9

# Enhancing Outfalls to Rivers

## 9.1 Surface water outfalls

River Skerne
Location – Darlington, Co Durham, NZ301160
Date installed – August to October 1995
Cost – £15,000 – cross connection survey, £23k - renewal of 13 headwalls, construction of pipe works and new chambers

Typical outfall before replacement

### Description

Although the water quality of the Skerne has been steadily improving, public perception of the river was one of a polluted watercourse. Along the core reach of the river restoration project there were 13 public surface water outfalls with ugly concrete headwalls marking their points of discharge. Those with grills were cluttered with plastic and other litter. The project provided a unique opportunity to instigate further improvements to water quality and visual amenity.

Initial inspection by Northumbrian Water of surface water drainage areas and some 1125 premises revealed a number of pollution sources from illegal connections of washing machines, dishwashers, showers, baths and toilets. The water company helped property owners to rectify irregularities before issuing certificates of compliance.

### Design

The aims of the design for the surface water outfalls were:

- to improve the quality of discharge by reducing silt, oil, petrol and floating solids reaching the river;
- to improve visual amenity by removing concrete headwalls and positioning discharge pipes below river water level;
- to reduce the number of outfalls and make future management and monitoring more efficient and easier.

New underground outfall chambers were designed such that the amount of both silt and floating solids discharged into the river would be reduced. Under low surface water flows, silt settles and is trapped in a sump. A dip plate ensures that any oil, petrol and floating sewage items are also retained in the chamber. These can all be removed using a suction unit at regular intervals and disposed of appropriately. Initially this was planned at a frequency of four times per year. Under high flows some effluent will be carried into the river but will be much diluted.

Inspection of the chambers is via recessed covers, incorporating turf, which lie just above ground level and so are visually unobtrusive. These allow sampling and pollution monitoring when needed.

Angled to discharge below low water level, the outfall pipe lies on a concrete apron which reduces scour during high flows. The outlet is turned to face downstream so that the river draws the discharge. Additionally, an underwater gabion was installed upstream of the outlet to reduce the risk of pipe damage by floating tree branches etc. Direct jetting via the chamber is possible if outlets become silted but they are expected to be self cleansing. The velocity of discharge achievable has been seen to make the river 'boil' after heavy rain.

At the large backwater (*see Technique 2.2*) three outfalls have been combined to run into one inspection chamber linked to a single outfall pipe.

The advantages of discharging to a backwater include:

- introduction of periodic flow into the backwater;
- potential for natural filtration of the discharge;
- ease of staunching 'off-river' should any pollution incident occur.



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

## Subsequent performance 1995 – 2001

The outfalls appear to be working effectively. The level of maintenance required has not been as frequent as previously envisaged and is now undertaken once a year. No blockages by siltation of the river bed have occured. The outfalls are now virtually invisible.

New outfall chamber under construction

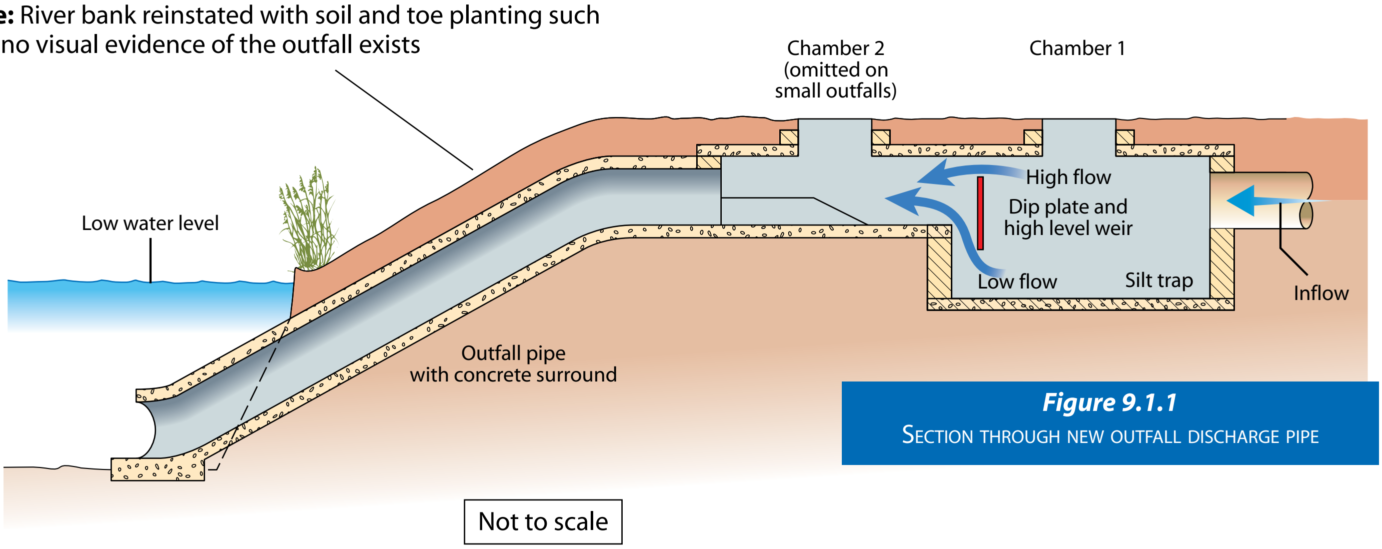


***Figure 9.1.1***
Section through new outfall discharge pipe

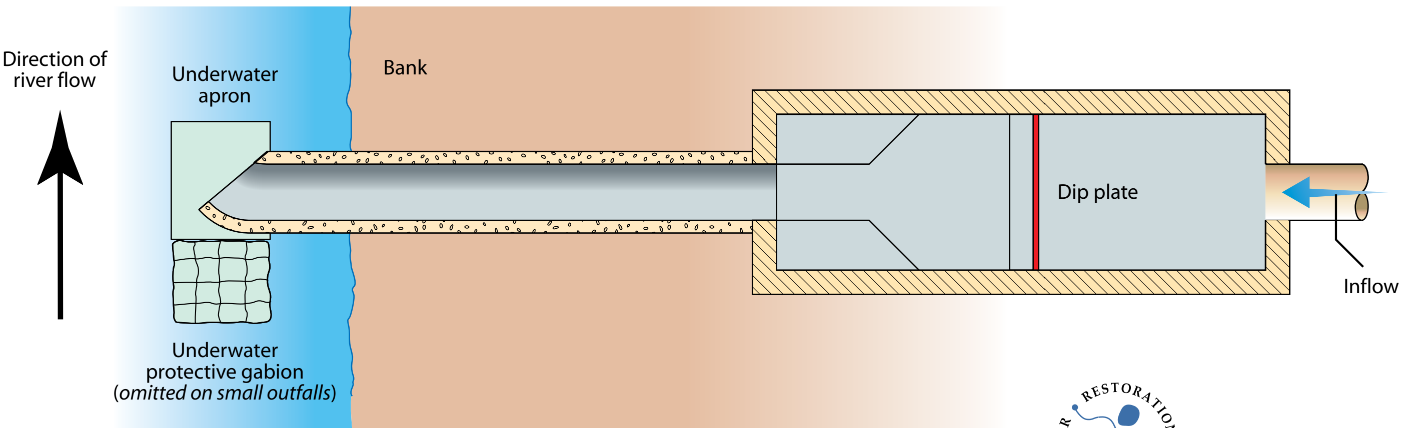


***Figure 9.1.2***
Plan of new outfall discharge pipe

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# Enhancing Outfalls to Rivers

## 9.2 Reedbed at Raglan Stream

River Cole

Location – Coleshill, Oxon/Wilts border, SU234935

Date of construction – Autumn 1995 – Spring 1996

Area – 640m$^2$

Cost – £500

Planting reedbed – Spring 1996

### Description

A new reedbed was formed in a redundant length of the Cole following the river's diversion to restore a smaller meandering course (*see Technique 1.2*). An adjacent small tributary stream, the Raglan Stream, was diverted to flow through the reedbed before entering the river.

The aim was to create a small buffer zone to help intercept silts contaminated with agricultural pollutants and to add habitat diversity to the river. The likely effectiveness of the reedbed as a buffer zone was considered to be low due to its small size and to its location, where river floods would frequently wash over it. The habitat potential was however high, and the marginal costs of construction small, so the reedbed was considered worthwhile and would demonstrate a useful river restoration technique.

### Design

The new river course (*Figure 9.2.1*) was excavated near parallel to the old, and the latter partially infilled to create a flat area elevated about 500mm above the new river bed. The two were separated by a ridge of hard gravelly clay soil about 0.8m above river bed.

The flat area was then contoured in a series of longitudinal furrows to hold ponded water between ridges of wet, but not saturated ground (*Figure 9.2.2*).

The Raglan Stream was diverted to feed water into the furrows, but because the stream dries up in the summer a supplementary feed of water was diverted from the River Cole. The river flows into the reedbed through a 0.15m diameter plastic pipe that



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

# Enhancing Outfalls to Rivers



discharges through a 90 degree bend which can be swivelled vertically to cut off the flow or reduce it, as required, to keep the reedbed wet but not flooded. This level of control was only critical during the establishment period of the reed.

Common reeds were introduced in spring 1996 using pot grown seedlings along one side of each furrow and seed along the opposite side (*Figure 9.2.3*). The use of two methods increased the likelihood of successful establishment and enabled the performance of each to be monitored.

***Figure 9.2.3***
Detail of reed furrow

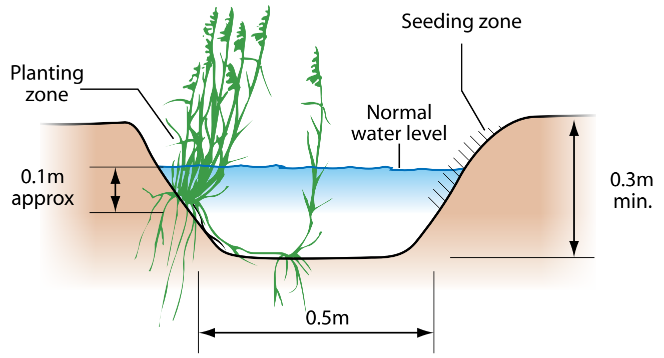
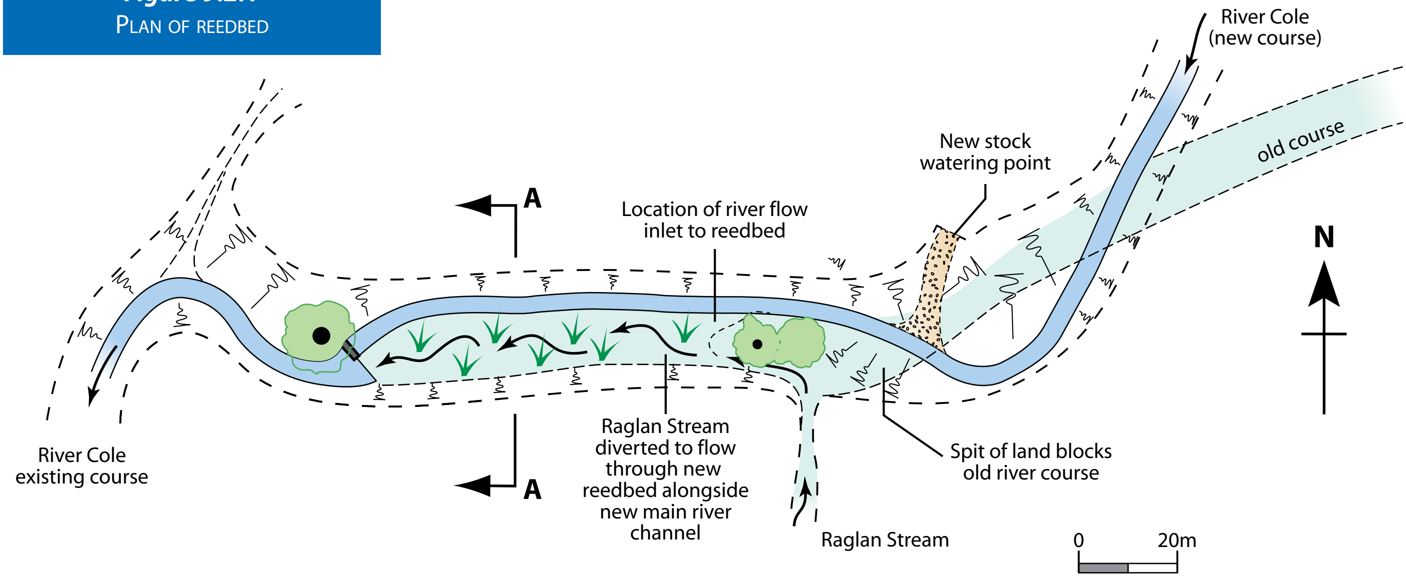



***Figure 9.2.1***
Plan of reedbed



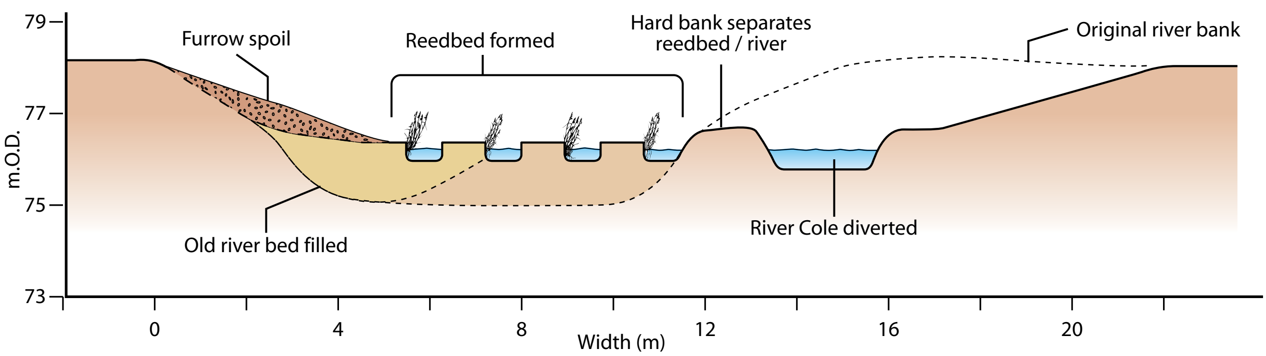
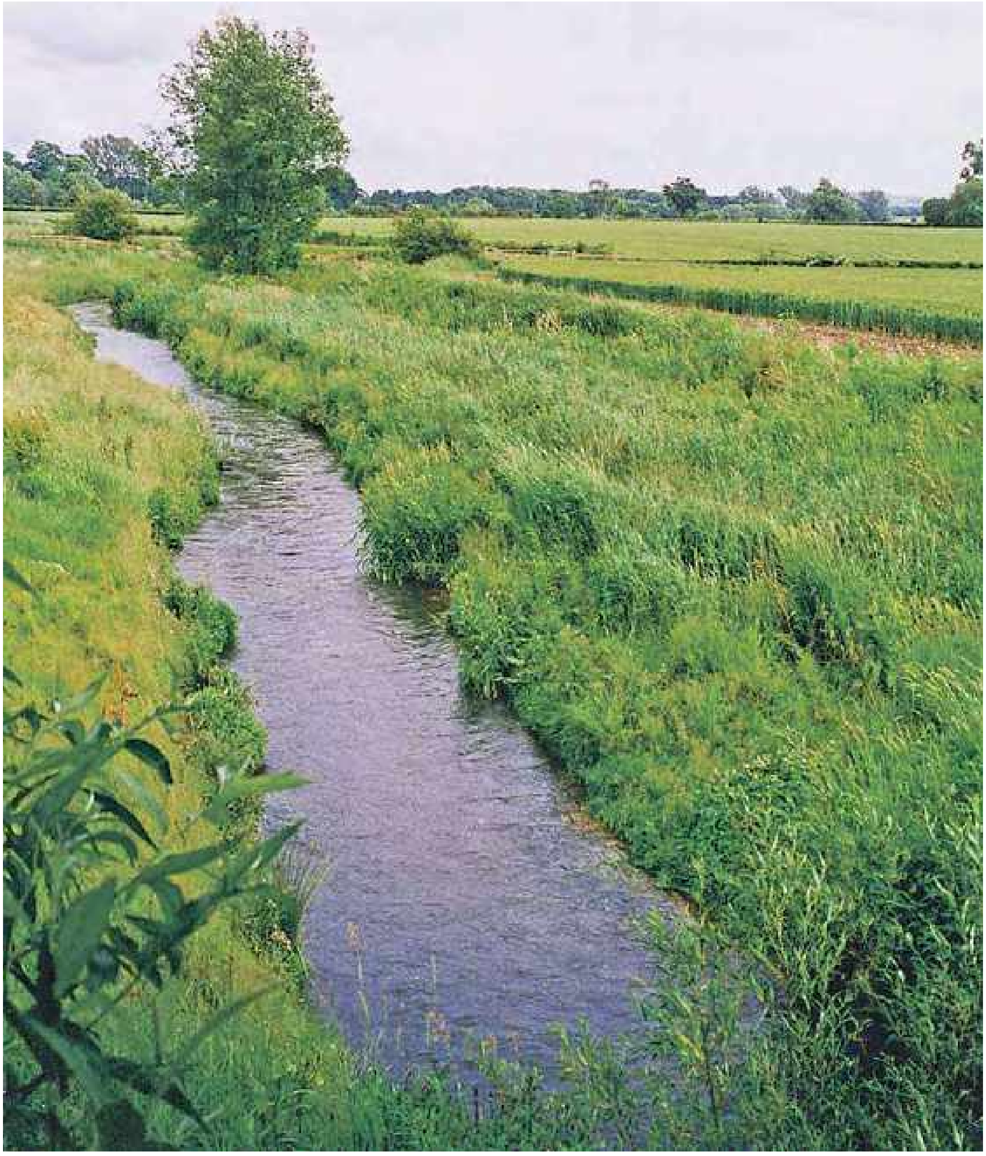




***Figure 9.2.2***
Section **A – A**

# Enhancing Outfalls to Rivers



Reedbed established – Summer 1998

## Subsequent performance 1995 – 2001

The reedbed established exceptionally well with 93% of seedlings surviving to maturity, although seed germination was perhaps only 50%, but still sufficient to achieve full colonisation within two growing seasons. Other aquatic species colonised the area naturally, including greater water plantain and soft rush. Concerns that the River Cole might damage the reedbed when in flood proved unfounded because the overall size of the new river and adjacent reedbed is much greater than the exisitng cross-section downstream so flood flow velocities are low.

These hydraulic conditions may lead to progressive siltation of the reedbed in the longer term, but for the foreseeable future a valuable habitat has been created that additionally provides a buffer against contaminated silts from the Raglan Stream reaching the Cole.

# 10 Utilising Spoil Excavated from Rivers

## 10.1 Landforms at Keepsafe and Rockwell

RIVER SKERNE

LOCATION – DARLINGTON, CO DURHAM, NZ301160

DATE INSTALLED – AUGUST 1995, SUMMER 1996

AREA – 1.5HA ROCKWELL AND 1.1HA KEEPSAFE (CIRCA. 19,000M$^3$ OF SPOIL CARTED TO LANDFORMS)

COST – £60,000 CARTING AND CREATION OF LANDFORMS

Rockwell after landform completion – 1998

### Description

The restoration of the River Skerne necessitated the disposal of circa19,000 m$^3$ of surplus spoil (*see Technique 1.4*). Two locations on the adjacent valley slopes (known as Rockwell and Keepsafe) were considered suitable for re-profiling and accommodating the spoil. These were the only areas that had not been either modified through industrial landfill or developed for housing. Although they retained some desirable features, they were out of keeping with the severely modified landscape around them. New landforms were designed to ameliorate the impact of the old landfill and to enable planting to screen unsightly buildings.

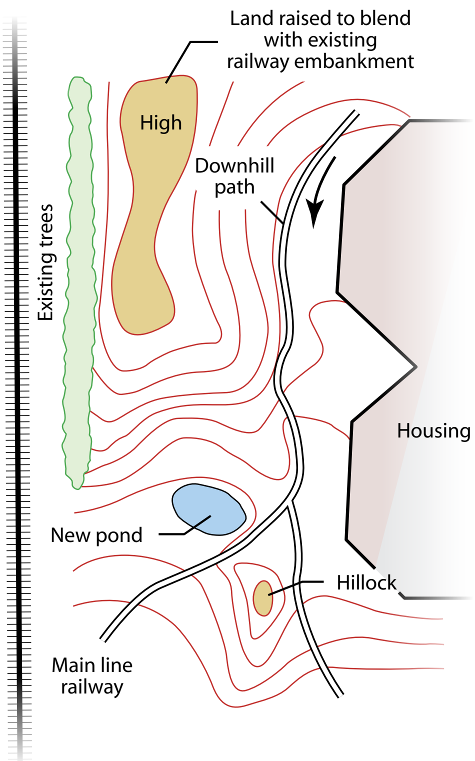
### Design

The landform of the two areas was generally designed to simulate naturally occurring 'gullies and hummocks' found in some parts of the north of England. Involvement of the community including schools, local wildlife trust and residents was deemed essential. Ideas for formal and informal paths were included for use in the detailed design.

*Rockwell (Figure 10.1.1)*

This area positioned between housing, the main railway and a nature conservation area, was rough land with some dumped builders rubble. As part of a community environmental project a pond was excavated in a former 'seep' on the valley side. Key features are gentle slopes facing the housing and small hummocks to provide topographical interest. French drains were installed in key places to prevent waterlogging of access routes and to alleviate surface water erosion problems.

***Figure 10.1.1***
PLAN OF ROCKWELL LANDFORM WORKS






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

# Utilising Spoil Excavated from Rivers

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*Keepsafe (Figure10.1.2)*
This was a field gently sloping towards the river. The new landform has introduced a small valley feature and has raised the land adjacent to the industrial estate, built on landfill. Carefully positioned tree and shrub planting screens the industrial area on one side and ties in with an original hedgerow on the other. Most importantly, a smooth topographical transition has been created at the old tip face. A land drain was incorporated in the newly formed valley which also acts as a dry route for walkers.

Once the landforms were complete a landscape architect was appointed to design and install a suitable planting scheme. Each was seeded with a low maintenance grass mix incorporating wildflowers, followed a year later with 10,000 trees and shrubs planted in discreet planting areas. Bulbs were also planted on the lower slopes.

## Subsequent performance 1995 – 2001

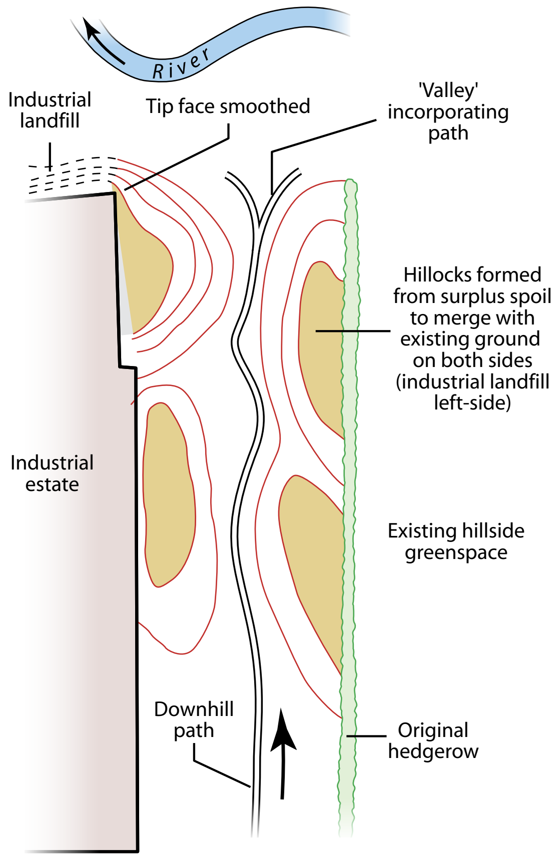
Participation in landscape design and planting has given the community ownership of these open spaces and may be a factor in the minimal level of vandalism experienced. Both areas blend with the surrounding landscape and they are not obviously artificial. Each is now more widely used by walkers taking natural desire lines. The tree and shrub planting is already helping to screen the industrial area and the railway.

The creative use of spoil in this beneficial way has overcome what would otherwise have been a prohibitively expensive operation of carting off site.

Keepsafe landform during construction

Similar view of Keepsafe after tree planting – 1998

***Figure 10.1.2***
Plan of riverside path to Skerne Railway Bridge



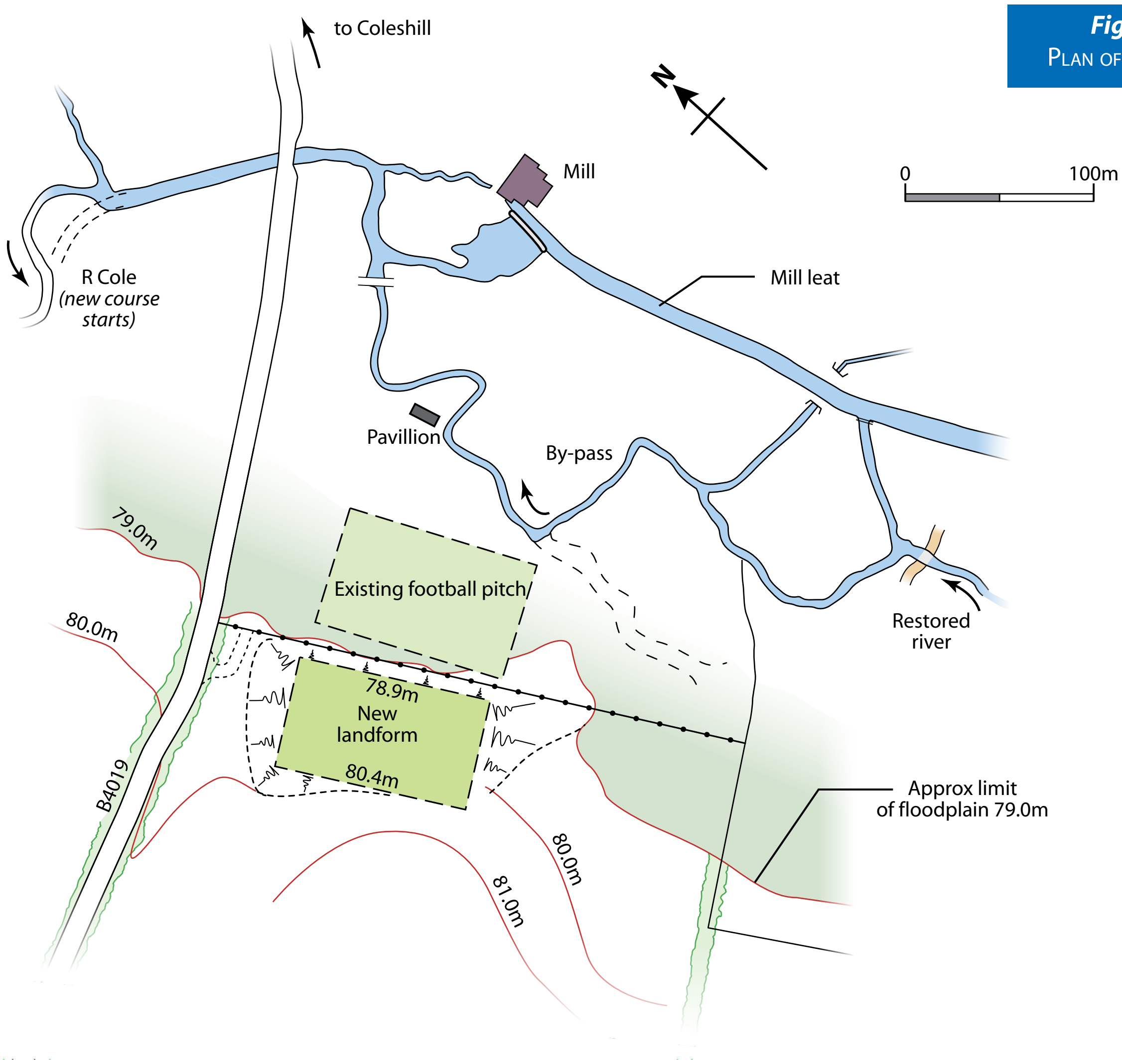
10

# Utilising Spoil Excavated from Rivers

## 10.2 Landform areas

RIVER COLE
LOCATION – COLESHILL, OXON/WILTS BORDER SU234935
DATE OF CONSTRUCTION – AUTUMN 1995 – JUNE 1996
AREA – 0.6HA (CIRCA 4,000M$^3$ – MAIN SITE)
COST – £13,600 CARTING AND CREATION OF LANDFORM

**Figure 10.2.1**
PLAN OF LANDFORM WORKS




## Description

Excavation to create over 1km of new meandering river channel resulted in circa 4,000m$^3$ of spoil that needed to be transported away from the riverside. This was used to re-contour a nearby area of sloping arable field just off the floodplain. The landform created resembles a natural river terrace. It is large enough to serve as a second football pitch to compliment an existing pitch located on the adjacent floodplain, if needed. In addition, shallow mounds of spoil were created at two locations on the floodplain to serve as stock refuges in times of flood.

## Design

Most of the material excavated was used to infill redundant lengths of the old straight river channel, but not all. As an intrinsic part of the overall scheme, several lengths were left unfilled and developed to create sheltered off-river habitats (*see Techniques 2.2 and 9.2*).

Spreading of surplus material on the floodplain was not considered complimentary to the river restoration project objectives and carting all spoil off site would have been too costly. The concept of terracing the adjacent valley side was therefore adopted.

# Utilising Spoil Excavated from Rivers

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The site for the terrace was chosen to assist the local football club whose pitch is located on the floodplain of the river and suffers periodic inundation. It was possible to ensure that the area of the terrace was large enough for a pitch and that it was elevated above flood levels. In practice, the new terrace was restored to arable production but the opportunity for future flood free recreational use remains.

Construction of the terrace was a straightforward operation involving bull dozing of top soil to one side (post harvest) for re-use, prior to carting and spreading of fill. Detailing involved smoothly graded contouring around the edges to blend at 1 in 40 with existing land levels and ensuring a 1 in 130 cross-fall over the terrace to maintain surface run-off.

Elsewhere two smaller landform features were created on the floodplain in the form of gently sloping shallow mounds that will serve as stock refuges in times of flood, in areas where this is critical (*see Technique 1.3*). These do not adversely affect flood storage capacity because the amount of spoil utilised is small in comparison to the substantial surplus of spoil carted to the main landform.

## Subsequent performance 1995 – 2001

The new terrace is in full arable use with only a small part lost to production for one season. Although not unduly intrusive within the landscape, part of the designed 1 in 40 transitional slopes were steepened at the end of the contract to accommodate additional spoil resulting from extra works.

Concerns that increased flood frequencies generated by the river restoration works would advance the need to establish a second flood free football pitch have not materialised to date. The restored river has not developed the amount of in-stream growth conservatively estimated in the design, and seasonal rainfall has been below average since construction. Both these factors may account for this although hydraulic modelling did predict a manageable situation for the football club.

The concept of re-profiling valley sides near to the floodplain has proved to be a very effective way of avoiding excessive spoil disposal costs without any obvious detriment to the landscape.

Participation in landscape design and planting has given the community ownership of these open spaces and may be a factor in the minimal level of vandalism experienced. Both areas blend with the surrounding landscape and they are not obviously artificial. Each is now more widely used by walkers taking natural desire lines. The tree and shrub planting is already helping to screen the industrial area and the railway.

The creative use of spoil in this beneficial way has overcome what would otherwise have been a prohibitively expensive operation of carting off site.

Construction of landform in arable field to right of football pitch – 1995

# 10 Utilising Spoil Excavated from Rivers

## 10.3 Cost-effective silt removal from an impounded channel

River Chess

Location – Blackwell Hall, Latimer, Buckinghamshire SU 980997

Date of construction – 1994/95

Area – circa 3000m²

Cost – Not available

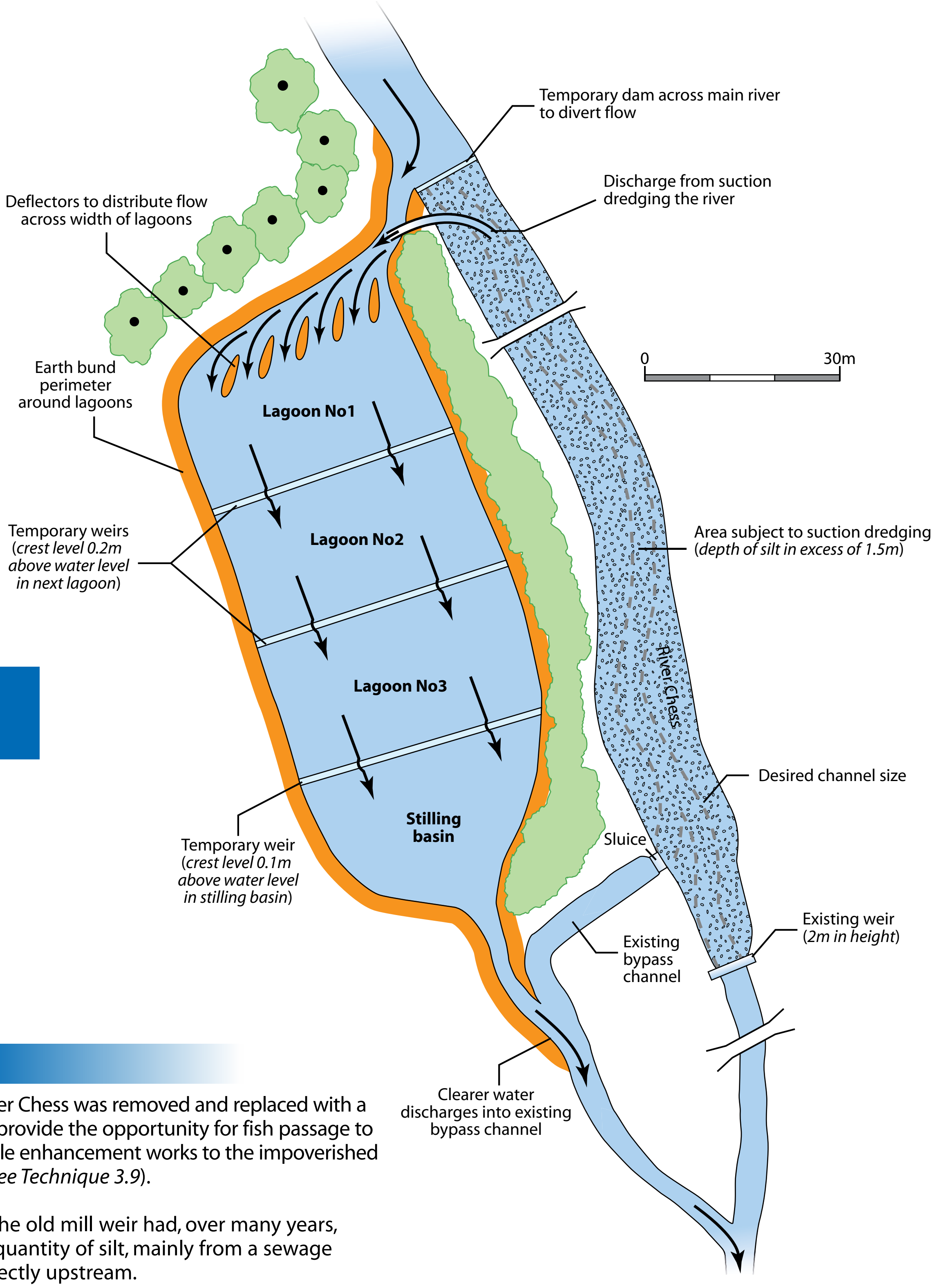


**Figure 10.3.1**
Plan of temporary silt trap lagoons

### Description

A mill weir on the River Chess was removed and replaced with a fish-pass. This would provide the opportunity for fish passage to be restored and enable enhancement works to the impoverished channel upstream (*see Technique 3.9*).

The channel above the old mill weir had, over many years, accumulated a vast quantity of silt, mainly from a sewage treatment outfall directly upstream.



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

# Utilising Spoil Excavated from Rivers



Mill weir and replacement fish-pass

Dredging and re-profiling of the wide silted lagoon behind the weir was carried out in association with the fish-pass works. Prior to the implementation scheme, the water company relocated its effluent outfall downstream of the site.

By lowering the water level, sufficient gradient was returned to the river to re-form a narrow sinuous channel within the previously deep over-widened and ponded section. The impounded channel size needed to be drastically reduced, both in width (8m to 2m) and in depth (in places silt was up to 1.5m deep).

To achieve this the accumulated silt retained by the old weir had to be removed. In order to avoid moving spoil off-site the dredged material was incorporated into an adjacent grass field. Removal off-site of such material is often expensive and, if sent to a landfill site, unsustainable.

## Design

Using an excavator a series of low bunds were constructed in the adjacent field. The earthworks followed the fall in land levels to allow gravity flow. These bunds formed three shallow lagoons and a stilling basin. The first lagoon incorporated deflectors to ensure an even distribution across the width of the lagoon. The lagoons were separated by low temporary earth weirs (*Figures 10.3.2 and 10.3.3*).

The silted river was temporarily dammed and de-watered via the old mill bypass sluice. The river was diverted via a bunded inlet channel through the 'silt-trap'. To remove the large volume of saturated silt, suction dredging was used, the discharge being pumped into the first lagoon. The silt laden river water proceeded through the 3 lagoons depositing its silt load before ultimately rejoining the existing bypass channel.

Retention time within the silt-trap was approximately 2-4 hours. In this way 1300m$^3$ of excavated and suspended material was removed from the stream. The area of field used was circa 3000m$^2$ resulting in a maximum increase in height over the field of circa 0.2m.

The silted lagoons were allowed to de-water for 1 month and the temporary weir materials (tarpaulin and sandbags) removed. The silt and earth bunds were then flattened and graded into the field. The surface was hand raked and the whole area grass seeded with a meadow mix.

Main Photo (*Top right*): Exposed silt, looking towards mill weir.
Inset above left: Dredged. Inset above right: 4 years later

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## Utilising Spoil Excavated from Rivers

Lagoons and stilling basin – February 1995

Lagoons, stilling basin and overspill – March 1995

Retained silt load – April 1995

As a grass field 4 years later

# Utilising Spoil Excavated from Rivers



***Figure 10.3.2***
Typical section through lagoons

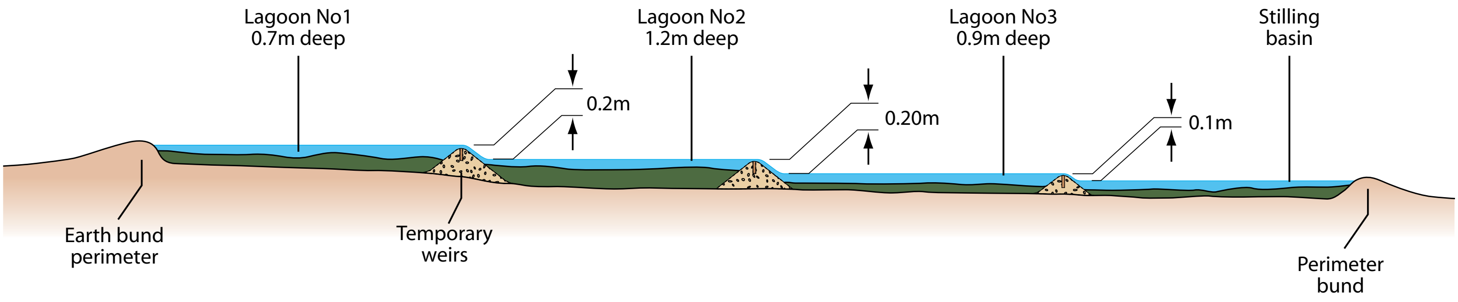
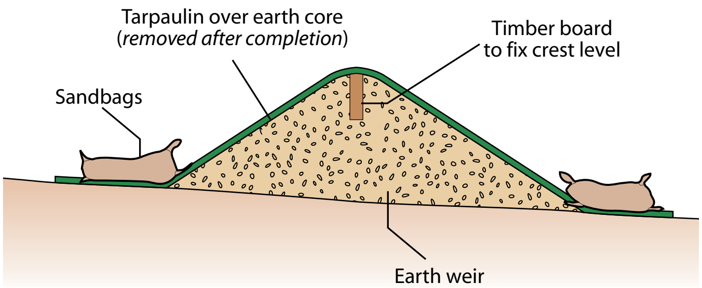



***Figure 10.3.3***
Typical detail of temporary weirs




Dewatering. View from inlet channel – April 1995

Graded, harrowed and seeded – June 1995

## Subsequent performance 1995 – 2001

Now fully grassed over, the field is not noticeably out of character. Indeed it appears to be a normal field.

Where sufficient gradient exists and loss of floodplain storage capacity is not affected or is not an issue, this technique for de-silting may be a suitable alternative to removal off-site.

Original Information Providers:
Steven Lavens
Chris Catling

# 10

## Utilising Spoil Excavated from Rivers

## 10.3 River Chess 2013 Update

A site visit in 2013 confirmed that the site continues to function as a normal field, further demonstrating the benefits of using this technique. In some areas the vegetation is dominated by common nettles (*Urtica dioica*), however this is not uncommon where there is a large amount of silt as nutrient levels are high.

| | |
|---|---|
| **River Chess** | Low energy, chalk |
| **WFD Mitigation measure** | Increase in-channel morphological diversity<br>Preserve and, where possible, restore historic aquatic habitat<br>Sediment management strategies (develop and review) which could include: substrate reinstatement, sediment traps, allow natural recovery minimising maintenance, riffle construction, reduce all bar necessary management in flood risk areas<br>Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone |
| **Waterbody ID** | GB106039029870 |
| **Designation** | None |
| **Project specific monitoring** | Invertebrates |


© RRC

The field 18 years after works – 2013

## Contact

Sarah Scott, Envrionment Agency (South East)
sarah.jane.scott@environment-agency.gov.uk, 01707 632371

# 11

# River Diversions

## 11.1 Diversion of a River Valley

### Sugar Brook

Location – Manchester Airport SJ7981
Date of construction – 1998
Length – 360m of main river plus a tributary
Cost – Not available

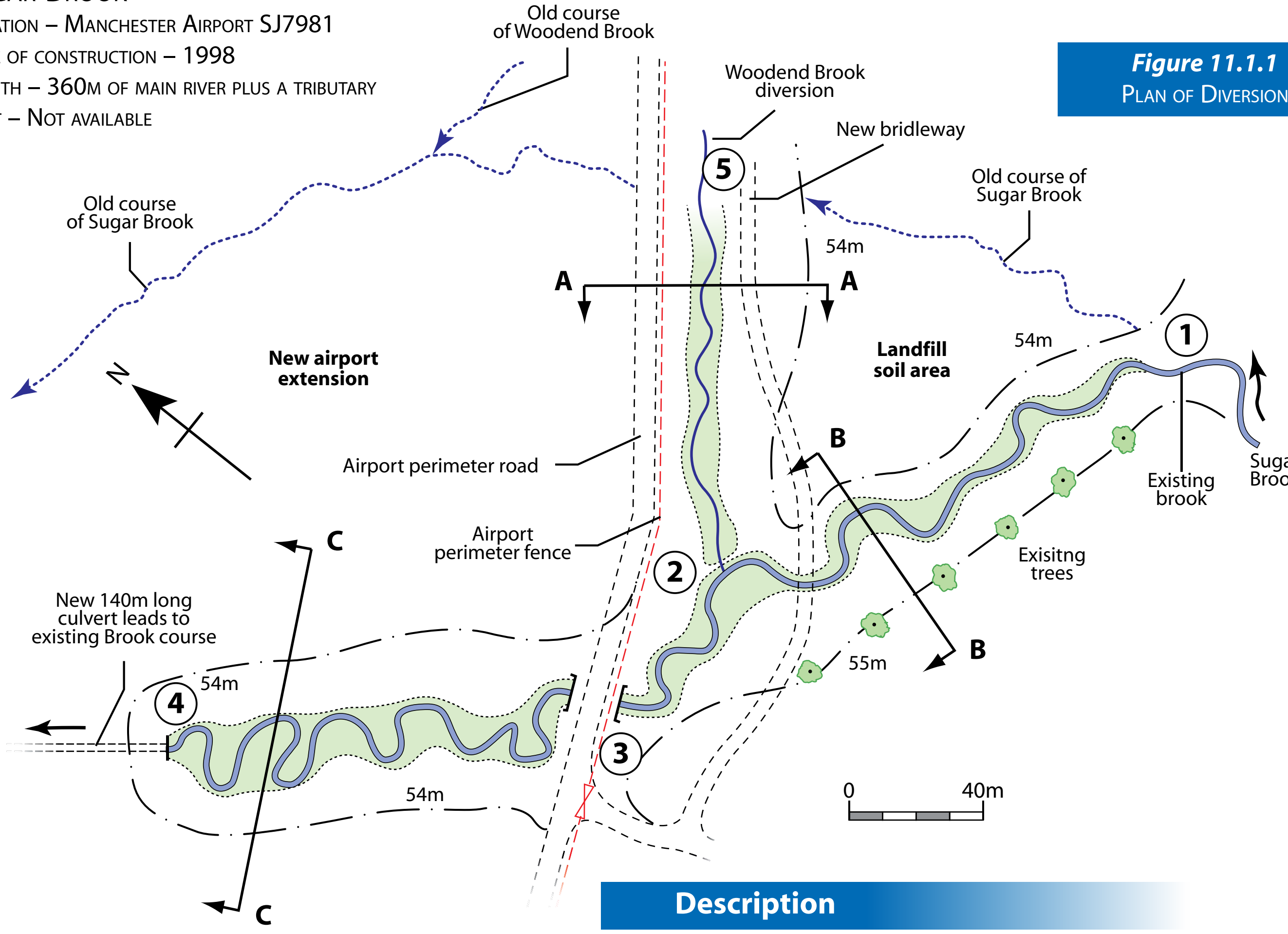



**Figure 11.1.1**
Plan of Diversion

**Key**

- Contours at 54/55m indicating top edge of new valleys created
- Indicates extent of relatively flat valley floor (floodplain) with small incised channel meandering through
- (1) Start of Sugar Brook diversion
- (2) Woodend Brook confluence
- (3) Perimeter road culvert
- (4) Airport culvert
- (5) Start of wetland on Woodend Brook

## Description

The construction of a second runway at Manchester Airport required the back-filling of a 350m long reach of Sugar Brook, and its valley, to bring ground levels up to the required elevation for the runway, the runway approaches and marginal safety grasslands. Rather than place the entire reach in a buried culvert the brook was realigned over a 500m long reach that reduced the length of culvert involved to 140m where it unavoidably passed under the runway approaches and lighting strip. The remaining length of the diversion, some 360m, was constructed as an open watercourse.

A small tributary stream, Woodend Brook, was similarly affected and needed to be diverted into the realigned Sugar Brook. This was achieved entirely in an open watercourse further avoiding culverting.

*Figure 11.1.1* shows the previous route of the two watercourses and the route of the diversions to the south that take them clear of the airport perimeter fence towards the new culvert under the airport approaches (airport culvert). This culvert reconnects directly to the existing Sugar Brook course at its exit. The length of the diversion equalled the length that it replaced, thus maintaining the same overall bed gradient.

# River Diversions 11

Sugar Brook before culverting, a reference site for the new channel

Many issues arose in the design of the watercourse diversions, but perhaps of greatest significance was the depth to which excavations needed to be taken to achieve the required bed levels. The new bed falls fairly uniformly at about 1 in 200 gradient between existing bed levels of Sugar Brook at each end of the 500m diversion. In contrast to this, the ground levels along the diversion route increased in elevation to heights of over 5m above the new bed. Channel depth of this magnitude (5m) far exceeded the natural channel depth of approximately 1m that are typical of Sugar Brook, so a novel approach to design was essential.

The diversion presented an opportunity to recreate the natural features found on unmodified reaches of the brook.

## Design

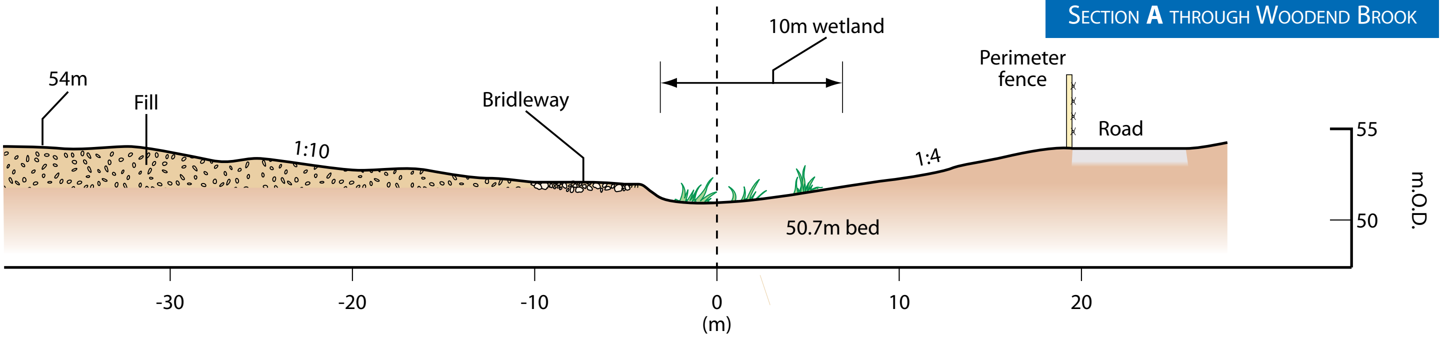
A preliminary outline design prepared at the planning permission stage indicated a slightly sinuous channel that was trapezoidal in cross-section over its full depth and lacked any of the detail and refinement needed to mimic the natural character of Sugar Brook. This approach aimed to achieve the least possible excavation width and set new bank tops around which various roads, paths and a surplus spoil disposal site were all positioned and linked to the subsequent planning permission. This resulted in an unduly narrow 'approved' corridor of land within which to achieve the detailed design of the diversion.

A trial excavation at the upper end of the diversion reach was undertaken to test the outline design. This was shown to be completely inappropiate. Apart from its deep 'canyon-like' appearance, the predominant clay soils could not be relied upon to remain stable at the depths of excavation involved. Undercutting of the toe of the slopes could be expected to accelerate collapse of the high banks.

A new approach to design was needed which recognised that the formation of the valley within which the brook naturally flows involved different geomorphological processes than those that sustain the small watercourse that is incised within the floor of the valley. Inspection of the undisturbed reach just downstream of the airport demonstrated a narrow rounded valley formed during glacial retreat with a fairly flat bottom of more recent fluvial sediments through which the brook course meandered. Cross-sectional templates were taken from this reference reach and used to design the new valley.

The approach to detailed design thus involved treating the diversion as a diversion of the valley of Sugar Brook and not as a channel diversion. If an acceptable valley form could be achieved then the creation of a small meandering stream within its floor became a relatively straightforward task.

**_Figure 11.1.2_**
SECTION **A** THROUGH WOODEND BROOK




Woodend Brook

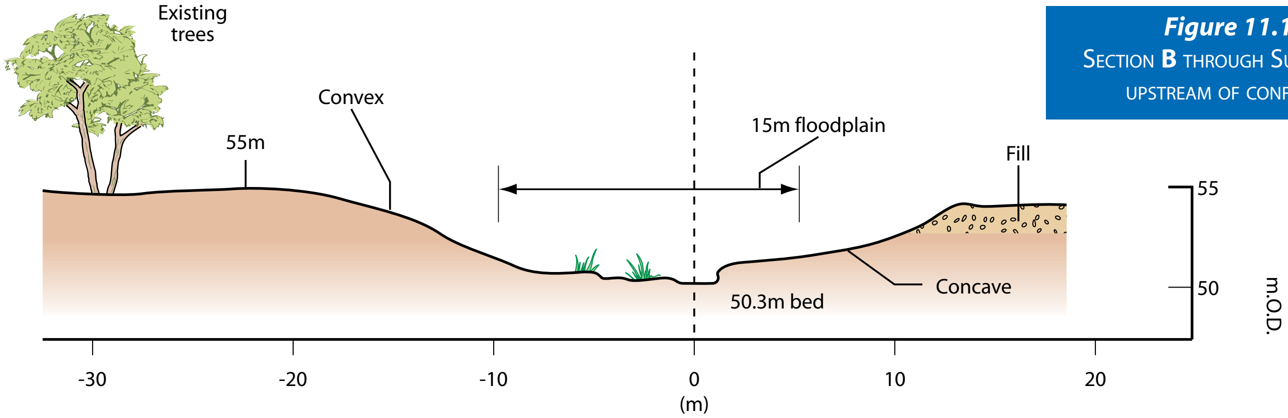
*Creating the New Planforms*
*Figure 11.1.1* shows the top edge of the newly created valleys of both Sugar Brook and Woodend Brook along contours of between 54 and 55 metres O.D. with a top width of between 30 and 50 metres. The relatively flat valley floor of each is also indicated at widths of between 10m and 20m.

The meandering plan form of Sugar Brook, which is cut into the valley floor by up to 1m only, was strongly influenced by templates of meander patterns elsewhere on the brook (*Figures 11.1.3 and 11.1.4*). Woodend Brook does not feature an incised course in the new floor but has been encouraged to form a wetland across its full width of around 10m (*Figures 11.1.2*). Natural channel incision is expected to develop slowly.

*Valley Profiles*
The manner in which the new valley side slopes were shaped was carefully excavated to mimic natural profiles which vary from concave, where ancient soil slips have arisen, to convex, where they have not. The mean slope associated with concave (slipped) profiles is likely to be flatter than when convex, creating desirable variations and mild sinuosity when looking down the valleys. Compound slopes involving both concave and convex slopes were also incorporated. Three cross-sections A, B and C indicate these variations which are also apparent on the photographs.

Sugar Brook looking upstream

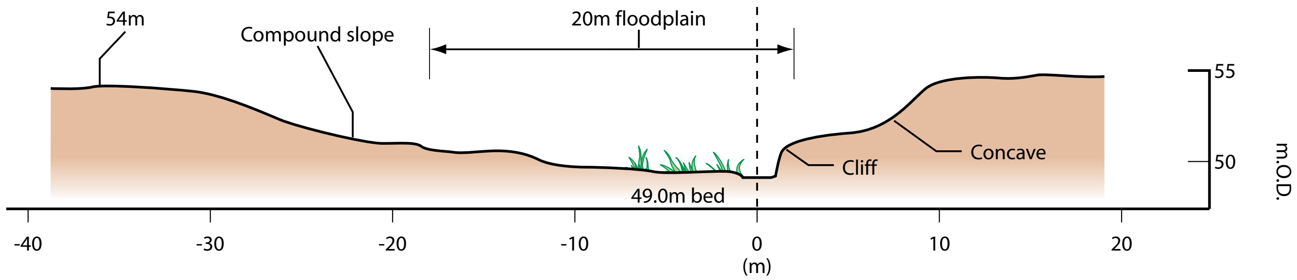
**_Figure 11.1.3_**
SECTION **B** THROUGH SUGAR BROOK
UPSTREAM OF CONFLUENCE






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

**_Figure 11.1.4_**
SECTION C THROUGH SUGAR BROOK DOWNSTREAM OF CONFLUENCE





Sugar Brook Valley below confluence – September 1999.


The river valley vegetation is developing well – November 2001.

## Subsequent performance 1995 – 2001

*The River Channel*
This was meandered down the valley floor following the design principles described elsewhere in this manual (*see Techniques 1.1, 6.2*). Cliffs, riffles, pools and shoals were all initiated within the excavated channel profiles, but it was expected that rapid changes would arise during subsequent flood periods. The aim of the design was to create a channel form that anticipated the type of regime that was appropriate whilst leaving it to the stream to adjust to a reasonably stable form over succeeding years.

Extensive marginal and bankside planting was undertaken as part of the planning permission and a monitoring programme was set up with the first survey in 1999, one year after construction.

Although the extent to which the form of the newly created valley could be naturalised is severely constrained by spatial limits relating to the early planning decisions, its overall appearance is good. It is certainly far better than the trapezoidal profiles envisaged at the start, which suggests that the concept of river valley diversion, rather than channel diversion, is one that needs to be taken up early in similar circumstances.

An MSc study in 2000 (M Guy, University of Nottingham) found that considerable geomorphological activity is occurring on the channel, with active erosion and deposition patterns. It appears that the channel is still adjusting to reach dynamic equilibrium but is comparable with the undisturbed stretches of the stream.

As part of a post project monitoring scheme baseline information was compiled using water quality, benthic invertebrate data, topographical and river corridor surveys. In the first year, monitoring results of the aquatic planting confirmed all species planted had begun to establish, but a short term abundance of annual watercress (*Nasturtium officinale*) was influencing low flow characteristics. Some self-seeding willow (*Salix spp.*) and alder (*Alnus spp.*) are already evident along the riparian channel.

No significant changes in water chemistry have been recorded, with the exception of fluctuating suspended solids during construction and very high flows. Within two years, the benthic invertebrate fauna of the new channel comprises almost all taxa found in the original. The remaining high scoring rare taxa have yet to return (*MSc dissertation 2001 Z. James*). Manchester Airport plc continues to monitor the site.

Original information providers:
Karen Williams
Pam Nolan
Malcolm Hewitt
RRC

# 11.2 Sugar Brook 2013 Update

| | |
|---|---|
| **Sugar Brook** | Low energy, clay |
| **WFD Mitigation measure** | Restore/increase in-channel morphological diversity<br>Preserve and, where possible, restore historic aquatic habitats |
| **Waterbody ID** | GB112069061350 |
| **Designation** | None |
| **Project specific monitoring** | Macroinvertebrates |

© RRC

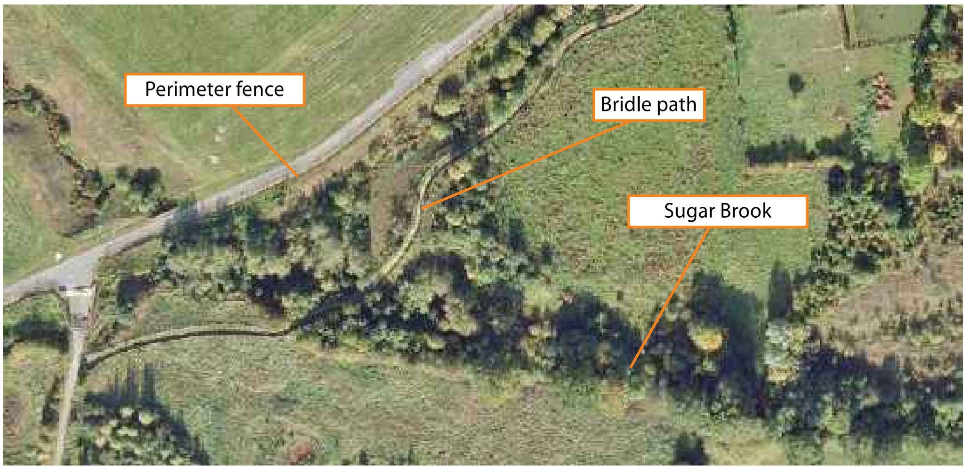
Looking upstream from the footpath bridge – March 2007

© RRC Looking upstream from the footpath bridge – July 2013

The self sown willow and alder mentioned in the 1998 – 2001 subsequent performance have now grown into a dense cover of trees. The photograph taken in 2007 shows the saplings growing along the bank and the more recent photograph taken in 2013 indicates that the channel is now completely shaded by this tree cover.

The channel would benefit from some sympathetic tree thinning to allow at least some daylight to penetrate through to the channel.

Aerial photograph of Sugar Brook showing dense tree cover

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## Contacts

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

11

# River Diversions

## 11.2 Clay Lined River

### River Nith

Location - West of New Cumnock, Ayrshire NS5412
Date of construction - April – September 2000
Length – 3km
Cost – £3,300,000

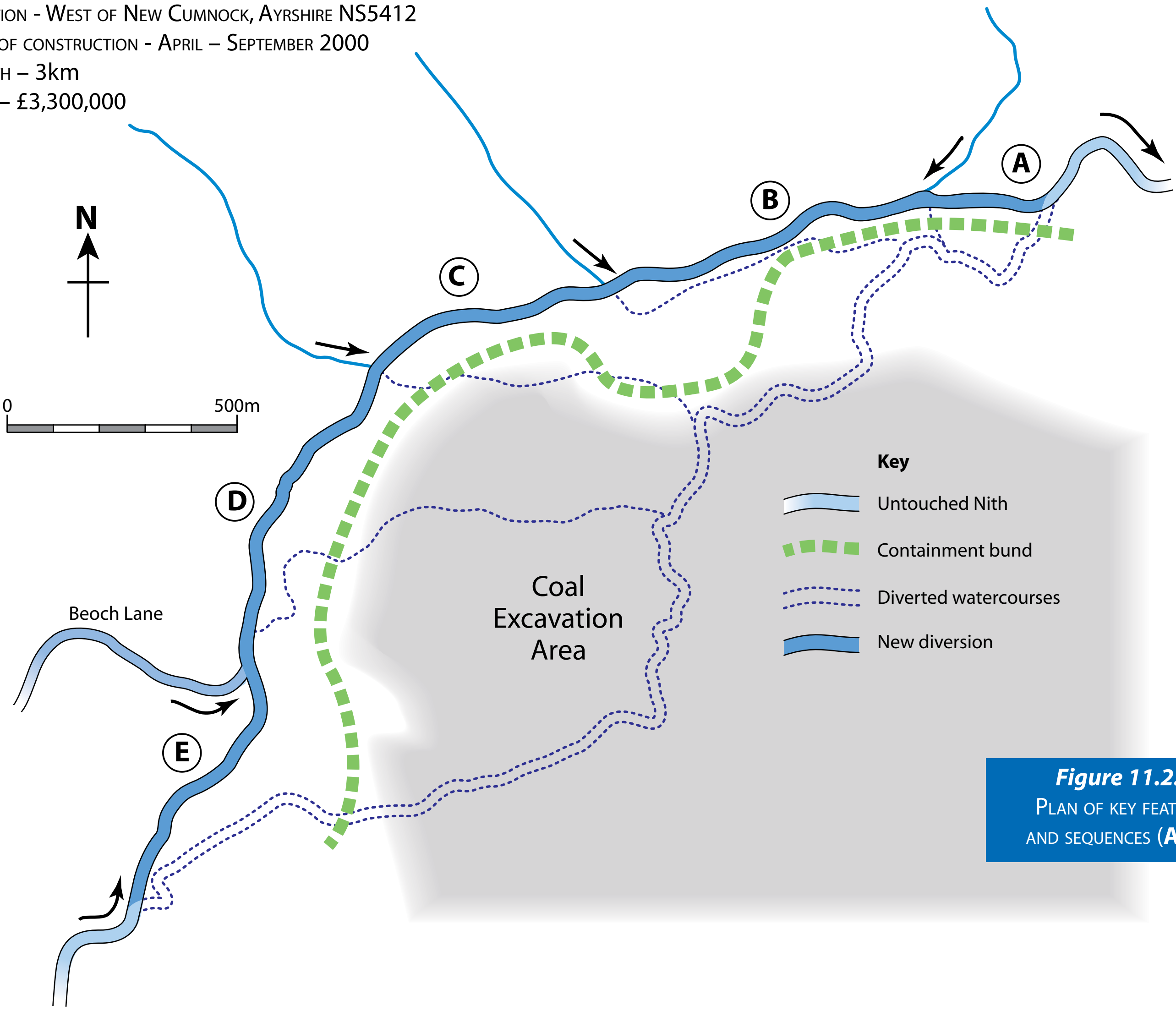



***Figure 11.2.1***
Plan of key features and sequences (**A – E**)

## Description

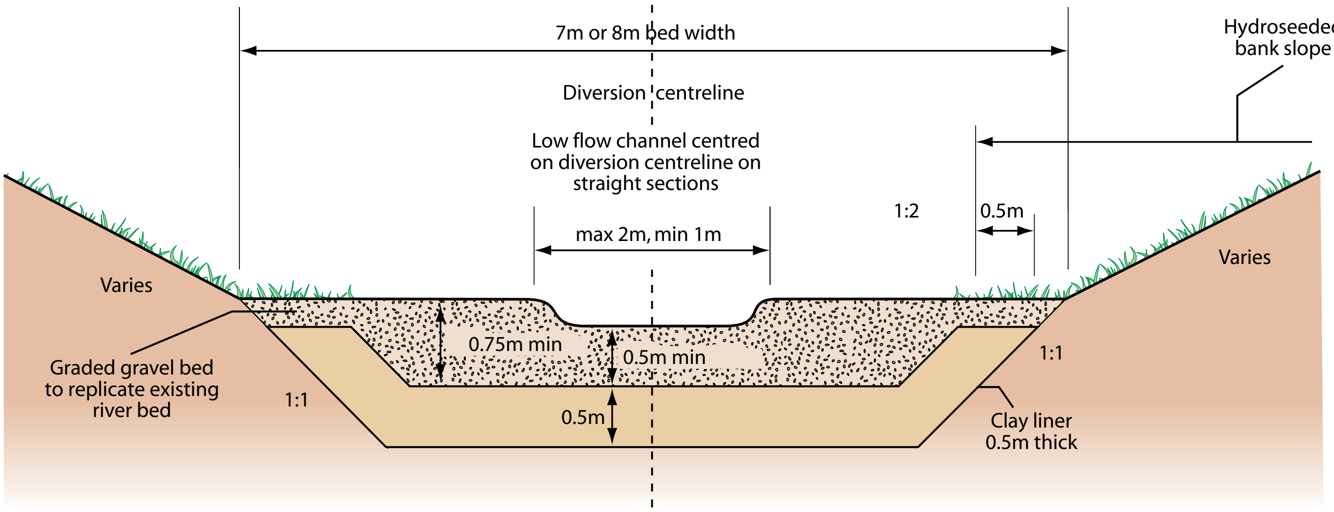
The River Nith rises at around 500m above ordnance datum (AOD) in the uplands of south-west Scotland and is an important salmon and trout fishery. It drops sharply within 7km to meander through a wide grazed valley floor at only 220m AOD. The Nith has a mixed gravel, pebble and boulder bed, with stable and eroding earth cliffs, a common feature of the banks.

In 2000 an existing adjacent open-cast coal site was extended requiring the permanent diversion of a 3km reach of the River Nith, Beoch Lane and three tributaries. The whole floodplain site covers an area of approximately $3km^2$.

The route of the diversion was restricted to a narrow corridor through areas of highly permeable strata and previous mine workings. In places the channel would need to be lined to prevent the river flowing below ground. In addition, to stop floodwater and ground water entering the opencast area, a containment bund, with an integral slurry wall constructed down to bedrock, was built between the new river channel and the coal excavation area.

The design flood standards adopted were the Mean Annual Flood for the river channel itself and the 1 in 50 year return period flood for the river corridor. Detailed hydraulic modelling established the diversion channel route and cross sections as well as the extent of flood protection measures required.

**Figure 11.2.2**
TYPICAL SYMMETRICAL CROSS-SECTION




## Description

A clay lined two-stage channel profile was adopted incorporating suitable run-pool-riffle sequences modelled on those in the existing river channel. Construction materials, including the 0.5-1m thick clay liner, river bed gravels and boulders, riffles and bund material, scour protection and in-stream features all came from the adjacent opencast excavations. It was anticipated that the new channel could match the length of the old one, but ultimately a reduction of 10% was necessary.

*Figure 11.2.1* shows the diversion channel to the north of the floodplain, with the containment bund protecting the opencast area. Works progressed from A to E upstream, enabling the tributaries and burn to be progressively captured by the new channel. These flows were used to wash silt from the new channel, then intercepted by temporary settlement lagoons at the confluence prior to controlled discharge to the Nith. On completion, flow from the River Nith itself was intercepted above point E and allowed to flow through the new channel.

The key components of the design are shown in *Figures 11.2.2 to 11.2.5* and include:

- a channel, between 0.5 and 1m deeper than the required depth, was excavated;
- along 80% of the diversion length a clay liner was compacted to form a barrier between the river flow and the permeable ground below. A very detailed specification was provided to the contractor regarding the quality of material, and the method of compaction;
- overlying the clay the new bed was formed from mixed cobbles, boulders, and gravels. Many thousands of cobbles and boulders, many of them covered in plant growth and harbouring invertebrate life, were carefully transplanted from the existing Nith and the captured tributaries to assist with the colonisation of the new channel;

Shaping the new channel within the clay lining

The 'constructed' run-pool-riffle sequence

- a 1-2m wide depression was formed to create the low-flow channel, centrally on straight sections and towards the outside on bends (*Figures 11.2.2 and 11.2.3*);
- precautionary stone rip-rap was placed on meander bends to maintain the designed planform;
- The bare banks were immediately hydroseeded with a grass mix to reflect the grassy moorland surroundings to maximise vegetation cover before the onset of winter.

Run-pool-riffle sequences were constructed by over-excavating the ground where the pools would be located. When forming the bed, cobbles and boulders were pushed into the graded gravel upstream of the pool, forming a raised bed and a central faster 'run' of water entering the pool.

Some natural erosion of the riverbank was accepted, though the design aimed to restrict the lateral migration of the river outside the clay liner. To further stabilise the banks planting was undertaken, including reeds and grasses along the water margins, and alder (*Alnus spp.*), ash (*Fraxinus spp.*) and willow (*Salix spp.*) alongside the rip-rap.

An extensive programme of electro-fishing was undertaken to transfer fry, parr and other life stages of fish from the length to be diverted to assist with colonisation of the new channel.

A matrix of wetland and other habitats was established in the new corridor with the intention of creating suitable habitats for a variety of wetland and grassland birds, otters, (*Lutra lutra*) insects and amphibians.

***Figure 11.2.3***
TYPICAL ASYMMETRICAL CROSS-SECTION

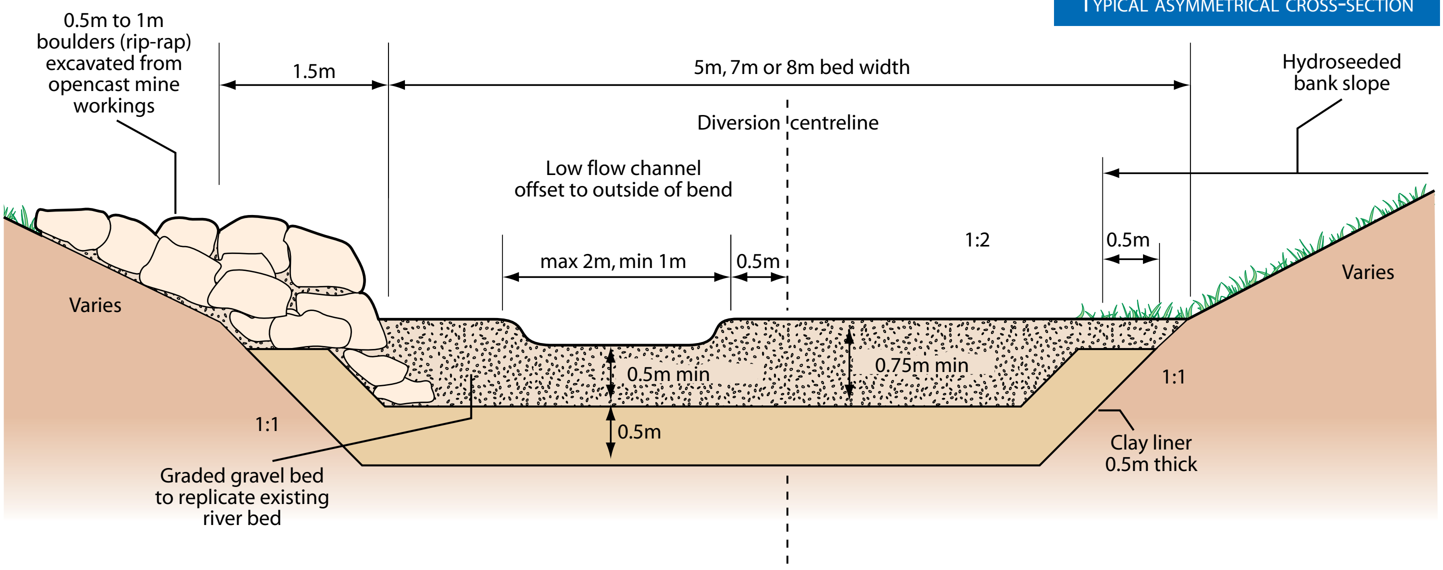
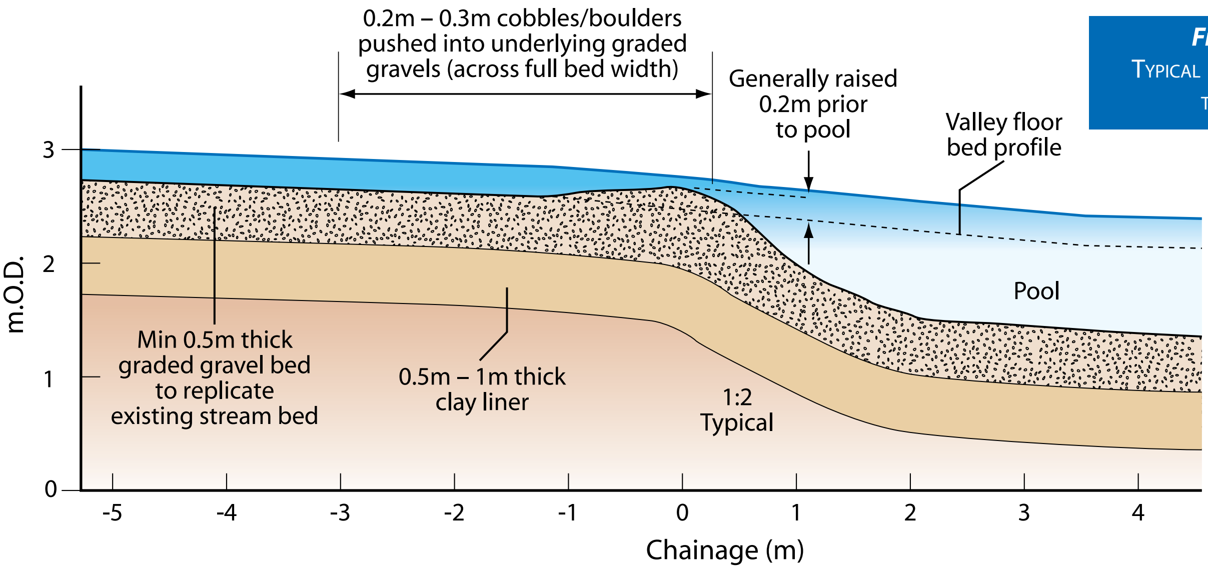


***Figure 11.2.4***
TYPICAL LONGITUDINAL SECTION THROUGH POOL




One year on and natural redistribution of in-channel sediments is helping to 'soften' the engineered channel

## Subsequent performance 1995 – 2001

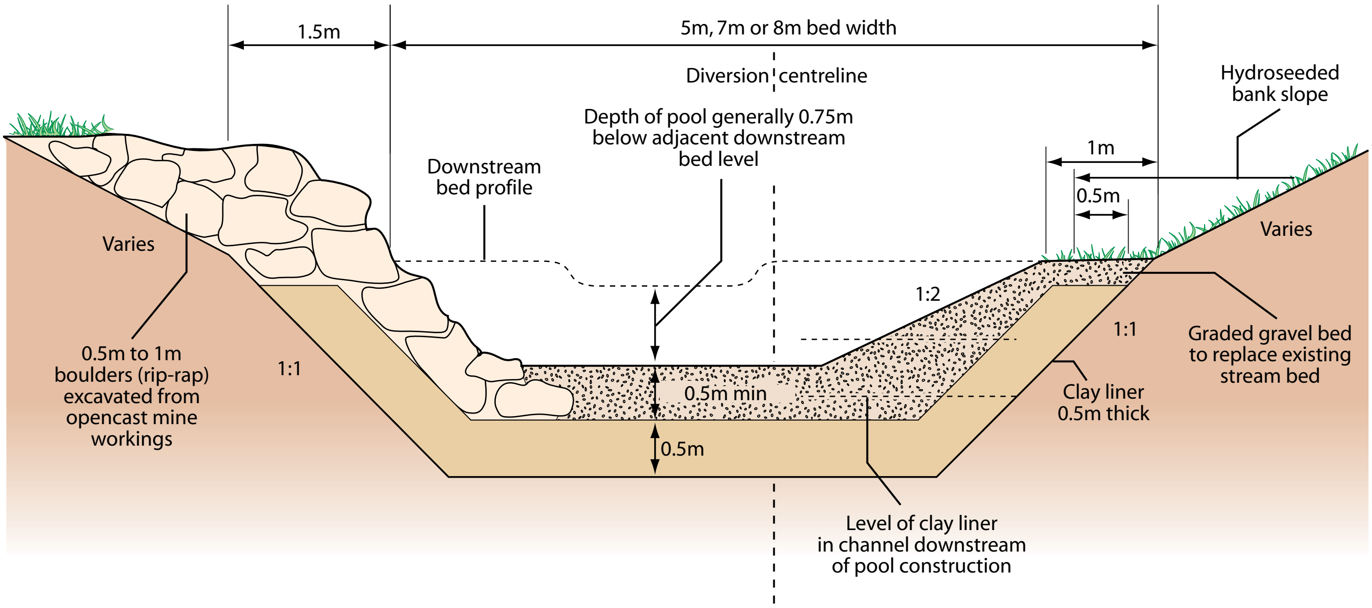
The ongoing biological and geomorphological performance of the diverted channel is being monitored under a PhD programme at the University of Stirling, sponsored by those sharing responsibility for the construction. A complete picture of the success of the project will only be possible following several more years of monitoring but the signs after twelve months are encouraging.

Recovery of the plant and benthic invertebrate communities is progressing well, although some species still remain low in abundance and others, found in the natural river, are absent from the diversion. This relates to low mobility and poor habitat and food availability due to the lack of vegetation. Fish have successfully recolonised the new channel, and the scheme has been hailed a success by the District Salmon Fisheries Board. Some additional planting is to be undertaken along the river-banks to provide in-stream shelter.

11

River Diversions

**Figure 11.2.5**
Typical pool construction




The overwide channel and plentiful bedload gives the river scope to shape its bed



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

River Diversions 11

The rip-rap is still very evident but the in-river form is developing well

During a 1 in 10 year flood event the channel planform remained stable with only minor bank erosion. Channel change was most apparent near tributary junctions; dynamic reaches in natural rivers. The bed material was mobilised, as it was in natural reaches up and downstream, and as a result the constructed low-flow channel was replaced by a natural thalweg. The movement of the bed material resulted in some reaches becoming shallower, and the creation of point bars not in the design, increasing diversity of water depths and velocities.

Sorting of the bed material has deposited finer material on the inside of meander bends, resulting in a more natural appearance than immediately following construction. Minor bed level and bank adjustment is anticipated as a result of further high flows, in the same way as would occur in a natural river, but this will not threaten the integrity of the diversion.

The works have an eight-year maintenance period that will encompass annual inspections and reporting of any erosion control and/or replanting works deemed necessary.

Original Information Providers:
Mark Welsh
Gordon Cartwright
RRC

11

# River Diversions

## 11.2 River Nith 2013 Update

| | |
|---|---|
| **River Nith** | High energy, gravel |
| **WFD Mitigation measure** | Restore form and function (channel and channel migration zone)<br>Make flow regimes more natural<br>Riparian planting |
| **Waterbody ID** | GBNI1NB030307129 |
| **Designation** | None |
| **Project specific monitoring** | Macroinvertebrate, Fish |

The diverted channel had a wide riparian corridor. However, there was not enough channel sinuosity, and back water habitats were created which were out of character with the natural form of the river. In places the gradient was over steepened which, after the first floods, caused some headward erosion in one of the tributaries, the Dalgig Burn. In addition, bank erosion, slumping and some erosion in tight meander sections occurred. The eroded material was deposited in the lower gradient sections downstream, almost filling the channel in places. While it did create some additional habitat diversity, it was not planned. Problems with erosion were addressed by placing more boulders into the channel. This was fairly cheap to do due to the proximity of material to the site (mining by-product) and the machinery that was available.

Following works, trees and shrubs started to colonise the banks and an increase in macroinvertebrates and fish was observed. Successful recovery of macroinvertebrate richness and abundance was recorded and after 12 months there was a 90% recovery over the whole channel. After 2 to 3 years there was little discernible difference in species composition between the impacted and control sections.

### Major changes

In 2004 the channel was moved again, roughly along the course of the original, because of a commercial decision to extend coal mining activities. This allowed the channel design to incorporate lessons from the former project's successes and limitations.

The channel realigned in 2004 after 7 years. Marginal vegetation has established and natural morphological processes are taking place – August 2011



## Contacts

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12

# Removing or Passing Barriers

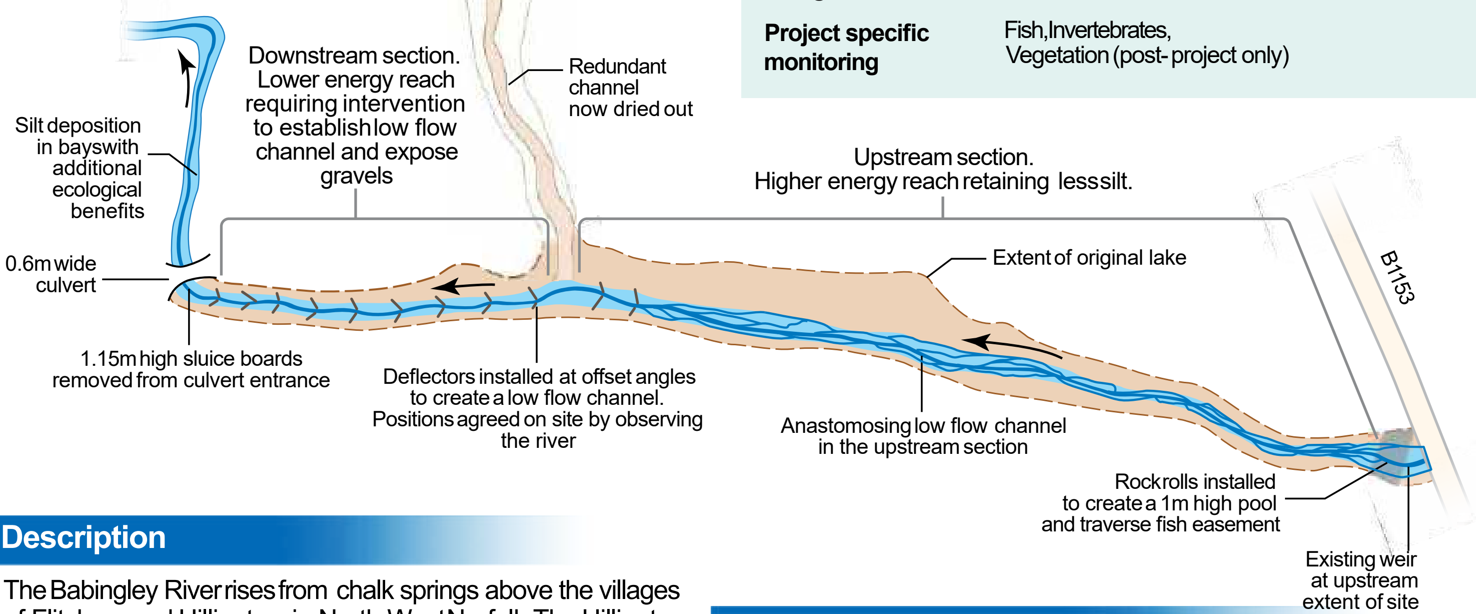
## 12.1 Restoring an on-line lake to a chalk stream

| Babingley River | Low energy, chalk |
|---|---|
| WFD Mitigation measure | Increase in-channel morphological diversity, Preserve and restore historic aquatic habitats, Remove obsolete structure<br>Sediment management strategies (develop and revise) which could include: Substrate reinstatement, Sediment traps, Allow natural recovery minimising maintenance, Riffle construction, Reduce all bar necessary management in flood risk areas<br>Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone |
| Waterbody ID | GB105033047620 |
| Designation | None |
| Project specific monitoring | Fish, Invertebrates, Vegetation (post-project only) |

### BABINGLEY RIVER

LOCATION - HILLINGTON, NORFOLK TF72532629
DATE OF CONSTRUCTION - 2006 – FEBRUARY 2007
LENGTH - 500M
COST - £600

**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.

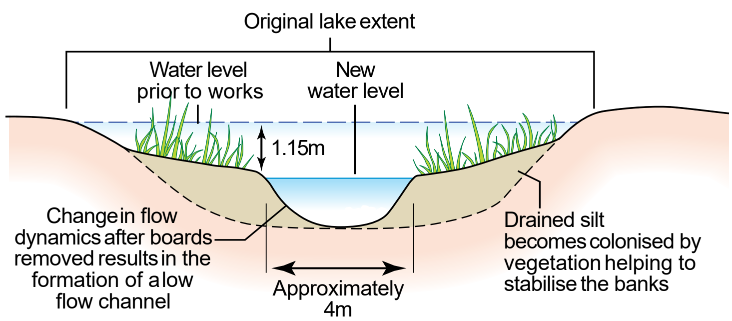



**Figure 12.1.2**
TYPICAL CROSS SECTION OF NEW CHANNEL IN DOWNSTREAM SECTION



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

# Removing or Passing Barriers

# 12

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

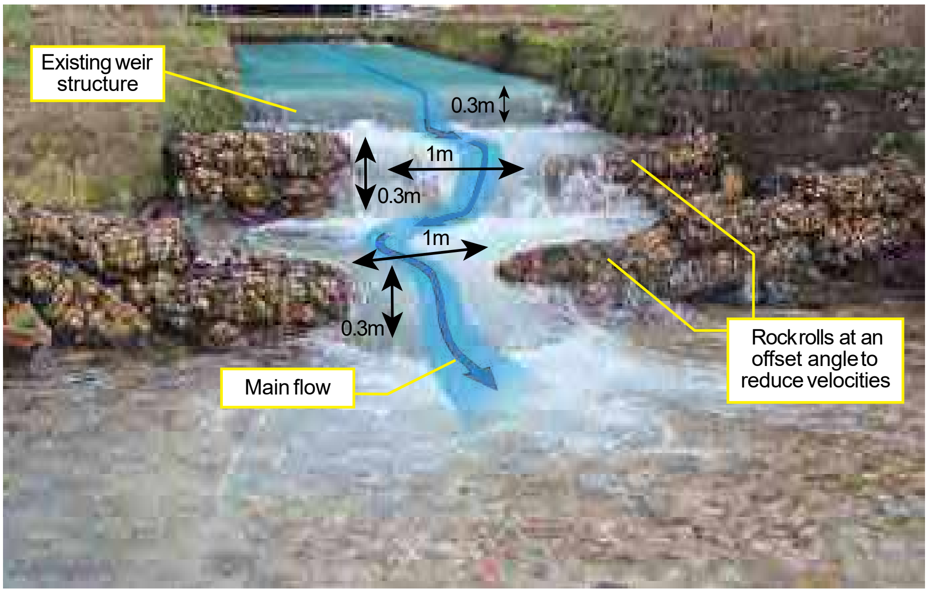





***Figure 12.1.3***
Pool and traverse fish easement created using rock rolls

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

*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

## Contacts

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## 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** | Install fish passes on side channels. Active removal of sediment |
| **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.

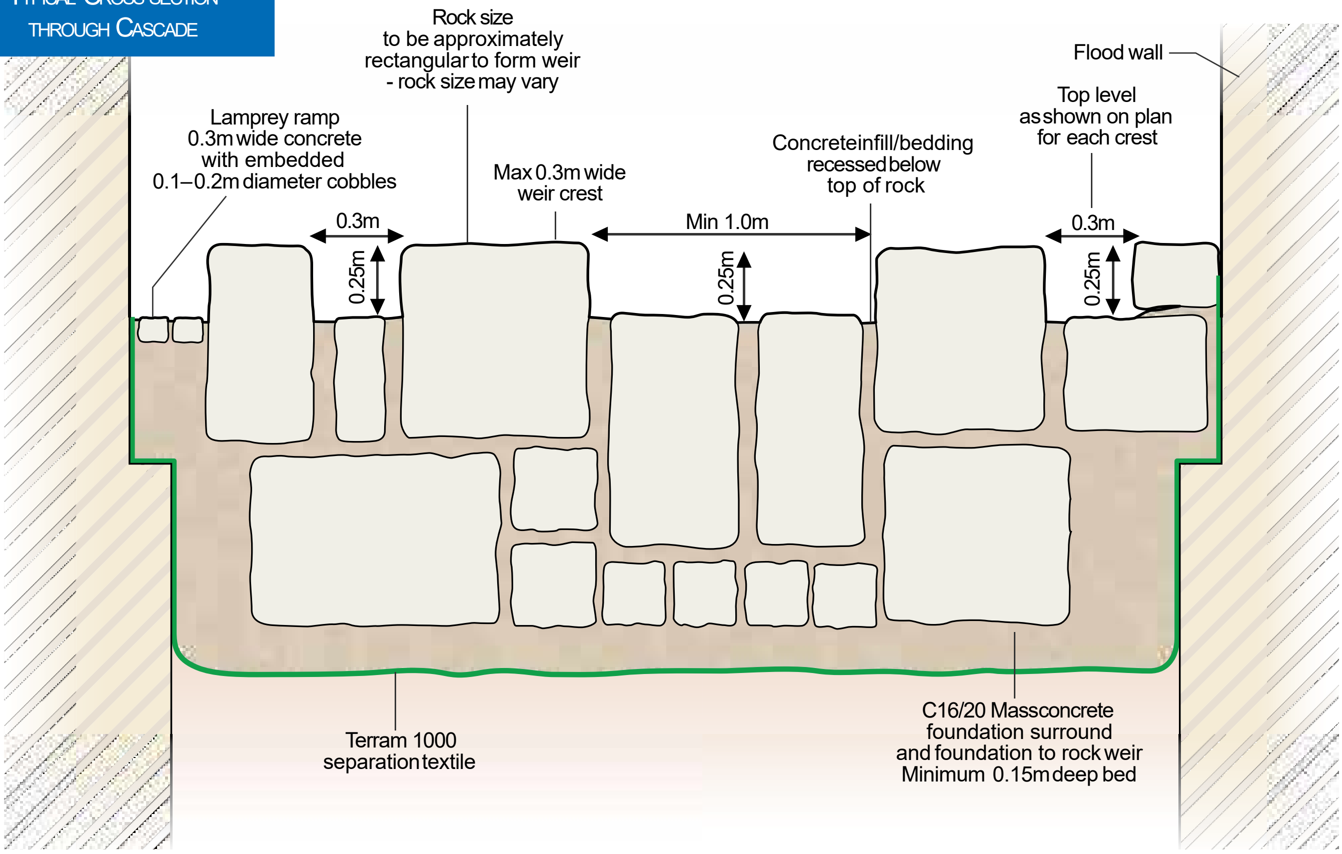
**2. Modify culvert bed**; the culvert had to be enlarged to incorporate the loss of capacity and increased roughness of the new cobble bed. The culvert bed was carefully excavated 0.3m below the existing level.

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




© Rivers Agency

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 each cascade was put in place it was not possible for machinery to travel back upstream of it again.

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12

Removing or Passing Barriers

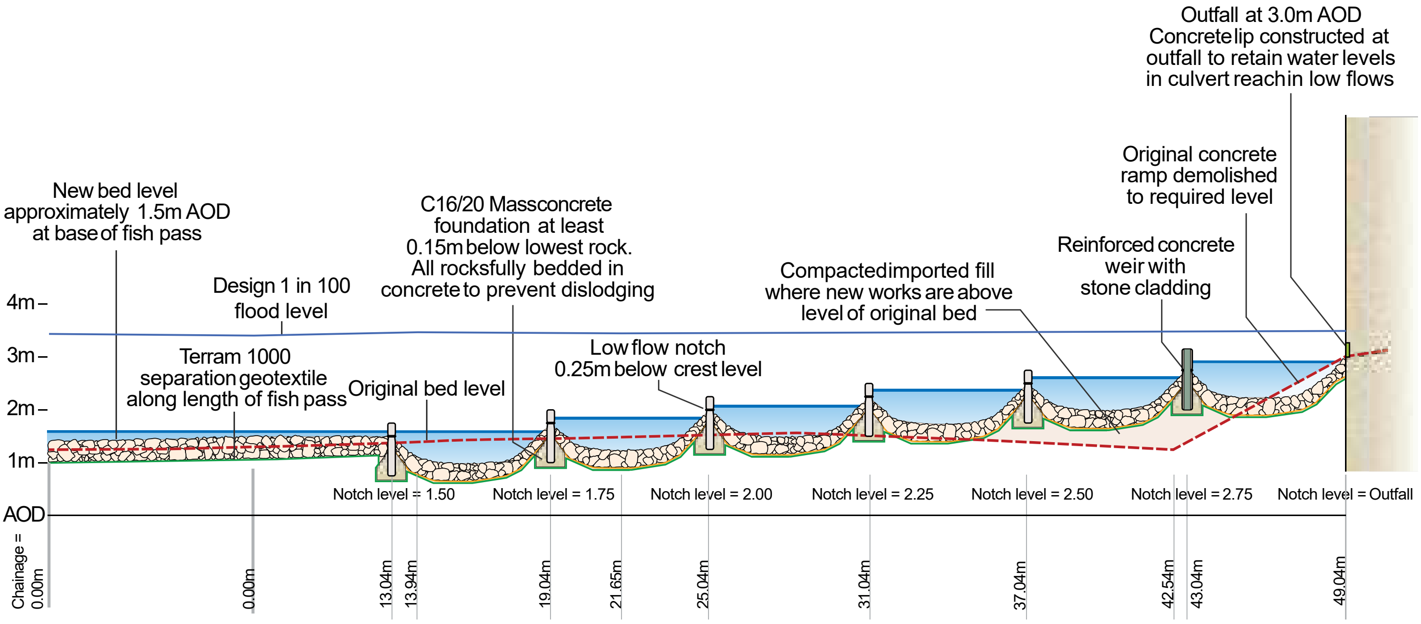


**Figure 12.2.2**
Longitudinal Section through Cascade Fish Pass

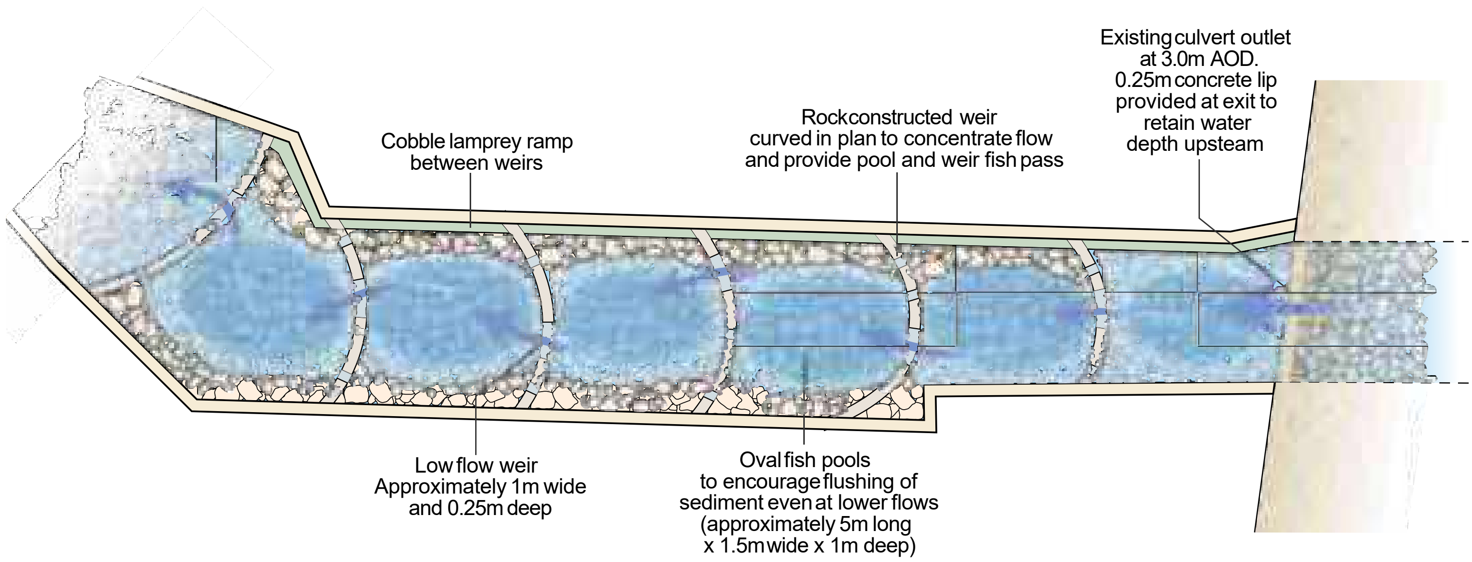


**Figure 12.2.3**
Overal plan of Cascade Fish Passage



**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

## Contacts

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# Removing or Passing Barriers

## 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** | Increase in-channel morphological diversity<br>Preserve and, where possible, restore historic aquatic habitats<br>Remove obsolete structure |
| **Waterbody ID** | GB109055029720 |
| **Designation** | None |
| **Project specific monitoring** | Geomorphology |

### Description

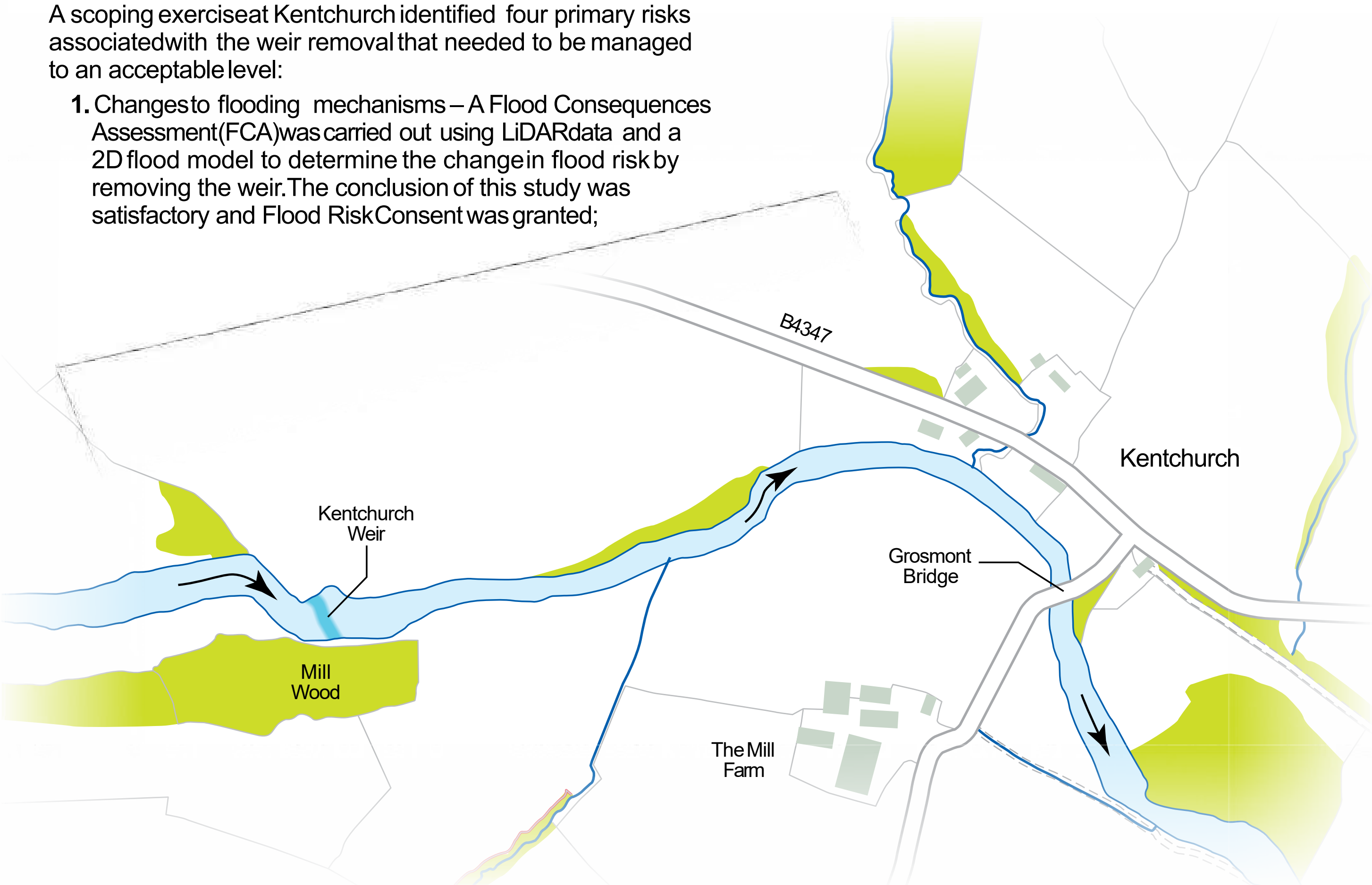
Kentchurch Weir, owned by Environment Agency Wales (now Natural Resources Wales), located within a large private estate, was thought to be a modern reconstruction of an older weir and was in the process of breaching. It was decided to completely remove the weir rather than repair it, also addressing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



# Removing or Passing Barriers



The 2.6m high Kentchurch Weir prior to removal – 2011

© Natural Resources Wales

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.

© Natural Resources Wales

Initial breakout of the weir on the left bank – 2011

© 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 sandbags 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

## Contacts

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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** | Increase in-channel morphological diversity<br>Preserve and, where possible, restore historic aquatic habitats<br>Remove obsolete structure |
| **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.

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

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

## 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.

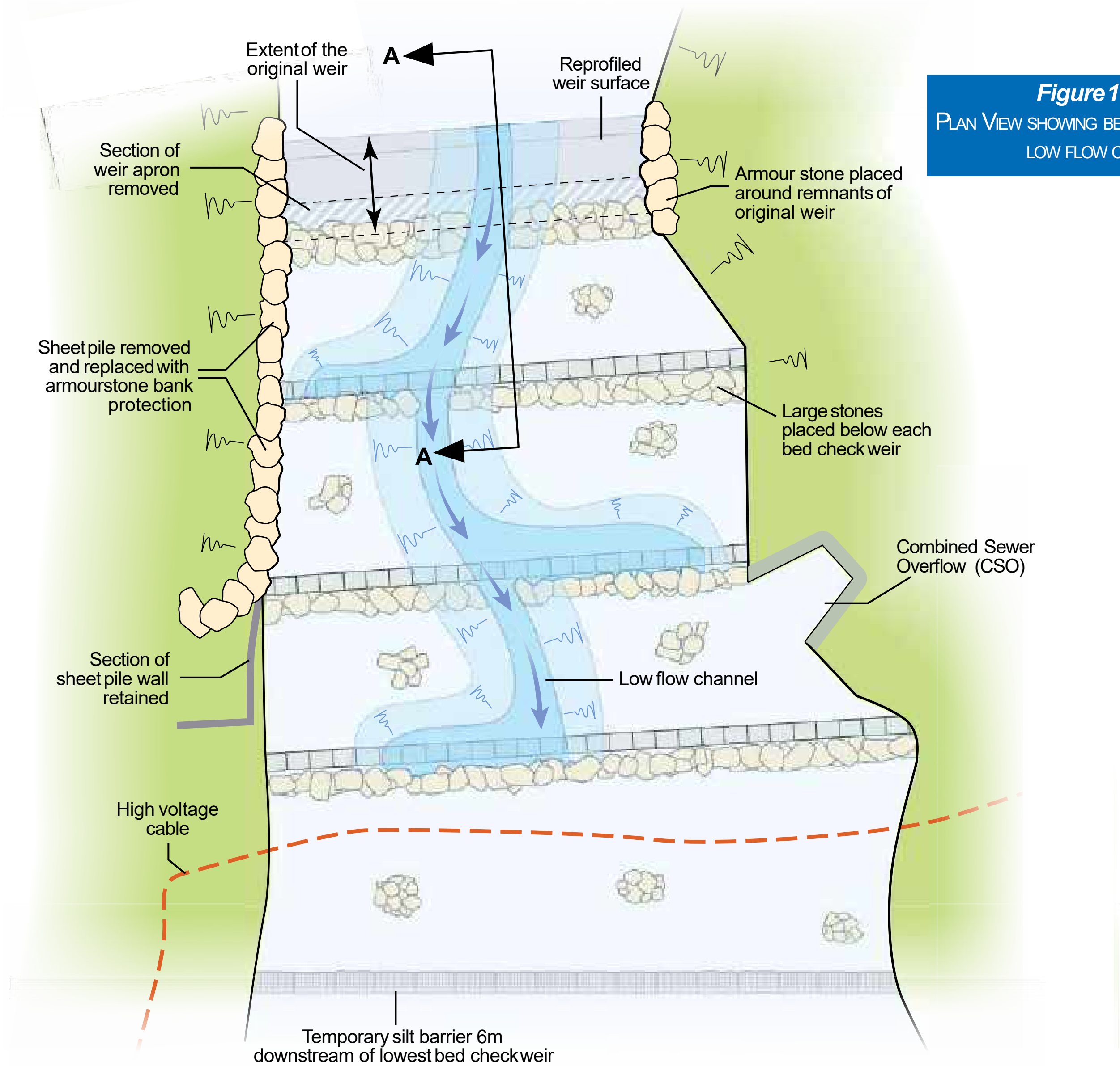
A hydromorphological assessment concluded that the impacts of the weir removal on sediment transport, water levels and the flow regime would be beneficial. It was established that there would be no increased flood risk and that there was likely to be a reduction in flood risk for at least one business 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.

# 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.

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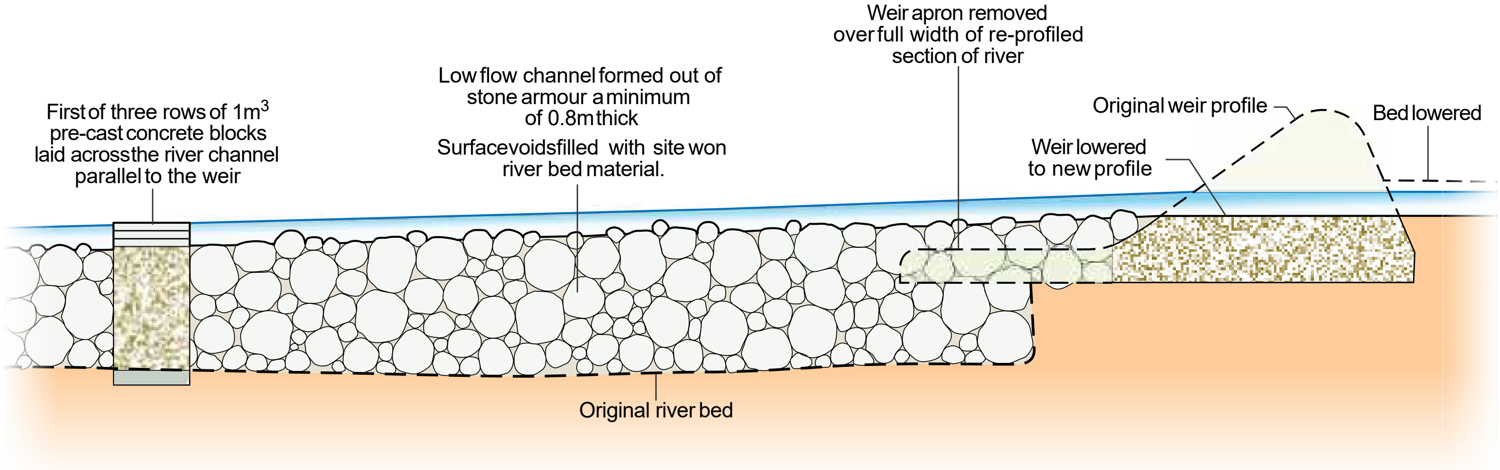
Removing or Passing Barriers

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






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



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

## 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

## Contacts

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## Reference material – Click here

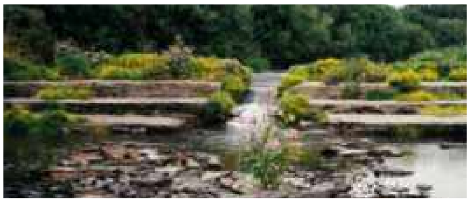
# 12 Removing or Passing Barriers

## 12.5 Replacing a weir with a rock ramp

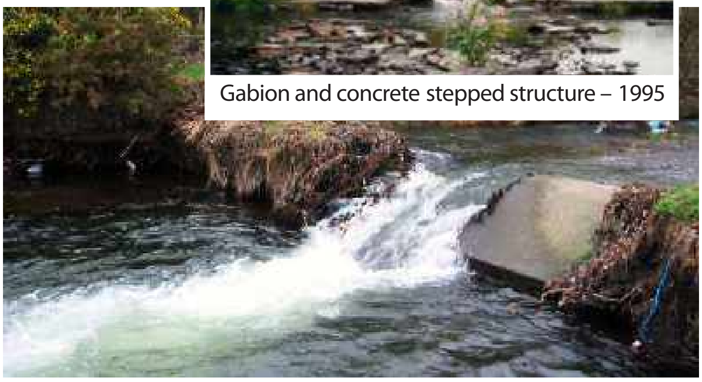
### River Neb

Location - Glenfaba, Isle of Man SC24648287
Date of construction - September 2006
Length - 75m rock ramp
Cost - £112,800

| | |
|---|---|
| **Type** | Medium energy, gravel |
| **Designation** | Protection under fisheries legislation for sea trout, salmon, European eel, brook lamprey and river lamprey |
| **Monitoring** | Electrofishing |



Gabion and concrete stepped structure – 1995



© Manx Utilities

Collapsing weir with deep scour hole used for swimming – January 2004

## Description

The River Neb is a short river on the Isle of Man known for its Sea Trout. The river has a large number of weirs originally installed for the mining and milling industries, interrupting flow, sediment and fish passage.

At Raggatt, 2 km from the coast, a large weir had been constructed in 1850 to feed water to Glenfaba Mill. In the mid 1980s the weir was in a poor state and was replaced with stepped concrete capped gabions. Total removal was not an option, so the aim was to maintain the existing head of water (to feed the mill leat) and to replace the existing dilapidated structure before it fell apart and released the accumulated sediment from above.

Strict fisheries legislation (Isle of Man Fisheries Act 2012 and Inland Fisheries Regulations 2017) required the new structure to be passable by all life stages of Sea Trout. The large deep scour pool was being used as a swimming pool but contained boulders and loose gabion wire that presented a safety issue.

Various plans were drawn up and reviewed over a number of years, initially focussed on a concrete weir and fish pass design, budgeted at £273,000. This was finally revised for a more environmentally friendly and 60% cheaper rock ramp design.

The aim was to create a sufficiently shallow ramp that allowed easy fish passage, mimicked a steep section of river and gave greater stability to the built structure at high flows. This would also remove the current maintenance and liability burden of the deteriorating weir.

## Design

The existing river, weir and scour pool were surveyed to calculate levels and volume of fill material. The design was to mass fill the 3m+ deep scour hole, add a geotextile membrane to prevent the heavy top stone from sinking in to the fill, and then place large 1-3 tonne rocks on this new base layer for the full 20m width and 40m length of the ramp. This was done in two stages, right bank first (leaving a narrowed channel with capacity for the 1 in 2 year event) then from the more accessible left bank to infill the flowing channel quickly to bring the bed up to the surface. The design required very low flows to enable completion of the left side, working in the wet (over-pumping or piping the low flow could also be used depending on flow volumes).

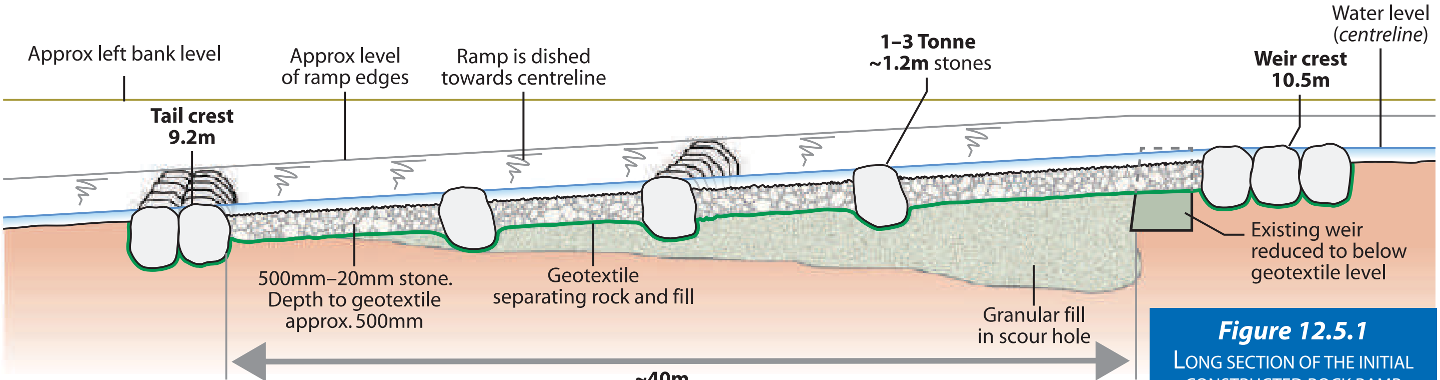



***Figure 12.5.1***
Long section of the initial constructed rock ramp



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

The proposed sequence and method of working was:

1. Raise the left bank level (construct a new flood embankment) to protect the extensive left bank floodplain (and old historic course of the Neb) from inundation.

2. Infill the scour hole with graded fill material (in this case crushed 250mm to 5mm concrete) working from the bank outwards.

3. Fill to half channel width, unroll the geotextile and begin to place the 1-3 tonne keystone rocks, gently sloping from the bank to the middle of the ramp (a 1 in 50 fall along the line of stones (groyne). The groynes act to direct flow from side to side and towards the dished centre of the ramp.

4. Define the crest level with three rows of the 1-3 tonne rocks.

5. Infill the areas between crest, groynes and tail with 500mm to 20mm stone. The keystone rocks prevent excessive movement within the ramp, and prevent the mass movement of stone infill from the ramp.

Once the first half channel is complete, move to the other bank and work quickly to raise the flowing channel.

6. Two layers of 1-3 tonne rock to be used to create hard bank protection to the ramp, the right bank mill leat and to the new embankment on the left bank.

At this point, when the works were 80% complete, a large storm event occurred breaching the new left bank embankment and bypassing the rock ramp, flooding the left bank floodplain and scouring and redistributing the rock ramp material.



Nearly completed rock ramp, embankment and vertical blockstone edge prior to storm - 2007

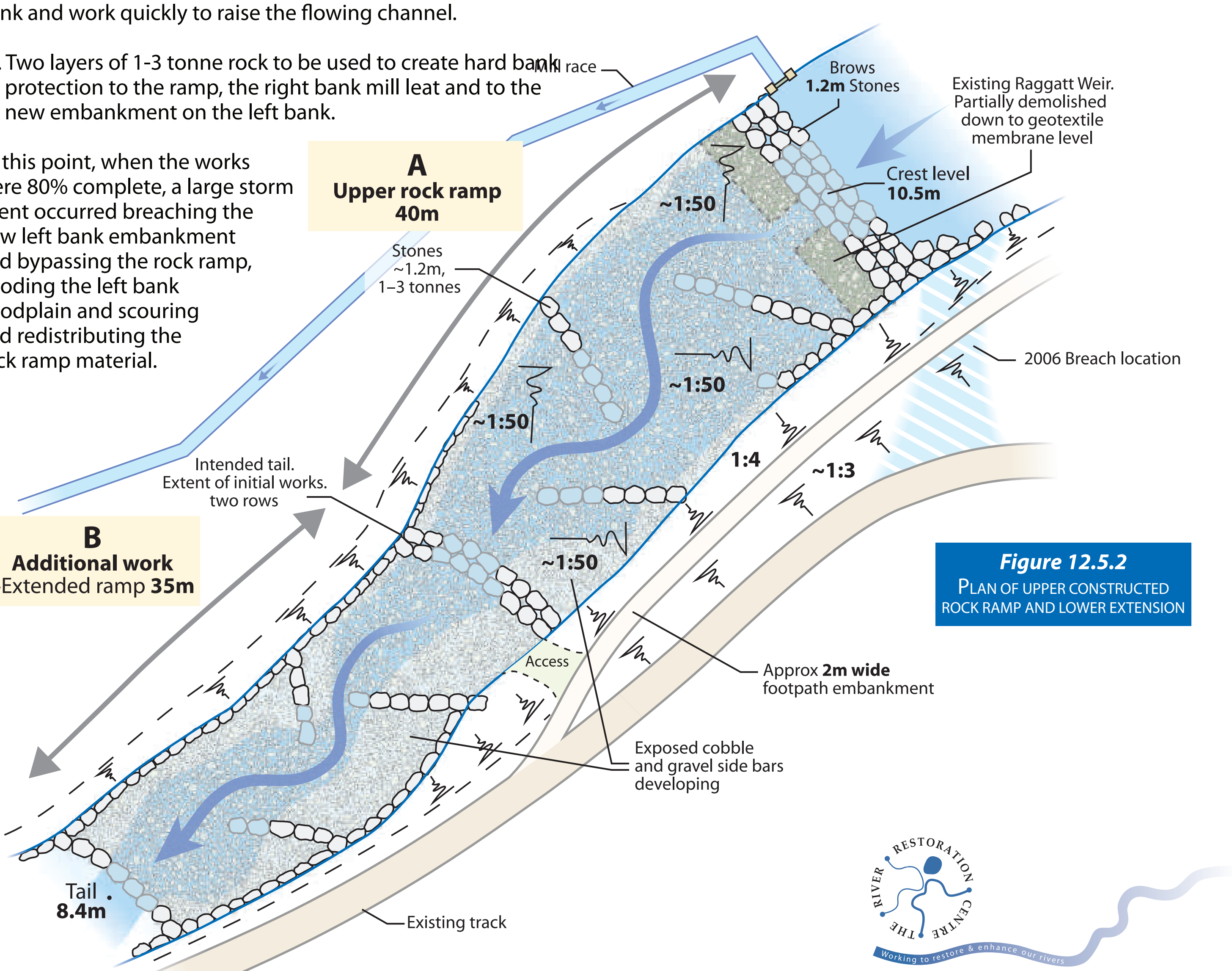



***Figure 12.5.2***
Plan of upper constructed rock ramp and lower extension

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

## Post-storm revisions

Following this the left bank and embankment design was revised and the ramp lengthened.

7. The vertical rock face was removed and the embankment was regraded to a slope of 1 in 4 from the 2m footpath top width down to the water's edge, creating a gentle vegetated slope with additional high flow capacity.

8. Turf and coir geotextile provided vegetation cover and initial protection. There was also addition of a Lintobent impermeable clay core liner to solve continued leakage within the narrow upstream end of the embankment.

9. The bankside rock armour was removed to enable the embankment protection matting to be dug in beneath the edge of the rock ramp surface. This spare rock was reused to add four further keystone groynes to lengthen the ramp by a further 35m, incorporating the material redistributed by the storm event, and add further rock groynes to add stability to the ramp. No further smaller rock infill was added. This was left to be filled by ramp redistribution and cobbles from upstream sediment supply.

Whilst this additional work added to the cost, the works still came in under budget at £112,000. In addition, the redesign removed an otherwise vertical hard engineered left bank wall and replaced it with shallow vegetated slopes, able to dissipate and spread high flows across the widened embankment area, reducing shear stress and erosion potential across the ramp.

Removal of the vertical edge stones and modified to a turfed shallow slope following the breach event.
Stones used to form the ramp extension – Nov 2007



Coir matting laid over the turf to provide initial protection - Nov 2007





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

## Subsequent performance – 2007 to 2019

Initial movement of stone at the bank edge, but the turf and coir remained intact. Preferential route then filled. – March 2008

© Manx Utilities

There was movement of the smaller rock (500mm down) as it settled and moved with subsequent flow events. Some adaptive management was required early on to fill in preferential flow routes that developed close to the embankment edge, due to settlement and scour.

The vegetated banks have colonised well and the re-profiled embankment and channel slopes fit better into the landscape than the initial rock armour walls. Gravel deposition has occurred on the left forming a marginal exposed gravel bar (further protecting the embankment toe).

An unexpected benefit of the work, resulting from the doubling of the ramps length, is the very high density of juvenile salmonids occupying the boulder strewn habitat of the ramp. 1000 juvenile salmon and trout were recorded in a 2010 electrofishing survey of the ramp itself.

Similar results of bypass channel and rock ramps being designed as compensatory habitat for salmonids have been implemented in Nordic countries. Where derelict/failing structures cannot be removed (water supply, heritage, etc.). Shallow gradient rock ramps have the potential to allow water, sediment and fish movement.

Settlement of the ramp and embankment. – 2009

© RRC

# 12

Removing or Passing Barriers

© RRC

Wide, shallow rock ramp crest also provides fish habitat – 2009

© RRC

Rock ramp looking upstream towards its crest and showing the extent of habitat available to juvenile fish – 2009

© Manx Utilities

The ramp is working well under higher flow conditions – 2010

© Manx Utilities

Still working well and providing habitat after 13 years – 2019

## Contacts

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12 Removing or Passing Barriers

# 12.6 Complete removal of a small low head weir

## RIVER GREAT OUSE

LOCATION - BUCKINGHAM, SP 69473350
DATE OF CONSTRUCTION - JUNE 2016
LENGTH - 5m (100m including bank works)
COST - £7,500 (but part of an existing £35,000 bank stabilisation scheme)

| | |
|---|---|
| **Type** | Low energy, clay |
| **Status** | Failing for fish (driver physical habitat modification). HMWB. Moderate (2016) |
| **Waterbody ID** | GB105033037860 |
| **Designation** | None |
| **Monitoring** | Fixed-point photos |


Intact 0.5m concrete weir – 2012 © RRC

## Description

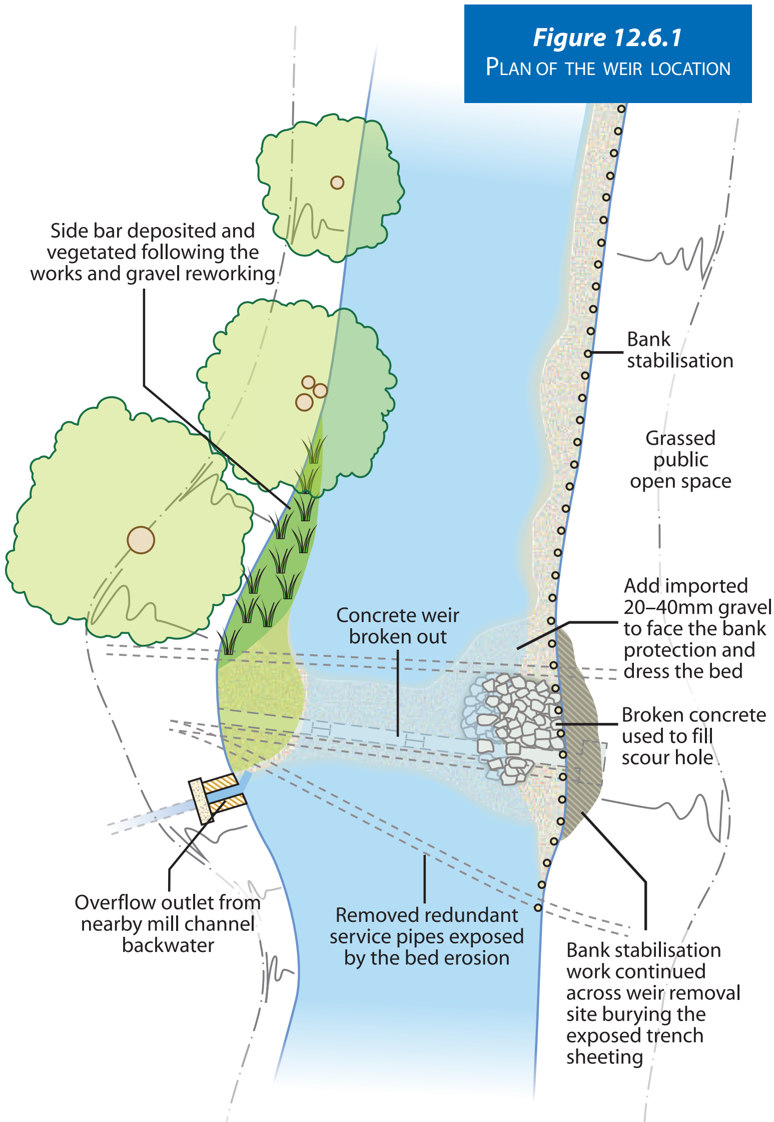
The River Great Ouse flows for approx. 20km before reaching Buckingham. Through the town the river has undergone significant alteration over the centuries - realignment, bank protection and impoundment by weirs, but still retains a linear riverside park.

At Chandos Park, a 15.5m long concrete weir retaining a depth of 0.5m was assessed during an early WFD investigation as preventing fish passage and impacting river morphology. The weir was already in danger of being outflanked where high flows and access by dogs had combined to cut a low channel around the structure's right edge where it transitioned into the grassed earth bank. The concrete weir had previously been extended, most likely as a result of similar bank erosion and outflanking.

In April 2016, the weir developed a void below the previously extended section, undermining the structure and dewatering the river above. Environment Agency staff removed the two sets of wooden sluice boards to reduce the head of water and to visually assess the implication of removal on the upstream impounded levels (a weir pool, University grounds and residential gardens).

Over the next few weeks the void continued to enlarge creating a significant 2m deep scour hole on the downstream side. By May all of the low flow volume was passing under the weir, effectively making it redundant. Removal was deemed to be the most desirable and cost effective solution to restore natural processes, improve fish passage and improve public safety.

***Figure 12.6.1***
PLAN OF THE WEIR LOCATION



The Environment Agency undertook an impact assessment that considered the effect of reduced impoundment on channel stability and habitat quality. Weirs are often convenient locations for service pipes to be laid across rivers. A number of pipes that were not previously visible or recorded had become exposed by the erosion at the weir and the EA undertook the investigation of these (confirmed as redundant).

The riparian land owners, Buckingham Town Council and University of Buckingham jointly funded the £7,500 removal work which was added to a pre-existing riverbank stabilisation contract just due to start on the immediate downstream bank. The cost of the work was significantly reduced by adding it to the existing contract.

## Design

Sedimats were installed downstream in three rows and checked on a regular basis to reduce fines being transported downstream. However, due to the nature of the weir failure there was very little in the way of silt built up behind the weir itself as it had already washed out.

The works involved were:

1. Working in the wet, break up and remove concrete weir using 13 tonne 360 excavator and breaker attachment.

2. Smaller concrete remnants used to infill the 2m deep scour hole. Larger concrete sections removed from site to a licensed waste facility.

3. Trench sheeting found beneath the weir extension. Folded over and buried in the void and bank.

4. Bank toe protected with a post and geotextile retaining line to tie in with the failed toe board replacement and regrading work.

5. Remove the identified redundant service pipes associated with the weir.

6. Grade existing bed gravels into voids and use 20-40mm imported gravels to dress the scour hole, concrete fill and to create shallow gravel bars at both bank edges.

7. Right bank edge formed by extending the low level chestnut stake and geotextile bank protection, and covering the remnant sheet piling. Upper earth bank regraded to gentle slope and seeded.

© RRC

Weir concrete used to fill scour hole – June 2016

© RRC

Large scour hole beneath weir – May 2016

© Cain Bio

Trench sheeting and concrete fill buried behind bank revetment line – June 2016

## Subsequent performance – 2014 to 2019

Following the barrier removal, water, sediment and fish can easily pass through the site. A vegetated gravel bar has developed on the left bank where the weir's scour had previously widened the river.

After the first year there was some immediate settlement and reworking of the gravel bed, exposing an old buried upstream concrete apron. This is currently acting as a low level bed check and is not particularly visible. No maintenance has been required or is expected.

The regraded and stabilised bank is part of a popular park used by recreational visitors (dogs and children play on the riffle and shallow gravel bars).

The riffle was observed being used by coarse fish (chub and minnow) for spawning and feeding, until a total fish kill in summer 2018.

Location of removed weir after a year – July 2016 © RRC

**Four fixed point photos tracking the progress of the work**

Failed weir –April 2016 © RRC

Weir removed – June 2016 © RRC

Imported gravel covering the concrete fill and creating accessible 'beaches' –Sept 2016 © RRC

Recovery after 3 years – March 2019 © RRC

## Lessons - for wider application

Usually, detailed background morphological and ecological survey work is necessary to ensure that the design allows for natural adjustment following the removal. Here, due to the timescale and urgent need to address the safety issues associated with the failed weir, this process was sped up and carried out by experienced EA geomorphology and fisheries staff.

Specificially, in this case, there was only a small difference between upstream and downstream water levels and bed levels. The boards could be removed to simulate reduced upstream levels, there were no protected species or high quality habitats present and all of the service pipes were redundant.

The quality of retained sediment within the impoundment of the structure would usually need to be assessed, especially in an urban setting. Due to the low head of the weir and its foregone failure, very little fine sediment was visible

Recovery after 3 and a half years – Oct 2019 © RRC

## Contacts

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Matthew Irvine, Cain Bio-Engineering – Contractor. Tel. 01725 467003

# 12 Removing or Passing Barriers

## 12.7 Bypassing fixed crest weir

River Cam
Location - Byron's Pool, Grantchester, Cambridgeshire TL436546
Date of construction - December 2010 – March 2011
Length - 110m
Cost - £150,000 (including footpath work and bridges)

| | |
|---|---|
| **Type** | Low energy, chalk |
| **Status** | Failing for physical habitat modification and Phosphate. HMWB. Moderate (2016) |
| **Waterbody ID** | GB105033042750 |
| **Designation** | Byron's Pool LNR, County Wildlife Site |
| **Monitoring** | Fish camera, electrofishing, water chemistry, velocity, macroinvertebrates |

### Description

The site is located within a semi-natural woodland owned and managed by Cambridge City Council as a Local Nature Reserve (LNR) and the bypass channel was one of a number of ecological enhancements carried out by the Council within the reserve prior to the construction of an adjacent housing development. The River Cam at Byrons Pool is within the Cam & Ely Ouse catchment. It was identified as a failing water body (2009 baseline) with a number of anthropogenic structures directly impacting fish populations classified as 'moderate status'. Historically a weir of some description has been at this location since recorded in the Doomsday Survey 1086.

The present day fixed crest weir and radial sluice was constructed in c.1949 and at the same time the weir pool was recut, partially in-filled and straightened with the aim of controlling discharge downstream and retaining water levels upstream for recreational use. With a head difference of c.960mm and a broad crest width of c.1500mm, it remains dry during normal flows and is a complete barrier to fish, eels and the development of natural river processes. The reach is impounded for approximately 1km upstream.

There is greater flow and morphological diversity immediately downstream of the weir with a predominant gravel substrate and some aquatic macrophytes in areas not shaded by the adjoining woodland.

Byrons Pool radial sluice gate and fixed crest weir. © Ellis Selway
The structure is a complete barrier to fish passage upstream and the weir is completely dry in normal flows – May 2011

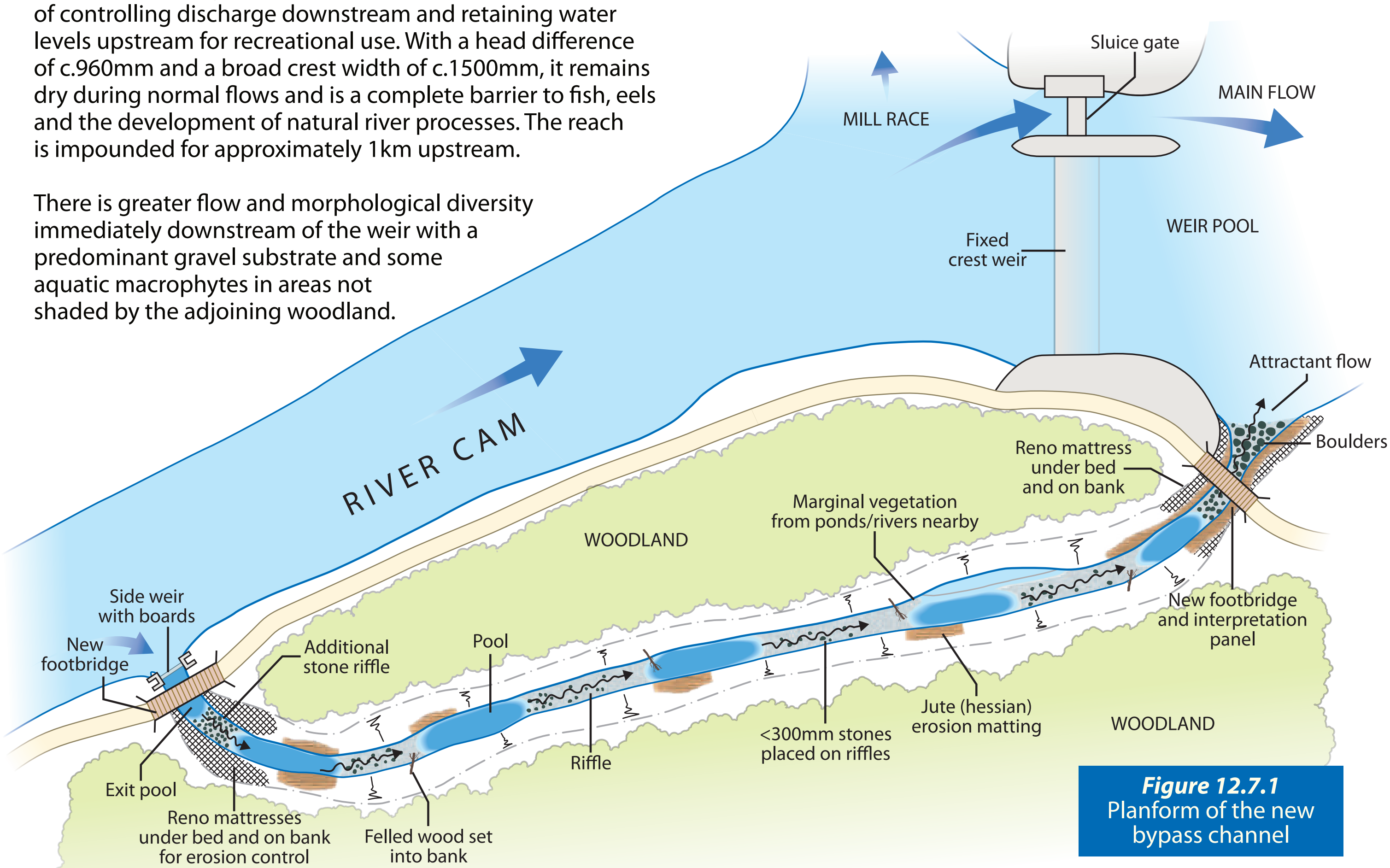


**Figure 12.7.1** Planform of the new bypass channel



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

The aim of the project was to develop a suitable 'natural' fish pass to bypass the existing weir to allow free passage for all of the present fish species and eels whilst restoring and enhancing key features identified in the Byron's Pool LNR Management Plan. The concept of a 'nature-like fish pass' is that as well as allowing passage it also mimics a natural side channel, adding habitat (especially for juvenile fish) that is missing due to the impoundment of the river.

When designing a fish bypass channel it is essential to ensure that the downstream entry to the pass is located in the attractant current where the fish tend to congregate. At this site, this would ideally be where water exits the sluice gate on the far bank, however this was not possible due to engineering and land ownership constraints. As a result the fish pass entrance was located as close as possible to the main weir and designed with a sufficient gradient to generate a flow velocity that would create an obvious attractant flow to the fish (which actively seek onward passage by swimming along an obstruction).

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Constructing the upper entry side weir to the bypass channel. – Nov 2010

## Design

The bypass channel gradient was essential to the design in order to ensure its future use by fish and eels and to afford channel stability. The new channel has a gradient of 0.1% with a 2% gradient at the downstream connection to generate an attraction water velocity within the range of 0.8 to 2m/s, both suitable for all fish species to be able to negotiate and sufficient to generate attractant flow into the main weir pool.

A preliminary topographic survey indicated that there might be a hard bed of gravels. However this was not found during excavation with material consisting primarily of river silts. A mixture of coarse gravels was imported to form a variable-width channel with pools and riffles.

The works comprised:

1. A bypass channel measuring 110m in length with an average width of 2m was created by excavating a heavily silted drainage channel running round the existing weir. The excavated material was spread within the woodland, outside of the floodplain, in an area of low botanical interest.

2. A small concrete side-weir was installed at the upper entry to the pass. Based on flood modelling the weir crest height was set at 7.7mAOD, 300mm below mean water level. This would allow control at times of low flow using stop boards, and for any maintenance operations.


Before (**a**) during (**b**) and immediately after (**c**) construction. The absence of a suitable bed material was overcome by using imported gravels to create a series of pools and riffles along the channel. Jute (hessian) matting was installed to provide erosion protection along the newly created banks – November 2010

Photos © Ellis Selway

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3. To provide stability and erosion control, matresses were installed at the upper and lower entry points, on the banks and below the gravel bed.

4. Imported gravels were used to form a bed of pools and riffles. These were sourced locally and included a mixed fill of claybound rejects (ranging from 20-100mm) and graded gravel (10-20mm).
   a. The series of pools (c.10m long x 2m wide x <0.7m deep) were designed to offer areas of rest where water velocity is <0.5m/s.
   b. The riffles (c.10m x 2m wide x <0.4m deep) offered an attractant water velocity of <1.4m/s to a maximum of 2m/s.

5. Felled timber, sourced from the site, was set into the bank protruding into the channel with the aim of deflecting flow and retaining the gravels. Hessian erosion matting was fixed along the opposite bank where there might be initial scour until vegetation became established.

6. Extra woody material and individual angular rocks, up to 200mm in diameter, were placed randomly in the channel to provide suitable refuge for fish such as bullhead (*Cottus gobio*) and to create habitat heterogeneity.

7. Marginal plants were translocated from adjacent ponds and the river margin to speed up the process of colonisation and add bank stability.

8. Two footbridges were built across the new bypass channel to maintain the riverside path access.

This technique demonstrates the importance of understanding the channel flow velocity requirements of fish within a bypass channel and the location of the attractant flow leading to the channel.

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Electrofishing the new bypass – a brown trout already occupying the habitat created. – May 2011

Additional riffle built using granite to allow minnows to exit the pass – April 2011

© Ellis Selway

An additional stop log installed on top of the side weir structure and turreted – April 2011

© Ellis Selway

## Modifications

Once the bypass channel became operational a number of modifications were required to overcome unforeseen problems:

### Bypass inflow and control structure

Initial discharge through the channel was excessive, swamping the riffles and producing a highly turbulent flow at the downstream entrance to the pass. An additional board was installed to the side-weir to reduce the flow entering the pass. However, this created a head difference of approximately 300mm between the 'exit pool' and the upstream water level such that minnows (Phoxinus phoxinus) were observed failing to swim over. To resolve this, three sections (450mm wide by 100mm deep) were cut out of this board reducing the head difference by 100mm. Even then, the flow through the 'turreted' board was still too high for minnows to negotiate so additional stone was added downstream of the exit pool using 200-300mm angular granite. This successfully raised the water level in the exit pool thereby eliminating the head difference.

### Bypass outflow

The water level at the pass outflow was initially very shallow (<100mm) and the water velocity was identified as potentially exceeding the maximum swimming performance of some of the fish species found in the River Cam. So a combination of gabion rocks and larger 300-450mm perturbation boulders were placed between the lower entry to the pass and the first riffle to baffle the flow, producing areas of slack water for fish to rest in whilst ascending into the pass. Flow velocity was later measured and was well within the maximum velocity parameters of 2m/s for the species present in the Cam.

All necessary documents were produced for the EA consenting process and Local Authority planning permission, including detailed design drawings, Design and Access Statement, Flood modelling and Flood Risk Assessment, Environmental statement and archaeological brief.

The attractant flow exits as close to the weir as the structure would allow. – April 2011 © Ellis Selway

Gabion rocks and perturbation boulders installed at the downstream entrance to the pass, to baffle the flow – April 2011 © Ellis Selway

## Subsequent performance – 2012 to 2019

2012 post works fish monitoring, through a combination of electrofishing, remote camera and visual observations, indicated that the bypass channel was being used by 11 fish species, 3 of which had been recorded on the remote cameras successfully exiting the pass. Spawning activity was observed and the 2012 survey showed an excellent population of brown trout (*Salmo trutta*). Water velocity, dissolved oxygen and temperature were also monitored following the works and all were within the physical and biological parameters required by most fish. However, it should be noted that the water velocity, as measured, in the upstream exit was at the limit for the passage of elvers (juvenile eels).

Invertebrate monitoring was also carried out in 2012 using kick sampling and demonstrated that the macro-invertebrate community in the bypass channel was well balanced. A number of oxygen demanding species were present, for example blue winged olive nymphs (*Serratella ignite*) and caddis fly (*Mystacides sp* and *Goera pilosa*), as well as more tolerant taxa such as river snails (*Notopala sublineata*). High BMWP and ASPT scores (140 and 5.38 respectively) reflected this.

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Entrance to the bypass channel, looking downstream towards the weir pool. The perturbation boulders have remained in position and marginal vegetation has colonised the banks – February 2013



Over the past eight years high flows and the accumulation of woody material has contributed to some vertical adjustment of the mattresses and movement of the perturbation boulders in the lower entrance to the pass. The stone mattresses should only have been used on the 'at risk' bed and lower banks, perhaps in-combination with green bank protection techniques.

There was an official launch of the pass by the Environment Agency Area Manager and the Mayor of Cambridge City Council in August 2011. Key stakeholders and volunteers were also invited. The pass was well received by users of the site and although not measured, use of the site increased after installation. After eight years, this increased visitor pressure has led to greater disturbance of the channel by people and dogs. There is evidence of a deterioration of rheophilic spawning opportunities due to fine sediment accumulation on the gravels.

There has been some addition of imported fine gravels but further action is needed to restrict access, reduce siltation and to enhance spawning. There is a follow up fisheries survey planned in 2020 to understand the impact from increased visitor pressure and to inform potential mitigation.

### a) Lessons – for wider application

This case study highlights the need for a 'hands on' approach during the initial operation of the pass and awareness that on-site modifications may be required. Pre and post monitoring is a vital aid in the decision making process and, at this site, identified the need for adjustments. The pass has influenced the delivery of other natural bypasses in the Ouse Catchment.

## Contacts

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