Evidence

Appraisal of river restoration effectiveness: Shopham Loop monitoring report

Report – SC070024/d

The Environment Agency is the leading public body protecting and improving the environment in England.

It’s our job to make sure that air, land and water are looked after by everyone in today’s society, so that tomorrow’s generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry’s impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned and funded by the Environment Agency.

Published by:
Environment Agency, Horizon House, Deanery Road,
Bristol, BS1 5AH

www.environment-agency.gov.uk

ISBN: 978-1-84911-348-9

Dissemination Status: Publicly available

Keywords:
Water Framework Directive; hydromorphology; evidence base; best practice; river restoration; monitoring;

Research Contractor:
Royal Haskoning UK, Burns House, Harlands Road,
Haywards Heath, West Sussex RH16 1PG, UK
Tel: 0144 445855

Environment Agency’s Project Managers:
Natalie Kieboom (nee Phillips), Judy England
Evidence Directorate

Collaborator(s):
River Restoration Centre, Environment Agency staff

Project Number:
SC070024/d

Evidence at the Environment Agency

Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

The work of the Environment Agency's Evidence Directorate is a key ingredient in the partnership between research, guidance and operations that enables the Environment Agency to protect and restore our environment.

This report was produced by the Scientific and Evidence Services team within Evidence. The team focuses on four main areas of activity:

- **Setting the agenda**, by providing the evidence for decisions;
- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards;
- **Carrying out research**, either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh

Director of Evidence

Executive summary

This project forms part of a broader Environment Agency project, ‘Managing Hydromorphological Pressures in Rivers’, which seeks to provide examples of the management of hydromorphological and sediment pressures in catchments to aid in the delivery of the Water Framework Directive (WFD).

The project used the Shopham Loop restoration scheme on the River Rother in West Sussex as a secondary case study, setting WFD relevant objectives against which to measure the effectiveness of the scheme. The objectives relate to hydromorphological and biological conditions within the river.

The results of monitoring undertaken before and after restoration were used to assess the effectiveness of the restoration against these objectives. It is important to note that the monitoring strategy for Shopham Loop was not originally designed to assess the restoration scheme in terms of the Water Framework Directive.

In terms of hydromorphology, the objectives relating to width, depth and sinuosity of the channel were met, although sampling limitations restricted the reliability of the results. Addressing the objectives relating to sedimentation and flow velocity is either limited or not possible as a result of a lack of monitoring data.

The assessment against the biological objectives was inconclusive due to a combination of the lack of survey data and the short timeframe over which monitoring was undertaken. The information that is available indicates that the macroinvertebrate community was already at good status or better in parts of Shopham Loop and that the community had responded to increased velocities and reduced fine sediment. Results also suggest that the conservation value of the species present was increasing. It is recommended that monitoring at Shopham Loop continues so that the trends that were beginning to develop can be monitored into the future. In addition velocity measurements and substrate observations are required to assess the impact of the restoration. Further analysis of mesohabitat data would be useful in examining the relationships between macroinvertebrate community and habitat change.

Low gradient rivers have limited response to geomorphological intervention, as their low energy makes them geomorphologically fairly inactive. More active rivers would be expected to show more morphological response to restoration. However, restoration in these rivers becomes higher risk.

It is important that post-project monitoring has clear objectives and is linked to the objectives of the restoration scheme. The objectives should be set following a review of the catchment context, historical events (e.g. floods, pollutions and riparian management) and current pressures. Future schemes should include pre- and post-restoration monitoring that includes both hydromorphological change and ecological response so helping to assess the effectiveness of the restoration against WFD relevant objectives.

The accompanying case study report, *Appraisal of River Restoration Effectiveness: Shopham Loop Case Study Report*, outlines the restoration measures implemented and identifies the lessons learned during the project. Two further reports present the findings from the primary case study involving the restoration of the Seven Hatches on the River Wylye in Wiltshire and the monitoring methods used in that case study.

Contents

1 Introduction 1
1.1 Project objectives 1
1.2 Structure of the report 2

2 The Water Framework Directive and river restoration 3
2.1 Water Framework Directive 3
2.2 WFD implementation – river restoration 3
2.3 Quality elements 4

3 Shopham Loop restoration scheme 7
3.1 Study area 7
3.2 Shopham Loop restoration scheme 9
3.3 Monitoring at Shopham Loop 13
3.4 Assessment of expected response to restoration 17
3.5 Water Framework Directive relevant objectives 20

4 Methods 24
4.1 Hydromorphology 24
4.2 Macrophytes 25
4.3 Macroinvertebrates 25
4.4 Fish 27

5 Results 28
5.1 Hydromorphological objectives 28
5.2 Macrophyte objectives 34
5.3 Macroinvertebrate objectives 35
5.4 Fish objective 39
5.5 Summary of results 45

6 Effectiveness of restoration measures 1
6.1 Statement of effectiveness 1
6.2 Limitations 2
6.3 Recommendations 2

References 4

List of abbreviations 5

Table 2.1 Biological quality elements and parameters used to measure quality 4
Table 2.2 Hydromorphological quality elements and parameters used to measure quality 6
Table 3.1 Full details of water body GB107041012810 9
Table 3.2 Pre- and post-restoration monitoring at Shopham Loop 14
Table 3.3 Expected hydromorphological response resulting from restoration scheme 17
Table 3.4 Physical characteristics on which ecological factors are dependent 19
Table 3.5 WFD relevant objectives and the data used to address objectives 20
Table 5.1 Mean and standard deviation of bankfull width and depth post restoration 29
Table 5.2 Width:depth ratio 29
Table 5.3 Mean and standard deviation of channel elevation (mAOD) 29
Table 5.4 Mean and standard deviation of channel elevation 33
Table 5.5 Macrophyte survey results in Shopham Loop 34
Table 5.6 Species diversity scores for Shopham Loop and Selham Bridge 35
Table 5.7 LIFE, PSI and CCI scores for Selham Bridge and Shopham Loop 36
Table 5.8 Species diversity scores at Shopham Loop 39
Table 5.9 Post restoration results of electric-fishing in Shopham Loop 39
Table 5.10 Results of electric-fishing at Environment Agency monitoring stations at Fittingworth (F) and Coultershaw (C) 41
Table 5.11 Results of electric-fishing in the floodplain scrape 43
Table 5.12 Fish results from canal cut, 2009 44
Table 5.13 Summary of results 47
Figure 3.1 Location of Shopham Loop 7
Figure 3.2 Mean daily discharge (monthly totals) at Halfway Bridge, River Rother 8
Figure 3.2 Map showing historical course of the river 10
Figure 3.3 Aerial photograph of the restoration site 12
Figure 3.4 Monitoring locations at Shopham Loop 16
Figure 5.1 Pre-restoration: no flow in the upstream end of Shopham Loop 31
Figure 5.2 Gravel riffle at upstream end of meander loop post-restoration 32
Figure 5.3 Glide section of Shopham Loop post-restoration 32
Figure 5.4 Riffle at downstream end of Shopham Loop post-restoration 32
Figure 5.5 Species diversity scores 36
Figure 5.6 ASPT EQR derived from RICT for Shopham Loop transects and Shopham Bridge 38
Figure 5.7 NTAXA EQR derived from RICT for Shopham Loop transects and Shopham Bridge 38
Figure 5.8 Electric-fishing results at Shopham Loop 40

1 Introduction

This project is part of a broader Environment Agency project, ‘Managing Hydromorphological Pressures in Rivers’, which seeks to provide practitioners with examples of how to manage hydromorphological and sediment pressures in catchments to aid the delivery of the Water Framework Directive (WFD).

This part of the project focuses on river restoration schemes. It uses the Seven Hatches river restoration scheme in the Hampshire Avon as the primary case study and the Shopham Loop scheme on the River Rother as a secondary case study. Monitoring reports and case study reports have been produced for both sites using existing pre- and post-restoration monitoring data already collected at the reach and water body scale, and data from the fieldwork undertaken as part of this project.

The monitoring reports (this report and Environment Agency 2014a) assess whether the restoration measures implemented at each site have been effective in meeting WFD relevant objectives. This was done by:

- analysing pre- and post-restoration monitoring data
- assessing the extent to which the results supported a number of WFD relevant objectives developed for the case study site

The two case study reports (Environment Agency 2014b, 2014c) document the restoration measures implemented at each site, identify the lessons learned and act as a guide to best practice for future river restoration schemes. This work will link with other projects being carried out by the Environment Agency at local and national level and will inform other research in this field. The recommendations from this project will be used to modify and update specific guidance contained in the Healthy catchments – managing for flood risk and WFD developed for practitioners available on the website: www.restorerivers.eu.

This report presents the findings on hydromorphological and ecological changes resulting from the Shopham Loop restoration scheme and makes an assessment of the scheme’s success based on the WFD relevant objectives developed as part of the project.

It is important to note that the monitoring strategy for Shopham Loop was not originally designed to assess the restoration scheme in terms of the Water Framework Directive. Further details of the link between river restoration and the Water Framework Directive are provided in section 2.2.

1.1 Project objectives

The overall objectives were to:

- develop WFD relevant objectives, building on the scheme’s original objectives, against which to measure the success of the restoration scheme
- quantify the hydromorphological and ecological changes resulting from the schemes and measure the success of the scheme against the new objectives
- document the restoration measures and capture any lessons learned during the implementation of the scheme

This report addresses the first two objectives, while the case study report (Environment Agency 2014c) relates to the third objective.

1.2 Structure of the report

Section 2 summarises the main requirements of the Water Framework Directive, discusses how these can be assessed and considers the links between these requirements and river restoration measures.

Section 3 introduces the Shopham Loop restoration scheme, providing details of the study area and a description of the rationale and main components of the restoration scheme. This section also presents the WFD relevant objectives.

Section 4 outlines the data analysis methods used to address each objective.

Section 5 presents the results of the analysis, making specific reference to the hydromorphological and biological quality elements and WFD relevant objectives.

Section 6 links the hydromorphological and biological conditions discussed in the previous section and assesses the effectiveness of the measures in achieving the WFD objectives.

Section 7 contains a short summary of the main outcomes, limitations and recommendations.

2 The Water Framework Directive and river restoration

This section summarises the main requirements of the Water Framework Directive, discusses how they can be assessed and examines the links between these requirements and river restoration measures.

2.1 Water Framework Directive

The Water Framework Directive sets a target for all EU Member States to aim towards achieving good ecological status (GES) – or in the case of heavily modified water bodies, good ecological potential (GEP) – in all waters by 2015 or, where justified, by 2021 or 2027.

For surface waters, GES is defined by the condition of the biological quality elements:

- plants
- macroinvertebrates
- fish

This is supported by the hydromorphological (hydrological regime, river continuity and morphological conditions) and physicochemical (temperature, oxygenation, salinity, pH and nutrient content) quality of the waters.

The ecological status of a water body is measured on the scale high, good, moderate, poor and bad. To be classified as high status, a water body must also have high hydromorphological status. For all other water bodies hydromorphology does not define status but is critical in providing the habitat to support the ecology.

2.2 WFD implementation – river restoration

The Water Framework Directive specifies that hydromorphology underpins ‘good ecological status’ and ‘good ecological potential’. It is widely accepted that hydromorphological integrity provides the foundation required to support ecological function. There are numerous studies describing links between biological pattern, ecological processes, and river form and physical processes, yet the underlying mechanisms are often known only in outline (Vaughan et al. 2009).

Under the Water Framework Directive the UK must ensure the protection and, where necessary, improvement of river and coastal hydromorphology adversely impacted by activities such as flood management and land drainage schemes. In artificial and heavily modified water bodies, a number of mitigation measures are identified within river basin management plans that aim to restore historically modified water bodies to good ecological potential. For a water body to reach ‘good ecological potential’ all the associated mitigation measures need to be in place. The measures include but are not limited to:

- good practice sediment management
- management and restoration of aquatic and riparian habitats
- improvements to fish passage

Many of the mitigation measures can also be classified as restoration measures.

The physical restoration of river systems has been identified as a route through which the aims of the Water Framework Directive can be implemented – despite a lack of detailed knowledge on the links between biological pattern, ecological processes, and river form and physical processes. There is therefore a need to assess the effectiveness of river restoration measures so that resources can be targeted at those which are effective in delivering WFD objectives. Effectiveness can be assessed with reference to the hydromorphological quality elements of a water body and the biological quality elements that they support. These are explained in more detail below.

2.3 Quality elements

2.3.1 Biological quality

The ecological status of a water body is measured in terms of the biology found within it and the physicochemical and hydromorphological elements which support that biology. Table 2.1 lists the parameters used to measure biological quality and the definition of high status as given in Annex V of the Water Framework Directive.

Table 2.1 Biological quality elements and parameters used to measure quality

Quality element	**Parameters used to measure biological quality**	**Definition of high status**
Phytoplankton	Taxonomic composition Abundance Frequency of planktonic blooms	The taxonomic composition of phytoplankton corresponds totally or nearly totally to undisturbed conditions. The average phytoplankton abundance is wholly consistent with the type-specific physicochemical conditions and is not such as to significantly alter the type-specific transparency conditions. Planktonic blooms occur at a frequency and intensity which is consistent with the type-specific physicochemical conditions.
Macrophytes and phytobenthos	Taxonomic composition Average macrophyte and the average phytobenthic abundance	The taxonomic composition corresponds totally or nearly totally to undisturbed conditions. There are no detectable changes in the average macrophyte and the average phytobenthic abundance.
Macroinvertebrates	Taxonomic composition Abundance Ratio of disturbance sensitive taxa to insensitive	The taxonomic composition and abundance correspond totally or nearly totally to undisturbed conditions. The ratio of disturbance-sensitive

Quality element	Parameters used to measure biological quality	Definition of high status
	taxa Diversity of macroinvertebrate taxa	taxa to insensitive taxa shows no signs of alteration from undisturbed levels. The level of diversity of macroinvertebrate taxa shows no sign of alteration from undisturbed levels.
Fish fauna	Species composition and abundance All the type specific disturbance sensitive species are present. Age structures of fish communities (to indicate any failures in the reproduction or development of any particular species)	Species composition and abundance correspond totally or nearly totally to undisturbed conditions. All the type-specific disturbance sensitive species are present. The age structures of fish communities show little sign of anthropogenic disturbance and are not indicative of a failure in the reproduction or development of any particular species.

2.3.2 Hydromorphological quality

If the hydromorphological conditions of a water body are undisturbed, or almost completely undisturbed, they can be used to classify a water body as having ‘high’ hydromorphological status. A water body cannot be classified as having high ecological status unless the hydromorphological status is high.

In all other situations (that is, when a water body is classified as having ‘good’ or ‘moderate’ ecological status or potential), hydromorphological characteristics must be of sufficient standard to support the biological quality elements found within the water body.

Where the water body has been significantly altered for ongoing anthropogenic purposes, it can be designated as a heavily modified water body where alternative environmental objectives to achieving GES apply. In these cases, mitigation measures to improve hydromorphological conditions must be put in place.

Table 2.2 lists the parameters used to measure hydromorphological quality and the definition of high status as given in Annex V of the Water Framework Directive.

Table 2.2 Hydromorphological quality elements and parameters used to measure quality

Quality element	Parameters used to measure biological quality	Definition of high status
Hydrological regime	Quantity and dynamics of flow in a water body	The quantity and dynamics of flow, and the resultant connection to groundwaters, reflect totally, or nearly totally, undisturbed conditions.
River continuity	Presence of barriers to the free movement of sediment, water and aquatic organisms in the channel	The continuity of the river is not disturbed by anthropogenic activities and allows undisturbed migration of aquatic organisms and sediment transport.
Morphological conditions	Physical characteristics of a water body which support a range of habitat niches, including: • pattern and form of the channel • type and structure of the substrate • structure of the banks • channel margins • riparian zones	Channel patterns, width and depth variations, flow velocities, substrate conditions and both the structure and condition of the riparian zones correspond totally or nearly totally to undisturbed conditions.

3 Shopham Loop restoration scheme

This section introduces the Shopham Loop restoration scheme, providing details of the study area and a description of the rationale and main components of the restoration scheme. It also describes the monitoring that has been performed, presents an assessment of the expected hydromorphological response and describes the WFD relevant objectives.

3.1 Study area

The River Rother is 48 km in length, rising in Empshott, Hampshire, and flowing to Stopham in West Sussex where it meets the River Arun. Shopham Loop is located downstream of Coultershaw Bridge near Petworth (Figure 3.1).

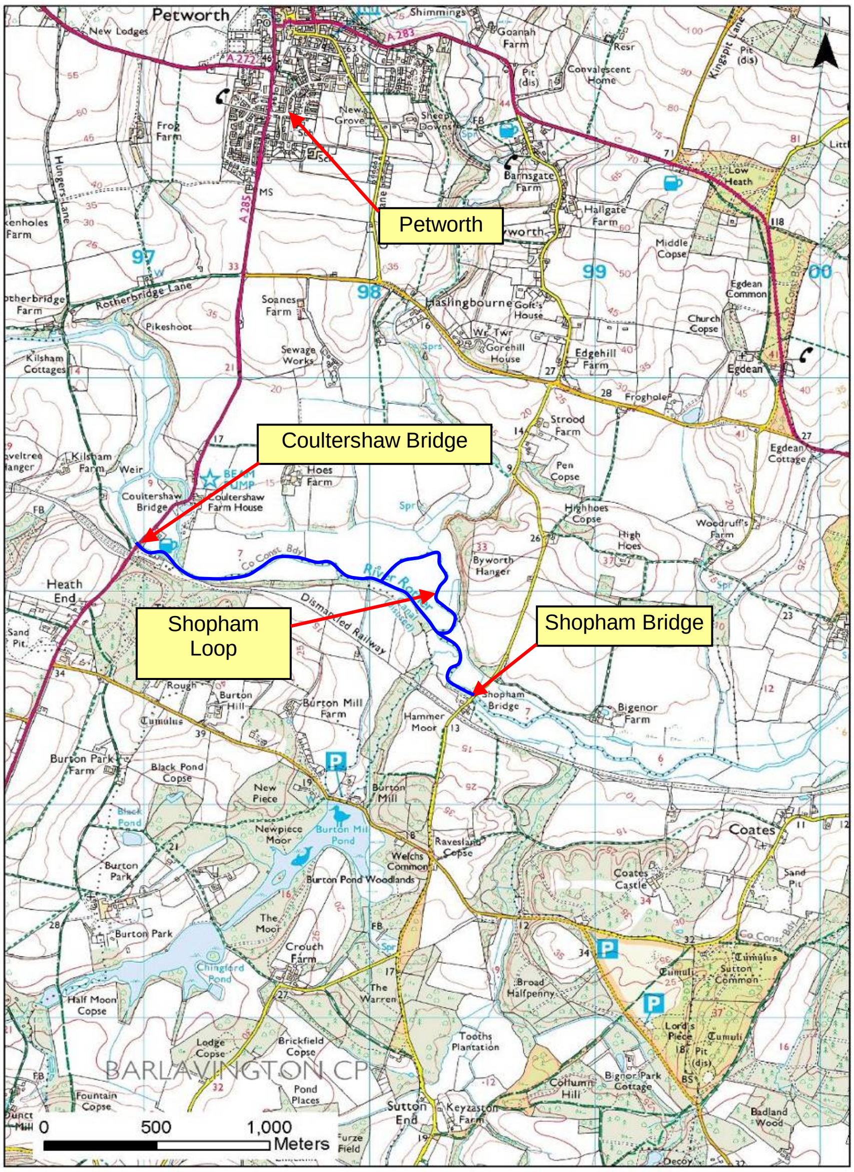


Figure 3.1 Location of Shopham Loop

3.1.1 Hydrological context

A review of the mean daily discharge for each month between 2000 and 2010 at Halfway Bridge, upstream of Shopham Bridge, shows that flow varied significantly during this period; the average daily flow varied from a low of 1.42 m^3/s in August 2006 to a high of 100 m^3/s in October 2006 (Figure 3.2).

The majority of flows in 2005 and 2006 in the years following the restoration were particularly low, with no high flow events exceeding 18 m^3/s until the large flood event in October 2006. High flow events are important for a restoration scheme since there are likely to be the most geomorphologically effective and have the most impact on hydromorphological processes.

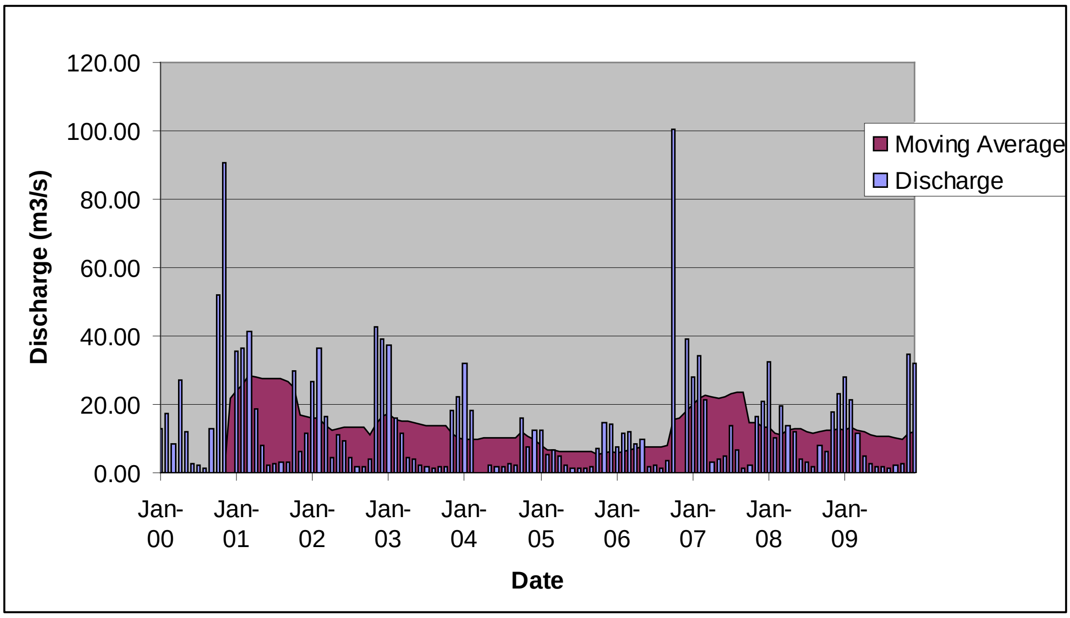


Figure 3.2 Mean daily discharge (monthly totals) at Halfway Bridge, River Rother

3.1.2 WFD catchment context

The environmental objectives for the River Rother are outlined in the South East River Basin Management Plan (Environment Agency 2009). Shopham Loop is located in the Western Rother water body (GB107041012810). The water body is currently of ‘poor’ ecological status. Full details of the condition of the water body and mitigation measures are provided in Table 3.1. The current status of the Western Rother for fish is ‘poor’, macroinvertebrates ‘good’ and macrophytes ‘good’.

The fish species driving the classification can be determined by identifying those species where the observed number of fish is less than expected according to the Environment Agency’s Fisheries Classification Scheme 2 (FCS2). The findings show that the observed roach catches are consistently less than expected across the water body (10 out of 12 sites). However, roach numbers predicted by FCS2 are considered quite high for this catchment by the Environment Agency Area team. The findings also show that the number of eel and chub caught at half the sites in the water body are lower than expected. Locally, Coultershaw Bridge, the nearest site to the restoration project, is classified as being at poor status driven by roach, minnow, gudgeon and bleak. Improvements to conditions for these species are likely to contribute towards the water body achieving ‘good’ or ‘high’ status for fish.

The catchment has moderate phosphorous status with both combined nutrient and diffuse agriculture sources identified as posing a risk to the ecology. Pesticides are also identified as posing a risk to good ecological status (Environment Agency 2009). Other pressures likely to be affecting the biology and hydromorphology of the River Rother have been identified as widespread sedimentation due to changing farming practices and the predominance of sandstone. In addition, groundwater abstraction and barriers to river continuity have been identified as issues in the catchment (Environment Agency Water Body Summary Sheet for Western Rother).

Table 3.1 Full details of water body GB107041012810

Water body ID	GB107041012810
Water body name	Western Rother
Current overall status	Poor (very certain)
Status objectives	Good by 2027
Hydromorphological designation	Not designated a heavily modified water body
Biological elements	Fish: currently poor Macroinvertebrates: currently good Macrophytes: good Phytobenthos: good
Hydromorphological supporting conditions	Quantity and dynamics of flow: does not support good (quite certain) Morphology: supports good
Mitigation measures	None

Source: Environment Agency (2009)

3.2 Shopham Loop restoration scheme

3.2.1 Historical modifications

The original course of the River Rother followed the meander loop shown in Figure 3.2. In 1795 as a result of the Rother Navigation, a canal cut was created with a lock structure at the downstream end and a small weir at the upstream end of the meander loop. The majority of flow was intended to remain in the meander loop with the canal cut used as necessary. Consequently, the meander loop retained a well-defined channel over its entire length of 800 m and, until the mid 1930s, supported a healthy population of fish and other wildlife. When the navigation was rescinded by an Act of Parliament, the lock gates fell into disrepair and were eventually removed. The canal cut became the preferential course of the river with the longer course of the loop slowing conveyance and encouraging silt deposition, particularly at the upstream end.

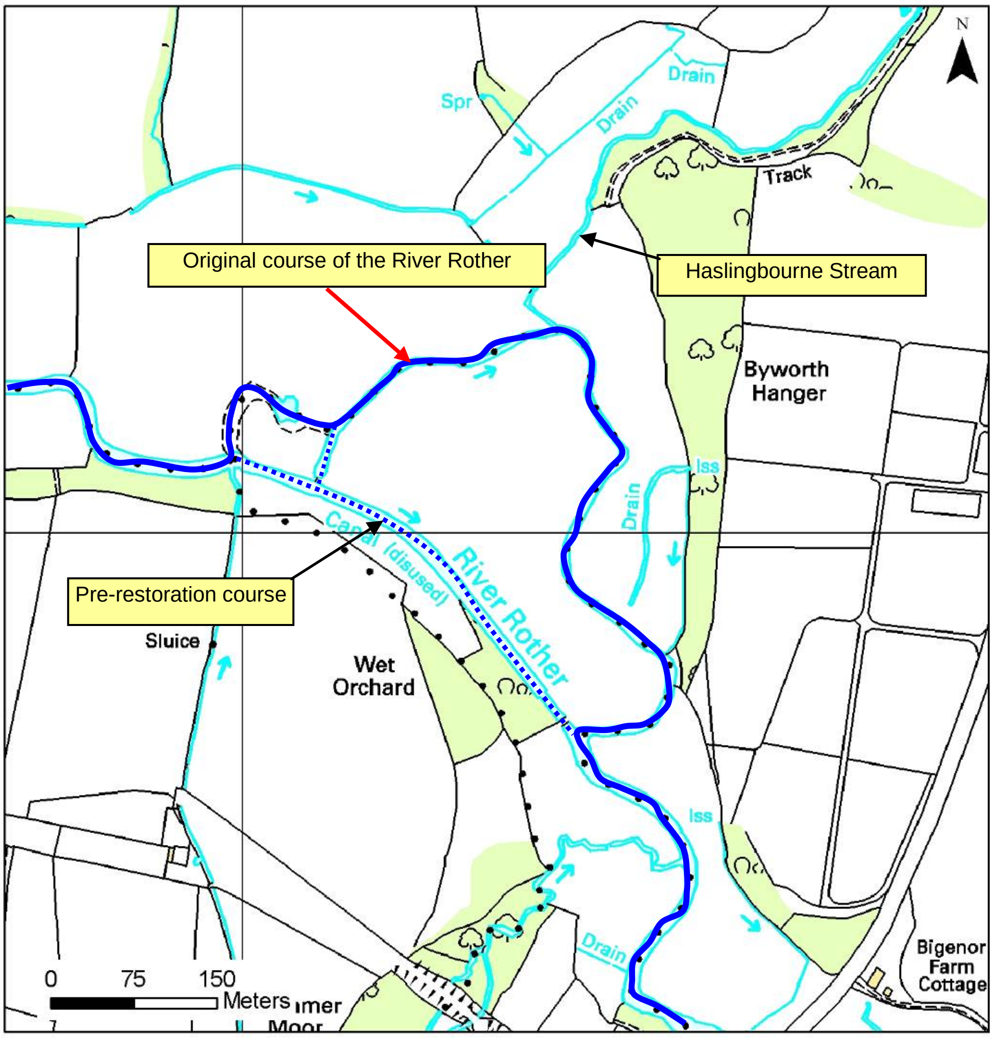


Figure 3.2 Map showing historical course of the river

3.2.2 Restoration works at Shopham Loop

Shopham Loop was selected as a site to undertake restoration works because of the degraded nature of the meander loop through siltation and the opportunity it presented to reinstate the former course of the river as highlighted in the Rother Fisheries Action Plan. The aim of the scheme was to improve the environment by:

- restoring 1 km of degraded watercourse and its interaction with the floodplain
- restoring natural river processes to benefit biodiversity
- safeguarding, enhancing and diversifying the fishery of the lower River Rother catchment
- preserving historical river structures associated with the Rother navigation

An appraisal and feasibility study was carried out by the River Restoration Centre (RRC) at Shopham Loop in 2001 (RRC 2011). The report’s preferred option was to close the canal cut with an earth bund, thereby diverting the river flow into the loop.

The restoration scheme consisted of the following main elements:

- construction of an earth bund just upstream of the old lock structure to divert all flow around the meander loop
- excavation of a new inlet channel to the loop to protect archaeological remains
- de-silting and reprofiling works around the meander loop
- installation of riffles at the upstream and downstream end of the meander loop to act as bed controls to prevent headward recession

The location of the restoration measures is shown in Figure 3.3. A more detailed explanation and justification of the scheme is provided in the Shopham Loop case study report (Environment Agency 2014c).

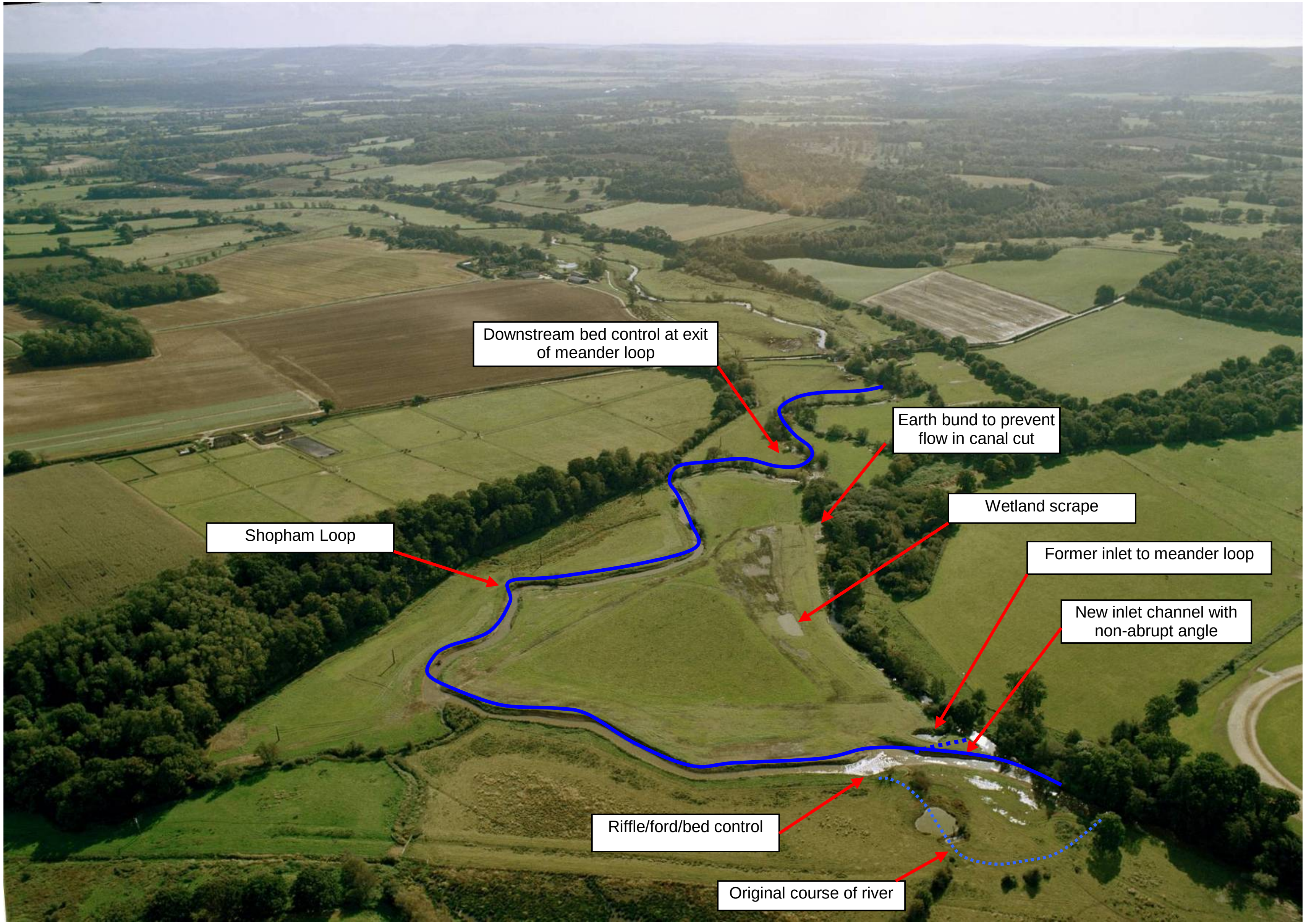


Figure 3.3 Aerial photograph of the restoration site

3.3 Monitoring at Shopham Loop

Monitoring of the hydromorphological and ecological conditions within Shopham Loop was performed by the RRC, Environment Agency and Southampton University before and after restoration. Further details of the monitoring are given in Section 4.

The monitoring programme sought to identify over three years:

- changes in geomorphology of the restored and adjacent reaches, looking at the evolution of features (velocity, banks, sidebars, point bars, vegetation establishment and so on) using a time sequence to give rates of morphological change
- changes in the hydrology and hydraulics of the restored and adjacent reaches to ensure the project has no adverse impact on flood levels and to enable detailed analysis of the in-channel hydraulic conditions within the restored reach
- the ecological response within the restored and adjacent reaches to document how flora and fauna adjust to the changing physical habitat over time – supplemented with the application of habitat suitability models to analyse the mechanisms driving observed changes
- the ecological response of the surrounding landscape and species influenced by the restoration of the river and the floodplain, and through changes in management
- the drivers of changes in channel morphology, substrate composition and the establishment/evolution of flora and fauna

It was intended to compare the nature of the restored physical habitat (that is, the project outcomes) with those anticipated during the design phase.

Although the restoration scheme was not implemented as part of the Water Framework Directive, the RRC and the Environment Agency undertook pre- and post-project monitoring at the site as shown in Table 3.2. Monitoring was carried out to assess the success or failure of the techniques used, such that the lessons learned could aid future restoration schemes. The monitoring was designed to be an integrated and holistic assessment, sensitive to changes in geomorphology, hydrology and hydraulics and the ecology within the channel.

Table 3.2 details the type of data collected and analysed to enable this assessment to be made and includes a description of the data and the year(s) in which they were collected. The survey locations are shown in Figure 3.4.

Routine monitoring locations were utilised to provide details of background conditions against which changes within the Shopham Loop could be assessed. Macroinvertebrates were compared with the site at Selham Bridge and fishery surveys with Fittleworth and Coultershaw. However, due to the difference in timings of surveys and methods direct comparisons were not possible. For other elements monitoring was restricted to the Shopham Loop and it’s vicinity with the River Rother acting at the ‘control’.   Environment Agency flow gauging stations at Fittingworth Hardham and Iping weir were used to assess discharge.

Table 3.2 Pre- and post-restoration monitoring at Shopham Loop

Dataset	Details	Location	Date
Pre-restoration			
River Rother cross-sections (design)	17 cross-sections through the River Rother	From Coultershaw Bridge to Shopham Bridge	2002
Shopham Loop cross-sections	14 cross-sections around loop	Entire loop	2002
River Rother longitudinal cross-section	Longitudinal section along the River Rother	From Coultershaw Bridge to Shopham Bridge	2002
Shopham Loop longitudinal cross-section	Longitudinal section along the loop	Downstream of Shopham Lock Bridge to upstream of Shopham Lock Weir	2002
Macroinvertebrate data	One-minute kick samples: 42 samples taken from 12 mesohabitats	Loop and canal cut	2002
Post-restoration			
Water level data	Water level measurements from three locations	Just upstream of the loop, within the loop (downstream of Haslingbourne Stream) and near Shopham Bridge	January 2006 onwards
Fish data	Electric-fishing	Shopham Loop	2005, 2006, 2007 and 2009
	Fish survey	Floodplain scrape	2006 ,2007 and 2009, 2010, 2013
	Survey of larvae	Loop and canal cut	2005
	Electric-fishing	Canal cut	2009
	Fry netting	Canal cut	2009
Macroinvertebrate data	One-minute kick samples in mesohabitats (cobbles, gravel, sand, woody debris, deep play, shallow clay)	Loop only (not canal cut) Various locations depending in location of mesohabitats	2005, 2006, 2007 and 2009
Macroinvertebrate data	Five fixed locations (three-minute kick samples)	Shopham Loop	2006, 2007 (all sites) and 2009 (one site)

Dataset	Details	Location	Date
Macrophyte data	Macrophyte surveys. The loop was divided into 100 m sections and records of species present and estimated coverage recorded	Shopham Loop	2005, 2006 and 2007
Environment Agency macroinvertebrate monitoring stations	Macroinvertebrate samples	Shopham Bridge and Selham Bridge	Shopham: 1989 to 20012 Selham: 1975 to 2013
Cross-sections	Cross-sections on the Rother and the loop	2005: two on the 2005: two on the Rother, 24 on the loop 2006: three on the Rother, 19 on the loop 2009: three on the Rother, 23 on the loop	2005, 2006 and 2009
Flow monitoring data	Three locations (Fittleworth, Hardham and Iping Weir). Fittleworth is not reliable at out of bank flows	Fittleworth: ~17 km downstream of loop Hardham: 20 km downstream of loop Iping Weir: 7.5 km upstream of loop	1995 to 2009
Physical biotope mapping	Physical biotope mapping around the loop		2009

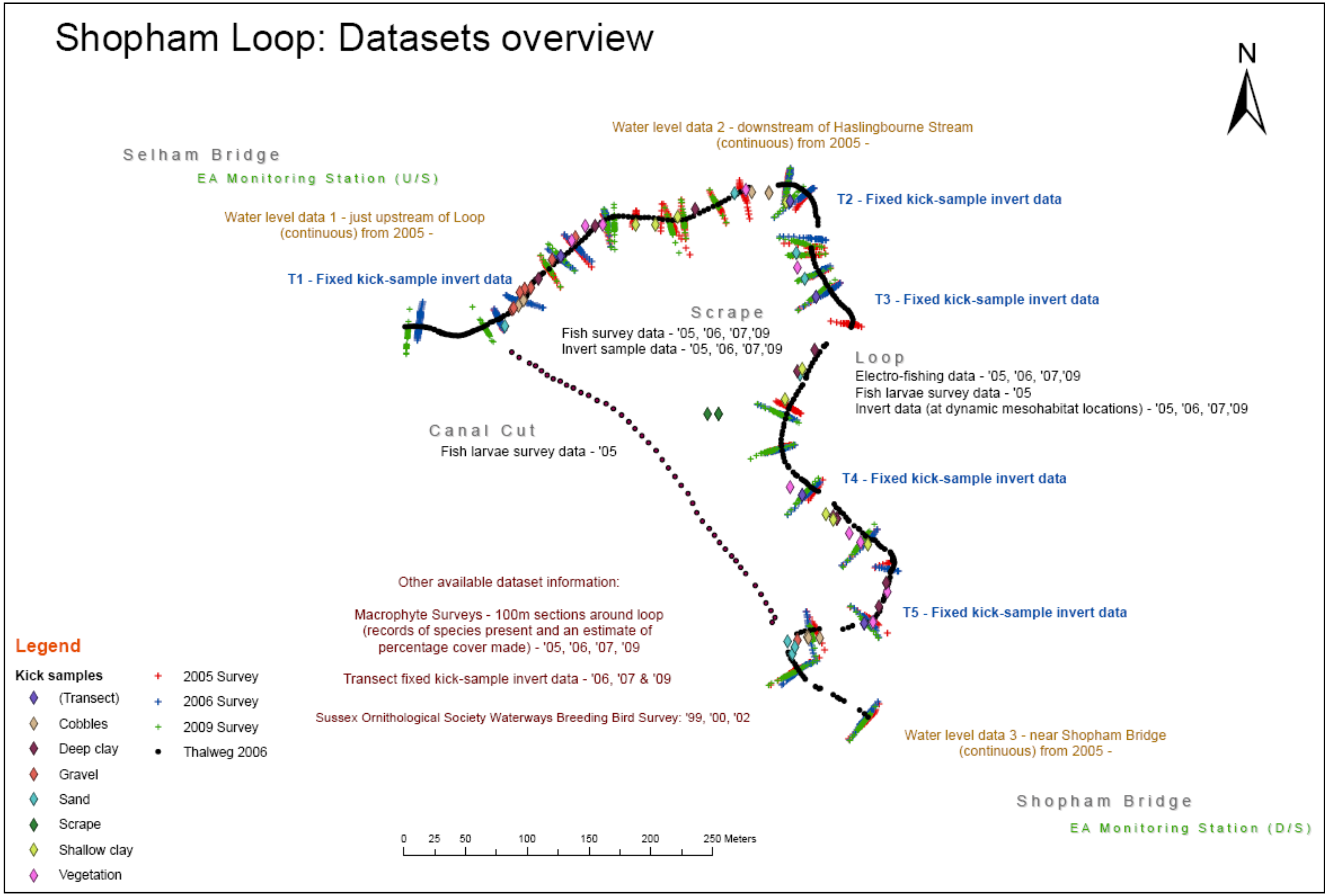


Figure 3.4 Monitoring locations at Shopham Loop

3.4 Assessment of expected response to restoration

The Shopham Loop restoration scheme was not implemented specifically to meet the requirements of the Water Framework Directive. The first stage of this project was therefore to consider the hydromorphological and biological response to the restoration measures. This response could then be used to develop objectives relevant for the Water Framework Directive and which could be used to measure the success of the restoration scheme. These objectives were set according to the SMART system (Specific, Measurable, Achievable, Realistic and Time-bound).

3.4.1 Hydromorphological response

The hydromorphological responses were assessed by considering the pre-restoration issues within the reach and the expected response to restoration, in relation to the quality elements identified in the WFD (that is, hydrological regime, river continuity and morphological conditions). Following this assessment, a link was made between each issue and the likely hydromorphological response to specific restoration measures on the issue. Draft objectives were set based on the expected hydromorphological changes resulting from the restoration scheme. The issues identified, the relevant restoration measures and the description of the expected hydromorphological response are outlined in Table 3.3.

Table 3.3 Expected hydromorphological response resulting from restoration scheme

Hydromorphological quality element	Description of the problem	Relevant restoration measures	Description of expected hydromorphological response
Hydrological regime			
Quantity and dynamics of flow	Historical channel alteration for navigation (which fell into disrepair) combined with changing catchment land use led to the silting up of a meander loop on the River Rother and subsequent river diversion.	Reconnection of meander loop and creation of riffles as bed fixes at each end of the loop. Creation of bund preventing splitting of the flows Retention of backwater habitat	Increased flow diversity. Continued function of canal cut as backwater with increased water levels and flushing during peak events.
River continuity			
Continuity providing for migration of aquatic organisms and sediment transport	Flow diversion and siltation problems reduce the biodiversity and fisheries quality of the site.	Reconnection of meander loop	Continuity reinstated

Hydromorphological quality element	Description of the problem	Relevant restoration measures	Description of expected hydromorphological response
	Canal gate debris may have obstructed fish passage Decreased length of river habitat		
Morphological conditions			
Channel patterns	Canal cut was a uniform, straight channel with low morphological diversity.	Reconnection of meander loop Cross-sectional design	Meander planform and cross-sectional design will encourage localised variability in channel width and depth.
Width, depth variation	Canal cut was of uniform width and depth except when gate debris occurred.	Reconnection of meander loop	Increased morphological diversity leading to localised creation of width and depth variations.
Flow velocities	Channelisation may have increased flow velocities while quantity and velocity of flow was exceptionally low in the loop.	Reconnection of meander loop	Increased flow diversity due to creation of riffles and meander
Substrate conditions	Siltation is a major issue in the Rother including at Shopham Loop.	Reconnection of meander loop Reconnection of the river with the floodplain above Shopham Loop on the left hand bank Embankment design to recreate the effect of the lock gates, prevent flows taking the quickest route and retain the backwater	Decreased siltation due to higher flow velocities within the river. Sediment deposited on the floodplain once out of bank More areas of gravel substrate in new riffle
Structure and condition of riparian	Lack of trees and riparian vegetation	Fencing to allow trees to establish	Increased height of

Hydromorphological quality element	Description of the problem	Relevant restoration measures	Description of expected hydromorphological response
zone	causing a dearth of shelter and shading around Shopham Loop Lack of marginal and aquatic vegetation due to the depth and uniform cross-section and flow of the river	and to replicate some of the habitat in the canal cut (continuous fencing on one bank only)	vegetation Increased coverage of vegetation Improved riparian structural integrity Areas of shelter and shading in the river to provide habitat for aquatic species
Floodplain connectivity	Lack of floodplain connectivity	Creation of scrape and lowering of upstream banks	Increased floodplain inundation and creation of habitat in the scrape

3.4.2 Biological response

Many of the underlying mechanisms that link biological pattern, ecological processes and river form and physical processes are often only known in outline (Vaughan et al. 2009). However, the application of biotope assessment is considered an effective way of assessing the effectiveness of restoration measures (see, for example, Kemp et al. 1999, Demars et al. 2013).

Despite the lack of detailed knowledge, it is possible to determine the general requirements for the species found in the River Rother based on the characteristics of river reaches where habitat is in good condition and there is a known evidence base. The physical characteristics of the river system on which the ecological factors are dependent are summarised in Table 3.4.

Table 3.4 Physical characteristics on which ecological factors are dependent

Species	Physical characteristics supporting good habitat
Salmonids	• Channel dominated by clean, stable gravel for spawning • Shallow areas with low flow velocities for nursery habitat • Appropriate cover – juveniles require areas of deep water, surface turbulence, loose substrate, large rocks and other submerged obstructions, undercut banks, overhanging vegetation, woody debris lodged in the channel and aquatic vegetation
Bullhead	• Swift to moderate, clear flows • Channel dominated by clean, stable gravel • Riffle habitat features

Species	Physical characteristics supporting good habitat
	• Macrophyte cover <40% • Shading • No barriers >18 cm • Tree roots/large woody debris
Coarse fish (roach, perch, eel, dace)	• Slow water • Variable depth • Dense weed • Silt substrate
Macroinvertebrates	• Presence of variously structured vegetation on banks, margins and in channel • Variety of in channel substrates and patches of flow velocity

The biological responses were developed by considering the link between the hydromorphological conditions and the likely impact on the biological quality elements of interest (macrophytes, macroinvertebrates and fish). The responses were developed following the SMART method and reflect the likely changes on biological conditions. The objectives are presented in Table 3.5.

3.4.3 Steering Group input

The draft assessment of responses was circulated to the Project Steering Group made up of staff from the Environment Agency and the River Restoration Centre. Based on their comments, some responses were removed and some modified. The final draft was approved by the Project Steering Group.

3.5 Water Framework Directive relevant objectives

The hydromorphological and biological WFD objectives developed for the Shopham Loop site are presented in Table 3.6, together with the rationale for their inclusion. Further details of the methods used to assess each objective are presented in Section 4. The results of the analysis are provided in Section 5.

Table 3.5 WFD relevant objectives and the data used to address objectives

Objectives	Rationale
Hydromorphological	
• Increased sinuosity immediately after implementation	• Increased sinuosity can increase morphological diversity by promoting erosional and depositional processes.
• Increased variation in depth and width three years after implementation	• Variation in width and depth is an indicator of the physical characteristics of a water body, which support a range of habitat niches. Increased variation in width and depth can enhance morphological

Objectives	Rationale
	conditions and provide varied habitats for fish, macroinvertebrates and macrophytes. More specifically, increased shallow areas promote the growth of water tolerant and aquatic plants, and provides good habitat for fish fry and macroinvertebrates.
• Increased variability in velocity and diversity of flow types immediately after implementation	• Localised and average flow velocities help to determine the hydrological regime and the overall morphological conditions within a river system. Higher flow velocities can provide benefits to macrophyte, macroinvertebrate and fish habitats by limiting sediment deposition
• Development of diverse bedforms within three years of implementation	• Bedforms are indicative of high morphological diversity and erosional and depositional processes.
• Increased height and coverage of riparian vegetation a year of implementation	• The primary hydromorphological benefit conferred by riparian vegetation is the reduction of bank erosion due to the stabilising effect of a strong root structure and protection from the direct force of the flow by plant biomass. In addition, the increased hydraulic roughness provided by bankside vegetation can help to slow flood flows thereby reducing flood risk downstream.
• Decreased sedimentation within the loop within two years of implementation	• Decreased sedimentation is an indication of faster flows and prevents the smothering of bed features.
Biological	
Macrophytes	
• Increased percentage cover of macrophytes within one year of implementation	• Increased percentage cover of macrophytes enhances the ecological quality of the river by improving habitat for fish and macroinvertebrates. It is also an indication of improved flow and substrate conditions.
• Increase in macrophyte species diversity in relation to faster flows and decreased siltation within one year of implementation	• An increase in the number of macrophyte species which prefer faster flows and reduced siltation reflects an improvement in the hydromorphology and, by extension, the ecological quality of the river.
Macroinvertebrates	
• Increase in macroinvertebrate species diversity within three	• Macroinvertebrate species form an important link in the aquatic food chain

Objectives	Rationale
years of implementation	and are representative of water quality and morphological conditions. An increase in species diversity will indicate general improvement in the ecological and morphological conditions in the river.
• Increase in species preferring faster flows (LIFE) and an increase in the proportion of sediment-sensitive invertebrates (PSI) within three years of implementation	• Higher flow velocities can provide benefits to macroinvertebrates by limiting sediment deposition. LIFE scores are used to assess flows whereby each taxon is assigned to a flow group depending on its preferred stream velocity. Flow scores are obtained for each taxon (by comparing flow group and abundance); these are subsequently used to generate the LIFE index. Higher scores reflect faster flow velocities. • A reduction in fine sediment deposition associated with faster flowing water will in turn change the benthic macroinvertebrate community structure. PSI scores can be used as a proxy to describe temporal and spatial changes in siltation – the higher the PSI score, the greater the number of sediment-sensitive taxa and by implication the lower the proportion of fine silt in the substrate.
• Good or better biological status of macroinvertebrates in the loop and increased conservation value within three years	• Observed benthic macroinvertebrate taxon (number of taxa, NTAXA) and taxa-sensitive to organic enrichment (average score per taxon, ASPT) are used to calculate riverine biological status for the Water Framework Directive. A high Ecological Quality Ratio (EQR) of observed to expected taxa is associated with high macroinvertebrate status. • The CCI scores are used to define the conservation status of the site. The index highlights sites that have a small number of regionally and locally rare species, and also sites that are highly diverse. The higher the CCI score, the higher the conservation value.
Fish	
• Increased diversity and abundance of native fish species within three years of implementation. In particular roach, minnow, gudgeon, bleak, eel and chub since these species are driving the poor fish status of	• An increase in these fish species would be indicative of improved hydromorphology and result in improved ecological quality of the river.

Objectives	Rationale
the water body.	
• Changed age structure of fish communities (increased presence of juvenile fish) within three years of implementation	• Long-term improvement in conditions for fish species through providing additional spawning habitat, could be expected to increase the presence of juvenile fish.

4 Methods

This section outlines the main methods used to analyse the data and to assess the effectiveness of the scheme in delivering WFD relevant objectives.

4.1 Hydromorphology

The following sections present each objective in turn and outline the methods of analysis used to assess each one.

4.1.1 Increased sinuosity

The sinuosity of the River Rother between Coultershaw Bridge and Shopham Bridge was calculated using the thalweg and Ordnance Survey (OS) mapping to identify the length of the channel. This was then used to calculate the sinuosity of the channel by comparison with the straight line length between the upstream and downstream cross-sections, using the following formula:

$$Sinuosity = \frac{Channel \quad length}{Straight - line \quad valley \quad length}$$

4.1.2 Increased variation in width and depth

Graphical representation of cross-sections

All cross-sectional data from the topographic survey (xyz data) were entered in a Microsoft® Excel spreadsheet. The data were plotted to enable a simple visual analysis of changes in the width and depth of the channel between the pre-and post-restoration surveys.

Statistical analysis

Using the graphical representation of the channel and the field measurements, the bankfull width, bankfull depth and width/depth ratio were calculated for each cross-section. Using this information, the average width and depth were calculated together with the standard deviation (SD) for width and depth across all cross-sections. The standard deviation is a measure of the average variance from the mean and is used to identify an increase or decrease in the width and depth variation – the higher the standard deviation, the greater the variation in the dataset and, by inference, the greater the variation in width and/or depth in the channel.

4.1.3 Increased variability in velocity and diversity of flow types

In the absence of any velocity measurements, an analysis of post-restoration conditions was made using the physical biotope mapping results. These were compared with the known baseline conditions pre-restoration.

4.1.4 Development of diverse bedforms

In the absence of q detailed bed survey, an assessment of the extent of bedforms was made based on the standard deviation of the channel bed elevation at five comparable cross-sections. An increased variance in channel elevation could be indicative of more diverse bedforms.

4.1.5 Increase height and coverage of riparian vegetation

No appropriate data were available to consider this objective.

4.1.6 Decreased sedimentation within the loop

No appropriate data were available to consider this objective.

4.2 Macrophytes

The methods used to address each macrophyte objective are presented below.

4.2.1 Increased percentage cover of macrophytes

The macrophyte survey results were used to estimate an overall coverage within the channel. The percentages for each year were compared to monitor the change before and after restoration.

4.2.2 Increase in macrophyte species diversity in relation to faster flows and decreased siltation

No appropriate data were available to consider this objective.

4.3 Macroinvertebrates

The methods used to address each macroinvertebrate objective are presented below.

4.3.1 Increase in macroinvertebrate species diversity

Species diversity

Species diversity is determined using the Shannon–Wiener Diversity index (*H*):

$$H = -\sum_{i=1}^{S} (pi \ln pi) - [(S-1)/2N]$$

where:

ni = number of individuals in species i

S = total number of species

N = total number of individuals

pi = relative abundance of each species, calculated as the proportion of a given species to the total number of individuals in the community $\frac{ni}{N}$

Scores will range between 0 (indicating low community complexity) and 4 (indicating high community complexity).

The replicates from each different substrate types were accumulated to calculate overall species diversity.

4.3.2 Increase in species preferring faster flows (LIFE) and sediment-sensitive species (PSI)

Lotic Macroinvertebrate Index for Flow Evaluation (LIFE)

Each taxon is assigned to a flow group depending on its stream velocity preference. Flow scores are obtained for each taxon by comparing flow group and abundance; these scores are subsequently used to generate the LIFE index. Higher scores reflect faster flow velocities. For more information see Extence et al. (1999).

Proportion of sediment-sensitive invertebrates (PSI)

PSI is a sediment-sensitive macroinvertebrate metric which can act as a proxy to describe temporal and spatial impacts. The index can be retrospectively calculated to track sedimentation trends through time.

The PSI approach is based on assessing the proportion of sediment-sensitive taxa recorded in a benthic macroinvertebrate sample and offers a cost-effective and reliable methodology for sedimentation screening. PSI scores can range from 0 (entirely silted river bed) to 100 (entirely silt-free river bed). For more information see Extence et al. (2013).

LIFE and PSI scores were determined from data collected between 2002 and 2009 for Shopham Loop and the ‘control’ site at Selham Bridge. The scores were provided directly by the Environment Agency and allow the following comparisons to be made:

- average scores for Shopham Loop with Selham Bridge – not taking into account the substrate and other differences between the sites
- changes in scores within Shopham Loop before and after restoration

4.3.3 Increased conservation value (CCI) and good or better macroinvertebrate status for the Water Framework Directive

Community Conservation Index for aquatic macroinvertebrates (CCI)

Each species is assigned a score reflecting its rarity and these scores are used to define an index for the site. The index highlights sites that have rare species and sites that are highly diverse – the higher the CCI score, the higher the conservation value. For more information see Chadd and Extence (2004).

CCI scores were determined from data collected between 2002 and 2009 for Shopham Loop and the ‘control’ site at Selham Bridge. The scores, which were provided by the Environment Agency, allow the following comparisons to be made:

- average CCI scores for Shopham Loop with Selham Bridge – not taking into account the substrate and other differences between the sites
- changes in scores within Shopham Loop before and after restoration

River Macroinvertebrate Classification Tool (RICT)

The River Macroinvertebrate Classification Tools (RICT) enables an assessment of the condition of ‘benthic macroinvertebrates’ listed in Annex V of the Water Framework Directive. The method assesses the condition of macroinvertebrates using the parameters; number of taxa (NTAXA) and average score per taxon (ASPT). An assigned EQR is used to classify the overall condition of macroinvertebrate populations in the water body for the Water Framework Directive.

Number of taxa is a direct measure of the richness in different types (taxa) of macroinvertebrate, which generally increases with ecological condition. A high number of taxa on a site indicate that water quality, habitat and food requirements are met. The index is calculated simply as the number of different macroinvertebrates collected.

The ASPT is the average of the pressure sensitivity scores of all macroinvertebrate families found in the biological sample. Pressure sensitivity scores were developed in the 1980s based on expert judgement. The pressure sensitivity score ranges from zero to 10; the presence of mayflies or stoneflies, for instance, indicates the cleanest waterways and is given a pressure sensitivity score of 10. The lowest scoring macroinvertebrates are worms which score one.

4.4 Fish

4.4.1 Increased diversity and abundance of native fish species

Increased diversity

Species diversity is determined using the Shannon–Wiener Diversity index (see section 4.3.1).

Increased abundance

The total number of fish caught for each species each year was compared. Assessment was limited to simple descriptive analysis of the observed four-year trends for each species.

The results of a pre-restoration survey were also used but these were not directly comparable with the post-restoration results because three depletion runs were undertaken and a longer reach was surveyed.

4.4.2 Changed age structure of fish communities (increased presence of juvenile fish)

No appropriate data were available to address this objective.

5 Results

This section presents the WFD relevant objectives that were developed to assess the performance of the scheme and a discussion of the effectiveness at meeting these objectives in terms of hydromorphological and ecological quality elements.

5.1 Hydromorphological objectives

The following sections outline the results of the data analysis and make an assessment of the effectiveness of the river restoration measures based on the WFD relevant objectives outlined in Table 3.5.

Where possible, results from Shopham Loop are compared with results from the Environment Agency monitoring stations to provide a ‘control site’. In theory, the WFD relevant objectives should not be achieved at the control site as no human intervention has occurred and therefore no significant changes to the system would be expected.

5.1.1 Increased sinuosity

The sinuosity of the River Rother between Coultershaw Bridge and Shopham Bridge post-restoration was 2,400/1,638 m = 1.47. Sinuosity increased from 1.21 to 1.47 due to the reconnection of the loop which increased the overall channel length by approximately 418 m.

Summary against objective

The restoration measures have increased the sinuosity of the River Rother by reconnecting the meander and extending the total channel length. It is likely that small-scale changes in the sinuosity have occurred naturally since restoration due to localised erosional processes, but it has not been possible to detect these changes with the information available.

5.1.2 Increased variation in width and depth

he results for bankfull depth and bankfull width are shown in Table 5.1, width:depth ratio in Table 5.2, and the mean and standard deviation of channel elevation in Table 5.3.

Table 5.1 Mean and standard deviation of bankfull width and depth post restoration

	Bankfull depth			Bankfull width		
	2005	2006	2009	2005	2006	2009
Shopham Loop						
Mean	2.76	2.53	2.94	11.45	11.40	10.25
Standard deviation	0.343	0.784	0.250	1.705	2.675	2.104
River Rother						
Mean	2.81	2.75	2.80	16.13	17.24	15.04
Standard deviation	0.396	0.622	0.59	1.386	2.553	3.749

Table 5.2 Width:depth ratio

Year	Section 4A	Section 7A	Section 12A	Rother Section A	Rother Section B	Mean
2005	8.84	7.74	7.76	8.65	11.33	8.86
2006	9.69	7.92	7.00	10.74	10.58	9.19
2009	6.52	6.09	4.56	8.46	8.72	6.87

Table 5.3 Mean and standard deviation of channel elevation (mAOD)

	2005	2006	2009
Mean	5.50	5.46	5.09
Standard deviation	0.89	0.93	0.94

Notes: mAOD = metres above Ordnance datum

The mean bankfull depth in Shopham Loop increased from 2.76 m to 2.94 m between 2005 and 2009. In the main River Rother, mean depth decreased in 2006 and then increased in 2009, although it remains slightly less than in 2005. The standard deviation in the main River Rother increased between 2005 and 2009 suggesting that the depth had become more variable. This is likely to be in part due to slight changes in the location of survey points but could also be attributable to natural variations in scour and deposition processes that have occurred in response to the reconnection of Shopham Loop. It is not considered that the changes in the depth are significant enough to impact on the hydromorphological or biological conditions of the channel. In Shopham Loop the standard deviation increased in 2006 but then decreased in 2009, although as mentioned, the overall mean depth increased. This suggests that erosional processes as a result of increased flows were causing channel incision but that there was no real increase in depth variability throughout the reach between 2005 and 2009.

The data in Table 5.2 and 5.3 support this increase in depth with lower width:depth ratios and lower overall channel elevation. The difference in the standard deviations of bankfull depth and channel elevation is because the latter includes the main Rother cross-sections, which may be influencing the overall variability.

Mean bankfull width in the main River Rother and Shopham Loop decreased between 2005 and 2009, with a corresponding increase in the standard deviation. So while the channel became generally narrower, width became more variable in the reach. Although the river system was likely to be adjusting naturally to the reconnection of the meander loop, this may not account for the full decrease in bankfull width observed in the reach. The larger adjustments to the bankfull width could be partially attributable to varying numbers of cross-sections recorded in each year, which means that data reflect width more accurately in some survey years.

Analysis of individual cross-sections supports these overall trends and highlights minor changes in channel form. At section 4A, there is evidence of channel deepening between 2005 and 2006, likely to be a result of bed scour during high flow events. There was also some bank retreat, possibly due to erosion and associated slumping. By 2009, the channel had become more trapezoidal in shape, with a decrease in depth compared with 2006 and erosion on the right hand bank. The left hand bank remains predominantly unchanged, with only minor changes in the cross-section.

Section 7A displayed only minor changes at the channel bed, with erosion and deposition occurring between 2005 and 2009. The width of the channel showed some unusual variation, with the channel narrowing in 2006 but widening in 2009. The narrowing could be due to bank slumping that occurred soon after restoration and before the banks became stabilised with vegetation. The subsequent widening could be the result of erosion that removed unstabilised slumped material.

Section 12A showed only minor changes between 2005 and 2006 but significant widening on the left hand bank in 2009. This is likely to be a result of erosive flows downstream of the riffle/bed control and to erosion on the outside of the meander bend.

Section B on the main Rother showed an increase in channel depth between 2005 and 2009 and also a shallower bank profile and wider channel due to erosion on the meander bend. Section A, further downstream, showed no major significant changes in the width and depth.

Summary against objective

Analysis of directly comparable cross-sections found some major changes to the channel in Shopham Loop. This is particularly evident at Section 12A where the channel became significantly wider between 2005 and 2009, likely in response to increased flow velocity downstream of the riffle/bed control.

In addition there were many minor changes to the width and depth in Shopham Loop. These changes are likely to be in response to natural erosional and depositional processes that occurred after the loop had been reconnected. It is not possible to conclude from these cross-sections that width and depth variation had increased, although it is evident that these characteristics of the channel are dynamic and do change over time.

Statistical analysis of bankfull depth shows that the overall channel depth had increased in Shopham Loop but that variance had decreased. In the main River Rother, the bankfull depth and the standard deviation increased. The increased channel depth is due to erosion causing channel incision.

The mean bankfull width in the main River Rother and Shopham Loop decreased between 2005 and 2009 with a corresponding increase in the standard deviation. While the river system is likely to be adjusting naturally to the reconnection of the meander loop, this may not account for the full decrease in bankfull width observed in the reach. The larger adjustments to the bankfull width are likely to be partially attributable to the fact that varying numbers of cross-sections were recorded in each year, meaning that particularly wide cross-sections influence results from some years more than others.

Width:depth ratios decreased at all cross-sections, reflecting the overall increase in depth.

Overall, the depth of the channel increased and the width decreased between 2005 and 2009. There appears to have been greater variation in width and depth in the main River Rother than in Shopham Loop, but the loop system is likely to have still been adjusting to the increased flow it was conveying.

5.1.3 Increased variability in velocity and diversity of flow types

Pre-restoration, the preferential course of the River Rother was via the canal cut while Shopham Loop only conveyed flow in flood events. Over time, deposition of sand in the loop during these flood events caused the loop to become cut off. This resulted in the upstream section of the loop becoming dry for most of the year (Figure 5.1). The downstream end of the loop conveyed flow from the Haslingbourne Stream, but flows from this tributary were low and the Shopham Loop channel was over-wide and over-deep resulting in slow flows and the establishment of terrestrial vegetation in the channel.

Figure 5.1 Pre-restoration: no flow in the upstream end of Shopham Loop

Post-restoration, physical biotope mapping performed in October 2009 showed a relatively diverse range of flow types, with varied velocities. A gravel riffle was found at the upstream end of the loop, exhibiting fast flow with unbroken standing waves (Figure 5.2). Downstream of this and as far as the Haslingbourne Stream confluence, the biotope was a run, with fast rippled flow. From this point, to the exit of the loop, flow alternated between more uniform, slow flowing glides (Figure 5.3) and faster flowing runs. At the exit of the loop, the bed control installed as part of the restoration was creating a riffle with fast shallow flow (Figure 5.4). Overall, the loop displayed a variety of flow types, with varied velocities. Large woody debris throughout the reach was further contributing to varied flow velocities by restricting flows in localised areas.

Figure 5.2 Gravel riffle at upstream end of meander loop post-restoration

Figure 5.3 Glide section of Shopham Loop post-restoration

Figure 5.4 Riffle at downstream end of Shopham Loop post-restoration

Summary against objective

Analysis of physical biotope mapping, photographs and knowledge of the baseline conditions pre-restoration indicates that flow velocity and flow type had become more variable as a result of the restoration scheme. This is largely because prior to restoration the loop only conveyed flow in flood events and the presence of constant flow throughout the year inevitably increased variability in flow velocities and flow type. Although the downstream half of the loop did previously convey flow from the

Haslingbourne Stream, the restoration scheme increased flow velocities and introduced varied flow types to this section of the loop by increasing the quantity of water throughout the year.

The installation of the bed controls at the upstream and downstream end of the loop created gravel riffles displaying fast, shallow flow – conditions not present in the loop pre-restoration.

5.1.4 Development of diverse bedforms

The mean and standard deviation of channel elevation at each of the five comparable cross-sections is presented in Table 5.4. The mean channel elevation decreased between 2005 and 2009 at each cross-section. The standard deviation also decreased at all cross-sections – apart from Section 7A – suggesting that the channel elevation had become less variable.

Table 5.4 Mean and standard deviation of channel elevation

Year	Section 4A		Section 7A		Section 12A		Rother Section A		Rother Section B	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2005	4.62	0.201	4.75	0.208	4.79	0.405	4.63	0.289	4.53	0.231
2006	4.52	0.336	4.85	0.259	4.53	0.259	4.29	0.326	4.60	0.285
2009	4.26	0.100	4.65	0.261	4.34	0.126	4.15	0.256	3.87	0.180

Summary against objective

Although the results showed less variation in channel elevation, this is not necessarily an accurate reflection of the presence or lack of diverse bedforms. The data are not of sufficient resolution to identify specific bedforms.

Limitations of methods and analysis

While it is possible to calculate the sinuosity of the River Rother before and after restoration, it would have been interesting to assess small-scale changes in sinuosity post-restoration that might have occurred as the channel adjusted to its new course. However, long profiles of the channel were only taken in 2005 and 2006, with varying resolution (91 points compared with 307). Survey points were not taken regularly or evenly spaced, making it difficult to detect small-scale changes in the sinuosity of the channel.

Cross-sections were not apparently taken at the same location in 2005, 2006 and 2009 with only two sections in the loop being directly comparable. If all the cross-sections had been directly comparable it would have been possible to detect small-scale changes in sinuosity.

The accuracy of cross-section surveys can be influenced by factors such as vegetation cover, meaning that the data in 2009, when riparian vegetation was more established, could be less accurate.

Varying numbers of cross-sections were taken in each year, therefore influencing the bankfull width and depth statistics.

There are no flow velocity data or discharge data for Shopham Loop, which makes a quantitative assessment of variation in velocity impossible.

Physical biotope mapping was only performed in one year post-restoration (2009). It is therefore not possible to compare this with either pre-restoration conditions or other post-restoration years.

The survey data available are not of sufficiently high resolution to accurately detect bedforms. Any changes apparent in the data could potentially be attributable to survey error (that is, readings taken at slightly different locations).

The depth and turbidity of the water prevented the identification of bedforms from the bank top.

5.2 Macrophyte objectives

The following sections address each of the macrophyte objectives. The limitations for each objective are similar in nature and are therefore presented at the end of this section.

5.2.1 Increased percentage cover of macrophytes

Total estimated percentage cover increased from 7–10% in 2005 to 13% in 2007 (Table 5.5). A similar composition of species was recorded within the surveys, with *Sparganium* spp. and *Phalaris arundinacea* among the most common and ubiquitous plants (RRC 2011).

Table 5.5 Macrophyte survey results in Shopham Loop

Statistic	2005	2006	2007	2009
Number of species	23	13	13	18
Number of genera	18	13	11	17
Total estimated % cover	7–10	8	13	n/a

Summary against objective

Analysis of macrophyte survey data shows that percentage cover increased between 2005 and 2007. Percentage cover is likely to have increased due to the gradual establishment of species in response to the increased flow conveyed around the loop.

Limitations of methods and analysis

The technique used to record macrophyte coverage in each year was not standardised and it is therefore difficult to make direct comparison between years. Macrophyte species presence should be recorded based on area coverage rather than the point basis or mixture of the two – as was the case for 2005.

An additional problem regarding species, particularly in light of the weight given to number of species, lay in defining what constitutes a riverine macrophyte. The high number of taxa reported for 2009, for example, may be partly attributed to the inclusion of species such as the stinging nettle (*Urtica dioica*), hogweed (*Heracleum* spp.), yarrow (*Scrophularia auriculata*) and ragwort (*Senecio* spp).

Results are not over a long enough timeframe to be certain about the trends in macrophyte coverage.

5.3 Macroinvertebrate objectives

The following sections address each of the macroinvertebrate objectives. The limitations for each objective are similar in nature and are therefore presented at the end of this section.

5.3.1 Increase in macroinvertebrate species diversity

Species diversity scores indicate a diverse assemblage of macroinvertebrates at both Shopham Loop and Selham Bridge (Table 5.6 and Figure 5.5).

In Shopham Loop, macroinvertebrate species diversity was higher in some locations pre-restoration; diversity decreased from 3.14 in 2002 to 2.12 in 2005. Species diversity increased between 2005 and 2009 but remained lower than the pre-restoration level. This increase in diversity is likely to be attributable to the development of a wider variety of habitats as the river re-naturalised and adjusted to its new course.

The results at the ‘control’ site at Selham Bridge suggest that macroinvertebrate diversity decreased in the catchment as a whole, probably as a result of the low flow conditions experienced in 2005 and 2006 (see section 3.1.1). Therefore, the increase at Shopham Loop may be attributable to the restoration scheme.

Table 5.6 Species diversity scores for Shopham Loop and Selham Bridge

	Shannon–Wiener diversity score				
	2002 (pre-restoration)	**2005**	**2006**	**2007**	**2009**
Shopham Loop	3.14	2.12	2.40	2.55	2.52
Selham Bridge	2.24	2.34	2.11	2.03	No results

Notes: Scores can range between 0 (indicating low community complexity) and 4 (indicating high community complexity).

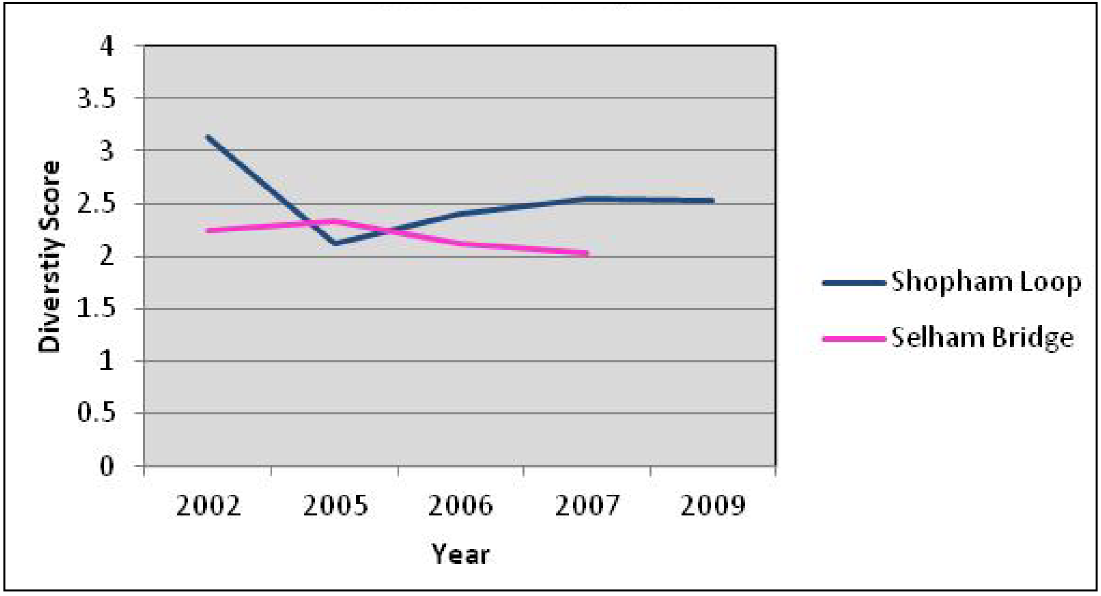


Figure 5.5 Species diversity scores

Summary against objective

Analysis of species diversity scores using the Shannon–Wiener Diversity index shows that diversity was higher pre-restoration. This is likely to be due to the presence of large amounts of sand and gravel substrate. Diversity decreased from 3.14 in 2002 to 2.12 in 2005. This is likely to be a result of disturbance to existing habitats during implementation and in response to the changing flow conditions throughout the loop. After 2005 species diversity increased but remained lower than the pre-restoration level. The increase in diversity is likely to be attributable to the development of a wider variety of habitats as the river re-naturalised and adjusted to its new course.

The results at the ‘control’ site at Selham Bridge suggest that macroinvertebrate diversity decreased in the catchment as a whole and therefore the increase at Shopham Loop can be largely attributed to the restoration scheme.

5.3.2 Increase in species preferring faster flows (LIFE) and proportion of sediment-sensitive invertebrates (PSI)

LIFE, PSI and CCI scores for Shopham Loop and Selham Bridge are presented in Table 5.7. The variation in number of samples and season they were collected over the years and between sites means that direct comparisons between the biotic indices should be treated with caution. However, the results indicate that:

- the species and family LIFE scores were generally higher at Selham Bridge than at Shopham Loop
- Shopham Loop scores increased post-restoration whereas those at Selham Bridge showed little overall change between 2002 and 2007.

This suggests that the macroinvertebrates responded to increased flow velocities within the Shopham Loop, particularly immediately after restoration. A corresponding increase in PSI may reflect the interaction between flowing water conditions and the movement of fine sediment at higher flows.

Table 5.7 LIFE, PSI and CCI scores for Selham Bridge and Shopham Loop

Site	Year	LIFE score (species)	LIFE score (family)	PSI score (family)	CCI score
Shopham Loop	2002 (pre restoration)	7.27	7.07	44.23	8.01
	2005	7.51	7.23	50.37	12.32
	2006	7.54	7.20	50.84	12.28
	2007	7.66	7.19	56.93	11.01
	2009	7.63	7.51	78.38	10.76
Selham Bridge	1998	n/a	7.09	53.49	n/a
	1999	n/a	7.36	55.60	n/a
	2000	n/a	7.06	44.00	n/a
	2001	7.4	7.09	57.89	4.5

Site	Year	LIFE score (species)	LIFE score (family)	PSI score (family)	CCI score
	2002	8.00	7.25	66.67	6.00
	2003	n/a	7.35	58.53	n/a
	2005	n/a	7.10	44.32	n/a
	2006	9.00	7.17	46.04	9.00
	2007	8.00	7.35	66.66	4.50
	2009	No data	No data	No data	No data
	2013	n/a	7.00	44.44	n/a

Summary against objective

Analysis of biotic scores indictes that family and species LIFE scores and PSI scores increased in Shopham Loop between 2002 and 2009. This increase was greater than that at the Selham Bridge ‘control’ site, suggesting that changes may be attributable to the restoration scheme.

5.3.3 Good or better biological status of macroinvertebrates in the loop and increased conservation value within three years

Analysis of RICT outputs can help explain what is driving the macroinvertebrate community composition. Based on ASPT score alone, the loop transects score either ‘good’ or ‘high’ (Figure 5.6). Based on NTAXA, only some areas of the loop attained ‘good’ or ‘high’ status (Figure 5.7). This suggests that water quality is not the deciding factor for macroinvertebrate community composition because the ASPT EQR is steady at either good or high. The variation in the number of taxa could be due to habitat or sampler effort, which could change with water depth. Very deep water can affect the sampling and could, in theory, reduce the number of taxa found without compromising the ASPT value. Another likely explanation is, if the habitat is shifting and changing, this would inhibit the number of taxa found without significantly compromising the ASPT as long as there was some acceptable quality habitat within the transect area. This variability suggests that the loop was still adjusting in 2007. Transect 1 performs favourably because it is located in the cobble area at the upstream end of the loop.

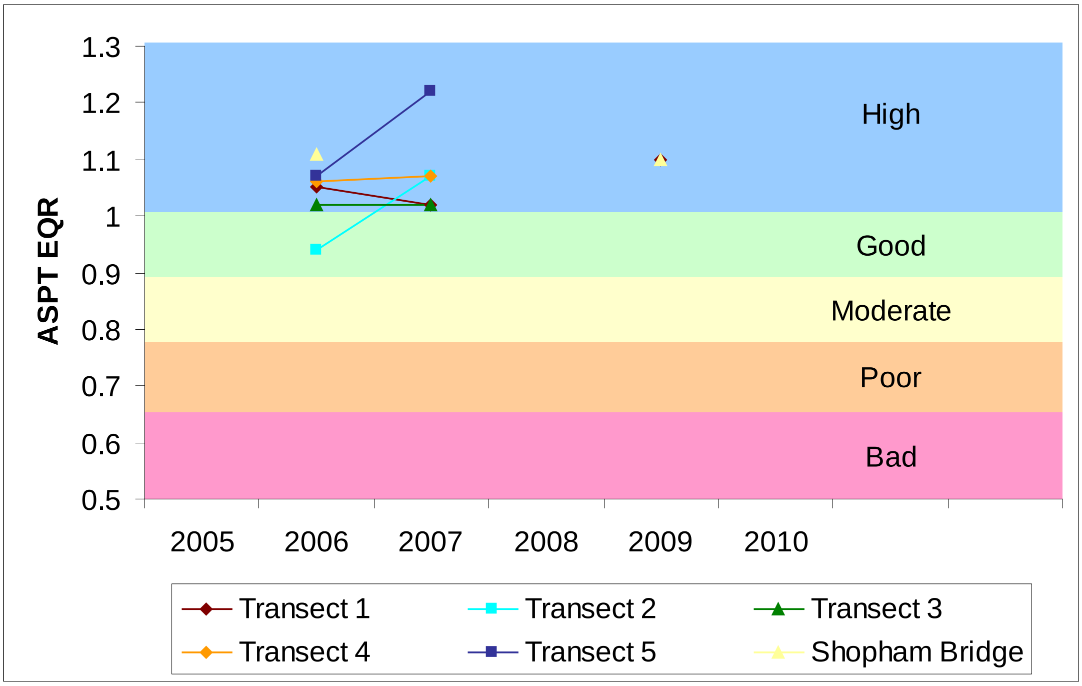


Figure 5.6 ASPT EQR derived from RICT for Shopham Loop transects and Shopham Bridge

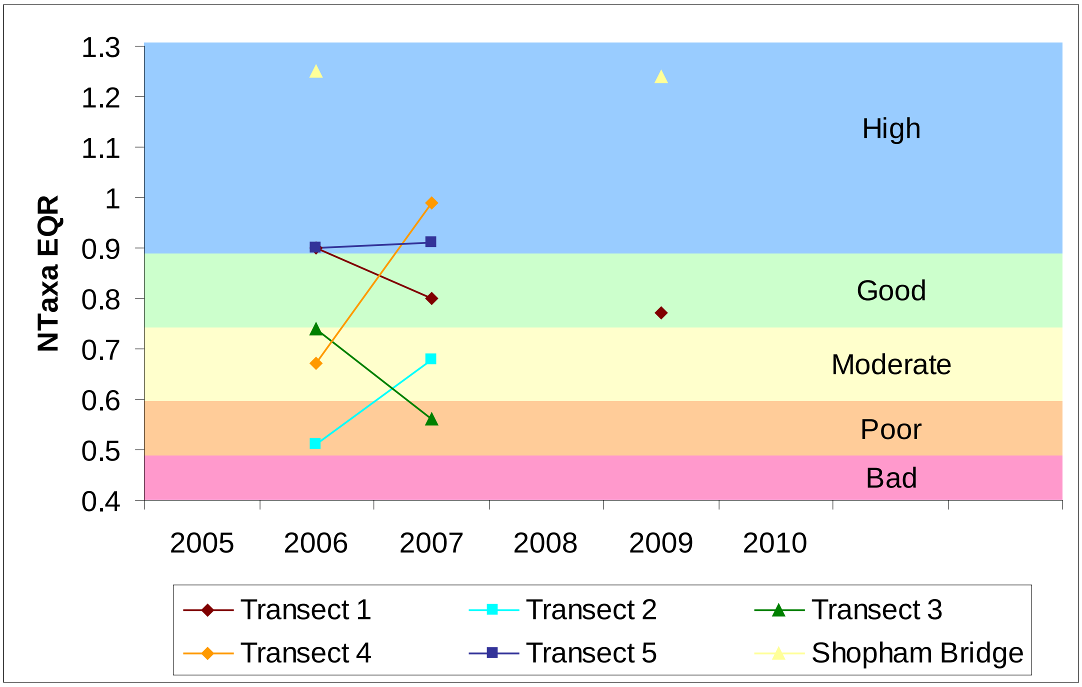


Figure 5.7 NTAXA EQR derived from RICT for Shopham Loop transects and Shopham Bridge

CCI scores in Table 5.7 are markedly higher in Shopham Loop than at Selham Bridge, indicating that the loop has a higher conservation value. The CCI score increased significantly immediately after restoration, suggesting that habitat was improved as a result of the restoration works. CCI scores at Selham Bridge decreased between 2002 and 2007, indicating that the changes seen in Shopham Loop may be attributable to the restoration scheme rather than natural variations.

Summary against objective

The RICT classification tool indicates that macroinvertebrate community composition is being driven by habitat and sampler effort rather than water quality.

Analysis of CCI scores shows that the macroinvertebrate population in Shopham Loop is of higher conservation value than in 2002. The CCI score at Selham Bridge decreased between 2002 and 2007, suggesting that the increase in the loop may be attributable to the restoration scheme.

Limitations of macroinvertebrate analysis

The variation in the number of standard kick samples and season in which they were collected over the years and between sites means that direct comparisons between the biotic indices should be treated with caution.

The collection of mesohabitat samples was linked to the location of the habitat which moved in location. This makes simple comparisons of before and after difficult. Additional analysis using alternative statistical techniques relating macroinvertebrate changes to the mesohabitat composition would be useful in understanding the changes as a result of the restoration scheme but are beyond the scope of this project.

The results of monitoring showed some macroinvertebrate response. Additional monitoring would help establish the long-term change.

5.4 Fish objective

5.4.1 Increased diversity and abundance of native fish species

Increased diversity

Species diversity increased after 2005, peaking in 2007 before declining slightly in 2009 (Table 5.8).

Table 5.8 Species diversity scores at Shopham Loop

	2005	**2006**	**2007**	**2009**
Number of species	12	16	15	12
α-diversity (Shannon-Wiener H)	0.77	1.64	1.83	1.76

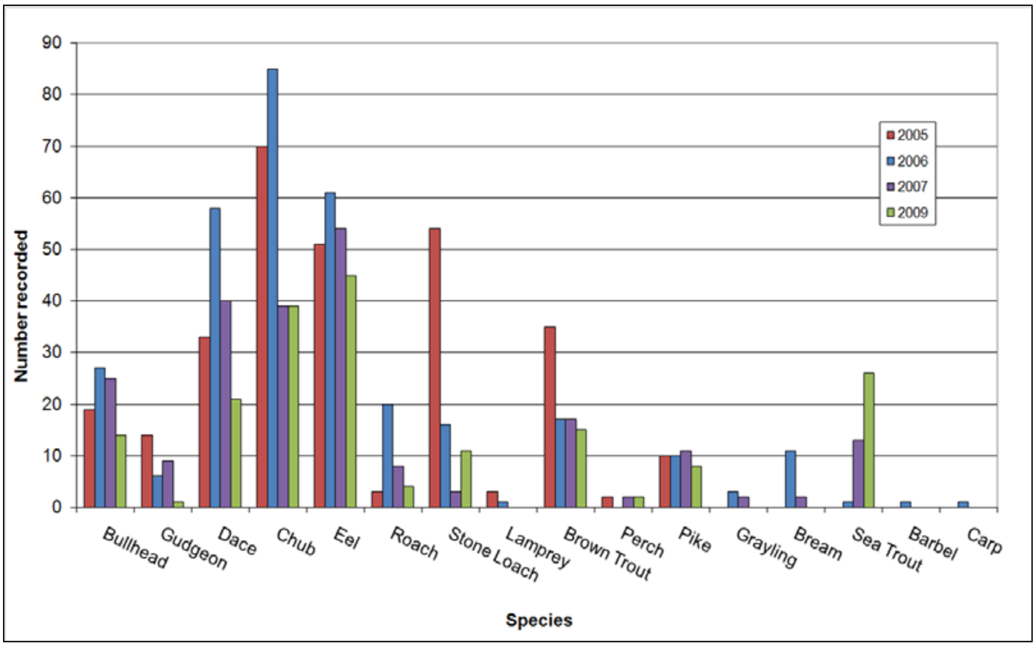
Notes: Scores will range between 0 (indicating low community complexity) and 4 (indicating high community complexity).

Increased abundance

The results of electric-fishing in Shopham Loop are presented in Table 5.9 and Figure 5.8. Table 5.10 presents the results of electric-fishing at the Environment Agency monitoring stations at Fittleworth and Coultershaw.

Table 5.9 Post restoration results of electric-fishing in Shopham Loop

Species	1997 (pre-restoration)	2005	2006	2007	2009
Minnow	794	1527	375	190	165
Bullhead	12	19	27	25	14
Gudgeon	137	14	6	9	1
Dace	131	33	58	40	21
Chub	17	70	85	39	39
Eel	28	51	61	54	45
Stone loach	1	54	16	3	11
Lamprey	64	3	1	0	0
Roach	33	3	20	8	4
Brown trout	1	35	17	17	15
Perch	18	2	0	2	2
Pike	0	10	10	11	8
Grayling	0	0	3	2	0
Barbel	0	0	1	0	0
Bream	9	0	11	2	0
Sea trout	0	0	1	13	26
Carp	0	0	0	0	0
Total (excluding minnow and fry)	451	294	317	225	186



Source: RRC (2009)

Figure 5.8 Electric-fishing results at Shopham Loop

The fish populations were dominated by minnow, although numbers of this species declined progressively in the loop after 2005. The overall number of fish caught was highest in 1997 (pre-restoration), but these results are not directly comparable to the post-restoration result as the survey included three depletion runs. Post-restoration, populations peaked in 2006 but declined in the following two years. The most significant change was in populations of sea trout, which increased from 0 in 1997 to 26 in 2009 and the number of stone loach which decreased from 54 in 2005 to 11 in 2009 (Table 5.10).

The post-restoration results suggest that Shopham Loop provides favourable habitat for bullhead, dace, chub, eel and brown trout as these species were caught in the greatest abundance in each of the survey years. Results from 1997 indicate that pre-restoration there were markedly lower populations of brown trout, chub and eels; this suggests that the favourable habitat may have been created as a result of the restoration scheme. Conversely, populations of lamprey fell from 64 in 1997 to 0 in 2009, and although these results are not directly comparable, they do suggest that habitat for lamprey was not as favourable. Lamprey favour areas with silt substrate and their apparent decline in the main river channel is likely to be related to the decreased sedimentation in Shopham Loop due to increased flow. These results are also likely to be attributable to the fact that lamprey are often only drawn from the substrate on the second or third passes when electric-fishing and so therefore are likely to be under-recorded on the annual single run survey. The creation of the backwater is likely to provide more suitable conditions for lamprey, but the lack of data collection makes it impossible to ascertain whether the habitat is being used.

While the electric-fishing results show that populations of gudgeon and dace have decreased since 1997, similar trends are evident at the Environment Agency monitoring stations. This suggests a catchment-wide decline in populations of these fish. The large difference is also likely to be in part due to the larger survey area and increase number of runs undertaken in the 1997 survey.

Table 5.10 Results of electric-fishing at Environment Agency monitoring stations at Fittingworth (F) and Coultershaw (C)

Species	2005		2006		2007		2008	
	F	C	F	C	F	C	F	C
Minnow	185	41	34	46	1	4	11	1
Bullhead	0	0	0	1	0	2	0	2
Gudgeon	32	10	18	37	2	4	1	1
Dace	10	23	18	30	5	11	1	8
Chub	2	3	5	8	0	4	0	9
Eel	31	2	62	5	8	3	19	12
Stone loach	7	1	5	0	1	3	2	1
Lamprey	3	0	3	0	1	1	0	1
Roach	29	11	17	16	6	13	7	4
Brown trout	0	0	0	1	1	0	1	1
Perch	1	0	1	7	1	0	6	6
Pike	3	3	16	10	6	8	5	5

Species	2005		2006		2007		2008	
	F	C	F	C	F	C	F	C
Grayling	0	0	0	0	0	0	0	0
Barbel	0	0	0	0	0	0	0	0
Bream	0	0	1	5	0	1	0	0
Sea trout	0	0	0	0	0	0	0	0
Carp	0	0	0	1	0	1	0	0
Total (excluding minnow)	303	94	180	167	32	55	53	51

Species	2009		2010	2011	2012	2013	2013
	F	C	C	C	F	C	F
Minnow	165	31	9	0	9	1	13
Bullhead	14	0	0	0	7	1	0
Gudgeon	1	5	2	0	0	0	1
Dace	21	8	1	3	9	3	3
Chub	39	5	0	0	2	1	2
Eel	45	10	3	1	11	1	2
Stone loach	11	5	0	0	4	4	3
Lamprey	0	4	1	0	0	0	1
Roach	4	3	11	3	1	4	3
Brown trout	41	0	0	0	0	0	0
Perch	2	7	2	0	1	1	0
Pike	8	3	17	3	1	0	1
Grayling	0	0	0	0	0	0	0
Barbel	0	0	0	0	0	0	0
Bream	0	0	0	10	0	0	0
Sea trout	0	0	0	0	0	0	0
Carp	0	1	1	0	0	0	0
Total (excluding minnow)	351	94	180	167	32	55	53

The data from Fittingworth and Coultershaw (Table 5.10) show a wide range of species is caught in all years of survey with consistent numbers of juvenile roach and bream showing up over the last few years. The wide variation in results suggests that wider catchment controls influence fish populations. The most significant difference between the datasets is that Shopham Loop had larger populations of sea trout, brown trout, chub and dace than the ‘control sites’ at Fittingworth and Coultershaw. It is important to note that the Environment Agency monitoring stations are fished more thoroughly by a three-sweep depletion netting method and so the loop data are likely to represent low-end estimates of populations. In the years following the restoration the populations vary greatly again suggesting that wider catchment controls are having an influence.

Floodplain scrape

The diversity of species present on the floodplain scrape increased after 2006 (Table 5.11). Populations of three-spined stickleback decreased from 1,000 in 2006 to seven in 2009. However, populations of bream increased from 15 in 2007 to 315 in 2009. The 2013 netting contained a large number of non native sunbleak which were removed and destroyed after the survey. With the benefit of this confirmed identification it is probable that the previous survey in 2010 may also have contained sunbleak which were misidentified as juvenile dace.

Table 5.11 Results of electric-fishing in the floodplain scrape

Species	June 2006	May 2007	July 2009	Nov 2010	Oct 2013
Eel	–	1	2	_	1
Tench	1	20	71	_	7
Dace	–	147	52	194?	–
Bream	–	15	315	72	–
Minnow	–	91	33	10	2
Three-spined stickleback	1000	843	7	17	–
Roach	–	7	205	68	73
Stone loach	6	–	–	–	–
Rudd	–	2	4	1	43
Chub	–	2	–	–	4
Gudgeon	–	1	28	20	–
Carp	–	1	–	–	–
Perch	–	–	2	–	–
Bream	–	–	–	–	–
Brown goldfish	_	_	2	–	–
Pike	–	–	–	1	2
Brown trout	–	–	–	1	–
Common bream	–	–	–	–	53
Motherless minnow/Sun bleak	–	–	–	–	307
Total number of species	3	11	11	9	9
Total individuals	1007	1130	721	384	492

Canal cut (backwater)

Table 5.12 shows the results of electric-fishing and fry netting in the canal cut performed in 2009. Two lamprey were caught, though it is likely lamprey were present larger numbers but were not picked up due to the very turbid water or were not drawn out of the silt. The canal cut is evidently providing suitable conditions for a range of species including perch, rudd, tench, pike, eel and bream. Fry netting at the upstream end of the canal cut found high populations of roach and perch.

Table 5.12 Fish results from canal cut, 2009

Species	Electric–fishing	Fry netting
Lamprey	2	–
Roach	32	–
Roach fry	45	480
Perch	27	100
Rudd	6	1
Tench	10	–
Pike	4	1
Eel	10	–
Bream	1	6
Hybrids	–	4
Total	137	592

Summary against objective

Species diversity results show that species diversity increased after 2005, peaking in 2007 before declining slightly in 2009.

Although the before and after restoration results are not directly comparable, they do suggest that habitat in Shopham Loop had become more favourable for pike, brown trout, sea trout, chub and eel as a result of the restoration works. Populations of lamprey decreased from 64 in 1997 to zero in 2009, possibly as a result of the decrease in areas of fine sediment in the loop.

Analysis of electric-fishing results from Shopham Loop suggests that fish populations peaked in 2006 and then declined. However, similar results occurred at the Environment Agency monitoring stations upstream and downstream of Shopham Loop, suggesting that populations declined throughout the catchment.

The most commonly occurring species in each survey year were bullhead, dace, chub, eel and brown trout, indicating that Shopham Loop provides favourable habitat for these species. The species driving the FCS2 diagnostic are roach, minnow, gudgeon and bleak and these are either not recorded or present in low numbers in Shopham Loop.

Populations of sea trout increased from zero in 1997 to 26 in 2009, indicating an improvement in habitat for this species. This was possibly due to the gravel riffles providing spawning areas and also because the deep and fast flow in the loop provided good holding water for sea trout

The canal cut provided suitable habitat for a range of fish species including perch, rudd, tench, pike, eel and bream. A large number of roach fry were netted at the upstream end of the canal cut, which considering that observed roach catches are consistently less than expected in the catchment according to the FCS2, is a positive indication.

Populations of fish in the floodplain scrape increased after 2006, although a decrease was observed between 2007 and 2009. A range of species were noted including dace, roach, rudd and tench. In recent years the presence of non-native species has been an issue. The large number of juveniles present within the scrape indicated the importance of such features in providing habitat and refuge from washout in high flows.

Limitations of methods and analysis

Due to a lack of pre-restoration data it is not possible to compare fish populations before and after restoration.

The sampling protocol within Shopham Loop still effectively gives a single result per year per site. Without many years of data or temporal replication in each year, it is difficult to comment with any certainty on how representative each result is.

It is important to standardise the time of year and conditions under which surveys are carried out and to maintain surveys at neighbouring sites that are in similar hydromorphological conditions.

Detecting small changes in biota, particularly fish response to habitat alteration, restoration or management changes is difficult. Monitoring in excess of 10 years is typically recommended to rule out natural variation.

5.5 Summary of results

The following sections collate the results to provide an overview of the effectiveness of the restoration measures in meeting the hydromorphological, macrophyte, macroinvertebrate and fish objectives. A summary of the objectives that were achieved and an assessment of the success of the monitoring are presented in Table 5.13.

5.5.1 Hydromorphological objectives

The restoration measures increased the sinuosity of the River Rother by extending the total channel length. It is likely that small-scale changes in the sinuosity occurred since restoration due to erosional and depositional processes, but it was not possible to detect these changes with the information available. Few peak flows were experienced during the assessment period and once these geomorphologically significant flows occur more channel adjustment can be expected.

The depth of the channel increased and the width decreased. There appeared to be greater variation in width and depth in the main River Rother rather than in Shopham Loop. However, the loop system was likely to still be adjusting to the increased flow that it was conveying and would be expected to continue to evolve as the loop experienced more geomorphologically significant flows.

Flow velocity and flow type became more variable as a result of the restoration scheme. This is largely because prior to restoration the loop conveyed flow only in flood events and so the presence of constant flow throughout the year inevitably increased variability in flow velocities and flow type. The installation of the bed controls at the upstream and downstream end of the loop created gravel riffles displaying fast, shallow flow – conditions that were not present in the loop pre-restoration.

5.5.2 Macrophyte objectives

Analysis of macrophyte survey data shows that percentage cover increased between 2005 and 2007. Percentage cover is likely to have increased due to the gradual establishment of species in response to the increased flow conveyed around the loop.

5.5.3 Macroinvertebrate objectives

Species diversity was highest prior to restoration and then declined rapidly immediately following restoration. This is likely to be a result of disturbance to existing habitats during implementation and in response to the changing flow conditions throughout the loop. Species diversity increased after 2005 but remained lower than the pre-restoration level. The increase in diversity is likely to be attributable to the development of a wider variety of habitats as the river re-naturalised and adjusted to its new course.

Analysis of LIFE scores shows that family and species LIFE scores and PSI scores increased in Shopham Loop between 2002 and 2009. This increase was greater than that at the Selham Bridge ‘control’ site, indicating that the changes may be attributable to the restoration scheme.

Analysis of CCI scores shows that the macroinvertebrate population in Shopham Loop was of higher conservation value than in 2002. The CCI score at Selham Bridge fell between 2002 and 2007, suggesting that the increase in the loop may be attributable to the restoration scheme.

5.5.4 Fish objectives

Species diversity results show that diversity increased after 2005, peaking in 2007 before declining slightly in 2009.

Although the pre- and post-restoration results are not directly comparable, they do suggest that habitat in Shopham Loop became more favourable for pike, brown trout, sea trout, chub and eel as a result of the restoration works. Populations of lamprey decreased from 64 in 1997 to zero in 2009, possibly as a result of smaller areas of fine sediment within the loop.

The most commonly occurring species in each survey year were bullhead, dace, chub, eel and brown trout, indicating that Shopham Loop provided favourable habitat for these species. The scrape areas provide valuable habitat for juvenile coarse fish.

Populations of sea trout increased from zero in 1997 to 26 in 2009, indicating an improvement in habitat for this species, possibly due to the gravel riffles providing spawning areas. Improved river continuity throughout the catchment may have also contributed to increases in sea trout population.

Table 5.13 Summary of results

Objective	Was objective achieved?	Was monitoring successful?
Hydromorphological objectives		
Increased sinuosity immediately after implementation	The restoration measures have increased sinuosity by reconnecting the meander loop.	It was possible to calculate sinuosity without using monitoring data. More detailed cross-sections that were directly comparable would have made it possible to detect small-scale changes in sinuosity.
Increased variation in depth and width three years after implementation	Variations in width and depth have increased in Shopham Loop, but less than in the main River Rother, suggesting that the loop was still adjusting to the restoration.	Cross-sectional surveying was partly successful, but many of the cross-sections were not directly comparable due to location errors during repeat surveys.
Increased variability in velocity and diversity of flow types immediately after implementation	By virtue of the fact that the loop previously only conveyed flood events but is now the preferential course of the river, variability in velocity and diversity of flow types increased.	No monitoring of flow velocities was performed either pre- or post-restoration making it impossible to quantify changes.
Development of diverse bedforms within three years of implementation	Data available are not detailed enough to address this objective.	Cross-sectional surveying was not successful in identifying specific bedforms. More detailed bed or bathymetric surveys are more likely to provide results of sufficient resolution.
Increased height and coverage of riparian vegetation a year of implementation	Insufficient data to address this objective	No monitoring of height or coverage of riparian vegetation was carried out.
Decreased sedimentation within the loop within two years of implementation	Insufficient data to address this objective	No monitoring of sedimentation was carried out.
Macrophyte objectives		
Increased percentage cover of macrophytes within one year of	The data available suggest that the percentage cover increased, but in the absence of detailed field results, it is not	Monitoring of macrophytes would have been more effective if based on a transect approach, allowing quantitative estimates of percentage

Objective	Was objective achieved?	Was monitoring successful?
implementation	possible to make further conclusions.	cover of individual species.
Increase in macrophyte species diversity in relation to faster flows and decreased siltation within one year of implementation	The data available are not detailed enough to address this objective.	See explanation above.
Macroinvertebrate objectives		
Increase in macroinvertebrate species diversity within three years of implementation	Species diversity increased after 2005 but remained lower than pre-restoration.	Repeat sampling at specific locations within the loop would have provided more suitable data to address this objective.
Increase in species preferring faster flows (LIFE), reduced fine sediment (PSI) and increased conservation value (CCI)	Although pre- and post-restoration results are not directly comparable, LIFE, PSI and CCI scores increased following restoration.	See explanation above.
Fish objectives		
Increased diversity and abundance of native fish species (for example, roach, perch, eel, gudgeon, minnow, bleak) within three years of implementation	Although pre- and post-restoration results are not directly comparable, they do suggest that habitat in Shopham Loop has become more favourable for bullhead, brown trout, sea trout, chub and eel as a result of the restoration works.	The survey methodology was successful but temporal replication (that is, repeated surveys over a defined window of time such as five surveys undertaken over an eight-week window) would help to even out any natural variation that might skew a single sample.
Changed age structure of fish communities (increased presence of juvenile fish) within three years of implementation	Insufficient data to address this objective.	Monitoring did not include age measurements and therefore did not provide suitable results for addressing this objective, however the scrape areas provide valuable fry habitat.

6 Effectiveness of restoration measures

This section assesses the effectiveness of the measures in achieving the WFD relevant objectives.

6.1 Statement of effectiveness

6.1.1 Effectiveness of hydromorphological measures

The results of the analysis suggest that the restoration measures were successful to some extent in meeting the following hydromorphological objectives:

- increased sinuosity
- increased variation in width and depth
- increased variability in velocity and diversity of flow types

Changes to sinuosity have occurred on a large scale with the reconnection of the meander. However, there are likely to have been small-scale changes in channel sinuosity resulting from erosional processes that the monitoring did not pick up. Variations in width, depth, velocity and diversity of flow types occurred on a small scale in localised areas.

A lack of detailed data (velocity, substrate, riparian vegetation and sedimentation rates) means conclusions in relation to the other objectives cannot be drawn. More detailed monitoring that includes bedforms, sediment data, riparian vegetation and repeat photographs and over a longer timeframe would have allowed a more robust analysis and assessment against all the objectives.

6.1.2 Response of biology to hydromorphological changes

The variation in the number of samples and season they were collected over the years and between sites means that direct comparisons between the biotic indices should be treated with caution and it is not possible to draw conclusions with high confidence. Further details on the limitations of the data are provided in Sections 5 and 7. However, the following sections assess the biological response where it has been possible to draw some conclusions.

Macrophytes

The results suggest that macrophyte coverage increased in the years following restoration, although this is based on estimated coverage over 100 m lengths and therefore the relatively small increase may not be attributable to the restoration measures. However, anecdotal evidence suggests that as a result of hydromorphological change, aquatic macrophytes have established in sections of the loop that previously had little or no flow.

Macroinvertebrates

Species diversity appears to have decreased following the scheme implementation, probably due to the disturbance to existing habitats. In the following years, species diversity increased and this is likely to be attributable to the development of a wider variety of habitats as the river re-naturalised and adjusted to its new course. In-channel and bankside vegetation and substrate conditions are likely to have affected macroinvertebrate communities.

LIFE, PSI and CCI scores increased in Shopham Loop, reflecting higher flow velocities and reduced fine sediment and indicating a macroinvertebrate population of greater conservation value.

Fish

Populations of sea trout increased markedly after 1997. This is likely to be partly in response to increased gravel substrate, which provides spawning habitat. The loop appears to provide favourable habitat for bullhead, dace, chub, eel and brown trout, due to a combination of varied velocities and the presence of in-channel vegetation which is particularly valuable due to an absence of this habitat in the catchment as a whole. The scrape areas provide valuable habitat for juvenile coarse fish.

6.1.3 Overall effectiveness of the measures

The restoration measures were effective in improving hydromorphological conditions in Shopham Loop, mainly because it now conveys flow throughout the year rather than only in flood events. The monitoring data are not sufficient to draw firm conclusions on many of the objectives, but they do indicate that the restoration may have improved habitat for macroinvertebrates and for fish.

6.2 Limitations

The restoration and monitoring at Shopham Loop were not carried out with the Water Framework Directive in mind and therefore in some cases the data collected are not sufficient to fully address the objective. This is particularly true for the biological data, where insufficient samples were taken and the timescales were too short to draw firm conclusions.

The absence of velocity measurements and substrate recording in the loop prevents the drawing of firm conclusions on some hydromorphological objectives, particularly those relating to velocity of flow and substrate.

The monitoring cannot reach firm conclusions on the success or failure of the restoration as the results suggest that changes were only becoming visible in 2009 and the full impact of the restoration may not be evident for several years.

6.3 Recommendations

- It is important that post-project monitoring has clear objectives and is linked to the objectives of the restoration scheme. The objectives should be set following a review of the catchment context, historical events (e.g. floods, pollutions and riparian management) and current pressures.

- Future schemes should include pre- and post-restoration monitoring that includes both hydromorphological change and ecological response so helping to assess the effectiveness of the restoration against WFD relevant objectives.
- It is also important that the objectives are specific as this reduces the likelihood of achieving an objective while causing a harmful environmental response. For example, an increase in percentage cover of undesirable species would rate as a success for an objective of increased macrophyte cover, whereas if the objective was specific to *Ranunculus* it would not.
- The timescales of objectives should vary between short, medium and long term and, where possible, be linked to specific species. In addition adaptive monitoring should be developed to demonstrate the success of the scheme. If appropriate, monitoring should be undertaken over a longer timeframe (5–10 years) to ensure that longer term changes are captured. Detailed baseline information should also be collected pre-restoration to enable the scale of changes to be fully assessed.
- To undertake meaningful statistical analysis it is recommended that replicated sampling is undertaken and a before–after–control–impact approach is adopted.
- It is recommended that monitoring at Shopham Loop continues so that the trends that were beginning to develop can be monitored into the future. In addition velocity measurements and substrate observations are required to assess the impact of the restoration. Further analysis of mesohabitat data would be useful in examining the relationships between macroinvertebrate community and habitat change.

References

CHADD, R. and EXTENCE, C., 2004. The conservation of freshwater macroinvertebrate populations: a community-based classification scheme. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 14, 597-624.

DEMARS, B.O.L., KEMP, J.L., FRIBERG, N., USSEGLIO-POLATERA, P. and HARPER, D.M., 2013. Linking biotopes to invertebrates in rivers: biological traits, taxonomic composition and diversity. *Ecological Indicators*, 23, 301-311.

ENVIRONMENT AGENCY, 2009. *River Basin Management Plan. South East River Basin District. Bristol: Environment Agency*. Available from: http://www.environment-agency.gov.uk/research/planning/124978.aspx [Accessed 3 January 2014].

ENVIRONMENT AGENCY, 2014a. *Appraisal of River Restoration Effectiveness: Seven Hatches monitoring report.* Evidence Report. Bristol: Environment Agency.

ENVIRONMENT AGENCY, 2014b. *Appraisal of River Restoration Effectiveness: Severn Hatches case study report.* Evidence Report. Bristol: Environment Agency.

ENVIRONMENT AGENCY, 2014c. *Appraisal of River Restoration Effectiveness: Shopham Loop case study report.* Evidence Report. Bristol: Environment Agency.

EXTENCE, C.A., BALBI, D.M. and CHADD, R.P., 1999. River flow indexing using British benthic macroinvertebrates: a framework for setting hydroecological objectives. *Regulated Rivers: Research & Management,* 15, 545-574.

EXTENCE, C.A. CHADD, R., ENGLAND, J., DUNBAR, M., J. WOOD, P. and TAYLOR, E.D., 2013. The assessment of fine sediment accumulation in rivers using macroinvertebrate community response. *River Research Applications*, 29, 17-55.

KEMP, J.L. HARPER, D.M. and CROS G.A., 1999, Use of ‘functional habitats’ to link ecology with morphology and hydrology in river rehabilitation, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 9, 159-178.

RRC, 2009. *Practical River Appraisal Guidance for Monitoring Options (PRAGMO): Guidance Notes on Suitable Post Restoration Project Monitoring.* Cranfield, Bedfordshire: River Restoration Centre.

RRC, 2011. *Monitoring of the Shopham Loop Restoration Project – Analysis and Evaluation*. A report for the Environment Agency. Cranfield, Bedfordshire: River Restoration Centre.

VAUGHAN, I.P., DIAMOND, M. GURNELL, A.M., HALL, K.A., JENKINS, A., MILNER, N.J., NAYLOR, L.A., SEAR, D.A., WOODWARD, G. and ORMEROD, S.J., 2009. Integrating ecology with hydromorphology: a priority for river science and management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 19, 113-125.

List of abbreviations

ASPT	average score per taxon
CCI	Community Conservation Index
EQR	Ecological Quality Ratio
FSC2	Fisheries Classification Scheme 2
GEP	good ecological potential
GES	good ecological status
LIFE	Lotic Invertebrate index for Flow Evaluation
NTAXA	number of taxa
OS	Ordnance Survey
PSI	proportion of sediment-sensitive invertebrate's
RICT	River Invertebrates Classification Tool
RRC	River Restoration Centre
SD	standard deviation
SSI	sediment-sensitive invertebrates
WFD	Water Framework Directive

Would you like to find out more about us or about your environment?

Then call us on
03708 506 506 (Monday to Friday, 8am to 6pm)

email
enquiries@environment-agency.gov.uk

or visit our website
www.gov.uk/environment-agency

incident hotline 0800 807060 (24 hours)
floodline 0345 988 1188 / 0845 988 1188 (24 hours)

Find out about call charges: www.gov.uk/call-charges

Environment first: Are you viewing this on screen? Please consider the environment and only print if absolutely recessary. If you are reading a paper copy, please don't forget to reuse and recycle if possible.