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Restoring Meanders to Straightened Rivers

1.8 Restoring a meandering course to a high energy river

ROTTAL BURN

LOCATION – GLEN CLOVA, ANGUS, SCOTLAND NO36936919
DATE OF CONSTRUCTION – TWO PHASES - MAY/JUNE 2012 AND AUGUST 2012
LENGTH – 1,200m
COST – £200,000

Rottal Burn	High energy, gravel
WFD Mitigation measure	**Click Here** to view details
Waterbody ID	5812
Designation	SAC
Project specific monitoring	Fish, Habitat, Macroinvertebrates, Plants, Birds, Morphology

Description

The Rottal Burn has a steep catchment of 17.05km² to its confluence with the River South Esk. The final 1km of the Rottal Burn between Rottal Lodge and its confluence with the River South Esk was realigned and straightened soon after the 1830s. In this final reach the steep catchment meets the South Esk glen. This reduces the gradient and results in deposition of bed material. The bed of the channelized burn was continually aggrading and sediment was sediment was being deposited at the confluence with the River South Esk. In response, sand, gravel and cobbles had been dredged and and used for agricultural embankments (up to 2.2m above field level) to reduce the frequency of flooding of the surrounding fields. In 2003, the stretch was dredged again, destroying the existing habitat.

The River South Esk and its tributaries are designated for Atlantic salmon (*Salmo salar*) and freshwater pearl mussel (*Margaritifera margaritifera*). Although spawning habitat was present in the burn, the lack of variation resulted in low numbers of juvenile salmonids and any fry produced were often washed out of the burn by spate flows. Working with the supportive owner of Rottal Estates, the fisheries trust saw an opportunity to improve the availability of fish habitat, and improve the overall habitat, by restoring the burn to a naturally functioning state and reconnecting it with its floodplain. This would support the recovery of sustainable populations of Atlantic salmon, brown trout (*Salmo trutta*) and, in the long term, freshwater pearl mussel (which is dependant on salmonids for the completion of its life cycle).

Council planning permission, a CAR engineering works (Controlled Activities (Scotland) Regulations) licence and a Habitat Regulations Appraisal, due to the site being within a SAC, were all necessary.

Dredged gravel forms an embankment on both banks. The channel runs in a straight line to the confluence with the River South Esk – May 2006

These techniques were developed to suit site specific criteria and may not apply to other locations

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Design

The scheme was designed to allow natural processes to shape the channel's features, rather than focusing on creating individual habitat areas. The new channel was over-sized compared to the existing straight cut, to allow space for the natural features to develop. It was also anticipated that the burn would actively adjust its course within the wide corridor between the old cut to the north and a knoll and new spoil bunds to the south (*Figure 1.8.1*).

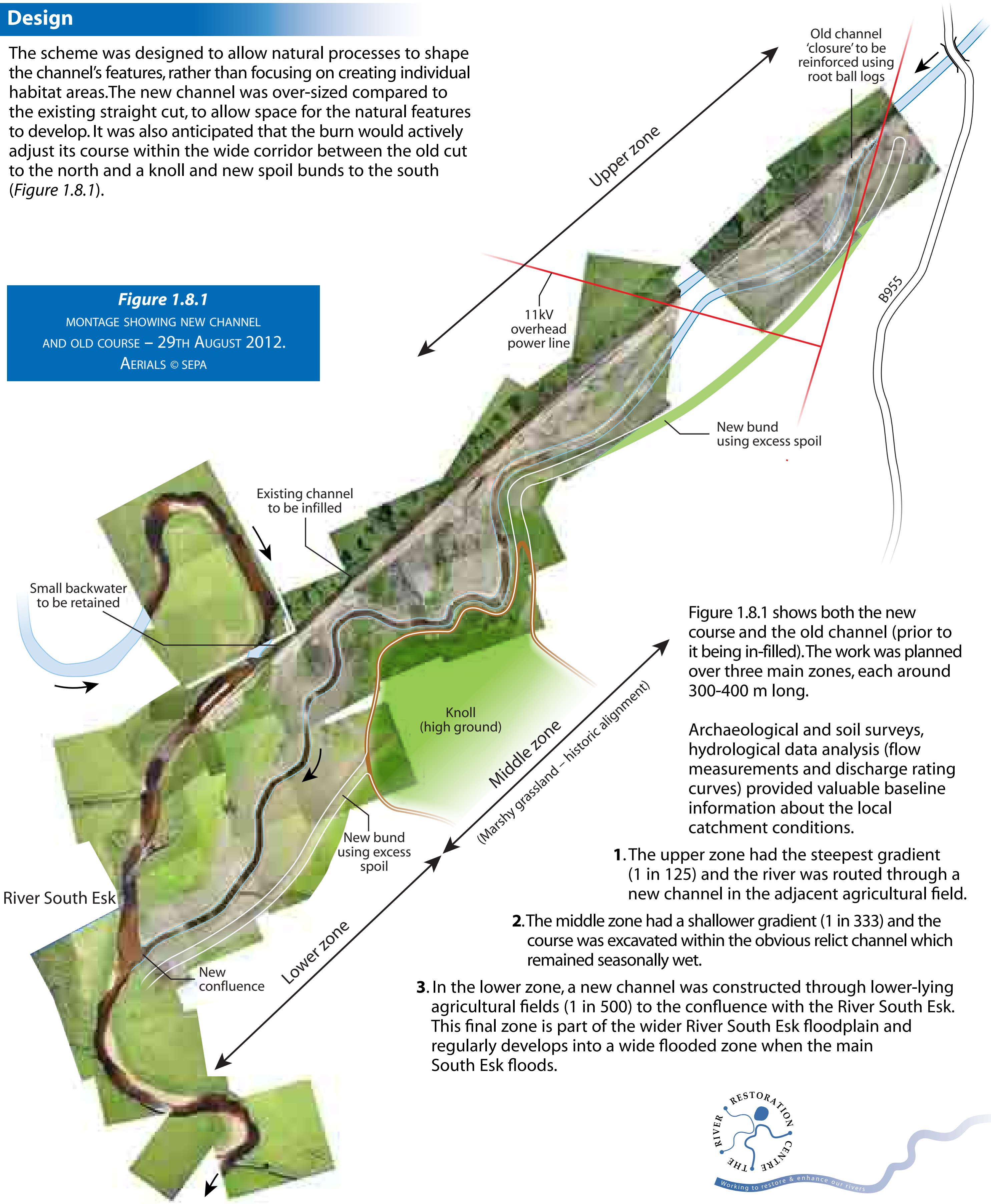

Figure 1.8.1
MONTAGE SHOWING NEW CHANNEL AND OLD COURSE – 29TH AUGUST 2012. AERIALS © SEPA

Figure 1.8.1 shows both the new course and the old channel (prior to it being in-filled). The work was planned over three main zones, each around 300-400 m long.

Archaeological and soil surveys, hydrological data analysis (flow measurements and discharge rating curves) provided valuable baseline information about the local catchment conditions.

1. The upper zone had the steepest gradient (1 in 125) and the river was routed through a new channel in the adjacent agricultural field.
2. The middle zone had a shallower gradient (1 in 333) and the course was excavated within the obvious relict channel which remained seasonally wet.
3. In the lower zone, a new channel was constructed through lower-lying agricultural fields (1 in 500) to the confluence with the River South Esk. This final zone is part of the wider River South Esk floodplain and regularly develops into a wide flooded zone when the main South Esk floods.

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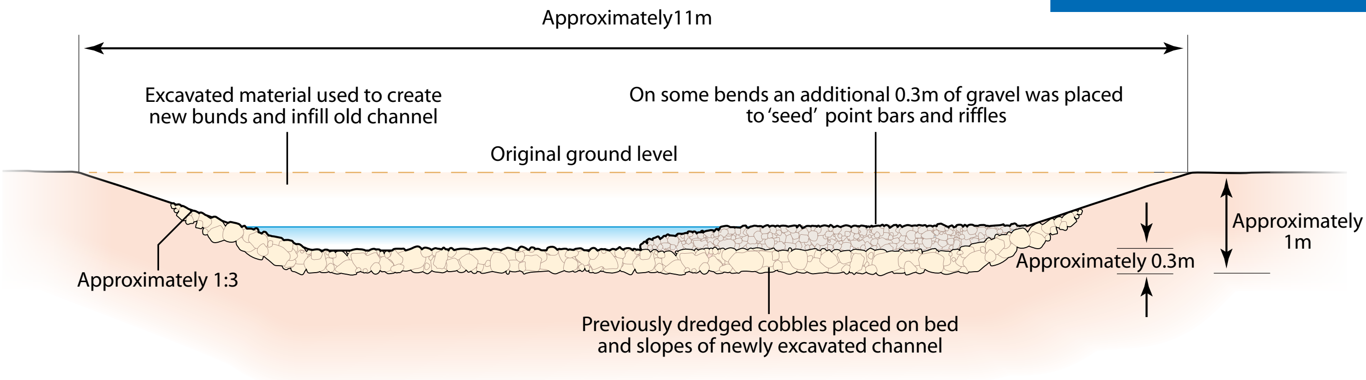
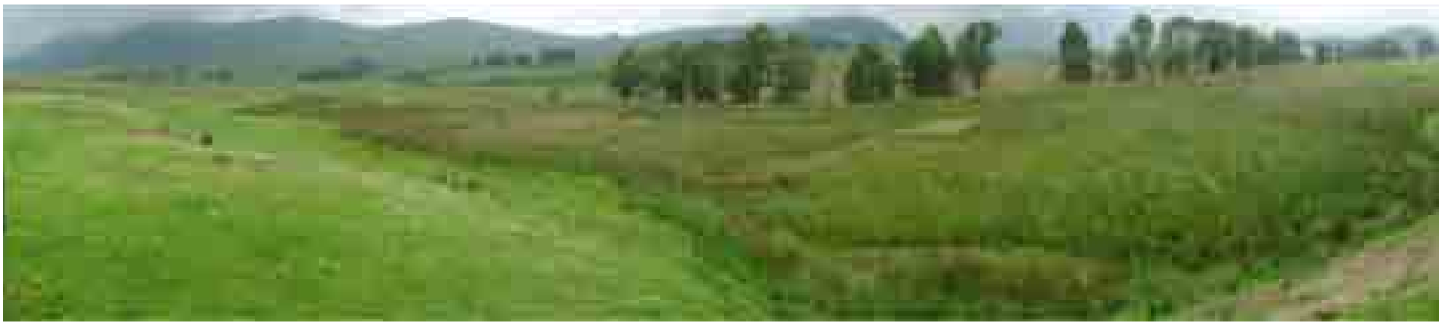
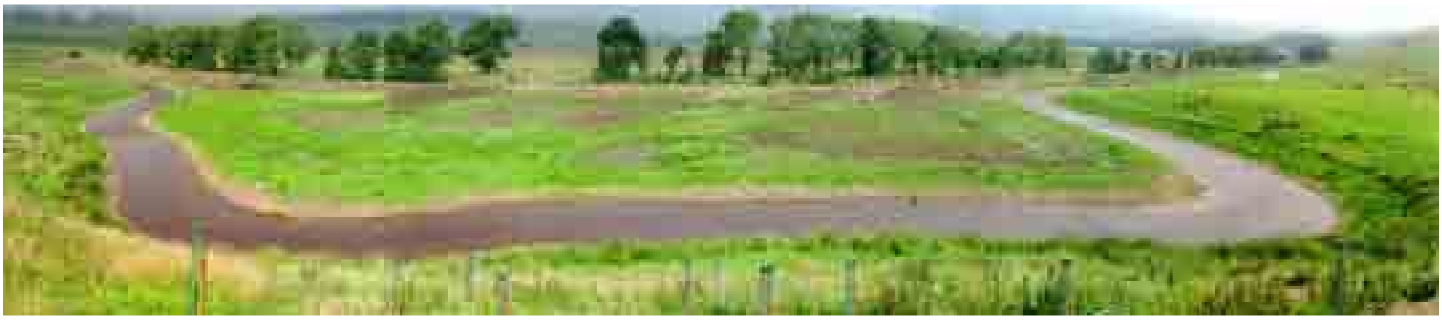
Figure 1.8.2
TYPICAL CROSS SECTION SHOWING A SIMPLE APPROACH TO THE CHANNEL DESIGN



The initial design concept specified the 45 degree bank angles of the upstream reach, and a varying bed profile at meanders. However, during construction the bank slopes were formed at shallower slopes of 1 in 3. This was to reduce the potential for erosion in the sandy soils and to help vegetation establishment.

In a further change, and working on the principle that the channel would quickly rework its material, the cross section at each meander was formed as a flat profile (similar to the straight runs – *Figure 1.8.2*). This allowed the bed of the channel to be used as a haul road for placing the gravel substrate. As a result, the channel profile remained relatively similar throughout but with distinct bed gradient changes over the three zones.





Three panoramas showing the development of the middle reach – 2011 to 2012

These techniques were developed to suit site specific criteria and may not apply to other locations

Restoring Meanders to Straightened Rivers

© K.MacDougall

The newly excavated channel, viewed from the knoll, following the old course – Sept 2012

© RRC

The channel is depositing and moving sediment, creating features – July 2013

Substrate previously dredged from the burn and won from the embankments was placed on the bed and banks of the newly excavated channel to an approximate depth of 0.3m. The median gravel size was 60mm with the range of material being fine sand to large cobbles. In thirteen locations, additional gravel was placed to a height of 0.3m above the surrounding design substrate level (*Figure 1.8.2*). These locations were where features were expected to occur and were intended as source material for natural processes to use to shape the burn.

The steeper upper section of the new channel would be subjected to the greatest erosional pressure, so the design width was increased to accommodate both sediment deposition and discharge.

A two-phase construction programme allowed the new dry channel to be constructed during late spring, with additional time given for vegetation to establish on the banks prior to the final opening.

Initially a downstream 'plug' was retained. However, due to both the site layout and the short window of opportunity for vegetation growth, this was removed and the downstream opened up. At the upstream extent, a pipe was installed between the existing and new channel to provide a small feeder flow to allow bankside and aquatic ecology to develop prior to the entire burn being diverted.

By cutting the new channel through the low lying, rush dominated wetland vegetation, very little vegetation establishment was needed in this middle reach. Careful turf stripping, storage and replacement helped to speed up the re-vegetation within such a short growing period. In late summer, flow from the existing channel was diverted into the new course.

Fine silt and sand transportation from the site works into the River South Esk was a major concern, with the river's designation for freshwater pearl mussel. Measures taken to mitigate this included straw bale silt trapping and allowing time for vegetation to establish before the new channel was connected.

Excavated spoil was stockpiled and then used to infill and landscape the old channel once it was dry. Excess material was used to create two left bank bunds to prevent out of bank flood flows from outflanking the knoll.

Wind-blown Scots pine from the estate, was used to reinforce areas of possible adjustment such as the initial bend into the new course. In early 2013 the tree planting was completed and a locally sourced riverbank wild grass seed mix was sown.

A number of challenges were faced during the construction including the presence of overhead services, the remote location, inclement weather, and the limited growing season at an altitude of 220m above sea level.

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Subsequent performance

The new channel was tested by a number of significant flow events, including a large spate just 36 hours after being diverted. This was followed in mid-October 2012 by one of the largest floods in 10 years.

As predicted, the upper reach has been more morphologically active, with new sediment supplying the formation of gravel bars. There has been some local erosion which has allowed a greater variety in channel width and depth to develop. In the middle reach, sand and gravel bars have formed and connectivity with the adjacent floodplain and wetland area has increased. Erosion has varied significantly depending on the bank material (peat, sand or gravel) showing that accurate prediction of channel adjustment is hard to achieve, and that sufficient space needs to be given to allow change to occur.

Bank erosion and channel adjustment are also leading to the erosion of the new upper bund. The main area to be monitored is close to the power lines. Should any stabilisation be necessary, this would be achieved through addition of further woody material.

The lower reach remains relatively unchanged after one year. This is partly due to the greater distance from the new input of bed material and also as the spate events have all thus far involved a simultaneous rise in both the burn and the main South Esk. This creates a ponded floodplain with low velocities and little energy to shape the lower burn.

A fisheries survey identified 30 salmon redds in the upper reaches of the restored channel, while sea trout and otters (*Lutra lutra*) have also been observed.

A monitoring network has been set up to assess the longer term performance of the project. Pre-work surveys included a fluvial audit, topographic assessment and geomorphic appraisal in addition to baseline fisheries, river habitat, bird, plant and aquatic invertebrate surveys. Post construction monitoring has included repeat topographic and aerial survey from a small remote control helicopter.

The as-dug channel with cobbles from the old dredgings embankment – 2012

© K.MacDougall

Subsequent deposition and erosion from, now unconstrained, natural processes – July 2013

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1.9 Reconnecting a remnant meander

River Rother
Location - Petworth, West Sussex from SU98051906
Date of construction - 2004
Length – 850m
Cost – £90,000

River Rother	Medium energy, sand
WFD Mitigation measure	**Click Here** to view details
Waterbody ID	GB107041012810
Designation	None
Project specific monitoring	Fish, cross sections, fixed point photograpy, water levels, macroinvertebrates, macrophytes

Description

The 'Shopham Loop' is a large meander bend which is part of the natural course of the Western River Rother.

The Rother was engineered for navigation in the 18th century. At Shopham a large meander bend was bypassed with a straight navigation channel that featured a lock gate at its downstream end. These gates impounded water to a depth of up to two metres, but did not pass any river flow. The flow was side spilled into the loop via a purpose built structure.

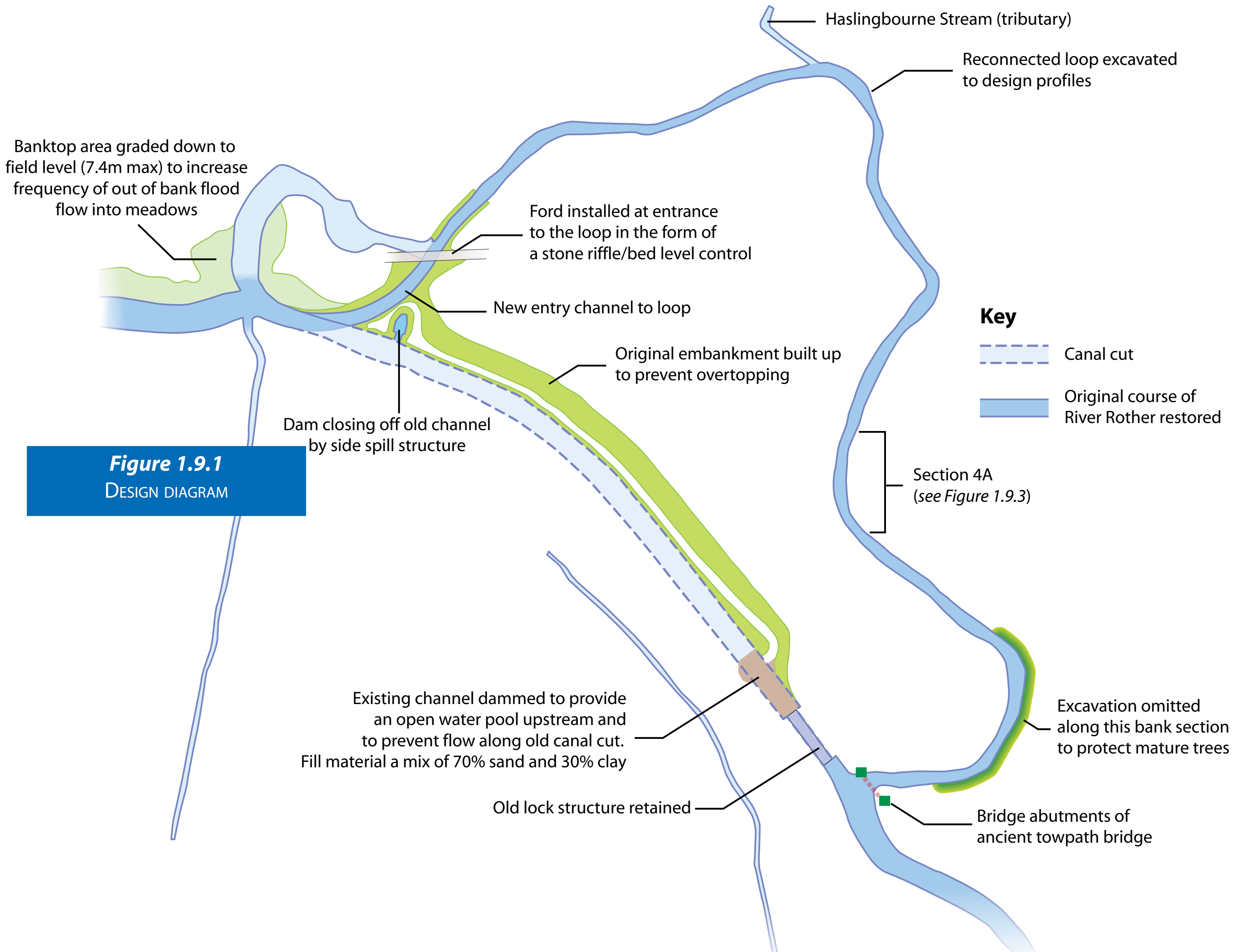


Figure 1.9.1
Design diagram

These techniques were developed to suit site specific criteria and may not apply to other locations

Restoring Meanders to Straightened Rivers

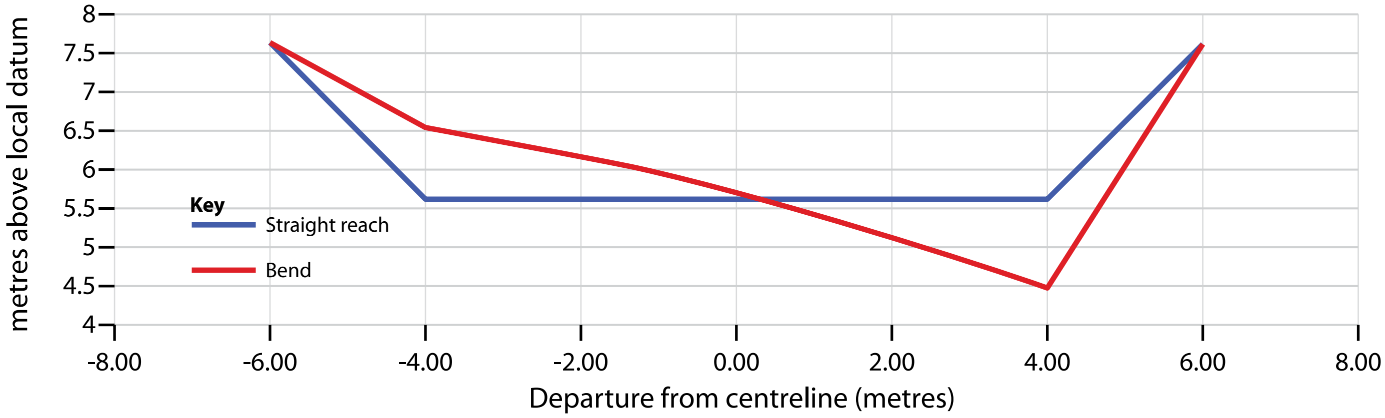


Figure 1.9.2
DESIGN CROSS-SECTIONS FOR STRAIGHT REACH AND BEND APEX

After navigation on the Rother ceased, the lock gates were removed which dropped the river level with flow passing freely down the cut. The side spill structure was also opened up to ensure that at least a part of the river continued to flow along the original course of the meander.

The loop rapidly became blocked with deposits of sand, as the flow velocity fell due to the reduced flow passing into the loop.

Concurrently the cut became enlarged due to bank erosion and the stonework of the old lock was partially washed out by floods. Several attempts were made to keep the old course of the River Rother open, but none was successful.

The project aimed to divert flow back through the meander loop, with a channel capacity that would remain self-cleansing. This would also restore the diversity of habitats associated with a meandering lowland river and increase floodplain connectivity.

Design

The canal cut was never designed to carry the river flow so it was decided to seal it off with an earth bund, just upstream of the old lock. This mimicked the function of the old lock gates. The entire river flow could then be diverted back into the historic course around the loop.

The reference point for the channel restoration design was a survey of the loop carried out in 2002. Additionally, the narrowest cross sections of the main River Rother channel were referenced against the cross sections collected from the loop and compared with channel dimensions sized by a geomorphologist.

The bank top width was determined by on-site observation of two stone abutment walls from an ancient bridge that provided a reliable representation of the historic channel width.

Two ancient stone abutment walls at the exit of the loop indicating the historic channel width – 2004

Expert judgement and field observation was supported by a model to inform the more detailed channel design However it was impractical to excavate the complex shapes optimised by this model. Therefore the loop was excavated to one of two basic cross-section designs, namely bend apices and straight reaches, while points on the transition between them were interpolated (*see Figure 1.9.2*). The bed level was set to reflect existing conditions in the River Rother at each end of the loop and to improve connectivity with the floodplain during high flow events. A large scrape was excavated to create wading bird habitat and to provide clay for construction of the bund.

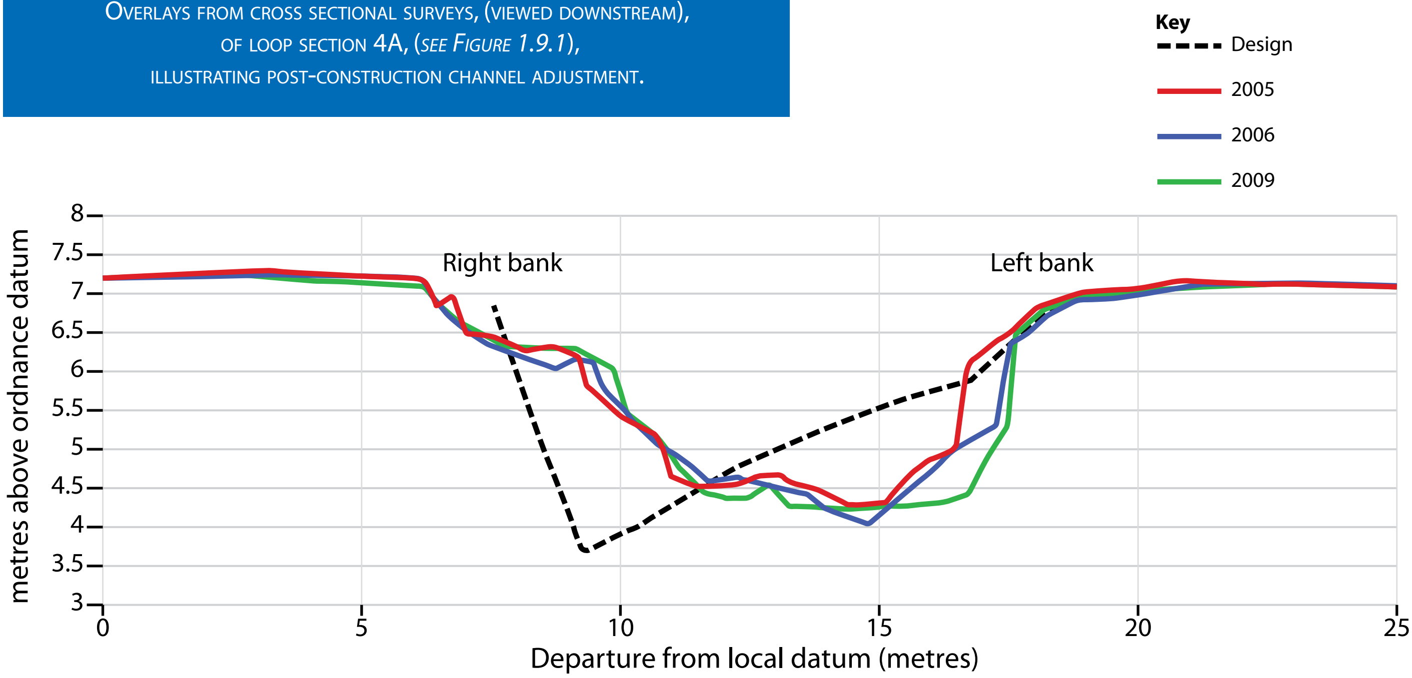
In order to prevent undermining of the stone abutment walls (which were of archaeological significance) at the downstream confluence, sheet piling was driven down to bed level across the river and a 'bed check' created from a base layer of coarse locally-sourced sandstone. At the entrance to the loop a ford was created for farm traffic and to serve as another bed check. It too was dressed with gravel to mimic a natural riffle.

A new gravel riffle was also constructed upstream of the site to replace a riffle that had formed in the canal cut, which became obsolete once the cut was sealed off. New gravels totalled £9,000, labour £13,000 and plant hire costs totalled £28,000.

The isolation of the canal cut left a long still water lagoon that provides valuable off river wetland habitat, which helped to achieve the overall biodiversity aims of the project. The old canal embankment alongside the cut was repaired and raised above the flood level, ensuring that this habitat would not be washed out by floodwaters. Conversely, the low canal embankments upstream of the loop were taken down to field level to trigger more frequent out-of-bank flows over the adjacent meadows.

Bed check riffle and ford at entrance to the loop post-construction – 2004

Figure 1.9.3
OVERLAYS FROM CROSS SECTIONAL SURVEYS, (VIEWED DOWNSTREAM), OF LOOP SECTION 4A, (*SEE FIGURE 1.9.1*), ILLUSTRATING POST-CONSTRUCTION CHANNEL ADJUSTMENT.



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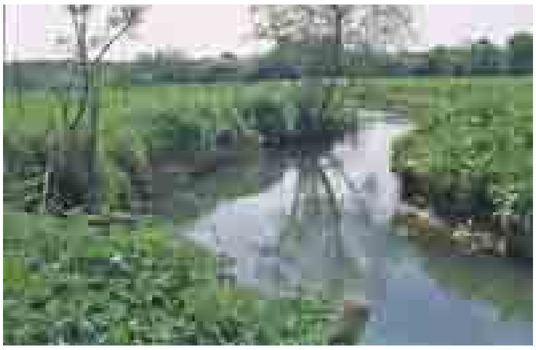
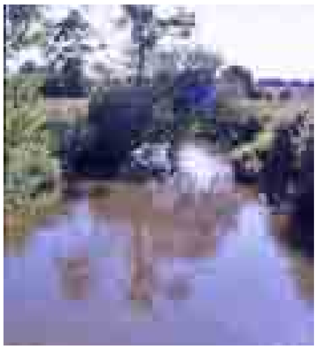
© RRC Sand in the meander loop pre-restoration – June 2004



© RRC Flow in the excavated meander loop post-restoration – 2005



© RRC The same meander loop (three years post works) – 2007

Subsequent performance

Virtually all of the initial bare banks had established a good cover of vegetation two years post-construction (2006). Mature woody vegetation retained during the project has contributed woody material to the channel, and species diversity of the floodplain has increased significantly, with many bird species regularly utilising the newly created wetlands.

The fish community of the restored loop was consistent with that of the wider Rother catchment. Higher than average populations of bullhead (*Ameiurus nebulosus*), chub (*Leuciscus cephalus*), brown trout (*Salmo trutta*), grayling (*Thymallus thymallus*), sea trout (*Trutta morpha trutta*) and barbel (*Barbus barbus*) have been observed. The stone bed check structures at the upstream and downstream ends of the loop have acted as spawning grounds for many of these fish species.

Monitoring of the site between 2002 and 2009 indicated a positive performance of the technique. Changes were observed in cross-sectional area (*see Figure 1.9.3*) suggesting a dominance of erosion over deposition in the loop. There was no significant (more than one metre) lateral channel change between autumn 2004 and a survey in 2006, but small-scale channel adjustment has been widespread. Therefore it can be concluded that the pre-restoration issue of sedimentation in the loop has been resolved and that the newly-excavated channel is slowly adjusting to a more natural, and desirable, form.

© RRC Shopham Loop post-restoration – 2009

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Reference material – Click **here**

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Restoring Meanders to Straightened Rivers

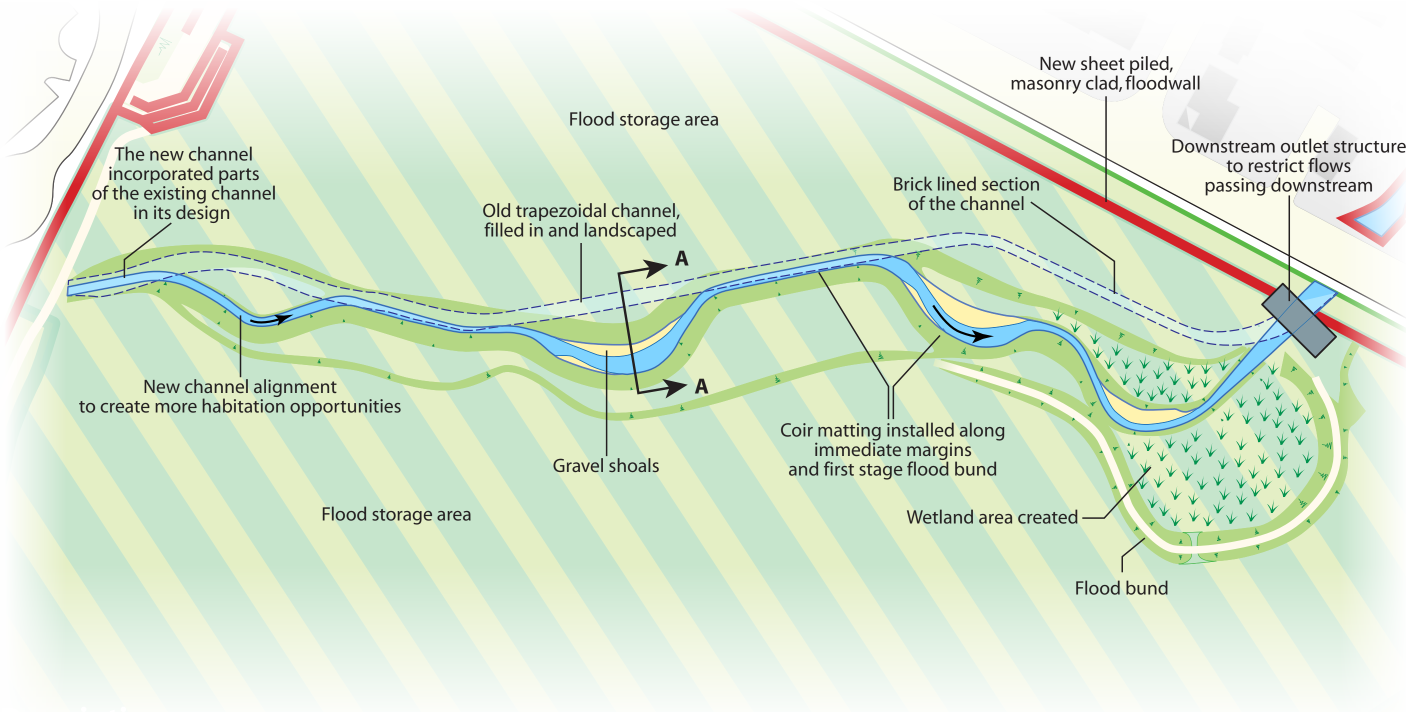
1.10 New meanders replacing a lined urban channel

BRAID BURN

LOCATION - INCH PARK, EDINBURGH NT277711
DATE OF CONSTRUCTION - LATE 2008 – MID 2009
LENGTH - 310M
COST - £110,000

Braid Burn	Medium energy, gravel
WFD Mitigation measure	Click Here to view details
Waterbody ID	3500
Designation	UWS
Project specific	BAP species (pre-only)

Figure 1.10.1
PLANFORM OF THE BRAID BURN THROUGH INCH PARK



The re-meandering of the Braid Burn at Inch Park was a small component of a wider flood alleviation scheme promoted by the City of Edinburgh Council, designed to protect against a 1 in 200 year flood, with additional allowance for climate change. The scheme utilised the flood storage capacity within Inch Park and so provided an opportunity to promote biodiversity and create habitat along the river corridor. The site is an Urban Wildlife Site (UWS) within the Edinburgh Urban Nature Conservation Strategy and delivers parts of Edinburgh's Local Biodiversity Action Plan (BAP) 2010-2015.

Inch Park is a well used recreational resource within the city, adjacent to a large shopping centre, residential properties and a primary school. The park has a mix of mature woodland and individual trees along with amenity grassland and is maintained by the City of Edinburgh Council. Prior to the works Himalayan balsam (*Impatiens glandulifera*) was widespread along the margins of the burn where it flows through the park. The council carried out an eradication programme during the few years prior to the flood prevention work starting on site.

The aim was to reintroduce diversity in the width, depth, flow rates and appearance of the burn, to allow natural morphological and ecological processes to take place following initial construction. This was achieved by replacing the brick and concrete channels with sinuous meanders, runs, riffles, shoals and gently sloping banks. A new wetland habitat was also created at the downstream end of the burn.

These techniques were developed to suit site specific criteria and may not apply to other locations

Restoring Meanders to Straightened Rivers

Design

Approximately 80% of the restored course was newly dug and 20% was made up of the retained channel, the banks of which were reprofiled.

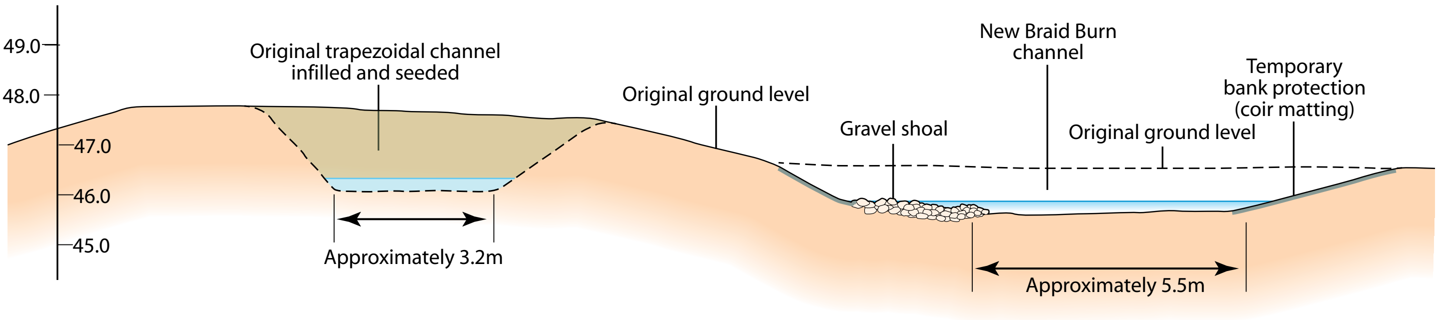
None of the brick and concrete sections of the existing channel were incorporated into the new design. These were all broken down and in-filled. Densely graded rock (lumpstone) of 0.075m to 0.3m was imported and used to form the riffles and shoals. Gravels for the new channel were recovered and re-used from the sections of the old course which were to be in-filled. It was deemed that over time natural processes would transport substrate, invertebrates and flora to the new sections of the burn. The hydraulic conveyance of the new naturalised course is at least as great as that of the lined channel, ensuring no increase in flood risk upstream.

As a precautionary measure coir matting was pinned in place along the channel margins and the first stage flood bund, to help protect the clay and soil banks until vegetation established.

© AECOM

Prior to works part of the channel through Inch Park was brick lined – April 2006

Figure 1.10.2
New Braid Burn channel and reprofiled banks
Section **A–A** (*see Figure 1.10.1*)



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New meander channel cut off-line. 0.075 – 0.3m lumpstone was used to create the riffle and shoal base to prevent excessive bed scour – January 2009

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The gently sloped banks provide additional capacity and promote the natural processes of sediment transport and vegetation colonisation – February 2009

The new meanders were created off-line and, once complete, were connected to the existing channel. Overpumping of some sections of the burn was necessary to maintain flow whilst works were carried out. The downstream end of each meander was opened up first and allowed to fill with water. Each meander was then left for a period to allow sediment to settle and reduce the potential for dirty water to pass downstream. The upstream end was then opened very slowly to control the initial flow through the new meander in order to prevent scouring of loose materials. During construction settlement ponds were created to control and retain muddy water draining from the site.

A debris screen was installed at the downstream outlet structure as part of the flood protection scheme to intercept floating debris and help prevent blockage of downstream culverts. A wetland has been created in a low-lying area adjacent to the outlet. The wetland is covered during higher flows enabling fine sediment and nutrients to be retained.

© AECOM

Eroded clay forming a stable cascade and adding to the diversity of features within the channel – May 2011

© AECOM

Wetland area at low flows. The height of the floodwall demonstrates the flood storage capacity within the park – March 2010

Subsequent performance

Following the works the river corridor is significantly wider, with a sinuous channel and more natural appearance. Riparian vegetation has colonised the banks and wider corridor, which now has a diversity of height, form and texture that was not present prior to the works.

The meanders have increased variability in the width and depth of the channel and have provided flow diversity. As a result a mosaic of habitats has been created for birds, mammals and invertebrates, increasing the overall biodiversity of the immediate area. Of particular note is the presence of otters (*Lutra lutra*) in the watercourse, previously absent from this section of the Braid Burn.

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The shoals around the meanders have trapped significant quantities of fine silt during high water events and vegetation has begun to colonise the sediment, disguising the lumpstone structures. Gravel has been transported out of some parts of the new meanders and replacement with gravel transported from upstream has been slow. At one location a less dense lens of sandy clay within the channel has eroded to form a small cascade and pool.

Informal footpaths have developed along both banks of the burn and are well used. Following the works the burn has become an integral part of Inch Park that brings ecological, aesthetic and recreational benefits to the area. In 2011 the scheme won a commendation for environmentally sustainable construction in the Saltire Society's Civil Engineering Awards.

The coir used to protect the first stage bund from erosion was a fairly dense weave matting which prevented all but the most vigorous species from penetrating. Natural colonisation of the bund was therefore slow. Coir matting with a more open weave would have allowed more rapid colonisation by a wider range of species. The coir matting used along the immediate margins of the burn worked as designed, quickly becoming covered by sediment.

Environmental Impact Assessment (EIA) ecological surveys (including bat, otter, badger and tree) were carried out before works commenced in order to establish the potential impacts. Routine inspection is carried out by the City of Edinburgh Council to monitor on-going morphological processes and to assess stability. This indicated that the new pool and cascade were stable and as a result this feature was retained. Planting within the meanders captures litter and other debris which passes downstream during high flow events. It is periodically necessary to clear this. Himalayan balsam has been noted following the works and continued invasive species management is being carried out.

The new course of the Braid Burn through Inch Park after two years. Marginal vegetation has established well and natural processes have enhanced the in-channel morphological features that were created – May 2011

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1.11 Returning a woodland stream to its former sinuous course

HIGHLAND WATER AT WARWICKSLADE CUTTING

LOCATION - NEW FOREST, 3KM SOUTH WEST OF LYNDHURST, SU273055
DATE OF CONSTRUCTION - AUGUST-NOVEMBER 2009
LENGTH – 2000m
COST – £214,500

Highland Water	Medium energy, gravel
WFD Mitigation measure	**Click Here** to view details
Waterbody ID	GB107042016720
Designation	SSSI, SAC, SPA, Ramsar, National Park
Project specific monitoring	Geomorphological surveys, cross and long sections, flow measurements, SSSI condition assessment

Description

Many rivers in the New Forest National Park were improved for grazing by cutting straight drainage channels during the 1850s, resulting in the abandonment of a network of historic woodland streams. These new channels had steeper gradients leading to down cutting and erosion of the underlying sands, gravels and clays.

One example of this degradation is on Highland Water, a small headwater sub-catchment (4.9km^2) of the Lymington River. Prior to restoration the channel was up to 1.2m deep and 4m wide restricting the natural seasonal flooding of the surrounding forest. The previously wet woodland and mire habitat had dried out and the increased channel size presented a barrier to the freely roaming forest animals.

The aim of this EU-Life Nature project was to stop the excessive vertical and lateral erosion and to restore the connection between the river and its floodplain. This would be achieved by reinstating the river's natural form and processes. The dual outcomes were to achieve favourable SSSI condition for wet woodland as well as an improvement in WFD status.

© Alaska

The degraded channel was restricting both natural river processes an easy access across the forest for roaming animals – 2009

These techniques were developed to suit site specific criteria and may not apply to other locations

Restoring Meanders to Straightened Rivers

Design

Historical maps were used to identify old or "lost" watercourses to guide the overall restoration design (*See Figure 1.11.1*). Where they could not be identified, the design was based on expert opinion through field assessment.

The work was was carried out in the following stages (*See Figure 1.11.2*):

Firstly, selected bankside trees on the existing channel were felled in order to create access for machinery. This also had benefits for landscape, aesthetics and ecology, as retaining a straight line of trees would have looked out of place in the forest environment.

Accumulated leaf litter and wood from the existing drainage course was then carefully removed and retained for reuse on site. In places a new channel was dug using an excavator, but only where no obvious channel could be found. The creation of idealised features was avoided, but some areas were more extensively cleared to create deeper pools to maximise gains for fish.

Gravels were transferred from the existing to the restored channel.

Flow was diverted from the existing to the restored channel, section by section (*See Figure 1.11.2*) from one crossing point to the next moving down the reach. Adopting this phased approach enabled a controlled diversion of the flow into the new channel, reducing the risk of initial channel instability occurring.

The existing drainage course was then in-filled using a mix of 8,000 tonnes of hoggin (as dug sand and gravel mix) and 800 tonnes of firm clay by-product, both sourced locally.

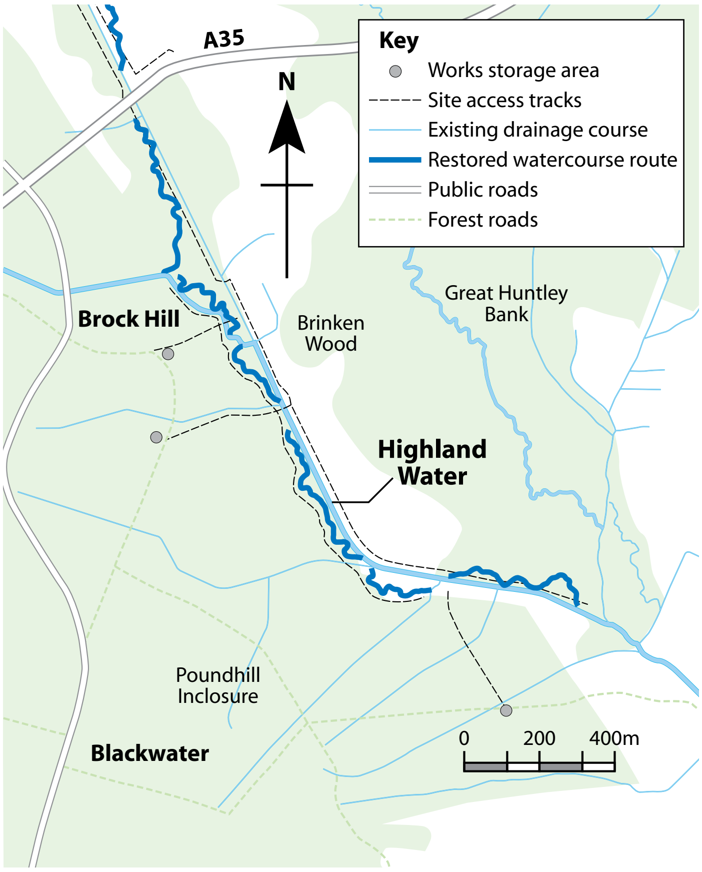

Figure 1.11.1
Map showing plan of restoration works at Warwickslade

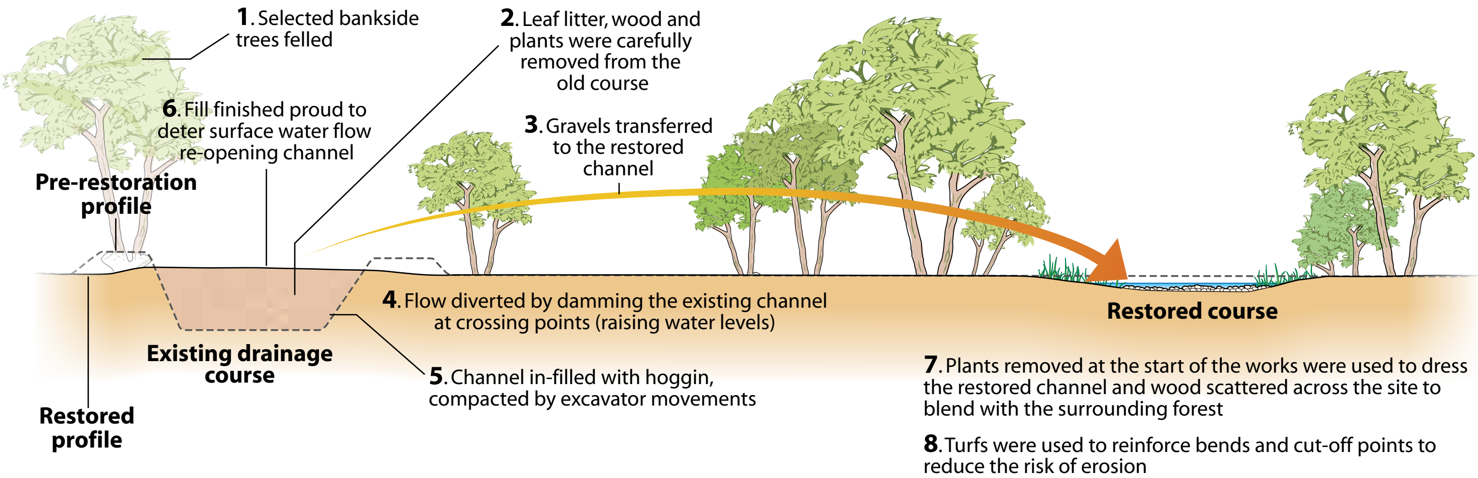

Figure 1.11.2
Stages of technique implementation

Restoring Meanders to Straightened Rivers

The clay was packed tightly at 10m intervals and at construction crossing points to prevent seepage. The rest of the channel length was then in-filled, with excavator movements helping to compact the fill as they moved across the site.

Fill levels were finished slightly above the surrounding ground level to deter any surface water channelling along the fill, which had yet to settle. This could have led to re-opening of the filled channel.

Dead wood was scattered across the site to aid the rapid recovery of the landscape and stop the route becoming a straight path for humans or grazing animals. Turfs removed from the existing course were used to reinforce bends and cut-off points to reduce the risk of erosion immediately post-construction.

Finally the soils, ferns and small plants which had to be removed from the banks during construction were re-used to 'dress' the finished work across the project area.

Sketch design diagrams were developed to provide an overview of the works. However, in this fragile habitat it was essential that that the contractor was sensitive to the local conditions, therefore most of the detailed project works decisions were made using on-site expert judgement.

© RRC

Clay infill was tightly packed at crossing points at 10 metre intervals along the channel to prevent seepage – October 2009

© Alaska

Innovative tramway designed to reduce the impact of works on the sensitive forest habitats, especially during wet site conditions – 2009

Restoring Meanders to Straightened Rivers

The reduced in-channel capacity of the restored course raised concerns about flooding onto the A35. A pool close to the road was widened to reduce the flood risk in this location, which would have caused major disruption.

An innovative tramway system was devised to enable materials to be moved along the line of the channel, even during poor weather, with no appreciable impact on the heavily designated forest habitat.

Project costs comprised plant hire and labour (£106,500), and infill materials (£108,000).

Critical to the success of this project was the preliminary consultation that took place with stakeholders, in particular the Verderers and Commoners. Initially, fears were raised about the time it would take for the scar of the works to heal, but speed of visual recovery due to the relocation of plants during construction has, as predicted, been rapid.

The work has been well received by the local communities with excellent media coverage. The success of the scheme has facilitated negotiations for future works at other locations across the New Forest.

Subsequent performance

The newly restored channel has been left to develop naturally and no post-construction adaptation has been necessary. A variety of morphological features and in stream habitats have been re-established and floodplain connection has been restored through more regular bank overtopping. This has helped to re-wet the surrounding woodland habitats. These enhancements have been quantified by a recorded improvement in SSSI condition scores for the area.

The use of high quality infill material was crucial to the success of the scheme. At other locations where a similar technique had been used the redundant channels had been in-filled with poor quality material, which left them vulnerable to erosion and re-opening.

© Alaska Well-placed shrubs and deadwood blend the old channel into the landscape within days – 2009

© Alaska Immediately post-construction flow begins to grade materials. Pools and riffles are developing – 2009

© Alaska The restored course includes both narrow and wide sections – 2009

Contacts

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3

Enhancing Straightened River Channels

3.10 Sinuous low-flow course in an over-wide urban channel

River Somer
Location - Midsomer Norton, Somerset ST66495420
Date of construction - May 2011
Length – 167m
Cost – £40,000

River Somer	Low energy, clay
WFD Mitigation measure	**Click Here** to view details
Waterbody ID	GB109053022250
Designation	None
Project specific monitoring	Habitat survey, fish, invertebrates

© Woodland Water & Gardens and D.Longley

Measuring existing channel dimensions prior to works – 2011

Description

The overall aim of this project was to improve an over-wide and heavily silted reach of the River Somer running through Midsomer Norton High Street. This involved removal of three small weirs and constructing a new sinuous channel that had sufficient morphological dynamics to remove the need for regular de-silting, reducing maintenance costs and disturbance.

Project objectives included: constructing a sinuous channel using local materials (including accumulated silt); providing diverse habitat features for fish (especially wild brown trout (*Salmo trutta*), plants and invertebrates native to the River Somer; improving the aesthetics of the reach within the town centre; increasing the opportunity for local people to encounter a range of river wildlife; and involving the local community in construction and long term maintenance.

The existing Midsomer Norton Flood Alleviation Scheme and flood relief channel was exacerbating the build-up of sediment by diverting higher "flushing" flows around the town centre reach. However, this also presented an opportunity to create a design which was not heavily constrained by flood risk concerns, since the High Street typically only received local surface floodwaters.

Several on-site factors limited the extent of the works. The channel is culverted at either end of the High Street. Vertical stone walls line the reach, with various surface water drainage pipes discharging into the channel. Two small footbridges cross the channel, along with three low weirs. The bed comprised mostly natural bedrock with some concrete screed to provide a level surface at the time of construction of the bridge piers and weirs.

The pre-restoration reach had a mean water depth of 0.5m and a mean channel width of 4.5m.

Design

The new sinuous channel design was constructed by forming berms to create a low flow channel, with higher flows able to over-top these features. This enabled the required capacity to be provided. The flood relief channel maintained the current level of flood defence to the High Street and allowed flows to be temporarily diverted away from the reach during construction.

The low flow channel width and spacing of the pool riffle sequence was informed by a suitable reference reach from the Somer catchment.

Accumulations of silt were removed from the channel and retained on site for use as backfill in the new design. Three weirs were removed, retaining only the two sides of each structure which were incorporated into the channel berms. This was at the request of the council who wanted to be able to install temporary boards across the channel to retain water depth, should severe drought conditions occur.

These techniques were developed to suit site specific criteria and may not apply to other locations

Enhancing Straightened River Channels

The berms were constructed from "white lias" limestone blocks from a nearby quarry. These were hand placed to mark the edge of the new low flow channel, allowing gaps for existing drainage pipes. The blocks varied in size to a maximum of approximately 0.40mx0.3mx0.15m. Planting bays along the edges of the new channel were lined with a heavy coir blanket and filled with the retained silt.

A carefully selected range of native riparian plants, such as brooklime (*Veronica beccabunga*), water forget-me-not (*Myosotis scorpioides*) and water mint (*Mentha aquatic*) were procured from a professional supplier as plugs. This was primarily informed by a survey undertaken within a reference reach. Consideration was given to plants whose flowers would be attractive in the urban setting and species which would encroach into the channel to adjust the width, but flatten during flood flows to ensure they would not reduce conveyance capacity. Plants which would increase the physical integrity of the berms were also chosen.

A 40mm–60mm angular gravel mix from a local supplier was used to dress the top of the berms and create the riffles.

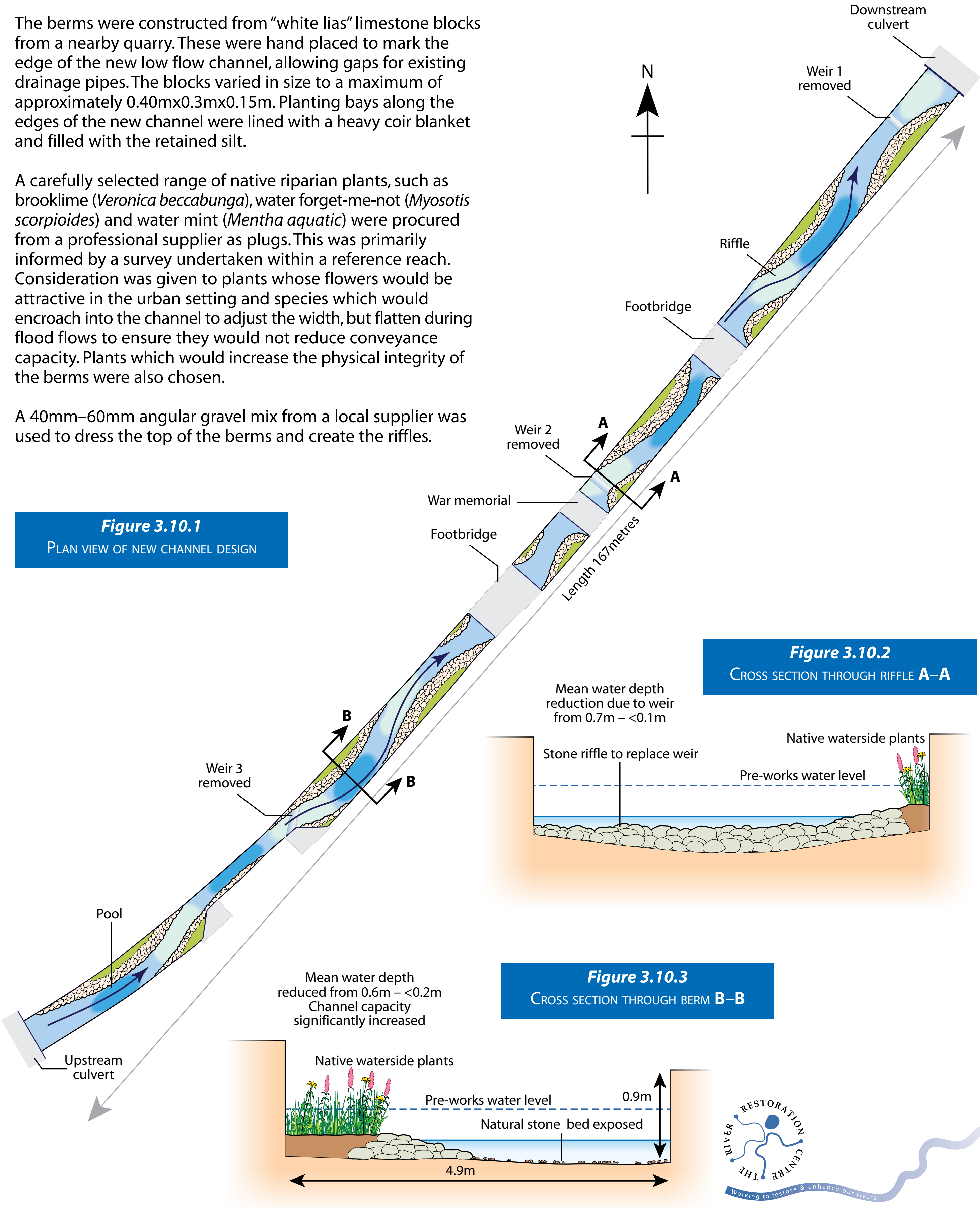

Figure 3.10.1
Plan view of new channel design

Figure 3.10.2
Cross section through riffle **A–A**

Figure 3.10.3
Cross section through berm **B–B**

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3

Enhancing Straightened River Channels

Limestone blocks laid out to delineate berm structure edges – 2011

© Woodland Water & Gardens

Silt is used to fill the marginal berms ready for planting – 2011

© Woodland Water & Gardens

Two sides of the weir have been retained and incorporated into the berms – 2011

© Woodland Water & Gardens and D.Longley

Local volunteers help to complete the planting phase – 2011

Subsequent performance

In June 2012 the first formal post project assessment and maintenance visit was carried out. This was to assess the condition of the channel against the original project design and aspirations in terms of ecology, aesthetics, resistance to flood flows, flow patterns, siltation and routine maintenance by volunteers.

This assessment indicated that the berms were intact and in good condition despite several high flow events. Plant communities had matured well, providing a diverse marginal habitat.

Kick samples revealed that aquatic organism diversity has increased since completion of the scheme. Whilst kick samples were being taken three-spined stickle-back (G*asterosteus aculeatus*) and bullhead (*Cottus gobio*) were captured. Many more stickleback were also observed in the slower channel sections. Freshwater shrimp (*Gammarus pulex*) were extremely abundant in the kick samples, indicating an improvement in aquatic conditions due to it's pollution intolerance and requirement for figh levels of dissolved oxygen. Some small silt deposits have formed in low flow areas, but the channel is generally self-cleansing. The project has been awarded a civic "Pride of Place" award for environmental enhancement from Midsomer Norton Town Council.

These techniques were developed to suit site specific criteria and may not apply to other locations

Enhancing Straightened River Channels

Maintenance, carried out by volunteers from the Friends of the River Somer group, has helped to keep the channel free of litter and nuisance species such as buddleia (*Buddleja davidii*), dock (*Rumex hydrolapathum*) and nettles (*Urtica dioica*).

Time spent discussing and explaining the principles and objectives of the scheme with stakeholders such as contractors, labourers and locals was well-spent. In this case it has facilitated the formation of the Midsomer Norton River Management Team who will help to ensure the continued success of the scheme.

The involvement of the local community from the outset has provided an opportunity to build a long term maintenance strategy, and has been an important legacy of the project.

In the right location and with a well considered design, this has proved an extremely cost-effective, adaptable and effective technique.

Section of the reach before, showing significant sediment accumulation – 2011

© Woodland Water & Gardens and D.Longley

During construction, just before the planting phase is due to commence – 2011

© Woodland Water & Gardens and D.Longley

One year after restoration showing development of diverse bankside vegetation – 2012

© Woodland Water & Gardens and D.Longley

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4

Revetting and Supporting River Banks

4.8 Bank protection using root wads

River Dulais
Location – Rhosmaen, Llandeilo, Carmarthenshire SN645243
Date of construction – March 2004
Length – 80m
Cost – £18,000

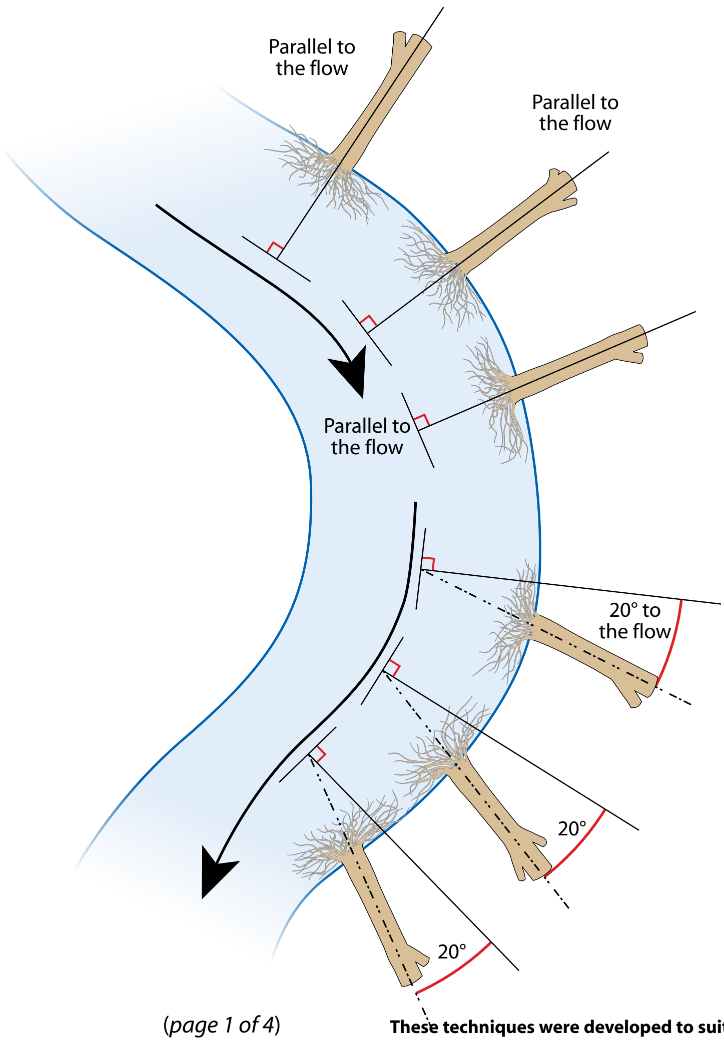
River Dulais	High energy, gravel
WFD Mitigation measure	Click Here to view details
Waterbody ID	GB110060036250
Designation	SAC, SSSI
Project specific monitoring	Fish

Description

The River Dulais (Afon Dulais) is a tributary of the River Towy, and is an important spawning habitat for migratory fish. The river had a history of instability and planform adjustment, with a channel cross section up to fifty per cent wider at this location than upstream reaches. Unrestricted grazing, by sheep and cattle, had resulted in a loss of bankside vegetation. This had reduced cover for fish and increased erosion, causing bank and bed instability. Coarse gravels were covered with a layer of fine silt deposits. For a period of three years the Environment Agency Wales (now Natural Resources Wales) worked with local landowners to fence off 4.9 km of the River Dulais to combat erosion. However, some sections were in need of more extensive bank protection in order to prevent further bank failure and allow vegetation to recover naturally.

This technique was designed to stabilise a highly mobile reach on the River Dulais using root wad revetment. It intended to demonstrate that soft engineering methods can be used as an alternative to blockstone, whilst also restoring physical habitat to degraded channels and maintaining geomorphological processes.

Figure 4.8.1
Plan showing position of root wads



© Salix

Growth of root wads along bank two years after installation. Brushwood protection can just be seen between root wad growth – 2006

These techniques were developed to suit site specific criteria and may not apply to other locations

Design

1

© Salix Trench excavated in bank – 2004

2

© Salix Excavator moving root wad into position– 2004

3

© Salix Installing root wad in bank– 2004

Forty root wads were installed over eighty metres of bank, with two to three metres of trunk left attached to the root wad. Crack willow (*Salix fragilis*), grey willow (*Salix cinerea*) and white willow (*Salix alba*) with an average trunk diameter of between 0.3m and 0.6m were used. Live willow was chosen as each tree should root and shoot to quickly bind the surrounding bank. All trees were sourced from within the Dulais catchment and two adjacent river valleys.

In some areas additional brushwood protection was needed in between the root wads. Careful thought was given to creating a smooth profile along the bank to reduce the risk of erosion. The riverbank above each root wad was protected by erosion control matting.

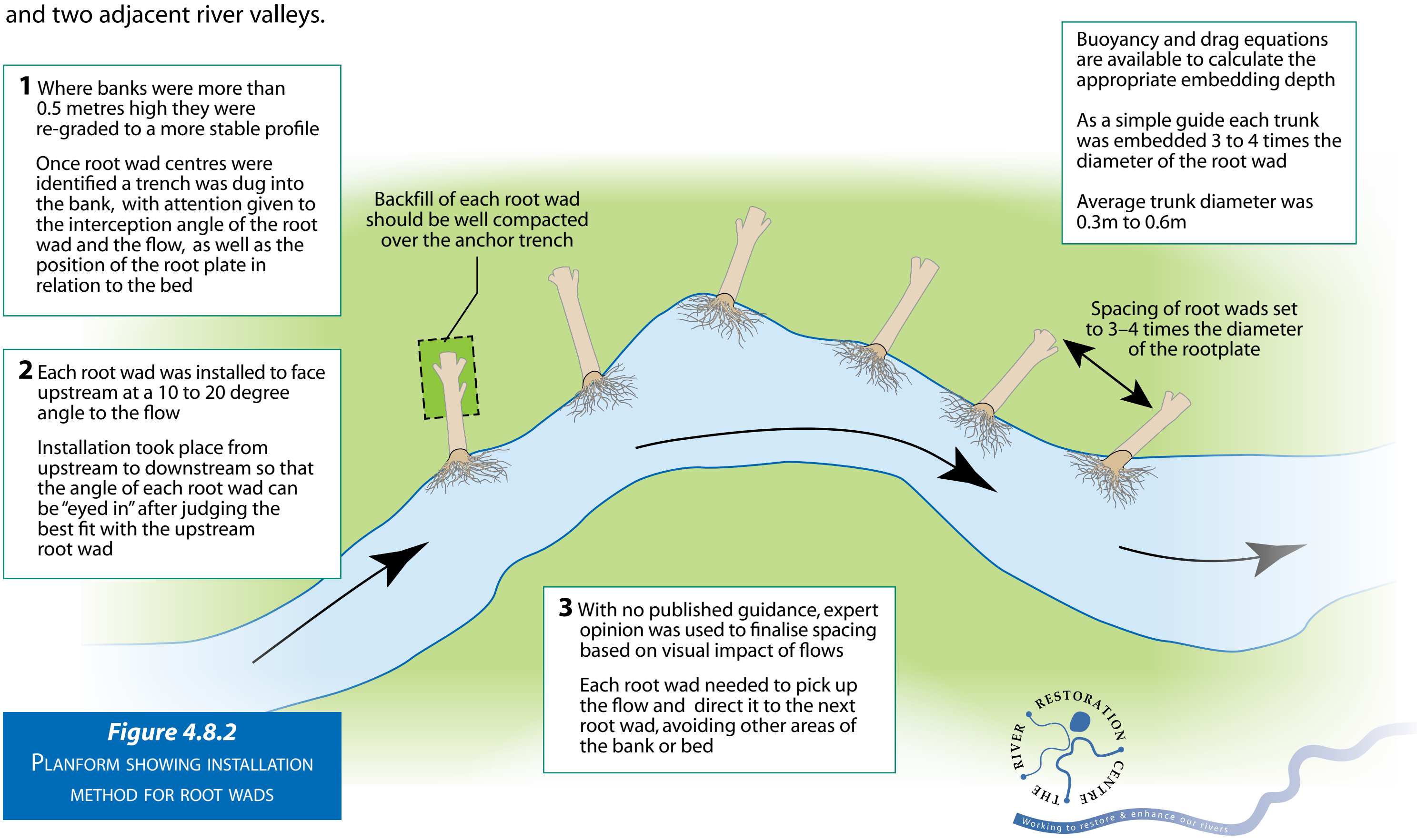


Figure 4.8.2
PLANFORM SHOWING INSTALLATION METHOD FOR ROOT WADS

4

Revetting and Supporting River Banks

© Salix

Rootwads immediately after installation looking downstream – March 2004

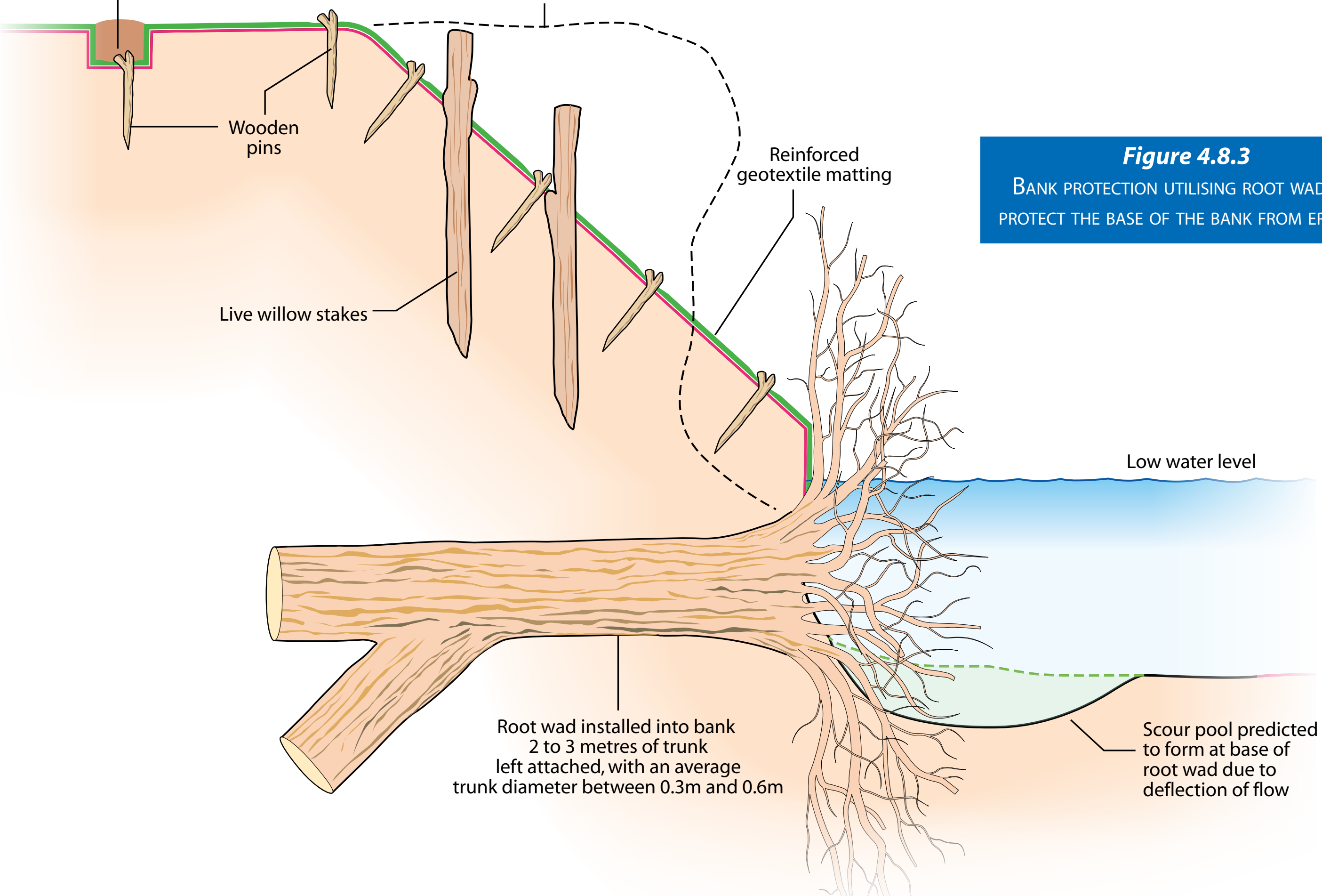


Figure 4.8.3
BANK PROTECTION UTILISING ROOT WADS TO PROTECT THE BASE OF THE BANK FROM EROSION

These techniques were developed to suit site specific criteria and may not apply to other locations

Subsequent performance

Stabilisation of a complex outer meander bend has been achieved and each of the root wads installed has grown well.

Monitoring encompassed HABSCORE and electro-fishing surveys, which were undertaken by the Environment Agency Wales just after construction in 2004 and again in 2006. Three sites were surveyed within the project reach, and a further three upstream to act as controls. At each site two semi-quantitative and one quantitative electro fishing surveys were carried out to determine population estimates for Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) fry and parr.

No marked differences were observed in fish densities between the two survey occasions, with some sites showing a reduction in fish numbers. However, it should be noted that the post-scheme surveys were undertaken just one year after the works and the full benefits are not likely to be realised until several years after implementation.

Where flow is focussed directly at the root wads, an area of localised scour has formed under the base of the exposed root ball. This provides an overhanging vegetated bank, which is a valuable new habitat feature.

Diverse bankside cover has established and cleaner gravels are present, with visibly less fine sediment. Overall the channel geometry is now similar to more well vegetated reaches of the river.

Due to its rural and over-wide location, maintenance of flow conveyance was not deemed to be an issue. Even with the very fast growth rate of willow no post-project maintenance (coppicing) was required.

© Salix

Over-wide eroding channel before restoration – 2003

© Salix

Root wads have become established, stabilising the bank and reducing erosion – August 2013

Contacts

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4

Revetting and Supporting River Banks

4.9 Brushwood mattress bank stabilisation on a tidal river

River Rother
Location – Scots Float TQ92302213
Date of construction – 2005
Length – 200m
Cost – £170,000

River Rother	Low energy, clay
WFD Mitigation measure	Click Here to view details
Waterbody ID	GB107040013670
Designation	SSSI
Project specific monitoring	Fixed point photography

Rother embankment erosion threatening to cause a breach, prior to restoration works – 2004

Description

This tidal section of the River Rother has undergone many centuries of river management for land drainage and navigation. The channel is characterised by long stretches of deposited littoral sediments. These preferentially deposit on the inside of meander bends with resultant erosion through rotational slips on the opposite (outer) banks. In some places breaching of the flood embankment is a concern.

The aim of this project was to prevent further erosion and a subsequent breach of the flood embankment by working with natural processes to encourage deposition on the eroding bank.

Design

A traditional brushwood mattress technique more commonly used on chalk streams was specified, to trap suspended sediment during tidal exchange and so stabilize the bank.

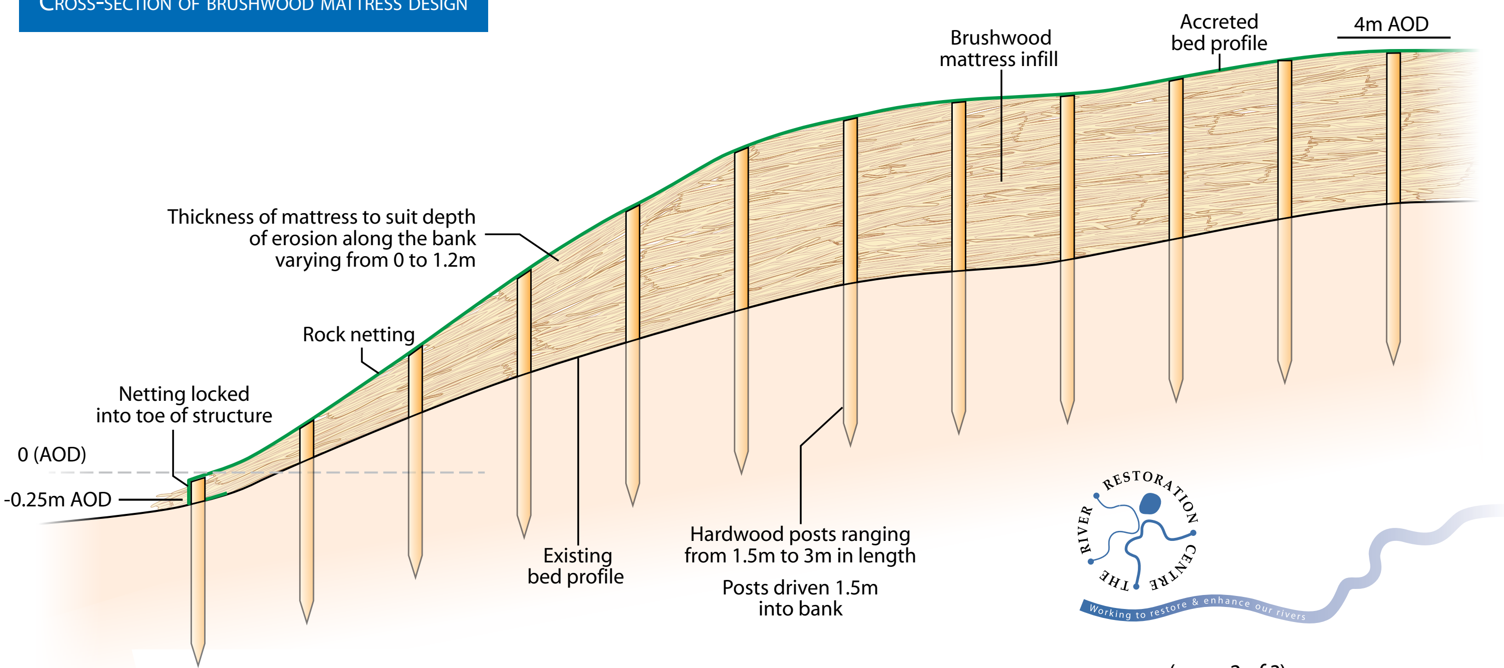
This technique can be used in estuarine environments with high sediment loads where the area is within the normal tidal range. The process of sediment deposition infills the mattress structure. Anaerobic conditions then develop which suspends decomposition of the internal woody skeleton, providing long-term integrity. There is nearby historic evidence from earlier stabilized areas that natural wood has remained intact for some 100 years.

Hardwood sweet chestnut (*Castanea staiva*) posts were used (minimum diameter of 0.125m). These ranged from 2.1m up to 4.5m in length to allow for the variation of the eroded bank profile and to ensure that at least 1.5m of each post was driven into the bank. The posts were installed in a 1m grid along a 200m section of bank, with an average width of 11m (*see Figure 4.9.1*) by a long-reach excavator. A hazel (*Corylus avellana*) brushwood mattress was then laid between the posts, using 3m to 4m long brush. Brush was installed to extend slightly beyond the last posts at the toe of the structure, to encourage sedimentation in this critical area by increasing roughness.

Installation of a matrix of sweet chestnut posts to secure the brushwood mattress – 2005

Figure 4.9.1

CROSS-SECTION OF BRUSHWOOD MATTRESS DESIGN



4

Revetting and Supporting River Banks

Brushwood laid between posts to form a matrix to trap suspended sediment – 2005

© Cain Bio-Engineering

The brushwood created walkways and safe access across the site. Hexagonal galvanised rock netting (generally used on rock and chalk escarpments to prevent rock falls) was stapled to the posts across the whole surface of the structure to prevent any brushwood being lost whilst silt was depositing. Completing this as soon as possible was essential to minimise the risk of the structure failing during construction in the event of an extreme tidal event occurring before the whole structure was stabilised. The final slope of the repaired bank had a design angle averaging 40°.

© Cain Bio-Engineering

Once brushwood mattress installation is complete, rock netting is secured to the posts to prevent wash out – 2005

Subsequent performance

Fixed point photography has shown that after seven years this technique is continuing to prevent erosion, with vegetation developing well, especially at the top of the bank.

Some of the brushwood became compressed by the weight of accreted sediment, leaving the netting standing proud above the brushwood. Cutting holes in the netting around the posts would enable it to settle with the compressed brushwood.

© Cain Bio-Engineering

Section of bank post-restoration showing successful accretion of sediments across most of the structure, with some netting still exposed – 2005

© Cain Bio-Engineering

Seven years post-restoration the structure has continued to retain sediments and has been stabilised further by vegetation on the upper bank – June 2012

Contacts

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These techniques were developed to suit site specific criteria and may not apply to other locations

5

Modifying River Bed Levels, Water Levels and Flows

5.6 Fixing whole trees into the river bank for flow diversity

River Avon

Location - Amesbury, Wiltshire. SU15834257
Date of construction - September 12th – mid October 2008
Length – 850m
Cost – £34,000

River Avon	Low energy, chalk
WFD Mitigation measure	Click Here to view details
Waterbody ID	GB108043022350
Designation	SAC, SPA, SSSI
Project specific monitoring	Fixed point photography, habitat mapping, RRC rapid assessment method

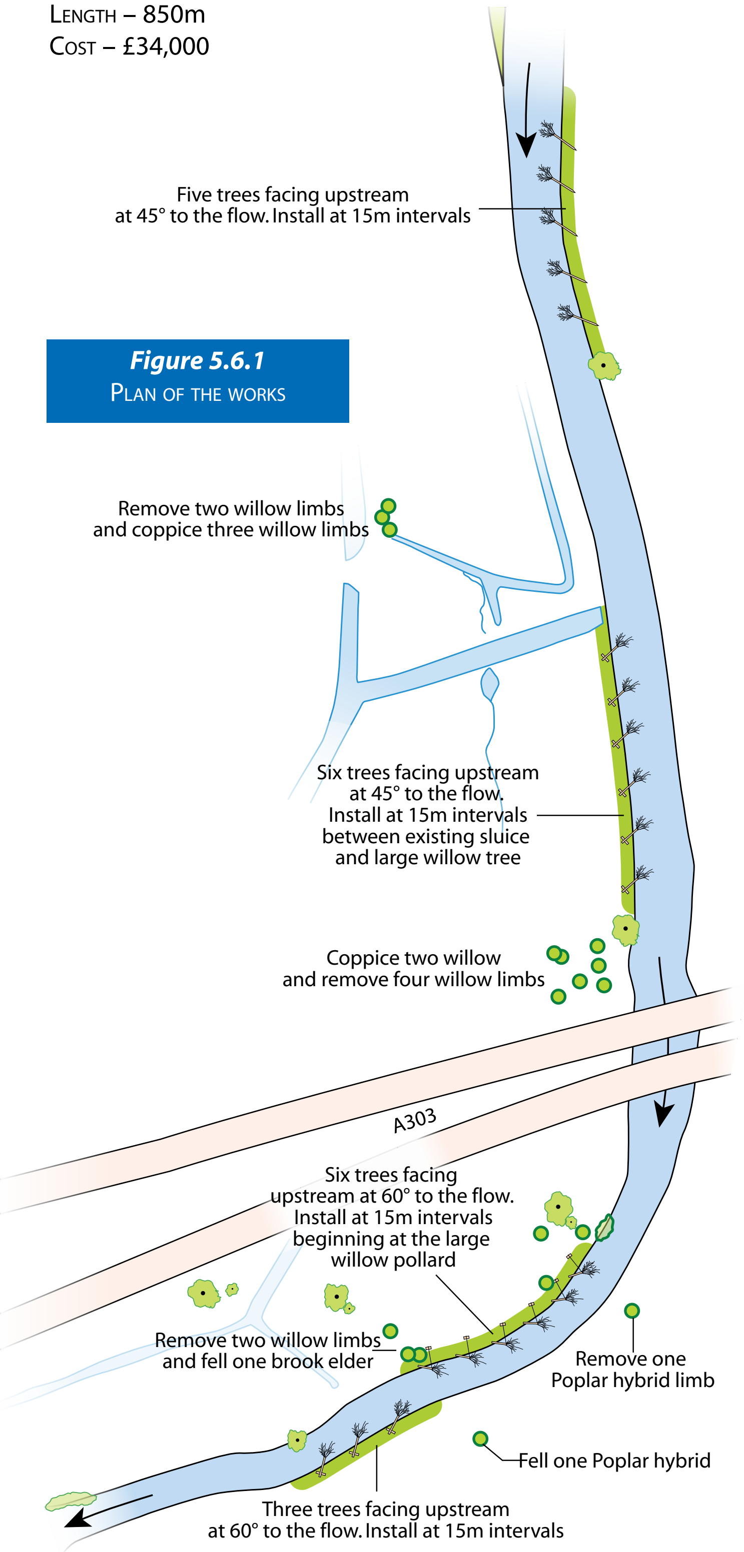


Figure 5.6.1
Plan of the works

Description

The River Avon STREAM EU LIFE project aimed to reinstate physical form and diversity, creating dynamic chalk stream habitats that are sustained by the river's natural flow regime. This particular technique was to introduce woody material (whole trees) to create a diversity of morphology and flow, particularly for SAC species such as bullhead (*Cottus gobio*), brook lamprey (*Lampetra planeri*), Atlantic salmon (*Salmo salar*) parr and the characteristic water crowfoot (*Ranunculus*) community.

As a result of historic dredging and siltation there was a lack of suitable gravel substrate for migratory salmonids to spawn on and there was a need for a shift from a uniform bed with silt-dominated substrate, to gravel and cobbles.

Though the site was within a well wooded corridor, the river had little in the way of bankside trees and the resultant lack of woody material input, along with historic dredging, had contributed to the lack of physical habitat diversity in the river.

Design

Large whole trees were installed on the left and right bank either side of A303 over a disrtance of 850m (*see Figure 5.6.1*).

Trees large enough to extend approximately 7m into the channel were used to reduce the free flowing width by 35% –50%. This reduction in high flow conveyance was deemed to be acceptable at this site following hydraulic modelling. The trees were placed at 45 – 60 degree angles, facing upstream to deflect overtopping flows towards the centre of the channel.

These techniques were developed to suit site specific criteria and may not apply to other locations

Modifying River Bed Levels, Water Levels and Flows

5

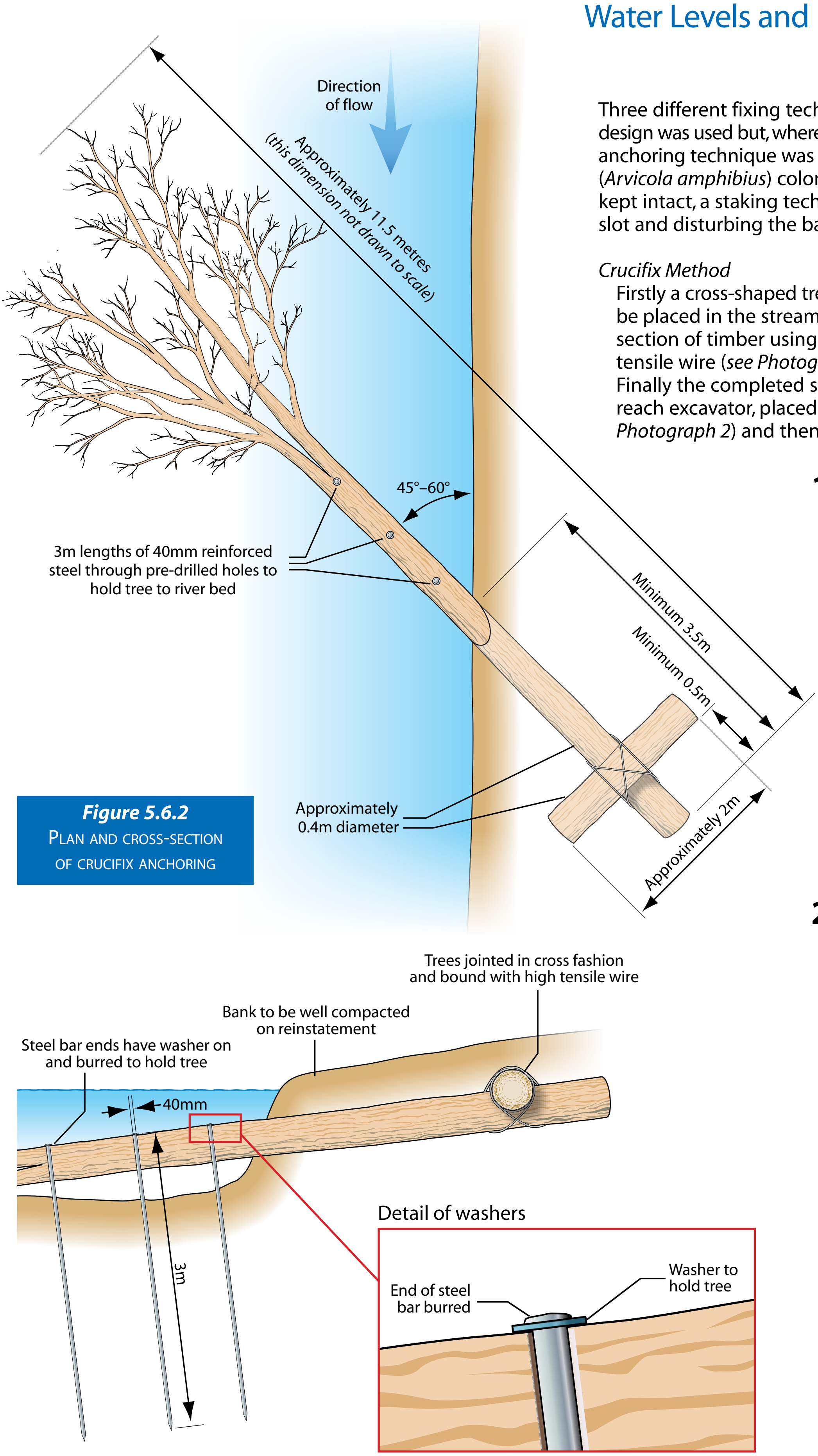


Figure 5.6.2
PLAN AND CROSS-SECTION OF CRUCIFIX ANCHORING

Three different fixing techniques were used. Initially a crucifix design was used but, where the bank was very soft, an alternative anchoring technique was utilised. Where there were water vole (*Arvicola amphibius*) colonies, or the riverside path had to be kept intact, a staking technique was used to avoid cutting a slot and disturbing the bank or path.

Crucifix Method

Firstly a cross-shaped trench was excavated. Then the tree to be placed in the stream was attached to another shorter section of timber using a mortise and tenon joint and high tensile wire (*see Photograph 1*), forming a crucifix shape. Finally the completed structure was lifted, using a long reach excavator, placed into the excavated trench (*see Photograph 2*) and then backfilled.

1

© Natural England

2

© Natural England

5

Modifying River Bed Levels, Water Levels and Flows

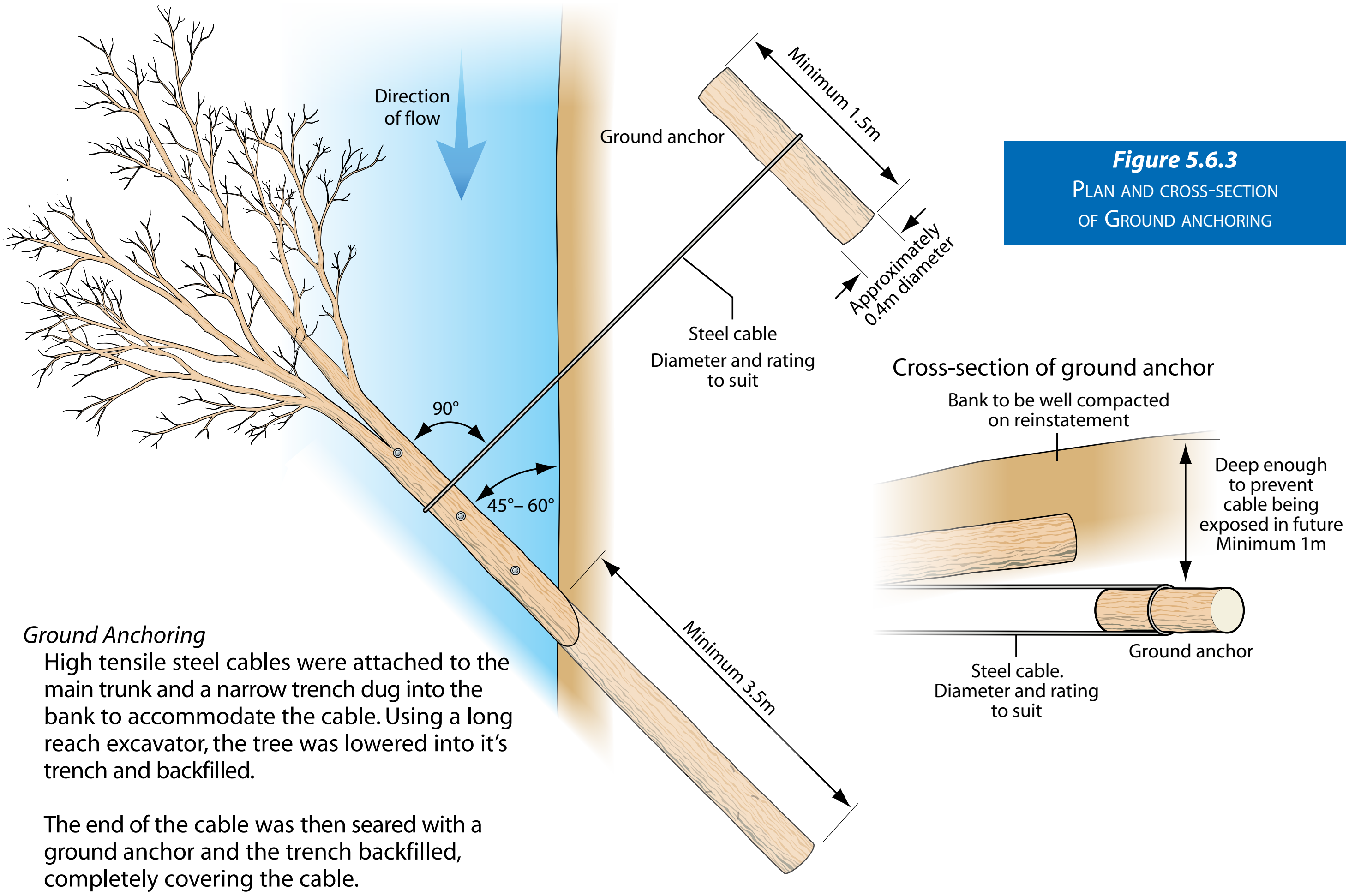


Figure 5.6.3
Plan and cross-section of ground anchoring

Ground Anchoring

High tensile steel cables were attached to the main trunk and a narrow trench dug into the bank to accommodate the cable. Using a long reach excavator, the tree was lowered into it's trench and backfilled.

The end of the cable was then seared with a ground anchor and the trench backfilled, completely covering the cable.

Staking

This was used where the river banks were soft. The end of the tree trunk to be used was sharpened and then pulled horizontally into the bank (using the long reach excavator), embeded by approximately 2 metres.

In all cases the trees were pinned to the river bed with 3m long, 40mm diameter reinforced steel bars to ensure that they did not move or pull free from the bank. Holes were drilled into the trunk before it was placed in the river. The structure was then pinned into place by the excavator bucket, pushing the bars through the pre-drilled holes into the river bed to a depth of 2m. The steel bars were a requirement to get flood defence consent for the work. However, understanding of how much achoring is required has improved.

Photograph of staking method

The sharpened end of tree trunks being pushed 2m horizontally into the bank using a long reach excavator – 2008

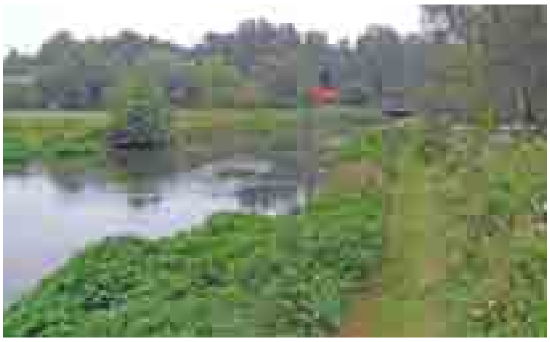
These techniques were developed to suit site specific criteria and may not apply to other locations

Subsequent performance

Reach-scale mapping of all sites was undertaken including fluvial audit, physical biotope mapping, river corridor survey and repeat photography. Results showed that the installation of woody material has created greater flow variability. There are now areas of marginal dead water and faster flowing water creating more varied habitat. Sediment accumulations are now concentrated at the channel margins rather than on the channel bed along the main flow path. This is keeping the gravel bed clean for spawning habitat and provides silty marginal habitat for brook lamprey.

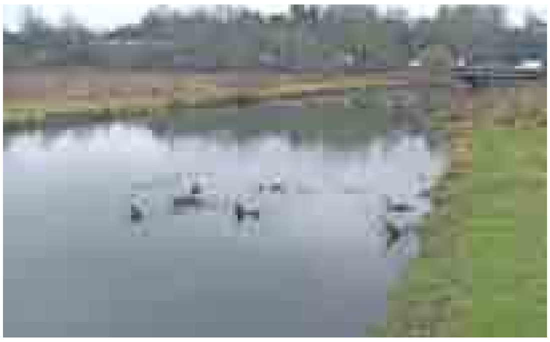
The dominant vegetation remains similar to that observed prior to restoration. Additional species were observed in 2009, including water crowfoot (*Ranunculus spp.*), watercress (*Cruciferae spp.*) and water mint (*Mentha aquatica*). The low gradient and deep channel remains a limitation on the extent and diversity of macrophyte growth within the channel.

The aquatic plants are annually managed by cutting throughout the River Avon catchment. The fishing club initially reported problems for their weed cutting boat, so in some reaches 1.5m to 2m was cut off the outer ends of the submerged trees. In other places they have been trimmed where they protruded above water level to reduce snagging of fishing lines and the cut weed.



Wide slow flowing channel lacking flow variability – August 2008

© RRC



Trees installed on the right bank. Submerged with branches just protruding out of the water – January 2009

© RRC

One year later, wood deflectors are collecting rafts of weed and providing shade, cover and habitat. Silt has been deposited between the deflectors.

Marginal plants are now starting to establish in the silt narrowing the channel – July 2009

© RRC

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Reference material – Click here

5

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Modifying River Bed Levels, Water Levels and Flows

5.7 Felling and placing trees for habitat and flow diversity

River Bure

Location - Blickling Estate, Norfolk. TG161301
Date of construction - Phase 1 - Nov. 2008
- Phase 2 - Nov. 2010
Length – 300m
Cost – approx. £5,000 (including staff wages, chainsaw fuel and volunteer expenses)

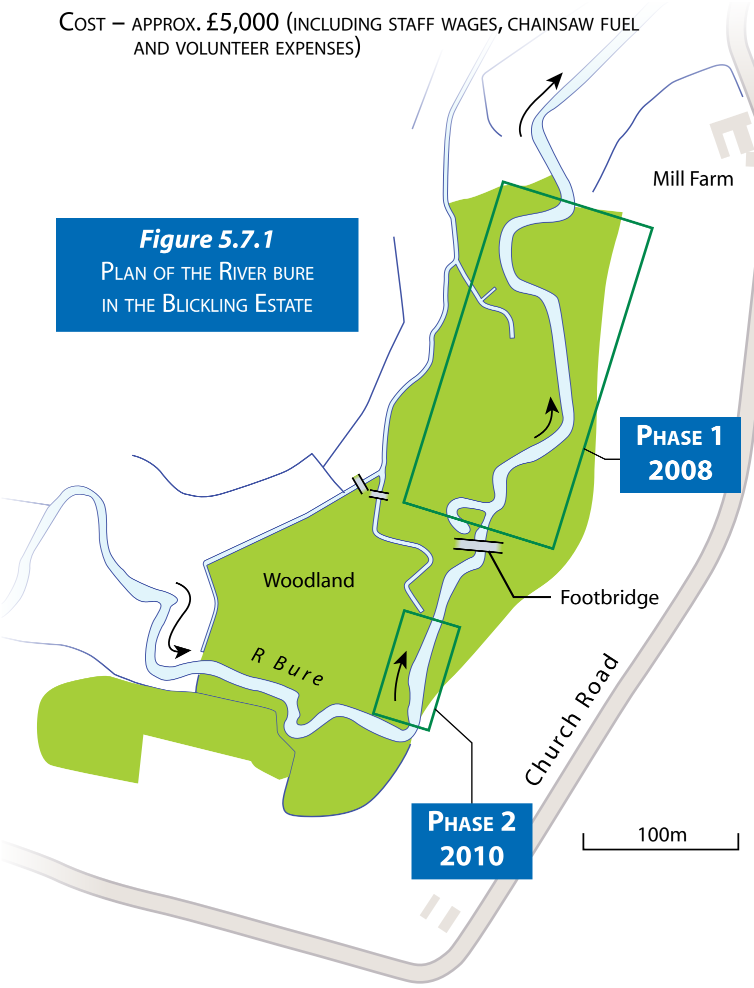

Figure 5.7.1
Plan of the River Bure in the Blickling Estate

River Bure	Low energy, gravel
WFD Mitigation measure	**Click Here** to view details
Waterbody ID	GB108049007170
Designation	SAC, SPA, SSSI
Project specific monitoring	Fish, macroinvertebrates, plants, sediment transport and distribution, flow velocity, substrate characteristics,

Woody material (entire trees) was felled into the channel in as natural a form as possible to increase flow variability. It was envisaged that the trees would either create scour or trap mobilised silt and sediment. Marginal deposition would eventually vegetate and stabilise creating a faster flowing, narrower channel with clean gravel substrate.

Description

The aim of the project was to re-establish the natural river processes interrupted by past management and to provide morphological, hydrological and habitat diversity. The project was completed in two phases. The project was low cost, used on-site materials and had minimal impact on the riparian zone.

The River Bure at Blickling National Trust Estate had been historically altered for milling and, more recently, meanders were cut off at the end of the 19th century. The local channel gradient is moderate (between 1 in 300 and 1 in 800) and the river has a gravel bed with a significant overlying silt layer in an over-widened channel. The river is flashy, prone to high flows during and after heavy rain especially in the winter. The riparian and adjacent land is well wooded, with alder and willow carr and remnants of ancient woodland.

Design

There was no formal desk-based design process for this technique beyond the broader planning of the improvement of the river reach. Rather, an intuitive approach was used in the field, as near as possible forming natural features with natural materials.

Flow diversity was achieved by felling whole trees in to the river channel and leaving them in situ as much as possible. Generally the selected trees were those which were leaning over the water already which were likely to eventually fall into the river. An application for Flood Defence Consent was submitted to the Enviroment Agency detailing this approach. The proposed works were accepted as in this particular location it was determined that there was no increase in flood risk to adjacent properties.

As a channel had to be kept open, some repositioning was made with the use of a small hand winch. Often a second felled tree pinned down one already lying in the water, so it was not always necessary to stake the trees to keep them in place. It was necessary to stake some of the trees. 1.5m peeled and pointed stakes were used to wedge the butt end of the felled trees until the tree became waterlogged. It was envisaged that a certain amount of movement of trees would occur in flood events.

The site was intended to remain dynamic adjusting to natural processes. The remaining riparian tree cover will continue to contribute fresh woody material. Due to the relatively low cost, materials used and support of the landowner it would be fairly simple to move the trees if problems arose, so there was scope to be bold with the works.

These techniques were developed to suit site specific criteria and may not apply to other locations

Modifying River Bed Levels, Water Levels and Flows

1 Select trees which are already leaning over the water and are likely to eventually fall in the river.

2 Fell them so that they remain attached to the stump (often referred to as 'laying' or 'hinging') or so that part of the trunk stays on the bank. Allow branches to penetrate the river bed to increase the stability of the tree and to prevent the tree from rolling or being mobilised by the flow.

3 Modify the position if necessary to maintain an open channel if the felled tree blocks the flow. If absolutely necessary, prevent movement with a 1.5m stake.

Once the wood is waterlogged it will become less prone to movement at low to medium flow events. However, significant flood events may still cause major re-working and movement. Similar schemes elsewhere have used tethering to prevent downstream movement of placed woody material.

4 Fell more than one tree on top of each other to provide a greater mass to the structure and give a dense web of branches.

Subsequent performance

Up to 2013 the technique has had no negative outcomes and no adaptive management has been necessary. There is a possibility that some of the material may move so the site is visited by the National Trust countryside staff a few times a year, especially after high flows, to see if there are any issues. So far no significant movement has occurred, despite significant flooding which occurred in March 2013.

There is scouring of fine sediment and exposure of gravel in areas where the structures have concentrated flow. The movement of sediment and the colonisation by marginal plant species around the wood structures can be seen. These observations appear to support effective narrowing of the over-widened channel and an increase in physical habitat complexity.

This technique has caused a local change in attitude to in-channel woody material in that requests from the fishing club to remove trees that have fallen in to the river have all but ceased. Instead the request is to modify their position so as not to block the river. This also has a benefit through reduced management costs from not having to use large machinery to lift or winch trees out of the river.

Pre-works monitoring was only undertaken for the second phase (2010) and consisted of flow velocity, substrate characteristics, fine sediment distribution, bed topography and aquatic plants. An upstream wood-free section has also been similarly monitored. Repeat surveys have been undertaken in 2010, 2011 and 2013. Results will be published at a later date as part of a PhD thesis. The project team has committed to continuing the survey work to enable critical evaluation of the works.

© Dave Brady

Before – Over widened silt laden channel

© Dave Brady

After – With narrowed channel and vegetated berms where silt has built up downstream of the felled trees – 2012

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Reference material – Click here

5.8 Gravel reworking to restore a low flow channel

River Darent
Location - Hawley Manor, Kent, TQ55207213
Date of construction - September 2005
Length – Approx. 250m
Cost – £1,800

River Darent	Low energy, chalk
WFD Mitigation measure	Click Here to view details
Waterbody ID	GB106040024222
Designation	None
Project specific monitoring	Invertebrates, vegetation

© Alconbury Environmental

Over-widened channel prone to low flows. Little or no marginal or submerged vegetation – July 2005

Description

The River Darent in the Dartford area has been heavily modified over many years, including changes to channel planform, the implementation of land drainage schemes and abstraction, leading to an over widened channel. Prior to restoration this section of river, two miles upstream of Dartford, was very uniform with a shallow gradient. The natural substrate is dominated by gravel but had become overlain by silt. Flow and habitat diversity was limited with negative impacts on fish and macroinvertebrate communities.

The aim of the project was to demonstrate that the processes that sustain a healthy chalk stream could be restored and the habitat protected during drought periods. This was to be achieved in a cost-effective way by re-working the in-channel gravels to form a low flow channel. The restoration work contributed to Chalk Rivers Biodiversity Action Plan (BAP) targets and complemented the implementation of the Darent Action Plan (1992).

Before (top), during (middle) and immediately after (bottom). The low-flow channel now occupies approximately 50% of the previous bed, supporting an improvement in flow depth and velocity – September 2005

© Alconbury Environmental

These techniques were developed to suit site specific criteria and may not apply to other locations

Modifying River Bed Levels, Water Levels and Flows

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Figure 5.8.1
Sequence of gravel redistribution and planting

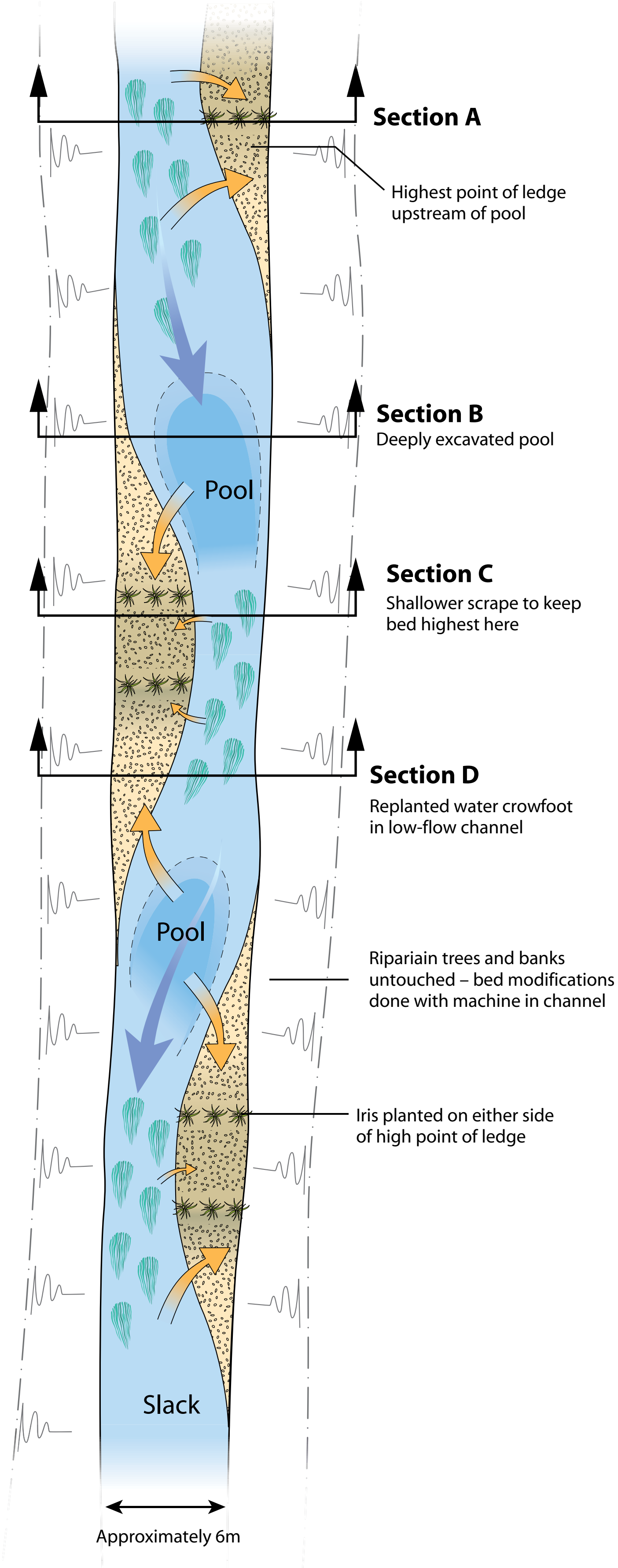
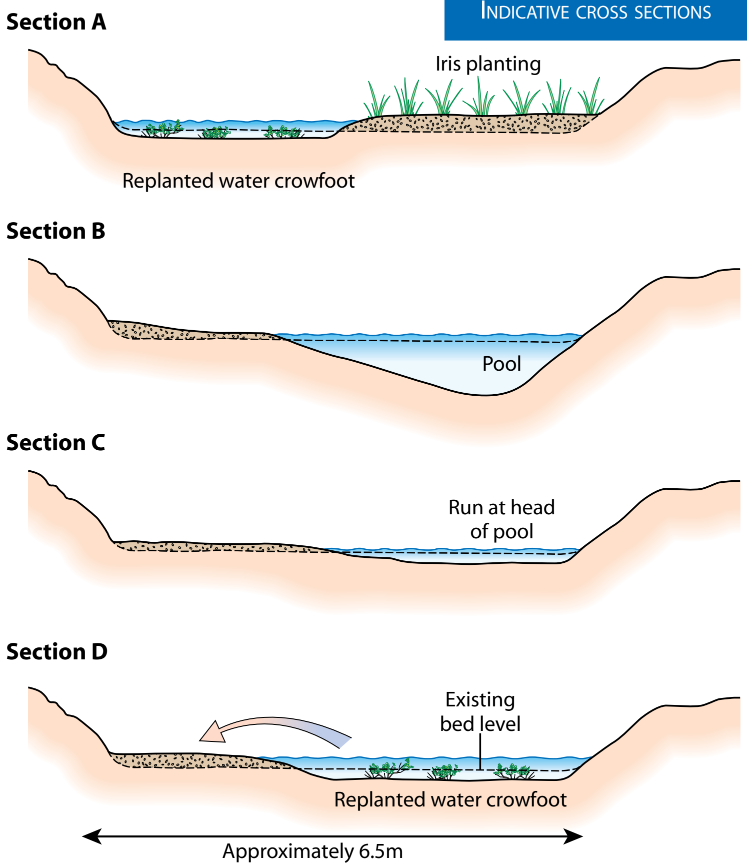


Figure 5.8.2
Indicative cross sections



Design

All of the bed modifications were carried out from within the channel, so that the banks and trees were left untouched. The channel was re-profiled using a long reach excavator creating a sinuous channel, with pool and riffle sequences, still within the confines of the original channel.

The excavator accessed the river where there were suitable gaps between trees and the creation of gravel berms at these points enabled the excavator to exit the river without damaging the completed work.

A low flow channel was created by moving small amounts of gravel in a meandering path. Part of the bed was kept at a higher elevation to create a sequence of riffles.

In other areas more significant quantities of gravel were redistributed enabling pools to be created. Pools, spaced at approximately 20m intervals, were designed to be self-cleaning. Gravels were placed upstream of each to narrow the flow and increase velocity to induce scour in these pools.

The whole of the construction phase was supervised by the designer who was on site throughout the work and provided instructions to the excavator driver.

Existing bankside trees with large root systems acted as natural deflectors and provided a variety of marginal habitat. A small amount of planting was carried out, including water crowfoot (*Ranunculus spp.*), yellow flag (*Iris pseudacorus*) and purple loosestrife (*Lythrum salicaria*). The water crowfoot was sourced locally from the Darent.

Subsequent performance

Photographic evidence shows that the in-channel features created as a result of the works have been maintained over the subsequent seven years and are still present. However, no detailed morphological assessment has been undertaken. Clean gravels can be seen throughout the reach and the low flow channel, pools and riffles provide improved fish habitat.

Comparison of pre and post-works invertebrate monitoring, using the Proportion of Sediment-sensitive Invertebrates (PSI) method, demonstrates an overall improvement in the composition of species indicative of good chalk stream habitat conditions. A significant increase in the numbers of less silt tolerant species, for example blue-winged olive mayfly (*Ephemerella ignita*), has been observed along with a decrease in more silt tolerant species, for example caddis fly (*Trichoptera spp.*). This supports the observations that the blanketing silt has been replaced by well oxygenated clean gravel. Further invertebrate monitoring is scheduled to be carried out at this site, and others on the Darent, in spring and autumn 2013.

Vegetation surveys were completed pre and post-works (2004 and 2008) using the Mean Trophic Rank (MTR) method. Successful establishment of the vegetation that was planted was observed. Dense areas of reedmace (*Typha latifolia*) fringe the river and a good proportion of water crowfoot was recorded in the channel following the works. These observations were supported by an improvement in the MTR score from 35 to 42.

Additionally, the work has provided a more attractive riverscape and as a result Dartford Borough Council is currently working to improve the standard of footpath access adjacent to the river.

This scheme represents a good example of a small scale, low cost technique. The scheme also demonstrates the value of having an expert on site during construction and what can sometimes be achieved within a day.

5 years on the channel is narrower and more sinuous. Vegetation, both submerged and riparian, has established well – May 2010

Contacts

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5

Modifying River Bed Levels, Water Levels and Flows

5.9 Replacing an armoured bed with boulder step-pools

Inchewan Burn
Location – Birnam, near Perth, Scotland NO017405
Date of construction – September – November 2007
Length – 100m
Cost – £100,000

Inchewan Burn	High energy, gravel
WFD Mitigation measure	Click Here to view details
Waterbody ID	150290
Designation	None
Project specific monitoring	Hydraulic habitat, fish

Description

The Inchewan Burn is a tributary of the River Tay SAC and flows through the village of Birnam. The upstream section retains much of its natural character, though in a heavily forested valley. The catchment is steep and flashy which has caused flooding in Birnam in the past.

In the 1970s the village was bypassed by the A9 trunk road, which runs alongside the main Edinburgh to Inverness railway. At this location a 100m reach of the burn was realigned and channelled between the supports for the road bridge. The channel was stabilised using concrete, gabion baskets and a stepped Reno Mattress base. These wire structures had begun to break down and became a barrier to Atlantic salmon (*Salmo salar*), a feature of the Tay SAC. In low flow conditions this reach had no surface water flow, with all water flowing through, rather than over, the loose stone and wire. This heavily degraded reach was restricting access to 3km of good spawning habitat upstream, though a steep natural chute restricts upstream fish movement until high flows.

Close up of the degraded Reno Mattress base – 2007

© A.Pepper

© RRC

Before restoration works showing complete failure of the wire structure and no surface flow – August 2006

Although the bed could be replaced, work on the banks was still heavily constrained as they provide structural foundations for the A9 (the concrete right bank) and support to the re-graded steep left bank (a three tier gabion wall).

The aim of the scheme was to recreate a boulder step-pool bed to mimic the natural upstream character of the burn, and so improve fish passage for salmon.

These techniques were developed to suit site specific criteria and may not apply to other locations

Design

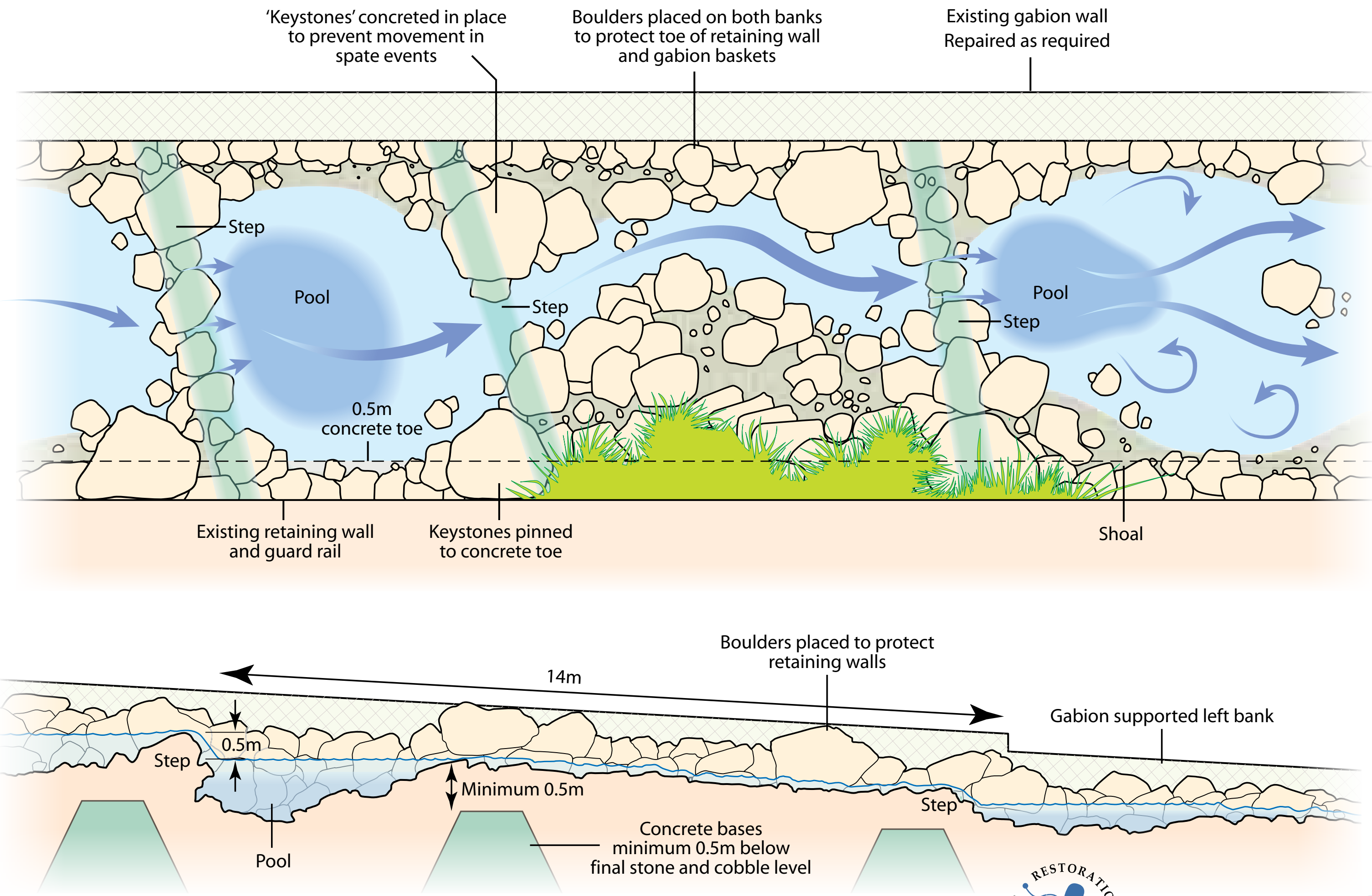
The method statement for the works was a simple concept based on utilising the gradient of the degraded reach (1 in 14) to form a series of step-pools, replicating as closely as possible the upstream bed form (*Figure 5.9.1*).

A schematic of the reach illustrating the repeat step and pool features (all varying in boulder arrangement) helped to guide the contractor. Further guidance was provided using the upstream reference site to aid discussions with the RRC and the supervising local ghillie.

© RRC

The natural channel, a few hundred metres upstream, showing the variable step-pool configuration formed by large boulders – November 2005

Figure 5.9.1
SCHEMATIC OF STEP-POOL SEQUENCES AND LONG PROFILE



This meant that the contractor only had minimal fixed dimensions (the number of steps, step drop and distance between steps) to guide the placement of boulders, and the instruction to make it resemble the upstream template reach as far as possible.

First, the wire from the disintegrating mattressing was removed. The cobbles that had been transported downstream were retained for reuse. The work was carried out during a dry period, with all of the low flow in the burn routed through a 0.5m diameter pipe.

The large boulders required for the bed were sourced from local field stone piles. These were lowered in to the burn and placed using a system of levers and pulleys. The largest (0.5 tonne) were used as 'keystones', mimicking the upstream channel where the largest boulders were integral to the step features, retaining the smaller interlocked boulders (the 'step') behind them.

The high gradient meant that there was a need to ensure that the keystones did not move. For this reason, a buried concrete base and steel pins were used to fix the most critical bed elements. Where concrete was to be used to bed-in the steps, it was specified to be buried at least 0.5m below the stone and cobble base to ensure that it remained unseen (*Figure 5.9.1*).

© SEPA

Wire from mattresses in bed removed. The stone was retained to use in the new step-pool system – 2007

© SEPA

Excavating for the concrete base to bed the larger boulders – October 2007

© SEPA

Steel pins in the concrete retaining wall toe awaiting boulder placement – 2007

The vertical concrete right bank (i.e. the road bridge footing) was constructed with a 0.5m wide toe which had previously been hidden beneath the wire mesh bed. This stepped ledge needed to be hidden by the new works (for aesthetic reasons and to prevent undercutting) and therefore provided a secure foundation for locating a number of the keystones. The boulders and concrete ledge were both drilled and the boulders then fixed in place with resin and steel pins.

Modifying River Bed Levels, Water Levels and Flows

Immediately after completion – December 2007

© RRC

Beneath the A9, five years after – May 2012

© RRC

Boulders were also placed along the gabion basket left bank retaining wall, partly to hide the gabions but also to protect them from the abrasive throughput of bed material which had destroyed the Reno Mattress base.

The restoration works were coordinated and supervised by the local ghillie, and funded by Transport Scotland, with input from RRC, SNH, SEPA, Scottish Native Woods and Perth & Kinross Council.

Subsequent performance

In December 2007, the local ghillie observed salmon, sea trout and brown trout (*Salmo trutta*) swimming through the reconstructed section of the burn and upstream once more. The work has made a dramatic improvement to the aesthetics of the reach, which is appreciated by regular users of a footpath close to the river bank.

Monitoring by the University of Stirling in 2009 compared the hydraulic habitat and fish density in the unmodified upstream reach with that of the restored reach. This showed that hydraulic habitat had been successfully restored and that juvenile salmon and brown trout were colonising this reach. However, passage upstream was being impaired by the shallow masonry culvert bed beneath the railway.

The success of the scheme was in part a result of basing its design on the upstream reference reach. This provided a visual template for restoration which could be easily understood as a 'shared vision' by the design engineers, stakeholders and contractor.

© RRC

The restored reach mimicking the step pool configuration of the upstream reach– May 2011

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Reference material – Click here

5.10 Creating 'natural' features in a heavily engineered flood scheme

River Valency

Location - Boscastle, Cornwall SX10009123

Date of construction - 2007/8

Length – 300m

Cost – not known (part of a £6.3m flood risk management scheme)

River Valency	High energy, gravel
WFD Mitigation measure	Click Here to view details
Waterbody ID	GB108049007170
Designation	None
Project specific monitoring	Fish

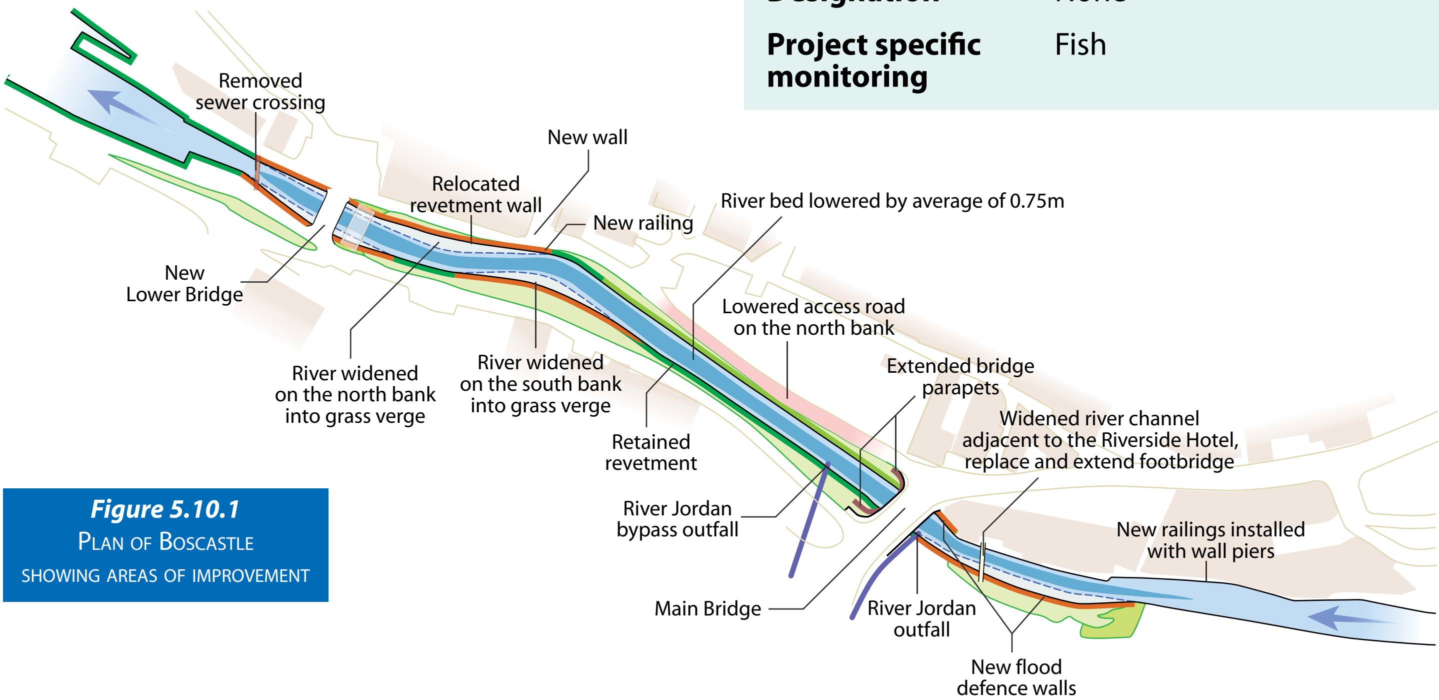


Figure 5.10.1
Plan of Boscastle
showing areas of improvement

Description

Boscastle village is located in a steep sided and narrow valley through which the River Valency flows down to the harbour. In 2004 an intense storm centred over the small wooded catchment caused massive erosion of sediment and river-side trees. This, combined with high flows, inundated the village with water and debris causing extensive damage.

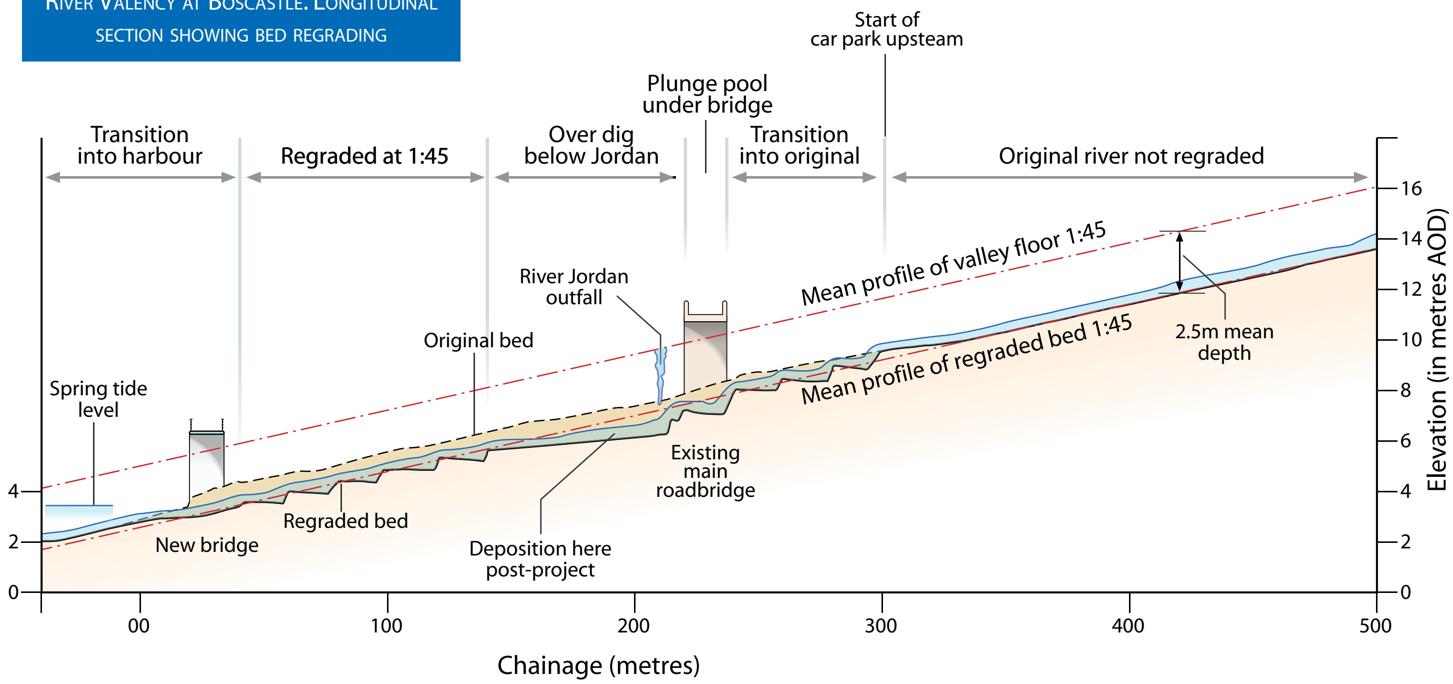
The village is of great historic value and is a main attraction for visitors to North Cornwall. The river itself is the centrepiece of the village. The process of Enviromental Impact Assessment (EIA) and landscape appraisal led to the best engineering design that would deliver the multiple flood risk, landscape and environmental objectives.

Enlargement of the river channel offered the only viable way to reduce flood risk and improve the flood capacity and sediment conveyance of the river. The scheme aimed to demonstrate 'best practice' in achieving this sympathetically, so avoiding a deep geometrically uniform channel. The channel was designed in such a way that it simulated the natural features found higher up in the undisturbed reaches of the river by engineering features into the excavated bedrock.

Natural cascade and pool upstream of Boscastle – 2006

Modifying River Bed Levels, Water Levels and Flows

Figure 5.10.2
RIVER VALENCY AT BOSCASTLE. LONGITUDINAL SECTION SHOWING BED REGRADING



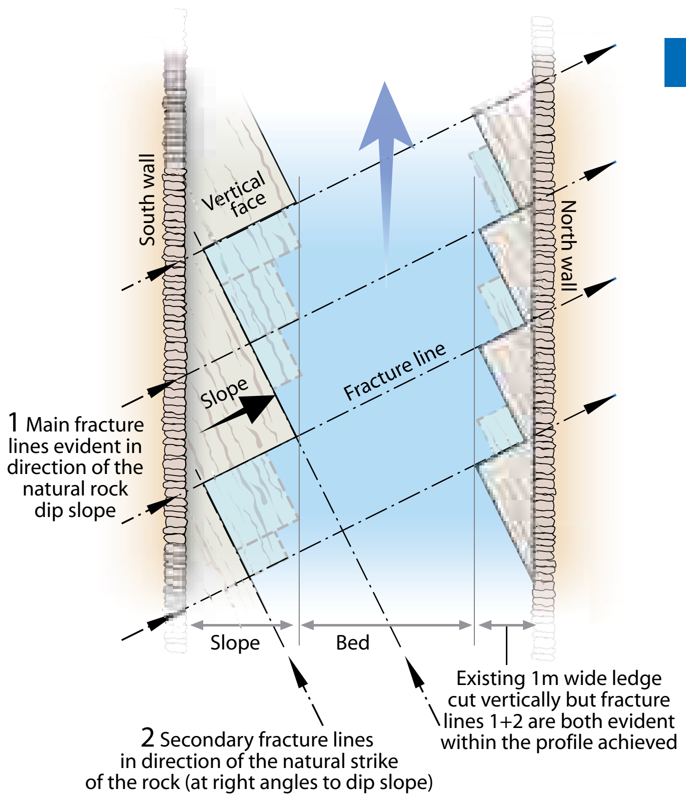


Figure 5.10.3
SIMPLIFIED PLAN OF THE RIVER CHANNEL SHOWING THE EFFECT OF NATURAL FRACTURE LINES WITHIN THE ROCK BREAK

Design

A detailed topographical survey of the longitudinal profile of the river was an important design tool. This enabled a new, lower bed gradient to be superimposed onto the original one, giving the 'best fit' with the levels upstream and downstream of the reach.

The natural valley slope at Boscastle is 1 in 45 and the channel bed upstream of the village has a depth of approximately 2.5m. Extending this channel depth down through the village to the harbour, the longitudinal section showed the original bed to be typically 1 metre higher. This helped to explain the loss of capacity through the village and its propensity to flood. Bed regrading to this 2.5m depth profile was therefore considered feasible (*Figure 5.10.2*).

The design of the cross section and longitudinal profile of the lowered bed involved close study of the natural characteristics of the rock visible in the upper river and in the harbour. The rock featured strong bedding planes that typically dip from left to right bank, angled downstream at about 45°. It had vertical fracture lines as well as regular intrusions of much harder quartz. Concept drawings were provided to show how the rock was to be removed. An engineer worked closely with machine operators to obtain the desired result of the left side sloping with the dip and the right side vertical along the fractures. Both sides were zig-zagged to stay within the 'character' stone retaining walls.

5

Modifying River Bed Levels, Water Levels and Flows

© Halcrow

The low flow course had to be entirely excavated to best mimic millennia of erosion of a hard rock bed.

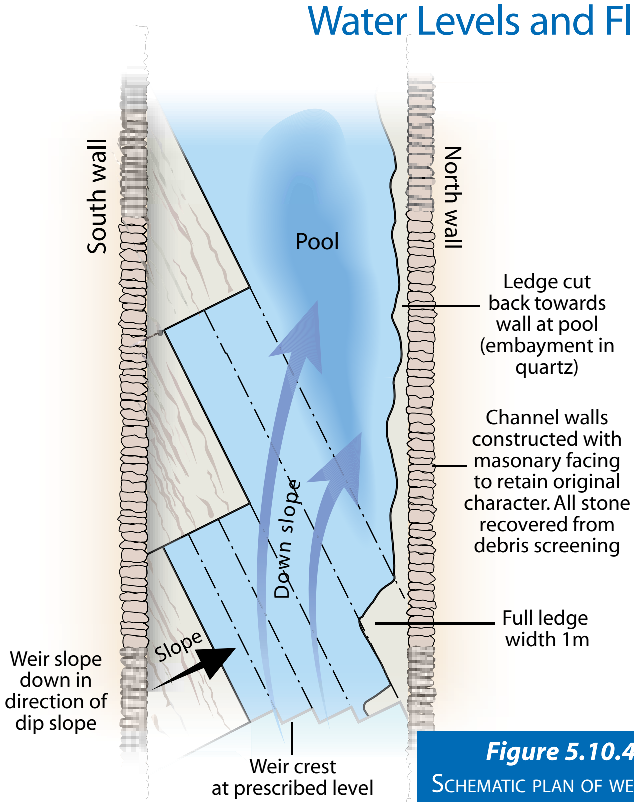


Figure 5.10.4
SCHEMATIC PLAN OF WEIR AND POOL IN QUARTZ STRATA

Understanding the geology and morphology of the river was critical to the design. This avoided the potential problems that can arise if the rock is broken out in a way that does not mimic the natural structure. For example simply cutting to a uniform profile could trigger subsequent collapse as the river erodes the rock back to a naturally stable profile.

Cascades with pools below were formed along the bed with nominally 0.2m drops at 9m intervals to approximate the 1 in 45 gradient. Excavation was only undertaken under the supervision of an experienced river engineer, enabling every aspect of the final topography to reflect the specific nature of the rock in situ as it was worked. The alternative of trying to detail the bed profile for the contractor would have been impractical.

© Halcrow

Deepened channel using natural fracture lines within the bedrock. Retaining walls becoming vegetated

These techniques were developed to suit site specific criteria and may not apply to other locations

Subsequent performance

The re-profiled river has performed well during the years since completion. The excavated profile has remained stable, as have the individually sculpted cascades, pools and embayments. Within the latter a good diversity of flow characteristics provides niche habitats, with some gravel in sheltered eddies as well as small beaches. It is also visually attractive, enhanced by the sound of the cascading water. This contrasts markedly with the flat, featureless river bed that existed before.

© Halcrow

Gravel beaches have formed within the bedrock channel

A single negative aspect has been the excessive deposition of stony sediment at one location. This is where the bed was significantly cut down below the optimum mean bed gradient of 1 in 45, to provide greater flow capacity where an overspill culvert of a tributary stream, the River Jordan, enters (*See Figure 5.10.2*). Bed material has simply filled this over-deepened pool to bring the bed back up to the 1 in 45 mean. Consequently there are no rock features in the bed here. This outcome was foreseen and this 'pool' had been designed such that the excess fine deposits would remobilise during flood flows, thus

© Halcrow

River Jordan outfall. The over-deepened pool has clearly filled with large stone sediment – October 2008

restoring channel capacity when required. As an additional part of the scheme, large sediment is now intercepted upstream of the village, but an intermediate reach has scoured clean and it is this larger material that has filled the pool. This is planned to be removed to see whether or not subsequent, finer sediment will remobilise as intended.

The project demonstrated that visual references for the contractor were essential, in the form of site visits and first hand explanations. This helped the design consultants and contractor to understand the complexity of the project's requirements.

Observations suggest that the key objectives of lowering the bed to provide greater flood capacity whilst creating a functioning and visually attractive landscape have been achieved. Electrofishing surveys carried out two years after completion found Atlantic salmon (*Salmo salar*) and other migratory fish such as eel (*Anguilla anguilla*) had navigated to the upper catchment.

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Reference material – Click here

6

Managing Overland Floodwaters

6.4 Breaching a flood bank to reconnect active floodplain processes

Burn of Mosset

Location - Forres, Moray, Scotland NJ04955727
Date of construction - 2008
Length - 500m
Cost - £100,000

Burn of Mosset	Medium energy, gravel
WFD Mitigation measure	Click Here to view details
Waterbody ID	23021
Designation	None
Project specific monitoring	Annual & reactive

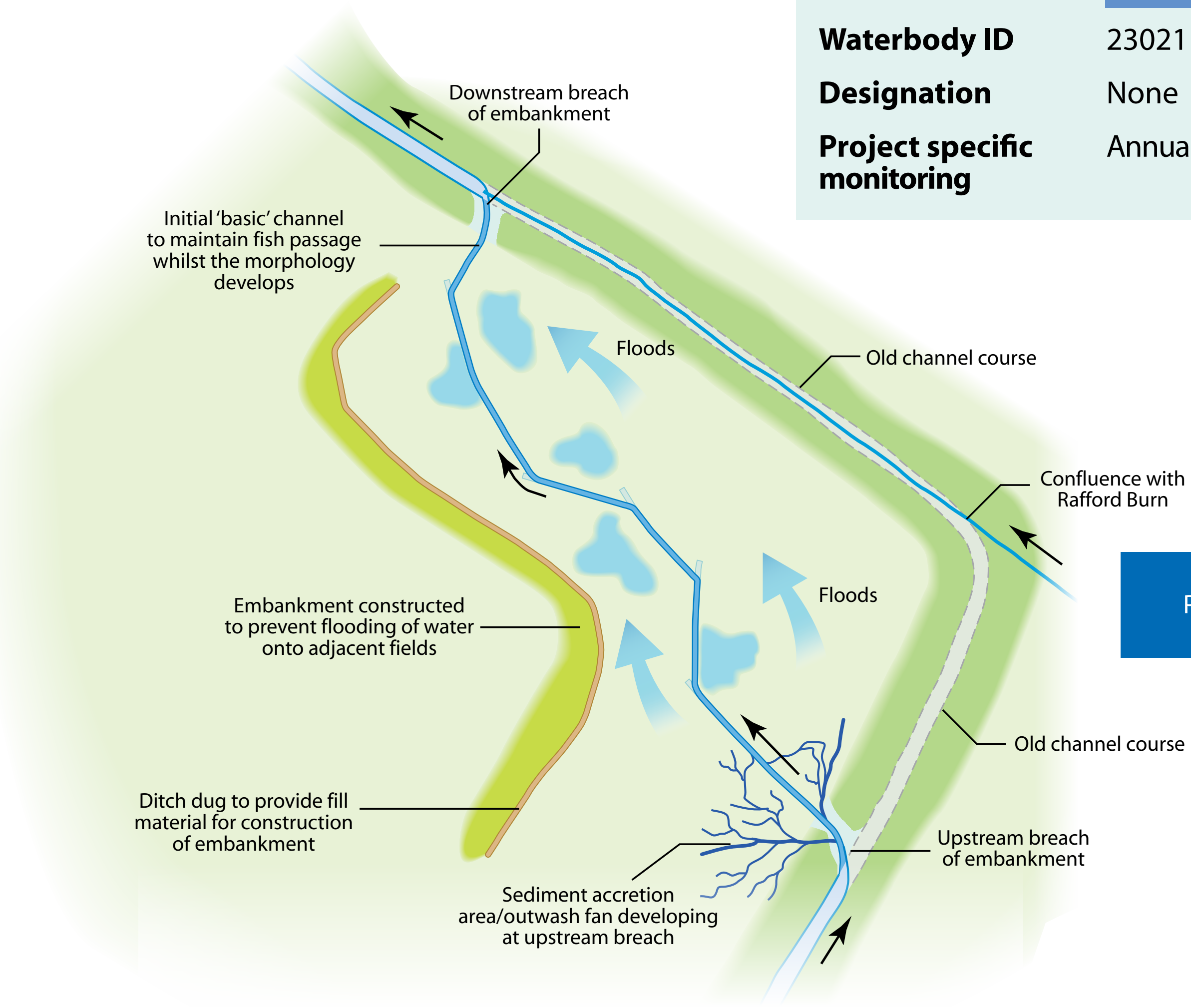

Figure 6.4.1
Plan view of the sediment acretion area

Description

The Burn of Mosset is a small but geomorphologically active gravel-bed stream that drains an area of 49km^2. It flows northwards through the town of Forres before entering Findhorn Bay. Forres has had a long history of flooding from the burn, with six events causing serious property damage and disruption within the last 50 years.

A new Flood Alleviation Scheme (FAS) included the construction of an upstream earth fill embankment dam designed to allow for discharges up to 8.5 m^3/s to flow through Forres, with excess floodwater temporarily stored behind the dam.

This upstream storage area, the focus of this case study included an extensive natural sediment accretion zone. It has a large capacity to store sands and gravels and also retain large woody material. This will reduce the risk of sediment blockage or damage of the dam control structure from sediment or large wood respectively.

The implementation of this natural sediment accretion zone replaced the need for a conventional sediment trap as part of the wider FAS.

The work aimed to create a mosaic of river and floodplain habitats by allowing active river processes to develop a multi-threaded (anabranched) system together with floodplain wet woodland features.

Prior to the work, the burn was a degraded perched watercourse and flowed around the edge of the field (*see Figure 6.4.1*), with dredged spoil deposits used to build the flood embankments, thus disconnecting the burn from its floodplain area.

Design

Two breaches of the existing embankments (*see Figure 6.4.1*) were created to allow flow to spill out across the floodplain. Their locations were selected using LiDAR imagery to identify low areas of land suitable for the course of the temporary "basic" channel, which was constructed to ensure that there was no interruption in migratory fish passage.

The overall aspiration was to then allow natural processes to develop a multi-thread watercourse. Initially the upstream breach in the bank was set to maintain 80% of the lower flows in the existing channel, and protected using thirty tonnes of locally sourced granite placed within the breach opening. This was to ensure that species within the existing channel could continue to use the available habitat whilst the new watercourse continued to develop.

A low embankment was constructed parallel to the new channel close to the site boundary (*see Figure 6.4.1*). this was to protect adjacent fields outside the area of the burn management works from flooding. Material was won from digging a small ditch which avoided the need to import fill over very soft ground.

Tree planting was undertaken as part of the scheme to encourage the development of wet woodland. Only tree species native to eastern Scotland and of local provenance were selected for planting including: common alder - *Alnus glutinosa* (25%); silver birch - *Betula pendula* (25%); sessile oak - *Quercus petraea* (25%); rowan - *Sorbus aucuparia* (15%); and goat willow - *Salix caprea* (10%).

Whips, between 0.45m and 0.6m in length were planted, as these tend to establish well and grow more quickly than more mature specimens. The whips were planted in clumps of three to five of the same species, spaced at two metre centres, with a planting density to allow for some failures. Mesh guards were not installed to protect the whips since there was a risk they would be washed off during a flood event and could pose a hazard to wildlife. Additionally, there was concern that any mesh could have introduced man-made debris into the natural environment downstream.

The upstream breach two years post construction: widening of breach and gravel deposit to the left; abandonment of the old course on the right (blue arrow=new route. red arrow=old route) – 2010

© Scot Avia

Sediment accretion area/outwash fan has developed at the upstream breach – July 2011

Subsequent performance

Approximately one year after the banks were breached in September 2009 the channel experienced an estimated 30m³/s flood flow (of the order of a 1 in 10 year event). The stone protection at the upstream breach was partially washed out, as anticipated. The breach enlarged such that the majority of the flow was diverted along the new route after the flow subsided. The result was rapid development of river features, including the formation of an outwash fan (*see Figure 6.4.1*). Some ecological degradation has occurred in the short term, as the old channel is now dry except during very high flow events.

The flow interacted with woody material situated in the widened upstream breach causing erosion on the right bank of the original channel. Measures were taken to mitigate against further erosion on th eopposite bank, since any breach occurring at this location could result in flooding of a significant area of valuable grazing land. Small scale on-going adaptive management is predicted to be necessary in the short to medium term until this modified river system becomes better established.

The wet woodland habitat remains in the early stages of development but has already attracted a diverse range of flora and fauna (especially birds). Many of the unprotected whips were eaten by deer soon after being planted; it is hoped that this floodplain feature will naturally recover over time.

© Royal Haskoning

Channel development. The acretion area is storing woody material and river sediments – March 2012

© Royal Haskoning

The material used to construct the low embankment was soft peat. The consistency of the material was subsequently found to be insufficiently resilient to avoid damage during flow events that spilled into the wider flood storage area. Minor breaches occurred in two locations along the embankment, which now allow water to flow in to the low area on the boundary of the site.

Overall this scheme illustrates what can be achieved when working with natural sediment transport processes in flood storage zones. In 2010, the Saltire Society of Scotland in association with the Institution of Civil Engineers awarded the Forres FAS its 'environmentally sustainable construction' commendation.

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Reference material – Click **here**

12 Removing or Passing Barriers

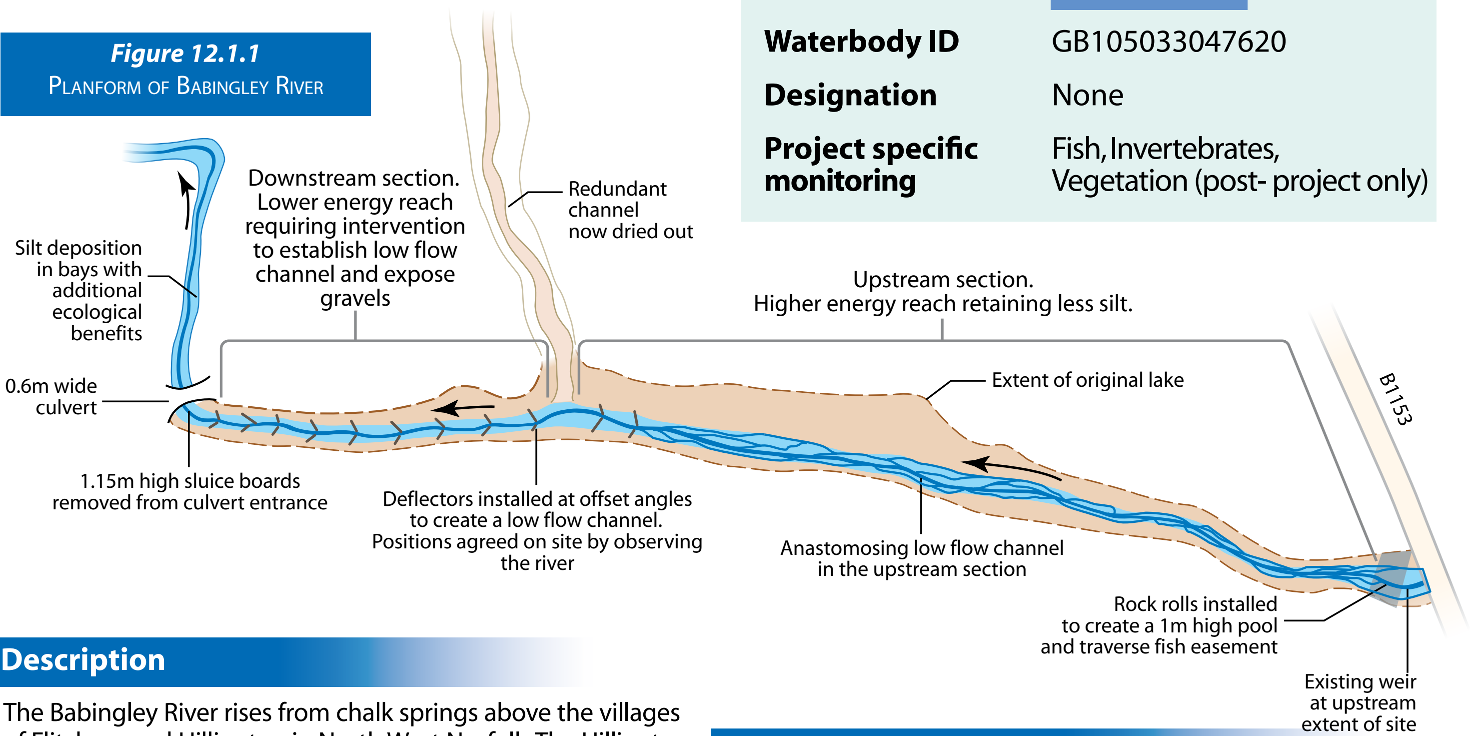
12.1 Restoring an on-line lake to a chalk stream

Babingley River

Location - Hillington, Norfolk TF72532629
Date of construction - 2006 – February 2007
Length - 500m
Cost - £600

Babingley River	Low energy, chalk
WFD Mitigation measure	Click Here to view details
Waterbody ID	GB105033047620
Designation	None
Project specific monitoring	Fish, Invertebrates, Vegetation (post- project only)

Figure 12.1.1
Planform of Babingley River



Description

The Babingley River rises from chalk springs above the villages of Flitcham and Hillington in North West Norfolk. The Hillington site is located close to the source and includes an impounded online lake known as the Broadwater. The aim of the project was to revert the lake back to 420m of river. This would resolve the water quality issues in the lake, remove barriers to fish passage, including eel (*Anguilla anguilla*), provide additional spawning habitat for wild brown trout (*Salmo trutta*). The sluice boards used to impound the lake were removed, lowering the water level. This concentrated the flow and enabled the river to cut a new channel. However, lowering the water level created a barrier at the upstream weir, which was addressed by a pool and traverse fish easement.

This low cost river restoration technique was possible at this site as the landowner owned both sides. The rural location of the site, and lack of infrastructure downstream, meant that flood risk modelling was not considered necessary.

Design

The work was designed to use the energy of the river to cut and form the new channel. The works were carried out in three distinct phases;

1.Controlled removal of downstream sluice boards
Six sluice boards, 1.15m high in total, were located at the downstream extent of the reach where the river flows through a 0.6m wide culvert. These maintained the water level in the impounded lake. The boards were removed using a staged approach enabling the lake level to be lowered in a controlled manner and allowing the amount of sediment released downstream to be regulated.

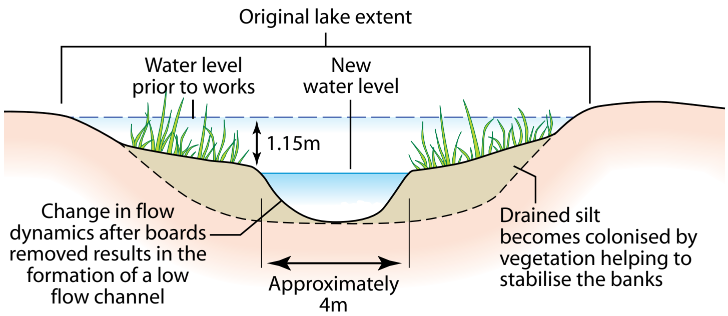


Figure 12.1.2
Typical cross section of new channel in downstream section

These techniques were developed to suit site specific criteria and may not apply to other locations

The board removal started in mid-September 2006 and one board was removed every two to three weeks. When the last board was removed in November 2006, the flow in the lake had concentrated sufficiently to start cutting a new channel. This took longer than planned which presented a risk to the impending spawning season, but given the long term benefits this was deemed to be an acceptable short-term impact.

Sediment release was the biggest concern. Careful control of sediment mobilisation was observed to reduce impacts to the habitat downstream. Below the sluice boards the river was characterised by bays and riffles. It was predicted the silt would deposit in the bays and eventually colonise with vegetation. This approach was deemed significantly less disruptive than using an excavator to remove the silt.

2. Pool and traverse fish easement using rock rolls

The removal of downstream sluices and resultant 1.15m drop in water levels created a barrier at the upstream end of the site where an existing weir was located. To enable fish to negotiate the weir a 'pool and traverse' style fish easement was installed using rock rolls. This was trialled as a low cost technique.

The easement was constructed using twenty rock rolls to create jumps approximately 0.3m high, the height that brown trout are able to traverse. Two lines of rock rolls were laid across the downstream face of the weir creating three steps for migrating fish to negotiate the barrier. A gap of approximately one metre was built into each line of rock rolls to concentrate the flow. These gaps were offset to reduce flow velocities through the easement and to create fish resting areas.

It was recognised that initially water would probably percolate through the rock rolls. However it was envisaged that the sediment would deposit in the rock rolls and they would quickly vegetate.

Downstream extent of the reach. The sluice boards have been completely removed – August 2007

Pool and traverse fish easement after completion. Vegetation has already begun to establish on the rock rolls – August 2007

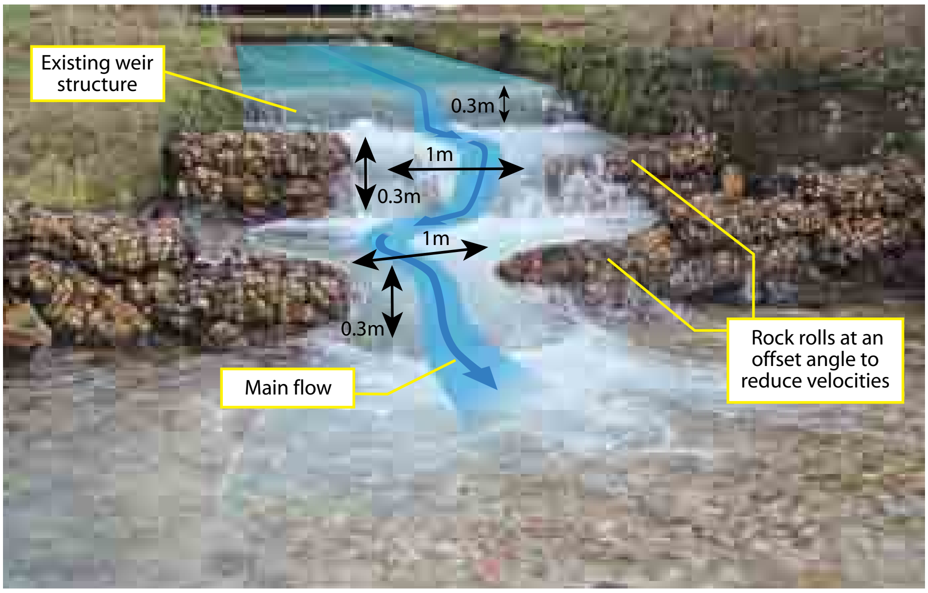


Figure 12.1.3
POOL AND TRAVERSE FISH EASEMENT CREATED USING ROCK ROLLS

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Mitigation for Barriers

3. Installation of deflector boards

After the sluice boards were removed and the water level lowered, the river began to cut a new channel into the silt. In the upper reach, where the gradient was steeper, the river was left to naturally continue this process. In the downstream reach the gradient was less and lacked the energy necessary to continue cutting into the remaining silt. The installation of a series of deflectors created pinch points that have concentrated flows sufficiently to cut down to the hard bed and create pool and glide sections. Twenty deflector boards were installed facing in an upstream direction over a 200m stretch.

The deflectors were generally installed in pairs, some opposite each other and some offset. The locations were determined by working with the river. Hillington Fly Fishing Club was responsible for this work so the addition of the deflectors did not contribute to the Environment Agency project cost.

© Environment Agency The newly installed deflectors face upstream and concentrate flow. The old silt bed has formed new banks and has since been colonised by vegetation – February 2007

© Environment Agency

One pair of deflector boards, installed at an offset angle, after six months. Marginal vegetation has rapidly colonised the silt helping to stabilise it further – August 2007

Subsequent performance

The upstream section of the restored river was quick to expose hard bed, and braided channels have formed here. The combination of newly exposed gravels and improved flows has increased the amount of available spawning habitat.

Downstream of the project site there were initial concerns that silt would smother the spawning gravels, but these have not been realised. As expected sediment has predominantly been deposited in wider slack water sections, forming bars and has assisted in natural channel narrowing. These have rapidly vegetated. Vegetation has also colonised the newly exposed silt helping to consolidate it and create juvenile habitat.

In the lower reaches of the project site the installation of deflectors has helped to concentrate the flow and create scour holes. These pools, up to a metre deep, provide refuge for fish and were occupied by brown trout soon after completion.

Some adaptive management of the pool and traverse fish pass has been required. The approach relied on the weight of the bags to keep them in situ. However, some movement did occur due to scouring of the soft bed and the rock rolls would have been better pinned in place. The rock rolls were repositioned manually and stabilised by ensuring that they were located on a hard bed.

Prior to restoration, expert judgement and angler records determined that there were little or no fish in the channel due to poor water quality and a lack of connectivity. A fish survey carried out one year after the completion of the project. Fish from several year classes were present in the channel. No further studies have been carried out to date (2013).

Post works vegetation monitoring was carried out in the form of a 'presence only' survey. This highlighted that a wide range of marginal and aquatic species had colonised the newly exposed silty margins. Species found included horned pondweed (*Zabbuchellia palustris*), water mint (*Mentha aquatica*) and lesser spearwort (*Ranunculus flammula*).

Invertebrate sampling has revealed that the site supports stonefly nymph (*Leuctra hippopus*), cased caddis larvae (*Goera pilosa*) and freshwater shrimp (*Gammarus pulex*). These species are indicative of fast flow and good water quality.

The work has created a self sustaining channel. No further management was planned, or has been necessary. The big advantage of this technique is that it works witht he natural processes of the river, producing a more stable environment.

© Environment Agency

Brown trout (*Salmo trutta*) present in the river four months after works were completed – February 2007

© Environment Agency

Prior to restoration works. The on-line lake was over deep due to the presence of sluice boards impounding water – August 2006

© Environment Agency

Post restoration works. The channel is narrower and shallower with diverse marginal vegetation and good spawning habitat – September 2007

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12

Removing or Passing Barriers

12.2 Step pool cascade fish pass and culvert bed improvement

Lodge Burn

Location - Coleraine town centre, N. Ireland NW02689199
Date of construction - April/May 2012
Length – 40m
Cost – £88,500

Lodge Burn	Low energy, clay
WFD Mitigation measure	Click Here to view details
Waterbody ID	GBNI1NB030301223
Designation	None
Project specific monitoring	Fish, River Corridor Survey (pre-project only) hydromorphology

Description

The aim of this project was to improve fish passage through a reach of the Lodge Burn in Coleraine. Part of a 1 in 100 year design standard Flood Alleviation Scheme, a cascade fish pass was constructed and a gravel bed installed within the culvert.

The Lodge Burn has a history of channel modifications including mill ponds, drainage works and culverting. Despite its relatively small catchment size (16.4km^2), it has historically been an important spawning and rearing tributary for migratory fish, given its proximity to the River Bann estuary and Atlantic Ocean (8.5km). The natural dominant substrate is gravels and cobbles, although this has been altered in some areas by dredging or siltation.

Initial scoping identified significant hydromorphological pressures within the town. The site was classified as "bad ecological status" for Water Framework Directive (WFD) in 2009. A major cause of this was identified as a perched culvert with a concrete bed and steep apron, located in the centre of Coleraine. This was obstructing sediment transport and fish passage. The location of this structure meant that re-design of the reach had to work within a very confined space between two high flood walls and within the culvert. The works consisted of a cascade fish pass and lowering of the culvert bed. Thorough site investigation was needed to ensure that the baffles within the culvert did not affect the integrity of the culvert, floodwalls or any adjoining buildings.

© Rivers Agency

Existing culvert beneath buildings was impassable to fish due to depth, velocity and slope of the concrete bed and apron – August 2010

The scheme involved liaison with the local council, WFD Catchment Stakeholder Group, local residents, statutory agencies and local fisheries interest groups. A 'salmon in the classroom' scheme was also undertaken with a local primary school, and the fish release was reported on BBC television and in the local press.

Design

The works were carried out in four key stages;

1. Flow management; works to install the step-pool cascade and improve the culvert bed had to be conducted in the dry. A fully isolated dry working area was achieved by sandbagging and over-pumping.

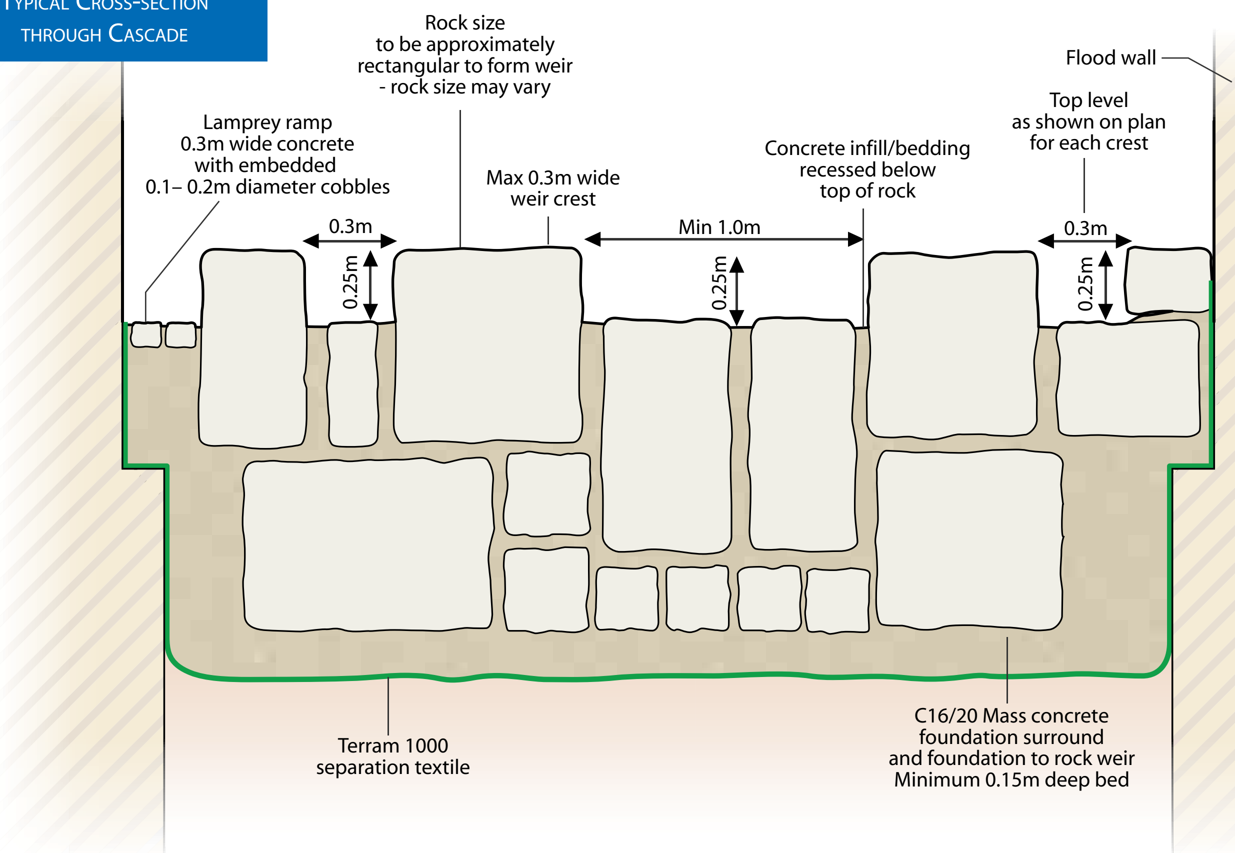
2. Modify culvert bed; the culvert had to be enlarged to incorporate the loss of capacity and increased roughness of the new cobble bed. The culvert bed was carefully excavated 0.3m below the existing level.

Stainless steel baffles (0.15m high) were secured across the culvert at 2.5m intervals to prevent scouring of the placed bed material.

3. Install natural bed in culvert; a mix of cobble and boulders (0.15m-0.3m) were placed across the bed and ramped up at the sides to concentrate low flows to the centre of the channel, in order to provide adequate water depth for fish entering the culvert.

At the culvert exit, larger boulders and a reinforced concrete lip were installed to maintain sufficient depth of flow within the culvert.

Figure 12.2.1
Typical Cross-section through Cascade



Cascade during construction – May 2012

4. Remove concrete apron and install cascade; the concrete apron was broken out creating a 1.5m drop to the channel bed. This was overcome by creating a series of six steps and pools, each with a crest 250mm lower than the previous one. The core of the first cascade was constructed with reinforced concrete as it would take the initial force of flows leaving the culvert. The remaining five were constructed of large rocks (0.5 to 1.5 tonnes) concreted in place to prevent washout (*Figure 12.2.1*).

A notch was designed in each structure to concentrate flows during periods of low water. Each pool had a minimum 1m depth, which generated areas of lower flow velocity in which fish can rest before continuing their ascent.

Spacing between cascades was 6m, therefore in total the pass extended for 36m downstream of the culvert.

A concrete brook lamprey (*Lampetra planeri*) ramp was designed into one side of the channel.

Due to the constrained working space, construction had to proceed in an upstream to downstream direction. Once ach cascade was put in place it was not possible for machinery to travel back upstream of it again.

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Removing or Passing Barriers

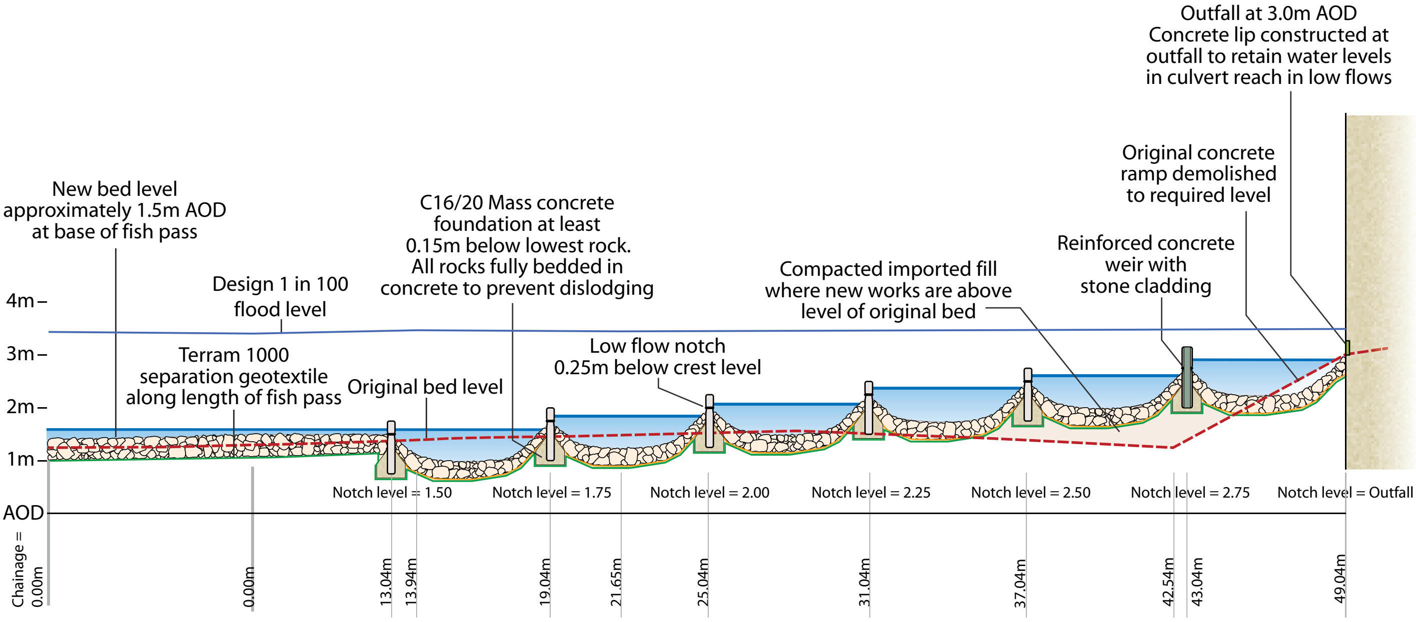

Figure 12.2.2
LONGITUDINAL SECTION THROUGH CASCADE FISH PASS

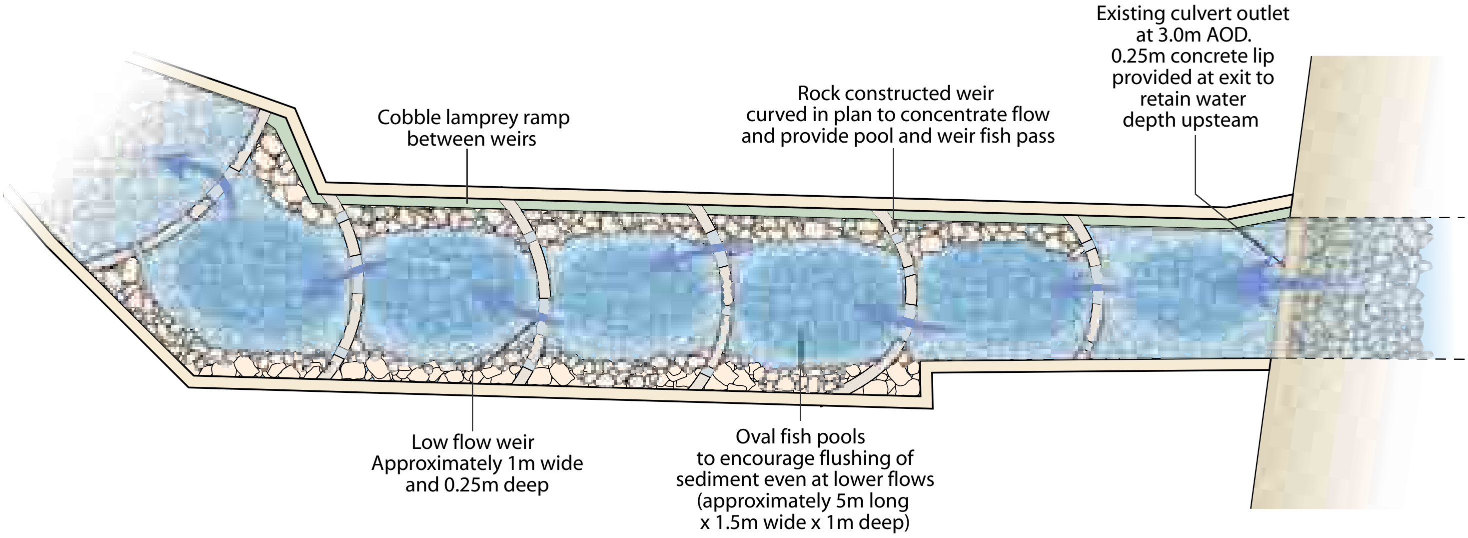

Figure 12.2.3
OVERAL PLAN OF CASCADE FISH PASSAGE

These techniques were developed to suit site specific criteria and may not apply to other locations

© Rivers Agency Culvert shortly after construction completed – May 2012

© Rivers Agency The channel post-construction during low flows – May 2012

Subsequent performance

This project is a good example of what can be achieved to improve fish passage in a very confined space. The new pass has had a positive response in terms of aesthetics.

Flooding shortly after construction caused some damage to the face of the first cascade. Gravel and cobble washout from the culvert resulted in the infilling of pools, however this material was removed subsequently by the Rivers Agency. This initial movement highlighted the importance of incorporating sufficient self-maintaining processes in pool design (i.e. sufficient flow to maintain the pool depth), as well as the need to anticipate early wash-out of excess material. The remaining cobble bed material within the culvert is now deemed to be stable.

Enhancement features within Flood Alleviation Schemes are often designed to perform in low flow conditions. It is also important that they are sufficiently robust to withstand flood events, as failure can often result in an increased flood risk and difficulty in carrying out maintenance works.

It was envisaged that some maintenance of the pass would be needed, so a demountable barrier was included in the floodwall design to allow channel access if required. A maintenance and management plan was developed to aid the decision making process for when intervention may be required.

Adult brown trout (*Salmo trutta*) were observed upstream of the culvert, suggesting effective passage was occurring. There was also evidence of an otter (*Lutra lutra*) using the channel edge close to the culvert. In addition a River Hydromorphology Assessment Technique (RHAT) survey was carried out to help quantify the effects of the scheme in the future.

© Rivers Agency High flow event in channel demonstrating good fish passage opportunity – June 2012

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12.3 Complete removal of a large weir

River Monnow

Location – Kentchurch, Monmouthshire/Herefordshire SO41022581
Date of construction – August 2011
Length – 500m (including backwater)
Cost – £100,000 (£60,000 demolition of weir)

River Monnow	Medium energy, sand
WFD Mitigation measure	Click Here to view details
Waterbody ID	GB109055029720
Designation	None
Project specific monitoring	Geomorphology

Description

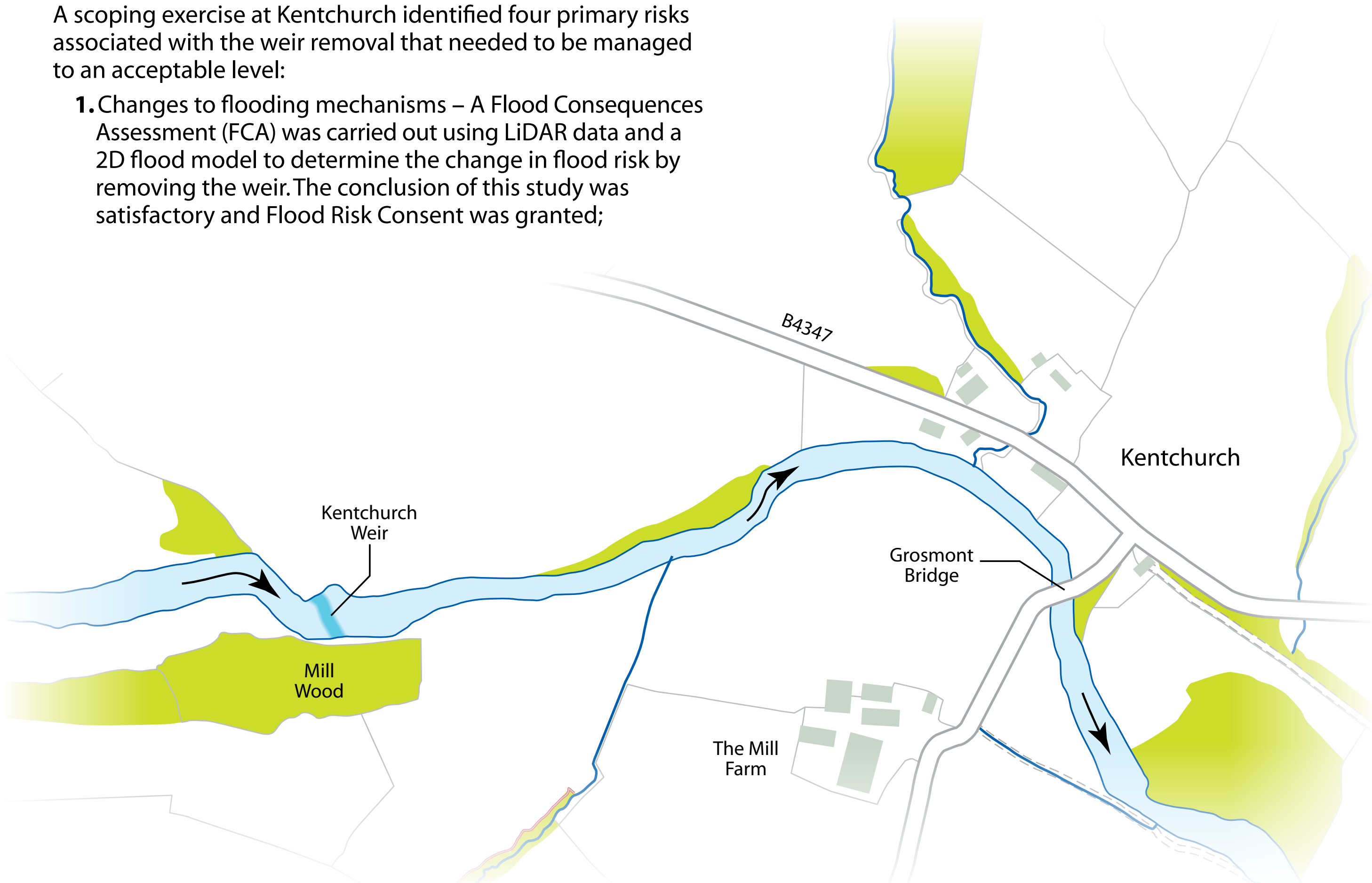
Kentchurch Weir, owned by Environment Agency Wales (now Natural Resources Wales), located within a large private estate, was thought to be a modern reconstruction of an older weir and was in the process of breaching. It was decided to completely remove the weir rather than repair it, also addressing the adverse effect it was having on WFD objectives including fish migration.

This 18 month-long project was to remove the 2.6m high weir which allowed migratory fish to access spawning grounds in the 160km of river upstream and natural morphological processes to operate.

A scoping exercise at Kentchurch identified four primary risks associated with the weir removal that needed to be managed to an acceptable level:

1. Changes to flooding mechanisms – A Flood Consequences Assessment (FCA) was carried out using LiDAR data and a 2D flood model to determine the change in flood risk by removing the weir. The conclusion of this study was satisfactory and Flood Risk Consent was granted;

Figure 12.3.1
Plan view showing the location of Kentchurch Weir



These techniques were developed to suit site specific criteria and may not apply to other locations

Removing or Passing Barriers

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The 2.6m high Kentchurch Weir prior to removal – 2011

2. Potential heritage value of the structure – A heritage study concluded that whilst a weir had been present in the vicinity of the site for many centuries, the current structure was considered a modern reconstruction. The works were permitted subject to the appointment of an archaeologist to document and record any findings of historic significance that arose during the excavations;
3. Release of sediment stored behind the weir. The team needed to ensure that the demolition work did not pollute the river, damage habitat or cause any other adverse impact. by taking all possible precautions to minimise this;
4. Geomorphological changes within the reach of the river affected by the weir, such as bank erosion.

A bathymetric survey of the river bed upstream and downstream of the weir, and sediment sampling from the reach upstream of the weir, were carried out for contaminant testing and particle distribution analysis. The latter was necessary to determine how much of the sediment behind the weir was composed of the potentially harmful finer sediment particles. These surveys revealed that the volume of material impounded behind the weir was significantly less than been anticipated. In addition the sediment analysis showed that no hazardous substances were present in the sediment and that the proportion of the finer grains within the impounded material was almost negligible.

The project team had good communications with the angling clubs and trusts that operate on the River Monnow and the contractor informed the team when they were about to undertake operations that were likely to disturb sediment.

Design

To remove the weir a 20 tonne 360° excavator and a 6 tonne swivel skip dumper were used. Demolition started with a 3m width on the left bank which was taken right down to bed level. Once the weir was breached a line of jumbo sand bags was used to channel the flow through this breach. This enabled the contractor to demolish the rest of the weir in the dry as the impoundments had been de-watered.

Initial breakout of the weir on the left bank – 2011

The River Restoration Centre
Working to restore & enhance our rivers

© Natural Resources Wales Breach in the weir on the left looking downstream from within the previous impoundment – 2011

© Natural Resources Wales Demolition of the remainder of the weir continued once the upstream impoundment had been de-watered – 2011

© Natural Resources Wales Line of jumbo sandbags channelling the flow through the initial breach allowing the remainder of the weir and material built up behind it to be removed – 2011

© Natural Resources Wales Looking upstream with the weir completely demolished. The drop in water level is evident on the left bank – 2011

The remaining weir was broken up and removed along with the accumulated sediment, which was largely fine sand and coarse gravel. Some 50m downstream of the works a sediment trap of straw bales held in place by jumbo sand bags was constructed to entrain any fine sediment released into suspension during the works. On the right bank A short length (about 2m) of weir was left in place, supplemented by some blockstone, to address the risk of local erosion. Much of the excavated material was reused locally.

Subsequent performance

The scoping study carried out before the weir removal constituted the pre-works monitoring, and included habitat and geomorphological assessments. After the weir was removed Environment Agency Wales continued monitoring the river as it adjusted to the removal of the weir and have commissioned the University of Cardiff, to study the changes in river morphology. Some anticipated channel adjustment has taken place, some of which will require intervention in order to prevent adverse consequences for farmers.

Monitoring every 3-4 months between July 2011 and January 2013 has documented the dispersal of impounded gravel from the reach upstream of the weir. In addition, transfer of these gravels downstream has resulted in the growth of point bar, resulting in decreased flood conveyance.

Specifically bank erosion has occurred in the reach upstream of Kentchurch Weir following its removal. The erosion followed very high flows on the River Monnow and was not believed to be solely due to the weir removal. Managing erosion of the river bank was included in the overall project budget, so bank protection works, in the form of bank re-grading, toe protection and bankside tree planting have recently taken place.

It is hoped to extend the monitoring to cover the effect of the river bank re-grading. Monitoring will continue through 2013 during a period of intervention to address erosion which is occcuring over a 250m length.

Looking upstream showing the exposed river bed after water levels have been lowered – 2011

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12

Removing or Passing Barriers

12.4 Weir lowering and rock ramp construction

River Calder
Location - Padiham, East Lancashire, SD78843308
Date of construction - March - May 2010
Length – 548m
Cost – £406,000

River Calder	Medium energy, gravel
WFD Mitigation measure	**Click Here** to view details
Waterbody ID	GB112071065490
Designation	None
Project specific monitoring	Fish

Description

Historically a degraded river due to its industrial heritage, water quality on the Calder has been significantly improved over the last 20 years allowing coarse fish populations to return. However, in-channel obstructions have prevented the migration of fish, including eels (*Anguilla anguilla*), to approximately 20km of spawning grounds and habitat further upstream.

The ambitious River Calder Fish Migration Improvement project was led by the Environment Agency and the Ribble Rivers Trust to link isolated sections of watercourse. The project aim was to restore fish passage on the River Calder. This was achieved by reducing the height of the existing weir structure as well as installing a rock ramp.

Padiham Weir was built in the 1950s to provide water to the now demolished power station. At 1.85m it was the largest weir on the Calder and created a total barrier to all fish migration. Since 2000 Padiham Weir had been the subject of a number of different fish passage proposals including a pool-and-traverse scheme, the installation of a technical Larinier fish pass, and even a white water canoe course.

At the location of Padiham Weir the River Calder has an average gradient of greater than 1 in 100, with a bankfull width of approximately 30m.

© Ribble Rivers Trust
A 7lb Atlantic salmon attempting to jump the weir – November 2006

© Environment Agency
Padiham Weir prior to works creating a total barrier to upstream fish migration – October 2005

Design

Prior to the works a dive survey established that the weir was in poor condition and liable to failure. It indicated that there was extensive sediment deposition upstream of the structure. A topographic survey established the bed levels upstream and downstream of the weir which then informed the calculations to determine the level and spacing of the bed check weirs.

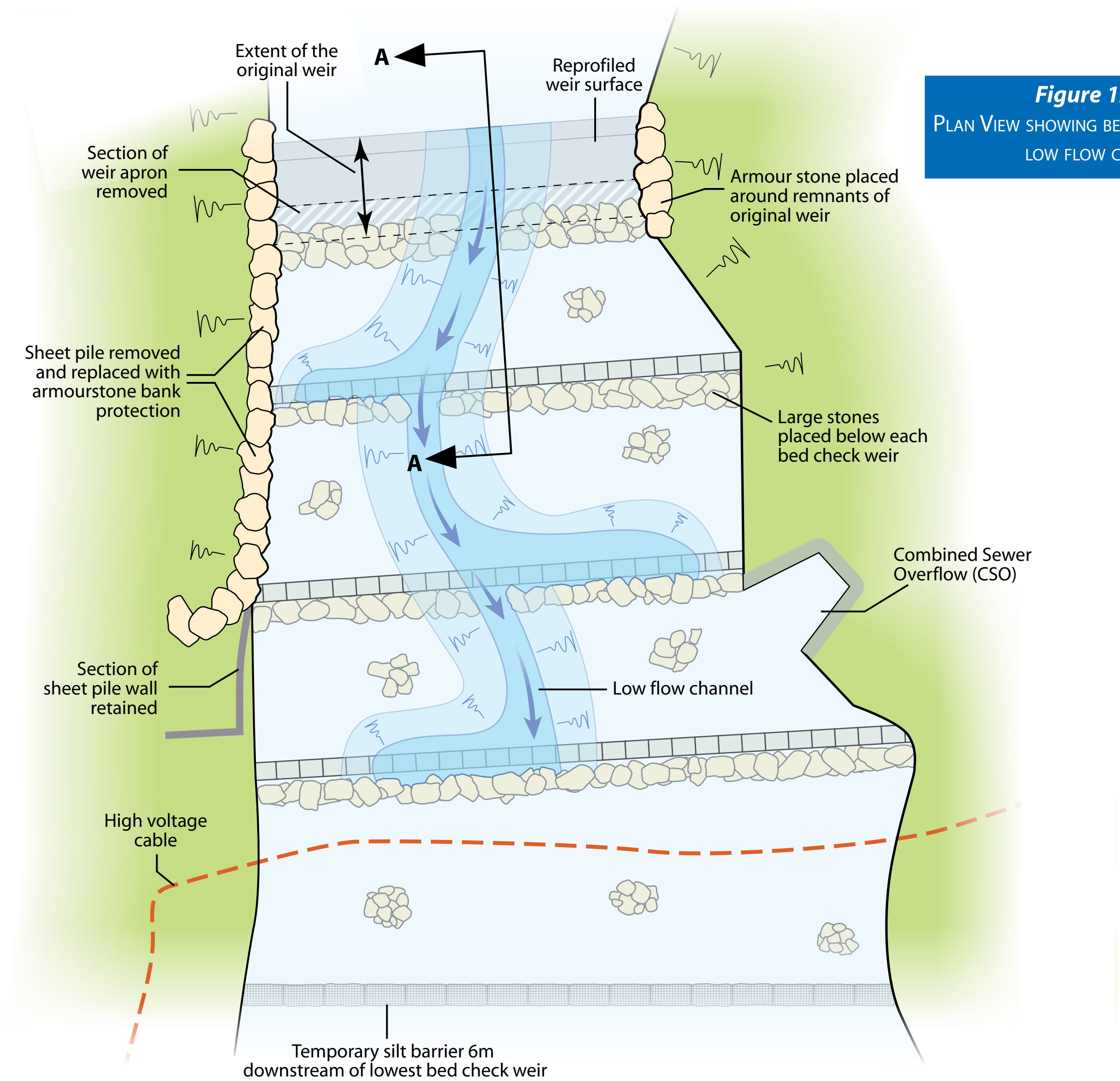
A hydromorphological assessment concluded that the impacts of the weir removal on sedimenttransport, water levels and the flow regime would be beneficial. It was established that there would be no increased flood risk and that there was likely to be a reduction in flood risk for at least one business due to the elimination of the weir's backwater effect. The banks were deemed stable enough to withstand the lowering of water levels. The left bank was already modified with stone blocks along the immediate upstream section and the right bank was gently shelving.

The end sections of the weir adjacent to the wing walls were left in place to assist with stability. The initial drop in water level following the weir removal was approximately 1m removing the impounding effect for approximately 500m upstream.

These techniques were developed to suit site specific criteria and may not apply to other locations

Removing or Passing Barriers

Figure 12.4.1
PLAN VIEW SHOWING BED CHECK WEIRS AND LOW FLOW CHANNEL



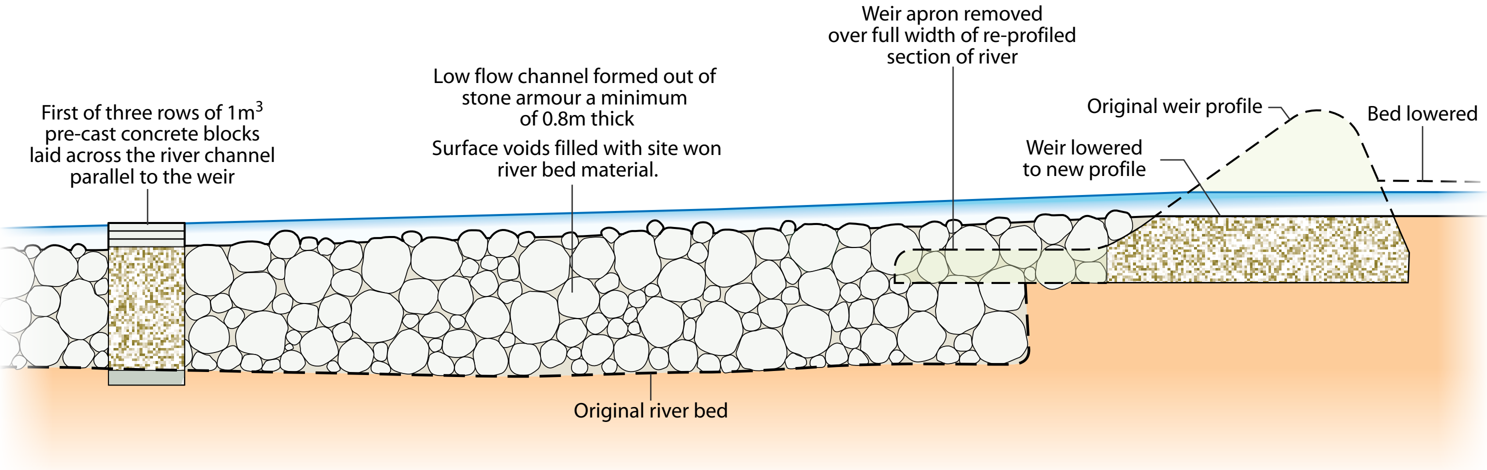
Additional site investigations were carried out prior to on the ground works commencing to address three main concerns;

1. A survey identified high voltage (HV) electric cables buried in the river bed. The project design was adapted to take these into account and location of the lowest bed check weir was chosen to ensure that the HV cable was protected.
2. Surveys confirmed that the sediment that had built up behind the weir was not contaminated. In order to reduce potential negative impacts downstream a temporary silt trap was constructed in-stream prior to works commencing. Located 6m downstream of the lowest proposed bed check weir, and downstream of the HV cable, the barrier was constructed from gabion baskets with an infill of straw bales and aimed at arresting the fine sediment fraction (silt) that had built up behind the weir over the last 50 years.
3. Liaison with United Utilities was necessary to ensure that the works, both during and after construction, would not interfere with the operation of the Combined Sewer Outflow (CSO) and that any impact could be mitigated. No further action was considered necessary.

Three bed check weirs, all 0.3m high, were installed in phases using an excavator, working from downstream up towards the existing weir structure. This work was undertaken from within a sheet piled cofferdam. To install each bed check weir a trench of 1m deep was dug and interlocking 1m³ pre-cast concrete blocks were set across the channel on aggregate bedding, parallel to the existing weir. The bed was lowered upstream of the existing weir. Stones (varying in size from large gravels to cobbles and boulders) were placed immediately downstream of each check weir to reduce the risk of scour causing instability of the structures. Stone armour was also placed at the toe of the existing weir structure, where scour had created a void, to help stabilise it. Once the installation of the bed check weirs was complete, the existing weir was partially deconstructed.

The weir crest was lowered through a combination of diamond wire cutting (wire saw impregnated with diamond dust that can be used for concrete cutting underwater) and hydraulic breaking. A central shallow (0.3m) v-shaped, low flow channel was created. The crest of the original weir was lowered by 1.45m and it now acts effectively as a fourth check weir.

Figure 12.4.2
Longitudinal Profile **A–A**



© Environment Agency

The site on completion. The low flow channel is visible through the centre of the bed check weirs – October 2010

Subsequent performance

The design was developed such that continued maintenance of the structures should not be necessary. The site now operates as a full weir removal would have, with the bed check structures effectively buried and blending well into the natural river bed.

The material used in the rock ramp was selected to withstand the expected stream power at the site, however exceptionally high flows over a sustained period during 2012 appears to have caused significant scour and erosion both above and below the weir. Flow volumes experienced during 2012 resulted in velocities capable of entraining the material used for the rock ramp (the 1 in 50 year return period flood event in June had a peak flow of 220m^3/s compared to median annual flood flow of 173m^3/s).

Once a portion of the material had been scoured out, the uneven bed surface was vulnerable to further scour and turbulence and allowed more material to be scoured out during subsequent high flow events. The issues experienced at this site as a result of high flood flows highlight the importance of setting the size of stone used for the stone armouring according to bankfull flows.

Upstream migration of fish species has been achieved with adult Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta*) observed upstream of the site. Juvenile population numbers are yet to be recorded upstream of the weir but have been identified immediately downstream.

Electrofishing surveys and redd counts were carried out following the completion of works, in the summer of 2010, to monitor migratory salmonid spawning for comparison with historic baseline data. However, bad weather and high flows in 2011 and 2012 have meant that the planned annual monitoring of fish has not been completed. Further electrofishing and redd counting is planned for summer 2013.

The site after three years. Some of the material entrained during high flood flows has been carried downstream but the majority has remained in the vicinity of the rock ramp and is visible near to the left hand bank – April 2013

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Reference material – Click here