Environment Agency

Evidence

Appraisal of river restoration effectiveness: Seven Hatches monitoring report

Report – SC070024/b

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Miranda Kavanagh

Director of Evidence

Executive summary

This project is part of a broader Environment Agency project entitled ‘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 Seven Hatches restoration scheme on the River Wylye in Wilshire as the primary case study, setting WFD relevant objectives against which to measure the effectiveness of river restoration and. The objectives relate to hydromorphological and biological conditions within the river.

Pre- and post-restoration monitoring was undertaken in 2006 and 2008 during the STREAM (Strategic Restoration and Management) project at the restoration site and at a control site upstream. Monitoring was extended for an additional year (2009) as part of this project. The monitoring data were used as the basis for making an assessment against WFD relevant objectives.

In terms of hydromorphology, all the objectives were met in the direct vicinity of where the measures were implemented. However, a number of factors prevent the magnitude of change from being determined accurately. The extent of hydromorphological response is likely to be constrained by the timescales over which monitoring was carried out and which did not capture any geomorphologically relevant events.

The assessment against the biological objectives indicates that overall macrophyte coverage and the extent of species that prefer faster flowing water increased at the restoration site. An even greater response was observed at the control site, though this was not seen in the wider catchment. Based on these data it is not possible to attribute the improvement with certainty to the restoration measures. The impact of the restoration works on macroinvertebrates was difficult to ascertain due to the high species diversity at both sites prior to the restoration and a lack of replicate survey data. In relation to fish, the restoration measures appear to have been initially successful in increasing the population of species that prefer faster flowing water. However, the number of these species caught in 2009 decreased. It is therefore recommended that wider catchment data are reviewed to determine if this trend is replicated elsewhere and that further monitoring is performed to assess long-term trends.

Despite not being able to draw firm conclusions on the response to restoration of some aspects of the river biology, the scheme has been effective in localised areas in providing hydromorphological conditions that are more conducive for the range of biological quality elements expected in the river. It is expected that these changes will result in improvements to macrophytes, macroinvertebrates and fish. However, the full impact will materialise over a longer timeframe than has been monitored thus far.

In order for effective monitoring of future schemes a scientific approach including control sites is needed. This should include setting the objectives within a catchment context and consideration of historical events (e.g. floods, pollutions and riparian management) and current pressures.

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

Contents

1 Introduction

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

Many millions of pounds are spent each year on river and habitat restoration with little understanding of the success or cost-effectiveness of many of the schemes.. This component of the project focuses on river restoration schemes and uses different measures to assess the effectiveness of these restoration techniques to restore good ecological status/potential for the Water Framework Directive. The Seven Hatches river restoration scheme in the Hampshire Avon catchment was the primary case study for the methodology. A secondary case study featured the Shopham Loop scheme on the River Rother in West Sussex.

The Seven Hatches scheme was assessed against site-specific environmental objectives aligned with WFD objectives and biological and hydromorphological quality elements adopted for the Water Framework Directive. Further details of the link between river restoration and the directive are provided in section 2.2.

This monitoring report and a separate case study report (Environment Agency 2014a) on the Seven Hatches river restoration scheme use existing pre- and post-restoration monitoring data, already collected at the reach and water body scale, and data from the fieldwork collected as part of this project. Separate case study and monitoring reports are available for the Shopham Loop scheme (Environment Agency 2014b, 2014c).

The case study reports outline the restoration measures implemented at each site and identify the lessons learned 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.

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 2014a) relates to the third objective.

1.2 Structure of this 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 Seven Hatches 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 or GEP is defined by the condition of the biological quality elements:

- plants
- benthic invertebrate fauna
- 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 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 considered 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 ecological status as given in Annex V of the Water Framework Directive. The WFD target is for all water bodies to reach ‘good’ ecological status (or potential in the case of heavily modified water bodies).

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 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.
Macroinvertebrate fauna	Taxonomic composition Abundance Ratio of disturbance	The taxonomic composition and abundance correspond totally or nearly totally to undisturbed conditions.

Quality element	Parameters used to measure biological quality	Definition of high status
	sensitive taxa to insensitive taxa Diversity of macroinvertebrate taxa	The ratio of disturbance-sensitive 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 and 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 Seven Hatches restoration scheme

This section introduces the Seven Hatches 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

3.1.1 The River Wylye catchment

Seven Hatches is located on the River Wylye in Wiltshire just upstream of Wilton (Figure 3.1).

The River Wylye is a tributary of the River Nadder, which meets the River Avon prior to flowing through Salisbury to the sea at Christchurch (Figure 3.1). The River Wylye rises through the Upper Greensand springs upstream of Kingston Deverill and reaches the River Nadder upstream of Wilton. The Wylye catchment is 430 km^2 and the river itself is 54 km long with two main tributaries, the Chitterne Brook and the River Till. The River Avon catchment covers an area of 2,996 km^2.

The Wylye has candidate Special Area of Conservation (cSAC) status and the length of the river is a Site of Special Scientific Interest (SSSI). The cSAC designation is based on the presence of several internationally rare or threatened species such as:

- brook and river lamprey (*Lampetra fluviatilis*)
- bullhead (*Cottus gobio*)
- Atlantic salmon (*Salmo salar*)
- Desmoulins' whorl snail (*Vertigo moulinsiana*)

In addition the river habitat characterised by a water crowfoot (*Ranunculus penicillatus* var. *pseudofluitans*) plant community.

The Avon system, including the River Wylye, has an extremely diverse fish fauna including wild populations of migratory sea trout (*Salmo trutta*) and brown trout. A wide range of coarse fish is present including:

- minnow (*Phoxinus phoxinus*)
- three-spined stickleback (*Gasterosteus aculeatus*
- dace (*Leuciscus leuciscus*)
- stone loach (*Noemacheilus barbatulus*)
- pike (*Esox lucius*)
- grayling (*Thymallus thymallus*)
- eel (*Anguilla Anguilla*)

- perch (*Perca fluviatilis*)
- roach (*Rutilus rutilus*)
- gudgeon (*Gobio gobio*)

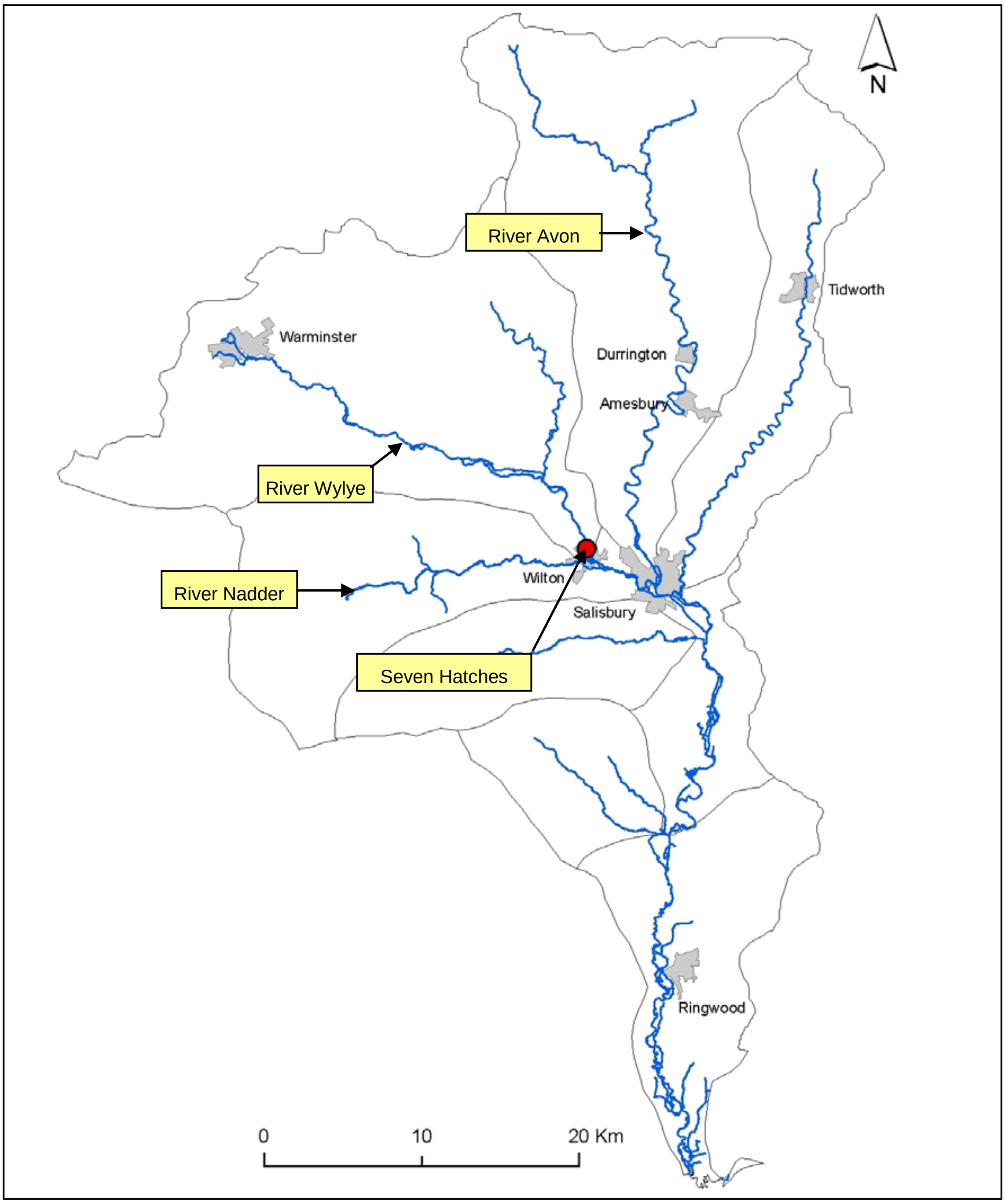


Figure 3.1 Location of Seven Hatches

3.1.2 Hydrological context

An analysis of mean annual flow in the River Wylye at South Newton from 1995 to 2009 shows that discharge ranged from a low of 2.12 m^3/s in 1997 to a high of 7.06 m^3/s in 2000 (Figure 3.2). Flows in the two years preceding the restoration implementation and in the year of implementation (2006) were low, followed by two years of above average flows. Figure 3.3 presents daily flow at South Newton between

1995 and 2009 and shows that high flow events (those that are likely to be most geomorphologically effective) occur relatively infrequently.

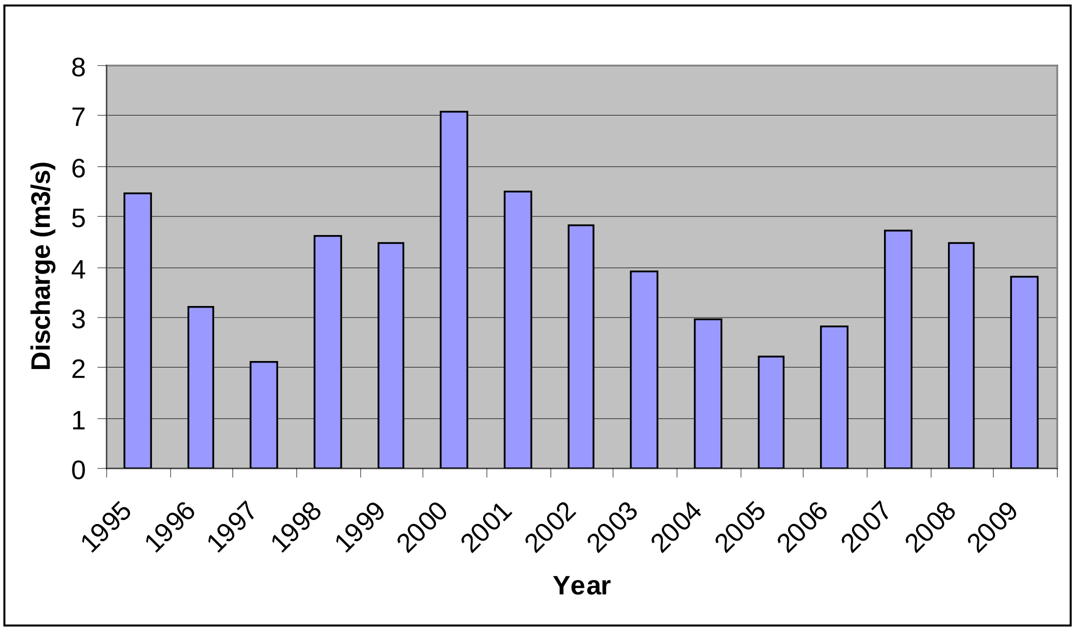


Figure 3.2 Mean annual discharge at South Newton

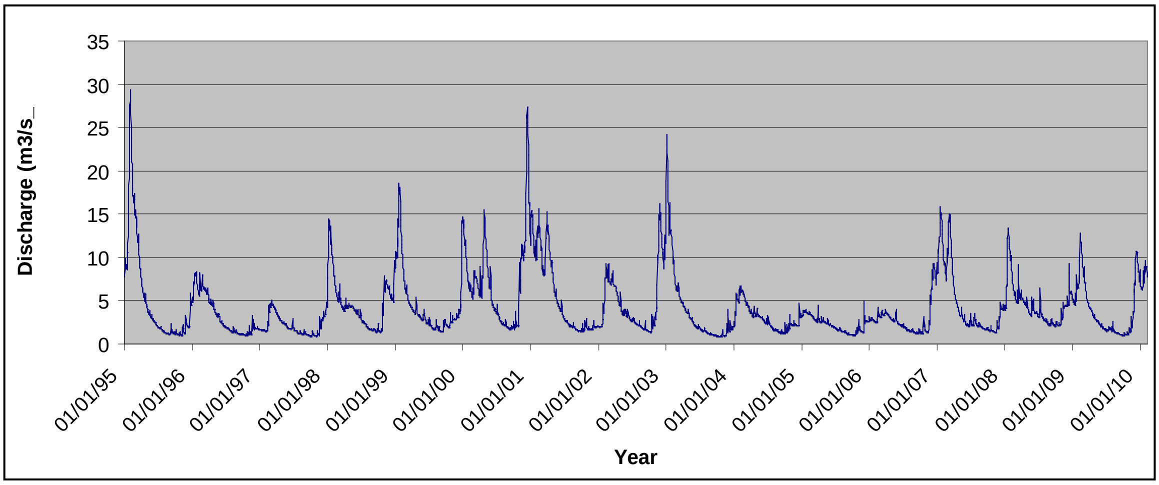


Figure 3.3 Daily flow at South Newton

3.1.3 WFD catchment context

The environmental objectives for the River Wylye are outlined in the South West River Basin Management Plan (Environment Agency 2009). Seven Hatches is located within water body GB108043022510 (Lower Wylye). The water body is currently designated as heavily modified, due to flood protection and urbanisation, and of moderate ecological potential. The current potential of the Lower Wylye for fish is 'moderate' and for macroinvertebrates 'high'. All supporting elements are classified as in 'high' status including ammonia, dissolved oxygen, pH, copper and zinc, except for phosphate which is 'good' status.

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). At the catchment scale, the diagnostic results show that observed minnow catches are less than expected across the half of the sites in the Wylye catchment (that is, four of the eight sites). The numbers of stoneloach, chub and salmon are less than expected at two of the eight sites. Lower than expected numbers of minnow are found at the two fish monitoring sites closest to the Seven Hatches restoration scheme (South Newton and Chilhampton Farm). However, these results are potentially skewed since the focus of the monitoring surveys in the Environment Agency's Southern Region is typically on salmonids so smaller fish (that is, minnow, stoneloach, spine loach, three-spined stickleback and bullhead) can be easily missed. The lack of minnow observed in the Wylye monitoring data is not considered by the Area team to be representative of actual numbers.

Diffuse source pollution and sediments have been identified through the WFD risk assessments as other pressures in the catchment which may be affecting the biology and hydromorphology of the River Wylye.

A number of mitigation measures are in place within the water body including:

- appropriate channel maintenance strategies and techniques
- retention of marginal aquatic and riparian habitats

Full details of the condition of the water body and mitigation measures are provided in Table 3.1.

Table 3.1 Details of water body GB108043022510

Water body ID	GB108043022510
Water body name	Lower Wylye
Ecological potential	Moderate
Status objectives	Good ecological potential by 2027
Hydromorphological designation	Heavily modified (due to flood protection, urbanisation)
Biological elements	Fish: currently moderate Macroinvertebrates: currently high
Hydromorphological supporting conditions	Quantity and dynamics of flow: currently supports good potential
Mitigation measures	**In place** • Appropriate channel maintenance strategies and techniques – woody debris • Appropriate channel maintenance strategies and techniques – minimise disturbance to channel bed and margins • Sediment management strategies (develop and revise) • Retain marginal aquatic and riparian habitats (channel alteration) • Appropriate techniques (invasive species) • Appropriate timing (vegetation control) • Appropriate vegetation control technique • Selective vegetation control regime • Increase in-channel morphological diversity **Not in place** • Educate landowners on sensitive management practices (urbanisation) • Operational and structural changes to locks, sluices, weirs, beach control and so on • Improve floodplain connectivity • Alteration of channel bed (within culvert) • Re-opening existing culverts

Source: Environment Agency (2009)

3.2 Seven Hatches restoration scheme

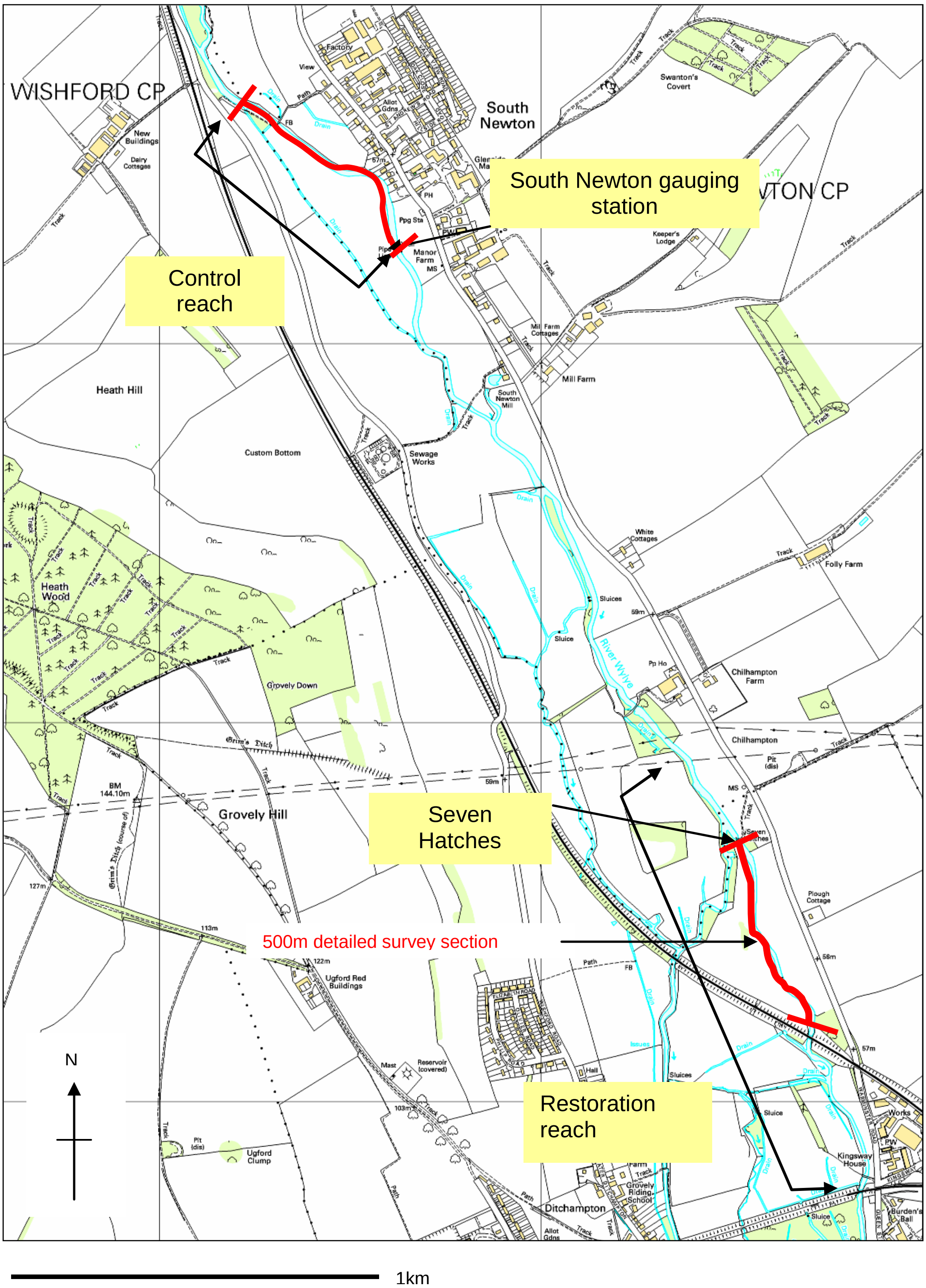
3.2.1 The STREAM Restoration Project

The STREAM (Strategic Restoration and Management) project was a £1 million four-year conservation project centred on the River Avon and the Avon Valley in Wiltshire and Hampshire with financial support from the European Commission's LIFE-Nature programme.

The River Avon and its main tributaries are designated as a Special Area of Conservation (SAC) and the Avon Valley is designated as a Special Protection Area (SPA) for birds. The STREAM project (2005-2009) involved strategic river restoration activities and linked management of the river and valley to benefit the river habitat including water crowfoot and populations of Atlantic salmon, brook and sea lamprey, bullhead, Desmoulin's whorl snail, gadwall and Bewick's swan. As part of the STREAM Restoration Project, restoration works were undertaken to improve the condition of the River Wylye at Seven Hatches.

The restoration reach is located downstream of Chilhampton Farm (Figure 3.4) and was selected due to the degraded nature of the channel. Past land drainage work had resulted in a reduction of bed level, loss of hard bed substrate, over-widening of the channel and the creation of raised flood banks, with an associated loss of hydrological connectivity with the floodplain over much of the project reach (RRC 2009). The slower flows and resulting siltation from the impoundments and historical land drainage had damaged favourable status for the water crowfoot macrophyte community and resulted in the absence of salmon spawning. The paucity of large woody debris had reduced the morphological variation present in the river, with an associated reduction in habitat quality and availability for, amongst others, bullhead, Atlantic salmon, brook lamprey and water crowfoot.

Further details on the selection of the restoration site and the implemented restoration measures are provided below and in the case study report (Environment Agency 2014a). Details on the control site upstream of Seven Hatches are given in section 3.5.



Notes: Details of the control site and its selection are given in section 3.5.

Figure 3.4 Location of restoration and control reaches

3.2.2 Restoration works undertaken at Seven Hatches

The implemented restoration works included a range of techniques aimed at enhancing the availability and quality of habitat for SAC species (bullhead, salmon, brook lamprey and water crowfoot). To achieve this, the restoration works were designed to:

- narrow over-wide channels, where necessary, to re-establish a sinuous channel of appropriate cross-sectional area with respect to present day hydrographs
- restore the historic bed level and increase the heterogeneity of bed morphology in previously dredged reaches through the reclamation and re-introduction of excavated gravel/stone bed material
- increase the amount of large woody material in the channel to increase the availability of this habitat type and the morphological diversity of the channel

Channel narrowing was carried out upstream of Seven Hatches by placing large tree trunks perpendicular to the bank with a line of posts along the front edge to create a berm. Large wood deflectors were also placed so as to protrude further out into the channel. Brushwood was then placed within the structure and the chalky soil which had been excavated out from the cattle drinks was placed on top. The brushwood and soil was then topped off with pre-planted coir mats and the whole structure was then cross-wired together (RRC 2009).

The pre-restoration channel had no riffles in the section downstream of Seven Hatches due to historic over-deepening and, as a result, flow was slow and uniform. The restoration scheme included the importing of gravel material to create three riffles between the hatches and the railway line with the aim of increasing flow velocities and flow diversity. The gravel was sourced off-site as it was not possible to source sufficient quantities on-site. Woody debris was pinned into the substrate to create varied flow characteristics. Downstream of the railway line additional log deflectors were placed in the channel with the aim of creating more diverse morphology. The erection of a fence approximately 10 m from the bank top has stopped livestock from accessing the riverbank throughout the reach with the aim of encouraging development of riparian vegetation and preventing sediment input through cattle trampling (RRC 2009).

The location of these restoration measures is shown in Figure 3.5. A more detailed explanation and justification of the scheme is provided in the case study report (Environment Agency 2014a).

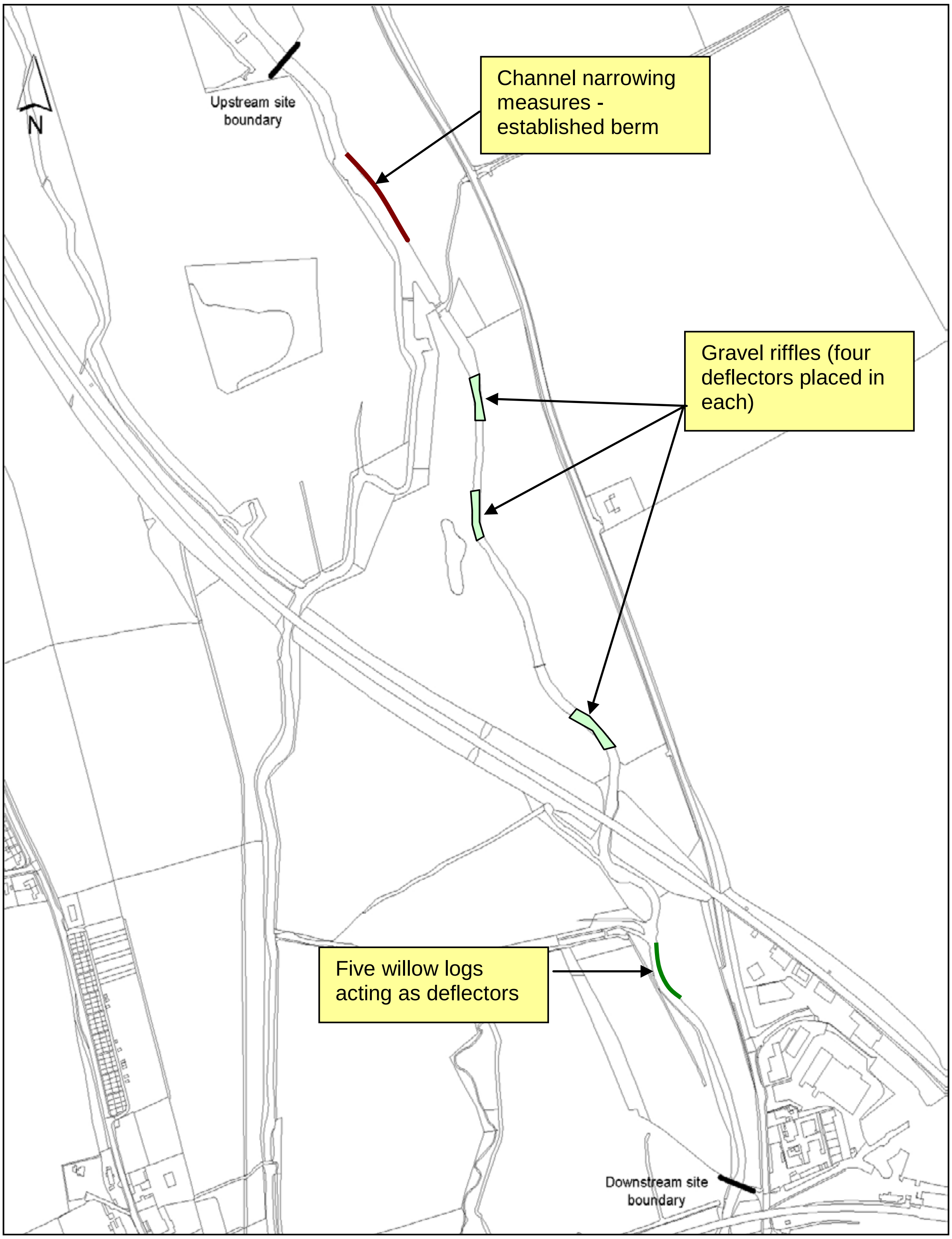


Figure 3.5 Location of restoration measures at Seven Hatches

3.3 Assessment of expected response to restoration

The Seven Hatches 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 to the Water Framework Directive and which could be used to measure the success of the restoration scheme.

One of the most accepted and well known methods for setting objectives is the SMART system (Specific, Measurable, Achievable, Realistic and Time-bound) as presented for the STREAM restoration project at Seven Hatches in a report by the River Restoration Centre (RRC 2009).

3.3.1 Hydromorphological response

The hydromorphological responses were assessed by considering the hydrological regime, river continuity and morphological conditions as well as pre-restoration issues (or pressures) within the reach in relation to the quality elements identified in the Water Framework Directive.

The River Wylye is a low energy, low gradient chalk river which has been historically modified for land drainage purposes. In addition, river continuity is limited by the presence of several water level control structures that cause impoundment, limit the transport of sediment and restrict fish passage. Low gradient rivers such as the Wylye have limited response to geomorphological intervention compared with more hydraulically energetic rivers. The low energy and disrupted river continuity mean that many of the impacts of restoration may be localised.

The issues identified, the relevant restoration measures and the description of the expected hydromorphological change are outlined in Table 3.2.

Table 3.2 Expected hydromorphological changes resulting from restoration scheme

Hydromorphological quality element	Description of the problem	Relevant restoration measures	Description of expected hydromorphological change
Hydrological regime			
Quantity and dynamics of flow	Historical channel modifications (widening and deepening) resulting in slow flows and lack of flow diversity	Installation of aquatic ledge Bed raising	Localised change in water depth Increased localised flow diversity No change in impounding effect
River continuity			
Continuity providing for migration of aquatic organisms and sediment transport	Possible issues with fish migration and sediment transport due to South Newton gauging weir and Seven Hatches	Restoration does not include structural modifications to in-channel barriers due to concerns expressed by some stakeholders about the impacts on flows.	Not applicable
Morphological conditions			
Channel patterns	Previous dredging has resulted in a uniform, straight channel with low morphological diversity	Installation of aquatic ledge (locally narrowing channel) and changes to riparian vegetation	Flow sinuosity will be promoted by the aquatic ledge and depositional features associated to increased flow variability caused by the ledge and riparian zone
Width, depth variation	Seven Hatches was previously dredged and was therefore of uniform width and depth	Installation of aquatic ledge locally narrowing channel and raising of channel bed	Increased variation in localised depth and width due to bed raising and channel narrowing and increased diversity of riparian zone
Flow velocities	Historical channel modifications (widening and deepening) resulting in slow flows and lack of	Installation of aquatic ledge	Increased morphological diversity in local restored areas Increased localised

Hydromorphological quality element	Description of the problem	Relevant restoration measures	Description of expected hydromorphological change
	flow diversity		flow velocities due to creation of riffles
Substrate conditions	Seven Hatches was previously dredged resulting in slow flows and siltation on the channel bed. Livestock trampling the banks has increased sediment supply to the channel	Gravel import. Installation of aquatic ledge	Decreased localised siltation due to higher flow velocities More localised areas of gravel substrate
Structure and condition of riparian zone	Livestock trampling the riverbank damaging structure and condition of riparian habitat and refuge (in addition to increasing erosion causing increased sediment supply – see substrate condition)	Fencing and creation of drinking areas to stop cattle trampling the river banks	Increased height of vegetation Increased coverage of vegetation

3.3.2 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 Wylye 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 3.3.

Table 3.3 Physical characteristics on which ecological factors are dependent

Species	Physical characteristics supporting good habitat
Flora characteristic of chalk stream rivers including water crowfoot (*Ranunculus penicillatus* spp. *pseudofluitans*)	• Clean gravel substrate • Swift to moderate, clear flows (riffles and runs) • Adequate in-channel light
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
River lamprey	• Channel dominated by clean, stable gravel for spawning • Appropriate shelter for spawning • Stable silt or sand dominated substrate for nursery habitats • Areas of shallow low velocity flow for nursery habitats • Organic detritus for nursery habitats • Tree roots/large woody debris for migration
Bullhead	• Swift to moderate, clear flows • Channel dominated by clean, stable gravel • Riffle habitat features • Macrophyte cover <40% • Shading • No barriers >18 cm • Tree roots/large woody debris
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 3.4.

3.3.3 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.

3.4 Water Framework Directive relevant objectives

The hydromorphological and biological WFD objectives developed for the Seven Hatches site are presented in Table 3.4. 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 3.4 WFD relevant objectives

Objective	Rationale
Hydromorphological	
• Increased variation in depth and width within three years of 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 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 provide good habitat for fish fry and macroinvertebrates.
• Increased localised and average velocities immediately after restoration	• 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 and providing clean gravel substrate.
• Increased area and frequency of exposed gravel substrate within three years of implementation	• A variety of flora and fauna rely on coarse substrates such as gravel, for example, salmonids must have access to clean gravels for spawning to prevent smothering of eggs, while bullhead need clean stones amongst which to find shelter and deposit eggs. River water crowfoot (*Ranunculus*) and water starwort (*Callitriche*) also need gravelly/stony substrate to take root. The habitat preference of certain macroinvertebrate species is flowing water over gravelly substrate. It is therefore important that existing gravels are not smothered by sedimentation and that, where possible, additional gravel habitat is created.
• Increased height and coverage of riparian vegetation within a year of	• The main hydromorphological benefit conferred by riparian vegetation is the reduction of bank erosion due to the stabilising

Objective	Rationale
implementation	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.
• Increased morphological diversity (based on width, depth and sinuosity and in-channel features) within three years of implementation	• Morphological diversity impacts on the biology of a watercourse and is influenced by the width and depth of the channel, channel sinuosity and in-channel features.
Biological	
Macrophytes	
• Increased percentage cover of macrophytes within one year of implementation	• The River Wylye is noted for its macrophytes, particularly water crowfoot communities, which form part of the SSSI designation and include species such as Ranunculus penicillatus var. pseudofluitans and Ranunculion fluitantis. Increases in the coverage of these communities therefore help to contribute to an improvement in the condition of the river. These communities also provide valuable habitats for fish and aquatic macroinvertebrates. It is therefore important that in-channel macrophyte coverage increases for the benefit of river habitats.
• Increase in number of macrophyte species preferring faster flows within one year of implementation	• The macrophyte species that are important in the River Wylye, such as the water crowfoot *Ranunculus penicillatus* var. *pseudofluitans* and starwort *Calitricho-Batrichion* communities, require swift flows in order to thrive. An increase in the number of macrophyte species which prefer faster flows therefore reflects an improvement in the hydromorphology and, by extension, the ecological quality of the river.
• Decrease in number of macrophyte species preferring slower flows within one year of implementation	• The River Wylye is designated as a SSSI in part for the macrophyte communities that it supports. These communities prefer swift flows, so a decrease in species which prefer slower flows is representative of an alteration of conditions towards those required by the designated species.
• Macroinvertebrates	
• Increase in macroinvertebrate species diversity and evenness within three years of	• Macroinvertebrate species form an important link in the aquatic food chain and are representative of water quality and morphological conditions. An increase in

Objective	Rationale
implementation	species diversity and evenness will indicate general improvement in the ecological and morphological conditions in the river.
• Increase in species preferring faster flows (LIFE) and increased conservation value (CCI).	• LIFE scores are used to asses flows whereby each taxon is assigned to a flow group depending on its preference of 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. • CCI scores are used to assess the conservation value of a site. The higher the score, the higher the conservation value. A site with a greater habitat diversity can be expected to support a greater richness of taxa and have a greater conservation value. • An increase in CCI and LIFE indices will be indicative of an increase in habitat diversity and of increased flow velocities.
• Increase in the proportion of sediment-sensitive invertebrates (PSI scores) within three years of implementation	• PSI is a sediment-sensitive macroinvertebrate metric which describes the extent to which the surface of river beds are composed of, or covered by, fine sediments. An increase of sediment sensitive taxa (hence PSI scores) will be an indication of more widespread gravel substrate, and less siltation. This is one of the aims of the restoration scheme.
• Increased taxonomic composition within three years of implementation	• This refers to the overall number of taxa present within the reach. An increase in this number would be indicative of good water quality and high vegetation coverage within the channel.
Fish	
• Increased abundance of fish species preferring clean fast-flowing water within three years of implementation	• The River Wylye is noted for its salmon and trout communities, both of which form part of the SSSI designation. These species prefer fast-flowing water, gravel substrate and areas of shallow flow for nursery habitat. An increase in these fish species would be indicative of improved hydromorphology and by extension, improved ecological quality of the river.
• Increased abundance of Atlantic salmon, bullhead and lamprey within three years of implementation	• The River Wylye is noted for its salmon, bullhead and lamprey communities, all of which form part of the SSSI designation. It is therefore important that these species become more abundant in the river.
• Changed age structure of fish communities (increased	• Long-term improvement in conditions for fish species such as bullhead, salmonids and

Objective	Rationale
presence of juvenile fish) within three years of implementation	lamprey (for example, through providing additional spawning habitat) could be expected to increase the presence of juvenile fish.

3.5 Monitoring at Seven Hatches

Monitoring of the hydromorphological and ecological conditions of the Seven Hatches site was undertaken as part of the STREAM project. Pre and post project monitoring was carried out at a control reach and the restoration reach both before the restoration works and after completion of the scheme.

3.5.1 Control site location and selection

The purpose of using a control site was to compare the relationship between physical and biological conditions as recorded at both sites on a given day rather than to compare the magnitude of change of either physical or biological parameters between sites.

The control reach was located approximately 2 km upstream of the restoration works (Figure 3.4). The selection of an appropriate control site was constrained by the fact that the Wilton Fly Fishing Club intended to implement further enhancement measures directly upstream of Seven Hatches in 2006.

The control reach was upstream of the enhancements that were proposed and includes an impounded section and a re-profiled river channel. Localised habitat restoration had been carried out above the South Newton gauging station (beyond its impounding influence) over the previous five years, with a low level vegetated walkway being constructed.

The control site was selected based on the similarity of reach characteristics to the reach selected for restoration, site access and other external factors that may potentially result in differences between the sites.

Parameters identified by Trainor and Church (2003) were among those used to visually compare the similarity of the control and restoration reaches during the initial site visit. Reach parameters considered included:

- depth variability
- width variability
- physical biotopes present
- bed substrate
- bank profile
- land use
- channel and bank modifications

3.5.2 Data collection

As part of the STREAM project, pre (2006) and post (2008) restoration monitoring was carried out at the restoration and control sites to:

- document the restoration works
- identify their possible influence on the physical habitat and ecology at the site

Biological and hydromorphological monitoring was linked both temporally and spatially to allow an assessment against the objectives.

The surveys performed as part of the STREAM project were repeated in 2009-2010 to allow for a more robust analysis and assessment as part of this project. Some additional surveys were also carried out to enable the success of the scheme to be assessed against the WFD relevant objectives more effectively. Additional monitoring data was provided by Wessex Water.

The following sections outline the data collected at Seven Hatches for the STREAM project and during additional monitoring undertaken as part of this project.

Table 3.5 lists the type of data been collected and analysed as part of this project and the STREAM project to enable this assessment to be made. It includes a description of the data and the year(s) in which they were collected.

Table 3.5 Summary of monitoring and analysis methods undertaken at Seven Hatches

Data type	Description	Year(s) monitored
Hydromorphological monitoring		
Physical biotope mapping	Geomorphological reach-scale data were collected through physical biotope monitoring. The physical biotopes used relate to the flow types defined within the established River Habitat Survey methodology and definitions of biotopes used in fluvial audits. 1:2500 mapping was used to record physical biotopes. See Figures 3.6 and 3.7 for location of physical biotope mapping.	2006 2008 2009
Cross-sectional survey	A detailed levelling survey was undertaken at eight cross-sections within the reach. The cross-sections were tied to Ordnance Survey datum and extended at least 5 m into the riparian zone. Readings were taken to reflect bankfull, water surface elevation, breaks in slope and habitat features. The survey was set out with appropriate survey control stations to ensure that the same cross-sections could be resurveyed (see cross-sections in Figures 3.6 and 3.7).	2006 2008 2009
Velocity measurements	One set of velocity measurements were undertaken once in 2006 and 2008 at each cross-section using an electromagnetic flow meter. Measurements were taken concurrently with the cross-sectional survey in August/September. Measurements were taken at 1 m intervals across	2006 2008

<table>
<tr><th>Data type</th><th>Description</th><th>Year(s) monitored</th></tr>
<tr><td></td><td>the channel at 60% of the water depth at each point to ensure consistency and obtain an accurate reading which was as unaffected by friction from the bed and banks as possible. No velocity measurements were taken in 2009.</td><td></td></tr>
<tr><td>Substrate observations</td><td>Substrate observations were taken at five locations – channel centre, both channel margins and two intervening points – along each cross-section in 2006 and 2008. Substrate was classified according to the definitions in the table below.
Substrate classification
<table>
<tr><td>Substrate</td><td>Particle size (mm)</td></tr>
<tr><td>Clay*</td><td><0.002</td></tr>
<tr><td>Silt</td><td>0.002–0.063</td></tr>
<tr><td>Sand</td><td>0.063–2</td></tr>
<tr><td>Gravel</td><td>2–16</td></tr>
<tr><td>Pebble</td><td>16–64</td></tr>
<tr><td>Cobble</td><td>64–256</td></tr>
</table>
* Clays were included with silts for the purposes of evaluation in the field. Therefore silt is used to refer to all sediments <0.063 mm in diameter.</td><td>2006
2008</td></tr>
<tr><td>Physical habitat survey</td><td>Measurements of depth, depth-averaged velocity and substrate (DVS) were taken at the established cross-sections throughout the survey reach. Velocity measurements were taken at equally spaced intervals across the channel and substrate was recorded at channel centre, both channel margins and intervening points.</td><td>2006
2008</td></tr>
<tr><td>Repeat fixed point photography</td><td>All features of relevance were recorded using fixed point photography within the same reach as the physical biotope mapping.</td><td>2006
2008
2009</td></tr>
<tr><td>Scheme performance baseline ‘as built’ survey</td><td>Using the same method as used for the cross-sectional survey, a mapping exercise was undertaken to map the location, nature, length and breadth of implemented physical changes (riffles and log deflectors).</td><td>2009</td></tr>
<tr><td>Long profile</td><td>Using the same method as for the cross-sectional survey, a detailed long profile was recorded, taking measurements in the centre of the channel at 1 m intervals from Seven Hatches to the downstream railway bridge</td><td>2009</td></tr>
<tr><td colspan="3">Biological monitoring</td></tr>
<tr><td>River corridor survey</td><td>A river corridor survey is a widely used and well-established ecological survey method. The survey was carried out along the entire length of the</td><td>2006
2008</td></tr>
</table>

Data type	Description	Year(s) monitored
	restoration and control reaches using the standard survey key (NRA 1992) and 1:2500 mapping as for the physical biotope mapping.	2009
Macrophyte survey	The macrophyte survey was undertaken alongside the river corridor survey, based on the methods identified in *Monitoring Ranunculion fluitantis and Calitricho-Batrachion Vegetation Communities* (Life in UK Rivers 2003). The survey employed the rapid assessment outlined in the SAC Monitoring Protocol (Life in UK Rivers 2003) and excluded a species quadrat survey. Percentage cover of macrophyte species was recorded at five transects across the river. See Figures 3.6 and 3.7 for location of transects.	2006 2008 2009
Fisheries survey	The electro-fishing techniques used are based on the methods explained in Conserving Natura 2000 Rivers Monitoring Series No. 4 (Cowz and Harvey 2003a), 5 (Cowz and Harvey 2003b) and 7 (Cowx and Fraser 2003). Electro-fishing was carried out in two sections in the restoration reach and two in the control reach. Each section was subject to three 'runs' to take account of those fish that escaped capture. See Figures 3.6 and 3.7 for location of electro-fishing reaches.	2006 2008 2009
LEAFPACS	A 100 m section was surveyed in the restoration and control reaches using the methodology set out in River LEAFPACS (UKTAG 2013, Annex 1). Surveying establishes the presence, and percentage of the river channel covered by a defined list of macrophyte species. The method enables an assessment of the condition of part of the quality element, 'macrophytes and phytobenthos'. The method assesses the condition of the quality element by combining information on the following parameters: • River Macrophyte Nutrient Index (RMNI) • River Macrophyte Hydraulic Index (RMHI) • number of macrophyte taxa which are not helophytes (NTAXA) • number of functional groups of macrophyte taxa which are not helophytes (NFG) • percentage cover of green filamentous algae (ALG)	2009
Macroinvertebrate sampling	Macroinvertebrate sampling was undertaken at one site within the Seven Hatches restoration reach and one site within the control reach using three-minute kick sampling and a one-minute	2007 2008

Data type	Description	Year(s) monitored
	hand search as detailed in Environment Agency (1999). A single sample was taken on each of the following dates: • 28 August 2007 (pre-construction) • 22 August 2008 (post-construction) • 25 August 2009 (post-construction) • 16 August 2010 (post-construction) • 10 August 2011 (post-construction) • 7 August 2012 (post-construction) • 5 September 2013 (post-construction) Samples collected prior 2007 were identified to mixed taxon level and data from 2010-2013 to family. Data were collected by Wessex Water. See Figures 3.6 and 3.7 for locations of data collection.	2009 2010 2011 2012 2013

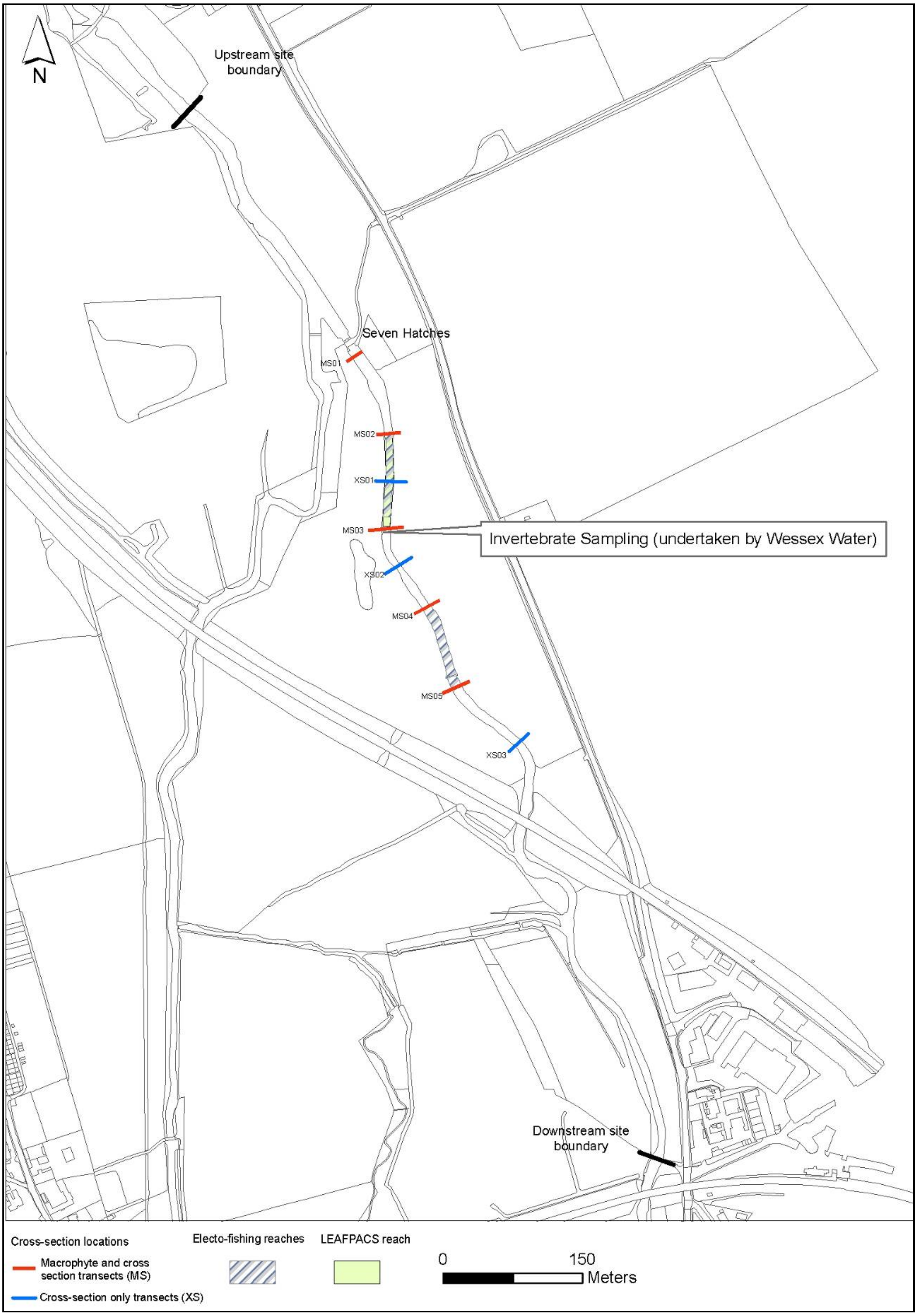


Figure 3.6 Hydromorphological and biological data collection at Seven Hatches restoration site

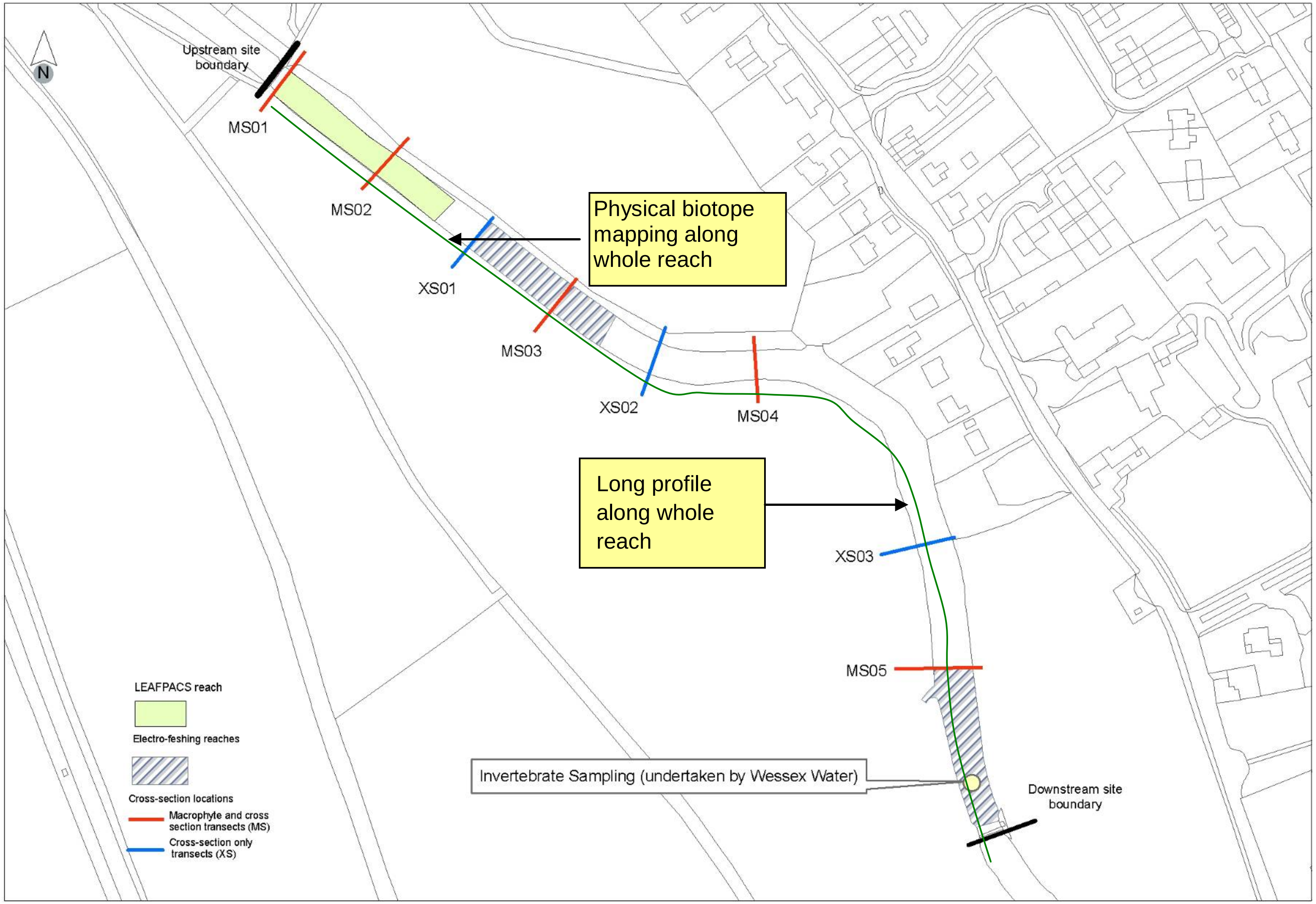


Figure 3.7 Hydromorphological and biological data collection at Seven Hatches control site

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

Table 4.1 lists the data used to assess the effectiveness of the restoration against the hydromorphological objectives.

Table 4.1 Data used to address hydromorphological objectives

Objective	Data
Increased variation in depth and width due to bed raising and channel narrowing	Cross-sectional survey and long profile
	Repeat photography
Increased localised and average velocity	Velocity measurements undertaken in 2006 and 2008
	Physical biotope mapping
	Repeat photography
Increased area and frequency of exposed gravel substrate	Substrate measurements
	Physical biotope mapping
Increased height and coverage of riparian vegetation	Repeat photography
	Macrophyte survey
Increased morphological diversity – based on width, depth, sinuosity and in-channel features	Cross-sectional survey and long profile
	Physical biotope mapping
	Repeat photography

4.1.1 Cross-sectional survey and long profile

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

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

The deepest point of the channel (equivalent to the focus of flow, or thalweg) was identified from each of the cross-sections and used 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 Velocity measurements

The difference in pre- and post-restoration velocities at each cross-section were calculated and compared to identify any changes. The overall mean velocity throughout the whole reach and the pre- and post-restoration differences were also analysed.

4.1.3 Physical biotope mapping

Physical biotope mapping undertaken in 2006, 2008 and 2009 was compared visually to identify any changes in the flow type, flow velocity and in-channel features.

4.1.4 Substrate observations

Assessments of substrate size were made in 2006 and 2008. These were visually compared to allow a qualitative assessment of changes to substrate condition to be made. Reference was made to a grain size chart with the Friedman and Sanders (1978) grain size classification in the field to ensure that the visual assessment of substrate size was as accurate as possible.

4.1.5 Macrophyte survey

The total coverage of riparian vegetation was estimated from the macrophyte survey results by summing the species coverage at each transect. Aquatic and emergent vegetation was excluded so that the figures included only terrestrial species growing away from the water and within 5 m of the bank top. An average coverage was then calculated for the restoration and control reaches in each year.

4.1.6 Repeat photography

Repeat photographs were used to address all the hydromorphological objectives. This included a visual comparison to allow a qualitative assessment of any changes.

4.2 Macrophytes

4.2.1 Increase in percentage cover of macrophytes

Riparian species were identified using river corridor macrophyte survey data as those with an Ellenberg indicator value for soil moisture ≥ 8. Total percentage cover of riparian macrophyte species (excluding negative indicator or invasive species) was derived by summing individual species cover at each transect. A graph of these data was plotted to illustrate the observed trends at both the restoration and control sites.

For the purposes of this assessment, the five transects represent repetitions within the study site so as to derive a representative mean value for percentage cover for each year to compare change over time.

4.2.2 Increase in macrophyte species preferring faster flows

One measure of macrophyte change to flow conditions may be determined by variation in the RMHI; however, these indices were not available at the time of writing.

Another method of assessment can be by phytosociological evidence (for example, see the classification and discussion in Rodwell et al. 1995) which indicates that a wide range of species may be involved, and that the *Ranunculion fluitantis* and particularly the *Calitricho-Batrachion* communities are 'most characteristic of fast to very swift, often spatey waters in small sandy or gravelly streams' (Rodwell et al. 1995). Consequentially, a change in the distribution and abundance of the key species making up the *Ranunculion fluitantis* community was taken in this project as an indicator of the flow regime change towards or away from favourable condition.

4.2.3 Increase in number of macrophyte species preferring slower flows

River corridor macrophyte survey data were used to identify riparian species that are more prevalent in slower flowing conditions. This includes:

- fennel leaved pondweed (*Potamogeton pectinatus*)
- common duckweed (*Lemna minor*)
- ivy leaved duckweed (*Lemna trisulca*)

The percentage coverage of these species in the three survey years was compared.

4.3 Macroinvertebrates

4.3.1 Increase in macroinvertebrate species diversity and evenness

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 number of individuals 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).

Species evenness

Species evenness (*E*) is a measure of biodiversity which quantifies how equal the community is numerically. It is calculated using the formula:

$$E = \frac{H}{\ln S}$$

where:

H = Shannon–Wiener diversity index

S = total number of species

E is constrained between 0 and 1. The less variation in a community between the species (that is, the more 'even' the community), the higher is the value of *E*.

Diversity scores for the restoration and control site will be limited to a single result for each year (based on a single sample being taken every year); any trend will be based on three points, that is, three results over three years. Without replication it is not possible to determine if any result is truly representative as a 'mean value' for any given year with the data available.

4.3.2 Increase in LIFE and CCI

LIFE and CCI scores were determined from data collected between 2007 and 2009 for the restoration and control reaches.

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 are subsequently used to generate the LIFE index. Higher scores reflect faster flow velocities. For more information see Extence et al. (1999).

LIFE index scores for the restoration and control reaches were provided by the Environment Agency.

CCI for aquatic macroinvertebrates

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 a small number of rare species and also sites that are highly diverse. The higher the CCI score, the higher is the conservation value. For more information see Chadd and Extence (2004).

CCI scores for the control and restoration reaches were provided by the Environment Agency. As the sampling protocol was limited to a single sample per year for both sites, any assessment is limited to simple descriptive analysis of the observed three-year trend. Without spatial replicates it is not possible to determine how representative each sample is and therefore the result from each year is based on a single sample rather than a mean value from multiple samples. The assessment is therefore simply descriptive.

Increase in PSI

The sediment-sensitive macroinvertebrate metric, PSI, can act as a proxy to describe temporal and spatial impacts. The index can be retrospectively calculated to track sedimentation trends over 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 method for sedimentation screening.

The PSI score describes the percentage of sediment-sensitive taxa present in a sample. Scores can range from 0 (entirely silted river bed) to 100 (entirely silt-free river bed). For more information see Extence et al. (2013).

Increased taxonomic composition

Increased taxonomic composition refers to an overall increase in the number of taxa recorded (NTAXA).

Values for the total number of taxa recorded on-site were provided for 2007, 2008 and 2009 for both the restoration and control sites. As the sampling protocol was limited to a single sample per year for both sites, any assessment is limited to simple descriptive analysis of the observed three-year trend. Without spatial replicates it is not possible to determine how representative each sample is. Each year's result is based on a single sample rather than a mean value from multiple samples. As such, the assessment is simply descriptive.

4.4 Fish

4.4.1 Increased abundance of fish species preferring clean fast-flowing water

Fish species considered to prefer fast-flowing water were:

- salmon
- trout
- grayling

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

4.4.2 Increased abundance of Atlantic salmon, bullhead and lamprey

Mean density of each species per square metre was determined for data collected between 2006 and 2009 for all four sites. Lamprey ammocoetes were sampled using 1 m^2 quadrats located within pre-identified suitable habitat consisting of fine silts; optimal habitat is defined as stable fine sediment or sand ≥15 cm deep, low water velocity and the presence of organic detritus. No assessment of the availability of suitable lamprey ammocoetete habitat within the reach was made. Assessment is limited to simple descriptive analysis of the observed three-year trends for each species.

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

For each species it should be possible to determine changes between the datasets recorded for each site over the three years. As there are multiple measurements taken for each year, it is possible to have more confidence in the mean (or median) value for fork length for each species at each site.

5 Results

This section presents the WFD relevant objectives 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 3.4.

The objectives were also applied to the control site as this may help to determine if hydromorphological changes observed in the restoration reach are attributable only to the restoration measures, or if natural variations are having a significant impact on the hydromorphology of the system. In theory, the WFD relevant objectives should not be achieved at the control site as no human intervention has occurred there since the pre-restoration survey in 2006 and therefore no significant changes to the system would be expected.

5.1.1 Increased variation in depth and width due to bed raising and channel narrowing

The cross-sections used to address this objective are shown in Appendix A. Table 5.1 shows the width to depth ratios at the restoration and control sites while Tables 5.2 and 5.3 show the mean and standard deviation of bankfull depth and width at the two sites respectively.

Table 5.1 Width to depth ratio at restoration and control sites

Site	Year	Cross-section*								Mean
		MS01	MS02	XS01	MS03	XS02	MS04	XS03	MS05	
Restoration	2006	9.1	8.4	7.5	7.4	8.3	8.4	9.1	10.1	8.5
	2008	9.2	16.1	9.4	12.0	8.3	9.2	9.0	12.0	10.6
	2009	9.2	17.0	9.7	11.4	7.5	9.1	9.6	9.6	10.3
Control	2006	19.7	21.8	16.4	15.5	15.9	15.1	8.8	13.0	15.8
	2008	20.1	21.6	16.0	13.7	18.1	16.9	8.7	12.7	16.0
	2009	21.6	19.5	17.5	13.9	17.4	15.2	10.8	12.8	16.1

Notes: For location of the cross-sections at the restoration and control sites see Figures 3.6 and 3.7 respectively.

Table 5.2 Mean and standard deviation (SD) of bankfull depth

Site	Statistic	2006	2008	2009	Difference
Restoration	Mean	1.8	1.6	1.7	-5.0%
	SD	0.2	0.4	0.3	n/a
Control	Mean	1.2	1.2	1.1	-5.5%
	SD	0.3	0.4	0.3	n/a

Table 5.3 Mean and standard deviation (SD) of bankfull width

Site	Statistic	2006	2008	2009	Difference
Restoration	Mean	15.0	16.9	16.7	+11.9%
	SD	1.8	2.4	2.5	n/a
Control	Mean	18.0	17.8	17.6	-2.6%
	SD	2.9	3.5	3.7	n/a

The higher width and depth ratios at the control site show that this reach is generally wider and shallower than the restoration reach both before and after restoration. However, there are only minor changes to the ratio between 2006 and 2009, reflecting the predominantly minor changes that have occurred in the width and depth at this site. The ratios at the restoration site show large increases (8.4 to 17.0, 7.4 to 11.4 and 9.1 to 9.6) as a result of the introduction of gravel riffles while the sections in between the riffles show only minor changes. These changes combine to increase the mean width to depth ratio from 8.5 to 10.3 between 2006 and 2009. The variability in width and depth is analysed further below using the mean and standard deviation of the bankfull width and depth.

Results at the control site show that, although mean bankfull depth remained similar between the three years (the small variation is likely to be within the limits of survey error), the amount of depth variation has changed. Standard deviation increased between 2006 and 2008 but had decreased by 2009. This suggests that depth variation had a net decrease between 2006 and 2009. 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 would be expected in a functioning river channel. The changes in the depth are not considered significant enough to impact on the hydromorphological or biological conditions of the channel.

The results also show that the mean bankfull width at the control site fell by 0.46 m between 2006 and 2009, and that there has been a corresponding increase in the standard deviation. While the river system is likely to be adjusting naturally to the channel narrowing measures that have been put in place previously through lateral accretion processes, this may not account for the full reduction in bankfull width observed in the control reach. The larger adjustments to the bankfull width are also likely to be partially attributable to the growth of riparian vegetation, which makes precise measurements of the bank top difficult by limiting access. The changes in the bankfull width are not considered sufficiently significant to impact on the hydromorphological or biological conditions of the channel.

The lack of major changes to the width and depth of the channel at the control site is confirmed by analysis of the cross-sections at the control site (Appendix A). However, they do illustrate some changes, for example, approximately 0.9 m erosion appears to have occurred between 2006 and 2008 on the right bank at MS03. This cross-section is located upstream of the meander bend in a reach where the bank toe is protected by willow spiling. The differences apparent in the bank lines may represent natural bank erosion, but may be attributable to settling or the partial failure of the willow spiling. Smaller changes can be observed on the right bank at XS02, MS04 and MS05; these are likely to be related to increased flow velocities during 2007 and 2008 around the outside of the meander bend. Minor changes occurred between 2008 and 2009 at cross-sections XS01, MS03 and XS02 which all display a small amount of erosion on the right bank, particularly below the water line (up to 1.2 m in XS02). This is likely to be in response to higher velocity flows on the outside of the meander bend. Sediment deposition is evident on the right hand bank in XS03 and this is likely to be in response to sediment accumulation due to increased growth of marginal vegetation.

Results at the restoration site show that the mean bankfull depth has fallen since 2006 as a result of the bed raising during restoration work. The standard deviation of the bankfull depth has increased accordingly, suggesting that depth has become more variable along the reach. This is further supported by analysis of the cross-sections (Appendix A), which show a significant decrease in the channel depth between 2006 and 2008 at MS02 (maximum 0.95 m), MS03 (maximum 0.73 m) and XS03 (maximum 0.77 m) due to the creation of gravel riffles. Between 2008 and 2009, however, there were only minor changes to the channel depth at these cross-sections. At MS02 the mean channel elevation decreased by 0.04 m, at MS03 it increased by 0.03 m and at XS03 channel elevation decreased by 0.05 m. This shows that only minor changes in depth are likely to occur at the riffles due to natural processes, although more significant changes may occur over a longer timescale.

Mean bankfull width increased by a total of 1.79 m between 2006 and 2009 (Table 5.3). This may be a natural response to the bed raising works undertaken at the site, as shown at XS02 where the left bank is eroding. However, a proportion of this change may be due to modifications to the bankline during restoration works. Also evident is an increase in the standard deviation of the bankfull width, suggesting that width variation is greater. Analysis of the cross-sections highlights an increase in channel width of 0.6 m on the right bank at MS01 at the upstream end of the reach. This is likely to be attributable to the erosive power of turbulent flow exiting the sluices at Seven Hatches, which are a short distance upstream of the structure. At all the remaining cross-sections where no restoration works have been undertaken, the cross-sectional profiles recorded in 2008 are very similar to those in 2006.

Some changes have occurred between 2008 and 2009, particularly at MS03 where the channel has narrowed as a result of increased marginal vegetation that has created an aquatic ledge in low flows. At cross-section XS02, the left hand bank is retreating in response to erosional processes. This is likely to be due to increased flow velocities downstream of the riffle. Minor changes in the bed elevation are evident at cross-section XS03 and are likely to be due to the natural mobilisation and deposition of bed material during high flows. The right bank at MS01 has retreated a further 0.5 m as a result of the erosive effect of turbulent flows downstream of Seven Hatches. The remaining cross-sections display no significant changes since 2008.

Limitations of analysis

No cross-section surveys were undertaken in the reach upstream of Seven Hatches where the channel narrowing measures were implemented. The cross-sections therefore do not accurately record all of the width variations that have occurred as a result of restoration. It is also not possible to link the channel narrowing measures with changes in channel depth.

Thick vegetation in some areas of the bank restricted access during the survey and, in some cases, prevented accurate survey to the bank top, particularly in the control reach. Although this added variation has the potential to mask small-scale geomorphological trends, the impacts are unlikely to alter the main findings of the repeat surveys.

Summary against objective

Analysis of cross-sections and repeat photography demonstrates there were small changes in the width and depth of the Seven Hatches control site in response to natural geomorphological processes such as erosion on the outside of the meander bend; bankfull depth decreased by 5.54% and bankfull width by 2.55% between 2006 and 2009. However, these changes do not reflect major variations in the geomorphological character of the reach. Any changes observed in the restoration site downstream are therefore likely to be a response to the restoration works themselves rather than any significant natural variation.

Analysis of the cross-sections from the restoration site shows increased variation in the channel depth and width in the restoration reach as a result of the installation of riffles and flow deflectors in the reach; bankfull depth decreased by 4.98% and bankfull width increased by 11.96% between 2006 and 2009. Analysis of repeat photography also shows that the channel width became more variable across the entire restoration reach, although no cross-sectional data are available to undertake a quantitative analysis of changes in this part of the reach.

The majority of changes observed in the restoration site are confined to those parts of the reach that have been directly affected by the restoration works. Slight variations were observed in other parts of the reach (for example, the spaces between riffles), but these are generally similar to those changes observed in the control reach. This suggests that the river had not (yet) fully adjusted to the restoration measures by 2009.

Overall, the restoration measures implemented at the restoration site have caused increased variation in width and depth, and as such can be considered to have delivered this objective effectively. The effectiveness of the measures may be limited by the apparent lack of response in the parts of the reach that have not been directly restored, although this is likely to be a result of the relatively short timescales over which monitoring has been undertaken. More significant changes are likely to occur in the future (for example, after geomorphologically effective flood flows) as the river gradually adjusts to the altered conditions.

5.1.2 Increased localised and average velocity

The results of velocity measurements recorded in 2006 and 2008 at 1 m intervals across the channel at each cross-section location in the control and restoration sites are presented in Table 5.4.

At the control site, these data show that the average velocity along the reach increased by 0.18 ms^{-1} between 2006 and 2008. This is likely to be attributable to the higher flow levels evident in 2008 (see cross-sections in Appendix A) rather than any changes to the nature of the channel. The overall trends within the control reach remain the same with the highest velocities in the upstream riffle and decreasing flows at the downstream end of the site due to impoundment behind South Newton gauging weir.

Table 5.4 Comparison of flow velocities in 2006 and 2008

Transect	Physical biotope		Mean velocity (ms^{-1})		Difference (ms^{-1})
	2006	2008	2006	2008	
Restoration site					
MS01	Riffle	Riffle	0.103	0.124	+0.021
MS02	Glide	Riffle	0.010	0.456	+0.446
XS01	Glide	Glide	0.010	0.104	+0.094
MS03	Glide	Riffle	0.010	0.207	+0.197
XS02	Glide	Glide	0.010	0.109	+0.099
MS04	Glide	Glide	0.010	0.091	+0.081
MS05	Glide	Glide	0.010	0.290	+0.280
XS03	Glide	Riffle	0.010	0.290	+0.280
Mean			0.020	0.210	+0.190
Control site					
MS01	Riffle	Riffle	0.330	0.550	+0.22
MS02	Rippled glide	Rippled glide	0.201	0.441	+0.24
XS01	Glide	Glide	0.120	0.320	+0.20
MS03	Glide	Glide	0.100	0.270	+0.17
XS02	Glide	Glide	0.163	0.273	+0.11
MS04	Glide	Glide	0.097	0.237	+0.14
XS03	Glide	Glide	0.050	0.170	+0.12
MS05	Glide	Glide	0.033	0.233	+0.20
Mean			0.132	0.312	+0.18

Comparison of the physical biotope mapping (Appendix B) confirms that the overall flow type remains the same, with much of the reach characterised as a glide with a riffle at the upstream end. Minor changes in flow velocities such as those evident from direct velocity measurements are not identifiable from these data. However, they are more evident in repeat photographs of the site as shown in Figure 5.1. These photographs show that the predominant glide flow type remains in each year. However, flow in 2008 and 2009 is rippled rather than of the uniform nature in 2006. A proportion of this increased surface rippling could be attributable to changes in localised weather conditions at the time of sampling (for example, increased wind shear on the water surface). However, this is also likely to indicate that flow velocity is higher, as shown by the velocity measurements, as a result of higher flow levels rather than because of changes in the channel form.

(a) (b) (c)

Figure 5.1 Control site in (a) 2006, (b) 2008 and (c) 2009

Results from the restoration site demonstrate that flow velocities increased by an average of 0.19 ms-1 between the two surveys. This is very similar to the average increase observed at the control site.

A more accurate indication of change in flow velocities within the reach can be obtained through analysis of trends at individual cross-sections. This shows that the greatest increases in velocity have occurred at the riffle locations, with an average increase of 0.307 ms^{-1}. This suggests that the restoration measures have successfully increased localised flow velocities, although a proportion of this variance is likely to be due to higher flow velocities in 2008, as illustrated at the control site. Increases at those cross-sections that have not been directly restored are generally very low, with the exception of MS05. These areas consist of comparatively deep, slow-flowing pools. The small scale of the flow increase may be a partial result of the installation of the large riffles, which create semi-impounded conditions in the deeper pools immediately upstream

Analysis of physical biotope mapping (Appendix B) shows that, upstream of Seven Hatches and downstream of the railway bridge, the biotopes observed in 2008 are the same as in 2006. However, the implemented restoration works have included creation of a series of riffles downstream of Seven Hatches, over which flow is fast, shallow and rippled rather than the glide observed in 2006 (Figure 5.2). The creation of the riffle features has therefore increased localised diversity of physical biotopes within the section subject to restoration and this includes increased velocity in these areas. The reaches between the riffles retain the glide flow type observed during the initial survey in 2006. The physical biotopes in 2009 showed no significant differences from 2008.

(a) (b) (c)

Figure 5.2 Restoration site in (a) 2006, (b) 2008 and (c) 2009

Limitations of method and analysis

The flow velocities measured in all but one location in the restoration site in 2006 were 0.01 ms^{-1}, suggesting that the flow velocity was below or close to the detection limit of the flow meter.

Velocity measurements were heavily influenced by the difference in water levels between 2006 and 2008, as shown by the increase in average velocity in the control reach.

No velocity measurements were taken in 2009, resulting in a small sample size and potentially unrepresentative results.

Summary against objective

Analysis of velocity measurements undertaken in 2006 and 2008 at the control site shows there was a slight increase in the average velocity along the entire reach. This is likely to be attributable to higher water levels which reduce the proportion of water in contact with the river bed and banks, reducing resistance and therefore increasing velocity.

Analysis of velocity measurements undertaken in 2006 and 2008 at the restoration site shows that the average increase was only marginally higher than at the control site. This is because any significant increases in velocity have occurred in localised areas where riffles have been introduced. In other areas, where the channel remains deep, only very minor increases were recorded. The average increase over the entire reach is therefore not the best indication of the impact on flow velocities and it is more appropriate to consider localised velocities.

Localised velocities increased significantly in the locations where gravel riffles had been introduced. As at the control site, increases in velocity in other parts of the reach are likely to be due to higher water levels in 2008 rather than additional changes to the morphology of the channel.

Overall, the restoration measures have caused increased localised velocities and as such can be considered to have effectively implemented this objective. The effectiveness of the measures may be limited by the apparent lack of response in the parts of the reach that have not been directly restored.

5.1.3 Increased area and frequency of exposed gravel substrate

Tables 5.5 to 5.8 present the substrate observations at the control and restoration sites at five points across the channel at each cross-section in 2006 and 2008.

The four tables are colour-coded as follows:

Silt dominated	Gravel dominated	Pebble dominated	Cobble dominated

Table 5.5 Seven Hatches control substrate record, 2006

Transect	Physical biotope	Right channel margin	Right of channel centre	Channel centre	Left of channel centre	Left channel margin
MS01	Riffle	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble
MS02	Glide	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble
XS01	Glide	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS03	Glide	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
XS02	Glide	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS04	Glide	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
XS03	Glide	Silt/ Sand	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS05	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt

Table 5.6 Seven Hatches control substrate measurements, 2008

Transect	Physical biotope	Right channel margin	Right of channel centre	Channel centre	Left of channel centre	Left channel margin
MS01	Riffle	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble
MS02	Glide	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble
XS01	Glide	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble
MS03	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
XS02	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble
MS04	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt	Silt/ Sand Silt
XS03	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS05	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt

Table 5.7 Seven Hatches restoration substrate record, 2006

Transect	Physical biotope	Right channel margin	Right of channel centre	Channel centre	Left of channel centre	Left channel margin
MS01	Riffle	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble
MS02	Glide	Silt/ Sand Silt	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
XS01	Glide	Silt/ Sand Silt	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS03	Glide	Silt/ Sand Silt	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
XS02	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS04	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt	Silt/ Sand Silt
MS05	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
XS03	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt	Silt/ Sand Silt

Table 5.8 Seven Hatches restoration substrate record, 2008

Transect	Physical biotope	Right channel margin	Right of channel centre	Channel centre	Left of channel centre	Left channel margin
MS01	Riffle	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS02	Riffle	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble
XS01	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS03	Riffle	Gravel/Pebble	Gravel/ Pebble	Gravel/ Pebble	Cobble	Gravel/ Pebble
XS02	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS04	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
MS05	Glide	Silt/ Sand Silt	Gravel/ Pebble	Gravel/ Pebble	Gravel/ Pebble	Silt/ Sand Silt
XS03	Riffle	Gravel/Pebble	Cobble	Cobble	Gravel/ Pebble	Silt/ Sand Silt

Results from the control site show that, in 2006, the channel was generally dominated by gravels, with more pebbles in the upstream section and silts accumulating in the slacker water in the channel margins. In 2008, the control site shows a greater dominance of pebble-sized material on the channel bed both in the upstream section of the reach and further downstream within the central channel. This is consistent with more pronounced armouring and greater scour and deposition processes associated with increased flow velocities during 2007 and 2008. As in 2006, silt was present along the channel margins in 2008, although it is more extensive along the right channel margin. This may be related to increased vegetation growth which reduces flow velocities and encourages sedimentation.

Results from the restoration site show that, in 2006, the reach is generally dominated by gravels in the centre of the channel, with extensive fine sediment deposition in the margins. By 2008, the creation of riffles has introduced increased gravel and pebble material at cross-sections MS02, MS03, and XS03. Silt has been replaced with either gravel or pebble along at least one margin within each of these cross-sections (Figure 5.3); this is likely to reflect the faster flows and transport of fine sediment through these sections. Increased presence of gravel was also observed at cross-sections where riffles have not been created (XS01 and MS04).

The coarsening of bed sediments is likely to be attributable to a combination of the direct addition of coarse sediments at the location of the new riffles, the downstream movement of coarse sediments during high flow events, and the preferential erosion of finer sediments from the riffles themselves as a result of increased flow velocities over the riffles. However, it is difficult to determine which of these factors is the most significant.

Work by Hjulström (1935) indicates that silts and sands require between 0.2 m/s and 1.5 m/s to become entrained. Gravels require flow velocities of between 0.5 m/s and 2.0 m/s to become entrained, while pebbles require up to 4.0 m/s. Flows recorded in 2008 are below the threshold of entrainment for the coarser sediments (gravels, pebbles and cobbles) found in the reach, although it is likely that flow velocities increase sufficiently during periods of high flow for downstream movement to occur. Flows across the riffles at MS02, MS03 and XS03 were sufficiently high for some movement of silts and sands to occur. This suggests that fine sediments are being eroded from the riffles during normal flows (probably in small quantities), resulting in a net coarsening of the substrate.

This may be related to increased transport of fine sediment as a result of higher discharge and flow velocities, as well as the restoration measures themselves. However, it is not possible to conclusively separate these influences with the data currently available. Flow data are limited to single sets of measurements for each year and as such are only representative of conditions at the time of sampling rather than longer term trends. Cobble substrate was noted within the riffle locations in 2008; this is likely to be large material imported during the restoration works that has become exposed as increased flow velocities have entrained the overlying gravel material.

(a) (b)

Figure 5.3 Channel margin at MS03 in (a) 2006 and (b) 2008

Limitations of method and analysis

Substrate measurements were not taken in 2009, resulting in a small sample size and potentially an unrepresentative sample that does not display long-term trends.

Large areas of gravel substrate were present prior to restoration works in both the control and restoration sites making comparison difficult.

Detailed grain size distribution or coverage data for the substrate were not available. This precluded any quantitative analysis and substrate analysis was therefore limited to simple comparisons of visual field observations.

Substrate data were only available for the restoration reach in which riffles had been installed and were not available for the narrowed reach. It is therefore not possible to determine whether the likely increase in flow velocities in this reach has resulted in a change in the substrate conditions.

Substrate conditions in the control and restoration reaches could be influenced by high flow events when sediment is entrained, gravel is exposed and larger substrate is deposited in some locations. It is therefore hard to link changes in substrate solely to the restoration works, as shown by changes at the control reach which are likely to be attributable to sediment movement and redistribution during high flow events.

Summary against objective

Analysis of substrate records from 2006 and 2008 demonstrates that the dominant substrate throughout the control reach became coarser, with an increase in the proportion of pebble-sized clasts. This is likely to be a result of more pronounced armouring and greater scour and depositional processes associated with increased flow velocities during 2007 and 2008. Increased marginal vegetation is also acting to trap sediment and has increased the amount of silt substrate on the right hand channel margin.

As a direct result of the restoration measures, there is increased gravel substrate in the restoration reach and, where riffles have been introduced, silt has been replaced with gravel substrate at the channel margins. An increase in gravel substrate at other cross-sections was recorded and this is likely to be a combination of increased flow velocity over the riffles and the restoration measures themselves.

Overall the restoration measures have increased the extent of exposed gravel substrate, but in most areas this is as a direct result of importing gravel to create riffles. Although there is some evidence of increased gravel material where riffles have not been created, this is likely to be partially attributable to the downstream transport of imported coarse sediment from the newly created riffles and increased winnowing of finer sediments as a result of increased flow velocities over the riffles. However, changes to the substrate at the control site mean that these changes may also to be partially attributable to natural processes within the system rather than as a result of the restoration.

The relatively small scale of changes in parts of the restoration reach that have not been directly restored (for example, areas between the new riffles) is likely to be a result of the relatively short timescales over which monitoring was carried out. More significant changes are likely to occur in the future (for example, after geomorphologically effective flood flows) as the river gradually adjusts to the altered conditions.

5.1.4 Increased height and coverage of riparian vegetation

The percentage cover of riparian vegetation at the restoration and control sites for each of the three monitoring years is shown in Table 5.9 and Figure 5.4.

Table 5.9 Percentage cover of riparian vegetation

Site	Year	Riparian vegetation cover (%) per transect					Mean	Standard error
		MS01	MSO2	MSO3	MSO4	MSO5		
Restoration	2006	26	24	25	23	12	22	2.55
	2008	39	30	36	38	19	32.4	3.70
	2009	47	28	44	31	22	34.4	4.78
Control	2006	61	49	35	17	26	37.6	7.88
	2008	70	53	60	50	26	51.8	7.31
	2009	38	56	54	59	28	47	5.98

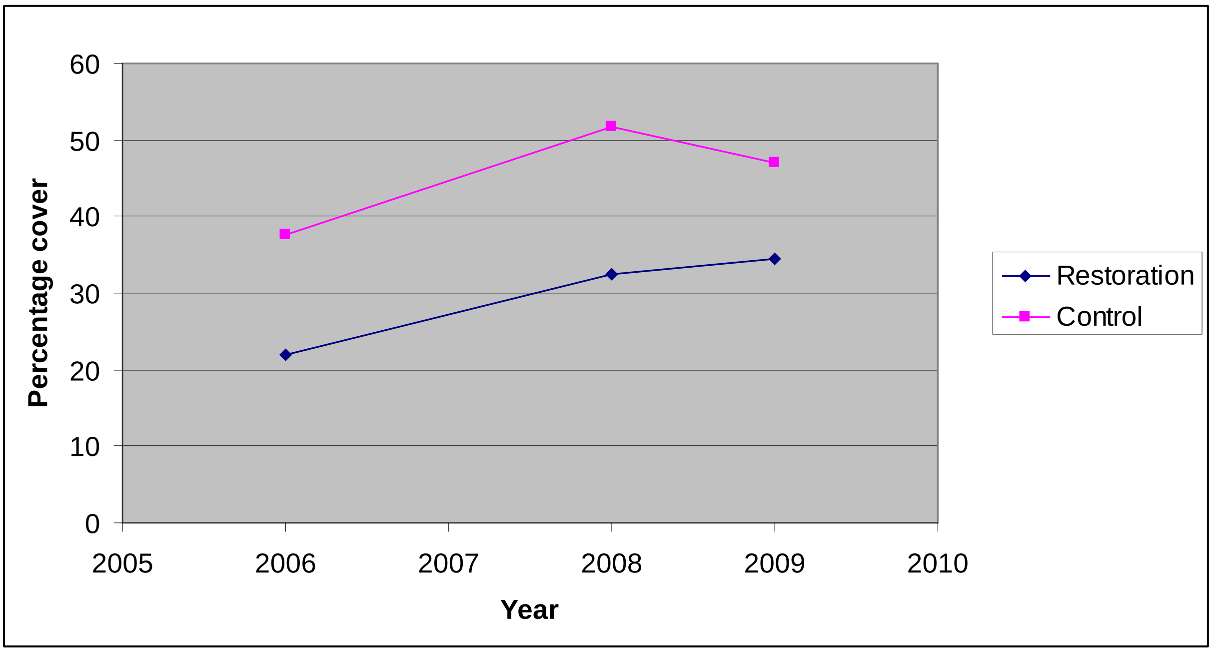


Figure 5.4 Percentage cover of riparian vegetation, 2006-2009

At the control site, mean coverage increased from 37.6% to 51.8% between 2006 and 2008 and then decreased to 47% in 2009. This shows a marked increase in the overall coverage of riparian vegetation. This increase could be the result of a combination of factors including:

- climatic conditions (temperature, rainfall) that are more conducive to vegetation growth
- fertilisers applied to adjacent farmland that has spread to the river banks and enhanced vegetation growth
- the natural succession over time that would be expected in any vegetation community

To a certain extent, these figures could be influenced by the presence of a greater variety of species, adding to the overall coverage. Repeat photographs illustrate the increased coverage and indicate that there is a general increase in the height of the riparian vegetation, particularly of the nettles on the right hand bank. This increase is likely to be a result of natural vegetation growth in the period between surveys which has potentially been enhanced by the spread of fertiliser from the adjacent agricultural land use.

At the restoration site, overall riparian vegetation cover is less than at the control site, but does show an increase between 2006 and 2009. The species present in 2009 consist only of grasses, with some planted willow saplings. The reason for the lower overall coverage in 2006 is that, unlike at the control site, the floodplain in the restoration reach was used for agricultural grazing and livestock had unrestricted access to the bank top and water's edge. This grazing resulted in a lack of cover and low diversity of species. One element of the restoration work was to install a fence approximately 10 m from the bank top to prevent livestock access and to create a buffer strip where riparian vegetation could become established. This accounts for the increase in overall vegetation cover in 2008 and 2009. The increase in overall coverage is relatively modest as a result of the timescales over which monitoring was undertaken. Continued increase in vegetation coverage would be expected in the future as vegetation becomes more established and widespread. Repeat photography of the buffer strip is shown in Figure 5.5. The 2008 photograph clearly shows that the height and coverage of vegetation has increased significantly as a result of these works. The photograph from 2009 shows that the buffer strip had recently been mown as part of ongoing maintenance. The height and coverage of vegetation has therefore temporarily decreased but overtime will quickly return to the extent seen in 2008.

(a) (b) (c)

Figure 5.5 Riparian vegetation in (a) 2006, (b) 2008 and (c) 2009

Limitations of analysis

The control and restoration sites are not comparable in terms of riparian vegetation as they have contrasting land use in the floodplain areas. The control site is not grazed and is in close proximity to tilled agricultural land whereas the restoration site was grazed by livestock. The restoration site is also subject to greater management and the buffer strip is mown regularly as part of this management.

None of the surveys undertaken included an assessment of overall coverage or height of riparian vegetation and it is therefore difficult to make a quantitative assessment.

The coverage and height of vegetation is likely to increase due to natural growth throughout the year. It is therefore difficult to attribute any changes solely to the restoration measures.

The riparian zone is subject to management and mowing, impacting on the height and coverage of vegetation.

Summary against objective

Analysis of riparian vegetation cover and repeat photography at the restoration site shows that coverage and height increased between 2006 and 2009. This is a direct result of the erection of a fence that has limited livestock access to the bank top. Some planting has also been undertaken during the restoration works. If the restoration had involved erection of the fence and livestock had been allowed continued access to the banks, it is unlikely there would have been an increase in the cover or height of vegetation.

Vegetation cover and height have also increased at the control site. At this site, however, livestock do not have access to the bank and there is the potential for fertilisers to spread to the riparian zone to enhance conditions for vegetation growth.

Overall, the restoration measures have increased the height and coverage of riparian vegetation due to the erection of a buffer strip fence. Some increase in height and coverage of vegetation would be expected due to natural growth patterns and this is confirmed by the increase evident at the control site.

5.1.5 Increased morphological diversity – based on width, depth, sinuosity and in-channel features

Width and depth variations

See Section 5.2.1

Sinuosity

The sinuosity of the channel in the control and restoration sites is shown in Figure 5.6 and summarised in Table 5.10.

Table 5.10 Sinuosity of the control and restoration sites

Site	Year	Sinuosity
Restoration	2006	1.0350
	2008	1.0350
	2009	1.0348
Control	2006	1.0158
	2008	1.0162
	2009	1.0162

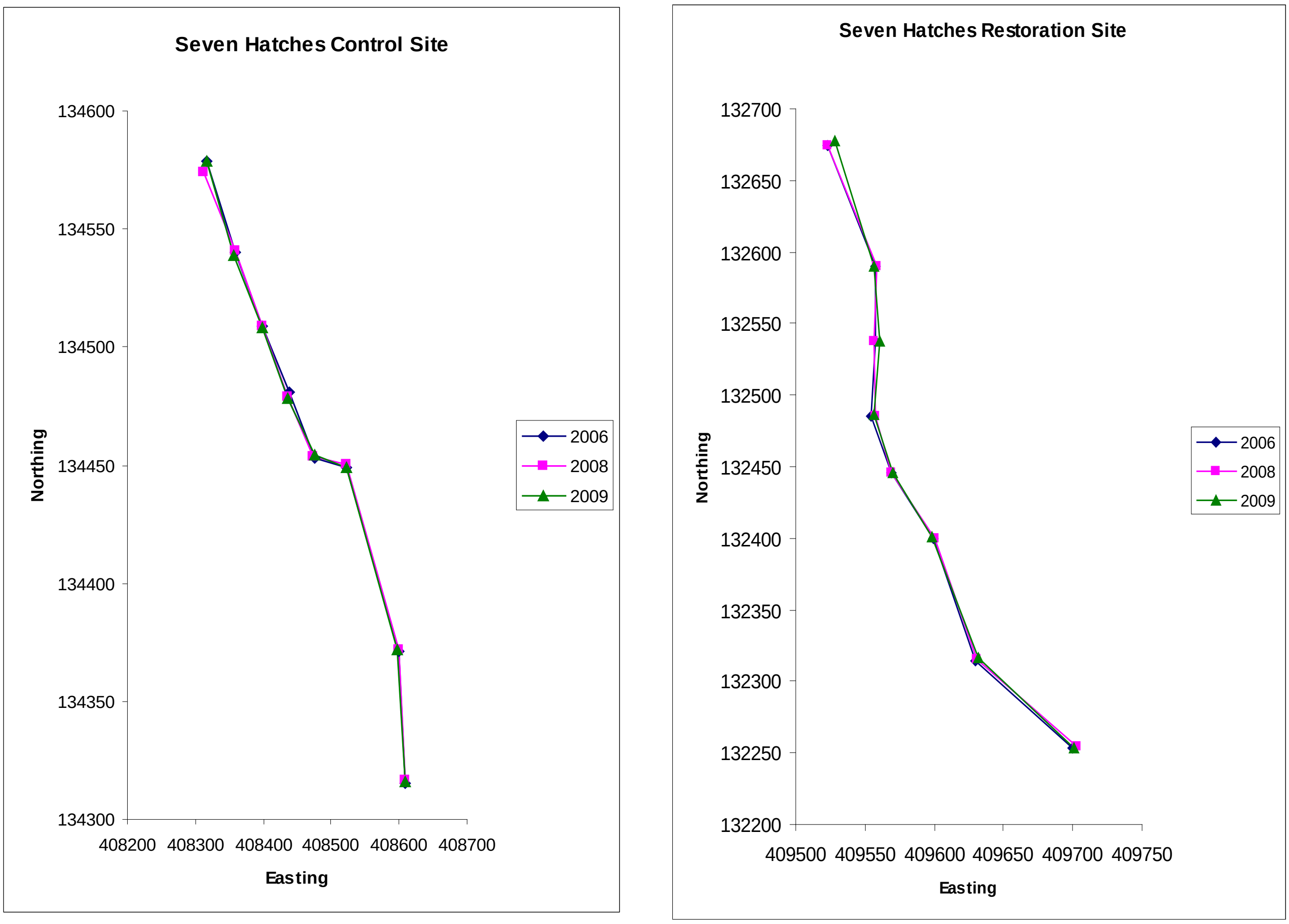


Figure 5.6 Changes in the thalweg at the control and restoration sites

Results from the control site demonstrate that the channel has low sinuosity. Although there are very slight differences, the sinuosity of the channel did not change between 2006 and 2009.

The restoration site results show that the sinuosity of the channel did not change between 2006 and 2009, although there are very minor variations between the last two surveys. This means that the restoration measures have not had any noticeable impact on the sinuosity of the channel.

In-channel features

In theory, in-channel features would develop as a result of higher flow velocities acting to reduce sedimentation and to increase the proportion of coarse sediments. A full analysis of flow velocities and substrate material is provided in sections 5.1.2 and 5.1.3.

Analysis of physical biotope mapping shows that the control site does not have many visible in-channel features. This is likely to be in part due to the deep channel that makes identifying in-channel features from the river bank difficult. The only change identified through the physical biotope mapping is an increase in silt deposition on the left hand channel margin approximately half way along the reach in the area behind the concrete deflector. This is likely to be the system naturally adjusting to the presence of the concrete deflector. The low variation in the flow velocities and substrate between 2006 and 2009 is the most likely reason for the lack of development of in-channel features in the reach.

At the restoration site, analysis of physical biotope mapping shows that several in-channel features were present pre-restoration, primarily downstream of the railway bridge. This included two gravel bars on the left hand bank immediately downstream of the railway bridge, silt deposition further downstream, and bank erosion and scour in localised areas. All these features remain in the subsequent surveys in 2008 and 2009, with the exception of one of the gravel bars. It is likely that this was washed away during high flows. No additional in-channel features were recorded in 2008 or 2009. Erosion and scour has continued and the bank has retreated since 2006, as shown in Figure 5.7.

In the upstream section of the reach, no in-channel features were recorded pre-restoration. In-channel features were created during the restoration work through the introduction of gravel, but no addition features were recorded in the areas between the riffles.

Figure 5.7 Bank retreat in the restoration reach in (a) 2006 and (b) 2009

Limitations of analysis

Cross-sections, velocity and substrate were not monitored in the reach upstream of Seven Hatches where the channel narrowing measures were implemented. It is therefore harder to make an assessment of changes in morphological diversity in this section of the reach.

The restoration measures were not specifically designed to increase channel sinuosity. However, it is possible that changes to sinuosity may occur as the system adjusts naturally.

In-channel features, particularly bed forms, were difficult to identify due to the depth of the channel.

Summary against objective

Overall, the restoration measures have successfully increased morphological diversity in the areas where gravel riffles were created. These measures have increased width and depth variation, introduced greater flow velocities and increased coarse bed substrate. The effectiveness of the measures may be limited by the apparent lack of response in the parts of the reach that have not been directly restored, although this is likely to be a result of the relatively short timescales over which monitoring was carried out. More significant changes are likely to occur in the future (for example, after geomorphologically effective flood flows) as the river gradually adjusts to the altered conditions.

Sinuosity

There has been no change in the sinuosity of the restoration or the control reach. However, the restoration measures do not appear to have been intended to increase sinuosity since the deflectors are overtopped during higher flows. It is possible that the restoration measures will result in increased sinuosity in the future, but long-term monitoring would be required to measure this.

In-channel features

Analysis of physical biotope mapping shows that the restoration measures have not directly resulted in the development of in-channel features in parts of the reach that have not been directly restored. However, the riffles that have been created are acting to increase morphological diversity in the vicinity of the restoration measures by increasing flow velocity and by creating areas of gravel substrate.

5.2 Macrophyte objectives

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

5.2.1 Increase in percentage cover of macrophytes

The percentage cover of macrophytes, excluding negative indicator species and invasive species, at each transect within the control and restoration sites are shown in Table 5.11 and Figure 5.8.

Table 5.11 Percentage macrophyte coverage

Site	Year	Macrophyte cover (%) per transect					Mean	Standard error
		1	2	3	4	5		
Restoration	2006	20	40	34	32	19	29.0	4.1
	2008	30	42	33	31	32	33.6	2.2
	2009	41	55	62	26	38	44.4	6.4
Control	2006	53	42	30	32	25	36.4	5
	2008	67	57	51	70	35	56	6.3
	2009	105	90	92	112	55	90.8	9.8

Notes: Excludes negative indicator species and invasive species.

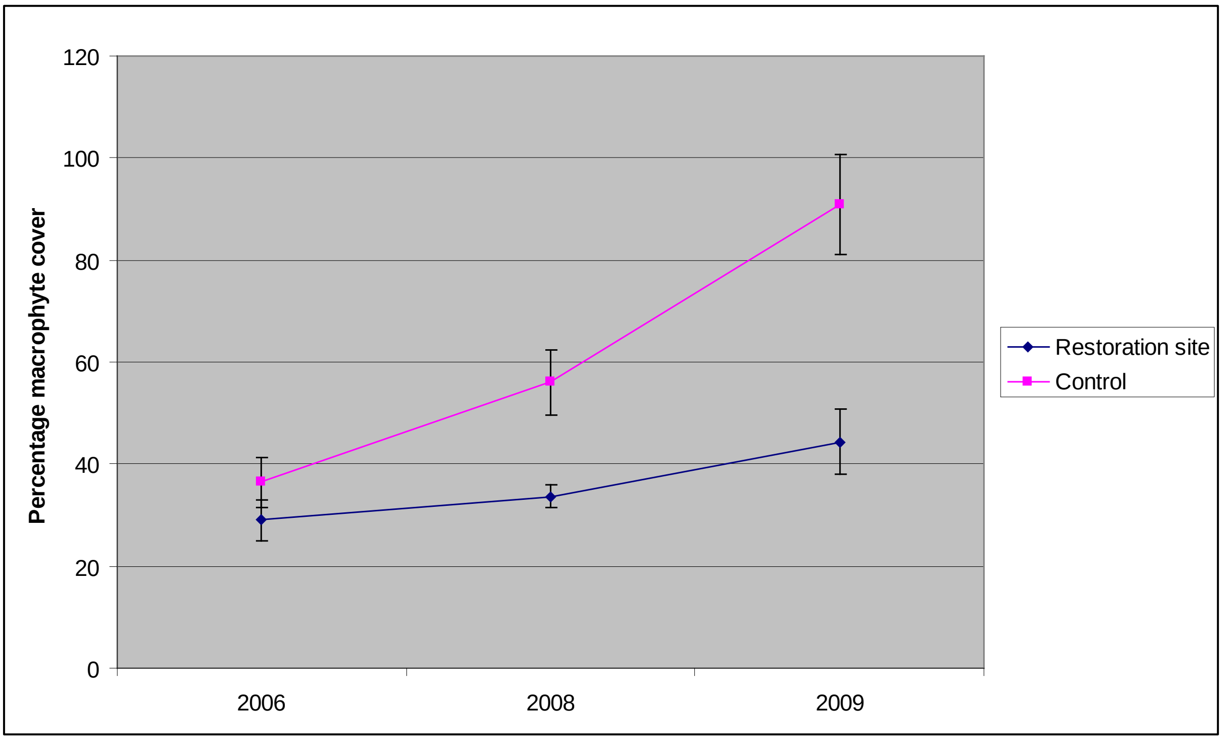


Figure 5.8 Percentage macrophyte coverage, 2006-2009

Although mean macrophyte coverage at the restoration site increased from 29% to 44.4% between 2006 and 2009, an unusual acceleration in macrophyte cover is seen at the control site where coverage increased from 36.4% to 90.8%. To determine whether this is a 'natural' increase in macrophyte coverage and therefore a valid control to compare the restoration site, or if this is a result of some isolated event, it is necessary to examine catchment-wide results to gain a greater contextual understanding of conditions.

Macrophyte data for the Lower Wylye was recorded by the Environment Agency from 1998 to 2008. This includes estimated percentage cover in 100 m long reaches. The results from 2000 to 2008 are shown in Table 5.12, with results from the control and restoration site for comparison. Both the restoration and control sites show an increasing percentage macrophyte coverage, which is not replicated in the wider catchment data. With the wider catchment data in mind, the large increase observed at the control site appears an unusual result and raises questions about the suitability of the site as a control as it is not representative of natural background variation. Potential explanations for the increase at the control site are a reduction in grazing from swans, a change in management or the accidental release of fertilisers into the water that has promoted growth in localised areas.

Using the wider catchment data as a 'control' site suggests that the increased coverage observed at the restoration site is attributable to the restoration measures.

Table 5.12 Lower Wylye catchment macrophyte coverage, 2000-2009

Year	Restoration site	Control site	Wider catchment
2000	Not available	Not available	64%
2001	Not available	Not available	Not available
2002	Not available	Not available	15%
2003	Not available	Not available	25%
2004	Not available	Not available	24%
2005	Not available	Not available	42%
2006	29%	36%	29%
2007	Not available	Not available	6%
2008	34%	56%	28%
2009	44%	91%	Not available

Summary against objective

Analysis of macrophyte monitoring results at the control site shows that the mean percentage cover increased from 36.4% to 90.8% between 2006 and 2009. Mean coverage at the restoration site increased from 29% to 44.4% in the same period. The rate of increase at the restoration site was therefore considerably less than at the control site. However, when comparing the results with wider catchment data, the rapid increase observed at the control site has not been replicated elsewhere, suggesting that it is attributable to localised changes in conditions as a result of management practices. Potential explanations for the increase at the control site are a reduction in grazing from swans, a change in management or the accidental release of fertilisers into the water that has promoted growth in localised areas. Using the wider catchment data as a ‘control’ site suggests that the increased coverage observed at the restoration site is attributable to the restoration measures.

The restoration works are likely to have had an impact on macrophyte coverage at the restoration site when gravel substrate was placed on the existing channel bed. Re-establishment of macrophytes is likely to occur over a longer timeframe and this could explain the lower overall percentage increase. However, when compared with the wider catchment data, the increases observed at the restoration site appear more significant, suggesting that the restoration has successfully improved conditions for macrophyte growth.

5.2.2 Increase in macrophyte species preferring faster flows

The percentage cover of species making up the *Ranunculion fluitantis* and *Calitricho-Batrachion* communities at the restoration and control sites are shown in Table 5.13. Average coverage at the control site increased from 8% to 32.6% and at the restoration site from 1.2% to 2.8% between 2006 and 2009.

Table 5.13 Percentage cover results for *Calitricho-Batrachion* and *Ranunculion fluitantis* community

Site	Year	% cover					Mean
		MS01	MS02	MS03	MS04	MS05	
Restoration	2006	1.00	0.00	0.00	5.00	0.00	1.20
	2008	2.00	1.00	3.00	1.00	0.00	1.40
	2009	1.00	10.00	2.00	1.00	0.00	2.80
Control	2006	22.00	4.00	1.00	12.00	1.00	8.00
	2008	11.00	4.00	2.00	23.00	2.00	8.40
	2009	76.00	12.00	12.00	48.00	15.00	32.60

The results from the wider catchment in the years 2000 to 2008 are shown in Table 5.14 where results from the restoration and control sites are given for comparison. These results show similar trends to the overall macrophyte coverage results as explained in section 5.2.1.

Table 5.14 Lower Wylye catchment *Calitricho-Batrachion* coverage

Year	Restoration	Control	Wider catchment
2000	Not available	Not available	58%
2001	Not available	Not available	Not available
2002	Not available	Not available	11%
2003	Not available	Not available	16%
2004	Not available	Not available	20%
2005	Not available	Not available	31%
2006	1.2%	8%	25%
2007	Not available	Not available	3%
2008	1.4%	8.4%	23%
2009	2.8%	33.6%	Not available

Summary against objective

Between 2006 (pre-restoration) and 2009 (post-restoration) there was an apparent 133% increase within the restoration section of the most important species making up the *Calitricho-Batrachion* community. During the same period, however, the same species increased within the control section by 308%.

But when comparing the results with wider catchment data, the rapid increase observed at the control site was not replicated elsewhere, suggesting that it was attributable to localised changes in conditions as a result of management practices. Potential explanations for the increase at the control site include:

- a reduction in grazing from swans

- a change in management
- the accidental release of fertilisers into the water that has promoted growth in localised areas

Using the wider catchment data as a ‘control’ site suggests that the increased coverage observed at the restoration site may be attributable to the restoration measures.

5.2.3 Increase in number of macrophyte species preferring slower flows

The results from the percentage cover of those species that prefer slowing flow conditions are shown in Tables 5.15 to 5.17. The data are inconclusive, though there does appear to have been a reduction in the presence of duckweed within the restoration section that may reflect the increased flows associated with the channel narrowing. If present, duckweed is often found in sheltered back-eddies or areas of impounded water. The presence of fennel leaved pondweed increased at both the restoration and control sites, but this could be indicative of more suitable climatic conditions rather than any decrease in the flow velocities.

Table 5.15 Percentage cover of fennel leaved pondweed

Site	Year	MS01	MS02	MS03	MS04	MS05	Average
Restoration	2006	0	0	0	0	0	0
	2008	0	0	0	30	5	7.0
	2009	0	0	0	15	10	5.0
Control	2006	0	10	0	10	1	4.2
	2008	0	10	5	5	1	4.2
	2009	1	40	5	5	5	11.2

Table 5.16 Percentage cover of common duckweed (*Lemna minor*)

Site	Year	MS01	MS02	MS03	MS04	MS05	Average
Restoration	2006	5	1	1	5	1	2.6
	2008	1	0	1	1	0	0.6
	2009	1	1	0	0	0	0.4
Control	2006	0	0	0	0	1	0.2
	2008	0	1	0	1	0	0.4
	2009	0	0	0	0	0	0

Table 5.17 Percentage cover of ivy leaved duckweed (*Lemna trisulca*)

Site	Year	MS01	MS02	MS03	MS04	MS05	Average
Restoration	2006	0	0	0	0	0	0
	2008	0	0	0	0	0	0
	2009	0	0	0	0	0	0
Control	2006	0	0	0	0	0	0
	2008	0	0	0	1	0	0.2
	2009	1	1	1	1	0	0.8

Summary against objective

There was a decrease in the presence of both common duckweed and ivy leaved duckweed in the restoration site. This could be related to the higher flow velocities in localised areas in the restoration site. At the control site the coverage of ivy leaved duckweed increased slightly between 2006 and 2009, but this could be attributable to natural variation.

Potamogeton pectinatus is a submerged macrophyte and takes its common name, fennel pondweed, from the feathery appearance of the leaves in water. It can grow in still or flowing water and is often considered a 'weed' species. Unlike the *Lemna* species whose free-floating distribution can be highly dependent on transient flows, *P. pectinatus* remains largely in place characterised by growth from a creeping stolon, which takes the form of dichotomously cylindrical branching stems and leaves. Therefore a decrease or increase in the percentage cover of this species may be indicative of changing flows over several years, whereas the *Lemna* species will be quickly flushed from a reach by spate events.

Limitations of macrophyte analysis

The analysis is limited to a description of the observed trends at both sites over the three years of monitoring. Regression analysis of the data could be undertaken to determine if there is a statistically significant difference between the two trends, but the sample size is insufficient to perform a meaningful statistical analysis and regression analysis would not actually help to compare the restoration site with the control site. A minimum sample size of 10 is recommended for meaningful statistics.

Results at the control site do not appear to reflect natural background variation when compared with wider catchment data, which therefore questions the location's suitability as a control site. The wider catchment data appear to provide a more suitable control baseline, although the survey methodology used to collect the catchment-wide data was based on estimated cover in a 100 m length. This is not likely to be as accurate as the method employed at the restoration and control sites which was based on transects.

One of the main limitations is that the restoration actions were implemented within sub-reaches of the site and were designed to create micro-habitats to increase diversity. The pre- and post-restoration surveys were not chosen specifically to sample within and compare between the micro-habitat areas and so the overall results for the reach may not reflect the small-scale changes to species distribution and abundance within the new habitats.

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 and evenness

Species diversity and evenness values for the control and restoration site are shown in Table 5.18 and Figures 5.9 and 5.10. Also presented in this table are the scores from the River Till to indicate the wider catchment conditions.

Table 5.18 Species diversity index for macroinvertebrates using Shannon–Wiener Index

Site	Year	Diversity score (H)	Evenness score (E)
Restoration	2006	2.68	0.73
	2008	2.21	0.60
	2009	3.63	1.00
Control	2006	2.55	0.70
	2008	3.71	0.75
	2009	3.58	0.92
River Till (Stapleford)	2006	1.55	0.21
	2008	2.45	0.37
	2009	2.41	0.34

Notes: H ranges between 0 (indicating low community complexity) and 4 (indicating high community complexity).

E is constrained between 0 and 1. The less variation in a community between the species (that is, the more 'even' the community is), the higher the value of E.

Figure 5.9 Species diversity index for macroinvertebrates using Shannon–Wiener Index

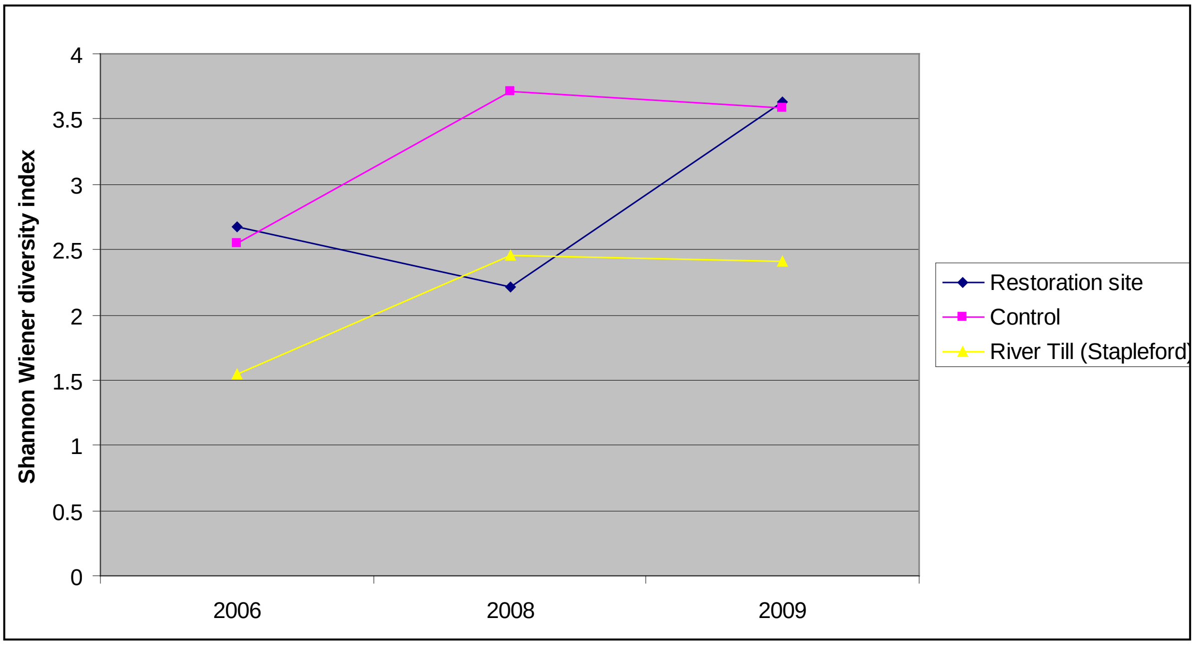
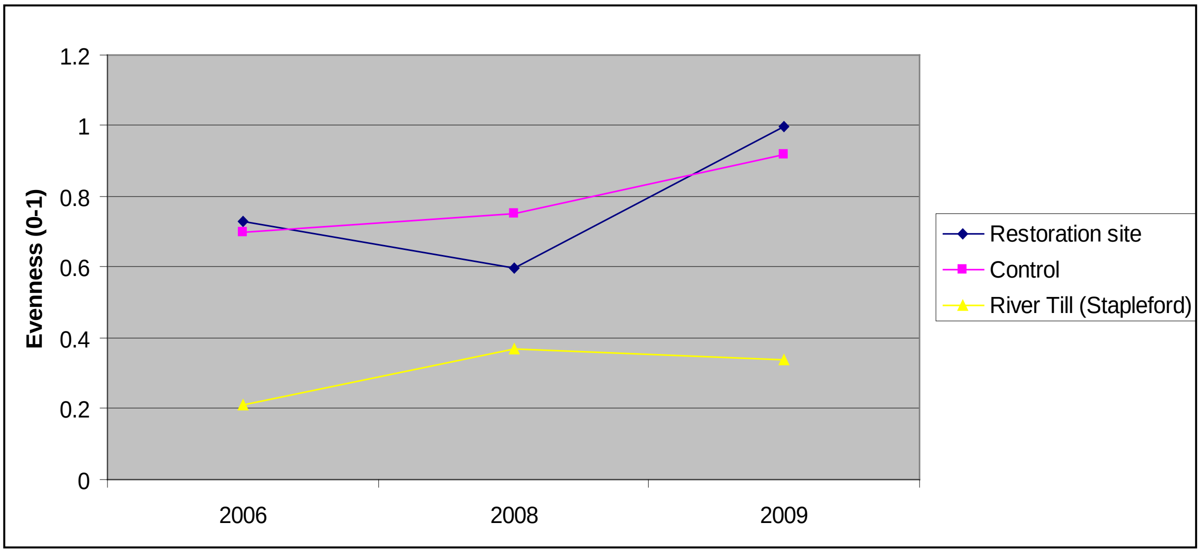


Figure 5.10 Species evenness for macroinvertebrates



Results for both the restoration and control sites indicate a highly diverse assemblage of macroinvertebrates throughout the monitoring programme. Although there are increases in both diversity and evenness over the three years of monitoring, at no point is either site displaying anything less than a highly diverse community – as expected for a site designated for this feature. The results for the River Till (a tributary of the Wylye) display an almost identical species diversity trend, though the overall diversity is lower.

The results suggest that the restoration site did not perform any better than the control site throughout the monitoring period. Both sites displayed similar level of species diversity and evenness during year 1 and year 3. During the second year the restoration site was, however, markedly lower for both values compared with the control site. Without replication it is not possible to statistically determine whether the trends observed for the restoration and control sites are significantly different.

The trend at the control site suggests that the results for year 1 may be artificially lower given the sudden jump in the scores for the second year, which is a similar trend to that recorded for the macrophyte coverage; macrophyte coverage and macroinvertebrate diversity are inevitably going to be closely correlated. The fact that similar trends are observed at the control site and in the River Till suggest that the decline in diversity at the restoration site in 2008 could be the result of habitat disturbance during implementation.

Summary against objective

Analysis of species diversity scores using the Shannon-Wiener diversity index suggests that the diversity of the invertebrate assemblage at the restoration site was never noticeably greater than that seen at the control site. During the second year of monitoring, diversity was in fact markedly lower at the restoration site and this is likely to be a result of disturbance of existing habitats during the restoration works. Without adequate replication it is not possible to determine whether the trends observed for the restoration and control sites are statistically significantly. A minimum sample size of 10 is recommended to perform meaningful statistics.

Analysis of species evenness scores using the Shannon-Wiener diversity index suggest that evenness of the invertebrate assemblage increased at both the restoration and control sites.

The actual diversity and evenness values at both sites indicate a highly diverse macroinvertebrate community, regardless of where it was recorded. This is to be expected given the site's conservation status.

5.3.2 Increase in species preferring faster flows (LIFE) and increased conservation value (CCI)

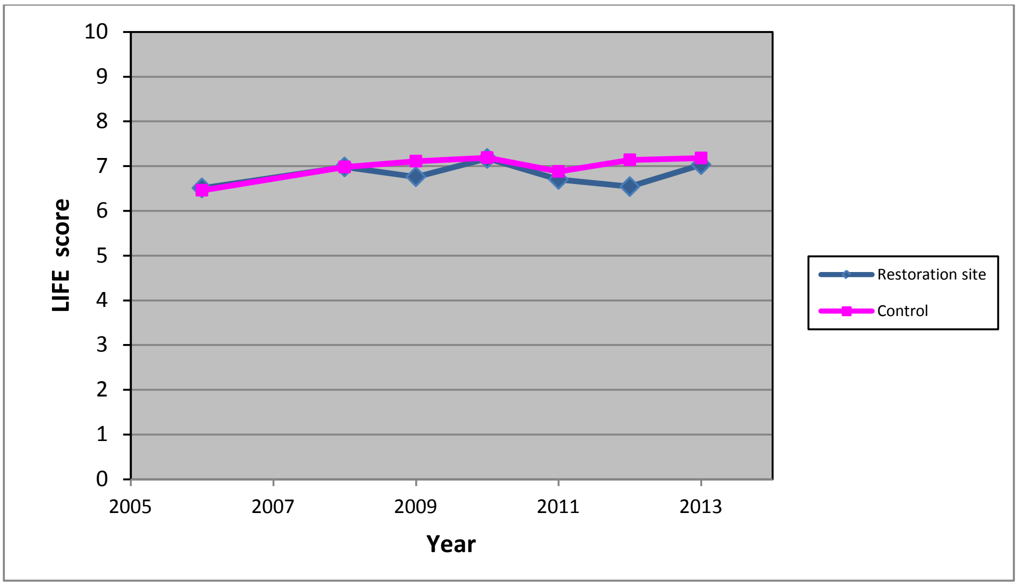
The LIFE and CCI scores for the restoration and control sites are presented in Table 5.19 and Figure 5.11.

Table 5.19 Summary of LIFE and CCI scores

Site	Date	LIFE score (species)	LIFE score (family)	CCI score
Restoration	28/08/2007 Pre-restoration	6.83	6.51	20.17
	22/08/2008 Post-restoration	7.40	6.98	21.75
	25/08/2009 Post-restoration	7.22	6.76	21.13
	16/08/2010 Post-restoration	n/a	7.17	n/a
	10/08/2011 Post-restoration	n/a	6.70	n/a
	7/08/2012 Post-restoration	n/a	6.54	n/a
	5/09/2013 Post-restoration	n/a	7.03	n/a
Control	28/08/2007 Pre-restoration	6.87	6.46	21.64
	22/08/2008 Post-restoration	7.30	6.98	23.02
	25/08/2009 Post-restoration	7.69	7.11	23.96

16/08/2010 Post-restoration	n/a	7.19	n/a
10/08/2011 Post-restoration	n/a	6.88	n/a
7/08/2012 Post-restoration	n/a	7.14	n/a
5/09/2013 Post-restoration	n/a	7.18	n/a

Figure 5.11 Family LIFE scores for macroinvertebrates



Summary against objective

The family level LIFE scores were consistent throughout the study period and examination of the taxa revealed a similar community at both sites both before and after restoration.

With the available data it is not possible to demonstrate that the restoration site performed better than the control site. The CCI scores at both sites reflect very high conservation scores with consistently very high taxon richness. A single specimen of the notable riffle beetle *Riolus subviolaceus* was found at both sites in 2009.

Given that both the restoration and control sites started with very high taxon richness (>20 CCI index), it is unlikely that this would significantly increase over time at either site. Any increase in species diversity and evenness significant in the macroinvertebrate community may take several years to establish.

5.3.3 Increase in proportion of sediment-sensitive invertebrates

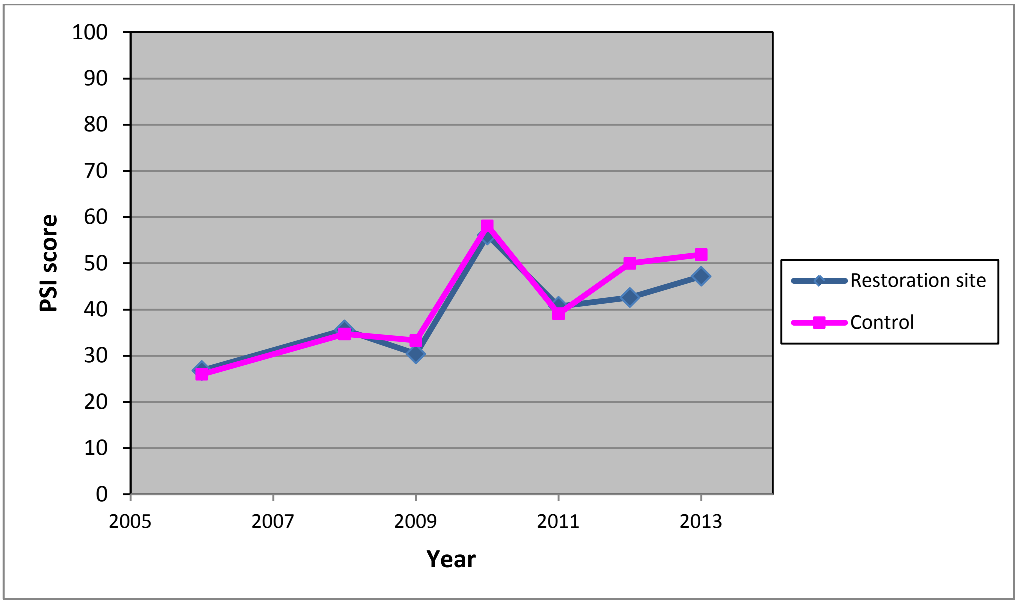
The PSI scores for the control and restoration sites are presented in Table 5.20 and Figure 5.12.

Table 5.20 PSI scores

Site	Year	PSI score

Restoration	28/08/2007 Pre-restoration	26.8
	22/08/2008 Post-restoration	35.6
	25/08/2009 Post-restoration	30.4
	16/08/2010 Post-restoration	56.1
	10/08/2011 Post-restoration	40.7
	7/08/2012 Post-restoration	42.6
	5/09/2013 Post-restoration	47.2
Control	28/08/2007 Pre-restoration	26.0
	22/08/2008 Post-restoration	34.7
	25/08/2009 Post-restoration	33.3
	16/08/2010 Post-restoration	58.1
	10/08/2011 Post-restoration	39.1
	7/08/2012 Post-restoration	50.0
	5/09/2013 Post-restoration	51.9

Figure 5.12 PSI scores for macroinvertebrates



Summary against objective

A review of the PSI scores derived from the macroinvertebrate data shows that there was an overall increase in the number of silt intolerant taxa recorded as a proportion of all taxa found at both the restoration and control sites.

The data do not support the hypothesis that the restored site improved in regard to impacts from siltation on macroinvertebrate species compared with the control site.

5.3.4 Increased taxonomic composition

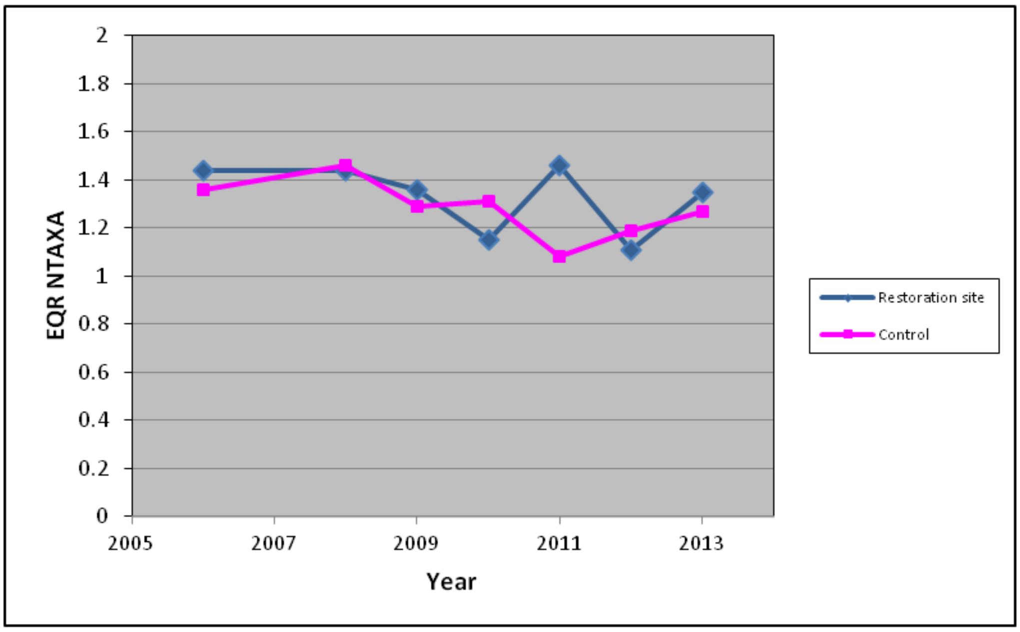
The NTAXA for the control and restoration site are presented in Table 5.21 and Figure 5.13.

Table 5.21 Number of taxa

Site	Date	NTAXA value (family)	NTAXA expected value from RICT	EQR NTAXA
Restoration	28/08/2007 Pre-restoration	39	26.01	1.44
	22/08/2008 Post-restoration	39	26.01	1.44
	25/08/2009 Post-restoration	37	26.01	1.36
	16/08/2010 Post-restoration	30	26.01	1.15
	10/08/2011 Post-restoration	38	26.01	1.46
	7/08/2012 Post-restoration	29	26.01	1.11
	5/09/2013 Post-restoration	35	26.01	1.35
Control	28/08/2007 Pre-restoration	38	26.80	1.36
	22/08/2008 Post-restoration	41	26.80	1.46
	25/08/2009 Post-restoration	36	26.80	1.29
	16/08/2010 Post-restoration	35	26.80	1.31
	10/08/2011 Post-restoration	29	26.80	1.08
	7/08/2012 Post-restoration	32	26.80	1.19
	5/09/2013 Post-restoration	34	26.80	1.27

Notes: EQR = Ecological Quality Ratio; RICT = River Invertebrates Classification Tool

Figure 5.13 Family NTAXA EQR for macroinvertebrates



Summary against objective

The EQR NTAXA value varied slightly throughout the study period with both sites following a similar trend with the exception of 2011 when a higher score was observed at the restoration site. Throughout the study the EQR remained consistently above the EQR boundary score (>0.85) for 'high status' as used in the RICT tool to classify water bodies for the Water Framework Directive. Examination of the taxa reveals a similar community at both sites before and after restoration.

Limitations of macroinvertebrate analysis

The monitoring protocol was limited to a single sample within the restoration site and a single sample taken in the control site annually. No replicates were taken elsewhere within the restoration site, which would provide more confidence that the sample was representative – by presenting the average values.

One of the main limitations is that the restoration actions were carried out within sub-reaches of the site and were designed to create micro-habitats to increase diversity. The pre- and post-restoration surveys were not chosen specifically to sample within and compare between the micro-habitat areas and so the overall results for the reach may not reflect the small-scale changes to species distribution and abundance within the new habitats.

There is no clear null hypothesis other than simply monitoring for change (that is, monitoring was set up without really considering what questions to answer). As such it is not possible to apply any form of statistical analysis to the data or to accurately determine if there are significant changes between the restoration and control sites.

Any trend analysis for each site is effectively based on three single points (one for each year). Without additional samples it is not possible to determine accurately if any single sample is representative of the site in any given year.

5.4 Fish objectives

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

5.4.1 Increased abundance of fish species preferring clean fast-flowing water

Figure 5.12 shows the density of salmon, trout and grayling in the Butcher Stream[1] from 2001 to 2009. These results provide more detail on the overall trends in fish populations in the wider catchment. It can be seen that salmon populations were lower in 2007, 2008 and 2009 than in 2006. A similar trend exists for populations of trout and grayling.

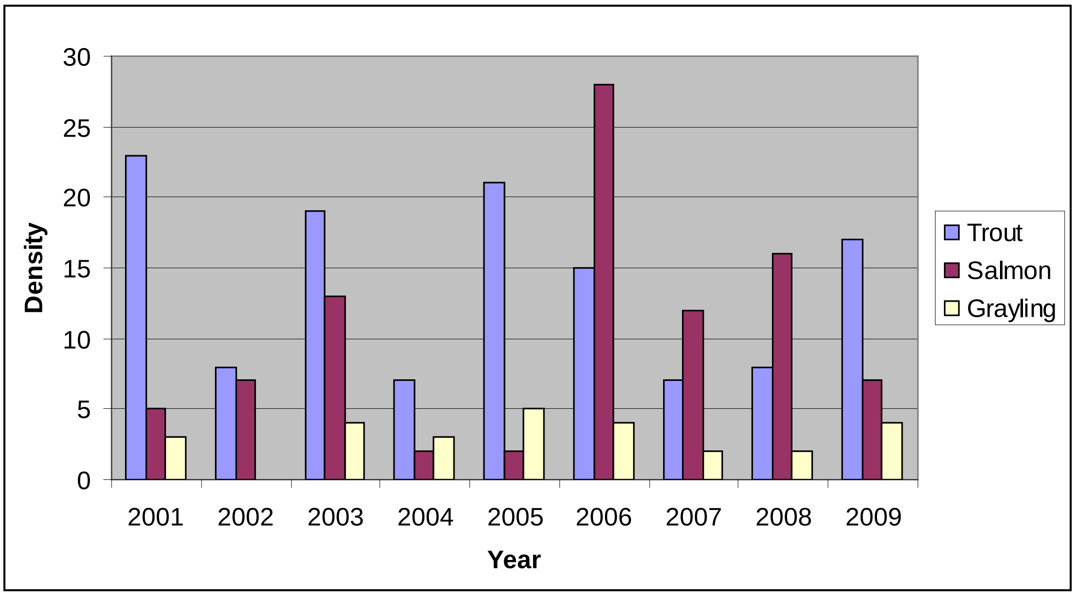
Figure 5.13 shows salmon parr numbers recorded between 2006 and 2009 at two sites in the restoration reach (SHR01 and SHR02) and two sites in the control reach (SHC01 and SHC02). There are no consistent trends across the four sites but the data show a peak in densities for 2008 at site SHR1. The lack of replication makes it difficult to have complete certainty with these findings; the large peak of salmon seen at SHR1 in 2008 could be representative but equally it could be a natural peak that a larger number of replicates would have evened out. Continued sampling over time would also help to better reflect the true trend. Comparison of these results with those observed at the Butcher Stream indicate that the trend was not repeated, indicating that the increase could be attributable to the restoration measures.

Figure 5.14 shows trout numbers recorded between 2006 and 2009 at the same four sites. The control sites appear to be consistently higher than both restoration sites, although both restoration sites show increased numbers of trout compared with the 2006 findings. Lack of replication again makes it difficult to be completely certain about these findings. Continued sampling over time would also help to better reflect any true trends.

Figure 5.15 shows grayling numbers recorded between 2006 and 2009 at the same four sites. There are no consistent trends across the four sites other than noticeable drops in numbers for 2008. Given that 2008 was a peak year for other notable species (salmon, bullhead) it is possible that the survey results are skewed by natural fluctuations in numbers, for example, seasonal variation such as the timing of spawning runs. Again the lack of replication causes problems.

Figure 5.12 Fish density at Butcher Stream

[1] Immediately above the sluices at Seven Hatches, the River Wylye splits into two channels just above the sluices – the main Wylye (known locally as the 'Union') and the Butcher Stream.



30
25
20
15
10
5
0
Density
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year
Trout
Salmon
Grayling

Figure 5.13 Salmon parr (*Salmo salar*) data for 2006, 2008 and 2009

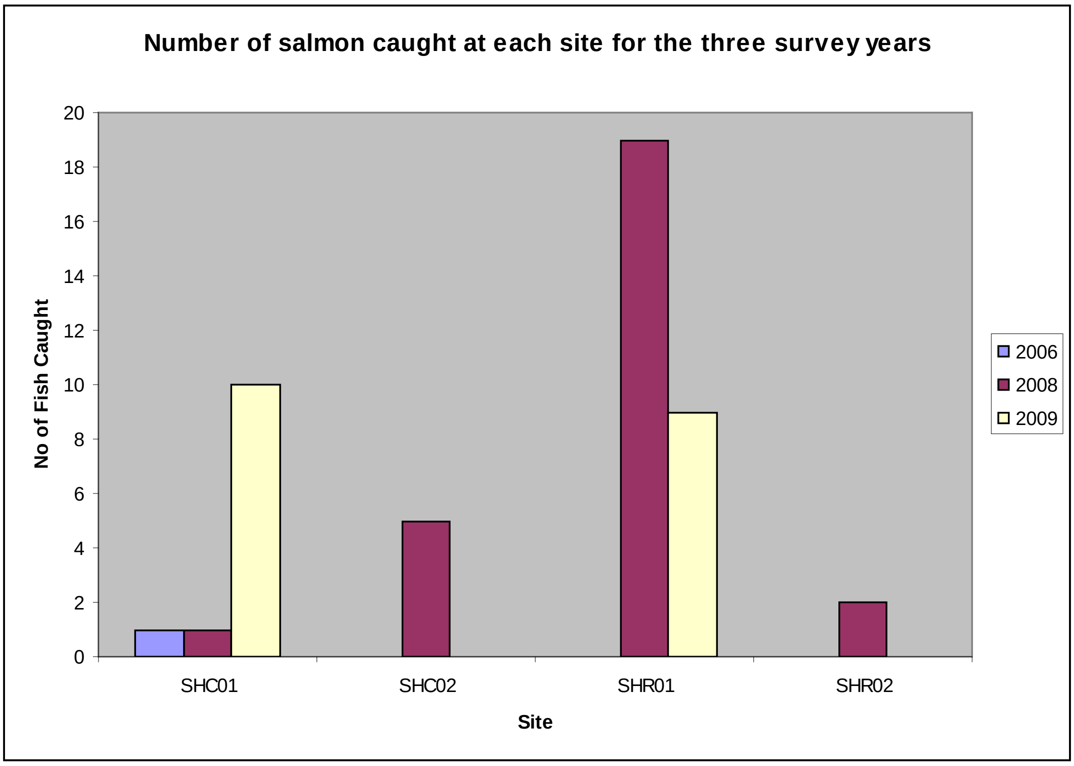


Figure 5.14 Trout (*Salmo trutta*) data for 2006, 2008 and 2009

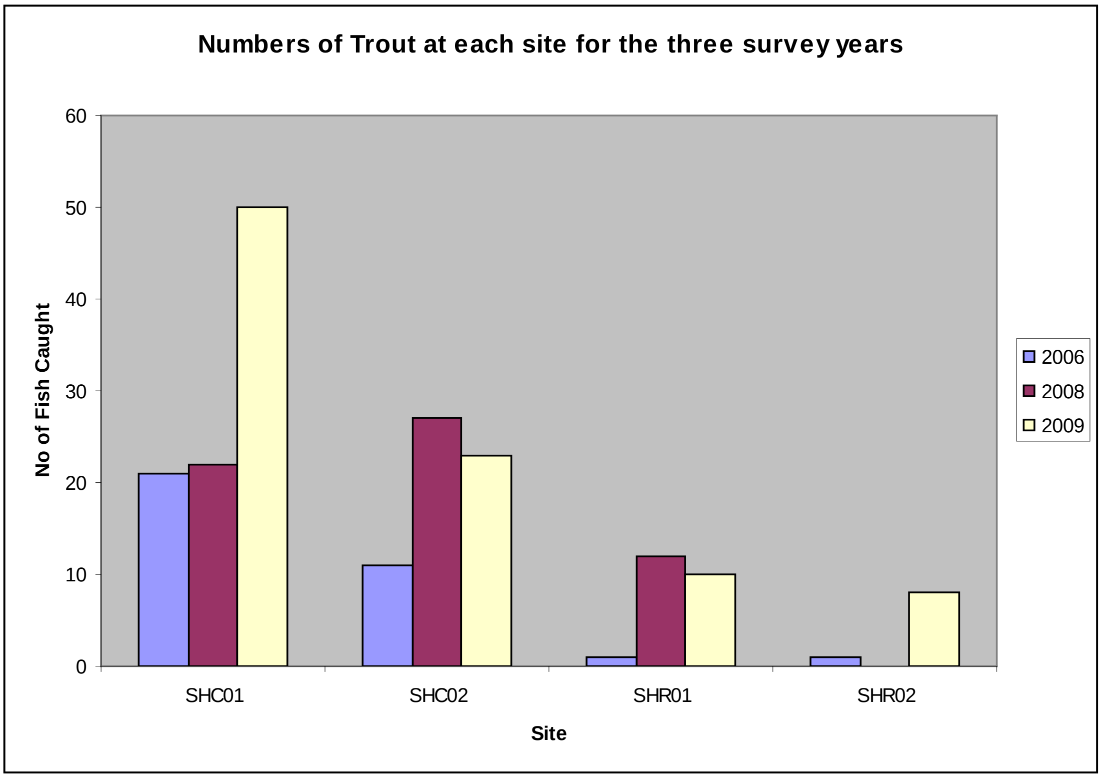
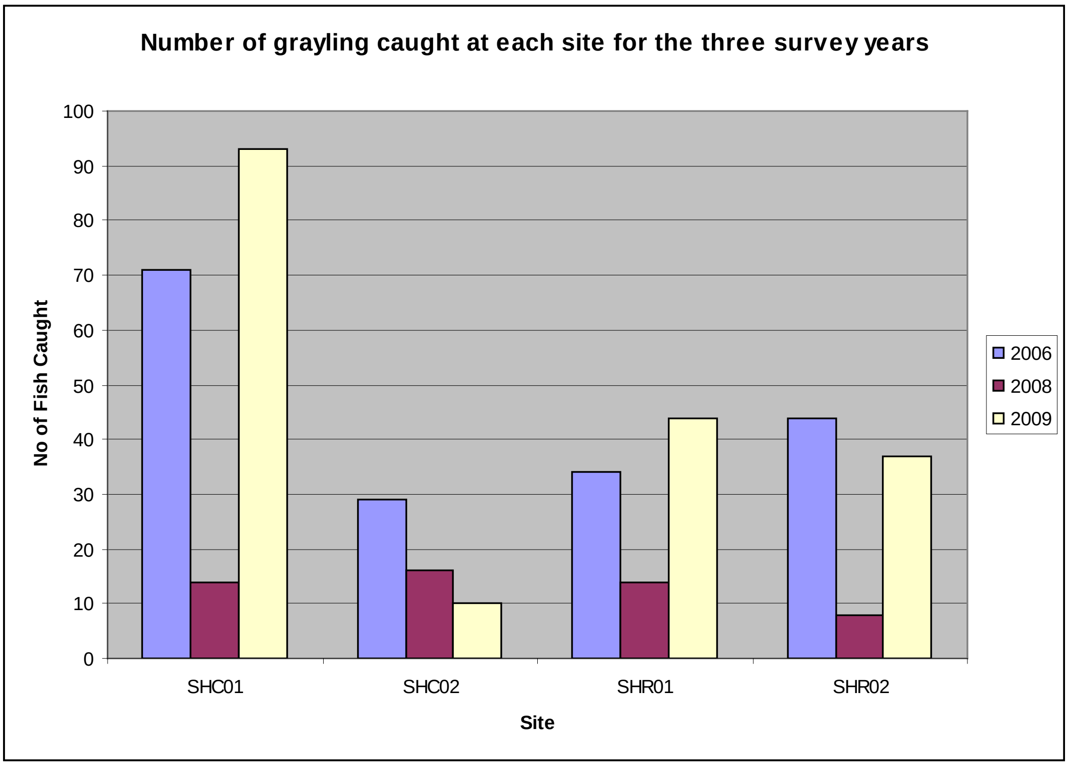


Figure 5.15 Grayling (*Thymallus thymallus*) data for 2006, 2008 and 2009



Summary against objective

The range and number of fish caught in 2008 and 2009 varied significantly compared with findings from 2006. The most important differences include an increase in the number of salmon and trout. This may be related to greater flow velocities experienced within the reach in 2008 and to the increased area of gravel substrate in the restoration reach, as these fish require swift clear water and prefer gravel substrate. These results are not replicated in the Butcher Stream where populations decreased post 2006. This suggests that the changes may be attributable to the restoration measures.

Populations of grayling decreased in the second year of monitoring before increasing in the third year. Again, these trends are not repeated at the Butcher Stream site, indicating that changes may be attributable to the restoration measures.

5.4.2 Increase abundance of Atlantic salmon, bullhead and lamprey

The recorded abundance of Atlantic salmon, bullhead and lamprey at the restoration and control sites are shown in Figures 5.16 to 5.18.

Figure 5.16 Lamprey (*Lampetra* spp.) data for 2006, 2008 and 2009

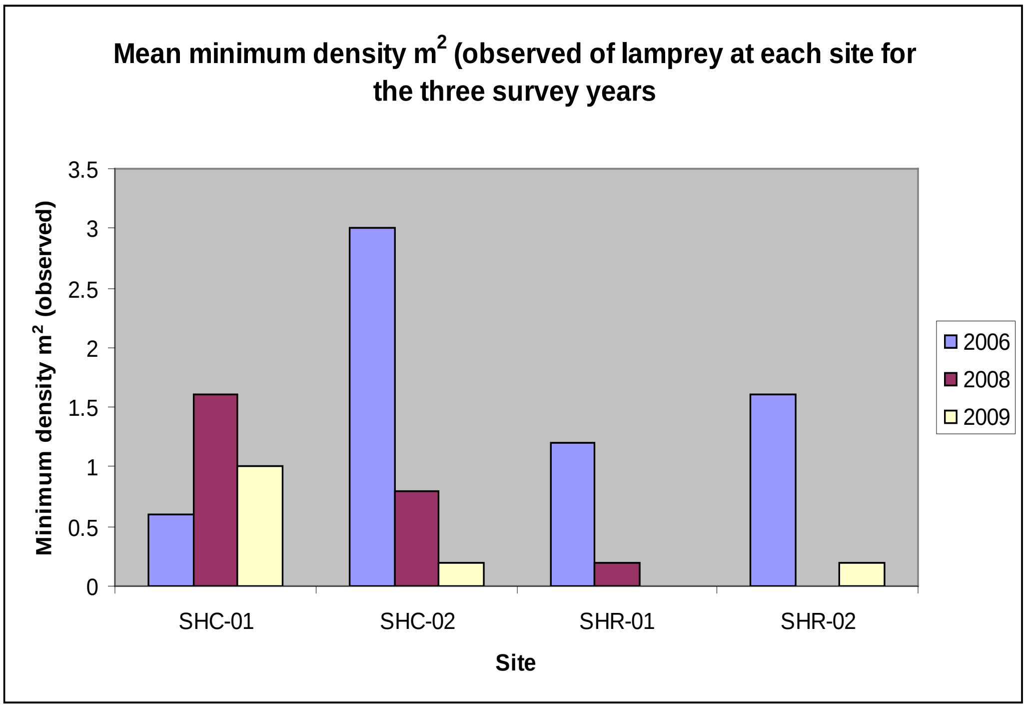


Figure 5.17 Bullhead (*Cottus gobio*) data for 2006, 2008 and 2009

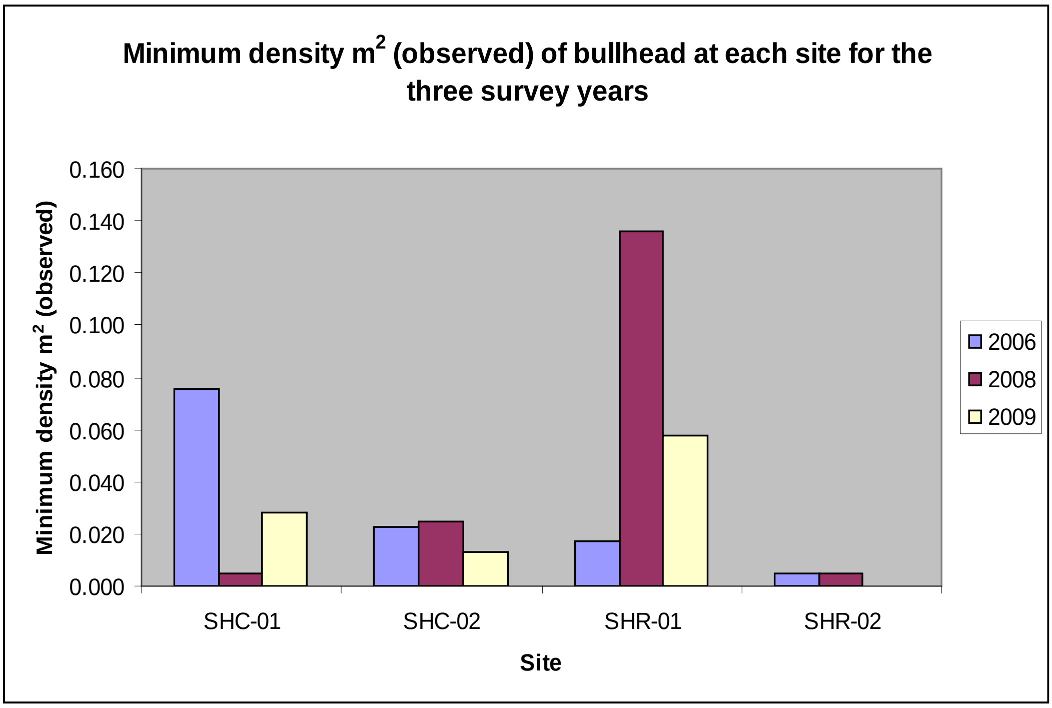
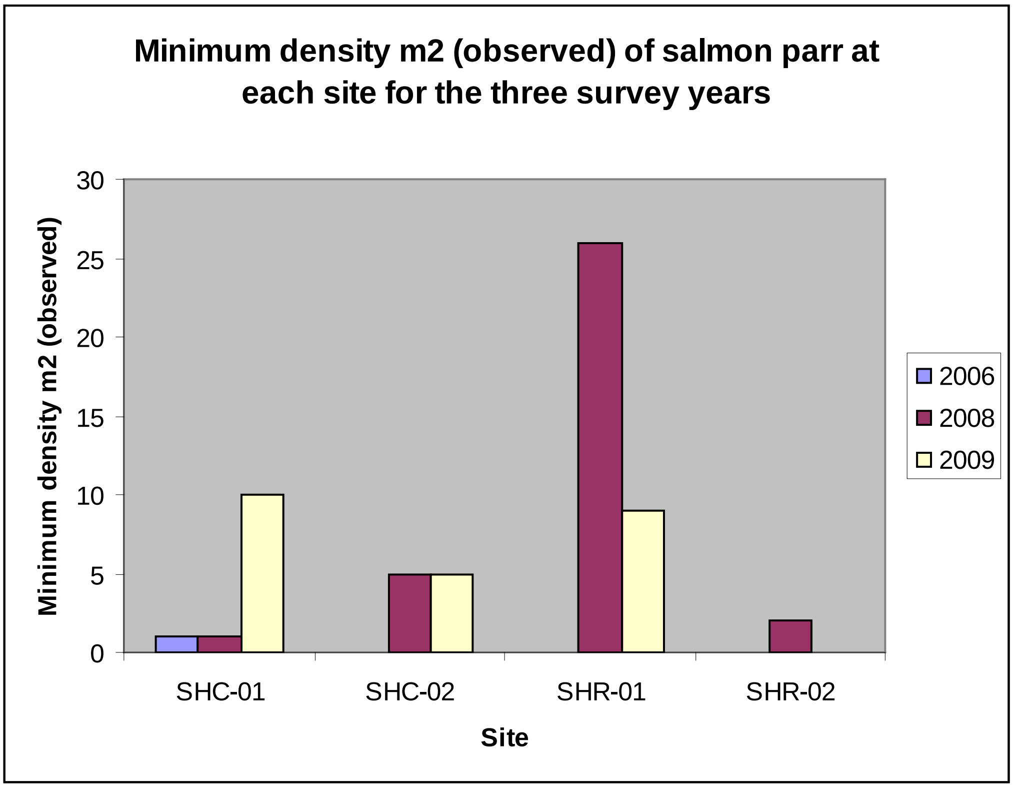


Figure 5.18 Salmon parr (*Salmo salar*) data for 2006, 2008 and 2009



Comparison between 2006 and 2008

In 2008 the total number of bullhead caught in the control site was 31 compared with 154 in 2006, and the number of lamprey caught was 17 compared with 60 in 2006. The minimum density of both bullhead and lamprey was much lower in 2008, apart from for bullhead at SHC02, than in 2006. These differences are likely to be due to the higher flow velocities and depth of flow experienced in 2008 making habitat conditions less suitable for these species. The greater number of bullhead caught at SHC02 compared with SHC01 in 2008 may indicate that this shallower and faster flowing section provided less preferable habitat for the fish species observed during higher flows than SCH02. This could be due to a lack of deeper, resting areas and shelter. More lamprey were still found in SHC01, possibly due to the continued presence of silted marginal habitat at this location.

More salmon were caught at the control site in 2008 than in 2006. This may be related to greater flow velocities experienced within the reach in 2008, as these fish require swift clear water. However, several other wider catchment conditions (such as water quality and prey availability) also influence fish populations, particularly of migratory fish.

At SHR01 the number of bullhead caught increased from 21 in 2006 to 101 in 2008 and then decreased to 21 in 2009. The increase may be due to the areas of shelter that have been created by the log deflectors and in the areas around large stones introduced as part of the restoration. The reason for the decrease in 2009 is not clear; comparison with wider catchment data is needed to enable any conclusions to be drawn.

The minimum density of lamprey is significantly lower in 2008 at both SHR01 and SHR02 than in 2006. Lamprey ammocoetes require shallow waters with low water velocity and the presence of organic detritus and/or plant material. The higher flow velocities and depth of flow experienced in 2008 may therefore have made habitat conditions less suitable for lamprey.

At the restoration site, increased numbers of salmon were caught in 2008 than in 2006 (21 and 0 respectively). The increase may be related to greater flow velocities experienced within the reach in 2008, as salmon require swift clear water. This may in part be due to the river restoration works, although it is not possible to separate this influence from the increase in flow velocity due to higher discharge within 2007 and 2008. Several other wider catchment conditions (such as water quality and prey availability) also influence fish populations, particularly of migratory fish.

Comparison between 2008 and 2009

Lamprey densities declined across all sites between 2008 and 2009. However, this result is limited due to lack of replication. Wider contextual data would help to determine if this decline happened throughout the catchment or if there were environmental pressures acting on this stretch alone.

SHC01 and SHC02 both indicate a general declining trend over time of bullhead densities between 2008 and 2009, whereas SHR01 shows an increasing trend over time. As with many of the other results it is difficult to have complete certainty with these findings due to the lack of replication. The large peak of bullheads seen at SHR01 in 2008 highlights the limited confidence in any single sample being representative for that year. A larger number of replicates might have evened out these large peaks. Continued sampling over time would also help to better reflect the true trend.

The number of salmon caught increased at the control site but decreased at the restoration site between 2008 and 2009. Several wider catchment conditions (such as water quality and prey availability) can influence fish populations, particularly of migratory fish. Wider contextual data might provide some information regarding salmon and bullhead numbers throughout the catchment (that is, was this peak was seen elsewhere?).

Summary against objective

Populations of lamprey at the control site decreased from 60 in 2006 to 17 in 2008 and 6 in 2009. The differences between the 2006 and 2008 data are likely to be due to the higher flow velocities and depth of flow in 2008 making habitat conditions less suitable for lamprey. Populations at the restoration site also decreased.

Populations of bullhead at the control site decreased from 154 in 2006 to 31 in 2008, but then increased to 49 in 2009. The differences between 2006 and 2008 are likely to be due to the higher flow velocities and depth of flow experienced in 2008 making habitat conditions less suitable. The greater number of bullhead caught at SHC02 than at SHC01 in 2008 may indicate that the faster flows in SHC01 were a less suitable habitat for bullhead. This could be due to a lack of deeper, resting areas and shelter. The increase in bullhead between 2008 and 2009 could be a result of flow conditions being similar to those observed in 2006, although it is not clear why the number of bullhead remained significantly lower than in 2006.

At SHR01 in the restoration reach, the number of bullhead caught increased from 21 in 2006 to 101 in 2008, and then decreased to 21 in 2009. The increase may be due to the areas of shelter created by the log deflectors and in the areas around large stones introduced as part of the restoration. The reason for the decrease in 2009 is not clear and would need comparing with wider catchment data to enable any conclusion to be drawn.

At the control site, the number of salmon caught increased from 1 to 4 between 2006 and 2008. This may be related to greater flow velocities experienced within the reach in 2008, as these fish require swift clear water. However, several other wider catchment conditions (such as water quality and prey availability) also influence fish populations, particularly of migratory fish. Numbers of salmon caught decreased in 2009.

At the restoration site, increased number of salmon were caught in 2008 than in 2006 (21 and 0 respectively) before returning to 0 in 2009. The increase may be related to greater flow velocities experienced within the reach in 2008, as salmon require swift clear water. This may in part be due to the river restoration works, although it is not possible to separate this influence from the increase in flow velocity due to higher discharge within 2007 and 2008. Several other wider catchment conditions (such as water quality and prey availability) also influence fish populations, particularly of migratory fish. The reason for decrease in 2009 is not known and would need comparing with wider catchment data to establish whether a similar decrease was seen throughout the catchment.

Overall, the restoration measures do not seem to have increased the abundance of bullhead and lamprey and numbers of these species actually decreased between 2006 and 2009. In the first year after restoration the numbers of salmon increased markedly, but then decreased in 2009. Further data are needed to establish long-term trends.

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

Figures 5.19 and 5.20 present size frequency plots for bullhead, lamprey and salmon parr species at the restoration and control sites respectively. The plots highlight the increase in salmon parr since the first year and the decline in lampreys over the same period.

In terms of age class distribution, only for bullhead is there sufficient data to make any kind of comparison. For bullheads the age classes are:

- 0+ (average length 40 mm)
- 1+ (average length 60 mm)

The restoration sites appear to clearly demonstrate two age class distributions for bullhead in 2008 – one peak at 40 mm and another at 60 mm). However, the 2009 data only retain the 60 mm age class. The control sites appear to show a large presence of 0+ bullheads in 2006, but no obvious older classes.

At the restoration site there is a visible shift in the age distribution of bullhead over the three years of the monitoring. The pre-restoration population was relatively small but was predominantly made up of 0+ individuals. Into the second year (the first year of post-restoration monitoring), the population increased noticeably with clear age classes (0+ and 1+); the 0+ population appears to be approximately twice the size of the 1+ population. By the third year, however, bullhead recruitment appears to have stalled with very few of 0+ fish present and the population consisted of predominantly 1+ individuals.

The trend seen at the control site is for a reduction in bullhead numbers over the three years of monitoring. In all three years the population is predominantly made up of 0+ individuals but no clear population of 1+ individuals.

Figure 5.19 Size frequency plots for key species at restoration sites

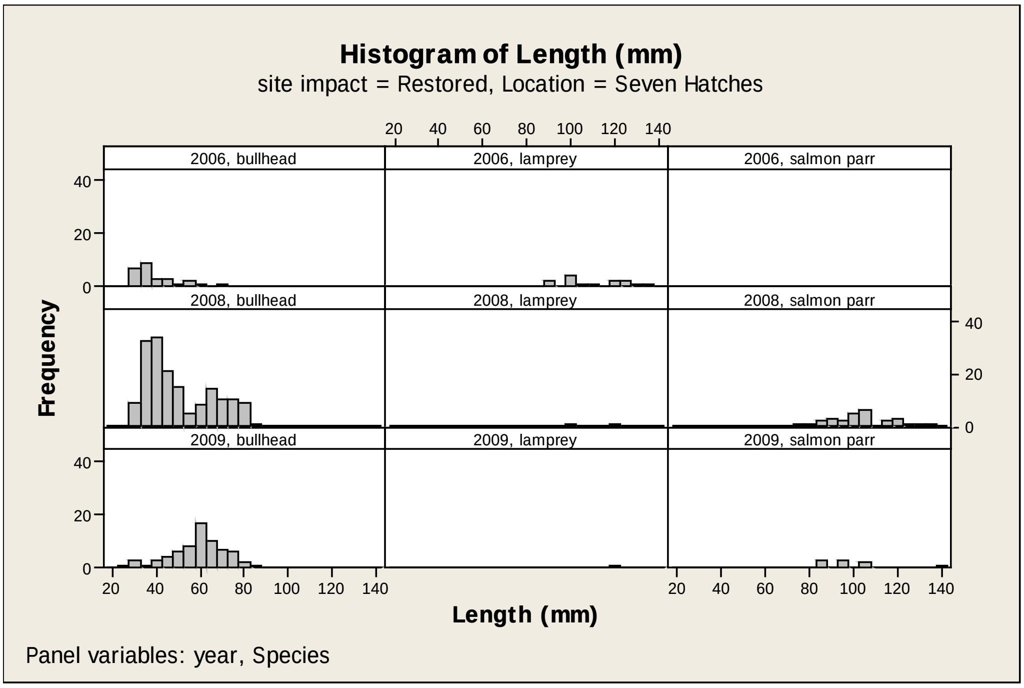
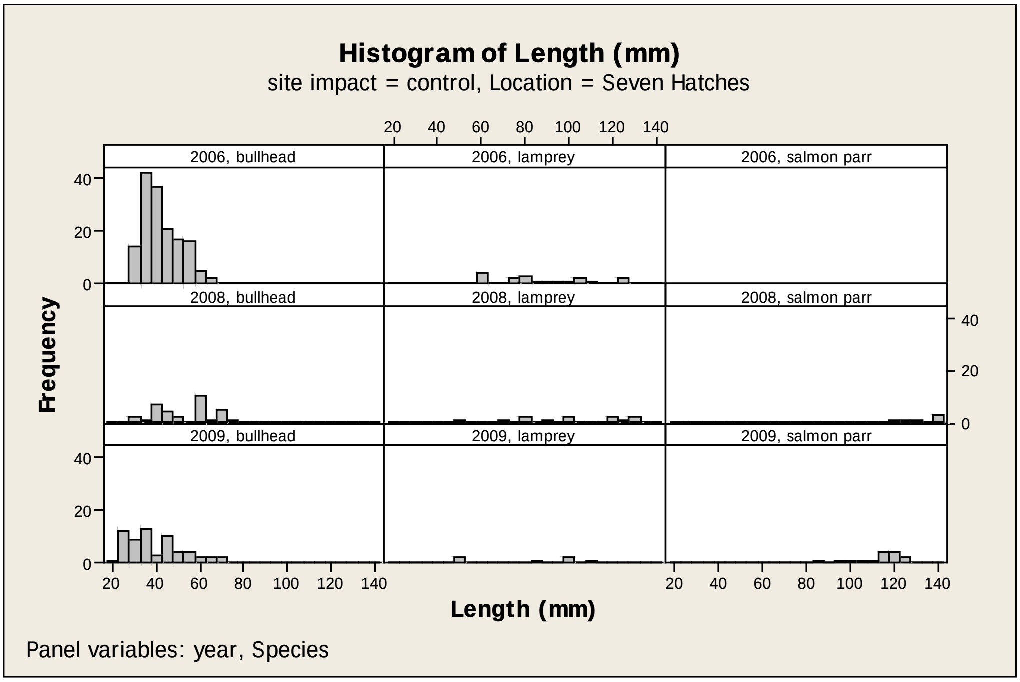


Figure 5.20 Size frequency plots for key species at control sites



Summary against objective

There was a visible shift in the age distribution of bullhead over the three years of the monitoring. The pre-restoration population was relatively small but was predominantly made up of 0+ individuals. Into the second year (the first year of post-restoration monitoring), the population increased noticeably with clear age classes (0+ and 1+); the 0+ population appears to be approximately twice the size of the 1+ population. By the third year, bullhead recruitment appeared to have stalled with very few of 0+ fish present and a population made up of predominantly 1+ individuals.

The trend seen at the control site is for a reduction in bullhead numbers over the three years of monitoring. In all three years the population is predominantly made up of 0+ individuals with no clear population of 1+ individuals.

It is difficult to determine the ‘natural’ situation for bullhead numbers over such a short timeframe and therefore difficult to attribute any fluctuation in numbers to the restoration itself. Monitoring for over 10 years is typically recommended to rule out natural variation.

Limitation of fish data analysis

Although catch depletion techniques (that is, three fishing runs at each site) were employed, the sampling protocol still effectively results in a single result per year per site. Without many years of data or temporal replication in each year, it is difficult to comment on how representative each result is.

Temporal replication (that is, repeated surveys over a defined window of time, for example, five surveys undertaken over an eight-week window) would help to even out any natural variation that might skew a single sample. Without temporal replicates it is not possible to determine how representative each sample is (that is, the result in each year is based on a single result rather than a mean value from multiple surveys). As such, the assessment is simply descriptive.

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

When assessing the age structure of fish, the only dataset where this was possible is bullheads as the overall numbers for other species were too small to clearly discern age classes.

5.5 Summary of results

The following provides an overview of the effectiveness of the restoration measures in meeting the hydromorphological, macrophyte, macroinvertebrate and fish objectives at Seven Hatches. Table 5.21 summaries this information.

5.5.1 Hydromorphological objectives

The restoration measures implemented at the restoration site caused increased variation in width and depth.

The restoration measures caused increased localised velocities along the length of each gravel riffle in the restoration reach (approximately 180 m of the 500 m reach). However, some of this increase is likely to be attributable to natural variations as a result of increased water levels, as shown in the results at the control site.

Although the restoration measures increased the extent of exposed gravel substrate, in most areas this is as a direct result of importing gravel to create riffles. There is some evidence of increased gravel material where riffles have not been created, but changes to the substrate at the control site mean that these are more likely to be attributable to natural processes within the system rather than as a result of the restoration.

The restoration measures increased height and coverage of riparian vegetation, but this is directly attributable to the erection of the buffer strip fence. Some increase in height and coverage of vegetation would be expected due to natural growth patterns and this is confirmed by the increase evident at the control site.

The overall effectiveness of the measures may be limited by the apparent lack of response in the parts of the reach that have not been directly restored, although this is likely to be a result of the relatively short timescales over which monitoring has been undertaken. More significant changes are likely to occur in the future (for example, after geomorphologically effective flood flows) as the river gradually adjusts to the altered conditions.

5.5.2 Macrophyte objectives

Macrophyte cover at the restoration site increased following the implementation of the restoration measures, suggesting that the measures were effective. However, this increase was considerably smaller than that observed at the adjacent control reach. This is likely to represent the considerable disturbance to bed conditions that occurred when the works were carried out. This apparent discrepancy could also be partially explained by other factors such as a large flood event which occurred before 2006, or a pollution event during which a high proportion of macrophytes were lost. Macrophyte cover at the restoration site is expected to increase further over time.

The proportion of macrophyte species which prefer swift flows increased at the restoration site, suggesting that the measures have been effective. However, this increase is considerably smaller than that observed at the control site. This may be representative of the bed disturbance and resulting loss of macrophyte cover while the works were carried out and the earlier loss of macrophytes which occurred prior to 2006. The proportion of macrophytes which prefer swifter flows is expected to increase further over time.

The proportion of macrophyte species which prefer slow flows decreased at the restoration site in response to an increase in flow velocities. Conversely, the proportion of these species at the control site increased slightly. This suggests that the restoration measures were effective in reducing the coverage of slow-flow tolerant species.

The changes in macrophyte composition at the restoration site appear to be relatively insignificant when compared with the results displayed at the control site. However, the changes in macrophyte communities at the control site could be partially attributable to unconfirmed external factors such as a large flood event or pollution incident which occurred prior to 2006 resulting in a loss of macrophytes, and the subsequent recovery of macrophyte communities in this reach. This may mean that the data for the control site are misleading and that the effectiveness of the measures at the restoration site is underestimated.

5.5.3 Macroinvertebrate objectives

The macroinvertebrate assemblage at the restoration site initially decreased as a result of the restoration works due to the bed disturbance that this involved. Although diversity subsequently recovered, this does not appear to have changed significantly more than that observed in the control site. However, species diversity was already high at both sites prior to the restoration works and so the measures may not be expected to have a significant impact on macroinvertebrate communities once they have recovered from the initial disturbance. It is therefore not possible to accurately determine the effectiveness of the restoration measure in terms of improvements to macroinvertebrate population diversity.

Macroinvertebrate species evenness increased at the restoration site but corresponding increases were also observed at the control site. It is therefore not possible to determine the effectiveness of the restoration measures on the evenness of macroinvertebrate communities.

The River Invertebrate Classification Tool (RICT) enables of the condition of ‘benthic macroinvertebrates’ listed in Annex V of the Water Framework Directive to be assessed. The method assesses the condition of macroinvertebrates using the parameters number of taxa (NTAXA) and average score per taxon (ASPT). A comparison of the observed/expected scores of NTAXA and ASPT from RICT as used for WFD classification indicates that there were only minor changes in the condition of benthic macroinvertebrates. However, this is to be expected because the observed scores pre-restoration exceeded the EQR boundary for ‘high’ status.

Family level LIFE scores were consistent throughout the study period and CCI scores remained high. It is therefore not possible state categorically that the measures had been effective in improving invertebrate communities at the restoration site. However, the high taxonomic richness observed at both sites suggests that a significant increase in response to restoration measures is unlikely to be expected.

A review of the PSI scores derived from the macroinvertebrate data shows that there was an overall increase in the number of fine sediment-sensitive taxa recorded as a proportion of all taxa found at both the restoration and control sites. However, the data do not support the hypothesis that the restored site had improved in regard to impacts from siltation on macroinvertebrate species in comparison with the control site.

The restoration measures had not increased taxonomic composition at the restoration site. It is therefore not possible to assess accurately the effectiveness of the restoration measures in terms of increased numbers of macroinvertebrate taxa.

5.5.4 Fish objectives

The restoration measures appeared to have been initially successful in increasing the population of fish that prefer faster flowing water. This is shown by the increase in salmon and trout populations in the first year after restoration. The magnitude of change was not replicated at the control reach, suggesting that the restoration measures were directly responsible. However, the number of these species caught in 2009 decreased. The local fisheries monitoring team observed peaks in their long-term operational data at individual sites which are usually associated with clustered spawning or the downstream migration of parr as flows drop off and favoured nursery habitat becomes more localized (Hopkins E, personal communication). Wider catchment data are required to determine if this trend is replicated elsewhere.

Further monitoring is required to fully understand the impact on salmon and trout populations. The restoration does seem to have been effective in increasing grayling populations, although this result required comparison with wider catchment data to establish whether the restoration measures were solely responsible.

The restoration measures do not seem to have increased the abundance of bullhead and lamprey, and numbers of these species actually declined between 2006 and 2009. In the first year after restoration the numbers of salmon increased markedly but then decreased in 2009.

The data are not sufficient to undertake a full analysis of the age distribution of lamprey and salmon parr. However, results suggest that the restoration has been successful in changing the age structure of bullheads with an increase in juvenile bullheads.

Table 5.22 Summary of results

Objective	Was objective achieved?	Was monitoring successful?
Hydromorphological objectives		
Increased variation in depth and width within three years of implementation	Width and depth variation has increased. Effectiveness of measures is limited by the apparent lack of response in other parts of the reach that have not been directly restored.	The cross-section surveys were successful in monitoring change in width and depth. However, additional cross-sections in the reach upstream of Seven Hatches would have enabled a better analysis as it was this section of the reach where specific narrowing measures were implemented.
Increased localised and average velocities immediately after restoration	Localised velocity increased along the length of each gravel riffle, but had minimal impact in sections of the reach that were not directly restored.	Velocity measurements were successful; however, the analysis could have been improved by monitoring throughout the restoration reach. A major limitation is that flow velocities are influenced by water levels and therefore comparison is subject to error.
Increased area and frequency of exposed gravel substrate within three years of implementation	The extent of exposed gravel substrate increased but in most areas this was as a direct result of importing gravel to create riffles.	Substrate monitoring was based on observations of sample size rather than the measurement of particle size. This limited the extent of quantitative analysis.
Increased height and coverage of riparian vegetation within a year of implementation	The buffer strip fence increased the height and coverage of riparian vegetation.	No specific monitoring was undertaken to record the height and coverage of riparian vegetation. Neither the river corridor survey nor the macrophyte transect survey record height or coverage accurately.
Increased morphological diversity (based on width, depth and sinuosity and in-channel features) within three years of implementation	Morphological diversity increased in the areas where gravel riffles were created. These measures increased width and depth variation, introduced greater flow velocities and increased coarse bed substrate.	See previous comments on width and depth, velocity and substrate monitoring.
Macrophyte objectives		
Increase percentage cover of macrophytes within one year of	The restoration work increased flow velocities and the extent of gravel	Monitoring was successful in measuring the change in macrophyte coverage.

Objective	Was objective achieved?	Was monitoring successful?
implementation	substrate with a corresponding increase in macrophyte cover. restoration. However increases observed at the control reach mean that the change cannot be attributed to the scheme.	However, results at the control site suggest macrophyte growth was greater than expected due to natural variation. Extending the survey to include the entire restoration reach would have enabled more accurate analysis. Repeated survey over time frame is recommended to allow recovery following the disturbance of the restoration work.
Increase in number of macrophyte species preferring faster flows within one year of implementation	The restoration work increased flow velocities and the extent of gravel substrate with a corresponding increase in species preferring faster flows. However increases observed at the control reach mean that the change cannot be attributed to the scheme.	See explanation above.
Decrease in number of macrophyte species preferring slower flows within one year of implementation	The restoration work increased flow velocities and the extent of gravel substrate with a corresponding decrease in species preferring slower flows. This pattern was not observed at the control reach suggesting that this objective was achieved.	See explanation above.
Macroinvertebrate objective		
Increase in macroinvertebrate species diversity and evenness within three years of implementation	The restoration and control sites both had highly diverse macroinvertebrate communities prior to the restoration scheme. It would appear that macroinvertebrate diversity decreased in the year after the restoration due to disturbance. Diversity increased the following	Increased replicates and additional monitoring locations would have enabled more robust analysis. Longer term monitoring would enable future trends to be identified.

Objective	Was objective achieved?	Was monitoring successful?
	year.	
Increase in CCI and LIFE scores within three years of implementation	As both restoration control sites started with very high taxon richness (>20 CCI), it is unlikely that either site would significantly increase over time.	See explanation above.
Increase in the proportion of sediment sensitive taxa within three years of implementation	According to the PSI scores derived from the macroinvertebrate data there was an overall increase in the number of sediment sensitive taxa recorded as a proportion of all taxa found at both the restoration and control sites.	See explanation above.
Increased taxonomic composition within three years of implementation	No increase in taxonomic composition was recorded at the restoration site.	See explanation above
Fish objectives		
Increased abundance of fish species preferring clean fast-flowing water within three years of implementation	The increase in the number of salmon and trout is likely to be related to increased flow velocities due to the restoration.	Survey methodology was successful but temporal replication (that is, repeated surveys over a defined window of time would help to even out any natural variation that might skew a single sample.
Increased abundance of Atlantic salmon, bullhead and lamprey within three years of implementation	Bullhead and lamprey abundance did not increase during the monitoring period. Salmon abundance increased immediately after restoration and then decreased.	See above.
Changed age structure of fish communities (increased presence of juvenile fish) within three years of implementation	Results suggest that the restoration was successful in changing the age structure of bullheads with an increase in juvenile bullheads.	See above.

6 Effectiveness of restoration measures

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

6.1 Statement of effectiveness

The ecological condition of the River Wylye at Seven Hatches was being adversely impacted by the hydromorphological conditions within the river. More specifically, historical over-widening and over-deepening of the channel had resulted in slower flows and siltation on the channel bed. This had smothered gravel habitats and consequently damaged favourable status for the water crowfoot macrophyte community, and resulted in the absence of salmon spawning. The paucity of large woody debris had reduced the morphological variation present in the river, with an associated reduction in habitat quality and availability for, among others, bullhead, Atlantic salmon, brook lamprey and water crowfoot.

6.1.1 Effectiveness of hydromorphological measures

The results of the data analysis suggest that, at the direct location where the restoration measures were implemented, they have been successful in meeting the following hydromorphological objectives:

- increased variation in width and depth
- increase in localised and average velocity
- increased area and frequency of gravel substrate
- increased height and coverage of riparian vegetation

The overall effectiveness of the measures may be limited by the apparent lack of response in those parts of the reach that have not been directly restored, although this is likely to be a result of the relatively short timescales over which monitoring took place. More significant changes are likely to occur in the future (for example, after geomorphologically effective flood flows) as the river gradually adjusts to the altered conditions.

6.1.2 Response of biology to hydromorphological changes

Macrophytes

The results suggest that, in the restoration reach, the coverage of macrophytes was increasing in response to the increased flow velocities and the presence of gravel substrate. There was also a slight shift towards species preferring faster flows and a decrease in species preferring slower flows. This suggests that the restoration measures were effective in improving habitat for macrophyte communities and in particular those that prefer faster flow velocities.

Macroinvertebrates

It is not possible to state categorically that the measures were effective in improving macroinvertebrate communities at the restoration site. However, the high taxonomic richness observed at both sites suggests that a significant increase in response to restoration measures is unlikely to be expected. Over an increased timeframe it is possible that macroinvertebrate diversity would increase due to the greater extent of gravel substrate and increased flow velocities.

Fish

The restoration measures appear to have been initially successful in increasing the population of fish that prefer faster flowing water. This is shown by the increase in salmon and trout populations in the first year after restoration. Increased macrophyte coverage is also likely to be contributing to increasing fish populations as it provides areas of shelter for spawning and evasion of predation. The magnitude of change seen at the restoration site was not replicated at the control reach, suggesting that the restoration measures were directly responsible. However, populations decreased in 2009. A review of wider catchment data is therefore recommended to determine if this trend is replicated elsewhere. Further monitoring to assess long-term trends would also be beneficial.

6.1.3 Overall effectiveness of the measures

The restoration measures were effective in localised areas in providing hydromorphological conditions that were more conducive for the range of biological quality elements expected in the river (for example, fish, macrophytes and macroinvertebrates). However, there is currently insufficient evidence to prove that the biology has improved. This is likely to be due in part to the short timescales in which monitoring was carried out.

6.2 Limitations

One of the main limitations is that the restoration actions were carried out within sub-reaches of the site and were designed to create micro-habitats to increase diversity. The pre- and post-restoration surveys were not chosen specifically to sample within and compare between the micro-habitat areas and so the overall results for the reach may not reflect the small-scale changes to species distribution and abundance within the new habitats.

The restoration and monitoring were not undertaken 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.

It is also not possible to reach firm conclusions from the monitoring 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 many more years. In addition, it appears the control site was undergoing changes in response to previous works undertaken within the reach, making comparison between the restoration and control sites difficult.

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.
- To capture longer term changes, monitoring should be carried out over a timeframe of approximately 10 years. Detailed baseline information should also be collected pre-restoration to enable the scale of changes to be fully assessed.
- It is recommended that the monitoring at Seven Hatches is continued as many of the effects of the restoration will take longer than this study to become apparent.
- Monitoring should aim to sample within and compare between micro-habitat areas so that the overall results for the reach reflect the small-scale changes to species distribution and abundance within the new habitats.
- To undertake meaningful statistical analysis it is recommended that replicated sampling is undertaken and a before–after–control–impact approach is adopted
- Monitoring of velocities and substrate was not effective in producing data of sufficient quality and resolution. Velocity measurements should be undertaken in a variety of flow conditions and repeated when water levels are similar. Substrate measurements should be taken using a sediment sieve to collect grain sizes and enable a more detailed analysis of sediment distribution.

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List of abbreviations

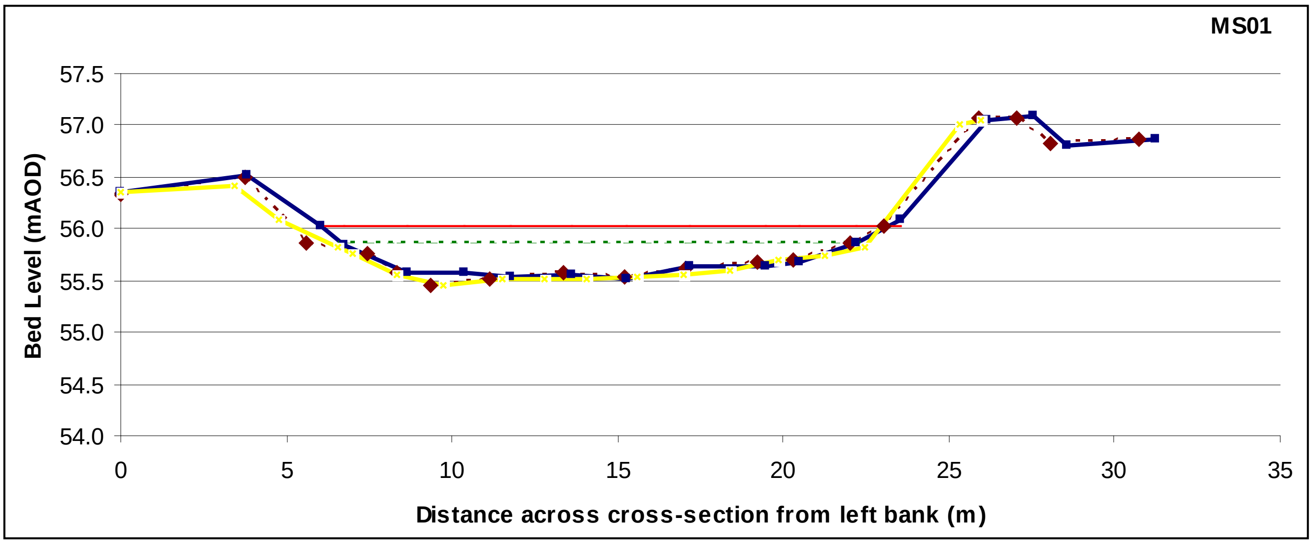
ASPT	average score per taxon
CCI	Community Conservation Index
cSAC	candidate Special Area of Conservation
EQR	Ecological Quality Ratio
FSC2	Fisheries Classification Scheme 2
GEP	good ecological potential
GES	good ecological status
LIFE	Lotic Invertebrate index for Flow Evaluation
NTAXA	number of taxa
PSI	proportion of sediment-sensitive invertebrate's
RICT	River Invertebrates Classification Tool
RRC	River Restoration Centre
SAC	Special Area of Conservation
SPA	Special Protection Area
SSI	sediment-sensitive invertebrates
SSSI	Site of Special Scientific Interest
WFD	Water Framework Directive

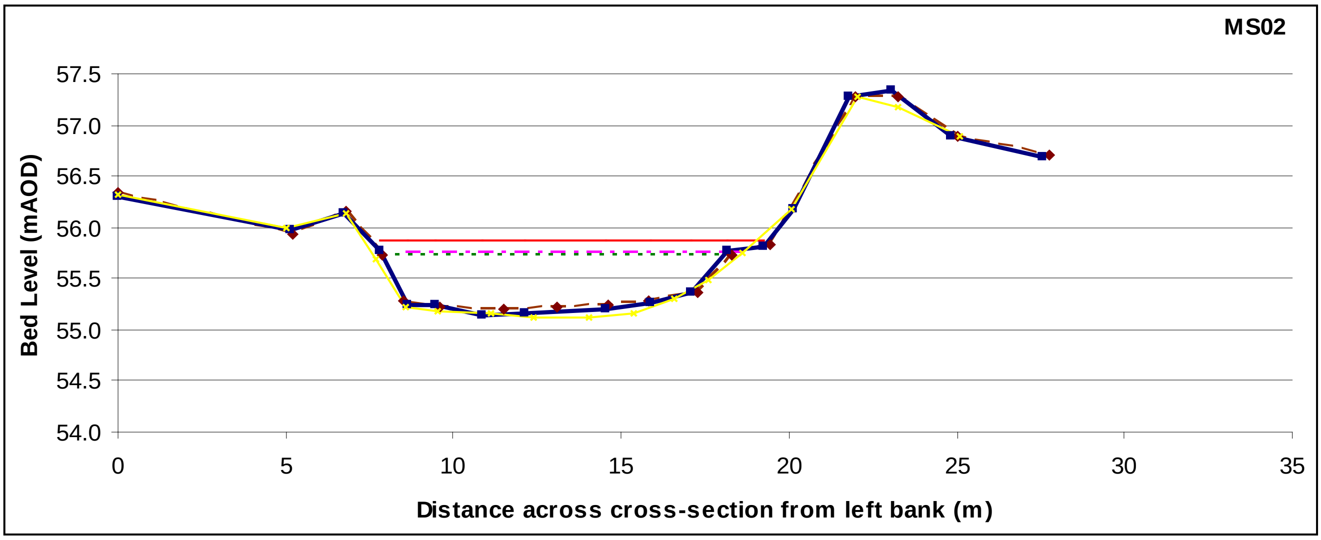
Appendix A: Seven Hatches cross-sections

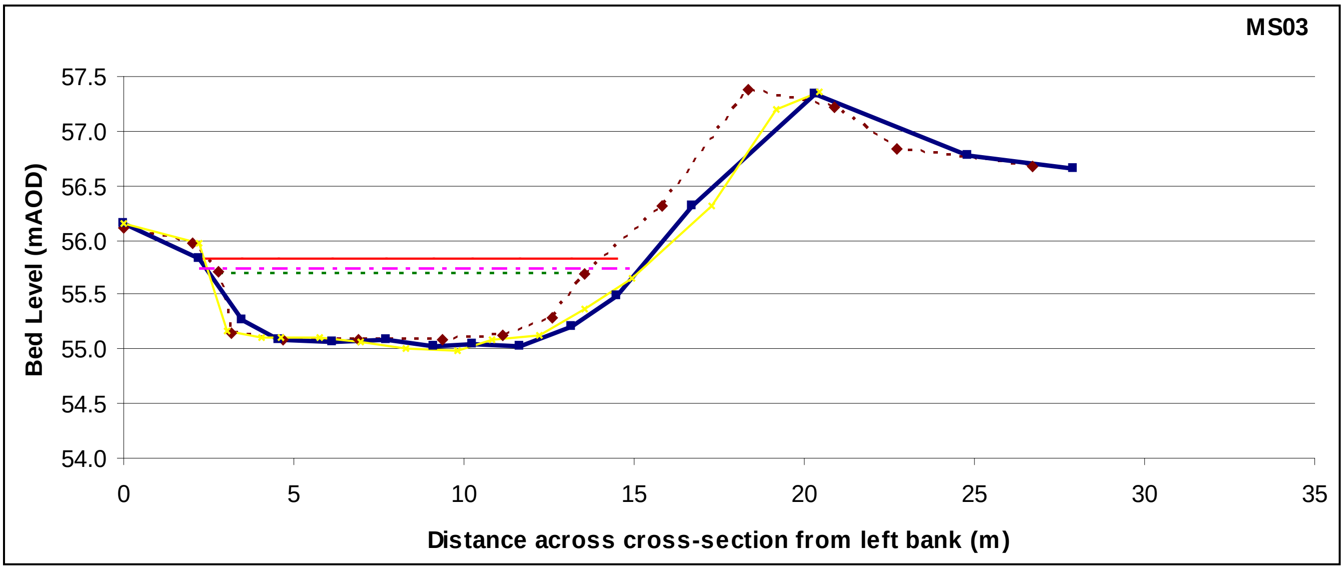
Control site

Key:

Bed elevation 2006	- - - - - - (dashed dark red)	Water level 2006	- - - - - - (dashed green)
Bed elevation 2008	——— (dark blue)	Water level 2008	——— (red)
Bed elevation 2009	——— (yellow)	Water level 2009	——— (dark orange)



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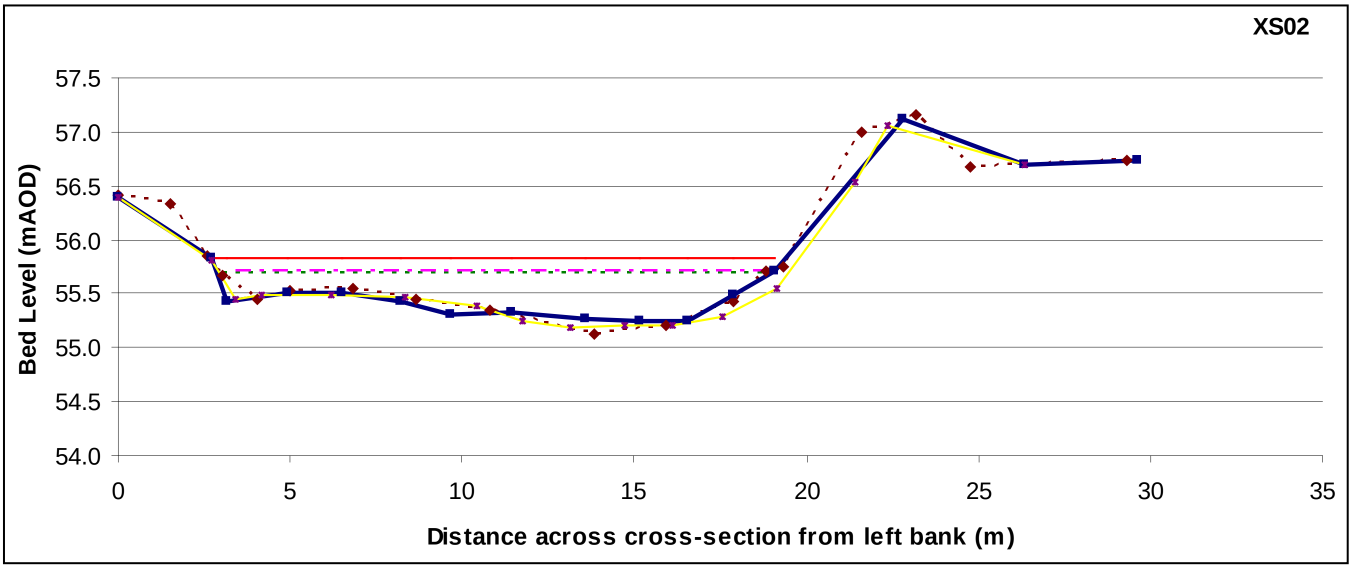
57.5
57.0
56.5
56.0
55.5
55.0
54.5
54.0
Bed Level (mAOD)
0
5
10
15
20
25
30
35
Distance across cross-section from left bank (m)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57.0
56.5
56.0
55.5
55.0
54.5
54.0
Bed Level (mAOD)
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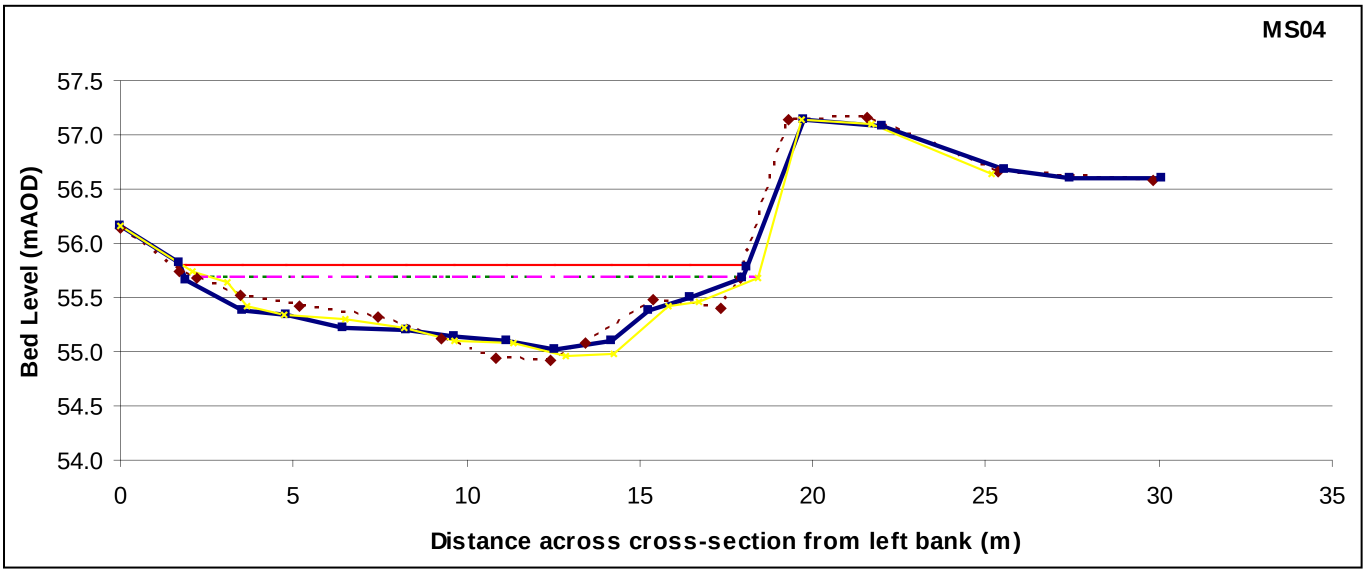
5
10
15
20
25
30
35
Distance across cross-section from left bank (m)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57.0
56.5
56.0
55.5
55.0
54.5
54.0
Bed Level (mAOD)
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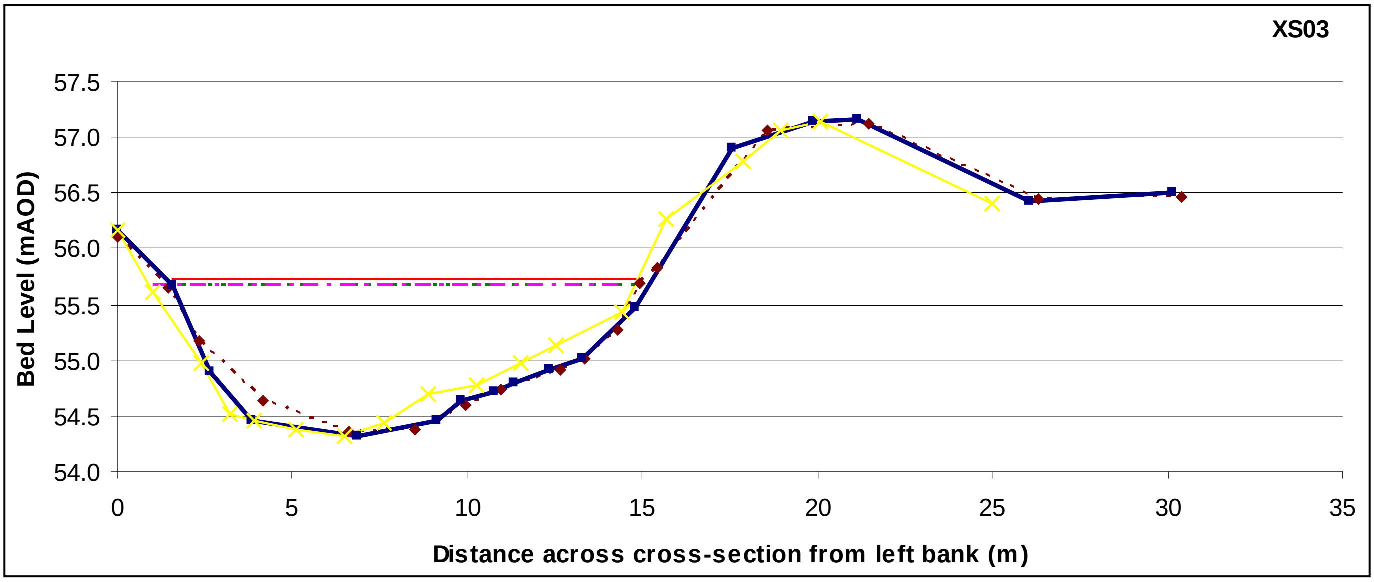
5
10
15
20
25
30
35
Distance across cross-section from left bank (m)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Bed Level (mAOD)
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57.0
56.5
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54.5
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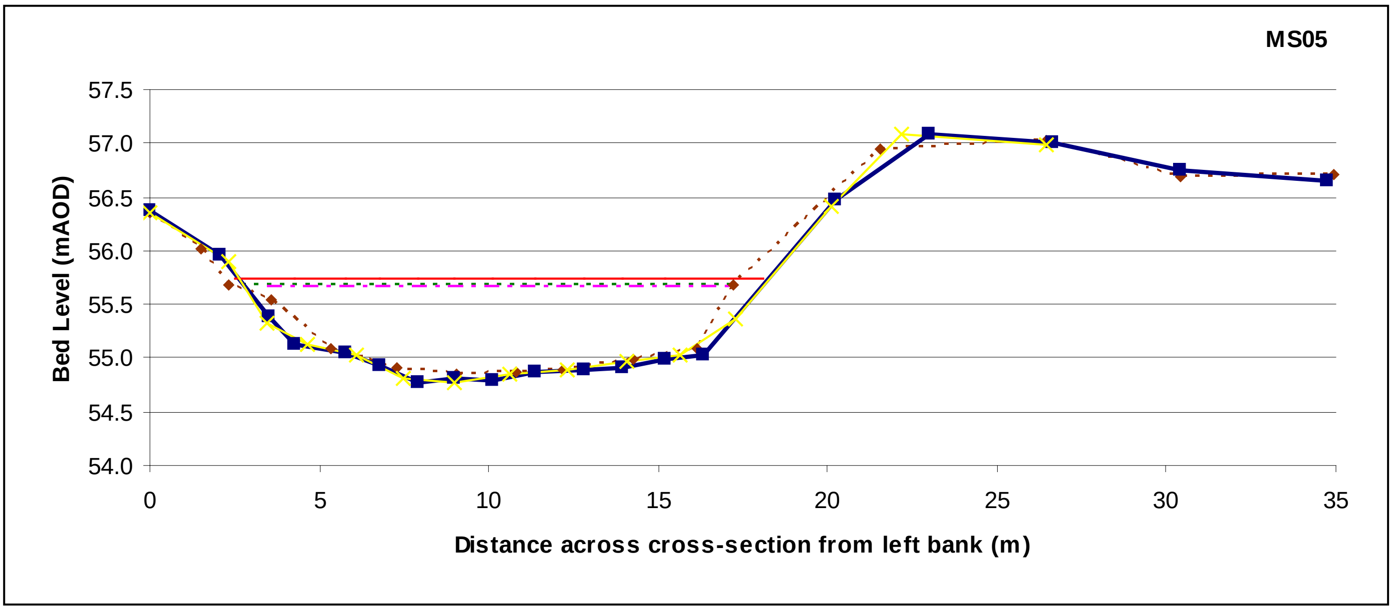
10
15
20
25
30
35
Distance across cross-section from left bank (m)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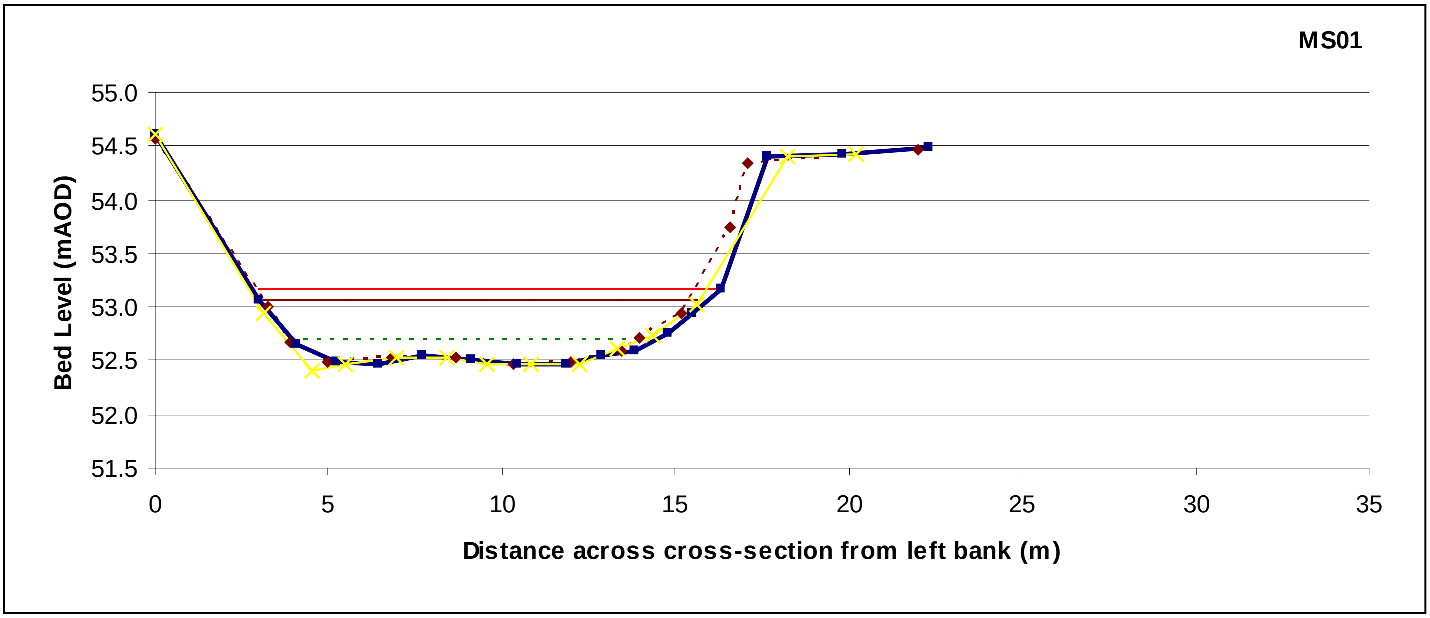
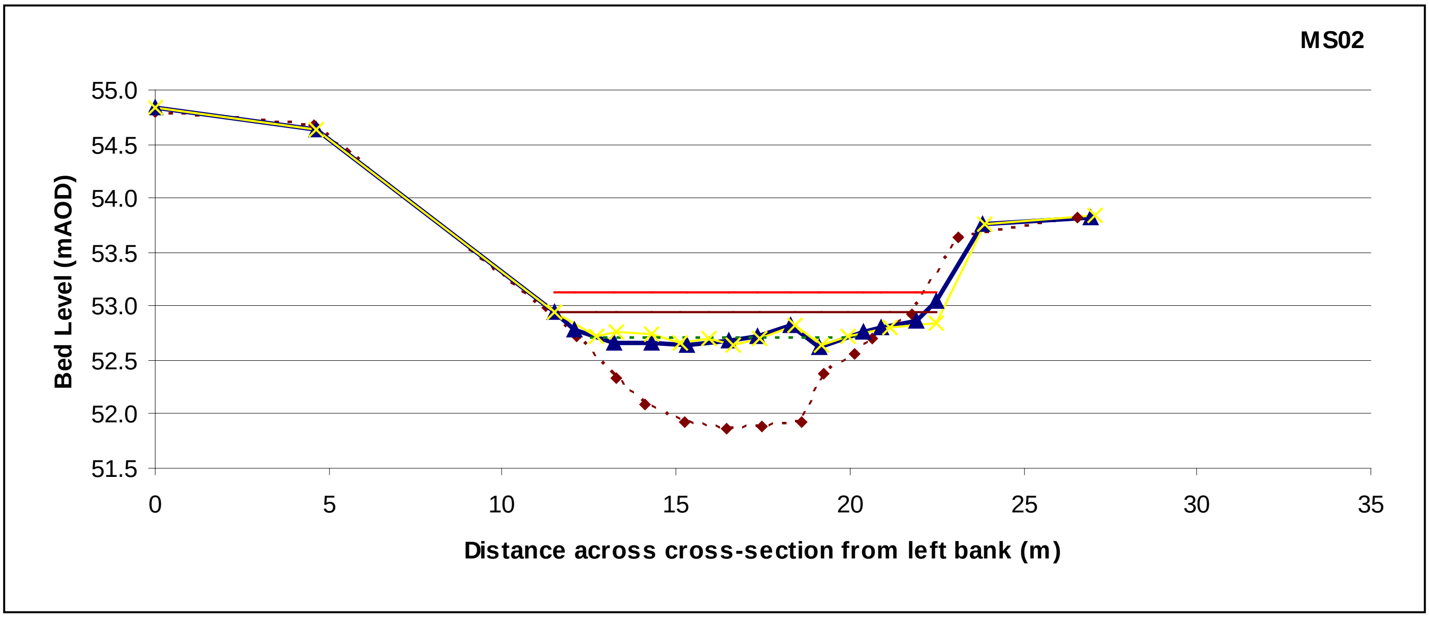
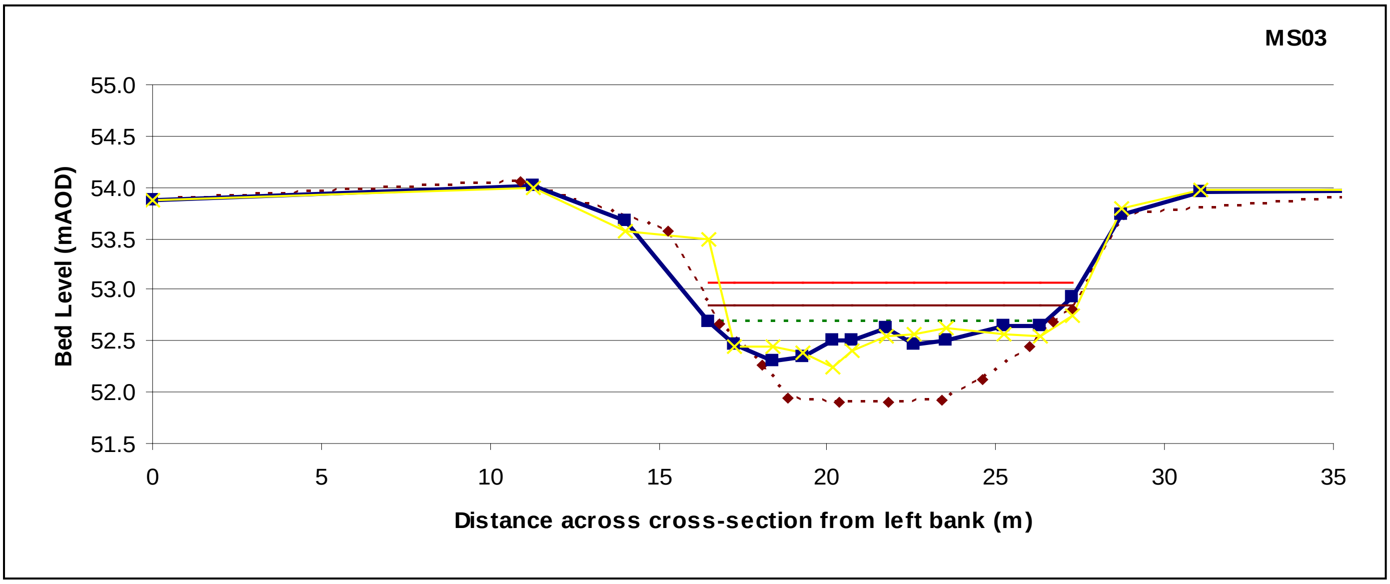
56.0
55.5
55.0
54.5
54.0
0
5
10
15
20
25
30
35
Distance across cross-section from left bank (m)

Restoration site

Bed elevation 2006 - Water level 2006
Bed elevation 2008 - Water level 2008
Bed elevation 2009 - Water level 2009



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Bed Level (mAOD)
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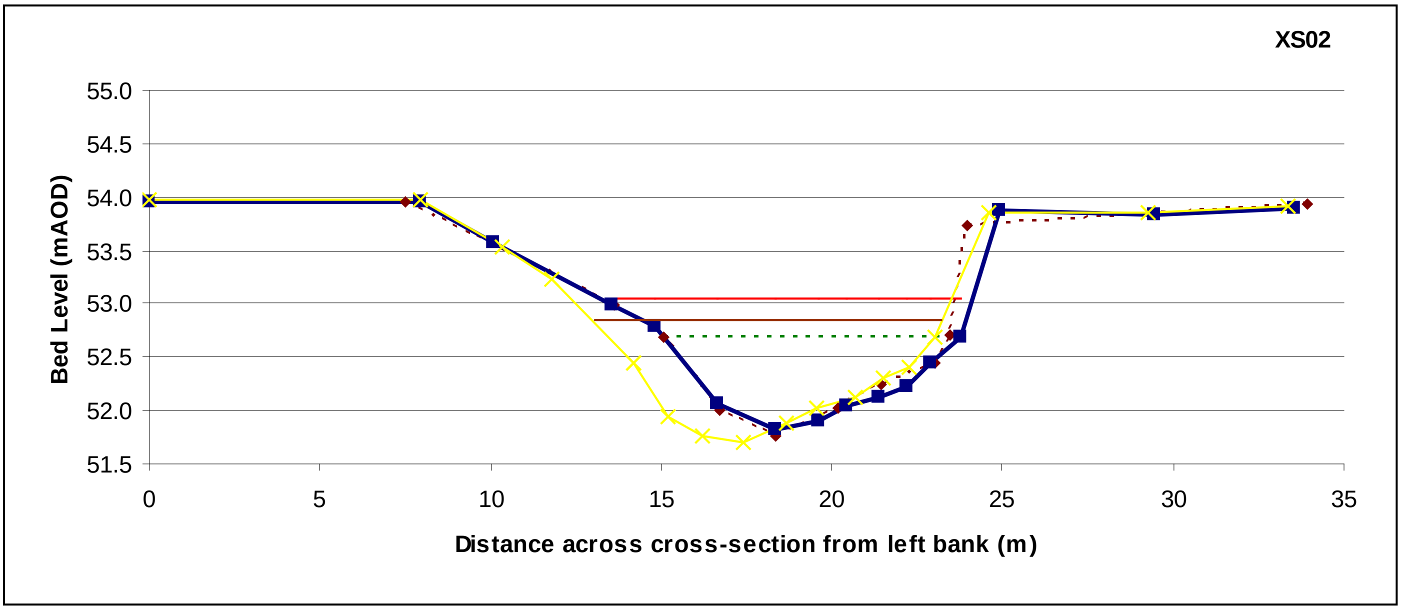
54.0
53.5
53.0
52.5
52.0
51.5
0
5
10
15
20
25
30
35
Distance across cross-section from left bank (m)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Bed Level (mAOD)
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54.0
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52.0
51.5
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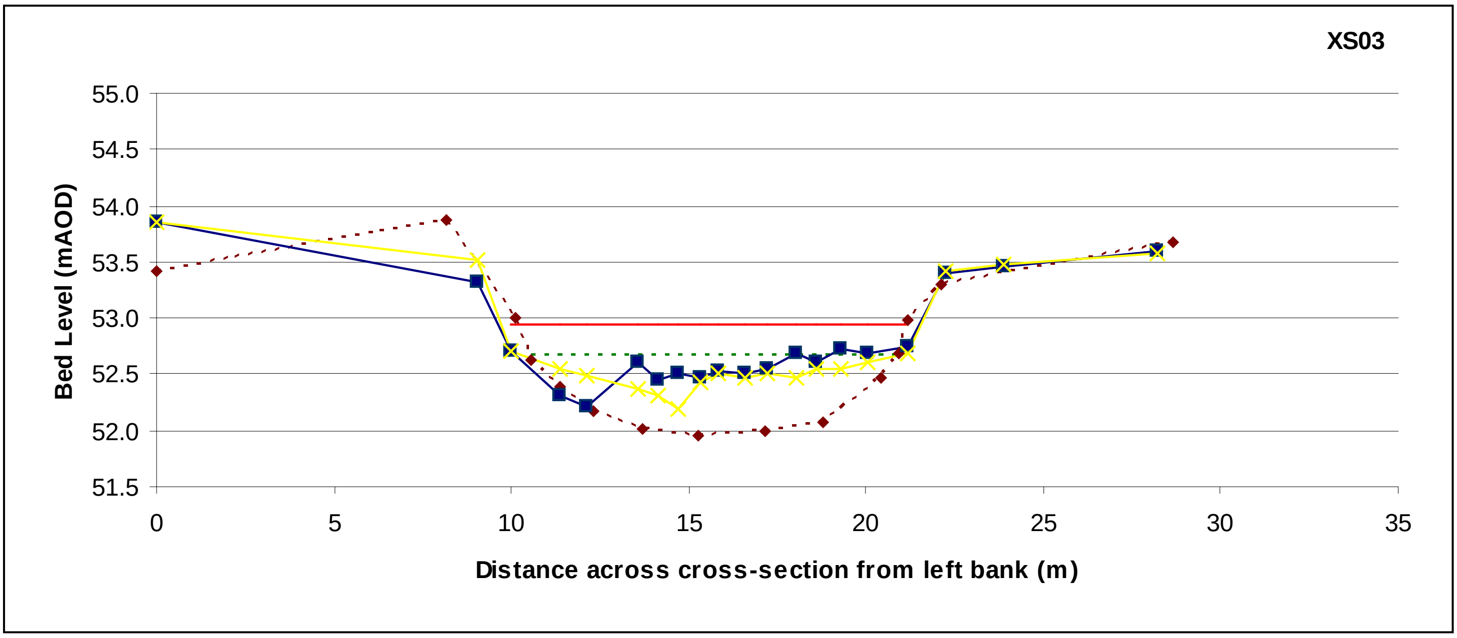
10
15
20
25
30
35
Distance across cross-section from left bank (m)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54.5
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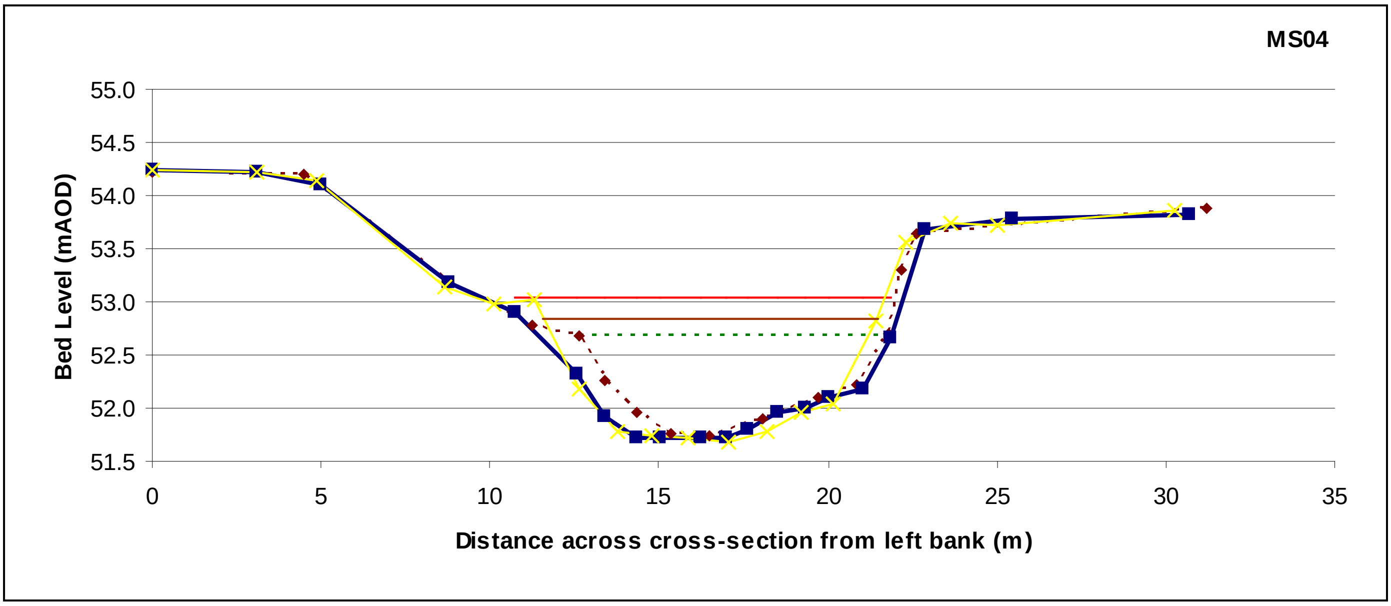
20
25
30
35
Distance across cross-section from left bank (m)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Bed Level (mAOD)
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54.5
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0
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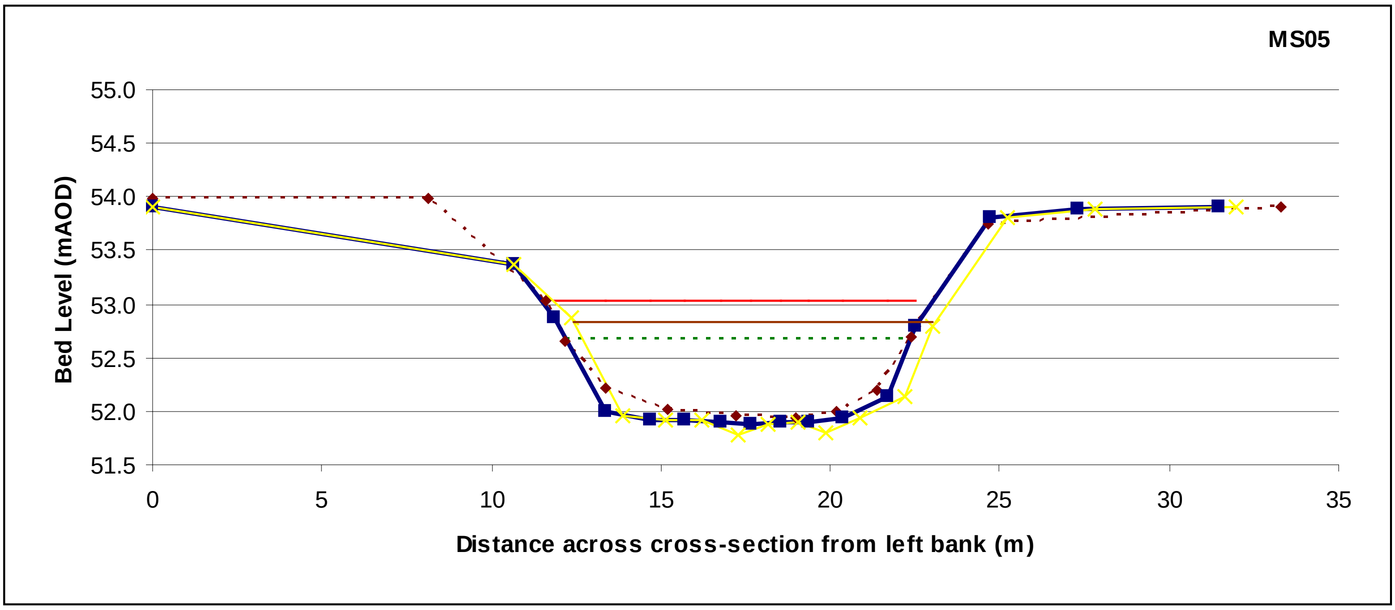
10
15
20
25
30
35
Distance across cross-section from left bank (m)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Bed Level (mAOD)
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54.5
54.0
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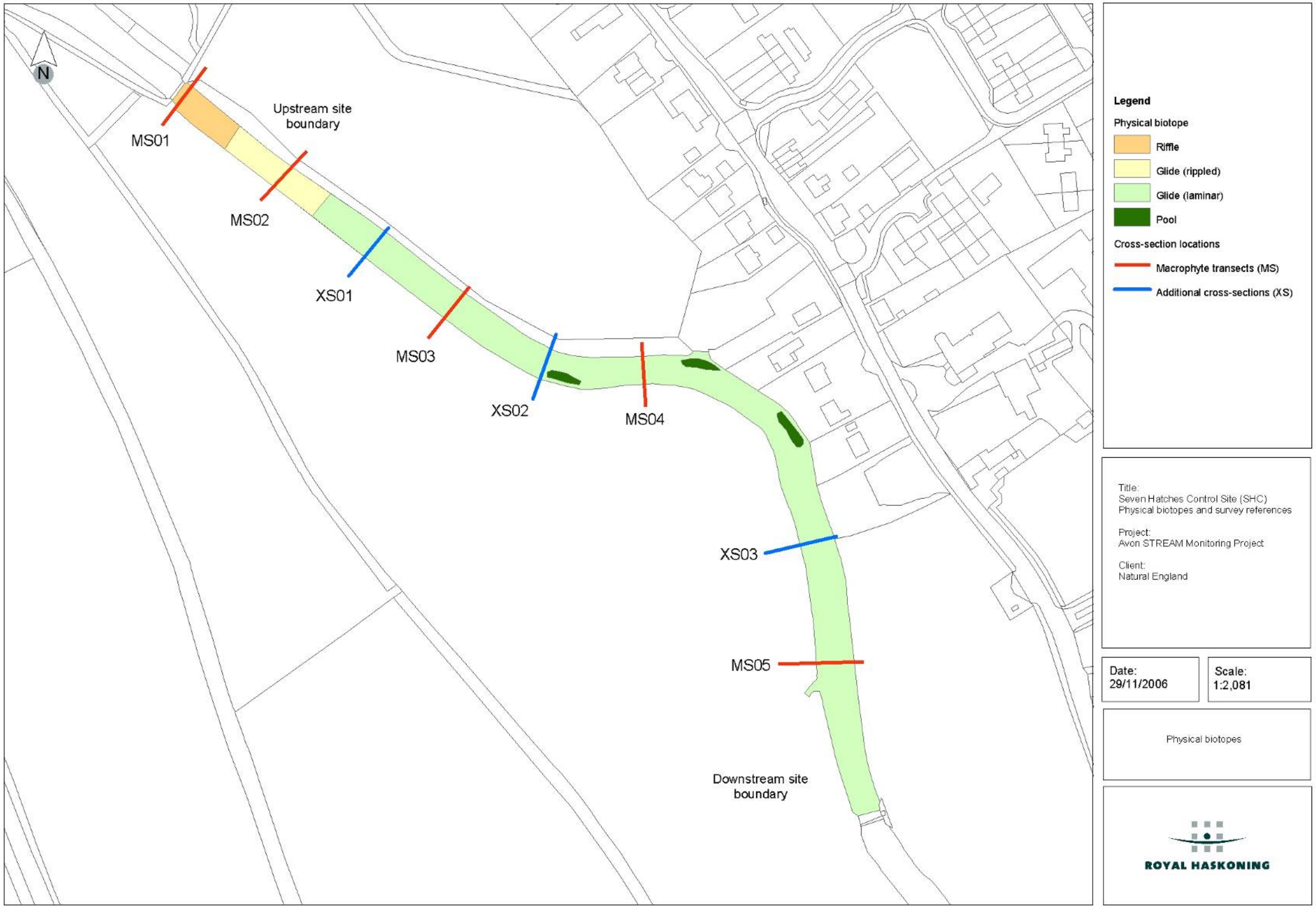
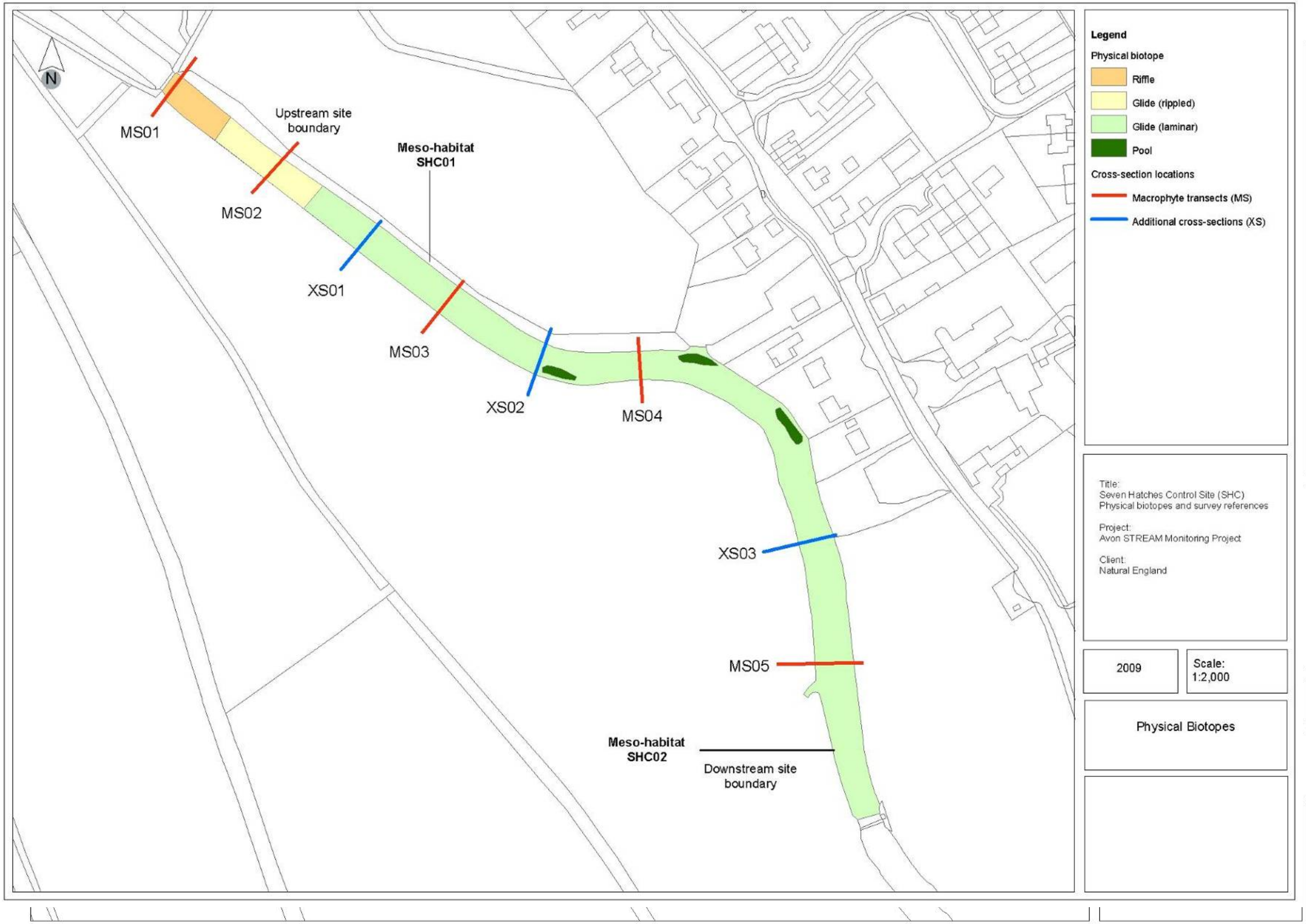
53.0
52.5
52.0
51.5
0
5
10
15
20
25
30
35
Distance across cross-section from left bank (m)

Appendix B: Physical biotope mapping


N
Upstream site boundary
MS01
MS02
XS01
MS03
XS02
MS04
XS03
MS05
Downstream site boundary
Legend
Physical biotope
Riffle
Glide (rippled)
Glide (laminar)
Pool
Cross-section locations
Macrophyte transects (MS)
Additional cross-sections (XS)
Title:
Seven Hatches Control Site (SHC)
Physical biotopes and survey references
Project:
Avon STREAM Monitoring Project
Client:
Natural England
Date:
29/11/2006
Scale:
1:2,081
Physical biotopes
ROYAL HASKONING



N
MS01
Upstream site boundary
MS02
Meso-habitat SHC01
XS01
MS03
XS02
MS04
XS03
MS05
Meso-habitat SHC02
Downstream site boundary
Legend
Physical biotope
Riffle
Glide (rippled)
Glide (laminar)
Pool
Cross-section locations
Macrophyte transects (MS)
Additional cross-sections (XS)
Title:
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Physical biotopes and survey references
Project:
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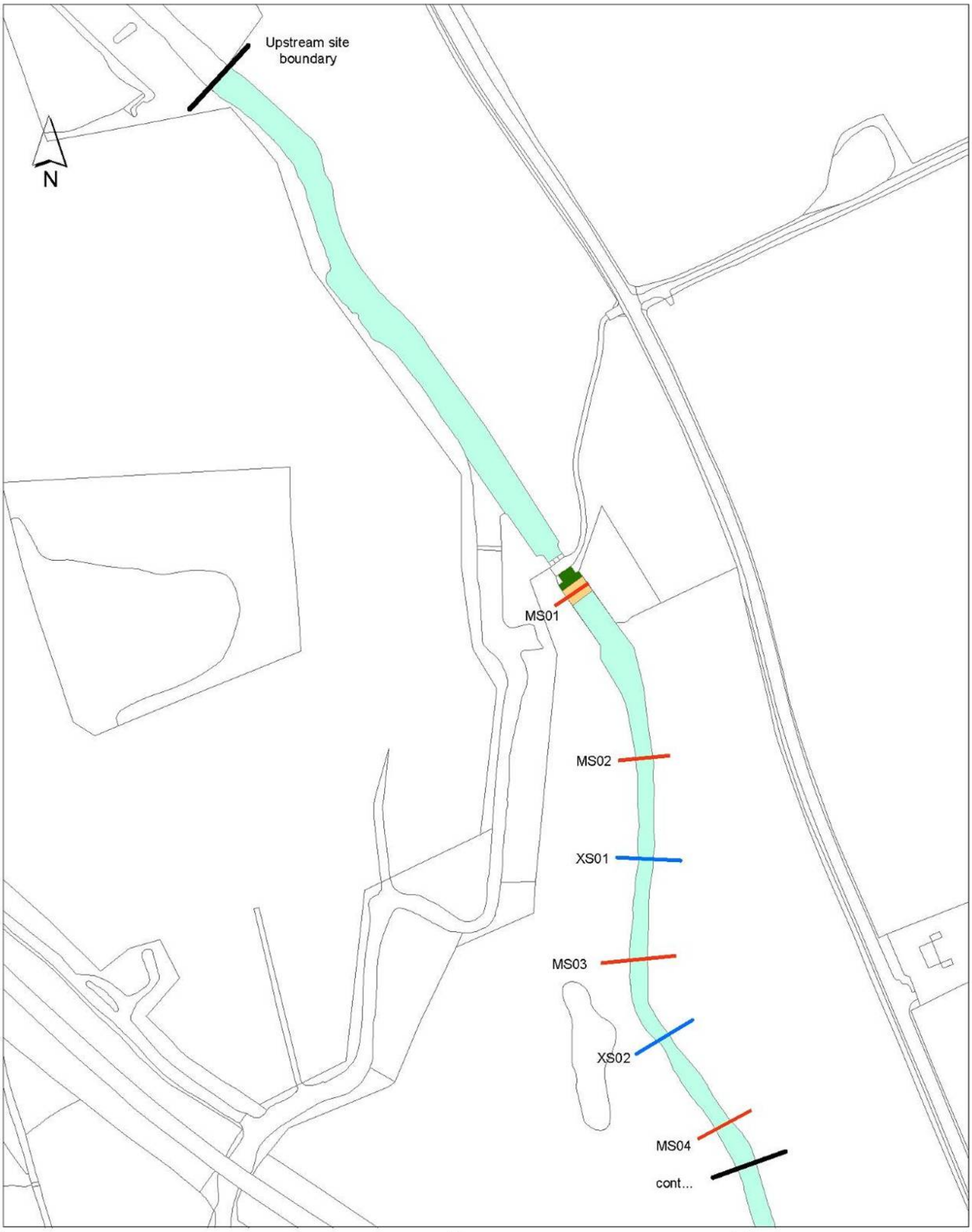
Client:
Natural England
2009
Scale:
1:2,000
Physical Biotopes



Legend

Physical biotope
- Riffle
- Glide (laminar)
- Pool

Cross-section locations
- Macrophyte transect (MS)
- Additional cross-sections (XS)

Title: Seven Hatches Restoration Site (SHR)
Physical biotopes and survey references

Project: Avon STREAM Monitoring Project

Client: Natural England

Date:
29/11/2006

Scale:
1:2,500

Physical Biotopes

ROYAL HASKONING


MS04
MS05
XS03
N
Downstream Site Boundary
Legend
Physical biotope
Riffle
Glide (laminar)
Pool
Cross-section locations
Macrophyte transect (MS)
Additional cross-sections (XS)
Title: Seven Hatches Restoration Site (SHR)
Physical biotopes and survey references
Project: Avon STREAM Monitoring Project
Client: Natural England
Date:
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Scale:
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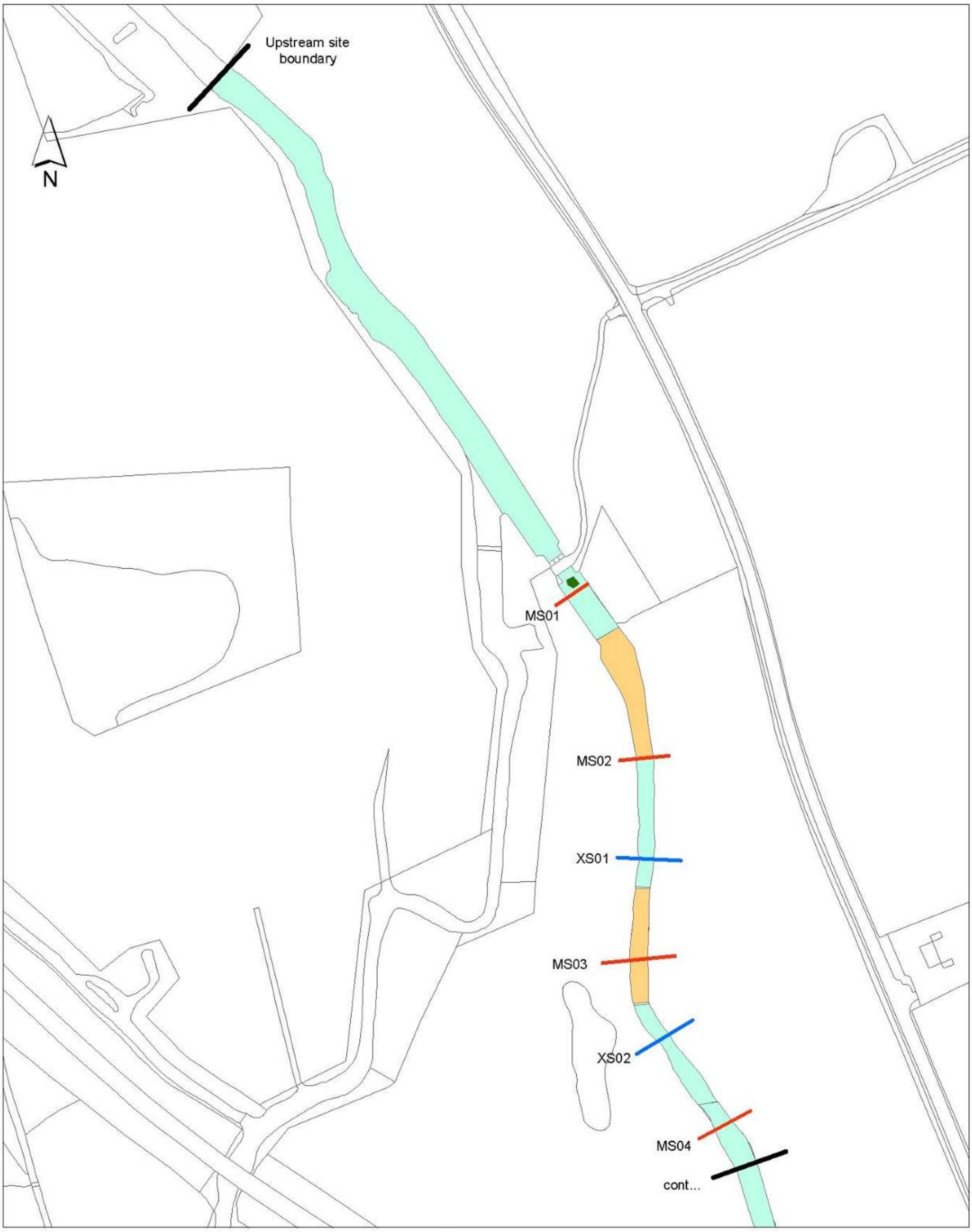
Physical Biotopes
ROYAL HASKONING



Legend

Physical biotope
- Riffle
- Glide (laminar)
- Pool

Cross-section locations
- Macrophyte transect (MS)
- Additional cross-sections (XS)

Title: Seven Hatches Restoration Site (SHR)
Physical biotopes and survey references

Project: Avon STREAM Monitoring Project

Client: Natural England

2008

Scale:
1:2,500

Physical Biotopes

ROYAL HASKONING


MS04
N
MS05
XS03
Downstream site boundary
Legend
Physical biotope
Riffle
Glide (laminar)
Pool
Cross-section locations
Macrophyte transect (MS)
Additional cross-sections (XS)
Title: Seven Hatches Restoration Site (SHR)
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Client: Natural England
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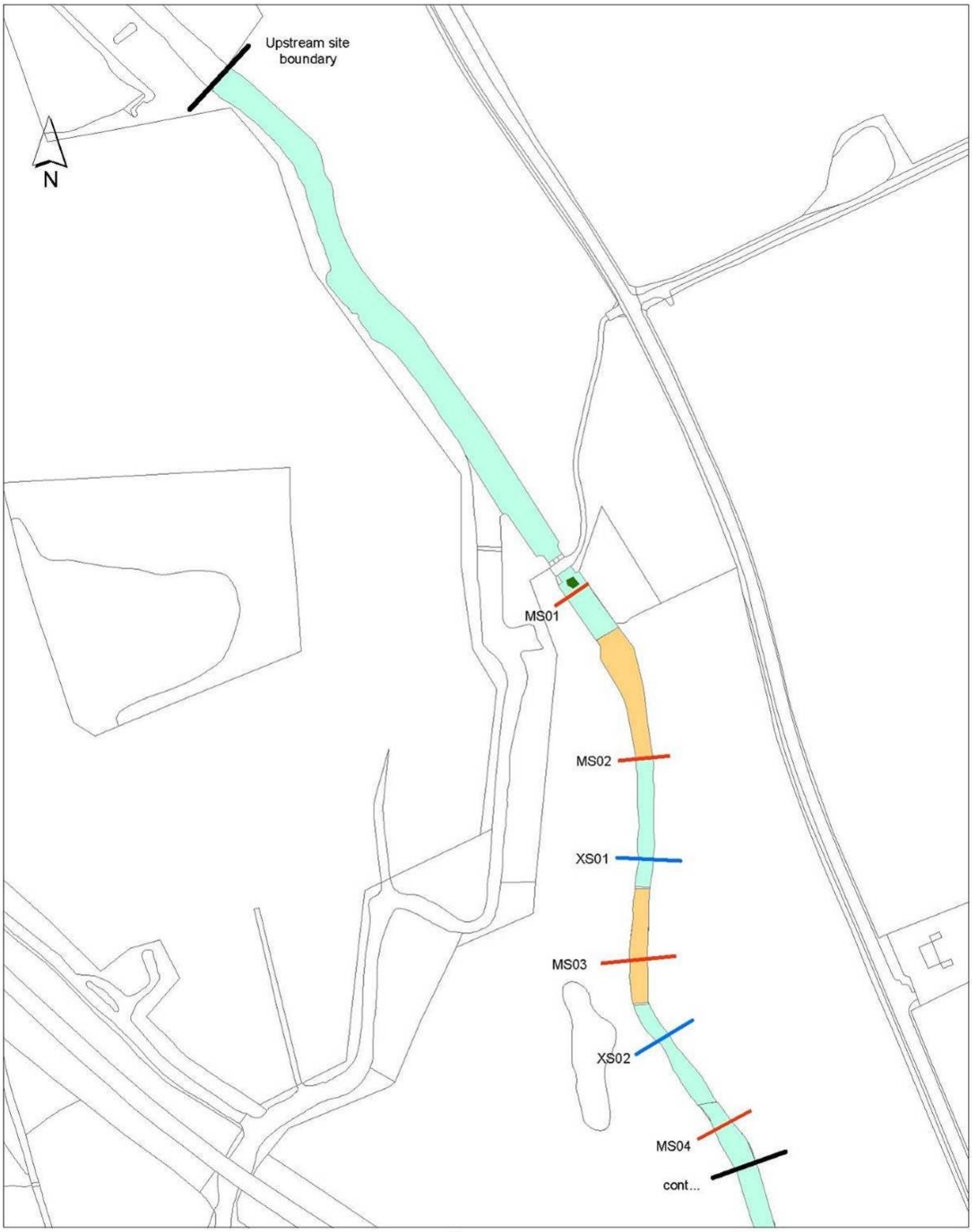
Physical Biotopes
ROYAL HASKONING



Legend

Physical biotope
- Riffle
- Glide (laminar)
- Pool

Cross-section locations
- Macrophyte transect (MS)
- Additional cross-sections (XS)

Seven Hatches Restoration Site (SHR)
Project: ARRE
Client: Environment Agency

2009

Scale: 1:2,500

Physical Biotopes

ROYAL HASKONING


MS04
MS05
XS03
N
Downstream site boundary
Legend
Physical biotope
Riffle
Glide (laminar)
Pool
Cross-section locations
Macrophyte transect (MS)
Additional cross-sections (XS)
Seven Hatches Restoration Site (SHR)
Project: ARRE
Client: Environment Agency
Physical Biotopes
2009
Scale: 1:2,500
ROYAL HASKONING

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