rock mattress should be shaped around it, avoiding damage to any roots. Should it be assessed on site that the tree poses a safety risk or risks compromising the stability of the channel and that it requires removal, then the rock mattress should continue into the river in alignment with the falling approach referred to above.

6.6 Interstitial Flow

The design of the culvert and channel sought to find a balance between providing a natural substrate that is resilient to high flow events whilst at the same time providing suitable flow conditions for fish passage. It is difficult to design / construct a substrate that is fully natural, as natural river substrates develop over many years of geomorphological processes. Furthermore, natural substrates tend to be mobile, which would not be acceptable for the fish pass channel. A larger substrate is therefore required and inevitably this means that interstitial flows through the designed substrate / mattress are higher than might occur naturally immediately following construction. It is likely that, over time, interstitial voids would fill with natural sediments, resulting in increased superficial flow.

It is difficult to quantify interstitial flow rates for the designed channel and mattress; the most accurate method to establish actual water levels would be to monitor flow conditions during channel commissioning. The template channel provided is the maximum size that can provide suitable conditions for fish passage (assuming no interstitial flow). This allows for material to be easily added to the channel to increase flow depths and / or enhance flow diversity. As noted in section 7.1, the depth of flow in the downstream part of the channel is close to the minimum required for fish passage at low to average flows. The commissioning procedure for the channel therefore includes a check on flow depth and interstitial flow. If required, the depth of flow can be increased either by narrowing the channel using additional rock rolls along the channel edges, or by adding randomly placed boulders into the channel. Such an exercise should be carried out under the supervision of by experienced fisheries ecologists and engineers.

6.7 Power Cable

It has been identified from the utility service surveys that there is a Scottish Power Energy Networks (SPEN) low voltage electricity cable emanating from the pumping station and crossing the proposed channel at a depth of potentially 1.2 m below existing ground level before continuing under the River Dee to the north. It is thought that this electricity cable is redundant and can therefore be removed where it crosses the fish pass channel. Correspondence between the client and SPEN is ongoing regarding this. If it is found that the electricity cable needs to remain available, it will require diverting below the open channel.

6.8 Raw Water Pipe Crossing

It has also been identified that there is a Hafren Dyfrdwy raw water pipe crossing the channel at the downstream end of the fish pass open channel. This is thought to connect the pumping station to the raw water extraction point on the river side of the weir abutment, via a manhole chamber which was identified on the topographic survey and is within the footprint of the open channel. However, the exact alignment of the pipe is not known and should be investigated prior to the commencement of the works. This water pipe and manhole are redundant and should therefore be removed to enable the construction of the channel. The pipe is to be broken out from the extraction point to a minimum of 0.5 m beyond the top of the open channel slope on the right bank of the channel. The exposed pipe end is to be filled with concrete (it is acceptable to use the same concrete as that used elsewhere on site) to prevent the formation of any seepage paths which could potentially destabilise ground adjacent to the open channel. The depth of the existing manhole chamber is unknown, and should also be investigated prior to the works. The manhole is to be removed, however the structure may be retained below the channel formation level only with the acceptance of the supervisor should its depth extend this far, as this is not envisaged to pose any risk to the stability or integrity of the channel. Any voids resulting from the removal of the manhole shall be filled with compacted Class 1A/6N/6P fill material.

6.9 Fencing and Landscaping

The excavation required for the inlet channel, culvert installation trench, and the downstream open channel, will result in surplus material which will require dealing with. To reduce the environmental and monetary costs of the disposal of this material off-site, it is the aim to reuse and redistribute as much of this material within the existing site as possible. It estimated that around 4350 m^3 of material will be excavated as part of the works. 2050 m^3 of this material is expected to be reused in the works such as for the fill reinstated at the sides of and above the culvert. This therefore leaves 2300 m^3 of material to be redistributed around the site. It is proposed that 1200 m^3 of this material will be used to fill the palaeochannel that crosses the field adjacent to the fish pass. The remaining 1100 m^3 of material will be spread in designated locations outside of the floodplain. Hydraulic modelling was undertaken which indicated that the distribution of this material as specified is unlikely to affect flood risk elsewhere.

The existing fence which surrounds the pumping station site will be bisected by the open channel, and will therefore require removal for this section of its length. It is intended that this removed section will be reinstated along the boundary of the new channel down to the riverbank.

Timber, ‘agricultural style’, fencing was preferred from a heritage and landowner perspective. Timber post and rail fencing to meet *MCWH Volume 3 Section 1 Detail H15* extends around the rest of the channel and headwalls to prevent damage to the channel erosion protection from cattle which may be present in the adjacent field. Gates are to be provided within the fencing to allow for access to the channel and headwalls for maintenance purposes. Further fencing is provided on top of and down the sides of the headwall to reduce the risk of a fall from height. If desired, the fence type can be changed based on NRW’s preferences, for example to include additional wires to prevent access by sheep.

Fencing specified is 1100mm high which is suitable for protecting pedestrians from falling.

6.10 Public Safety

As stated in *CIRIA C786 Culvert Screen and Outfall Manual,* unauthorised access to culverts should be discouraged. Long culverts and culverts that flow fast and full all pose greater hazards than shorter culverts with slower flowing water. Potential harm or damage to people who enter a culvert either deliberately or accidentally that can occur include death or injury as a result of entering or being swept into the culvert during a flood and becoming trapped, and poisoning or asphyxiation from gases/lack of oxygen in a confined space.

It is considered unlikely that someone would deliberately enter the culvert in this location as it has a permanent depth of water in it and has little headroom. The culvert is located in a rural area on private land, with little likelihood of children playing nearby. Fencing provided around the inlet channel and downstream open channel for erosion protection purposes will likely deter people from accessing the culvert from either end. Additionally, the lack of debris / security screen, and the fact that the culvert is straight and of even slope with no change in cross section, means that there is little risk of someone becoming trapped inside.

It is also considered unlikely that someone would accidentally enter the culvert. While kayakers utilise the river upstream of the culvert inlet, velocities in the main river channel remain higher than those entering the culvert meaning that kayakers would likely wash past the inlet as opposed to being drawn into it.

For further details on how public safety has been assessed with regards to the fish pass, refer to the residual risk register in Appendix C.

6.11 Outputs

The following outputs have been produced:

- A Risk Register to accompany the detailed design, developed throughout the design process in discussion with NRW.
- Detailed design drawings showing the final design (refer to Table 6-1 below).
- A Detailed Design Report (this report) to include detailed design aspects including any changes made to the design following outline design. An assessment of flood risk is included.
- A pre-construction package including CDM Pre-Construction Information, Works Information including specifications and Site Information.

Table 6-1 Design Drawings List

Drawing No.	Drawing Title
60672359-ACM-XX-XX-DR-CE-200000	Location Plan
60672359-ACM-XX-XX-DR-CE-200001	Existing Plan
60672359-ACM-XX-XX-DR-CE-200003	Site Access Plan
60672359-ACM-XX-XX-DR-CE-200004	General Arrangement
60672359-ACM-XX-XX-DR-CE-200010	Culvert Inlet Plan
60672359-ACM-XX-XX-DR-CE-200011	Culvert Inlet Headwall Sections Sheet 1 of 2
60672359-ACM-XX-XX-DR-CE-200012	Culvert Inlet Headwall Sections Sheet 2 of 2
60672359-ACM-XX-XX-DR-CE-200013	Culvert Outlet Plan
60672359-ACM-XX-XX-DR-CE-200014	Culvert Outlet Sections
60672359-ACM-XX-XX-DR-CE-200015	Culvert Long Section
60672359-ACM-XX-XX-DR-CE-200016	Culvert Cross Section
60672359-ACM-XX-XX-DR-CE-200020	Channel Plan
60672359-ACM-XX-XX-DR-CE-200021	Channel Long Section
60672359-ACM-XX-XX-DR-CE-200022	Channel Cross Section
60672359-ACM-XX-XX-DR-CE-200023	Channel Cross Section - Pumping Station Infrastructure
60672359-ACM-XX-XX-DR-CE-200024	Channel Outlet Plan
60672359-ACM-XX-XX-DR-CE-200025	Channel Outlet Sections
60672359-ACM-XX-XX-DR-CE-200030	Landscaping Plan
60672359-ACM-XX-XX-DR-GT-200040	Ground Investigation General Arrangement
60672359-ACM-XX-XX-DR-GT-200041	Culvert Long and Cross Sections
60672359-ACM-XX-XX-DR-GT-200042	Channel Long and Cross Sections

7. Design Performance

7.1 Fish Passage

The expected hydraulic performance of the bypass channel was reviewed against fish passage requirements. Conclusions are shown as follows:

- Mean depths of the deepest part of the open (1.5 m width) and culverted bypass channel were suitable for all target species, exceeding 0.30 m under all flow scenarios (Q10, Q50, Q95) (Table 4-4 and Table 4-5). One exception was for the open channel '1% slope' at Q95 where mean depth was 0.28 m. However, the use of angular rocks in the design creates further variation in depth throughout the bypass channel that is not captured by the hydraulic model results. It should be noted that interstitial flows have the potential to reduce the depth of flow available for fish passage (refer to section 6.6). Mitigation is included in the commissioning procedure for the channel; refer also to the last bullet point in this list.
- Discharge from the bypass constituted 2.35%, 3.14% and 6.28% of ADF under Q95, Q50 and Q10 scenarios, respectively. Best practice guidance suggests a minimum target discharge of 5% ADF for fish attraction to a route of passage, however, the guidance also notes that there can be no prescriptive definition of discharge requirements and that these will be dependent on site specific factors (Armstrong et al., 2010). Horseshoe Falls Weir is reported to be flow sensitive primarily due to abstraction requirements and the fish pass flow was determined and agreed during the outline design phase (AECOM, 2021). Armstrong et al. (2010) also outlines French guidelines for larger (>100 m^3/s) watercourses, where fishway discharges of 1% - 5% of the competing flow at the obstruction are recommended during the migration period (Larinier, 1992). Bypass flows constitute 8.7%, 5.1 and 2.8% of Q95, Q50 and Q10 flows, respectively. This range of estimated discharge percentages through the bypass channel indicated that flows should be ≥ 1% - 5% of the competing flow at the Weir during key migratory periods for the range of target species.
- Mean velocities through the culvert and open channel were suitable for facilitating the passage of larger trout (>25cm) and Atlantic salmon (Table 4-4 and Table 4-5). To create adequate attraction flow for Atlantic salmon, water velocity is greater at the downstream entrance to the bypass. Mean cross-section velocities at the bypass entrance ranged from 0.8 - 1.2 m/s for all flow scenarios (Q10, Q50, Q95), which was in the range of burst swimming speeds for most target species (Table 3-1). Rock mattresses and angular stone substrate will provide heterogeneous flow conditions, maximising the chances of successful passage for all species, including weaker swimmers such as smaller brown trout, lamprey, European eel and bullhead (Solomon and Beach, 2004) (Table 3-1).
- Larger boulders could also be included in the channel to provide additional diversity in flow conditions and areas of shelter. Specific placement is required, under supervision by experienced fisheries ecologists and engineers (see Section 8), to encourage the formation of suitable flow conditions for fish passage. Substrate will also provide potential habitat for bullhead across a range of flows (Solomon and Beach, 2004).
- Fish can be deterred by the presence of overhead cover and sudden changes in lighting, for example at the entrance to an enclosed fish pass. The light / dark interface at the culvert entrance could be softened through the introduction of planting at the culvert headwall. Planting and landscaping are not within AECOM's scope and it is recommended that NRW gives consideration to including planting at the culvert headwalls.

7.2 Flood Risk

Hydraulic modelling was carried out to assess the changes to water levels around the proposed fish pass. The only notable changes were in the location of the channel itself, where the excavation of a channel through the floodplain locally altered water depths. This is not considered to be of concern from a flood risk perspective. The hydraulic modelling carried out for this design does not constitute a full flood risk assessment but there was no indication from the model results that the fish pass would affect flood risk elsewhere.

The impact of placing leftover material from the excavation for the culvert installation and open channel construction on the floodplain was assessed using the hydraulic model. The results indicated that the placement of material as specified would be unlikely to affect flood risk elsewhere.

7.3 Sedimentation and Maintenance

The design has sought to minimise maintenance through the following measures:

- Avoiding screens
- Providing freeboard above the Q10 water level to allow floating debris to pass through the culvert
- Avoiding changes in culvert geometry or gradient along its length
- Specifying resilient substrate and materials
- Using fencing to reduce the risk of damage
- Providing conservative protection at areas of potentially high turbulence (downstream of culvert and downstream of weir at the point where the channel joins the main river)

The river is likely to carry the majority of coarse sediment past the upstream entrance to the fish pass channel. Finer sediment or floating debris that does enter the culvert is likely to be washed through the channel without being deposited. The most likely maintenance intervention is therefore the supplementation of coarse gravels should these be washed out during high flow events and the remaining channel substrate is considered to be unsuitable for fish passage.

The Horseshoe weir may locally impound bedload transport along the River Dee, but the position and angle of the upstream hydraulic intake to the fish pass are such that it is unlikely that a significant amount of coarse sediment would enter the fish pass from the river. At upstream interface, the bed of the fish pass is raised above the bed of the River Dee, so only a very small proportion of the coarse bed load of the River Dee could potentially enter the fish pass by saltation transport. Bed material in traction is unlikely to enter. Fine sediment in suspension, and small floating debris, would transport straight through the channel and culvert.

With reference to section 6.3 on the culvert design, this makes it unlikely that a 'live bed' layer of coarse sediment will deposit along the bed of the fish pass. Sediment entering the fish pass by saltation would be of a size that is likely to be transported straight through the channel during a single peak flow event, despite the roughening effect of embedded boulders and the layer of angular gravel. Should any coarse material enter the bypass it would probably be transported through the pass without any significant impact on fish passage, flooding or design resilience.

The fish bypass outflow to the River Dee downstream of Horseshoe Falls is onto bedrock, so the outflow jet would have no impact on scour or sediment transport patterns.

7.4 Sustainability

In order to reduce the carbon that will be produced as a result of the construction and operation of the scheme over its design life, the following design decisions have been made.

An assessment was made during the optioneering process on how changing the alignment and construction type of the fish pass would affect its environmental performance. The chosen option scored 3 out of 4 for the environmental criterion, showing good performance for fish passage when combined with an open channel for part of its length while resulting in lower embodied carbon when compared to the alignment along the longer palaeochannel.

Material excavated to facilitate the construction of the open channel and the placement of the culvert pre-cast units will be reused on site as far as practicable. If the material is deemed suitable, it will be utilised as Class 1A fill to backfill around and above the culvert. Areas of site have been identified as suitable locations for the redistribution of remaining material. These include filling in the existing palaeochannel that crosses the site, and the remaining material being spread in designated locations outside of the floodplain. This will help reduce carbon by reducing the volume of material that will need to be imported as fill around the culvert and transported off-site to be disposed of elsewhere. Additionally, existing fences within the field that will require removal to facilitate the construction of the channel will be reused and reinstated.

It is recommended that low carbon concrete is to be used for the pre-cast culvert units. Utilising pre-cast products also results in lower embodied carbon when compared to casting in-situ, in part due to reduced wastage of concrete and simplification of construction. To reduce the use of concrete further, the length of the culvert has been minimised as far as possible while maximising the use of the field for the landowner and reducing the visual impact to the weir that result from having an open channel for part of the fish pass length.

The construction of a new channel inevitably requires the use of imported stone substrate. A natural loose substrate was preferred where possible, but rock mattresses were used where stone sizes were otherwise deemed to be excessive. The use of mattresses reduced the amount of excavation and the amount of rock used in the channel construction. Where possible, natural vegetation was used to provide erosion protection.

8. Construction Considerations

The following key issues were incorporated into the design and require monitoring / acceptance by the supervisor on site:

- Prior to commencement of works, an appropriate means of setting out shall be agreed with the Contractor. The level of as-built information to be recorded on the marked-up drawings shall be agreed with the Contractor.
- As discussed above, the alignment of the open channel at the downstream end is subject to the findings of investigation into the depth and construction of the existing wall at the right-hand end of the weir, as well as verification of geotechnical parameters. It is to be ensured that all excavations are to be undertaken <u>outside of the exclusion zone</u> set up around the wall, as described and displayed on AECOM Drawing 60672359-ACM-DR-CE-200023. The alignment of the open channel may need to be adjusted and moved away from the wall to accommodate this, unless an assessment by a structural engineer indicates otherwise.
- The Contractor will ensure that there are sufficient measures in place to control/prevent water seepage into the working area. It is envisaged such temporary works will need to incorporate an effective temporary cut-off barrier as a primary control measure and the Contractor shall need to make allowance for pumping (where appropriate) as a secondary control measure only. Any water pumped out from the working area will be passed through silt water treatment/settlement tanks before discharge to the watercourse.
- Construction would be carried out in accordance with an approved method statement
- The in-situ concrete works would be constructed in an isolated dry working area prior to the connection of the fish pass to the river channel to manage the risk of pollution.
- Construction would require supervision as well as a quality/testing plan to ensure accurate construction. In particular, ensuring the ground is suitable to achieve a 1 in 3 slope behind the headwalls and at the inlet channel to ensure slope stability through removal of soft / loose soils.
- Excavation down to the channel/culvert construction trench formation level may expose unexpected ground conditions or structures that necessitate a change in design of construction approach.
- Works should be carried out in a way to minimise ecological impacts and in accordance with any required licenses:
    - Construction activities should seek to minimise the risk of existing trees, including their roots, being disturbed. Additional ecological surveys may be required should tree felling be needed.
    - Construction should be completed according to the INNS Management Plan.
    - Vegetation clearance should avoid the bird breeding season
    - Confirmation of access route is required. Depending on the route chosen, it would be necessary to confirm any constraints (e.g. ecological, public access, land ownership).
    - Reinstatement of riverbank post-construction, including replanting of trees and seeding with grass seed. A temporary erosion control blanket should be placed on any reinstated areas of riverbank. Additional landscaping design may be required beyond basic reinstatement; this is to be confirmed by NRW.
- Contractor’s access design is to be approved by the Supervisor, ensuring adequate provision is made for protecting topsoil quality, preventing impacts on the land and maintaining adequate drainage.
- The Contractor should propose suitable concrete mixes which aim to have a lower carbon content. The Site Supervisor should consider these proposals and make a suitable judgement on the most appropriate option, considering the related carbon footprint.
- There are several hold points where it is the responsibly of the Site Supervisor to assess the area of the weir works against the design assumptions. Work should pause at these points to allow for

the Site Supervisor to carry out the necessary review of the existing conditions. These hold points can also be found in the Appendix 0/1 of the Specification.

a. Once the setting out points have been identified. This is to check the setting out points indicated on the drawings accurately reflect their indicated location on site. Available topographic survey information is limited and satellite imagery has been used to determine the location of some features, which may reduce the accuracy of the drawings.

b. Setting out of the exclusion zone adjacent to the existing wall the right-hand of the weir which is dependent on the depth of the wall. A larger exclusion zone than what is shown on the drawings may require the alignment of the channel to be moved away from this wall to accommodate this at the discretion of the Site Supervisor.

c. The water depths in the river at the downstream end of the channel require to be checked during the setting out of the channel to ensure the depth is sufficient. Minor excavation work may be required and the channel adjusted accordingly to avoid the channel being steepened beyond 1% gradient.

d. Once the existing manhole at the downstream end of the open channel has been uncovered. Depending on the depth of the manhole, part of the structure may be retained below the channel formation level only with the acceptance of the Site Supervisor.

e. When the material has been excavated from the construction trench and is assessed for re-use on site as backfill around above the culvert as Class 1A material. Site-won material shall be reused only with the prior acceptance of the Site Supervisor that it is suitable. If it is not suitable for re-use, material will need to be imported to site for use instead.

f. It is very difficult to adjust the culvert substrate once the full culvert has been installed. Therefore, the first three culvert units shall be installed, including substrate, under the direction of the Site Supervisor. This is to ensure the substrate is suitably installed. These culverts shall serve as reference panels for the remainder of the culvert.

g. Establishing the locations where leftover earth resulting from the excavation of the open channel and culvert construction trench should be redistributed. Volumes of remaining material have been calculated and it is proposed that the existing palaeochannel is filled in and the remaining material is spread thinly at the south of the site. However, this should be confirmed as suitable by the Site Supervisor on site.

h. Before temporary works are removed, the channel shall be inspected by the Site Supervisor before commencing the commissioning procedure. Further channel adjustments may require to be made during the commissioning procedure, so construction access to the channel shall remain in place until commissioning has been completed.

i. When determining the location of fencing after the culvert and open channel have been constructed. The location of the fencing is at the discretion of the Site Supervisor, however it must prevent erosion of the open channel from cattle in the field while access must also be provided for maintenance and operational purposes, including management of vegetation and clearance of a culvert blockage.

9. Maintenance

The fish pass has been designed with a view to minimise maintenance requirements without unacceptable compromises in safety or other areas of the project aims. There would need to be a period of post-construction monitoring as well as long term monitoring and maintenance to ensure the fish pass continues to operate as intended.

Monitoring should focus on the following areas:

- Establishment of seeded areas and other vegetation
- Damage resulting from floods
- Sediment or debris at the fish pass entrance, within the fish pass or at its exit. Depending on the quantity and exact location, this would not necessarily require removal. Potential cases for removal would be if fish passage is affected, if flow conditions change to such an extent that scour could occur or if public safety is affected.
- Signs of tampering or poaching
- Scour of the riverbed downstream of the fish pass channel
- Movement of any substrate
- Condition of stop log grooves
- Checking culvert and headwall concrete condition and signs of any movement
- Signs of access by livestock especially cattle which could cause damage to erosion protection features

The design approach has endeavoured to avoid the need for routine maintenance. Ad-hoc maintenance could include:

- Introducing additional substrate to replace lost substrate or improve channel flow conditions
- Make repairs to / replacing substrate within the culvert
- Clearing blockages, debris or undesirable accumulations of sediment

It should be noted that the culvert would be a confined space and would require appropriately competent personnel to carry out any maintenance activities.

The behaviour of the fish pass in practice and how the river might respond to the structure cannot be predicted with complete accuracy. Early experience with the fish pass would inform the required frequency for future intervention.

10. Summary and Recommendations

10.1 Summary

This design report sets out AECOM's approach to the design of the fish bypass channel at Horseshoe Falls Weir, near Llangollen. It is based on hydraulic modelling and engineering calculations. The design approach itself is a compromise between a wide range of requirements including fish passage performance, landowner preferences, managing landscape / heritage impacts, ensuring public safety and achieving good whole-life value and sustainability. On-going inspection and maintenance would be required to ensure the fish pass continues to operate as intended.

The proposed bypass channel includes the following elements:

1. Construction of an open channel / channel inlet for approximately 6 m (5% of the fish pass length) from the upstream tie-in with the River Dee to the culvert inlet, incorporating rock mattress scour protection to the bed and lower part of the banks with erosion control matting above.
2. Installation of a pre-cast reinforced concrete culvert for approximately 60 m (47% of the fish pass length), placement of a reinforced concrete headwall with wingwalls at either end and incorporating a bed substrate comprising of small boulders embedded in concrete with gravel infill.
3. Construction of an open channel for approximately 62 m (48% of the fish pass length) downstream of the culvert, incorporating the following elements:
    a. Removal of redundant existing low voltage electricity and raw water extraction infrastructure along the fish pass channel alignment
    b. Rock mattress scour protection at the upstream and downstream extents of the open channel and loose boulder scour protection in between to line the channel bed and part of the banks, including the banks of the River Dee at the downstream tie-in of the proposed channel banks into the river banks.
    c. Erosion control matting to the upper portion of the channel banks
4. Redistribution of excess material resulting from excavations for the culvert and open channel on-site.
5. Reinstatement, grass seeding and fencing.

10.2 Recommendations

The current recommendations are as follows:

- Additional ecological surveys may be required depending on the timing of construction works and the chosen access route. Some of these surveys are seasonal and would need to be carried accordingly. EPS licences may be required for some of the works.
- A River Habitat Survey (RHS) may be required to establish a consistent baseline of river conditions, including river corridor and riparian habitats, updated from the former 2014 version. This would provide a measure of the scheme's success.
- Further heritage input may be required to inform the construction approach.
- Further correspondence with Scottish Power Energy Networks should be sought to coordinate the approach to removing/diverting the existing low voltage electricity cable which spans the site.
- Hafren Dyfrdwy should continue to be consulted as the asset owners regarding the removal and plugging of the raw water pipe between the extraction point and the pumping station and the removal of some or all of the associated manhole.
- Arrangements should be made to ensure vegetation clearance is carried out at an appropriate time in advance of construction. Landscape design may be required to mitigate / reinstate any areas of removed vegetation following construction. Additional landscaping could be carried out to

further enhance the site and provide dappled lighting to mitigate the sudden change in lighting at the culvert entrance.

- Any necessary permits should be applied for in advance of construction (e.g. NRW Flood Risk Activity Permit, planning permission if required).
- A suitably experienced contractor should be appointed to carry out the works.
- Construction should be undertaken under the supervision of suitably qualified and experienced professionals as several unknowns exist and important design checks / decisions are required during construction. The supervisor should work with the contractor to identify and realise opportunities to improve the sustainability of the fish pass, either in its design, materials or construction methods.
- If any design assumptions are found to be different on site, or if any design changes are required, it is recommended that the designers are consulted.
- The channel construction, and in particular its commissioning, should be carried out under the supervision of an experienced aquatic ecologist.
- On-going monitoring and maintenance would be required, in particular to monitor the response of fish to the presence of the fish pass and the culvert performance in terms of blockage.
- Landowner agreement is required for both construction and maintenance.
- If any fish passage monitoring is carried out, it is recommended that any findings in relation to the fish pass are shared / published to facilitate the sharing of lessons for future projects.

11. References

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Appendix A Services Search

Fast-track Utility Search Report

Geophysical Survey Report

Appendix B Design Drawings

Drawing No.	Drawing Title
60672359-ACM-XX-XX-DR-CE-200000	Location Plan
60672359-ACM-XX-XX-DR-CE-200001	Existing Plan
60672359-ACM-XX-XX-DR-CE-200003	Site Access Plan
60672359-ACM-XX-XX-DR-CE-200004	General Arrangement
60672359-ACM-XX-XX-DR-CE-200010	Culvert Inlet Plan
60672359-ACM-XX-XX-DR-CE-200011	Culvert Inlet Headwall Sections Sheet 1 of 2
60672359-ACM-XX-XX-DR-CE-200012	Culvert Inlet Headwall Sections Sheet 2 of 2
60672359-ACM-XX-XX-DR-CE-200013	Culvert Outlet Plan
60672359-ACM-XX-XX-DR-CE-200014	Culvert Outlet Sections
60672359-ACM-XX-XX-DR-CE-200015	Culvert Long Section
60672359-ACM-XX-XX-DR-CE-200016	Culvert Cross Section
60672359-ACM-XX-XX-DR-CE-200020	Channel Plan
60672359-ACM-XX-XX-DR-CE-200021	Channel Long Section
60672359-ACM-XX-XX-DR-CE-200022	Channel Cross Section
60672359-ACM-XX-XX-DR-CE-200023	Channel Cross Section - Pumping Station Infrastructure
60672359-ACM-XX-XX-DR-CE-200024	Channel Outlet Plan
60672359-ACM-XX-XX-DR-CE-200025	Channel Outlet Sections
60672359-ACM-XX-XX-DR-CE-200030	Landscaping Plan
60672359-ACM-XX-XX-DR-GT-200040	Ground Investigation General Arrangement
60672359-ACM-XX-XX-DR-GT-200041	Culvert Long and Cross Sections
60672359-ACM-XX-XX-DR-GT-200042	Channel Long and Cross Sections

Appendix C Designer’s Risk Register

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