River Worth, Keighley (Woodhouse Road to River Aire):

Advisory Visit

	River Worth: Keighley
River	Worth (West Yorkshire)
Waterbody Name	Worth from Bridgehouse Beck to R Aire
Waterbody ID	**GB104027062891**
Management Catchment	Aire and Calder
River Basin District	Humber
Current Ecological Quality	Moderate
U/S Grid Ref inspected	SE 06009 40209
D/S Grid Ref inspected	SE 07653 42112
Length of river inspected	3km

Wild Trout Trust Report – Following a Site Visit on 27/10/2017

1. Introduction

A site visit and habitat appraisal was carried out at the request of Philip Sheridan, Helen Parsons (Friends of the River Worth) and Michael "Muppet" Pascal (Bradford district Community Empowerment Network/Friends of River Worth). Habitat was examined at accessible points as between Woodhouse Road bridge and the confluence with the main River Aire. The surveyed reaches fall within a single Water Framework Directive (WFD) waterbody - GB104027062891 – designated as heavily modified. More information on the classification of this waterbody can be found on the following web page:
(http://environment.data.gov.uk/catchment-planning/WaterBody/GB104027062891).

The Worth here is classified as being Moderate Ecological Status under the most recent (2016) WFD assessments. That classification is primarily due to a rating of "moderate" for combined macrophytes and phytobenthos in the biological elements and "moderate" for Phosphate in the physico-chemical elements. The assessment judges both fish and invertebrates to be "good".

This report refers to a reach between an upstream limit at (National Grid Reference) SE 06009 40209 and a downstream limit at SE 07653 42112. Observations of habitat quality and potential issues were recorded at locations throughout the reach in a downstream to upstream sequence. Findings at each location are presented in the same sequence for simplicity.

The particular niche requirements of native brown trout (*Salmo trutta*) in rivers such as the Worth allow a relatively simple but effective assessment of positive and negative habitat features to be carried out. Brown trout require well-oxygenated water, structurally varied habitat, healthy riparian flora/fauna and connectivity between markedly different habitats at different stages in its life-cycle. As a result, ensuring those features are present also generates multiple, wider biodiversity benefits.

To understand this easily, it is helpful to appreciate the requirements of three key lifecycle stages of wild trout. These three key stages are spawning, juvenile and adult phases. Each phase has specific habitat features that are necessary for successful completion. If those features are not all present within a single habitat "patch", there is a requirement for good "connectivity" such that the fish can migrate between the habitat features throughout the full lifecycle. Clearly, this makes connectivity incredibly important – even for those species that do NOT make marine migrations.

It is important to stress that trout do not exist in a vacuum. The food-webs that they belong to have many components. The various members of those food-webs (and the energy-sources that they depend on; such as leaf-litter and in-stream algal films) very often bridge the (perceived) gap between the aquatic and terrestrial habitats of a river corridor.

In other words, there is not a meaningful biological separation between the wettest parts of the habitat and the land surrounding a river channel. It is all strongly connected – and problems in one part of the system frequently have knock-on effects in other parts. Realising that problems within rivers are commonly solved by tackling issues in the surrounding landscape is an important mental leap. Given that bottlenecks can arise from problems on land or in water, it is useful to examine habitat requirements and consequences of particular limiting factors (where crucial habitat features are absent):

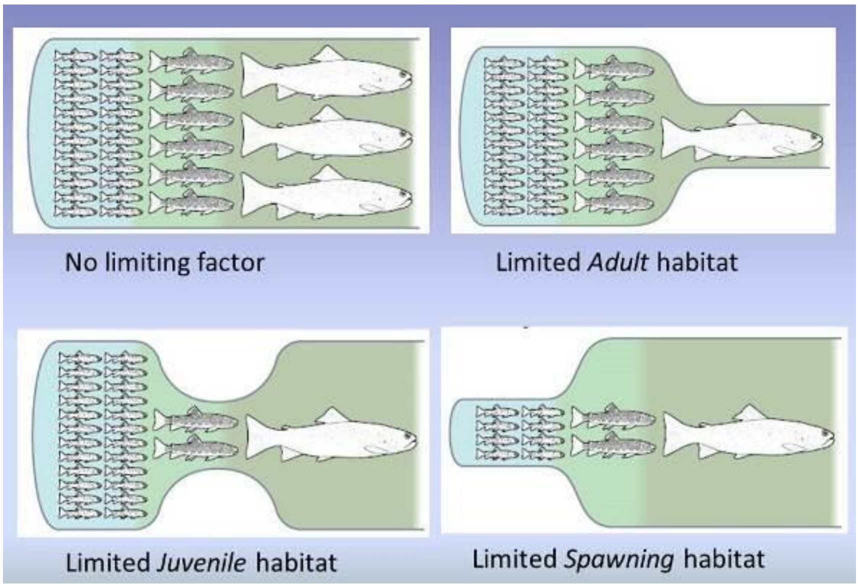

Figure 1: The impacts on trout populations lacking adequate habitat for key lifecycle stages. Spawning trout require loose mounds of gravel with a good flow of oxygenated water between gravel grains. Juvenile trout need shallow water with plenty of dense submerged/tangled structure for protection against predators and wash-out during spates. Adult trout need deeper pools (usually > 30cm depth) with nearby structural cover such as undercut boulders, sunken trees/tree limbs and/or low overhanging cover (ideally trailing on, or at least within 30cm of, the water's surface). Excellent quality in one or two out of the three crucial habitats cannot make up for a "weak link" in the remaining critical habitat.

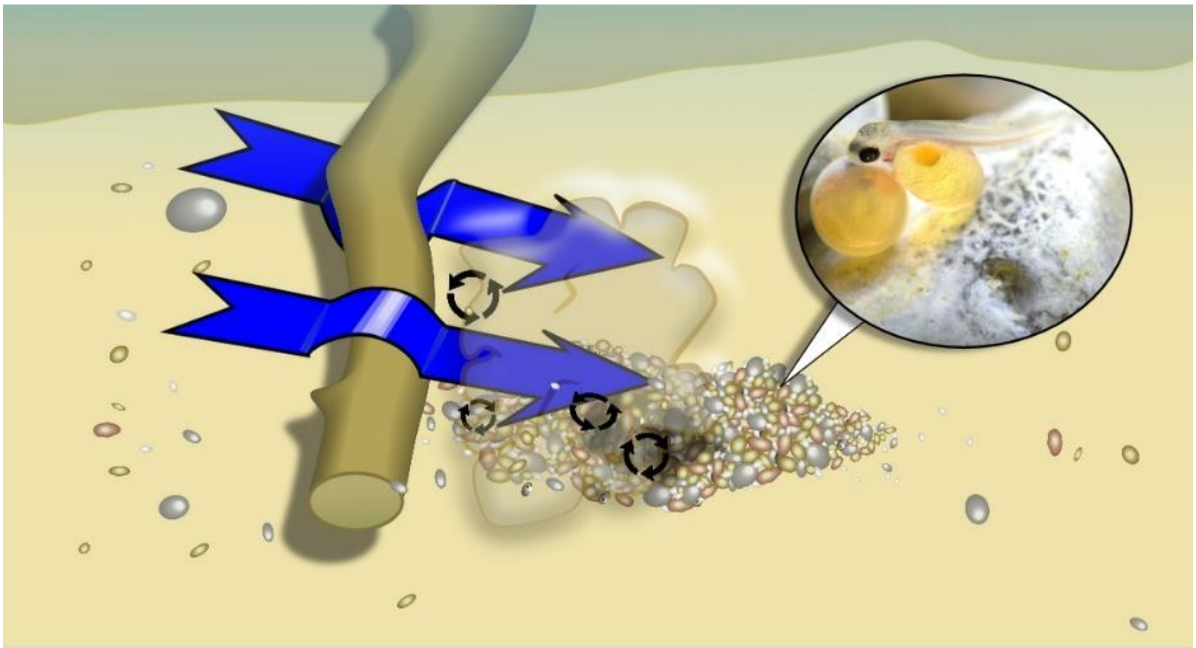

Figure 2: Features associated with successful trout spawning habitat include the presence of silt-free gravels. Here the action of fallen tree limb is focusing the flows (both under and over the limb as indicated by the blue arrows) on a small area of river-bed that results in silt being blown out from between gravel grains. A small mound of gravel is deposited just below the hollow dug by focused flows. In these silt-free gaps between the grains of gravel it is possible for sufficient oxygen-rich water to flow over the developing eggs and newly-hatched "alevins" to keep them alive as they hide within the gravel mound (inset) until emerging in spring.

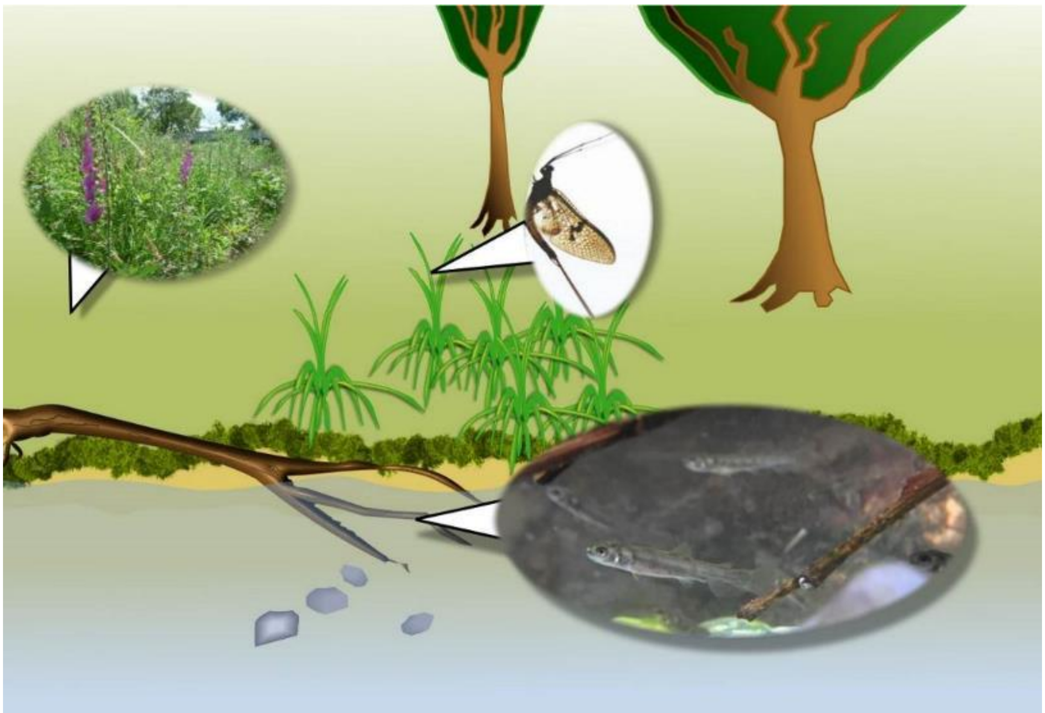

Figure 3: Larger cobbles and submerged "brashy" cover and/or exposed fronds of tree roots provide vital cover from predation and spate flows to tiny juvenile fish in shallower water (<30cm deep). Trailing, overhanging vegetation also provides a similar function and diverse bank-side vegetation has many benefits for invertebrate populations (some of which will provide a ready food supply for the juvenile fish).

Figure 4: The availability of deeper water bolt holes (>30cm to several metres), low overhanging cover and/or larger submerged structures such as boulders, fallen trees, large root-wads etc. close to a good food supply (e.g. below a riffle in this case) are all strong components of adult trout habitat requirements.

With these broad descriptions of the elements of spawning, juvenile (nursery) and adult trout habitat in mind, measures to address the issues identified during the survey can more easily be described.

Throughout the report, normal convention is followed with respect to bank identification i.e. banks are designated Left Bank (LB) or Right Bank (RB) whilst looking downstream.

2. Habitat Assessment

At the downstream limit of this visit (SE 07653 42112), the conditions in the main River Aire were examined below the confluence with the River Worth. The main river is a wide and powerful watercourse at this point. Consequently, the presence of trailing and submerged complex cover are vital factors for wild fish populations – providing respite from spate flows and keeping a healthy balance between predators and prey species. This latter factor was highlighted by the presence of goosander on the reach during the visit (in habitat which is very simple and lacks cover, predators become too efficient and prey populations can crash). For these reasons, the stable woody cover noted is extremely valuable (Figs. 5 and 6).

Figure 5: An example of valuable complex cover and refuge habitat in the form of a fallen tree on the opposite bank. Because it is still attached to the bank at the root-end (and lying roughly parallel to the main flow), this feature provides secure respite from spate flows for fish that will move into the "brashy" matrix of the submerged portions of the crown. With the crown still attached it is extremely unlikely to move and does not present a flood risk.

Figure 6: Low-level and partially-submerged bushy vegetation (again on the far bank) providing the same valuable functions as the fallen tree in Figure 5.

On the River Worth a short way upstream from the confluence with the Aire at SE 07350 41953, repair work to a bridge damaged during a spate in 2015 is visible – as well as the vertical sheet piling used to contain the river within this developed area (Figs. 7 and 8).

Figure 7: Repair work to bridge and vertical sheet-piling revetments.

Figure 8: Sheet piling flood defences (showing proximity to housing).

Understandably, property owners and the local council want to prevent the river entering its floodplain at this point (now that it has been developed). The knock-on effect of that situation is that much more powerful flood flows are passed on downstream.

The technical explanation for this is that the shear velocity – which is another way to describe the force that flowing water can exert on a structure experiencing that flow – is greatest under "bank-full" conditions. In a river that is well connected to its floodplain, those bank-full conditions:

1) Are level with the surrounding land.
2) Allow the velocity and force of the flow to dissipate across a much wider area once the floodplain is inundated with water that spills out of the banks.

In contrast, when that dissipation of force across a wide floodplain is not allowed and, instead, *raised up to a level above the floodplain whilst confined in a narrow chute*; then the destructive power of that water is significantly greater.

At the same time, the quality of the habitat within the channel is reduced under the normal flows that are experienced for 95% of the time. By increasing the cross-sectional area and making the sides vertical, a lack of variety in structure, depth and flow velocities over the cross-section of the river is created. Biological diversity relies on physical diversity in the habitat to create enough different opportunities for a range of species to exploit.

These factors (reducing the risk of flood damage and improving conditions for wildlife) provide strong arguments to incorporate greater upstream management of floodwater flows. While it is unlikely that the flood defences could be removed at the location in Figs. 7 and 8, greater opportunities to improve the habitat could still be provided by upstream management of floodwater flow and storage.

Just upstream of the Aireworth bridge at SE 07347 41859, there is an unusual - and apparently modern - structure in the channel (Figs. 9 and 10). Confirmation through Environment Agency personnel involved in the consenting process for this structure will provide a definitive identification. However, it may have been installed as a kind of 'hydrobrake' in an attempt to protect the damaged bridge downstream from future spate flows.

The apparent presence of monitoring equipment (Fig. 10) may support this conclusion, although that would more usually be associated with flow-gauging and data-collection. Overall, it seems likely that the structure is associated with the significant sensitivities to flood risk and associated damage to infrastructure.

Figure 9: Modern (gabion) structure which splits low flows into three narrow channels (each impassable in an upstream direction by most fish under most conditions). The first of the three low flow channels one hugs the RB, one runs down the centre and one hugs the LB. All three discharge onto a shallow, smooth concrete apron that is impassable to fish. The gabion mesh is already beginning to degrade and will form a "gill net", a trapping hazard to aquatic life as the degradation progresses.

Figure 10: Upstream channel and telemetry/instrumentation associated with the structure.

Given the density of development and infrastructure sited within the floodplain of this relatively steep and flashy river, it is imperative that flood risk is understood and managed properly. The inevitable pinch points towards the valley bottom (when sited below the steep runoff profile from the surrounding hills) create a problematic situation.

It is in directly comparable situations like Hebden Bridge, Pickering, Sinnington and Holnicote (two-minute video case study here: https://www.youtube.com/watch?v=BcuriB5q1Zc) where huge potential has been demonstrated to effectively manage flood risk by implementing measures upstream of bottlenecks.

The structure shown in Figs. 9 and 10 is imposing a significant, negative impact on the biodiversity of the recovering "post-industrial" River Worth. It is impassable to upstream-migrating fish (many species of freshwater fish, including "non-migratory" trout and grayling migrate between different habitats in order to complete their lifecycle). Consequently, it reduces the capacity of the system to be re-colonised following a pollution event. A more subtle impact is the reduced potential for "gene-flow" between members of breeding populations that would, otherwise, be able to mate and produce better-adapted offspring.

The capacity of river systems (including their surrounding, and linked, riparian habitats) to provide societal benefits is strongly related to their ability to support diverse biological communities. These benefits include – but are not limited to - reduction of deaths due to respiratory disease, mental health and wellbeing, flood risk mitigation, food security through pollinating insects, reduction in urban heat-island effects and direct financial benefits associated with increased amenity value (e.g. positive financial return on investment for river habitat restoration works measured by West Country Rivers Trust: http://urbantrout.blogspot.co.uk/2015/11/never-mind-environment-what-about-our.html).

Viewed in this light, and with the opportunity to utilise a more biodiverse landscape to achieve upstream controls on floodwater flow to reduce flood risk, it makes sense to examine better options at SE 07347 41859. For instance, replacing the current installation with a roughened "rock ramp" is likely to be more resilient than the currently-degrading gabion structure. As well as being more robust, this would also greatly improve connectivity for aquatic fauna between the main River Aire and the habitat upstream of this point on the River Worth.

It would be valuable to combine this with identifying and exploiting opportunities to create lateral connections between the river and its floodplain upstream of developments (or even within developed areas where such temporary floodwater storage can be accommodated). The reconnection of river to areas of natural floodplain carries great opportunities to increase biodiversity – and societal benefits. Similarly, understanding the movement of floodwater through the system and increasing "roughness" within appropriate sections of the channel upstream of flooding bottlenecks is also an excellent opportunity. Done correctly it can create win:win:win benefits to wellbeing within local/wider society, biodiversity and cost-effective flood risk management.

Upstream from this structure at SE 07321 41745 there is a long, relatively shallow run (Fig. 11) that is reportedly favoured by grayling. Although obviously straightened, this is an extremely isolated example within the urban development where the river is actually connected to a small area of floodplain in the form of a grassed amenity area (Fig. 12). The supply of substrate that spans a range of particle sizes from sands, gravels, pebbles cobbles and small rocks/boulders creates potential for structural diversity. It would be beneficial to increase structural variety (section 3. Recommendations) to create the best ecological benefits from the opportunity provided – and to counter unsympathetic dredging.

Figure 11: Gravelly, cobbled run with (rare) connectivity to floodplain. The unmown buffer strip is extremely valuable in biological terms.

Figure 12: Grassed area enjoyed by local walkers with flood defence wall to the left of the frame and unmown buffer strip to the right. The opportunity for at least some natural over-land flow during spate conditions (and the refuge habitat created by the unmown buffer strip) are ecologically valuable features that should be preserved. The extent and value of the buffer vegetation could be extended by encouraging the wildflower seedbank for a greater proportion of the bank (with a mown ride/path maintained for walkers).

Dredging that has been carried out in this section has removed much of what, otherwise, would be providing better in-stream habitat. This is confusing from a flood-damage-mitigation perspective. If the structure directly downstream is designed to slow the pace of water reaching the bridge below – then it appears counter-productive to try to increase conveyance within the section immediately above it which has floodplain storage available.

Similarly, although there is likely to be concern within the local community, the dredging directly underneath the A650 bypass bridge will continually be undone by the re-supply of substrate from upstream. There is an inherent overall channel form and capacity that will emerge naturally through redistribution of bed material at this point. Measures that attempt to remove too much of that material will significantly increase the demand for it from the upstream channel – which could have unpredictable destabilising results (example illustrated in scale model which has these exact processes operating in miniature here: https://youtu.be/OAZ_BuyM41s).

The more cost-effective solution at this location would be periodic management of any vegetation that became established on the deposited material if it began to pose a threat to the stability of the bridge under spate conditions. There may be a degree of natural control on vegetation growth anyway - due to the shading beneath the bridge. Consequently, any interventions should be needed less frequently (and at a cheaper, less extensive scale) than the dredging which accelerates the demand and replacement of existing material.

Figure 13: Recent dredging has been replaced with gravel and cobbles under the A650 bridge. This is an inevitable consequence on a steep, rain-fed river. As well as the position on a bend (where deposition is favoured on the inside of that bend) it is common to find that the riverbed beneath large bridges has been levelled artificially. This produces a break in the natural longitudinal bed-slope of the river – and the flat "pan" which results acts as a natural sediment trap.

Unfortunately, the larger substrate/boulder habitat removed from the reach below the bridge and pictured in Figs. 11 and 12 is generally too large to be replaced by natural erosion and deposition in the near future.

The boulder and cobble substrate directly upstream of the A650 bridge - combined with relatively steep gradient - creates variation in current pace and depth at different points over the channel cross-section. There is a general lack of trailing, overhead and partially submerged brash or vegetation cover. However, this is partially mitigated by the presence of a variety of cobbles and boulders that break up the flow and also create some "bolt holes" in the form of gaps between their undersides and the river bed (Fig. 14). In the background of Fig. 14, the gradually-collapsing weir at SE 07216 41705 is visible.

While the crest of the weir was still intact (and despite technical difficulties with stabilising stone on steep, smooth substrate in powerful flows), the older "rock-ramp" structures designed to ease fish passage (Fig. 16, left of frame) would have been an important measure to limit (but not erase) the negative effects of this "impoundment".

Water is said to be impounded when it is held back by a dam which artificially raises the surface water-level and creates a stilled "pond" of water on its upstream side. This also interrupts the downstream transport of riverbed material which is vital for the formation of high quality habitat.

Figure 14: Unimpounded and higher quality habitat downstream of the collapsing weir (background) compared to the impounded section upstream (Fig. 15).

In fact it is likely that, overall, the most damaging effects of impounding structures are the impacts on water flow and substrate transport. Of course, the significance of barriers to migration should not be ignored. At the same time, the ecological damage resulting from impoundments (particularly when they occur in a series of structures within the same watercourse) is not as widely discussed nor addressed when compared to engineered fish pass installation. Although extremely valuable when no other alternative exists, there are significant limitations with engineered fish pass structures. Major limitations include:

- They do not improve river habitat upstream of the impounding structure (nor do they re-establish the natural transport of bed material)
- They can never be 100% efficient for any one species (and their effectiveness for different species will always vary – what suits one species does not suit all species)
- They do not meaningfully improve downstream migration of young fish (which negates any benefits to enabling adult fish to travel upstream to spawn)
- The continued existence of impounded reaches of river significantly increases mortality due to predation (notably for downstream-migrating "smolts" of marine-migratory species of salmonid fish).

It is easy to assume that having a fish pass fitted to a weir takes away the negative impacts of that weir. In reality, a fish pass is a least-worst mitigating factor – though in some cases they may enable a critical minimum benefit which is just sufficient to allow viable populations of fish to exist. More detailed information on this subject is available via the open-access publication on the following link: http://onlinelibrary.wiley.com/doi/10.1111/faf.12258/full

Figure 15: The impounding effect of the weir at SE07216 41705 is reducing as the weir gradually collapses. Habitat in the upstream reach is beginning to improve (note the deposited cobble "point bar" towards the upper, middle part of the frame on the RB).

Although there is still an impounding effect evident, the collapsing weir (Figs. 15 and 16) is now enabling some recovery to the upstream habitat. The longitudinal slope of the riverbed will gradually re-grade while the increase in erosion and deposition processes in the previously-impounded reach create more varied habitat.

Figure 16: The wooden boards indicate the previous height of the weir crest. Note the brash accumulation at what was previously the entrance to the rock-ramp fish pass on the LB (left of frame).

Further upstream at SE 07060 41491 the straightened-nature of the river is visible downstream (Fig. 17) and upstream (Fig. 18) of the road bridge on Dalton Lane.

Figure 17: Facing downstream, the high-vertical walls constrain the river to accommodate surrounding development. The high gradient of the river (which is amplified, by straightening since the same vertical change in elevation occurs over a shorter path-length) and development of marginal vegetation help to create slightly more varied habitat than would occur in impounded reaches. The effective increase in gradient by straightening (in an already steep catchment) is one of the factors contributing to the difficulty in managing flood risks at downstream bottlenecks.

Figure 18: Although facing into the sun, it is possible to see the straightened and constrained character of the river.

The bridge, high walls, steep gradient and straightened nature inevitably create a flood risk scenario that is difficult to manage at this location. The hydraulic limit imposed by the bridge and the straight, steep channel, with walls that increase the bank-full depth to a level above the floodplain all combine to produce hazardous conditions during high spate flows.

It is almost impossible to build effective "hard" flood defences at this bottleneck (and downstream to the next pinch-point). The extreme rainfall events that are predicted to become more frequent with climate change are likely to overwhelm current defences more frequently than local communities would find acceptable.

The pace and power of the water – and the speed with which the floodwater will be conveyed into the existing pinch-points are too much to be realistically managed by building higher flood-defence walls. At the same time, the in-stream conditions also limit the development of varied habitat through deposition of gravels and finer substrate which would occur in a more naturally meandering channel.

Consequently, there is a huge opportunity to increase the effectiveness of existing hard defences – while at the same time also increasing the potential to accrue benefits from wider ecosystem goods and services. The use of what are often termed "natural flood risk management" technique

The Dalton Mill buildings make channel access more difficult in the section directly upstream of the bridge on Dalton Lane. However, access at SE 06959 412 directly upstream of the mill revealed a shallow point-bar depositional feature within the straightened channel (Fig.19) and mid-channel bar formation associated with (coppiced) mid-channel trees (Fig. 20).

Figure 19: Photo facing downstream at SE 06959 41266. The point bar on the RB (right of frame) is supporting some marginal vegetation growth – which in turn helps to consolidate the depositional feature. This also creates an increase in depth towards the LB (left of frame) by encouraging bed-scour. The result is at least a limited degree of meandering flow within this straightened/walled section of river.

The straightening of the channel (in combination with banks that are defined by stonework) is limiting the potential for meandering flow and depth-variation across the channel. Nevertheless, some geomorphological processes can still act to produce a limited amount of variation in depth and velocity throughout the cross-section. Tree roots – whether growing in the margins or the centre of the channel – act to retain more bed material and cause the localised formation of depositional features (Fig. 20).

Figure 20: Flow being split to the left and right of the channel, while the tree-roots also favour deposition of substrate in the water that is slowed in the lee of those roots down the centre of this reach. This central ridge, with deeper and/or faster-flowing water on either side, is an excellent example of trees generating much more physical variety in river channels.

Figure 21: Streamy, cobbled run at SE 06907 41204 (reported to be favoured by the local dippers).

With one spotted on the day, the reports of this section being very good for dipper sightings are clearly well-founded. The shallow, streamy water and cobbles/small boulders that dot the channel look to be ideal habitat for a variety of aquatic invertebrates. The depth and pace of water, along with multiple fishing perches on rocks, are very typical of the feeding grounds favoured by dipper. Again, the very straight nature of the channel means that it is advisable to explore opportunities to re-introduce a degree of meandering flow.

Stands of Japanese knotweed (invasive, non-native species) were noted from the bridge at SE 06817 41153 (Fig. 22). Each plant has a root system that can spread over approximately a seven-metre radius. Additionally, the plants and their roots are adapted to growing in volcanic rock within their native range. Because of these characteristics Japanese knotweed can cause significant damage to walls and foundations. It is also associated with reduced native floral and faunal diversity due to its aggressive competitive ability which eventually ousts almost all growth of native plant species. In turn, the fauna that depends on those native plant species are also lost from areas infested with Japanese knotweed.

Figure 22: Japanese knotweed on the LB (right of frame). In common with all of the sections found in the developed reaches of the river, an artificially-straight channel is reducing some of the structural variety that would otherwise be naturally produced by substrate deposition and erosion.

Progressing upstream to a vantage point at SE 06641 41169 revealed an impounded, straightened and over-wide river (Fig. 23). This is reported to be very similar to the situation that previously existed upstream of the collapsing weir pictured in Fig. 16. Where weirs are large enough to produce a really extensive impounding effect, the dramatic simplification of the habitat is easy to see.

It is that simplification which is associated with excessive efficiency of mobile predators (in turn associated with fragile "boom and bust" dynamics for both prey and predator populations). Also, the homogenous conditions will favour a much less diverse range of species compared to physically varied habitat. These factors are compounded by the previously-highlighted problems with downstream salmonid fish migration and bed-material transport.

Figure 23: An extensive impounded reach photographed facing upstream at SE 06641 41169. Due to the overall high-gradient of the natural riverbed, a relatively large weir structure is probably responsible for such a large impounding impact.

The expectation that a substantial weir would be required to impound the length of channel shown in Fig. 23 appears to be supported judging by what is visible of a structure downstream (Fig. 24).

Figure 24: Continuation of impoundment downstream from photograph in Fig. 23. The crest of a large weir is just visible beneath the bridge towards the lower/centre of the frame in the far background of this picture (enlarged in the inset). The height-difference between the flat, reflective water at the crest and the more broken water below is substantial.

Continuing upstream to the bridge at SE 0637140877, a weir structure which seems to have been previously associated with an adjacent pond (now filled in) has been fitted with gauging instrumentation (Fig. 25). The glassy, powerful (and shallow) flow down the steep face of the weir will be completely impassable to most fish species under almost all conditions.

Figure 25: Weir fitted with gauges visible on the RB (left of frame). This installation is probably formally incorporated into EA river levels monitoring. To the right of the frame there appears to be a back-filled lagoon/mill pond which may have been altered to facilitate calibration of flow-gauging. The power of the laminar flow of water over the weir itself is a severe barrier to upstream fish migration.

There are precedents to refer to where fish-passage easements have been incorporated (with attendant re-calibration of gauging equipment). The WTT can offer some guidance on beginning to pursue that course of action as appropriate.

Upstream of the sections covered so far in the report, the channel modifications become at least somewhat less comprehensive. In other words, there is an increase in the potential for some natural processes to create better habitat.

Although the path of the river is still commonly influenced by stonework and tree-planting, the retaining walls are frequently much lower. In addition, the size and frequency of impounding structures decrease also. There are notably more riparian trees (Fig. 26) and even an example of a near-completely disintegrated weir. This latter example at SE 06224 40511 (Fig. 27) is extremely important in the context of allaying fears on the consequences of weir removal (and allowing weirs such as that in Fig. 16 to continue to return to a natural stream bed).

Figure 26: Still a modified channel, but some increased vegetation and bank-full depth that is closer to the level of the floodplain (though the channel is quite "incised" and generally lacks good connectivity to surrounding floodwater storage)

Figure 27: Probably the site of an old weir structure that has degraded over time or been demolished in the past.

The trees are generally present as a narrow, single file (i.e. Fig. 26) that line the banks and create a canopy of quite uniform height and density. A dual benefit to in-stream structural diversity and also light/shade regime could come from the installation of stable tree "kickers". This is where the crown of a coppiced tree is cabled securely to its own stump and allowed to swing in-line with the current against the riverbank. This produces the same valuable refuge habitat that is created by natural dead-fall of trees into rivers. However, there is an advantage in being able to reliably anchor that woody material so as to avoid increased risk of debris blocking structures downstream. It also helps to offset both the general reduction in natural tree-cover in many rivers systems – as well as the tendency for fallen wood to be removed from channels when it does arise naturally. Section 3 (Recommendations) includes more information on this simple and cost-effective intervention.

There are multiple opportunities throughout the reaches upstream of the gauging weir pictured in Fig. 25. A typical example of these opportunities is given in Fig. 28. Installing a scattered arrangement of tree kickers throughout the reach would be a low-cost and low-tech improvement to the habitat.

Figure 28: Opportunities for tree kickers to increase structural and light-regime variation at SE 06133 40376.

There are also examples of naturally-arising variety in cross-sectional depth and current velocity. These create a wider variety of niche habitats, which in turn provides opportunities for a wider range of species. The deposition of a cobble "point bar" at SE 06025 40213 is an excellent example of this (Fig. 29). These features naturally form at – and in fact fundamentally create – the inside edges of natural meanders. The deposition of material in this way can, in some cases (i.e. the Sheffield Don tributaries following the 2007 floods), cause concern where any material is seen as a potential blockage to the conveyance of floodwater. However, just as with the removal of material deposited in the flat "pan" below the A650 road bridge, the removal of such material actually accelerates the demand for its replacement with material derived from upstream.

Figure 29: Cobble, gravel and small boulder "point bar" depositional feature creating varied depth and current speed over the cross-section of the channel at SE 06025 40213.

At the upstream limit of the visit undertaken for this report (SE06009 40209), the view upstream from a small road bridge revealed a wider "buffer strip" of woodland (Fig. 30). However, a small weir is also reported to be present just upstream of what could easily be seen during the visit.

As well as the opportunities to introduce a little more structural variety into the watercourse (through hinging or "laying" of saplings in the manner of hedge-laying, as well as tree-kickers where appropriate), there would be great value in exploring the potential to remove the weir from that section. The re-connection of breeding populations that are currently separated by this barrier and the re-establishment of natural bed-transport are both significant ecological benefits.

At the same time, as a larger goal, it is likely to be crucial for the effective flood-risk management in Keighley to explore any and all opportunities to increase lateral (floodplain) connectivity (as shown in the Holnicote video example earlier in this report) as well as intercepting flash-floodwater in the very headwater sections of the Worth system. This short videos explain the importance of intercepting and increasing the infiltration of rainfall in protecting downstream developments from flooding: https://youtu.be/00tcTY_UEk4.

The issues of the unavoidable bottlenecks created by the historic development of the river corridor and floodplain in its lower reaches make it essential to explore upstream and natural flood risk management measures. The sophisticated approaches taken for Hebden Water are extremely relevant to the Worth in this respect: http://www.treesponsibility.com/the-source/understanding-hebden-water-catchment/

Figure 30: Upstream limit - more extensive riparian woodland and varied geomorphology.

Adopting a combined approach of traditional and natural flood defences would provide multiple benefits for Keighley and its rivers. Setting back flood walls where possible within developments could even lead to the creation of floodwater storage capacity within developed (or perhaps previously unconsidered) areas. A prominent example in Sheffield is the creation of an amphitheatre-shaped pocket park that can now provide floodwater storage in the city centre (as well as being a valuable green space): https://youtu.be/oexE1N4WwvU.

3. Recommendations

A brief summary of recommended actions would be to:

- Produce and share materials (and consider the creation of interpretative signage) to de-mystify, reduce apprehension to, and explain the benefits of weir degradation/weir removal in terms of BOTH habitat creation and perceived flood risk. Only after highlighting those issues should fish passage be introduced as an accompanying benefit.
- Consider guided walks on this topic – linked to wildlife-spotting and activities such as Riverfly sampling.

- Push for the notching/removal of as many impounding structures on the River Worth as possible.
- Discuss options with the Environment Agency with respect to the gauging weir(s) on the Worth – with emphasis on opportunities for removal, bypassing or (as a last resort) instalment of easement structures that can be accounted for by recalibrating the monitoring gauges.
- With guidance from the WTT, undertake a light-touch installation programme for tree kickers where suitable opportunities exist (after obtaining all relevant permissions). An example video explaining the method and effects can be viewed here: https://vimeo.com/72720550.
- With guidance from the WTT, undertake scattered and light-touch laying of saplings into river margins to create refuge habitat which is essential for over-winter survival, shelter from spate flows and balanced predator/prey interactions. Both laying of saplings and installation of tree kickers would also contribute to the reclamation of at least some meandering flow within the straightened channel. It would also help to diversify the range of riverbed particle-sizes that are retained during spate flows.
- Explore opportunities to link up with regional invasive plant species control initiatives as a means of reducing and controlling Japanese knotweed infestations (e.g. Yorkshire Wildlife Trust invasive species forum: http://www.ywt.org.uk/what-we-do/creating-living-landscapes-and-living-seas/west/yorkshire-invasive-species-forum and Aire Rivers Trust Invasive Non-Native Species interests https://aireriverstrust.org.uk/category/inns/)
- Explore the potential for replacing the presumed hydro-brake, gabion structure with a robustly-constructed "rubble mat" or "rock ramp".
- Liase with local and regional planning authorities to push for the adoption of "upstream thinking" and natural flood-risk management through interventions and land-use changes in the headwaters of the Worth. See Pont Bren study outcomes for examples of effective practices, https://www.woodlandtrust.org.uk/publications/2013/02/the-pontbren-project/ along with the relatively local and physically closely-comparable Hebden Water case study material: http://www.treesponsibility.com/the-source/understanding-hebden-water-catchment/).
- Seek opportunities to increase lateral connection of the river to areas of its floodplain which can safely be inundated with floodwater during spates (to provide protection to premises and housing-equivalents at the bottlenecks downstream). For example, Sheffield and Rotherham's Centenary Riverside Park has multiple pond and wetland habitats that are directly connected to the adjacent River Don by means of large-diameter buried pipes: http://www.wildsheffield.com/reserves/centenary-riverside. The site was previously a huge steel foundry.
- Where possible, look for ecological benefits associated with increased lateral connectivity (opportunities to create wetlands/wet woodland that are connected to the river – or simply the inclusion of leaky debris dams that also improve in-channel habitat).
- Supportive planting of trees (and potentially understory species) could be beneficial at any available sites throughout the river corridor. This applies whether in the upper reaches as part of flood risk mitigation or lower down to increase biodiversity and to maximise ecosystem goods and services provision. Examples of societal benefits (in addition to wellbeing engendered by access to green space) include passive cooling, air pollution

absorption and as a resource for pollinating insects away from intensive agro-chemicals application.

Although assistance from the Wild Trout Trust is in high demand, it may also be possible to provide support in setting up and helping to deliver the habitat work aspects of the above suggestions. Maintaining a dialogue with our Conservation Officers is the easiest way to progress with assisted practical work and training. In the specific case of the Worth – the Trout in The Town programme manager can draw on experience in many post-industrial rain-fed urban rivers – along with Prof. John Grey's ongoing projects on the wider Aire catchment. In combination, this provides a highly relevant resource for protecting and improving the River Worth.

A more detailed project proposal could be produced once an overall plan of action is settled upon through discussions with local stakeholders – including relevant riparian owners. There would appear to be a natural role for Keighley "Big Local" to be central to that process.

4. Acknowledgement

The WTT thanks the Environment Agency for supporting the advisory and practical visit programmes (through which a proportion of this work has been funded) in part through rod-licence funding.

5. Disclaimer

This report is produced for guidance and not for specific advice; no liability or responsibility for any loss or damage can be accepted by the Wild Trout Trust as a result of any other person, company or organisation acting, or refraining from acting, upon guidance made in this report.