Severn Rivers Trust

Fish Passage Options Appraisals – River Stour

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RSK GENERAL NOTES

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1 INTRODUCTION

1.1 Project Background

The Severn Rivers Trust has formed a partnership with the Environment Agency, Worcestershire Wildlife Trust and the Wildlife Trust for Birmingham and the Black Country to deliver the '*Salmon in the Stour*' project. This project aims to improve the River Stour and its tributaries for the benefit of wildlife and people. It is in its early stages and is expected to run for four years.

The River Stour was once an important industrial watercourse and currently suffers from numerous issues including poor water quality, degraded and heavily modified habitat, litter, invasive species and poor access for people to take advantage of the amenity value (e.g. to connect with nature, participate in angling etc.). Many physical modifications have resulted in an unnatural channel form and function. Such modifications include reinforced banks, concrete lined sections of channel, weirs, and culverts, many of which present obstacles, or completely impassable barriers, to fish movement.

The '*Salmon in the Stour*' project objectives are to:

- remove barriers to fish migration and improve flow and channel morphology;
- provide habitat for threatened wildlife;
- re-naturalise artificial banks;
- tackle the spread of invasive species;
- identify and resolve sources of pollution;
- improve access for people; and
- celebrate the watercourses' history and heritage.

1.2 Study scope

The Severn Rivers Trust has employed RSK Environment (hereafter RSK) to undertake a study to evaluate the potential options for improving fish passage at four locations along the River Stour where weirs are located. In addition to the fish passage options appraisal RSK has also been tasked with providing topographic surveys at each of the locations.

The four study sites are as detailed in Table 1.1.

Table 1.1. Sites on the River Stour for which fish passage options appraisals and topographic surveys were undertaken.

Site name	Watercourse	Nearest Postcode	Approximate location (National Grid Reference)
Furnace Hill	River Stour	B63 3LZ	SO 96657 84517
Bells Mill	River Stour	DY8 5HS	SO 88238 85901
Bells Mill Fishery	River Stour	DY7 5QT	SO 87998 85943
Kidderminster Furniture Warehouse	River Stour	DY10 1AE	SO 82974 75978

2 SITE ASSESSMENT AND OPTIONS APPRAISAL

Details of the site assessment and fish passage options appraisal for each of the four weirs are provided in the following sections.

2.1 Furnace Hill

2.1.1 Survey timings

The site was visited by RSK's aquatic ecologists, who are experienced in fish passage assessments (including the SNIFFER WFD111 barrier assessment method) and fish passage options appraisals, on 18th April 2018 at approximately 08:00.

2.1.2 Prevailing weather and river / flow conditions

At the time of the survey the weather was a mixture of clear skies and light cloud. Rainfall during the days immediately preceding the surveys had been relatively low resulting in moderate flow conditions (i.e. not low flow or high / spate flow conditions). This enabled the key elements of the structure and the channel upstream and downstream of the structure to be viewed clearly. Notwithstanding this, the depth of the weir pool combined with turbid water meant that the channel bed within the deeper weir pool could not be seen.

2.1.3 Ownership and current function

According to local Environment Agency staff the weir and surrounding land are privately owned although further information was not available at the time of writing this report. RSK understands that the Environment Agency do have access to landowner details should these be required in the future. Notwithstanding this the weir forms part of the bridge footings for Furnace Hill road which crosses the River Stour at NGR: SO 96675 84520. The local council highways authority is therefore likely to express an interest in any proposals for this location to ensure that the integrity of the road bridge at this location is not adversely affected.

2.1.4 Topographic survey

The topographic survey was undertaken in the morning on 25/04/2018 by RSK's Geophysics team with Up and Under (also an RSK business) providing specialist access safety support. Surveys were carried out at a scale of 1:1 and set to Ordnance Survey grid and datum and referenced using Leica Geosystems Smartnet. The outputs are provided in Appendix 1 as individual PDF outputs and original .DWG files are also provided in electronic format.

2.1.5 Site description

The structure at this location comprises a vertical face weir with a flat crest and at the time of the surveys a head loss of 1.27 m (Figure 2.1).

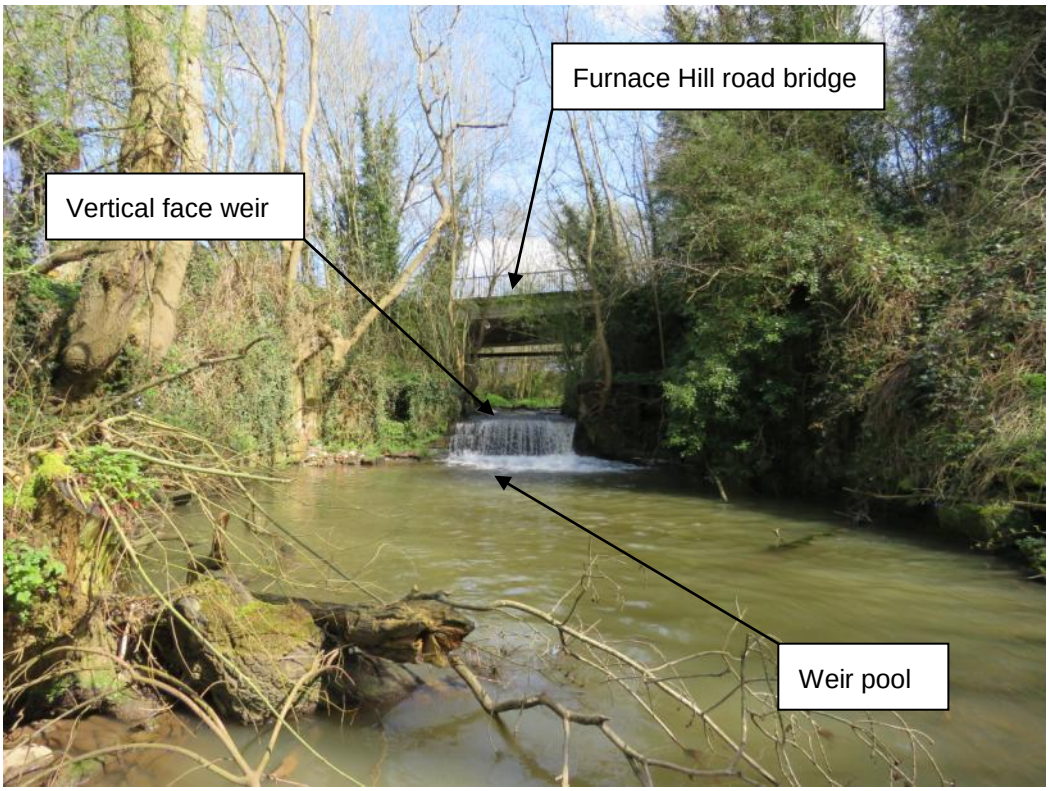

Figure 2.1: The weir and downstream weir pool underneath Furnace Hill road bridge.

The weir appeared to be constructed primarily from large stone blocks with retaining walls comprised of smaller stone blocks on either side of the weir crest (Figure 2.2).

Figure 2.2: Close up photograph of the weir face with the stone blocks from which it is comprised visible.

Immediately upstream of the weir the channel widened into a uniform rectangular channel flanked on either side by the concrete bridge support structures.

Figure 2.2: Photograph looking in a downstream direction from the upstream side of the road bridge.

The river bank on the true left of the channel (left hand bank when looking in a downstream direction) was very high and very steep. The bank was heavily vegetated with a mixture of scrub and trees and a road ran along the top of the bank (Figure 2.3). There was some evidence of active erosion of the lower part of the bank at the point where the river bends sharply round to the right approximately 20 m downstream of the weir.

Figure 2.3: Photograph showing the steep, vegetated bank on the true left of the river channel approximately 20 m downstream of the weir.

The true right hand bank of the river immediately downstream of the weir comprised block stone retaining walls with multiple trees and other vegetation growing out of gaps between stones or on the stone faces (Figure 2.4).

Figure 2.4: Photograph showing the block stone retaining wall on the right hand bank immediately downstream of the weir.

Approximately 20 m downstream of the weir the block stone walls gave way to steep, vegetated banks. A small industrial unit, yard and static caravan were situated on top of the right hand bank (Figure 2.5).

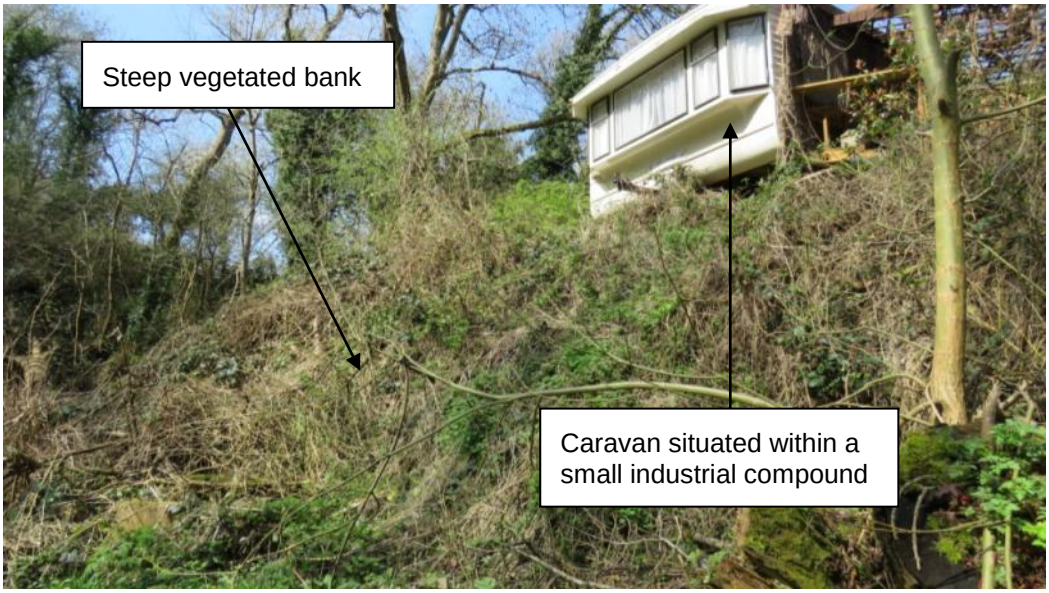

Figure 2.5: Photograph showing the steep, vegetated bank and static caravan within an industrial compound on the true right of the river channel approximately 20 m downstream of the weir.

The river channel itself included a substrate comprised predominantly of boulders interspersed with cobble, pebble and occasional small patches of gravel. Woody debris was abundant as was litter. With the exception of the relatively still water within the weir

pool the rest of the channel was comprised mainly of riffle or run flow types with depths predominantly less than 0.3 m.

Japanese knotweed (*Fallopia japonica*) was observed on the right hand bank immediately below the caravan.

Upstream of the weir the channel was a relatively uniform, trapezoidal shape with steep vegetated banks and a flow type comprised mainly of shallow glide (Figure 2.6). The substrate was predominantly silt.

Figure 2.6: Photograph showing the river channel immediately upstream of the weir.

A small tributary entered the main channel approximately 5 m upstream of the road bridge (Figure 2.7).

Figure 2.7: Photograph showing the small tributary entering the main channel.

A full habitat assessment was not required as part of this study. Notwithstanding this, brief observations for a short distance upstream of the weir showed habitat that

currently offers relatively little in-channel habitat diversity with respect to flow types, substrate composition, channel sinuosity, water depths or refuges (with the exception of some urban debris / litter and woody debris in the channel). Overall the habitat upstream appeared to be of poor quality for fish.

2.1.6 Fish species considerations

According to data provided by the local Environment Agency fisheries team, the only fish species recorded from upstream of Furnace Hill weir is bullhead (*Cottus gobio*). However, the following native fish species were recorded from surveys undertaken at various distances downstream of the weir at Furnace Hill:

- Atlantic salmon (*Salmo salar*)
- Barbel (*Barbus barbus*)
- Bleak (*Alburnus alburnus*)
- Brook lamprey (*Lampetra planeri*)
- Brown / sea trout (*Salmo trutta*)
- Bullhead (*Cottus gobio*)
- Chub (*Squalius cephalus*)
- Dace (*Leuciscus cephalus*)
- European eel (*Anguilla anguilla*)
- Gudgeon (*Gobio gobio*)
- Minnow (*Phoxinus phoxinus*)
- Perch (*Perca fluviatilis*)
- Pike (*Esox lucius*)
- Roach (*Rutilus rutilus*)
- Roach and common bream hybrid (*R. Rutilus* x *Abramis brama*)
- Rudd (*Scardinius erythrophthalmus*)
- Stoneloach (*Barbatula barbatula*)
- Ten-spined stickleback (*Pungitius pungitius*)
- Three-spined stickleback (*Gasterosteus aculeatus*)

Lamprey ammocoetes of unconfirmed species were also recorded along with two non-native fish species:

- Carp (*Cyprinus carpio*)
- Golden orfe (an ornamental variety of *Leuciscus idus*)

A formal barrier assessment was not requested as part of this study. Notwithstanding this it was obvious during the survey that the structure would represent a significant obstacle, and likely a complete barrier, to all fish species and life stages likely to occur in the river. This would be the case for the majority, if not all, flow conditions that might be expected at this location. The key features inhibiting the passage of fish are:

- a large head loss across the structure (1.27 m at the time of the survey);
- a vertical downstream weir face resulting in plunging flow and a non-adherent nappe; and
- shallow water depth (relative to the head loss) immediately downstream of the weir (water depth was approximately 0.4 m at the time of the survey).

2.1.7 Fish passage options appraisal

Following liaison with the Severn Rivers Trust and local Environment Agency fisheries staff it is recognised that the preference is to propose a fish passage solution which would cater for all fish species and life stages occurring, or likely to occur, within the River Stour. Notwithstanding this, the upper reaches of many natural or unmodified rivers would comprise a steeper gradient concurrent with coarse substrate types (e.g. predominantly boulder, cobble and pebble), shallow water depths and higher velocity river flow. This habitat type is typically dominated by fish species such as bullhead, brown trout (including juvenile sea trout) and juvenile salmon with occasional eels. As such the fish passage options appraisal below will address the options for all-species fish passage improvements and fish passage improvements which are better suited to those species likely to be seeking access to the upper reaches of the river (e.g. predominantly adult salmonids and eel).

The following sections provide a brief summary of the various fish passage options considered for the Furnace Hill weir. Information contained within the Institute of Fisheries Management (IFM) fish pass manual (Armstrong *et al*., 2010[1]) together with various other publications, website reports and the project teams significant professional experience has been used to inform the options appraisal.

2.1.7.1 Do nothing

It is a specific aim of the project to provide fish passage options for each of the structures surveyed. Consequently it is recognised that a 'do nothing' approach is not considered likely to be acceptable to the client or other parties involved in the '*Salmon in the Stour*' project. Notwithstanding this it is important to consider the likely benefits of any proposed improvements relative to the likely costs of delivering them.

In the case of Furnace Hill weir, the intimate association between the weir and the road bridge, combined with very steep banks, creates a complicated site for which many proposed improvements are likely to be considered either technically unfeasible or disproportionately costly. The options discussed below thus need careful consideration in relation to the likely benefit to fish populations throughout the entire catchment. In order to do this an assessment of the upstream and downstream habitat would be required together with costed options for habitat improvements.

For salmonid fish species, for which it is assumed there is a strong desire to provide fish passage improvements, HABSCORE (Barnard and Wyatt, 1995[2]) would provide a

[1] Armstrong, G S, Aprahamian, M W, Fewings, G A, Gough, P J, Reader, N A and Varallo, P V (2010). Institute of Fisheries Management fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales, Version 1.1. Institute of Fisheries Management.

[2] BARNARD, S. and WYATT, R.J. (1995) A guide to HABSCORE field survey methods and the completion of standard forms. Report to NRA No . 401; WRc.

useful assessment of the current suitability of the habitat for juvenile salmonids and adult brown trout. If the habitat is considered to be of relatively poor quality (i.e. not able to support large numbers of salmonids) then the cost of habitat improvements will also require consideration alongside the costs of any fish passage improvements. Although only a relatively short section of the upstream river channel was observed during the surveys, the initial appearance is that the habitat is of poor quality for salmonids and probably also for other species which might ordinarily be found in the upper reaches of rivers (e.g. bullhead and eel).

With regard to European eel, RSK's aquatic ecologists have recently developed a coarse resolution, rapid habitat evaluation tool in cooperation with Environment Agency staff (Walker, 2016[3]). Although still undergoing field trials it is considered that this tool will be useful for providing a rough assessment of the suitability of riverine habitat for supporting eels of different sizes. This tool could be used in this instance to inform whether or not the habitat upstream of the weir was likely to be suitable for supporting eels. Observations during the site visit suggest that the habitat would require some improvements prior to being considered 'good quality' for eels or other fish species.

In the case of bullhead, although no formal habitat assessment tool currently exists, there is sufficient published information available to inform a habitat assessment for this species. This includes the Life in UK Rivers publication series (Tomlinson and Perrow, 2003[4]; Cowx and Harvey, 2003[5]).

In the absence of a suitably detailed habitat assessment it is not possible to provide further commentary of the suitability of the upstream habitat for different fish species. The cost of any potential habitat improvements that may be required cannot therefore be discussed as part of this appraisal. Notwithstanding this, given the largely urban nature of the river's catchment it is likely that considerable habitat improvements would be required to facilitate the recolonisation of the river upstream of Furnace Hill weir by fish (and in particular salmonids species) and it is not inconceivable that the cost of such improvements, coupled with the cost of fish passage facilities would result in disproportionate costs (e.g. relative to the perceived ecological and amenity benefits). In such a case it may be prudent to consider a 'do nothing' approach with regard to improving fish passage at this location and instead focus efforts on habitat improvements and improved connectivity elsewhere in the catchment, at least in the immediate future.

It is likely that the weir will one day become destabilised which may require repairs or complete structure replacement to protect the Furnace Hill road bridge. At such time there should be a requirement to consider fish passage facilities as part of the repair or replacement works if they have not been resolved prior to this.

[3] Walker, P. (2016). Habitat assessment for European eel. Environment Agency Research Report. RSK Project 856369. 16pp.

[4] Tomlinson ML & Perrow MR (2003). Ecology of the Bullhead. Conserving Natura 2000 Rivers Ecology Series No. 4. English Nature, Peterborough

[5] Cowx IG & Harvey JP (2003). Monitoring the Bullhead, Cottus gobio. Conserving Natura 2000 Rivers Monitoring Series No. 4, English Nature, Peterborough

2.1.7.2 *Structure removal*

The removal of in-river structures, especially those which pose a barrier or obstacle to fish, offers the benefits of restoring longitudinal connectivity within the watercourse and re-establishing a more natural hydromorphological channel form and processes to the river.

Whilst this option represents a preferred choice from an ecological / hydromorphological perspective it is unlikely to be considered acceptable. The weir is intimately associated with the Furnace Hill road bridge and as such removing all of it or even part of it may have implications for the stability and safety of the bridge structure. Furthermore, the river bed would require significant reprofiling to create a suitable gradient over the >1 m head loss to facilitate fish passage. Complete or partial weir removal is thus not considered to be a viable option for this site.

2.1.7.3 *Bypass channel*

Naturalised bypass channels are often cited as a preferred option for improving fish passage where structure removal is not considered a feasible option. Such channels increase longitudinal connectivity within rivers and can also offer the additional benefit of providing supplementary aquatic and riparian habitat which can be used by a variety of wildlife including fish (Dodd *et al*., 2017[6]). In many cases it is considered that naturalised bypass channels offer the highest (ecological) benefit relative to the construction costs (Dickie *et al*., 2014[7]). Notwithstanding this the design and construction costs for such channels is typically higher than other technical fish passage solutions.

Due to the low gradient needed for a nature-like bypass channel to be effective as a fish passage solution, where a relatively high head loss occurs the space required to construct the channel in can be significant. In the case of Furnace Hill weir, the steep banks, road bridge and surrounding urban environment do not enable such space to be found or used. Consequently this option is considered to be technically infeasible and is not considered further.

2.1.7.4 *Rock ramp*

Rock ramps employ the use of carefully placed boulders (or rocks) to dissipate energy and create low velocity areas over an elongated ramp or slope which fish can then use to overcome an otherwise impassable head loss. When designed and constructed correctly they can provide fish passage for a variety of different species and life stages (see Armstrong *et al*., 2010[8] *and references therein*) and have the additional benefit of a relatively natural appearance. They can also provide habitat which can be used by a range of species including fish, aquatic invertebrates and birds (e.g. dippers).

[6] Dodd, J.R., Cowx, I.G., Bolland, J.D. (2017). Efficiency of a nature-like bypass channel for restoring longitudinal connectivity for a river-resident population of brown trout. *J. Environ. Manage.* 15(204): 318-326.

[7] Dickie, I., Doku, A., Guiu, R., Wade, T., Ramsden, L., Hall, T., Hill, M., Butterworth, A. (2014). Estimation of the benefits of enhanced regulations for fish barrier management –Final Report to Defra. eftec. 59pp.

[8] Armstrong, G S, Aprahamian, M W, Fewings, G A, Gough, P J, Reader, N A and Varallo, P V (2010). Institute of Fisheries Management fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales, Version 1.1. Institute of Fisheries Management.

Rock ramps are highly complex in terms of their design and subsequent construction. There are many examples of rock ramps which have required multiple re-visits to 'fine-tune' the design to achieve the desired flows. As such, in addition to their high initial design and installation costs there can be unforeseen additional costs to tweak installations. Furthermore, rock ramps are typically only considered suitable for structures with a head loss not exceeding 1 m.

With regard to Furnace Hill weir, there is potentially sufficient room to install a rock ramp and achieve the required *ca* 5% gradient. However, due to the large head loss (>1.2 m), presence of a large weir pool and potential impacts on the river bank stability downstream (e.g. due to erosion on the outside bend on the downstream channel) this option is likely to be considered unviable from a technical feasibility or disproportionate cost perspective. The cost of the construction materials alone would not be insignificant regardless of the technical difficulties associated with mobilising construction plant into the steep sided channel.

2.1.7.5 Easements or barrier modification

Easements are modifications undertaken on structures which facilitate fish passage but are not considered to be a technical fish pass structure. There are various types but all are typically best suited to low-head structures or weirs with sloping faces. Typically they fall into one of the following categories:

- creating streaming flow and heterogeneous conditions;
- adherent (non-aerated) nappes;
- notches and gaps;
- baulks;
- baffle systems;
- preliminary weirs (pre-barrages, check weirs etc.); and
- modifications to the channel bed.

For Furnace Hill weir, the large head loss and vertical weir face prevents any such easements from being considered suitable with the exception of preliminary weirs which are discussed further in Section 2.1.8.1.

2.1.7.6 Technical fish passes

Technical fish passes fall into one of two categories:

i) pool fish passes; and

ii) baffled fish passes.

There are various selection criteria which render one or the other type of technical fish better suited to an individual situation. Typically all of them are constructed alongside an existing barrier as this reduces the risk of any additional flood risk associated with the construction of the fish pass. In some cases it can even reduce the overall flood risk for a given location.

For Furnace Hill weir, the steep sided banks and concrete support structures for the road bridge do not provide an opportunity for a fish pass to be constructed in a location

which bypasses the structure by being constructed within either bank. The only realistic option identified during this study therefore would be to construct a fish pass within the main channel leading directly to the weir crest. To render such a pass functional it is also likely that modifications would need to made to the weir itself to ensure that sufficient flow was maintained through the fish pass under a suitable range of river flow (discharge) conditions. In their simplest form this could include mounting baffle structures to the upper weir crest which, in addition to directing the majority of the flow down the pass would also help maintain a sufficient depth of water and reduce velocities over the weir crest.

Several potential problems were identified with such a proposal however. It is unlikely that the weir could be physically modified in such a way as to enable the downstream entrance to the fish pass to be located at, or at least very close to, the toe of the weir. Such modifications are likely to face opposition from the bridge structure owners (assumed to be the highways agency) due to the potential for adverse impacts on the structural stability of the bridge. The pass would therefore not be in accordance with best practice guidelines as described in Armstrong *et al*. (2010[9]).

A further potential issue is that of flood risk. Experience from other studies has shown that there is a presumption from the Environment Agency against agreeing to new in-channel constructions. Any feasibility study pursuing the option of an in-channel technical fish pass would likely need to demonstrate no increase in flood risk including no increase in upstream water levels.

The location of the weir and river channel also poses technical difficulties. The steep-sided and high banks would make it very difficult to mobilise suitable construction equipment and plant to enable efficient construction to take place. It is likely that these difficulties are not insurmountable given an unlimited budget but they would certainly increase the overall construction and project management costs.

The technical difficulties and high costs associated with any type of technical fish pass solution render it unlikely to represent a viable option.

2.1.8 Recommended option

Following the fish passage options appraisal process, which accounts for the significant limitations at Furnace Hill weir, there are two potential options which are likely to be proceedeable at this location subject to a detailed feasibility study being undertaken.

2.1.8.1 Pre-barrages and baffles

The installation of a series of preliminary weirs downstream of the weir would raise the tail water level thus reducing the overall head difference between the upstream and downstream reaches at Furnace Hill weir. To facilitate passage for a wide range of fish species the pre-weirs would need to be designed such that the head loss across each of them was sufficient to enable the desired species to pass. Notches would likely be required to improve passability at lower flows and it may be necessary to fit additional

[9] Armstrong, G S, Aprahamian, M W, Fewings, G A, Gough, P J, Reader, N A and Varallo, P V (2010). Institute of Fisheries Management fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales, Version 1.1. Institute of Fisheries Management.

structures (e.g. bristle mats or eel tiles) to facilitate the passage of poorer swimming species.

Velocities and water depths over the broad crest of the weir are likely to prove difficult for some fish species or smaller life stages to surpass. It may therefore be necessary to retrofit baffles across the weir crest to increase / maintain water depths and to dissipate energy and reduce water velocities. Alternatively the pre-barrage structure levels could be set at levels suitable to create sufficient impoundment to reduce velocities and increase depths over the weir crest which would negate the need for additional interventions (e.g. baffles).

The precise arrangement of the pre-weirs and baffles requires further exploration if the project proceeds to detailed feasibility study and outline design stage. A further requirement of the feasibility study would be to ascertain whether or not the proposals would be likely to increase flood risk.

Without progressing designs further it is not possible to accurately calculate the construction and project management costs for the above proposal. The complications associated with the very high and very steep banks and the busy road bridge will require engagement with a suitably experienced civil engineering contractor. Notwithstanding this, based on other similar projects, at less complicated sites, the estimated costs for installation of at least six pre-barrages to overcome the head loss at this location are £120,000 to £200,000. Whilst unlikely to be considered justifiable financially (e.g. relative to perceived ecological and amenity benefits) in the short term, this option should be considered as a possible concept in the future.

2.1.8.2 Eels and minor species

The distance from this weir down through the River Stour and onwards to the tidal limit on the River Severn is close to 100 km. It is likely that the number of eels which do, or theoretically would, reach this part of the catchment is small relative to areas further downstream but it is certainly possible that at least some eels are capable of reaching this location in the absence of any obstacles / barriers. Many types of eel pass are relatively low cost and can be designed to aid the passage of other fish, particularly so-called ‘minor species’ such as minnow, bullhead and stone loach.

A bristle-substrate lined gutter type of pass is probably more suitable for this mixed species purpose but there has been recent discussion in the industry about their tendency to become clogged with debris more than similar passes made using eel-tile lined gutter passes. The tree-lined channel and associated woody debris in the channel and large amounts of litter arising from the urban environment would increase the likelihood of such clogging. If such a pass is considered it is therefore recommended that eel tiles are used as a preference to bristles. The gutter pass should be mounted such that it is gravity fed from the main channel and so that the gradient is suitably low so as to provide lower velocity flows against which minor species should be able to swim. The material used to create the gutter should not be a metal or other material which is likely to stolen for sale as scrap metal.

The estimated costs for designing and installing a pass of this nature would be £12,000 to £20,000.

2.1.8.3 Do nothing

As discussed in Section 2.1.7.1 it is acknowledged that a ‘do nothing’ approach at Furnace Hill weir is unlikely to be considered as the preferred option. Notwithstanding this, if the option for installing pre-barrages proves to be technically infeasible or unaffordable it is highly unlikely that any other options can be considered for this location given the current situation with regard to the Furnace Hill road bridge. Furthermore, as previously stated, the combined cost of resolving fish passage issues and improving and maintaining a suitably high quality upstream habitat require careful consideration against the benefits of similar expenditure in other parts of the catchment.

Taking the full options appraisal discussion into account a ‘do nothing’ approach should be considered further as a potential option for this location, at least in the immediate future. An alternative, interim measure may be to provide the eel / minor species passage improvement discussed in Section 2.1.8.3.

2.2 Bells Mill

2.2.1 Survey timings

The site was visited by RSK's aquatic ecologists, who are experienced in fish passage assessments and fish passage options appraisals, on 18th April 2018 at approximately 10:00. The site and structure owner was present and directed surveyors to suitable locations for viewing the weir structure from above, downstream and upstream.

2.2.2 Prevailing weather and river / flow conditions

At the time of the survey the weather was a mixture of clear skies and light cloud. Rainfall during the days immediately preceding the surveys had been relatively low resulting in moderate flow conditions (i.e. not low flow or high / spate flow conditions). This enabled the key elements of the structure and the channel upstream and downstream of the structure to be viewed clearly. Notwithstanding this, the depth of the weir pool combined with slightly turbulent and turbid water meant that the channel bed within the weir pool could not be seen.

2.2.3 Ownership and current function

The site is privately owned and this includes the old mill buildings, the weir structure and the river banks and land in the immediate vicinity of the weir. The weir does not have any current function although the owner has previously engaged with the Environment Agency to discuss the possibility of restoring the mill to a working state, potentially for hydropower production.

The buildings at the site are used primarily for residential purposes although the owner also has several kennel buildings used to house working dogs which he trains.

2.2.4 Topographic survey

The topographic survey was undertaken in the morning on 26/04/2018 by RSK's Geophysics team with Up and Under (also an RSK business) providing specialist access health and safety support. Surveys were carried out at a scale of 1:1 and set to Ordnance Survey grid and datum and referenced using Leica Geosystems Smartnet.

2.2.5 Site description

This site comprises a complex of structures which form part of the original water mill. The structures of interest include a vertical face weir with an elongated, sloping crest and two sluice structures (Figure 2.8).

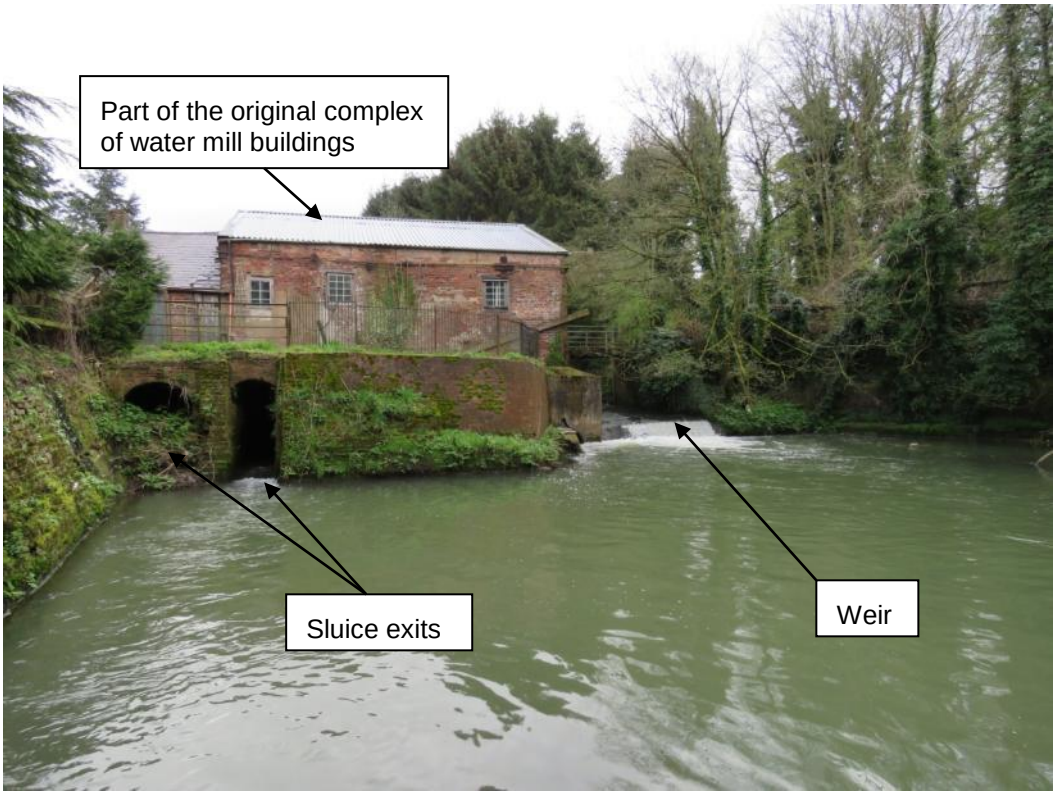

Figure 2.8: Photograph illustrating the main features of interest at Bells Mill with respect to fish passage issues.

The weir appeared to be constructed from small stone blocks or bricks and concrete. The weir crest was approximately 5 m long and just under 3 m wide with a gentle slope running in an upstream to downstream direction. The weir crest terminated with a vertical drop, and non-adherent nappe, into the weir pool (Figure 2.9). Water depths over the weir face were estimated at less than 10 cm with the true right hand side of the weir having no flow over it at the time of the survey. The head loss at the weir face was approximately 0.5 m with an additional head loss between the upstream end of the weir crest and the downstream end of the weir crest of approximately 0.2 m. This equates a total head loss across the weir structure of *ca* 0.7 m.

Water depths within the weir pool were varied due to variations in the bed level likely resulting from years of scouring. Adjacent to the toe of the weir depths were estimated by the current structure owner (based on previous measurements undertaken with large poles) at 1.2 m with depths increasing to more than 2.5 m at *ca* 8 m downstream from the weir.

Figure 2.9: Photograph illustrating the main features of interest at Bells Mill with respect to fish passage issues.

The upstream inlet to the sluice is located on the true right hand side, and upstream side of the weir (Figure 2.10). It can be manually closed using a winding sluice gate although the landowner advised that is never used.

Figure 2.10: Photograph of the upstream sluice inlet.

The downstream exit from the sluice, which bypasses the weir, is located on the true right hand side of the weir (Figure 2.11). There is a small head loss between the exit location and the weir pool water level of *ca* 0.15 m. The total head difference between the upstream sluice inlet bed level and the downstream weir pool water level was approximately 0.8 m.

Figure 2.11: Photograph illustrating the main features of interest at Bells Mill with respect to fish passage issues.

The true left hand bank comprised brick and block stone retaining walls at the base of very steep and high, wooded banks (Figure 2.12). The Stourbridge canal runs roughly parallel to the river at the top of the aforementioned banks.

Figure 2.12: Photograph of the true left hand bank immediately downstream of Bells Mill weir.

Approximately 20 m downstream of the weir a small undercut section of bank with exposed roots was observed (Figure 2.13). Upon closer inspection there was a 'tunnel' running further into the bank. While the location of the hole / potential burrow so close to the water level probably precludes it from being used as a permanent holt by otters it had potential to serve as a temporary resting place or 'couch' and any proposed activities at this location should take this into consideration.

Figure 2.13: Photograph showing the location of a potential otter resting place.

The true right hand bank comprised an unstable brick retaining wall with multiple dog kennels and the mill gardens situated immediately beyond this (Figure 2.14 and Figure 2.15).

Figure 2.14: Photograph showing the unstable brick retaining wall immediately downstream of the sluice exits on the right hand bank. Kennels can be seen in the top of the photograph.

Figure 2.15 : Photograph showing the right hand bank at the downstream end of the weir pool approximately 20 m downstream from the weir and sluice structures.

The upstream channel was impounded with predominantly glide flow type and a silt covered substrate. The banks were straight and predominantly vegetated with a dominance of trees (Figure 2.16).

Figure 2.16: Photograph looking upstream from a small footbridge above the weir at Bells Mill.

The river channel immediately downstream of the weir and sluices included a weir pool superseded by a much narrower, shallower and physically diverse channel including a mix of riffle, run and glide flow types and a mixed substrate comprised of boulders, cobble, pebble and gravel.

2.2.6 Fish species considerations

According to data provided by the local Environment Agency fisheries team the following native fish species were recorded from surveys undertaken at locations upstream and downstream of the weir at Bells Mill:

- Atlantic salmon (*Salmo salar*)
- Barbel (*Barbus barbus*)
- Bleak (*Alburnus alburnus*)
- Brook lamprey (*Lampetra planeri*)
- Brown / sea trout (*Salmo trutta*)
- Bullhead (*Cottus gobio*)
- Chub (*Squalius cephalus*)
- Dace (*Leuciscus cephalus*)
- European eel (*Anguilla anguilla*)
- Gudgeon (*Gobio gobio*)
- Minnow (*Phoxinus phoxinus*)
- Perch (*Perca fluviatilis*)
- Pike (*Esox lucius*)
- Roach (*Rutilus rutilus*)
- Roach and common bream hybrid (*R. Rutilus* x *Abramis brama*)
- Rudd (*Scardinius erythrophthalmus*)
- Stoneloach (*Barbatula barbatula*)
- Ten-spined stickleback (*Pungitius pungitius*)
- Three-spined stickleback (*Gasterosteus aculeatus*)

Lamprey ammocoetes of unconfirmed species were also recorded along with two non-native fish species:

- Carp (*Cyprinus carpio*)
- Golden orfe (an ornamental variety of *Leuciscus idus*)

A formal barrier assessment was not requested as part of this study. Notwithstanding this it was obvious during the survey that the structure would represent a significant obstacle, and likely a complete barrier, to most fish species and life stages likely to occur in the river. This would be the case for the majority, if not all, flow conditions that might be expected at this location. The key features inhibiting the passage of fish are:

- a head loss across the structure of *ca* 0.7 m at the time of the survey;
- a vertical downstream weir face resulting in plunging flow and a non-adherent nappe; and

- shallow water depth over the extended weir crest.

Potential exceptions to this include adult Atlantic salmon and trout which may be able to leap over the weir crest, especially during higher flows, and navigate their way up the weir providing water depths were adequate over the weir crest.

2.2.7 Fish passage options appraisal

Following liaison with the Severn Rivers Trust and local Environment Agency fisheries staff it is recognised that the preference is to propose a fish passage solution which would cater for all fish species and life stages occurring, or likely to occur, within the River Stour. As such the fish passage options appraisal below will address the options for all-species fish passage improvements.

The following sections provide a brief summary of the various fish passage options considered for the Bells Mill weir. Information contained within the Institute of Fisheries Management fish pass manual (Armstrong *et al*., 2010[10]) together with various other publications, website reports and the project teams significant professional experience has been used to inform the options appraisal.

2.2.7.1 Do nothing

It is a specific aim of the project to provide fish passage options for each of the structures surveyed. Consequently it is recognised that a 'do nothing' approach is not considered likely to be acceptable to the client or other parties involved in the '*Salmon in the Stour*' project. Notwithstanding this it is important to consider the likely benefits of any proposed improvements relative to the likely costs of delivering them.

In the case of Bells Mill weir, several potentially feasible options exist for improving fish passage, at least for some species and life stages if not all. The options discussed below however need careful consideration in relation to the likely benefit to fish populations throughout the entire catchment. In order to do this an assessment of the upstream and downstream habitat would be required together with costed options for any habitat improvements. Habitat assessment options are as discussed previously in Section 2.1.7 of this report.

In the absence of a suitably detailed habitat assessment it is not possible to provide further commentary of the suitability of the upstream habitat for different fish species. The cost of any potential habitat improvements that may be required cannot therefore be discussed as part of this appraisal. Notwithstanding this a 'do nothing' approach is not proposed for this site.

2.2.7.2 Structure removal

The removal of in-river structures, especially those which pose a barrier or obstacle to fish, offers the benefits of restoring longitudinal connectivity within the watercourse and re-establishing a more natural hydromorphological channel form and processes to the river.

[10] Armstrong, G S, Aprahamian, M W, Fewings, G A, Gough, P J, Reader, N A and Varallo, P V (2010). Institute of Fisheries Management fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales, Version 1.1. Institute of Fisheries Management.

Whilst this option represents a preferred choice from an ecological / hydromorphological perspective it is unlikely to be considered acceptable to the current owner of the structure.

The weir forms a significant component of the Bells Mill complex of buildings and structures. Removal of the weir would require significant works to ensure the future stability of the adjacent retaining walls, buildings and other structures. Furthermore it would require significant works to re-profile the river bed to ensure a suitable gradient over the *ca* 0.7 m head difference between the upstream and downstream levels.

Although the technical difficulties and associated costs of pursuing this option make it an unlikely solution for this location the weir does not have an existing function which precludes its removal. It is therefore recommended that this option is explored further prior to progressing other options. The first stage of this would be to determine whether there are likely to be any objections from the structure owner.

2.2.7.3 Bypass channel

Naturalised bypass channels are often cited as a preferred option for improving fish passage where structure removal is not considered a feasible option. Such channels increase longitudinal connectivity within rivers and can also offer the additional benefit of providing supplementary aquatic and riparian habitat which can be used by a variety of wildlife including fish (Dodd *et al*., 2017[11]). In many cases it is considered that naturalised bypass channels offer the highest (ecological) benefit relative to the construction costs (Dickie *et al*., 2014[12]). Notwithstanding this the design and construction costs for such channels is typically higher than other technical fish passage solutions.

Due to the low gradient needed for a nature-like bypass channel to be effective as a fish passage solution, where a relatively high head loss occurs the space required to construct the channel in can be significant. In the case of Bells Mill a potential option exists utilising an existing low lying, wet channel with a downstream entrance on the true right hand bank immediately downstream of Bells Mill fishery weir. If the rough line of this channel was followed the length of the bypass channel would be in the region of 350 m to 400 m total length. Whilst this may seem excessive, the impact on the landowners property with respect to land take would be minimal which may increase the likelihood of the proposal being acceptable. The net habitat gain, assuming the channel was designed and constructed appropriately, would also be large providing significant ecological benefit. Notwithstanding this the cost for the design and construction of this channel would not be insignificant.

2.2.7.4 Rock ramp

Rock ramps employ the use of carefully placed boulders (or rocks) to dissipate energy and create low velocity areas over an elongated ramp or slope which fish can then use to overcome an otherwise impassable head loss. When designed and constructed correctly they can provide fish passage for a variety of different species and life stages

[11] Dodd, J.R., Cowx, I.G., Bolland, J.D. (2017). Efficiency of a nature-like bypass channel for restoring longitudinal connectivity for a river-resident population of brown trout. *J. Environ. Manage.* 15(204): 318-326.

[12] Dickie, I., Doku, A., Guiu, R., Wade, T., Ramsden, L., Hall, T., Hill, M., Butterworth, A. (2014). Estimation of the benefits of enhanced regulations for fish barrier management –Final Report to Defra. eftec. 59pp.

(see Armstrong *et al*., 2010[13] *and references therein*) and have the additional benefit of a relatively natural appearance. They can also provide habitat which can be used by a range of species including fish, aquatic invertebrates and birds (e.g. dippers).

Rock ramps are highly complex in terms of their design and subsequent construction. There are many examples of rock ramps which have required multiple re-visits to 'fine-tune' the design to achieve the desired flows. As such, in addition to their high initial design and installation costs there can be unforeseen additional costs to tweak installations. Furthermore, rock ramps are typically only considered suitable for structures with a head loss not exceeding 1 m.

With regard to Bells Mill weir, there is sufficient space to install a rock ramp and achieve the required *ca* 5% gradient. However, due to the presence of a large and deep weir pool will make this option technical difficult and the amount of material required to in-fill the weir pool to create the rock ramp is likely to result in high costs. This option is therefore considered unlikely to be suitable for this location.

2.2.7.5 Easements or barrier modification

Easements are modifications undertaken on structures which facilitate fish passage but are not considered to be a technical fish pass structure. There are various types but all are typically best suited to low-head structures or weirs with sloping faces. Typically they fall into one of the following categories:

- creating streaming flow and heterogeneous conditions;
- adherent (non-aerated) nappes;
- notches and gaps;
- baulks;
- baffle systems
- preliminary weirs (pre-barrages, check weirs etc.); and
- modifications to the channel bed.

For Bells Mill weir, the head loss prevents many such easements from being considered suitable with the exception of preliminary weirs. Pre-weirs could be used to reduce the overall head loss although shallow depths over the weir crest section would also need addressing via the use of baffles. The use of pre-weirs has the potential to increase the risk of flooding upstream of this site by raising tailwater levels which is likely to prove unacceptable to both the land owner and the Environment Agency. Notwithstanding this the option has significant enough potential to warrant further exploration including an analysis of flood risk by a suitably qualified hydrologist.

2.2.7.6 Technical fish passes

Technical fish passes fall into one of two categories:

i) pool fish passes; and

[13] Armstrong, G S, Aprahamian, M W, Fewings, G A, Gough, P J, Reader, N A and Varallo, P V (2010). Institute of Fisheries Management fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales, Version 1.1. Institute of Fisheries Management.

ii) baffled fish passes.

There are various selection criteria which render one or the other type of technical fish better suited to an individual situation. Typically all of them are constructed alongside an existing barrier as this reduces the risk of any additional flood risk associated with the construction of the fish pass. In some cases it can even reduce the overall flood risk for a given location.

At Bells Mill weir the best-practice approach of siting a technical fish pass adjacent to the weir would not be possible due to the nature of the steep left hand banks and the mill building and retaining walls on the left hand side of the weir. However, the sluice which runs to the left of the weir may represent a potential option.

A bottom baffle (Larinier) style fish pass would fit within the confines of the sluice channel / culvert. This would offer multi-species fish passage opportunities although it was not clear during the surveys whether there is sufficient room to also include an eel pass. An eel pass could however be fitted onto the main weir for relatively little cost. Assuming the sluice and culvert structures are of sufficient dimensions and structurally sound enough to accommodate this type of pass then this represents a feasible option for improving fish passage at Bells Mill.

There are however some potential issues which would require resolutions at the detailed feasibility study and design stage. To comply with best practice the downstream entrance to a fish pass should ideally be located adjacent to the main weir toe to ensure the highest chance of fish locating it. This would not be the case with the proposed solution however and the design would need to demonstrate suitable attraction flow and angle exiting the fish pass to guide fish to its entrance. To achieve this flow it is likely that the channel upstream of the sluice would require some modification to ensure sufficient flow could be directed down the fish pass. This would require agreement from the landowner.

2.2.8 Recommended option

Following the fish passage options appraisal process there are three potential options which could be proceedable at this location subject to a detailed feasibility study being undertaken. These include:

i) a naturalised bypass channel;

ii) a series of notched pre-barrages and baffles on the weir face; and

iii) a bottom baffle technical fish pass in the culvert leading to the sluice on the main weir.

The recommended option is a series of notched pre-barrages and baffles on the weir face to aid upstream migration of fish generally and eel tiles mounted on the base of the culvert located on the true right hand side of the weir to facilitate the upstream passage of eels and smaller / minor fish species.

The estimated costs for this option are £2,000 to £4,000 for the eel tile pass and £40,000 to £80,000 for the pre weirs and baffles.

2.3 Bells Mill Fishery

2.3.1 Survey timings

The site was visited by RSK's aquatic ecologists, who are experienced in fish passage assessments and fish passage options appraisals, on 18th April 2018 at approximately 13:30.

2.3.2 Prevailing weather and river / flow conditions

At the time of the survey the weather was a mixture of clear skies and light cloud. Rainfall during the days immediately preceding the surveys had been relatively low resulting in moderate flow conditions (i.e. not low flow or high / spate flow conditions). This enabled the key elements of the structure and the channel upstream and downstream of the structure to be viewed clearly.

2.3.3 Ownership and current function

According to Environment Agency sources the weir is privately owned although further details were not available at the time of preparing this report. The weir is not known to have any existing function.

2.3.4 Topographic survey

The topographic survey was undertaken in on 27/04/2018 by RSK's Geophysics team with Up and Under (also an RSK business) providing specialist access health and safety support. Surveys were carried out at a scale of 1:1 and set to Ordnance Survey grid and datum and referenced using Leica Geosystems Smartnet.

2.3.5 Site description

This site comprises a single weir structure made from block stone / masonry blocks with brick wing walls (Figure 2.17). The weir has a broad, block stone crest with water depths of approximately 0.1 m at the time of the survey and a vertical weir face with plunging flows into a weir pool and a non-adherent nappe (Figure 2.17). The head loss was estimated at *ca* 1 m on the day of the survey.

Figure 2.17: Photograph illustrating the main features of interest at Bells Mill with respect to fish passage issues.

Water depths within the weir pool were varied due to variations in the bed level with a maximum recorded depth of 1.77 m.

A small gully / back channel with flowing water in it was located on the true right hand bank approximately 4 m downstream from the weir in the main channel (Figure 2.17 and Figure 2.18). This gulley originated from an overgrown and fully sedimented channel passing through some wetted woodland habitat (Figure 2.19) and pastureland on the right hand bank. The gulley was traced back as far as the pasture in front of the Bells Mill house.

Figure 2.18: Photograph of the downstream end of the small gulley / back channel.

Figure 2.19: Photograph of the middle section of the gulley / back channel showing how sedimented and overgrown the channel has become.

The habitat upstream of the weir was predominantly impounded with glide flow type and a predominantly silt covered substrate (Figure 2.20). The channel was straight with a very high and steep, partially wooded left hand bank and a lower left hand bank with mainly woodland and scrub.

Figure 2.20: Photograph showing the upstream habitat looking downstream towards the weir from a viewing point *ca* 50 m upstream of the weir.

Immediately downstream of the weir was a weir pool followed by a mixture of run, riffle and glide habitats (Figure 2.21). The substrate was a mix of cobble, pebble and gravel interspersed with some finer sand or silt patches. Both backs were steep with the left hand bank being a lightly wooded slope and the right bank being near vertical with

arable fields at the top of the bank. The banks had become unstable and collapsed in several places.

Figure 2.21: Photograph looking downstream from the tail end of the weir pool.

2.3.6 Fish species considerations

According to data provided by the local Environment Agency fisheries team the following native fish species were recorded from surveys undertaken at locations upstream and downstream of the weir at Bells Mill:

- Atlantic salmon (*Salmo salar*)
- Barbel (*Barbus barbus*)
- Bleak (*Alburnus alburnus*)
- Brook lamprey (*Lampetra planeri*)
- Brown / sea trout (*Salmo trutta*)
- Bullhead (*Cottus gobio*)
- Chub (*Squalius cephalus*)
- Dace (*Leuciscus cephalus*)
- European eel (*Anguilla anguilla*)
- Gudgeon (*Gobio gobio*)
- Minnow (*Phoxinus phoxinus*)
- Perch (*Perca fluviatilis*)
- Pike (*Esox lucius*)
- Roach (*Rutilus rutilus*)
- Roach and common bream hybrid (*R. Rutilus* x *Abramis brama*)

- Rudd (*Scardinius erythrophthalmus*)
- Stoneloach (*Barbatula barbatula*)
- Ten-spined stickleback (*Pungitius pungitius*)
- Three-spined stickleback (*Gasterosteus aculeatus*)

Lamprey ammocoetes of unconfirmed species were also recorded along with two non-native fish species:

- Carp (*Cyprinus carpio*)
- Golden orfe (an ornamental variety of *Leuciscus idus*)

A formal barrier assessment was not requested as part of this study. Notwithstanding this it was obvious during the survey that the structure would represent a complete barrier, to all fish species and life stages likely to occur in the river. This would be the case for the majority, if not all, flow conditions that might be expected at this location. The key features inhibiting the passage of fish are:

- a head loss across the structure of >1 m at the time of the survey;
- a vertical downstream weir face resulting in plunging flow and a non-adherent nappe; and
- shallow water depth over the weir crest.

2.3.7 Fish passage options appraisal

Following liaison with the Severn Rivers Trust and local Environment Agency fisheries staff it is recognised that the preference is to propose a fish passage solution which would cater for all fish species and life stages occurring, or likely to occur, within the River Stour. As such the fish passage options appraisal below will address the options for all-species fish passage improvements.

The following sections provide a brief summary of the various fish passage options considered for the Bells Mill Fishery weir. Information contained within the Institute of Fisheries Management fish pass manual (Armstrong *et al*., 2010[14]) together with various other publications, website reports and the project teams significant professional experience has been used to inform the options appraisal.

2.3.7.1 Do nothing

It is a specific aim of the project to provide fish passage options for each of the structures surveyed. Consequently it is recognised that a 'do nothing' approach is not considered likely to be acceptable to the client or other parties involved in the '*Salmon in the Stour*' project. Notwithstanding this it is important to consider the likely benefits of any proposed improvements relative to the likely costs of delivering them.

[14] Armstrong, G S, Aprahamian, M W, Fewings, G A, Gough, P J, Reader, N A and Varallo, P V (2010). Institute of Fisheries Management fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales, Version 1.1. Institute of Fisheries Management.

In the case of Bells Mill fishery weir, several potentially feasible options exist for improving fish passage, at least for some species and life stages if not all. The options discussed below however need careful consideration in relation to the likely benefit to fish populations throughout the entire catchment. In order to do this an assessment of the upstream and downstream habitat would be required together with costed options for any habitat improvements. Habitat assessment options are as discussed previously in Section 2.1.7 of this report.

In the absence of a suitably detailed habitat assessment it is not possible to provide further commentary of the suitability of the upstream habitat for different fish species. The cost of any potential habitat improvements that may be required cannot therefore be discussed as part of this appraisal. Notwithstanding this a 'do nothing' approach is not proposed for this site.

2.3.7.2 Structure removal

The removal of in-river structures, especially those which pose a barrier or obstacle to fish, offers the benefits of restoring longitudinal connectivity within the watercourse and re-establishing a more natural hydromorphological channel form and processes to the river.

This option represents a preferred choice from an ecological / hydromorphological perspective and given that the structure has no known extant function it is proposed that this option be given further consideration. Notwithstanding this, communication received from local Environment Agency staff suggests that this option has already been discounted due to the close proximity of this structure to another weir at Bells Mill. For the purpose of this study other options are therefore considered.

2.3.7.3 Bypass channel

Naturalised bypass channels are often cited as a preferred option for improving fish passage where structure removal is not considered a feasible option. Such channels increase longitudinal connectivity within rivers and can also offer the additional benefit of providing supplementary aquatic and riparian habitat which can be used by a variety of wildlife including fish (Dodd *et al*., 2017[15]). In many cases it is considered that naturalised bypass channels offer the highest (ecological) benefit relative to the construction costs (Dickie *et al*., 2014[16]). Notwithstanding this the design and construction costs for such channels is typically higher than other technical fish passage solutions.

Due to the low gradient needed for a nature-like bypass channel to be effective as a fish passage solution, where a relatively high head loss occurs the space required to construct the channel in can be significant. In the case of Bells Mill Fishery weir, a potential option exists utilising the existing low lying, wet back channel / small gulley with a downstream entrance on the true right hand bank immediately downstream of the weir (Figures 2.17, 2.18 and 2.19). The net habitat gain, assuming the channel was designed and constructed appropriately, would provide significant ecological benefit.

[15] Dodd, J.R., Cowx, I.G., Bolland, J.D. (2017). Efficiency of a nature-like bypass channel for restoring longitudinal connectivity for a river-resident population of brown trout. *J. Environ. Manage.* 15(204): 318-326.

[16] Dickie, I., Doku, A., Guiu, R., Wade, T., Ramsden, L., Hall, T., Hill, M., Butterworth, A. (2014). Estimation of the benefits of enhanced regulations for fish barrier management –Final Report to Defra. eftec. 59pp.

Notwithstanding this the cost for the design and construction of this channel would not be insignificant.

2.3.7.4 Rock ramp

Rock ramps employ the use of carefully placed boulders (or rocks) to dissipate energy and create low velocity areas over an elongated ramp or slope which fish can then use to overcome an otherwise impassable head loss. When designed and constructed correctly they can provide fish passage for a variety of different species and life stages (see Armstrong *et al*., 2010[17] *and references therein*) and have the additional benefit of a relatively natural appearance. They can also provide habitat which can be used by a range of species including fish, aquatic invertebrates and birds (e.g. dippers).

Rock ramps are highly complex in terms of their design and subsequent construction. There are many examples of rock ramps which have required multiple re-visits to 'fine-tune' the design to achieve the desired flows. As such, in addition to their high initial design and installation costs there can be unforeseen additional costs to tweak installations. Furthermore, rock ramps are typically only considered suitable for structures with a head loss not exceeding 1 m.

With regard to Bells Mill Fishery weir, there is sufficient space to install a rock ramp and achieve the required *ca* 5% gradient. However, the >1 m head loss will make this option technical difficult and potentially not feasible. This option is therefore considered unlikely to be suitable for this location.

2.3.7.5 Easements or barrier modification

Easements are modifications undertaken on structures which facilitate fish passage but are not considered to be a technical fish pass structure. There are various types but all are typically best suited to low-head structures or weirs with sloping faces. Typically they fall into one of the following categories:

- creating streaming flow and heterogeneous conditions;
- adherent (non-aerated) nappes;
- notches and gaps;
- baulks;
- baffle systems;
- preliminary weirs (pre-barrages, check weirs etc.); and
- modifications to the channel bed.

For Bells Mill Fishery weir, the large head loss prevents any such easements from being considered suitable and therefore such options are not considered further.

2.3.7.6 Technical fish passes

Technical fish passes fall into one of two categories:

[17] Armstrong, G S, Aprahamian, M W, Fewings, G A, Gough, P J, Reader, N A and Varallo, P V (2010). Institute of Fisheries Management fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales, Version 1.1. Institute of Fisheries Management.

i) pool fish passes; and

ii) baffled fish passes.

There are various selection criteria which render one or the other type of technical fish better suited to an individual situation. Typically all of them are constructed alongside (i.e. bypassing) an existing barrier as this reduces the risk of any additional flood risk associated with the construction of the fish pass. In some cases it can even reduce the overall flood risk for a given location.

At Bells Mill Fishery weir the best-practice approach of siting a technical fish pass adjacent to the weir would be possible on the true right hand bank although significant excavation would be required due to the height of the banks / depth of the channel and the large head loss that needs to be overcome.

A bottom baffle (Larinier) style fish pass with associated eel tile pass would represent the most preferable solution due to the large range of fish species that can use such passes. This type of pass would offer multi-species fish passage opportunities although the overall construction requirements are not insignificant and access to the site would require the creation of access routes through what appears to be high quality wetted woodland habitat. Furthermore, the benefits of creating a fish pass at this location without addressing fish passage issues at Bells Mill would be limited. Nonetheless, this represents a potential option for this location.

2.3.8 Recommended option

Following the fish passage options appraisal process there are two potential options which could be proceedable at this location subject to a detailed feasibility study being undertaken. These include:

i) a naturalised bypass channel; and

ii) a bottom baffle (Larinier) technical fish pass with associated eel pass.

The recommended option is a naturalised bypass channel as discussed below.

2.3.8.1 Naturalised bypass channel

This option would provide the most benefit from an ecological perspective and is therefore the recommended option for Bells Mill Fishery weir. The creation of the additional channel, which could include backwaters and / or resting pools, would also increase the overall capacity of the river which may provide benefits with respect to flood risk (subject to a flood risk assessment). Fish passage issues could be resolved for the full range of species occurring within the River Stour as well as creating additional function habitat including spawning, foraging and refuge areas.

There are two limiting factors which may prevent this option being taken forward. The first is the whether or not permission could be obtained from the landowners to undertake the proposed works and habitat creation. The second is the high cost of undertaking a project of this scale.

The estimated costs for a bypass channel of at least 20 m total length (to achieve a maximum gradient of 5% - a gradient of 4% would be offer better passage opportunities for more fish species however) as discussed in this section would be £70,000 to £140,000.

2.4 Kidderminster Furniture Warehouse

2.4.1 Survey timings

The site was visited by RSK's aquatic ecologists, who are experienced in fish passage assessments and fish passage options appraisals, on 18th April 2018 at approximately 16:30.

2.4.2 Prevailing weather and river / flow conditions

At the time of the survey the weather was a mixture of clear skies and light cloud. Rainfall during the days immediately preceding the surveys had been relatively low resulting in moderate flow conditions (i.e. not low flow or high / spate flow conditions). This enabled the key elements of the structure and the channel upstream and downstream of the structure to be viewed clearly. Notwithstanding this, the depth of the weir pool combined with slightly turbulent and turbid water meant that the channel weir pool bed could not be seen.

2.4.3 Ownership and current function

According to Environment Agency sources the weir structure and adjacent land are privately owned. No information was available at the time of preparing this report regarding the current function of the weir. Notwithstanding this, according to Environment Agency sources there may be services located upstream of the weir which are protected by its presence – presumably by reducing river bed scour.

2.4.4 Topographic survey

The topographic survey was undertaken on 24/04/2018 by RSK's Geophysics team with Up and Under (also an RSK business) providing specialist access health and safety support. Surveys were carried out at a scale of 1:1 and set to Ordnance Survey grid and datum and referenced using Leica Geosystems Smartnet.

2.4.5 Site description

This site comprises a compound weir structure including a sloping central section and two stepped wings (Figure 2.21). The head loss across the structure was approximately 0.45 m on the day of the survey.

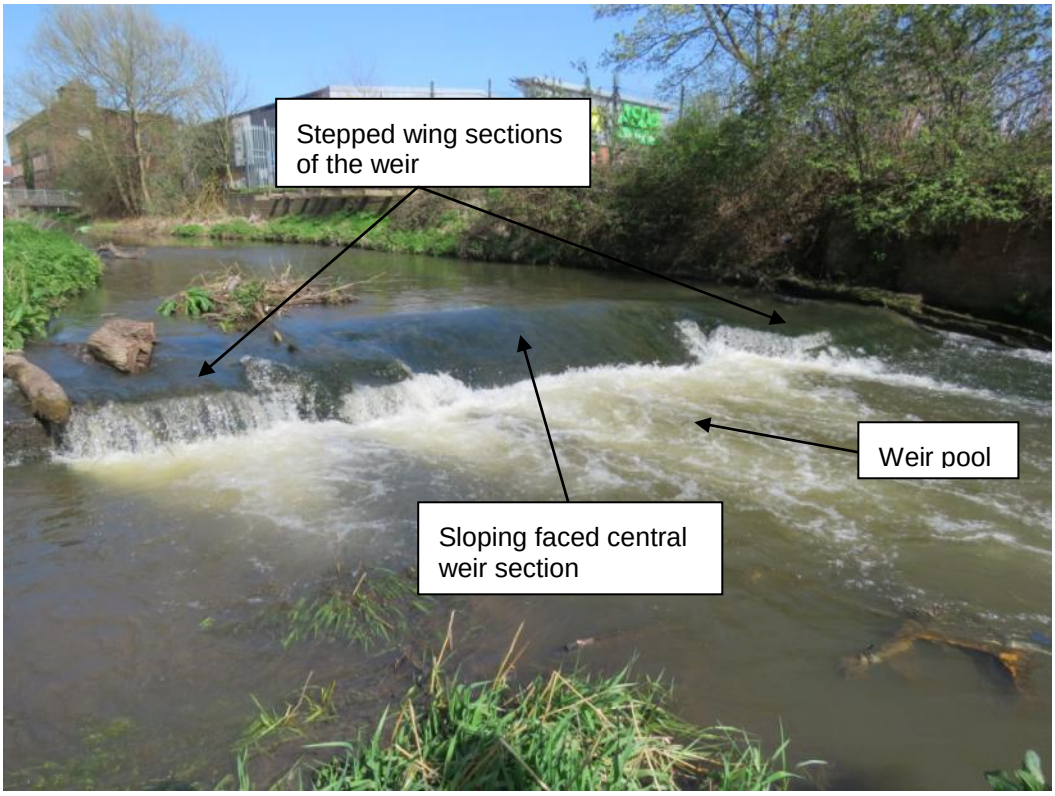

Figure 2.21: Photograph illustrating the main features of interest at Kidderminster Furniture Warehouse weir.

There was streaming flow over the central, sloping-faced section of the weir with a small standing wave and turbulent conditions at its base. Water depth over the weir face was approximately 0.15 m. Flow over the wing sections was predominantly plunging with the exception of the farthest true left section of the weir where the nappe appeared to be adherent.

An additional concrete structure was also observed approximately 10 m upstream of the main weir structure (Figure 2.22). According to the Environment Agency it is likely that this is concrete protection above a buried sewage transfer pipe. Further investigation into the purpose of this structure should be undertaken as a priority for any subsequent feasibility studies due to the potential for any changes in downstream bed or water levels associated with fish passage improvements to impact upon this structure (e.g. due to increased scour). Furthermore, if the water levels were to drop significantly (e.g. due to very low river flow levels during prolonged periods of no rainfall or due to downstream alterations to the weir structure) this could result in this structure becoming an obstacle to fish.

Figure 2.22: Photograph illustrating the structure upstream of the main weir believed to be a buried sewage transfer pipe.

The habitat upstream of the weir was predominantly uniform with glide flow types and a substrate that appeared to be predominantly gravel interspersed with sand and occasional boulders. There were multiple patches of submerged linear macrophyte also visible.

Figure 2.23: Photograph of the river channel upstream of the weir structures.

There were narrow, low lying banks on either side of the river channel, both of which contained stands of Himalayan Balsam and Japanese Knotweed. The land immediately beyond the banks included industrial units and warehouses and a large supermarket.

Figure 2.24: Photograph showing the river channel downstream of the weir.

The river channel downstream of the weir was straight but with more variable flow patterns compared with the upstream channel. Glide, run and riffle areas were all observed with some marginal slack water areas. The substrate was similar to that upstream but with some coarser substrate types present in patches.

2.4.6 Fish species considerations

According to data provided by the local Environment Agency fisheries team the following native fish species were recorded from the River Stour:

- Atlantic salmon (*Salmo salar*)
- Barbel (*Barbus barbus*)
- Bleak (*Alburnus alburnus*)
- Brook lamprey (*Lampetra planeri*)
- Brown / sea trout (*Salmo trutta*)
- Bullhead (*Cottus gobio*)
- Chub (*Squalius cephalus*)
- Dace (*Leuciscus cephalus*)
- European eel (*Anguilla anguilla*)
- Gudgeon (*Gobio gobio*)
- Minnow (*Phoxinus phoxinus*)

- Perch (*Perca fluviatilis*)
- Pike (*Esox lucius*)
- Roach (*Rutilus rutilus*)
- Roach and common bream hybrid (*R. Rutilus* x *Abramis brama*)
- Rudd (*Scardinius erythrophthalmus*)
- Stoneloach (*Barbatula barbatula*)
- Ten-spined stickleback (*Pungitius pungitius*)
- Three-spined stickleback (*Gasterosteus aculeatus*)

Lamprey ammocoetes of unconfirmed species were also recorded along with two non-native fish species:

- Carp (*Cyprinus carpio*)
- Golden orfe (an ornamental variety of *Leuciscus idus*)

A formal barrier assessment was not requested as part of this study. Notwithstanding this the structure is likely to be an obstacle to many fish species and life stages, at least under some flow conditions.

2.4.7 Fish passage options appraisal

Following liaison with the Severn Rivers Trust and local Environment Agency fisheries staff it is recognised that the preference is to propose a fish passage solution which would cater for all fish species and life stages occurring, or likely to occur, within the River Stour. As such the fish passage options appraisal below will address the options for all-species fish passage improvements.

The following sections provide a brief summary of the various fish passage options considered for the weir at Kidderminster Furniture Warehouse. Information contained within the Institute of Fisheries Management fish pass manual (Armstrong *et al*., 2010[18]) together with various other publications, website reports and the project teams significant professional experience has been used to inform the options appraisal.

2.4.7.1 Do nothing

It is a specific aim of the project to provide fish passage options for each of the structures surveyed. Consequently it is recognised that a 'do nothing' approach is not considered likely to be acceptable to the client or other parties involved in the '*Salmon in the Stour*' project. Notwithstanding this it is important to consider the likely benefits of any proposed improvements relative to the likely costs of delivering them.

In the case of the weir at Kidderminster Furniture Warehouse, several potentially feasible options exist for improving fish passage, at least for some species and life stages if not all. The options discussed below however need careful consideration in relation to the likely benefit to fish populations throughout the entire catchment. In order

[18] Armstrong, G S, Aprahamian, M W, Fewings, G A, Gough, P J, Reader, N A and Varallo, P V (2010). Institute of Fisheries Management fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales, Version 1.1. Institute of Fisheries Management.

to do this an assessment of the upstream and downstream habitat would be required together with costed options for any habitat improvements. Habitat assessment options are as discussed previously in Section 2.1.7 of this report.

In the absence of a suitably detailed habitat assessment it is not possible to provide further commentary of the suitability of the upstream habitat for different fish species. The cost of any potential habitat improvements that may be required cannot therefore be discussed as part of this appraisal. Notwithstanding this a 'do nothing' approach is not proposed for this site.

2.4.7.2 Structure removal

The removal of in-river structures, especially those which pose a barrier or obstacle to fish, offers the benefits of restoring longitudinal connectivity within the watercourse and re-establishing a more natural hydromorphological channel form and processes to the river.

This option represents a preferred choice from an ecological / hydromorphological perspective, however, local Environment Agency staff have indicated that this is unlikely to be considered as an acceptable solution for this location, potentially because of upstream services (e.g. the sewage transfer pipe). Notwithstanding this, given that the weir does not have any known extant function it is proposed that the removal of either the whole weir, or at least the central sloping section, together with reprofiling of the river bed is considered further as a potential option for this site.

If there are features of this site which prevent this being a viable option then this report should be updated to include this reasoning.

2.4.7.3 Bypass channel

Naturalised bypass channels are often cited as a preferred option for improving fish passage where structure removal is not considered a feasible option. Such channels increase longitudinal connectivity within rivers and can also offer the additional benefit of providing supplementary aquatic and riparian habitat which can be used by a variety of wildlife including fish (Dodd *et al*., 2017[19]). In many cases it is considered that naturalised bypass channels offer the highest (ecological) benefit relative to the construction costs (Dickie *et al*., 2014[20]). Notwithstanding this the design and construction costs for such channels is typically higher than other technical fish passage solutions.

Due to the low gradient needed for a nature-like bypass channel to be effective as a fish passage solution, where a relatively high head loss occurs the space required to construct the channel in can be significant. In the case of the weir at the Kidderminster Furniture Warehouse there is insufficient room to create a naturalised bypass channel and this option is therefore not considered further.

[19] Dodd, J.R., Cowx, I.G., Bolland, J.D. (2017). Efficiency of a nature-like bypass channel for restoring longitudinal connectivity for a river-resident population of brown trout. *J. Environ. Manage.* 15(204): 318-326.

[20] Dickie, I., Doku, A., Guiu, R., Wade, T., Ramsden, L., Hall, T., Hill, M., Butterworth, A. (2014). Estimation of the benefits of enhanced regulations for fish barrier management –Final Report to Defra. eftec. 59pp.

2.4.7.4 *Rock ramp*

Rock ramps employ the use of carefully placed boulders (or rocks) to dissipate energy and create low velocity areas over an elongated ramp or slope which fish can then use to overcome an otherwise impassable head loss. When designed and constructed correctly they can provide fish passage for a variety of different species and life stages (see Armstrong *et al*., 2010[21] *and references therein*) and have the additional benefit of a relatively natural appearance. They can also provide habitat which can be used by a range of species including fish, aquatic invertebrates and birds (e.g. dippers).

Rock ramps are highly complex in terms of their design and subsequent construction. There are many examples of rock ramps which have required multiple re-visits to 'fine-tune' the design to achieve the desired flows. As such, in addition to their high initial design and installation costs there can be unforeseen additional costs to tweak installations.

With regards to the weir at the Kidderminster Furniture Warehouse the creation of a rock ramp fish pass represents a potentially viable option. This solution, if designed and constructed correctly would provide a passage solution with a more natural appearance and function than a technical fish passage solution. This therefore represents a more preferable solution from an ecological perspective. However, the higher costs compared with other potential options for improving fish passage at this location are an important consideration.

2.4.7.5 *Easements or barrier modification*

Easements are modifications undertaken on structures which facilitate fish passage but are not considered to be a technical fish pass structure. There are various types but all are typically best suited to low-head structures or weirs with sloping faces. Typically they fall into one of the following categories:

- creating streaming flow and heterogeneous conditions;
- adherent (non-aerated) nappes;
- notches and gaps;
- baulks;
- baffle systems;
- preliminary weirs (pre-barrages, check weirs etc.); and
- modifications to the channel bed.

In the case of the weir at Kidderminster Furniture Warehouse it may be feasible to install low cost baffles on the weir face and install a separate eel / lamprey pass using eel tiles to provide a multi-species fish passage solution. In the event that the slope angle is considered too great for low cost baffle solutions it may be possible to install a deep-notched preliminary weir to reduce the overall head loss to make the structure more passable. The notch and sloping weir face could be modified to include eel tiles to further improve their passability. In the case of the weir face it is likely that eel tiles

[21] Armstrong, G S, Aprahamian, M W, Fewings, G A, Gough, P J, Reader, N A and Varallo, P V (2010). Institute of Fisheries Management fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales, Version 1.1. Institute of Fisheries Management.

would only be required on one or both sides of the sloping face but not all the way across it. These options represent relatively low cost solutions for this location although there would be no additional benefits such as those associated with weir removal or a rock ramp fish pass.

2.4.7.6 Technical fish passes

So called technical fish passes typically fall into one of two categories:

i) pool fish passes; and

ii) baffled fish passes.

There are various selection criteria which render one or the other type of technical fish better suited to an individual situation. Typically all of them are constructed alongside an existing barrier as this reduces the risk of any additional flood risk associated with the construction of the fish pass. In some cases it can even reduce the overall flood risk for a given location.

At the Kidderminster Furniture Warehouse weir site there is sufficient space on either side of the weir to site a technical fish pass. There appears to be a greater proportion of the river flow passing at the true left hand side of the weir and thus according to best practice this side would be the preferred location to site a fish pass. Notwithstanding this, there is brick retaining wall on that side of the weir would need to be removed. Whilst the wall appears to be in a relatively poor state of repair it may still serve a purpose in protecting land / property behind it and this should be evaluated prior to developing detailed designs for a fish pass in this location.

A bottom baffle (Larinier) style fish pass with an associated eel / lamprey pass would represent a technically feasible option to improve passage for a wide range of fish species and life stages. Should a technical fish pass be identified as a preferred option then a Lariner is likely to represent the preferred type.

2.4.8 Recommended option

Following the fish passage options appraisal process there are three potential options which could be proceedable at this location subject to a detailed feasibility study being undertaken. These include:

i) weir removal;

ii) a notched pre-weir and low cost baffles; and

iii) a bottom baffle technical fish pass.

The recommended option is weir removal.

2.4.8.1 Weir removal

Although weir removal can often be seen as a very high cost solution there is sufficient evidence to suggest that over the long term the costs associated with maintaining an existing structure and constructing and maintaining a fish pass can be significantly higher. A longer term view is therefore advised rather than a lower cost ‘quick fix’. This option would provide the most benefit from an ecological and hydromorphological perspective and is therefore the recommended option for the weir at Kidderminster

Furniture Warehouse. It is acknowledged that there may be services present in the channel upstream of the weir (e.g. in the form of a sewage transfer pipe) and the likelihood of these being affected and any mitigation required to protect them requires further investigation. Notwithstanding this there should be a presumption towards weir removal if this is considered technically feasible.

Assuming there are no significant issues associated with the services in the upstream channel the estimated cost for weir removal and channel reprofiling at this location is £30,000 to £50,000.

The construction of a notched preliminary weir and retrofitting of baffles and eel tiles to the weir face may represent an attractive alternative due to the relative technical ease and potentially lower cost. However, this would prolong the existence of the weir and the other impacts that an in-river structure such as this has on the river channel (e.g. impoundment and altered flow patterns, impacts on sediment transfer etc.). As such this should only be pursued if the option of weir removal cannot be achieved due to technical issues rather than cost savings.

The estimated cost for installing a single, notched preliminary weir, low cost baffles and eel tiles at this location is £25,000 to £45,000.

3 ADDITIONAL CONSIDERATIONS

3.1 Protected species

Surveys for protected species were not requested as part of this study and were therefore not undertaken. Notwithstanding this there were numerous features at the different sites which might provide refuge, breeding, foraging or commuting habitat for protected species or other species of conservation interest. Selected examples include:

- undercut banks and tree roots provide potential resting places for otters;
- block stone or brick walls, bridges and trees with peeling bark, knot holes etc provide potential roosting features for bats;
- vegetated banks provide potential habitat for water voles;
- wooded banks and scrub provide potential refuge, foraging and commuting habitat for a range of species including otters and badgers; and
- trees, scrub or vegetated banks provide potential nesting places for birds.

Any detailed feasibility studies undertaken at the four sites discussed in this report should also include an ecological constraints / preliminary ecological appraisal (PEA) survey which may determine the need for further detailed surveys for selected protected species. Such surveys may identify a need for mitigation measures at part of any proposals to improve fish passage to ensure that protected species are not unnecessarily disturbed or damaged.

It is also plausible that relic populations of white-clawed crayfish remain in the upper reaches or tributaries of the River Stour. Surveys to determine whether or not populations remain should be undertaken as a priority. This should include a desk-based review of available survey data to identify those reaches for which information is lacking or out of date. The removal of barriers within rivers could facilitate the spread of invasive non-native crayfish species which could result in the loss of any remaining white clawed crayfish.

3.2 Invasive species

After habitat loss / destruction, invasive non-native species are widely regarded as the second biggest threat to global biodiversity. Surveys for invasive species were not requested or undertaken as part of this study. Notwithstanding this Japanese knotweed and Himalayan balsam were observed on several occasions and signal crayfish are known to present in the catchment. Any detailed feasibility study should thus allow for a survey to determine the presence and extent of invasive species at each site and provide costed proposals for dealing with them to ensure that proposed fish passage improvements do not contribute to the further spread of these species.

APPENDIX 1
TOPOGRAPHIC SURVEY OUTPUTS

193441 River Stour
Furnace Hill Weir.pdf

193441 River Stour
Bells Mill Weir

193441 River Stour
Bells Mill Fishery Weir

193441 River Stour
Kidderminster Furnitu