Water Framework Directive Advisory Visit

Bradford Beck

24-10-2012
Introduction

This report is the output of a site visit undertaken by Paul Gaskell of the Wild Trout Trust to the Bradford Beck in Bradford, West Yorkshire on October 24th, 2012. Comments in this report are based on observations on the day of the site visit and discussions with Kevin Sunderland who kindly hosted the walkover survey on behalf of the Bradford Beck restoration project (http://bradfordbeck.blogspot.co.uk/) and Aire Rivers Trust.

Normal convention is applied throughout the report with respect to bank identification, i.e. the banks are designated left hand bank (LHB) or right hand bank (RHB) whilst looking downstream.

1.0 Catchment / Fishery Overview

The Bradford Beck is captured as a single waterbody (reference number: GB104027062860, national grid reference SE 11013 33390) under the Water Framework Directive (WFD) river basin management plans. It is classified as a heavily modified waterbody and is currently assessed as having “poor” ecological potential. Notable categories responsible for this designation are both invertebrate survey scores (poor) as well as quality and dynamics of flow that do not support “good” status. Excerpts of the Bradford Beck supporting information for the WFD classification are collated over the page (Fig.1).

In addition to the WFD classification datasets, the Beck has been observed to be subjected to higher loadings of suspended solids relative to other similar streams during high flows (http://www.whatdotheyknow.com/request/73801/response/179972/attach/3/FOI%20Request%20Mr%20Grook.pdf) and the general, intermittent polluting impact of the numerous Combined Sewer Outfalls (CSOs) are also noted – although these are apparently not well captured by the available WFD water sampling regime. Furthermore, the Beck enjoys some notoriety for the extensive network of underground passages through which it flows beneath the city of Bradford (http://environment.nationalgeographic.co.uk/environment/photos/underground-rivers/#/environment-underground-rivers-bradford-beck-england_46396_600x450.jpg and http://www.urbanghostsmedia.com/2012/05/subterranean-britain-the-tunnels-of-the-bradford-beck/)
Where modifications to the channel are less drastic, the Beck displays typical characteristics of an upland stream - i.e. a cobble and boulder-strewn river bed subjected to lateral scour and depositional processes. However, the extensive proportion of the total channel network that is forced underground (and the inclusion of an underground flood-relief channel) highlights the very extreme nature of the term “heavily modified” as it applies to the Bradford Beck.
Beck. Figure 2 indicates the proportions of “open” and “subterranean” channel between the principle headwaters on the Pennine Hills (the Pinch Beck and the Pitty Beck in the lower left corner of the frame) and its confluence with the main river Aire (circled in red).

Figure 2: Open (blue) sections of channel versus underground sections of the main channel (thick black line) and underground flood relief tunnel (thick yellow line) of the Bradford Beck. Confluence with river Aire circled in red. Total length of the Beck is approximately 10 miles

2.0 Habitat Assessment

The Beck was surveyed at a number of typical sites from a downstream to upstream direction – beginning with its confluence with the River Aire (photographed from national grid reference SE 15110 37978, Fig. 3) and culminating with examinations of sites on the Pinch Beck and Pitty Beck. An
adult trout was observed in the lower (heavily urbanised) reaches during the site visit – and Kevin Sunderland has sighted good numbers of fish in certain sections during the summer of 2012.

The Baildon Bridge weir on the main river adjacent to the confluence with the Bradford Beck is a prime candidate for easement of fish-passage and such improvements in connectivity would be a significant boon to “metapopulation” dynamics of fish populations. In other words, the freedom to move between high quality areas of habitat would benefit the viability and stability of fish populations throughout the whole system – including the Bradford Beck. When one part of the system may be suffering impacts, the potential for emigration to alternative habitat and post-impact immigration/recolonisation facilitates resilience and recovery.

Figure 3: Baildon Bridge weir on the River Aire - with the Bradford Beck joining towards the centre/left of the frame (left of the dark brown-walled industrial premises)

The Beck, just before it discharges into the main river, shows typical characteristics of a mature post-industrial Pennine river corridor, with high (millstone grit) retaining walls and a jumble of large block-stone boulders (probably arising from degradation of walls and other stone structures within the channel). The milky tinge to the water is perhaps indicative of fine
particulate mineral suspension that is typically derived from urban surface water drainage. This may also be compounding the previously-mentioned particulate loadings that are likely to include contributions from “non-surface water” components of the combined sewer outfall discharges. As well as any chemical pollutants that may be associated with such particulate material – there will be a simple physical impact of such particulate material whether in suspension (e.g. interference with gill function) or when deposited on the stream bed (e.g. homogenisation of microhabitat or reduced intra-gravel oxygen supply that is vital for trout eggs as well as many invertebrates).

Irrespective of any chemical pollutant effects, there will be a degree of purely physical impact that may range from positive/relatively benign through to potentially lethal depending on the organism in question. Quite a lot is known, for example, with respect to the physical sediment-tolerance traits of stream-dwelling invertebrates. Examining the proportion of sediment-tolerant versus sediment-intolerant invertebrates may be very instructive in diagnosing some of the driving forces behind the “poor” invertebrate diversity scores recorded by the Environment Agency (EA). This may be particularly helpful if combined with more standard indices of organic pollution tolerance (i.e. Biological Monitoring Working Party/BMWP or Average Score Per Taxa/ASPT scores):

Figure 4: Bradford Beck channel at SE 15097 37892; just upstream of its confluence with the River Aire
Although all watercourses naturally contain a proportion of fine and coarse sediments – healthy watercourses are able to redistribute particulate material such that a wide variety of microhabitats are formed. Typically, fine sediments are redistributed away from the central/fastest flowing areas and collect where the flow is slowed (e.g. by frictional forces acting in the margins or around river-bed obstructions – or ultimately in wide, estuarine deltas). The extent to which the full-width of the stream bed (including surfaces of boulders) carries a coating of fine sediment may indicate some or all of the following:

- A generally higher than normal supply of such sediments (indicated by studies of suspended sediment loadings during spate flows) into the watercourse
- Nutrient enrichment that may promote the formation of “sticky” microbial growth on substrate
- A channel cross section that has been artificially enlarged to the extent that scouring flows are prevented or artificial impounding of the flow by structures such as weirs (i.e. fine sediment falls out of suspension).

In the case of the Bradford Beck, there does not seem to be a shortage of strong “bed-shear” velocities (i.e. powerful current flows) that should normally help to re-distribute over-supply of fine sediments (see Fig. 7 for rationale). Conversely, the former two conditions should not be ruled out.

Another major specific constraint to the viability of stable trout populations are the multiple, relatively small, barriers to migration. A good example exists at SE 15128 37627 (Fig. 5). Unfortunately, whilst such structures can look relatively innocuous, they represent a serious barrier to many fish – including trout of breeding age. The lack of depth available to enable swimming that persists over the wide flat apron makes progress either impossible or highly dangerous and exhausting. Efforts to identify and tackle key barriers (i.e. those that separate habitat suitable for adult fish from spawning and “nursery” habitat) will be well spent if the goal is to restore healthy populations of fish such as brown trout and grayling.

There are a variety of options for improving fish passage that range from a few hundred pounds up to several hundred thousand pounds – depending on the scenario and local considerations. Consequently, each barrier must be
considered on a case-by-case basis; another reason for prioritising key structures based on existing habitat resources.

![Image of shallow, laminar-flow over flat concrete apron (bridge invert).](image)

Figure 5: Shallow, laminar-flow over flat concrete apron (bridge invert). Although low in height, the shallow flow represents a serious barrier to most fish species. As witnessed by Kevin Sunderland, this type of structure may be passable to minnows, but the vast majority of adult trout would find this barrier impassable at base flow in its current condition.

Section 3 (Recommendations) outlines potential options for fish passage easement, including removal of impounding structures that are likely to have additional beneficial effects on the quality of the habitat via improvements to geomorphology.

Whilst the sight of some fish successfully ascending a potential barrier can be encouraging – the fact that such attempts are visible can indicate a problem (i.e. jumping fish indicate that free passage is not available at that point). It is important to consider the cumulative effects of these obstacles – even when some fish are seen ascending them. There are additional costs over and above the potential physical damage or draining of energy reserves that are incurred by the fish that actually get over a barrier. For example, simple calculations of how many fish fail to ascend a barrier are a great illustration of the cumulative impact effect. Some work done by Dr. Ed Shaw in conjunction with Prof. Lerner (currently with the Bradford Beck restoration project) and Eckart Lange at the Catchment Science Centre at the University of Sheffield graphically illustrates the problem - even when more than 9 out of 10 fish successfully ascend each weir (Fig. 6). For many of the typical
barriers that are present on the Bradford Beck, the proportion of successful fish ascents will be much less than 5 out of 10; and in fact will quite realistically often be less than 1 out of every 10 fish making the attempt. Additionally, the delays incurred also significantly increase the proportion of fish that are taken by predators.

Although trout have a tendency to seek access to small tributaries for spawning, they can also spawn in the larger tributaries and main-river channels (providing suitable habitat exists). Provision for passage at key locations that enable adult fish to access suitable spawning habitat can, therefore, be augmented with creating additional spawning habitat in the main river channel. Of course, there may be natural constraints that prevent such habitat creation in particular locations – so a combined strategy of improving connectivity and seeking appropriate/feasible habitat creation is recommended.

Figure 6: The cumulative impact of barriers that prove impassable to a proportion of fish is clear – even when over 90% of fish can successfully ascend each barrier (e.g. with a highly-efficient and well-maintained fish pass in place). The realistic figures of far less than 50% of fish successfully ascending – such that the majority of fish cannot ascend each individual barrier – obviously has a much more serious implication for the numbers of breeding fish that need to reach spawning habitat upstream of the barriers in place on a river system.
The high retaining walls typical of the above-ground, urban sections of the Bradford Beck have an influence on geomorphological processes (patterns of erosion and deposition) acting on the Beck. When considering all river types, such effects fall into three main categories:

- The channel is made to be wider and/or deeper than the natural channel - causing much slower and more uniform flows
- The defined channel is much straighter than that which would naturally occur – causing a reduction in pool frequency and reducing overall structural variety
- The channel is not connected to its flood-plain and the walls are high and vertical - so that when increased volumetric discharge is experienced under spate flows – extremely high velocities are generated.

In contrast to many lowland rivers that may have a combination of lower longitudinal bed-slope and/or lower volumetric discharge, the Bradford Beck can, to a degree, overcome the first of these three impact categories. Its steep bed-slope and periodically high volumetric discharge allows for the recreation of some geomorphological features within the channel. The deposition of sloping “point bars” of cobble and boulder substrate – leading to the lateral scour pool formation pictured in Fig.7 – has resulted from flow conditions that were sufficiently energetic to bring about significant river-bed redistribution.

Conversely the combination of the latter two categories of the effects of straightened, high-walled channels have tended to result in few pools and very little retention of gravels that would provide any potential for spawning. In fact, the scour pools that are present tend to form when the river is forced to turn a corner or at the foot of weir structures. These latter pools are, of course, accompanied by poor-quality, impounded habitat upstream of each weir structure. A major effect of impoundment is that it tends to reduce the frequency that pool and riffle sequences can form within the channel.

Although a few, small gravel “shoulders” were deposited in the lee of boulders protruding from the stream bed, these only amounted to a very limited opportunity for main-river spawning.
Figure 7: Point bar formation on the LHB (right of frame) generating some nice variety in depth and flow. The impressively large substrate size (small boulders) is an indication of the huge spate flows that must periodically occur within the Bradford Beck’s in high-walled sections. In some sections, the “strand line” of trash can be over 10ft above the height of the river at normal flow. Despite this, a coating of fine sediment is still present in many of the reaches that obviously experience these massive flow velocities.

A major challenge for restoration of such features will be retaining spawning gravel substrate within the urbanised reaches (i.e. particles in the 10 to 50-mm/0.4 to 2-in diameter range). This issue is discussed further in section 3 (Recommendations).

The comments applicable to migration barriers, impoundments and impacts of channel straightening/walled sections will, of course, apply equally to all similar reaches (e.g. those found around the gauging weir at SE 15129 37500; Fig.8). Additionally, weirs that are used for gauging purposes already have a precedent for using calibrations to account for fish-passage-easement structures (e.g. Graham Peirson of the E.A. using a low cost baffle pass on a gauging weir to pass coarse fish).
Another component of habitat that was often only present in limited quantities within the walled and urbanised sections of habitat (e.g. the short above ground section at SE 15871 32998; Fig.9) was the dense cover provided by such elements as submerged tree roots, trailing branches or similar debris matrices. The intermittent high flow velocities may, in part, be responsible – as retention of such features may prove challenging. However, provision of stable examples of such cover can provide vital calm spots within spate flows that provide valuable refuge for fish (especially juveniles). Such calm-water refugia help fish to avoid being swept away downstream over barriers that are impossible to re-ascend. The same cover during normal water flow also provides:

- Vital protection for fish from predators
- Additional microhabitats for invertebrates
- A passive cooling effect of several degrees that may be vital for cold-water species such as trout and certain invertebrates during hot weather
Figure 9: The best example of the available submerged, marginal cover (far bank) within walled sections of the Beck. Other sections almost totally lacked any similar cover - and there would be value in creating greater provision within the reach pictured here. This would augment the nice “rubble mat” stream bed and flow depth/pace favoured by juvenile trout – providing there is connectivity to spawning habitat nearby.

Much higher quality habitat is also present on the Bradford Beck, for example the sections at SE 15072 37397 (Fig. 10) and SE 14308 33222 (Fig. 11)

Figure 10: Example of higher quality and more varied habitat at SE15072 37397. However, due to the straightening of the channel, gravel at tail end of pool/head of riffle is not well-retained and is consequently of poor quality and quantity. The section would benefit from restoration measures.
Having a variety of mature trees, shrubs and herbaceous vegetation exerts a profound influence on the opportunities for fish refuge areas, structural habitat complexity and inputs of both leaf material and terrestrial invertebrates to the stream. These latter two elements contribute significantly to both invertebrate and vertebrate components of the aquatic food web. Whilst it is possible to have “too much of a good thing” and variety is always to be sought, in the context of the Bradford Beck, these wild, overgrown sections offer highly valuable alternative niche opportunities compared to the more heavily modified sections.

For sections without high walls on both sides (e.g. Fig.10), it may be easier to promote the retention of spawning gravels due to the capacity for spate flows to be dissipated across a shallower flood plain. It is necessary to recognise the importance of the process of “sorting” (or grading) of spawning gravels if they are to support good trout-egg survival. This occurs naturally when structures such as fallen trees force a localised concentration of river flow downwards into the stream bed. The resultant scour-hole provides excellent adult habitat – but an important by-product is that the material arising from the hollow is deposited downstream of the scoured bed. Larger pieces of gravel are dropped where the focussed flow is still relatively fast. As the flow progressively dissipates and slows – gravel settles
out according to its particle size. Consequently, the irregular-shaped and ill-fitting pieces of gravel are formed into loose (silt-free) mounds of similar particle sizes. This loose mound is necessary for good intra-gravel flow of oxygenated stream water – and its attendant ability to prevent trout eggs from suffocating. If suitable structures that aid the retention of gravels can be installed, these could potentially be combined with deliberate introductions of flow deflectors that would promote localised bed-scour and gravel sorting. Section 3 (Recommendations) gives more detail.

Such natural stream bed processes are entirely absent from approximately a mile of the channel upstream of SE 15266 36496 (Fig.12). Instead a smooth red-brick drainage gulley carries the entire flow of the Beck. As well as lacking any viable habitat for most species of aquatic plants and animals, it would prove extremely difficult for fish to travel up the full length of this channel – due to its continual laminar flow. There are no “resting spots” within this sheet of uniformly flowing water – and consequently this part of the channel is a mile-long barrier between potential fish populations. Good adult fish habitat exists directly downstream of the section (Fig. 13)

![Figure 12: Brick-lined gulley carrying the flow of the Bradford Beck for approximately a mile](image-url)
The issue of connecting good spawning habitat to the rest of the system is perfectly exemplified by the situation at the weir at SE 13527 33127; Fig. 14 (where the Bradford Beck is known as the Middle Beck). Approximately 200 m upstream of this weir there is a small tributary (Bull Greave Beck) that is a rare example of potential trout-spawning habitat (Fig. 15). Clearly, the weir currently prevents adult fish further downstream in the system from gaining access to this vital habitat.

Figure 13: Good habitat (especially for adult trout) directly downstream of the discharge point of the brick-lined gulley at SE15266 36496

Figure 14: Impassable weir preventing access for fish in the main channel downstream of this point to potential spawning tributary 200 m upstream
Figure 15: Although subject to sediment inputs from livestock and general access crossing point - the fenced section upstream contained some potential spawning habitat that could be improved with minimal work. Such streams are often overlooked - but are where significant gains can be made in improving the viability of self-sustaining fish populations. This also highlights the benefits of appropriate fencing schemes.

In fact, further photographs provided by Kevin Sunderland following the site visit further indicate the value of this tributary, pending a relatively modest effort to improve some aspects. First of all, unlike many comparable tributaries on similar Pennine rivers, there is no barrier at the confluence of the Bull Greave Beck with the Middle (Bradford) Beck; Fig. 16.

Figure 16: Confluence of Bull Greave Beck (lower right) with Middle (Bradford) Beck
In addition, there are unlikely to be substantive concerns over flood risk associated with any habitat works – as there are already sizeable debris dams on the beck; Fig. 17

Similarly, any efforts to ensure that the culverted sections of Bull Greave Beck remain passable to fish will be extremely worthwhile. There is no apparent issue with fish gaining entry to the downstream end of the culvert pictured in Fig.18. However, there could be an opportunity to provide deeper, baffled flow that would aid upstream passage through the culvert and exit from the upstream end (Fig. 19). See section 3 (Recommendations) for further details.
Figure 18: Bull Greave Beck - downstream entrance to culverted section

Figure 19: Upstream end of culvert that may cause some difficulties for fish exiting in an upstream direction (i.e. towards the camera)

With respect to the two major headwater tributaries (the Pinch Beck and the Pitty Beck), E.A. electric fishing surveys have recorded adult trout captures up to around 14” in length (e.g. on the Pitty Beck at Fig. 20).
Figure 20: Pitty Beck scour pool formed on the outside of a bend and at the base of the stone wall in a section of engineered channel that benefits from good riparian woodland habitat and in-channel redistribution of bed material during spate flows.

However, there are further opportunities to improve conditions in these vital areas of trout recruitment that can aid the re-colonisation of downstream sections of the Bradford Beck. There are large inputs of both sediment and associated nutrients due to unrestricted livestock grazing and trampling of the banks (Fig. 21) as well as poorly-designed crossing points (Figs. 22-23).

Figure 21: Livestock overgrazing and trampling of Pitty Beck photographed by Kevin Sunderland; a significant source of sediment and nutrients to the watercourse
There is also what is believed to be a CSO discharging into some high quality habitat on the Pitty Beck (Fig. 24), the site of which may be suitable (at least physically) for reedbed/artificial wetland treatment to be installed. If pursued, great care should be taken to avoid the impoundment and fish-passage issues evident on the urban reed-bed scheme at Chellow Dene (also on the Bradford Beck system); Fig. 25. Whilst delivering undoubted water quality benefits, connectivity is not well catered for in that particular scheme. However, in the case of the CSO discharge into the Pitty Beck,
there would be no need to divert the main flow of the river through a created reed-bed. A far simpler design would involve breaking the outflow pipe along its length for some distance back from its current discharge point. The wetland could then be developed in the region of broken pipe so that the clean effluent discharges into the river.

Figure 24: CSO on good quality habitat on Pitty Beck (photographed by Kevin Sunderland)

Figure 25: Entrance to reedbed (centre and right of frame) created to improve water quality on the Chellow Dene Beck (flowing out to the bottom right corner of frame) at SE 13349 33702. The controlling (weir) structure that diverts flow through the reedbed would be an impassable barrier for fish attempting to migrate upstream. This weir would be easily tackled by a simple rock pile/rock ramp easement or a small pool pass (pre-barrage).
3.0 Recommendations

Significant improvements to the Bradford Beck will depend on three main areas of action:

1. Green infrastructure modifications that improve the quality/reduce the frequency of effluent discharges from CSOs – especially in the heavily urbanised/subterranean portions of the river

2. Improvement/creation of in-channel and riparian habitat in both urbanised and headwater components of the Bradford Beck system (including improved land-management around sensitive headwater streams)

3. Creating greatly improved connectivity between habitat that is suitable for the three key lifecycle stages of trout (and grayling):
   a. Spawning habitat
   b. Juvenile habitat
   c. Adult habitat

This habitat may already exist, or it may be possible to create patches of such habitat during a programme of works. Particular considerations exist when attempting daylighting (i.e. digging out of underground sections) in order to maximise the quality of the resulting habitat.

Concentrating on the latter two main areas of action (as the green infrastructure question is largely beyond the scope of this habitat advisory report), the following recommendations are made.

3.1 Habitat improvements

3.1.1 Existing open channel areas

Uniform areas of walled channel (e.g. Figs. 4 and 9) would benefit from additional in-channel structure and habitat variation. Refuge areas during spate flows should also be created. To this end, the secure attachment (i.e. 8-mm braided steel cable attached using expansion bolts to bed-rock or stable stonework) of coniferous brash would be a valuable addition to the habitat. An example of one such installation that has withstood multiple spate flow events between the winter of 2011- and winter 2012 on the South Yorkshire River Don is given in Fig. 26. Based on its success and
stability in an area sensitive to downstream flood risk, extension of the technique to provide additional marginal cover (Fig. 27) is now proposed on the Don system.

Figure 26: Trial coniferous brash bundle attached to rock anchor point using braided steel cable and expansion bolts

Figure 27: Proposed anchoring method for marginal brash to augment existing coniferous brash installation

Using anchor points on retaining walls may also reduce the need to survey for underground services (electricity, gas, sewerage, telecommunications)
that is imperative when driving pins into the stream-bed (often adopted in other methods of anchoring).

Spawning habitat improvement may be possible in some areas of walled channel – but it is recommended to make initial efforts at sites such as SE15072 37397 (Fig.10). Here it may be possible to create a gravel-retaining baffle – such as a modified “K-dam” type structure pinned to the streambed at the tail of an existing pool (Fig.28). Unlike a normal K-dam that has a single notch, placed centrally; a modified version could incorporate two relatively wide notches placed approximately at 1/3rd and 2/3rds of the way across the channel cross-section respectively. This type of design should promote accumulation/retention of a central mound of gravel with current seams running either side. The diagonal supporting “legs” of the K will prevent erosion of the banks downstream of such a placement.

Upstream of the K-dam structure, gravel with particles of diameters in the 10 – 60-mm range could be introduced in the downstream half of the existing pool. Introducing a bed of gravel around 300 mm deep would be a good benchmark. However, care must be taken to avoid creating another barrier so such introductions need to be carefully evaluated. To this end, the pool dimensions and features (such as sinuosity) that would retain gravel of the diameter that is suitable for spawning can be calculated. Recommended expert input should be sought from, for example, Richard Hey (contact details available via WTT). As a corollary, on sections of low gradient, it would be possible to predict when smothering with fine silt would occur.

The design brief for the creation of spawning riffles of the correct dimensions should incorporate the option to explore increased sinuosity as a means of aiding gravel retention. This could either augment, or in some cases replace, the need for K-dam type structures designed to aid gravel retention and formation of spawning-gravel mounds. An expert assessment of the potential for gravel supply via natural bank erosion (which is likely to be restricted by the straightening and armouring of the river channel) should also be made as part of this specialist consultation. This will inform on the requirement for localised importation of gravel – as well as identifying opportunities to improve natural gravel supply by re-instating natural geomorphological processes.

It would be important to include stable large-scale cover within and around this potential spawning pool – otherwise trout may not feel sufficiently safe
from predation to utilise the available gravels. Suitable forms of adult cover would include securely-anchored submerged woody debris (both in the margins and mid-channel), bushy overhanging vegetation (within 10 to 30 cm of the water surface at base flow) or secure marginal coniferous brash installations.

Figure 28: Schematic of K-dam to retain and shape mid-channel gravel bar for enhanced spawning. Note incorporation of cover for adult fish. K-dam logs pinned in place using 2-m lengths of 19-mm diameter steel reinforcing bar. Geotextile should be stapled to the upstream face of the cross-channel log and extend beneath introduced gravel for at least 5 m upstream (pinned to bed) to prevent under-cutting of the structure. A formal design for the pool dimensions should be sought from appropriate expert input (e.g. Richard Hey). A specific design may also include additional sinuosity (to aid gravel retention). Sinuosity could be produced by direct bank modification and/or installation of flow deflectors to both direct flow and (perhaps) selectively erode suitable bank areas.

For sections of headwaters that are impacted by excessive trampling and associated sediment/nutrient supply – cattle crossing or cattle drinking bays are recommended in conjunction with fencing off the river corridor; Fig. 29.
Figure 29: “Top-hung” hinged water gates (left) installed as a controlled access and crossing point and purpose-built drinking bays (right) to limit trampling and over-grazing impacts on the watercourse.

For areas hosting species of particular conservation value that require cattle-trampled banks (e.g. certain dragonflies and marsh plants), provision can be made for patches of this kind of habitat by the use of managed crossing points and drinking bays (or alternatively the wetland scrapes suggested below that may also be used to provide livestock watering). In order to maximise the biodiversity, a fenced-off buffer strip ideally >5m wide should, however, account for the majority of riparian habitat. This keeps the damaging sediment over-supply and over-grazing to a minimum (improving water quality and also providing opportunities for valuable herbaceous and woodland flora to develop). Access gates should be included within the fence-line in order that periodic light grazing or mowing can be carried out in order to maximise floral – and associated invertebrate and vertebrate faunal - diversity. Tree planting can also be carried out within the fenced buffer strip in order to promote both biodiversity and flood-risk benefits (via attenuation of surface water runoff). Such attenuation could also be enhanced by identifying areas suitable for flood-plain wetland scrape creation in order to provide additional flood-water storage upstream of the urbanised river reaches. **N.B.** a period of at least 3 to 5 years (depending on rate of vegetation growth) to allow herbaceous vegetation and trees to become well established before any grazing should be allowed.

As highlighted in Section 5 of the Upland Rivers Habitat Manual ([http://www.wildtrout.org/sites/default/files/library/uplands_section5.pdf](http://www.wildtrout.org/sites/default/files/library/uplands_section5.pdf)), the correct siting of water gates and drinking bays is vital (Fig. 30). Incorrect positioning of such structures is a waste of valuable time and resources. If placed on the inside of river-bends, sediment deposition tends to “maroon”
the drinking bay on dry land. Conversely, the higher erosive forces acting on the outside of river bends can undercut or destroy drinking bays – or may even lead to a radical change in the course of the river in extreme cases.

![Diagram of correct and incorrect positioning of drinking bays]

Figure 30: Correct and incorrect positioning of drinking bays

The headwater streams and potential spawning tributaries may also benefit from channel dimension modification to promote supply and retention of gravels in the 10 to 60-mm diameter range. This should be combined with stable woody debris introduction (to promote gravel-sorting) in order to maximise spawning opportunities.

3.1.2 Daylighted sections

A unique and vital opportunity for high quality river habitat creation exists when excavating buried channels. It is important, as a minimum, to provide sufficient lateral space for the channel to adopt a naturally meandering path.
wherever possible. As well as providing a greater variety of microhabitat niches for all flora and fauna, a meandering channel will also tend to have better retention of the spawning gravel substrate that is in such short supply throughout the main river system. Provision for appropriate pool and riffle sequence formation (via localised bed scour and depositional processes) is an equally important consideration. The primary alternative approaches to achieving these aims are:

- Generating a healthy riparian corridor of mixed herbaceous and woodland species and providing sufficient scope for the beck to meander naturally (with any required flood defences set back from this corridor)

- A more formally designed channel to be dug according to precise calculations that work with available space

Both of the approaches would require securely-anchored woody debris structure to promote bed scour and depositional processes as well as cover for adult and juvenile fish. It should also be borne in mind that with the more precise designed option, unpredictability in natural systems can be very difficult to account for. The natural flow dynamics may well alter (or in extreme cases bypass) features that are intended to be permanent. Where sufficient space can be won to allow natural channel meandering processes to occur, the greatest benefits to biodiversity are conferred. It is also likely to provide better opportunities for spreading and managing peak flow events to minimise flood risk. See the great work of the Quaggy Waterways Action group on the restored section of the Quaggy in Chinbrook Meadows (bottom of the page on this link: [http://www.qwag.org.uk/quaggy/q_natural.php](http://www.qwag.org.uk/quaggy/q_natural.php))

3.2 Connectivity improvements

3.2.1 Culverts

For sections of cylindrical culverts (e.g. Fig. 19) the best option (where removal is impractical) would be replacement by “box” culverting of greater width and cross-section – ensuring that the base of the box culvert was sunk sufficiently deeply into the ground (ideally 60 cm or 1/3 of its depth) so as to allow a natural stream bed to develop and persist within that base. A cheaper and less radical option that would still convey important benefits to connectivity would be installation of baffles in the base of the existing
culvert. Where debris accumulation is of a particular concern, baffles can include sloping upstream “shoulders” to combat this (Fig. 31).

Figure 31: Wooden baffles in the base of a cylindrical culvert section that include a resin “shoulder” on the upstream side to prevent debris accumulation whilst still promoting greater water depth and baffled water flow

3.2.2 Weirs

Wherever possible, the best environmental outcome will invariably arise from removal of impounding structures. This could range from partial to complete removal. As a minimum, partial removal could involve cutting a notch into the structure in combination with a formal fish pass – or a fish passage easement. A more extensive (but still incomplete) removal could be taking out a substantial proportion of the weir. This could be undertaken for several reasons including (but not limited to):

- Preserving the propensity for mid-channel island formation (a rare habitat type) downstream of the impounding structure
- Limitation of erosive forces upstream of the structure
- Showcasing of construction techniques for weirs with heritage value

Reducing or removing the impounding effect of weirs allows a much greater diversity of habitat to form upstream of the weir site (in the previously impounded reach). This promotes greater microhabitat diversity for aquatic flora and fauna of all types. It also tends to expose a greater width of riverbank that can subsequently become colonised by a variety of terrestrial animals and plants – including trees that can convey significant climate
moderation and pollutant-sequestration benefits. A fantastic precedent for pragmatic and cost-effective weir removals (on the River Irwell system) can be found in the partnership project between the North West region E.A. and the Irwell Rivers Trust. This project was the runner up in the professional category for the 2012 Wild Trout Trust/Orvis conservation awards and has achieved the removal of some 15 weirs between 2011 and 2012 for a cost of only £180,000.

There is no fish pass that is as effective as the absence of a barrier. However, in cases where removal of an impounding structure is not achievable, it is often possible to bring about the “least-worse” case in terms of accessibility for fish. Due to the unique circumstances surrounding every barrier, it is strongly recommended that expert advice is sought on a case-by-case basis. This should be carried out following a prioritisation of the barriers that, once tackled will give the greatest linkage between habitats for adult fish and potential spawning areas.

Some cost-effective options for fish passage easements on two basic types of barrier (a flat-shallow apron (e.g. Fig. 5) and a steeply sloping faced weir (e.g. Fig.14)) are provided in figures 32 to 35:

**Pre-barrage solutions**

These break the barrier down into a series of manageable steps – with good depth generated to aid passage up through the slots.

Figure 32: Substantial “pre-barrage” pool creation in order to tackle a steep, high weir. The pre-barrage structures in this example are made using cast concrete.
A solid, smooth plume of water (i.e. lacking “entrained air” indicated by frothy white flow) greatly assists the fish in swimming up into the slots. The formation of such plumes is promoted by manufacturing a smooth, curved lip (ideally with side walls to contain the flow) known as an “adherent nappe”.

![Image of fish swimming up slots](image1)

**Figure 33**: Low cost pre-barrage easement constructed using wooden sleepers bolted to existing stonework. Note the smooth, metal "adherent nape" that is providing a solid plume of water at the downstream exit point of the lowest step (left hand side of frame towards background).

**Vertical slot/baffled flow type solutions**
This type of approach will not work on vertical-faced weirs, but will work well on gently sloping weirs – and can be made to work on even quite steeply-sloping weir faces.

![Diagram of vertical slot easement](image2)

**Figure 34**: Vertical slot easement for a sloping-faced weir (alternating slots to prevent a continuous plume forming from top to bottom of the structure). These can be constructed from a variety of materials according to availability - from cast concrete to wooden sleepers bolted in place.
Figure 35: Potential approach to structures that consist of both a sloping face and a level apron. Note alternative construction of adherent nape using cut and shaped notch in wooden sleeper.

For all vertical slot type easements, the following considerations will aid performance:

- Maintaining a head difference between the pools of under 25cm (ideally much less).
- Smoothly rounding off the upper surface of each lateral beam (to limit turbulence)
- Angling each lateral beam slightly upstream from its junction with the side-wall towards its slot-end (to generate better “resting-pool” conditions between each lateral beam)
- Notching the downstream lip of the weir at the exit point of the easement (to reduce/remove the need for fish to jump into the easement and to provide good “attraction flow” into the easement)
- Notching or lowering the part of the weir that is feeding into the upstream end of the easement structure (to ensure good flow within the structure and prevent “attraction flow” being generated at other points of the downstream edge of the weir).

As mentioned in the last two bullet points above, managing what is known as “attraction flow” is an important consideration for fish passage. Fish will
orientate themselves towards (i.e. be attracted to) what they perceive as the predominant flow-path of water coming down or around a structure. This is the evolutionary strategy that can help them to jump over or swim through natural barriers. It is important, therefore, to produce a strong attraction flow at the downstream entrance to fish passage easement structures. This not only guides fish into the easement – it also helps to prevent damage that occurs when fish throw themselves repeatedly at solid stone walls. It is also a significant confounding factor when attempts are made to combine fish passes with hydropower developments on weirs. The majority of the attraction flow in those cases inevitably arises at the discharge from the power-generation mechanism.

For the mile-long section of brick-lined gulley (Fig. 12), the best outcome for that section would be breaking up of the base of the gulley to enable a more natural stream-bed to reform - as in the Quaggy example (another great existing example can be seen on the River Irwell system, supplied along with this report). It may be that there are insurmountable obstacles to achieving that. In that instance, it would be beneficial to install features to break up the laminar flow of water and allow fish to rest during their upstream progress. These could be as basic as breeze blocks affixed to the gully-bed in a scattered arrangement. Bolting of wooden batons or moulded concrete fins (or indeed any measures used in tackling standard culverts) could also be employed to the same end. The establishment of low, overhanging cover by the planting of small trees such as goat willows (or even artificial structures to mimic this effect) – would encourage fish to utilise the gulley for upstream migration. It would also significantly reduce the predation risk faced by fish in the artificial channel (a vital consideration if connectivity improvement is to be meaningful).

As a final note on connectivity, there may be an opportunity to utilise the knowledge of some of the urban explorers who frequent the subterranean sections of the Bradford Beck. Information (or even better, photographs) on the existence of likely barriers within the underground reaches may be expensive to obtain by alternative means. The Beck beneath Bradford is known as “Macro” in the urban exploration community, and could be a means of identifying potential correspondents via internet searches.
4.0 Making it Happen

The Bradford Beck restoration project is an ambitious and well-formulated project and, as such, will be well on track with respect to identifying funding streams. Consequently, the most useful contribution that the WTT is likely to be able to offer is that of continued advice and participation in specific habitat project design work. It may be possible to incorporate the completion of some of the works suggested here as part of a WTT Practical Visit (http://www.wildtrout.org/content/advice-and-practical-help). The Practical Visit programme utilises the completion of habitat works by WTT staff as a means to provide hands-on training to groups of recipients. Although such support can be made available free of charge to recipients (up to a value of £1800 for staff time and materials) – demand is extremely high and the number of such events limited by our available sponsorship funding. We are happy to discuss equivalent funded works.

It is imperative that all relevant permissions (including but not limited to licences and signed Flood Defence consents) are obtained before undertaking any work in or around river channels. This is especially important in heavily urbanised areas – and the particular risks associated with urban development. The E.A. and local councils can help to advise on necessary permissions processes.

5.0 Acknowledgement

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6.0 Disclaimer

This report is produced for guidance only and should not be used as a substitute for full professional advice. Accordingly, 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 comments made in this report.