Assessment of physical habitat condition and development of restoration actions for the River Wye SAC in Wales

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Crynodeb Gweithredol

Mae Afon Gwy yn cefnogi poblogaethau o ystod o organebau a chynefinoedd prin sydd â phwysigrwydd cenedlaethol a rhyngwladol, ac mae rhan fawr o rwydwaith yr afon wedi'i dynodi'n Ardal Cadwraeth Arbennig. Yn ogystal, mae llawer o lednentydd a'r brif afon yn Safleoedd o Ddiddordeb Gwyddonol Arbennig. Mae cadw ac adfer yr hydromorffoleg i gefnogi'r nodweddion dynodedig yn flaenoriaeth o ran rheoli Afon Gwy. Yng Nghymru, cynhaliwyd Archwiliad Afonol yn ddiweddar ar hyd llawer o afon Gwy a'i phrif lednentydd, a chynhyrchwyd Gweledigaeth Adfer ar gyfer Gwy Uchaf. Mae'r rhain yn awgrymu bod cyflwr geomorffolegol da i'w weld ar rannau mawr o'r ardal cadwraeth arbennig, prin yw'r cyfyngiadau ar y sianel, a'i bod yn cefnogi ffurfiau/nodweddion sianel cymharol naturiol. Fodd bynnag nodwyd ystod o effeithiau posibl hefyd, gan gynnwys addasiadau uniongyrchol i'r sianel (e.e. coredau neu ail-alinio'r sianel), pwysau gwasgaredig (e.e. mewnbynnau gwaddod mân) a dylanwadau i fyny'r afon o ardal cadwraeth arbennig (e.e. cronfeydd Cwm Elan). Gallai'r rhain effeithio ar y nodweddion dynodedig, a gallent gyfrannu at lunio barn bod yr ardal cadwraeth arbennig/safleoedd o ddiddordeb gwyddonol arbennig cyfansoddol mewn cyflwr 'anffafriol'.

Mae'r adroddiad hwn yn crynhoi astudiaeth ddesg gan ddefnyddio'r Archwiliad Afonol a'r Weledigaeth Adfer, ynghyd â data ychwanegol o'r Arolwg Cynefinoedd Afonydd ac awyrluniau, i asesu cyflwr hydromorffoleg ardal cadwraeth arbennig Afon Gwy a nodi opsiynau i'w adfer. Yr amcanion penodol oedd:

1. Asesu cyflwr presennol cynefin ffisegol pob un o 44 o ddalgylchoedd y Gyfarwyddeb Fframwaith Dŵr sy'n gorgyffwrdd â'r ardal cadwraeth arbennig a nodi'r newidiadau angenrheidiol i gyflawni 'Cyflwr Ffafriol'.
2. Asesu a yw cyflwr hydromorffoleg 58 o gyrff dŵr y Gyfarwyddeb Fframwaith Dŵr sy'n draenio i Afon Gwy Cymru yn ddigon da i gefnogi Statws Ecolegol Uchel.
3. Disgrifio camau adfer posibl, mewn perthynas â maint gwahanol rannau o'r afon, gan eu cysylltu ag amcanion cadwraeth ar gyfer rhywogaethau a chynefinoedd yr ardal cadwraeth arbennig/safleoedd o ddiddordeb gwyddonol arbennig.
4. Cynnal dadansoddiad cost a budd cychwynnol er mwyn nodi cyfyngiadau economaidd-gymdeithasol tebygol ar adfer ffisegol.

Asesu cyflwr ardal cadwraeth arbennig

Er mwyn cyfuno data o wahanol ffynonellau (e.e. Archwiliad Afonol, Arolwg o Gynefin Afon) a chael y cydymffurfiad gorau â Monitro Safonau Cyffredin a chanllawiau'r Gyfarwyddeb Fframwaith Dŵr, cymerwyd ail sampl o ddata'r Archwiliad Afonol a'r awyrluniau mewn fformat Arolwg Cynefinoedd Afonydd. Cofnodwyd data ar hap bob 50m a gynhyrchwyd gan ddefnyddio System Gwybodaeth Ddaearyddol. Lle bynnag yr oedd yn bosibl, arolygwyd lleiafswm o bump o ardaloedd 500m o bob sianel, yn unol ag arweiniad Monitro Safonau Cyffredin. Ar ddyfrffyrdd hirach, cymerwyd samplau bob 1-2km. Mae'r arweiniad Monitro Safonau Cyffredin yn rhoi saith o feini prawf i'w defnyddio i asesu cyflwr hydromorffolegol safle o ddiddordeb gwyddonol arbennig/ardal cadwraeth arbennig, y gellid amcangyfrif chwech ohonynt o'r data sydd ar gael ar gyfer afon Gwy. Y seithfed oedd y sgôr SERCON ar gyfer naturioldeb llystyfiant ar lan yr afon, sy'n galw am fersiwn wedi'i haddasu o gasgliad data'r Arolwg Cynefinoedd Afonydd yn y maes. Datblygwyd gweithdrefn tri cham syml er mwyn ceisio nodi effeithiau hydromorffolegol y tu hwnt i 'ôl droed' uniongyrchol ail-alinio sianeli ac atgyfnerthu argloddiau neu lannau: i) nodwyd effeithiau cyffredinol gwahanol addasiadau (e.e. newidiadau i ddeunyddiau ar wely'r afon, storio gwaddodion, sefydlogrwydd glannau, lled y sianel), ii) cymharwyd pob rhan o'r afon o'r Archwiliad Afonol lle'r oedd addasiad â'r rhannau nesaf i fyny ac i lawr yr afon, a iii) ystyriwyd bod presenoldeb yr effeithiau a ragfynegwyd yn dystiolaeth bod addasiad yn effeithio ar y sianel.

Ar draws y 44 o gyrff dŵr, barnwyd bod dau yn unig mewn cyflwr ffafriol: Nant Bachell a'r Nantmel Dulas. Rhwystrodd cyfyngiadau ar y data asesiadau dibynadwy o wyth corff dŵr arall. Y rheswm mynychaf dros fethu oedd diffyg pren garw yn y sianel, gan effeithio ar 69% o gyrff dŵr. I'r gwrthwyneb, ychydig iawn a fethodd o ran llystyfiant ar lannau'r afon, gan adlewyrchu nifer y coetiroedd llydanddail ar hyd Afon Gwy a'i llednentydd. Methodd gyfran fawr o'r cyrff dŵr ar un neu fwy o'r meini prawf addasu uniongyrchol (cynllunio ar gyfer addasiadau, strwythurau yn y sianeli, Dosbarth Addasu Cynefin): ≥41% o gyrff dŵr ymhob achos. Dangosodd tua hanner (49%) o'r cyrff dŵr dystiolaeth o gynnydd o ran gwaddodion mân uchel.

Dyfeisio opsiynau adfer

Mae ynni cymharol uchel y rhan fwyaf o'r sianeli yn yr ardal cadwraeth arbennig yn awgrymu y credir bod adfer naturiol – neu gyn lleied o ymyrraeth â phosibl – yn ffordd ymarferol o sicrhau adfer ffisegol yn sgil ystod eang o effeithiau mewn llawer o sefyllfaoedd. Y dull cyffredinol fyddai tynnu i ffwrdd y cyfyngiadau o'r afon lle bo'n bosibl a chaniatáu adfer naturiol. Er mwyn gwerthuso hyn, gwnaethom: i) amcangyfrif gallu'r sianeli ymhob corff dŵr i ail-weithio'u deunyddiau ar eu gwely, gan gymharu amcangyfrif o rym yr afon â maint y graen yn y deunyddiau ar y gwely, a ii) edrych ar y gwaddodion sydd ar gael ymhob rhan o'r afon, y gallai'r sianel eu hail-weithio a faint o lystyfiant prennaidd sydd ar lannau'r afon fel arwydd o sefydlogrwydd y glannau. Yn y rhan fwyaf o achosion, daethpwyd i'r casgliad bod rhyw fath o adfer naturiol yn briodol – efallai gyda chymorth i dynnu i ffwrdd y rhwystrau'n rhannol/yn gyfan gwbl (e.e. coredau). Cyflwynir cynlluniau adfer ar gyfer y 34 o gyrff dŵr y barnwyd eu bod mewn cyflwr anffafriol a lle'r oedd data digonol ar gael i ganiatáu asesiad cymharol ddibynadwy.

Asesiad y Gyfarwyddeb Fframwaith Dŵr

Defnyddir chwe phrif reol i ddyfarnu hydromorffoleg yn Statws Uchel y Gyfarwyddeb Fframwaith Dŵr: mae dwy yn dadansoddi gorchudd tir y dalgylch, mae'r drydedd yn archwilio parth glannau'r afon, mae'r bedwaredd yn defnyddio Dosbarth Addasu Cynefin, mae'r pumed yn ystyried effeithiau posibl argloddiau rheilffordd ar gysylltedd, ac mae'r rheol olaf yn ystyried addasiadau uniongyrchol i'r sianel. Roedd modd amcangyfrif y rhan fwyaf o'r rhain o'r data a oedd ar gael. Roedd cyflwr parth glannau'r afon yn cysylltu â'r coetiroedd llydanddail, y gwŷr eu bod yn cydberthyn ag effeithiau gwaddodion mân yn y sianel. Rhagfynegwyd y Dosbarth Addasu Cynefin o'r data gan ddefnyddio model atchweliad wedi'i galibro â set ddata Gwaelodlin yr Arolwg Cynefinoedd Afonydd, gan gysylltu ag is-set o amrywiolion yr Arolwg Cynefinoedd Afonydd y gellid eu cofnodi o'r Archwiliad Afonol i'r Dosbarth Addasu Cynefin. Methodd bob un o'r 58 o gyrff dŵr y Gyfarwyddeb Fframwaith Dŵr yr asesiad Statws Uchel, heblaw dau sef Rhiwnant ac Afon Arban, ond roedd data prin ar gyfer y ddau hyn, gan gyfyngu'r hyder yn yr asesiad. Y rheswm mynychaf dros fethu oedd maint y gorchudd tir artiffisial/dwys – glaswelltir wedi ei wella yn nodedig – yn y dalgylch.

Dadansoddiad â mwy nag un set o feini prawf

Roedd yr opsiynau adfer yn destun dau ddadansoddiad cost a budd. Roedd y cyntaf yn broses sgrinio syml o'r holl opsiynau adfer posibl, er mwyn amlygu'r risgiau a'r manteision mawr ar lefel y corff dŵr. Seiliwyd hyn ar ddyfarniadau syml o newidiadau posibl i berygl llifogydd ac erydu i'r isadeiledd teithio (ffyrdd a rheilffyrdd), adeiladau a thir fferm. Crynhowyd manteision ecolegol posibl y gwahanol opsiynau adfer o ran y manteision posibl i nodweddion dynodedig yr ardal cadwraeth arbennig.

Canolbwyntiodd yr ail ddadansoddiad ar bedwar corff dŵr enghreifftiol, a dangosodd sut y gellid datblygu dadansoddiad ehangach â mwy nag un set o feini prawf er mwyn pennu risgiau a manteision posibl y gwahanol opsiynau adfer. Ystyriodd y risgiau i gyfres o wasanaethau economaidd a chymdeithasol a ddarperir gan ddalgylch yr afon a'r cyfyngiadau tebygol ar gyfer pob opsiwn adfer, gan ganolbwyntio ar weithgarwch economaidd, amaethyddiaeth, pysgodfeydd a choedwigaeth gysylltiedig a'r dylanwadau ar berygl llifogydd i fusnesau nad ydynt yn rhai amaethyddol a chartrefi.

Executive Summary

The River Wye supports nationally and internationally important populations of a range of rare organisms and habitats, and a large part of the river network is designated as a Special Area of Conservation (SAC), along with many tributaries and the main stem being Sites of Special Scientific Interest (SSSIs). Conserving and restoring the hydromorphology to support the designated features is a priority for managing the River Wye. Within Wales, a Fluvial Audit has recently been carried out along much of the Wye and its main tributaries, and a Restoration Vision for the Upper Wye produced. These suggest that large parts of the SAC appear to be in a good geomorphological condition, with few constraints upon the channel and supporting relatively natural channel forms/features, although a range of potential impacts was also identified, including direct modifications to the channel (e.g. weirs or re-alignment of the channel), diffuse pressures (e.g. fine sediment inputs) and influences upstream of the SAC (e.g. the Elan Valley reservoirs). These could impact upon the designated features, and could contribute to the SAC/constituent SSSIs being considered to be in ‘unfavourable’ condition.

This report summarises a desk based study using the Fluvial Audit and Restoration Vision, along with additional River Habitat Survey (RHS) data and aerial photographs, to assess the condition of hydromorphology in the River Wye SAC and identify restoration options. The specific objectives were to:

1. Assess the current condition of physical habitat in each of the 44 Water Framework Directive (WFD) catchments that overlap with the SAC and identify changes required to achieve ‘Favourable Condition’.
2. Assess whether the hydromorphology of the 58 WFD waterbodies draining into the Welsh river Wye is in sufficient condition to support High Ecological Status.
3. Describe potential reach-scale restoration actions, linking them to conservation objectives for species and habitats of the SAC/SSSIs.
4. Carry out an initial cost-benefit analysis to identify likely socio-economic constraints on physical restoration.

SAC condition assessment

To combine data from different sources (e.g. Fluvial Audit, RHS) and maximise compatibility with Common Standards Monitoring (CSM) and WFD guidelines, Fluvial Audit data and aerial photographs were resampled into an RHS format. Data were recorded at 50m ‘spot-check’ intervals generated using GIS. Wherever possible, a minimum of five 500m reaches were surveyed from every channel, consistent with the CSM guidelines. On longer water courses, samples were taken every 1-2km. CSM guidance gives seven criteria for use in assessing SSSI/SAC hydromorphological condition, of which six could be estimated from the data available in the Wye. The seventh was the SERCON score for bank vegetation naturalness, which requires a modified version of RHS data collection in the field. To try to identify hydromorphological impacts beyond the immediate ‘footprint’ of channel re-alignment, embankments or bank reinforcement, a simple three stage procedure was developed: i) the generic impacts of different modifications were identified (e.g. changes to bed material, sediment storage, bank stability, channel width), ii) each Fluvial Audit reach where a modification was present was compared with the reaches immediately upstream and downstream, and iii) the presence of the predicted impacts was considered to be evidence that a modification was affecting the channel.

Across the 44 waterbodies, only two were judged to be in favourable condition: Bachell Brook and the Nantmel Dulas. Limitations in the data prevented reliable assessments of a further eight waterbodies. The most frequent reason for failure was a lack of coarse wood in the channel, affecting 69% of waterbodies. Conversely, very few failed on riparian vegetation, reflecting the extent of broad leaved woodland along the Wye and its tributaries. A large proportion of waterbodies failed on one or more of the direct modification criteria (planform modification, in-channel structures, Habitat Modification Class (HMC)): ≥41% of waterbodies in every case. Approximately half (49%) of the waterbodies showed evidence of elevated fine sediments.

Devising restoration options

The relatively high energy of most of the channels within the SAC suggests that in many situations, natural recovery – or minimal intervention – is thought to be a feasible approach to physical restoration from a wide range of different impacts. The over-riding approach would be to remove the constraints from the river wherever possible and allow natural recovery. To evaluate this, we: i) estimated the ability of the channels in each waterbody to re-work their bed material, comparing the estimated stream power to the grain size of the bed material, and ii) for each reach, looked at the availability of sediment that the channel could re-work and the extent of woody bank vegetation as a measure of bank stability. In most instances, it was concluded that some form of natural recovery – perhaps with assistance to partly/wholly remove obstructions (e.g. weirs) – is appropriate. Restoration plans are presented for the 34 waterbodies judged to be in unfavourable condition and where sufficient data were available to allow a relatively reliable assessment.

WFD assessment

Six main rules are used for classifying hydromophology at WFD High Status: two analyse catchment land cover, the third examines the riparian zone, the fourth uses HMC, the fifth considers the potential impacts of railway embankments on connectivity, and the final rule considers direct modifications to the channel. Most of these could be estimated from the data that were available. The condition of the riparian zone was linked to the extent of broad leaved woodland, which is known to correlate with fine sediment impacts in the channel, whilst HMC was predicted from the data by using a regression model calibrated with the RHS Baseline data set, linking the subset of RHS variables that could be recorded from Fluvial Audit to HMC. All but two of the 58 WFD waterbodies failed the High Status assessment, the Rhiwnant and Afon Arban, but limited data were available for both, limiting confidence in the assessment. The most frequent reason for failure was the extent of artificial/intensive land cover – notably improved grassland – within the catchment.

Multi-criteria analysis

The restoration options were subjected to two cost-benefit analyses. The first was a simple screening of all candidate restoration options, to flag major risks and benefits at the waterbody scale. This drew on simple judgements of the potential changes in flood and erosion risks to travel infrastructure (roads and railways), buildings and farmland. Potential ecological benefits of different restoration options were summarised in terms of the potential benefits to the SAC designated features.

The second analysis focused on four sample waterbodies and illustrated how a broader multi-criteria analysis could be developed to scope potential risks and benefits of the different restoration options. It considered the risks to a series of economic and social services provided by the river catchment, and the likely constraints for each restoration option, focusing on economic activity associated agriculture, fisheries and forestry and the influences on flood risk to non-agricultural businesses and homes

1. Introduction

The River Wye is a large and diverse river system, supporting nationally and internationally important population of a range of rare organisms and habitats. Its importance for nature conservation is recognised in the main stem and many of its main tributaries being designated as Sites of Special Scientific Interest (SSSIs) and, more recently, much of the river network was designated as a Special Area of Conservation (SAC). This latter designation recognises the presence of nine species in addition to the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation community. Conserving and restoring the hydromorphology to support these designated features is a priority for managing the River Wye (Dyson, 2008).

The Wye catchment has been well studied over recent decades, covering the ecology, water quality and physical habitat. In recent years there has been an increasing focus upon the hydromorphology of the river system and the extent to which it supports the ecology: in the SAC context, notably the designated features. The current report builds on two recent documents that focus upon the physical habitat: i) a Fluvial Audit of much of the Upper Wye and many of its main tributaries (Jeffries *et al*., 2007) and ii) a vision for restoring the hydromorphology of the Upper Wye (Halcrow, 2012). By using the data and the principles set out in these two reports, the current work aims to assess the current condition of the hydromorphology in the SAC and set out potential restoration options where problems are identified.

Within Wales, the River Wye SAC encompasses a diverse range of rivers, varying in characteristics such as size, gradient, underlying geology, sediment transport and supply, and bed material. Jeffries *et al*., (2007) provide a detailed description of many of the waterbodies within the SAC, with the main exception being the River Irfon and its tributaries. This hydromorphological diversity reflects, and in part controls, the diverse water quality and range of organisms observed across the catchment (Edwards & Brooker, 1982; Clews & Ormerod, 2009). On the basis of the Fluvial Audit, large parts of the SAC appear to be in a good geomorphological condition, with few constraints upon the channel and supporting relatively natural channel forms/features (Jeffries *et al*., 2007). Conversely, a range of issues has been identified that may impact upon the hydromorphology (both form and process) of the Wye, and in turn the designated features, and which could contribute to the SAC/constituent SSSIs being considered to be in ‘unfavourable’ condition. These include direct modifications to the channel (e.g. weirs or re-alignment of the channel), diffuse pressures (e.g. excess fine sediment inputs from activities in the riparian zone and wider catchment) and influences within the Wye catchment, but upstream of the SAC, such as the Elan Valley reservoirs (Jeffries *et al*., 2007). Jeffries *et al*., (2007) provide a systematic description of the hydromorphology and potential impacts for the main tributaries and main stem of the Wye, in addition to mapping many of the hydromorphological features in GIS. In the process, they identified a series of reaches that are in poor condition geomorphologically (e.g. sections of Dulas Brook) and so may be considered potential targets for restoration work, but no formal condition assessment was performed.

The relatively high energy of most of the channels within the SAC suggests that in many situations, natural recovery – or minimal intervention – is thought to be a feasible and desirable approach to physical restoration from a wide range of different impacts (Halcrow, 2007). The over-riding approach would be to remove the constraints from the river wherever possible and allow natural recovery. 'Analogue' reaches in the Upper Wye help to clarify the desired endpoint of restoration (Halcrow, 2007). In planning such restoration, consideration of the habitat requirements of the designated SAC features and the broader ecology are essential. In many instances the desired endpoint of restoration – an unconstrained, semi-natural channel – will be the same for the hydromorphology and the ecology. Nevertheless, it is important to recognise that this may not always be the case as some river reaches judged to be of high gemorphological quality and with little anthropogenic impact may not naturally support the designated SAC features (Jeffries *et al*., 2007).

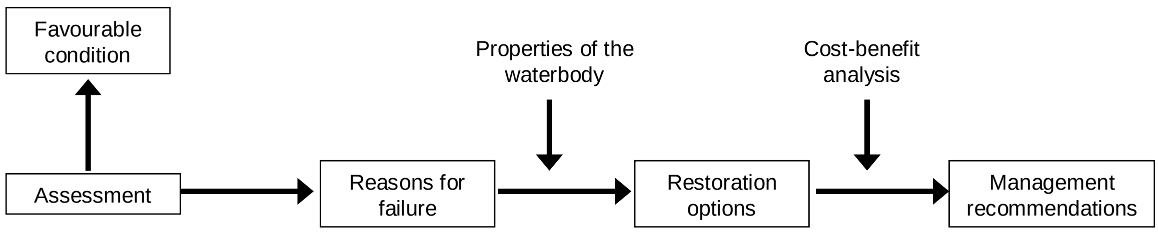
Overall objectives and scope

The current report builds on the Fluvial Audit and the Restoration Vision to assess the current hydromorphological condition of the Wye and provide explicit restoration options. The study was primarily desk based using the Fluvial Audit GIS and report, but also making use of River Habitat Survey (RHS) data and aerial photographs. The main objectives were to:

1. Assess the current condition of physical habitat in each SAC unit, based on the most recent CSM guidelines (JNCC, 2014), and identify changes required to achieve 'Favourable Condition'.
2. Assess whether the hydromorphology of Water Framework Directive (WFD) waterbodies draining into the Welsh river Wye is in sufficient condition to support High Ecological Status (Environment Agency, 2010).
3. Describe potential reach-scale restoration actions, linking them to conservation objectives for species and habitats of the SAC/SSSIs.
4. Carry out an initial cost-benefit analysis to identify likely socio-economic constraints on physical restoration

For the SAC, the three tasks (1, 3 and 4) were treated sequentially (Fig. 1). The reasons for failing to be judged in 'favourable condition' immediately suggest potential restoration options, but this process also took into account key characteristics of the waterbody (e.g. its ability to transport sediment) in settling upon an approach to the restoration. Once restoration options were proposed, they were subjected to a cost benefit analysis to identify potential benefits and constraints. This took the form of a simple screening of all waterbodies for which restoration options were proposed, and the development of a more detailed process illustrated with four waterbodies.

Figure 1. The overall process followed in this report, leading from waterbody-level assessment to management recommendations.

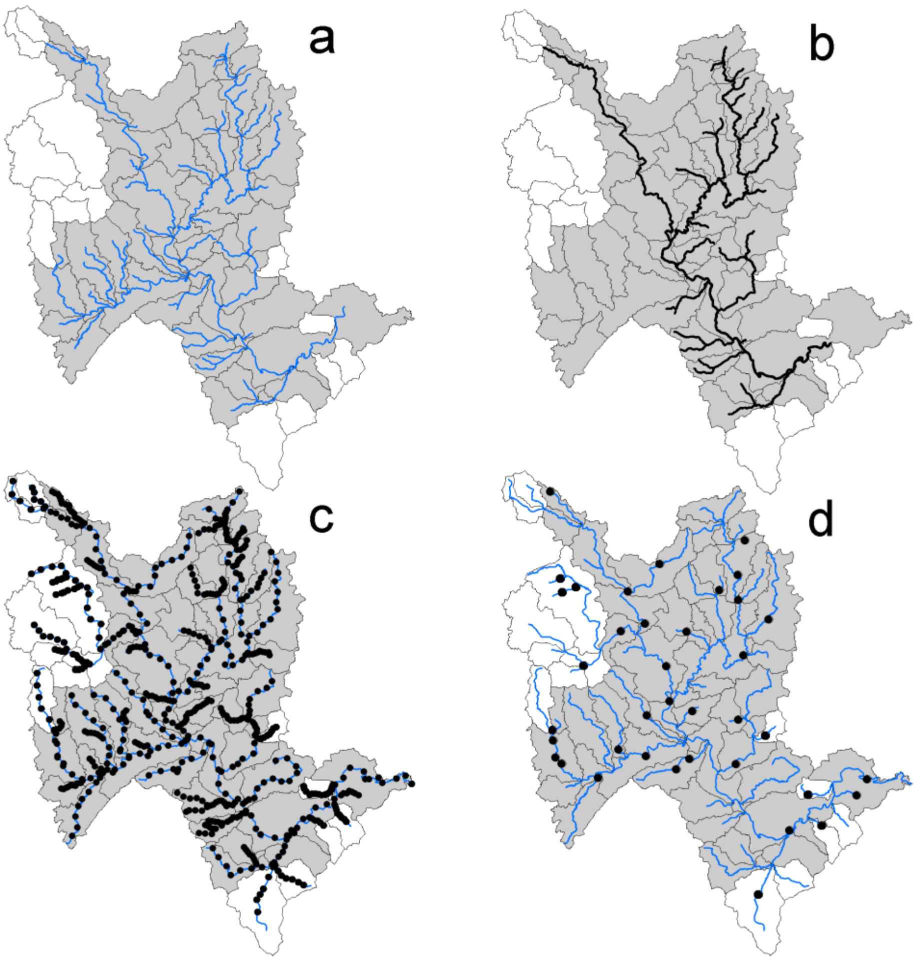


Spatial scale/level of reporting

The SAC covers much of the Wye catchment within Wales (Fig 2a). Within the scope of this project, the Wye is sub-divided into 58 WFD catchments, 44 of which overlap with the SAC. The focus was upon the main channels ('blue lines') represented by the SAC boundary or used for WFD assessments and supplied by NRW. Comparing these two river networks, in some instances the SAC includes small tributaries not included in the WFD, whilst the WFD boundary frequently extends further into the headwaters than the SAC (Fig. 2a versus 2d). Condition assessments were made for:

1. The SAC sub-divided into WFD waterbodies. In some instances a WFD waterbody only contains a very short section of designated river (600m), but most WFD waterbodies contain 2–25 km (mean = 7.4km) of SAC channel.
2. The component SSSIs, based on the results of (1). This coarser scale was used for previous assessments, so will allow a direct comparison.
3. Complete WFD waterbodies (*n* = 58). Some of these only had aerial photography or 1-3 RHS.

Figure 2. Extent and data availability: (a) SAC river network, (b) extent of the Fluvial Audit, (c) complete set of 500m reaches sampled from Fluvial Audit and/or aerial photographs (n=560), and (d) WFD river network showing all RHS data from 2006 onward (n=38). Catchments shaded in grey represent WFD waterbodies that host a part of the SAC.



2. SAC condition assessment

Overall rationale/outline method

Updated CSM guidelines for SSSIs/SACs were published in January 2014 (JNCC 2014). Like WFD High Status guidelines (Environment Agency, 2010), they are based largely on the use of RHS data. After a review of the literature and some initial experiments with the data, a two part approach was developed for data collection:

1. Resampling as much information as possible from Fluvial Audit and aerial photographs into an RHS format
2. Supplementing this with more detailed summaries of Fluvial Audit data, so as to extract the maximum possible information from the survey.

The reasons for this were:

- The initial review indicated that large parts of the RHS required by the CSM/WFD guidelines could be calculated from the Fluvial Audit. Many of the classifications (e.g. flow types, substrata) are the same and the components of Fluvial Audit that are mapped in GIS are directly compatible with RHS 'spot check' and 'sweep up' sampling.
- It provided a common framework for combining the three data sources (existing RHS, Fluvial Audit, aerial photographs)
- It ensured the greatest compatibility with assessments of other catchments by following the national guidelines wherever possible
- It allowed us to tap into: i) the 2007-8 RHS Baseline survey to provide broader context during waterbody assessments, and ii) a recently developed tool for predicting expected physical habitat and making comparisons among river reaches (Vaughan *et al*., 2013).
- An additional output from the work will be a database in a familiar format that can be readily re-analysed or used as a basis for future work.

Combining the different data sources in this way, it was possible to use the majority of the CSM guidelines in waterbody assessments (Table 1). Data were limited outside of the Fluvial Audit area, reducing the confidence in the assessment, and the data availability is presented with all waterbody assessments.

Comparison of the observed hydromorphology to un-modified conditions and other rivers in Wales and England

The ability to compared observed conditions to those expected for semi-natural or pristine conditions is widely recognised as a valuable component of quality assessments. Such 'reference' conditions may either be generated with a predictive model, as for RIVPACS/RICT, or observed at comparable reference/benchmark locations (e.g. Raven *et al*., 2010). Work is underway to develop a typology of British rivers that will assist in making such comparisons (e.g. Newson *et al*., 1998; Greig *et al*., 2006; Orr *et al*., 2008), but currently there is no generally accepted typology. As an alternative, river reaches can be matched on similar geographical conditions (e.g. altitude, channel slope) and used as a basis for

Table 1. CSM guidelines (JNCC, 2014) and the extent to which they could be assessed in the Wye, based on current data.

Category	Criterion	Possible in Upper Wye?
Channel planform	≤5% of the waterbody should be artificial, re-aligned or constrained	Yes – where Fluvial Audit or RHS data are available
RHS Habitat Modification Score Class (HMC)	≥65% of 500m reaches within the waterbody should be HMC1, with the remainder HMC2	Yes – HMC can be predicted with a reasonable degree of accuracy from the data collected
Bank vegetation naturalness (uses a score from the System for Evaluating Rivers for Conservation (SERCON))	Mean score 4–5	**No**
Riparian zone vegetation naturalness (uses a second SERCON score)	Mean score 4–5	Yes
Coarse woody debris	≥75% of 500m reaches within the waterbody with woody debris recorded	Yes – where Fluvial Audit or RHS data are available
In-channel structures	'*If present, structures should have no (or a minor) effect on migration, sediment transport and habitat structure*'	Yes – where Fluvial Audit or RHS data are available
Fine sediment	'*No unnaturally high levels of silt*': 'silting' highlighted as an impact on RHS form or ≥3 spot checks (i.e. 30% of channel) with silt as the predominant material.	Yes – where Fluvial Audit or RHS data are available, albeit using slightly different criteria for assessing fine sediment

comparing the hydromorphology at equivalent locations or making predictions for new locations (Jeffers, 1998). Where this is based on RHS data, the 2007–8 RHS Baseline of England and Wales provides a large data set (n = 4884) for developing such methods (Seager *et al*., 2012).

We have recently developed a model for predicting aspects of river hydromorphology, based in GIS (Vaughan *et al*., 2013). This uses two variables: specific stream power, a widely used variable that describes a stream's ability to transport sediment, and catchment area, which acts as a scaling variable. Stream power has long been applied in fluvial geomorphology to help to predict and explain different planforms and other channel characteristics (e.g. van den Berg, 1995; Knighton, 1999; Bizzi & Lerner, 2014). The model was developed using the RHS Baseline database, and the predictive models tested extensively (Vaughan *et al*., 2013).

The model was used in two ways to assist with the condition assessment for the river Wye. The first was an attempt to predict the 'pristine' physical conditions for each river reach. This allowed an 'observed versus expected' comparison, similar in principle to the RIVPACS/RICT. For this purpose, models were re-calibrated using a subset of the RHS Baseline data set (n = 428) which only contained reaches in Habitat Modification Class 1 (HMC1; little or no direct modification to the channel). The extent of artificial or intensive land cover, following the definition used in the WFD High Status rules (Environment Agency 2010), was also added, so that predictions could be made for situations where no artificial/intensive land cover was present. As such, the model should give the best possible estimates of the prevalence/extent of different channel forms/physical habitat features in the absence of anthropogenic impacts

The second way in which the model was applied was to identify the 100 most similar surveys from the RHS Baseline against which to compare each location sampled in the Wye. Having similar specific stream power, and being of similar size, the nearest neighbours are expected to function in similar ways to the location being assessed (Vaughan *et al*., 2013). This places each reach in a broader context of whether, for example, it is among the least modified reaches of its 'type'. Nearest neighbours for each reach were identified just in Wales (see example in Figure 3), and in England and Wales combined, so that the most relevant comparison can be made.

Sampling scheme

Wherever possible, five 500m reaches were surveyed from every channel represented by the SAC boundary, ensuring that coverage was consistent with the CSM guidelines (JNCC, 2014). Where a waterbody contained multiple tributaries, each one was surveyed in this way (e.g. the Hirnant, Llanwrthwl Dulas and main stem of the Wye within waterbody GB109055042250). For longer water courses, samples were taken every 1-2km, as this is considered to be a good compromise between survey effort and capturing the local variation in the physical environment (Wilkinson *et al*., 1998; Raven *et al*., 2010; JNCC, 2014). Where an existing RHS was available, that 500m reach was not resampled. Spot-check sampling points, and the locations of the complete 500m reaches, were positioned by generating points at 50m intervals along the complete length of the river network using the 'Construct Points' tool in ArcGIS (Fig. 4). A combination of the Fluvial Audit GIS layers and aerial photographs were used to derive RHS data based on a detailed series of rules (see Appendix 1 for details).

Figure 3. Example of nearest neighbour analysis for a location on the upper Ithon. Part (a) shows the location of the reach, (b) the 100 nearest neighbours in Wales (red triangles) compared to the Ithon (black square) and the complete RHS Baseline for Wales and England (grey circles), and (c) the geographic location of the 100 nearest neighbours.

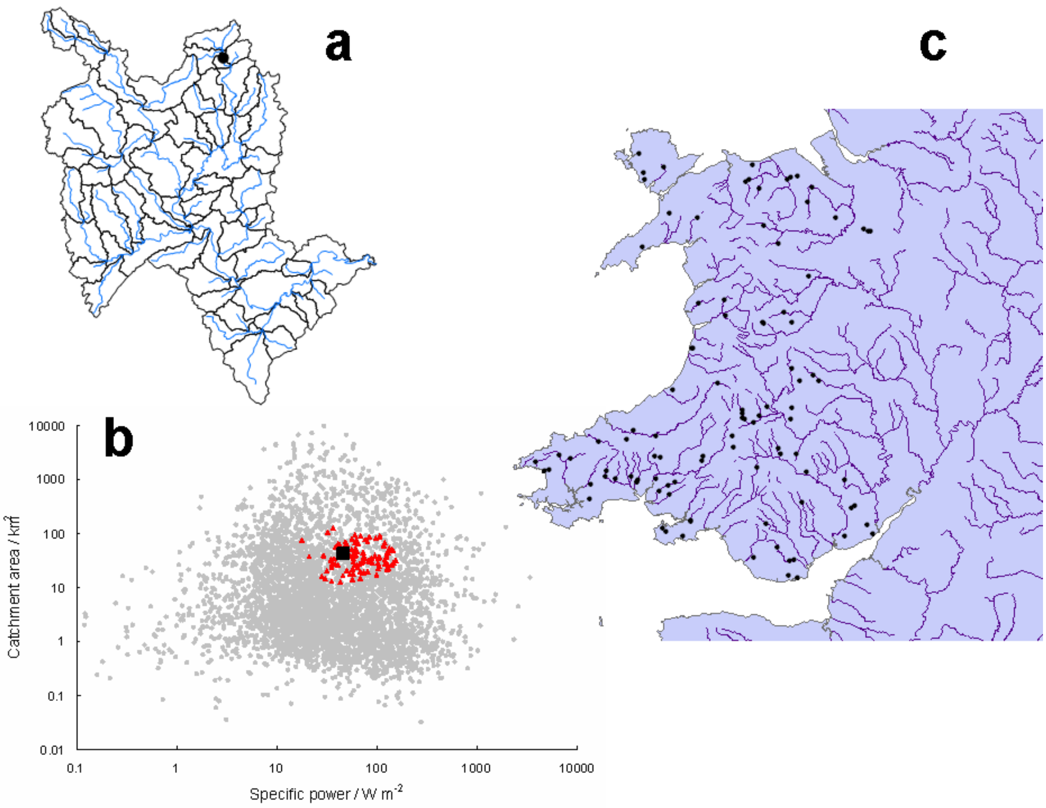
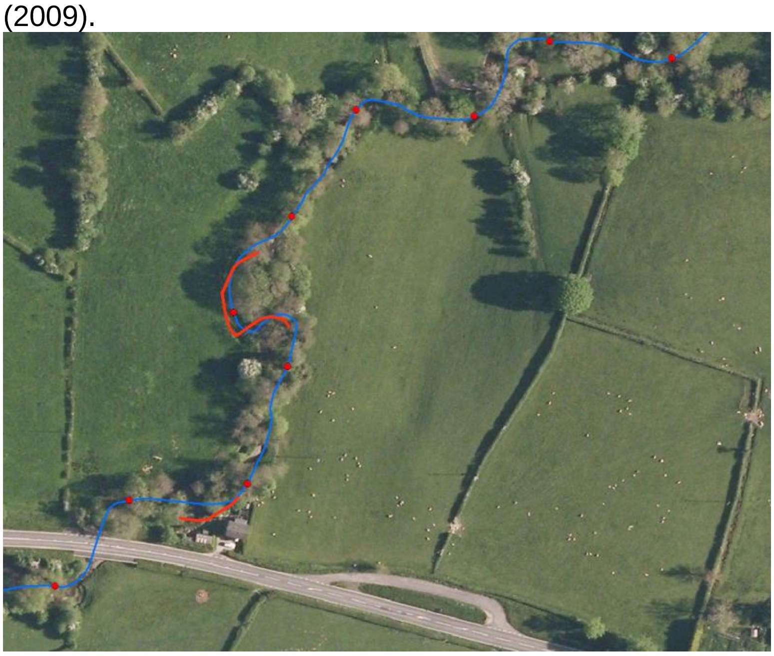


Figure 4. A small section of the Mithil Brook with aerial photography, 50m ‘spot-check’ markers (red circles) and the Fluvial Audit bank protection layer (red lines). Aerial imagery: Infoterrer (2009).



Some waterbodies either had no Fluvial Audit data, or only partial coverage, and so the assessment had to rely primarily upon aerial photographs, supported by 1:25 000 scale Ordnance Survey maps. Contrary to some studies where aerial photographs have been a valuable basis for collecting hydromorphological data, the extensive tree cover along many of the stream channels in the Wye catchment limited the data that could be collected in this way. Along many of these sections extensive use was made of OS mapping to support the photographs, **but the extent of channel modifications will almost certainly be underestimated: most notably bank protection**. The extent of different data sources is noted along with the site assessments so that this limitation is explicit.

For several of the CSM criteria, the mean value of a metric is required (e.g. mean SERCON score, prevalence of coarse wood; Table 1). Where a waterbody contained only one channel, a simple mean could be calculated, whereas weighted means were calculated when waterbodies contained two or more tributaries: means were first calculated from the individual channels, before weighting the results by the length of the channel (i.e. its contribution to the overall waterbody) in the final mean. Using the example of GB109055042250, averages were first calculated separately for the Hirnant, Llanwrthwl Dulas and main stem of the Wye, and then a weighted average calculated for GB109055042250. This weighting procedure was necessary to account for the different sampling densities on channels of different lengths (shorter tributaries having a greater number of samples per unit length). A similar process was used for calculating the SSSI summaries, with the means for individual channels being weighted by their relative contribution to the total river length within the SSSI.

For some measures (e.g. percent of locations in HMC 1, mean SERCON score; Table 1), 90% confidence limits were calculated around the waterbody or SSSI means using bootstrapping (Buckland, 1984). This provided a degree of confidence in the assessment of whether a waterbody passed or failed a particular criterion (e.g. mean SERCON score ≥4): where the CSM threshold fell outside the range between the upper and lower 90% confidence limits, the pass or failure of a rule could be ascribed with a high degree of confidence.

Data collection and assessment criteria

CSM guidance (JNCC 2014) gives seven criteria for use in assessing SSSI/SAC hydromorphological condition (Table 1), of which six could be estimated from the data available in the Wye. The seventh was the SERCON score for bank vegetation naturalness, which requires a modified version of RHS data collection in the field (JNCC 2014). The data collection and approach used to assess the habitat will be described for the other six in turn.

Channel planform

Modifications to the planform were measured directly for the complete length of channel within the SAC boundary. A broad definition was taken, encompassing embankments and bank protection as constraints upon the channel, in addition to re-alignment. Within the Fluvial Audit extent, the total length of modification was measured directly within each waterbody catchment from the 'Embankments' and 'Bank protection' GIS layers using the Geospatial Modelling Environment (Beyer, 2011). Re-alignment was not always recorded systematically in the Fluvial Audit (Jeffries *et al*., 2007), with some sections recorded in the 'Historical changes' layer, others identified from the comments in the 'G_reach' layer, and additional sections highlighted in the written summaries (Section 4.2 of Jeffries *et al*., 2007), of which some could not be found in the accompanying GIS data. In the case of the latter, the extent was usually unknown. The assessment was relatively conservative in the sense that where comments suggested that re-alignment was 'possible' or 'probable' it was considered to be present. Where Fluvial Audit data were not available, no bank protection, embankments or re-aligned planform were observed from the aerial photographs.

Once the data were compiled and the total length of mapped modifications calculated, each waterbody was manually screened to identify sections where: i) bank protection was present on both banks, or ii) >1 modification was present. In the case of the former, the channel length with bank protection was calculated by subtracting the length of the shorter section of reinforcement (left or right bank) from the total length of bank protection recorded in the waterbody catchment. Doing this at every point where bank protection was present on both banks ensured that the total length of protection for the waterbody related to the length of channel, rather than length on both banks. Where multiple modifications were present simultaneously, the length of overlap was measured directly from the GIS layers (measure tool) and summed for each waterbody. This was then subtracted from the total length re-aligned or with embankments or bank protection to arrive at the final channel length with a modified or constrained planform. This is presented as a percentage of the total channel length to fit with the CSM rule (Table 1).

In addition to the simple assessment of the direct 'footprint' of modifications, a simple assessment was made of the evidence that modifications were having an impact that could be detected in the Fluvial Audit data. Very detailed data would be required – probably including temporal replication – to get an accurate assessment of the impact that individual structures may or may not be having on the channel. In lieu of this, a simple assessment was performed at the scale of the Fluvial Audit reach – the finest resolution at which most of the relevant Fluvial Audit data were available. Two stages were involved:

1. A table was drawn up of the physical modifications observed in the Upper Wye (e.g. embankments, weirs) along with their generic impacts upon geomorphic processes and the 'signal' (symptoms) of those impacts that may be observed in the Fluvial Audit (Table 2). The symptoms fall into five categories: coarsening of the bed, fining of the bed, reduced bank stability, sediment storage and a change in channel width. For each type of modification, this led to a series of simple hypotheses that could be tested using the Fluvial Audit data.
2. Among-reach comparisons were made based on the predicted symptoms (Table 2). Each Fluvial Audit reach where a modification was present was compared with the reach immediately upstream and the reach immediately downstream. Within reach changes were assessed in comparison to the reach upstream, whilst downstream impacts were assessed by comparing the downstream reach both to the reach with the impact, and the reach upstream of that. For each type of channel modification, the potential symptoms of impact were set out and ≥1 Fluvial Audit variable used to look for the expected change (Table 3). A count was made of the number of categories in which a change consistent with an impact was observed, based on the five general classes (coarsening, fining, sediment storage, bank stability, channel width). For the purposes of the current report, potential evidence of impact was recorded when >50%

of the categories suggested that impacts could be present (e.g. three out of five for bank protection).

Table 2. Generic assessment of channel modifications found in the Upper Wye: their potential impacts upon geomorphic processes, symptoms that may be observed and variables from Fluvial Audit or RHS that may help to identify the impacts.

Type of modification	Potential impacts	Symptoms of impacts	Evidence from Fluvial Audit or RHS
Group 1 – re-configuration of the channel cross section or planform			
Channel re-alignment, bank re-profiling and re-sectioning	• Subsequent adjustment in channel cross-section. Direction of adjustment (i.e., reduction or increase in width or depth) depends on the local balance between flow and sediment supply. • Change in bed surface composition corresponding with cross-sectional adjustment (i.e., narrowing and deepening leading to coarsening of bed).	• Width or depth change • Change in bed surface composition	Within reach: • Increased abundance of larger substrata (gravel/pebble, cobbles) • Reduced abundance of silt/sand substrata • Reduced percent coverage of fines • Reduced frequency of bars • Relevant comments from the Fluvial Audit surveyors Downstream: • Increased abundance of silt/sand substrata and marginal silt deposits • Increased frequency of bars • Narrowing of channel
Group 2 – parallel bank alterations			
Embankments parallel to river	• Hydrograph modification - elimination of overbank flow would increase peak discharge in the channel. • Channel deepening in response to increased peaks and enhanced sediment transport. • Coarsening of the channel bed. • Riverbank instability. • Deposition of eroded material in downstream reaches. If deposited on bars, enhanced bank erosion may occur. • Connectivity to floodplain only during extreme discharge events. • During extreme events, increased residence time of floodwaters on floodplain.	• Reduction in alluvial bars • Coarsening of riverbed • Increased specific stream power	Within reach: • Increased abundance of larger substrata (gravel/pebble, cobbles) • Reduced abundance of silt/sand substrata • Reduced percent coverage of fines • Reduced frequency of bars • Increased extent of fluvial erosion of banks • Relevant comments from the Fluvial Audit surveyors Downstream: • Increased abundance of silt/sand substrata and marginal silt deposits • Increased frequency of bars
Bank defences and reinforcement	• Limiting width adjustment could lead to channel incision that may undermine defences. • Reduced sediment supply from the riverbanks could lead to channel incision, bank instability and bed coarsening	• Local channel deepening – increased specific stream power • Increased bank erosion in	Within reach: • Increased abundance of larger substrata (gravel/pebble, cobbles) • Reduced abundance of silt/sand substrata

	downstream. • Loss of riparian vegetation. • Loss of bank roughness could be associated with higher near-bank flow velocities exiting reach and therefore increased bank erosion downstream. • Local scour of banks around reinforcing measures.	reaches immediately upstream or downstream • Unravelling of protection measures	• Reduced percent coverage of fines • Reduced frequency of bars • Relevant comments from the Fluvial Audit surveyors Downstream: • Increased extent of fluvial erosion of banks • Increased abundance of larger substrata (gravel/pebble, cobbles) • Reduced abundance of silt/sand substrata • Reduced frequency of bars • Widening of channel Upstream: • Increased extent of fluvial erosion of banks
Bridges	• Restricted flow area and thus increased flow velocities through the section. • Enhanced sediment transport through the impacted section, potentially resulting in channel deepening and a local coarsening of the riverbed. • Turbulence around piers and associated local scour of the bed. • Bed material eroded from the bridge section may be deposited downstream leading to aggradation, bar growth and increased bank erosion. • Hydrograph modification - restriction of flow during flood events could cause increased flood risk upstream and lower peaks downstream. • Restricted flow through section could also result in local steepening of the water surface, exacerbating erosion of the bed. • Lowering of the channel bed at the impacted section may cause the formation of a knickpoint that could migrate upstream, propagating incision and riverbank instability. • Woody debris may be trapped at piers during high discharges, increasing stage, flood risk and local scour issues.	• Local channel deepening – increased specific stream power • Local channel coarsening • Downstream aggradation, bar growth and bank erosion • Upstream incision • Upstream flooding	Within reach: • Relevant comments from the Fluvial Audit surveyors: ‘G_reach’ and ‘Structures’ GIS layers
Groynes and croys	• Deflecting flows away from the riverbanks should promote fine-grained sedimentation onto riverbanks, potentially narrowing the channel • Concentrating flows in the middle of the channel should	• Local channel narrowing and coarsening of thalweg • Downstream widening	Within reach: • Local increase in prevalence of largest substrata • Marginal silt deposits • Channel narrowing

	promote sediment transport and potentially incision. • Coarsening within the middle of the channel to be expected, with the thalweg moved away from the banks. • Deposition of material mobilised from the thalweg may reduce channel widths downstream. Bar growth could be associated with increased rates of bank erosion.	and fining of bed	Downstream: • Increased prevalence/coverage of fine sediments • Channel narrowing
Group 3 – perpendicular/floodplain alterations			
Road or railway embankments crossing the floodplain perpendicular to river	• Hydrograph modification - alteration of locations and volumes of riverbank overtopping and flow return to channel. • Increased flood risk upstream of embankments. • Potentially increased residence time of floodwaters on floodplain. • Channelised flow on floodplains where culverts present.	• Increased flood risk upstream	• Widening upstream, narrowing downstream
Group 4 – poaching of the banks			
Poaching (livestock, footpaths/access points)	• Riverbank directly affected by animal access, with riparian vegetation reduced or non-existent. • Local trampling of riverbank soil increases surface runoff and soil erosion from the floodplain and bank. • Failure or slumping of altered riverbanks. • The increased fines delivered to the channel would be flushed but would be associated with organic pollutants. • Disturbance of the riverbed would destroy any natural features such as pools and riffles and mobilise fines that would be flushed downstream. • A gradual coarsening of the bed is to be expected, potentially leading to pavement forming.	• Local loss of natural bed forms • Local coarsening of the riverbed • Fining of the riverbed downstream of impacted reach • River bank instability	Within reach: • Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines • Increased frequency of bars • Relevant comments from the Fluvial Audit surveyors Downstream: • Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines • Increased frequency of bars
Group 5 – outfalls/intakes, pipe crossings and trash screens			
Outfalls and intakes with reinforcement	• Hydrograph modification – increased discharge downstream of outfalls and reduced discharge downstream of intakes with greater influence during low to moderate events. • Increased sediment transport capacity downstream of outfalls leading to erosion of the bed and banks. Coarsening of the bed surface could occur. • Reduced sediment transport capacity downstream of	• Bed and bank erosion downstream of outfalls • Coarsening of the bed downstream of outfalls • Aggradation and fining downstream of intakes	Within reach: • Relevant comments from the Fluvial Audit surveyors: 'G_reach' and 'Structures' GIS layers

	intakes could induce aggradation with fining of the bed surface. • Local scour associated with turbulence around intake and outfall structures.		
Trash screens	• Interrupted movement of coarse wood • Turbulence around the edges of the structure could cause local scour of the bed.	• Local channel coarsening	Within reach: • Relevant comments from the Fluvial Audit surveyors: 'G_reach' and 'Structures' GIS layers Downstream: • Reduced prevalence of coarse wood
Group 6 – river bed and continuity disturbance			
Fords	• Disturbance of the riverbed would destroy any natural features such as pools and riffles and mobilise fines that would be flushed downstream. • Coarsening of the bed is expected, potentially leading to pavement forming. • See below for impacts associated with fords involving weirs.	• Local loss of natural bed forms • Local coarsening of the riverbed • Fining of the riverbed downstream of impacted reach	Within reach: • Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines • Increased frequency of bars • Relevant comments from the Fluvial Audit surveyors Downstream: • Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines • Increased frequency of bars
Weirs	• Bed elevation locally fixed at the weir, leading to a shallow water surface slope upstream of the weir and a steepened water surface slope downstream of the weir. • Reduced sediment transport capacity upstream of the weir should lead to a fining of the riverbed and overall aggradation, potentially increasing flood risk. Aggradation of bars could exacerbate bank erosion. • Coarsening of the riverbed should be expected downstream of the weir as sediment supply is reduced and sediment transport capacity is increased. Other changes may include incision, narrowing and reduced rates of meander migration.	• Upstream channel widening and fining • Downstream channel narrowing and coarsening • Reduction in alluvial bars downstream	Within reach: • Increased frequency of ponded sections • Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines Downstream: • Increased abundance of larger substrata (gravel/pebble, cobbles) • Reduced abundance of silt/sand substrata • Reduced percent coverage of fines • Reduced frequency of bars • Narrowing of channel Upstream:

			• Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines
Culverts	• Bed elevation locally fixed at the culvert, leading to a shallow water surface slope upstream of the culvert and a steepened water surface slope downstream of the culvert. • Reduced sediment transport capacity upstream of the culvert should lead to a fining of the riverbed and overall aggradation, potentially increasing flood risk. Aggradation of bars could exacerbate bank erosion. • Coarsening of the riverbed should be expected downstream of the culvert as sediment supply is reduced and sediment transport capacity is increased. Other changes may include incision, narrowing and reduced rates of meander migration. • Culverts are often blocked during high flows, and upstream flooding could be frequent.	• Upstream channel widening and fining • Downstream channel narrowing and coarsening • Reduction in alluvial bars downstream	Within reach: • Increased frequency of ponded sections • Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines Downstream: • Increased abundance of larger substrata (gravel/pebble, cobbles) • Reduced abundance of silt/sand substrata • Reduced percent coverage of fines • Reduced frequency of bars • Narrowing of channel Upstream: • Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines
Abstraction/ hydropower installations	• If abstraction involves impoundment, then impacts will be similar to weirs. If not, then discharge is locally reduced, potentially causing a similar aggradation of the riverbed. Widening could be an issue downstream. • Hydropower installations would involve an impoundment and would generate impacts similar to weirs.	• Upstream channel widening and fining • Downstream channel narrowing and coarsening • Reduction in alluvial bars downstream	Within reach: • Increased frequency of ponded sections • Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines Downstream: • Increased abundance of larger substrata (gravel/pebble, cobbles) • Reduced abundance of silt/sand substrata • Reduced percent coverage of fines • Reduced frequency of bars • Narrowing of channel Upstream: • Increased abundance of silt/sand substrata and marginal silt deposits • Increased percent coverage of fines

Group 7 – gravel extraction			
Gravel extraction	• Results in a local lowering of channel elevations. • At these locations, the water surface topography will be quite varied, potentially enhancing bed scour and destabilising riverbanks. • Depending on the scale of gravel extraction, a knickpoint could be generated that would migrate upstream and drive bed incision. • Reduced bed material supply from mined area could cause incision in downstream reaches as well. • Incised reaches may undergo an evolution that involves destabilising the banks, bank collapse, widening and subsequent aggradation to achieve a new adjusted form and profile. • Widespread lowering of the channel bed may result in lowering of the water table with adverse impacts on floodplain vegetation. • Overall coarsening of the riverbed.	• Local channel deepening • Potential coarsening at location and upstream • Channel widening upstream	Within reach: • Larger dominant substratum type • Reduced prevalence of silt/sand substrata, increased prevalence of gravel/pebble/cobble • Reduced prevalence of bars • Relevant comments from the Fluvial Audit surveyors: 'G_reach' layer Downstream: • Channel incision and narrowing due to reduced sediment supplies from upstream Upstream: • Larger dominant substratum type • Reduced prevalence of silt/sand substrata, increased prevalence of gravel/pebble/cobble

Table 3. Hypothesised changes among Fluvial Audit reaches that could indicate hydromorphological impacts (‘symptoms of impact’) of channel re-alignment, embankments and bank protection. Arrows indicate the direction of change expected if impact is occurring, whilst black cells were not considered. The second half of the table lists the Fluvial Audit variables that were used.

	Within reach				Downstream					Upstream
	Coarsening	Fine sediment	Sediment storage	Bank stability	Coarsening	Fine sediment	Sediment storage	Bank stability	Channel width	Bank stability
Re-alignment	↑	↓	↓			↑	↑		↓	
Parallel embankments	↑	↓	↓	↓		↑	↑			
Bank protection	↑	↓	↓		↑	↓	↓	↓	↑	↓

Coarsening:
- Increased coverage of gravel or cobble bed materials between the three categories recorded: ‘absent’<‘present’<‘dominant’

Fine sediment:
- Increased coverage of fines or sand bed materials between the three categories recorded: ‘absent’<‘present’<‘dominant’
- Increase percent fines cover
- Increased marginal silt: ‘absent’<‘present’<‘extensive’

Sediment storage:
- Number of bars (stable or unstable) per kilometre (i.e. number of bars / Fluvial Audit reach length)

Bank stability:
- Percentage of bank length with fluvial erosion recorded (GIS Erosion layer)

Channel width:
- Average width as recorded in GIS G_reach layer

This represents a simplistic approach to screening the Fluvial Audit for evidence of impact, and would undoubtedly benefit from further development. For the current purposes, it provided a relatively straightforward way of screening several hundred channel and bank modifications for evidence of impact, which has application both to CSM and WFD assessment (Environment Agency, 2010; JNCC, 2014). The >50% criterion is arbitrary, but provided a basis for identifying the reaches with the widest range of potential impacts. Further work to refine the list of impact indicators and to improve the ability to separate potential impacts from background variability among reaches should be the priorities for this.

Habitat Modification Score (HMS)

Using Fluvial Audit data, many of the variables necessary for calculating HMS and HMS class (HMC) are available, whereas others are not recorded in a systematic fashion (e.g. extent of bed reinforcement). However, based on previous work (e.g. Vaughan, 2010), many of the individual variables combined in HMS are consistently correlated with one another, creating the opportunity to predict HMS based on a sub-set of the variables normally used to calculate it.

Using the 2007-8 RHS Baseline database, a linear regression model was fitted to a sub-set of RHS variables that could be recorded from the Fluvial Audit (Table 4). The resulting model was an effective predictor, explaining >80% (R^2 = 0.81) of the variation in HMS across 4087 surveys from the RHS baseline. As a consequence, it was used to predict HMS from all 500m reaches with Fluvial Audit data.

Table 4. RHS variables, derived from Fluvial Audit data, used to predict HMS.

Part of survey	Variable
Spot-check	Bank modification – reinforced
Spot-check	Bank material - artificial
Spot-check	Bank modification – artificial berm
Spot-check	Bank modification – embanked
Sweep-up	Channel obviously re-aligned
Sweep-up	Channel obviously impounded
Sweep-up	Number of outfalls (minor, intermediate and major combined)
Sweep-up	Number of weirs (minor, intermediate and major combined)
Sweep-up	Number of culverts

One omission from this model that is relevant to the Upper Wye is poaching of the banks. Although it contributes to the HMS, in the RHS Baseline data set poaching is associated with lower HMS, as it is largely associated with rural areas, where major hard engineering works may be less extensive (leading to lower HMS). As a consequence, if poaching was included in the regression model, it had a negative coefficient (i.e. increased poaching associated with lower HMS), which could have led to negative HMS estimates where poaching – but no other modifications – were present. For this reason poaching was excluded from the model and so the predicted HMS may under-estimate true HMS in some locations. Poaching generally makes a modest contribution to HMS, with a mean of 25 points at locations where poaching is recorded. In situations where hard engineering is also present, the lack of a poaching score is likely to have little impact upon the HMC. However, in the absence of other impacts, this would be enough to mis-classify a location as HMC1 rather than HMC2. As a consequence, some caution is needed in interpreting the HMC results/rule.

SERCON Riparian zone vegetation naturalness score

In contrast to the SERCON score for 'bank vegetation naturalness', the riparian zone naturalness score can be calculated directly from RHS. A full description of the method is provided in the CSM guidelines (JNCC, 2014). This was calculated from the aerial photographs, allowing a direct comparison across the complete area. Buffer strips 5m and 50m wide were generated around the river network in ArcGIS to assist with this process.

Coarse woody debris (CWD)

Two alternative criteria are described for the prevalence/abundance of CWD in the CSM guidelines (JNCC, 2014). The Fluvial Audit 'CWD' layer maps the position of individual debris, allowing the frequency with which coarse wood occurred in the 500m reaches sampled across the Wye to be readily calculated. Judging whether CWD was ‘extensive’ *sensu* RHS was not possible. The first CSM rule was used therefore: 75% or more of RHS sites have woody debris present (JNCC, 2014). This was interpreted as being 75% with coarse wood recorded as ‘present’ or ‘extensive’ – the guidelines are unclear on this point. In all cases, at least five 500m reaches were present in every waterbody, with the exception of those <2.5km in length. Where this was the case, the limited number of samples (<5) is highlighted in the results. Confidence limits (90%) were also calculated to assign a degree of confidence to passing/failing the 75% rule.

To provide additional context for interpreting the CWD results, the prevalence of coarse wood amongst the 100 nearest neighbours in the RHS Baseline data set for Wales, and England and Wales, was also calculated.

Direct modifications to the channel

The CSM guidelines require an assessment of the impacts made by structures in the channel, but do not include a threshold comparable to that for the percentage of the planform that is modified (JNCC, 2014). The guidance focuses on structures likely to affect continuity of the river, for water, sediment or organisms. The Fluvial Audit ‘Structures’ layer was used for this analysis, as surveyors noted whether structures such as bridges and weirs were having an impact in the field, and described the nature of the impact (e.g. ponding, local scour). Although this does not provide a basis for quantifying the impacts, as the severity of modifications is not recorded, it does provide a much more sensitive basis for assessing impacts than examining whole Fluvial Audit reaches, as for bank protection, realignment and embankments. Many in-channel structures are expected to generate some local scouring, but for the current assessment, the focus was upon ponding as an indicator that continuity was being interrupted. In the Wye, such impacts were present at 4% of bridges, 50% of culverts, 8% of fords and 83% of weirs. A stringent criterion was used: the presence of one or more structures with evidence of impeding the flow was considered sufficient to produce a failure on this rule. This could be re-visited to allow for a greater degree of modification and/or be supported by the reach-by-reach analysis of the Fluvial Audit data described above.

Fine sediment

CSM guidelines for siltation use aspects of RHS that could not be derived from Fluvial Audit: ‘silting’ noted as a ‘major impact’ or at least one third of spot checks in the waterbody recording silt as the predominant substratum (JNCC, 2014). Given the guidance in the RHS manual that a thin layer of silt coating a coarse substratum should not be recorded as silt, along with the relatively high stream power in western Britain (Vaughan *et al*., 2013), the former criterion may be of limited value. Conversely, Fluvial Audit records several relevant variables to describe elevated fine sediment, but no assessment was possible where only aerial photographs were available.

The approach here was in two parts. The first was to calculate the frequency with which silt was recorded as a bed material for comparison against the expected probability of silt being present. Presence of silt was taken to be fines ‘present’ or ‘dominant’ as a bed material in the Fluvial Audit or silt ‘present’ in RHS spot checks – the latter included the additional records from the spot check of silt being present at >1% of the 500m reach but missing from the 10 main spot checks (Environment Agency, 2003). Previous work has shown that the presence of silt is highly predictable based on the stream power (Vaughan *et al*., 2013). The difference between the observed prevalence (percentage of 500m reaches in a waterbody with silt present) and the mean predicted probability of silt being present from the same 500m reaches provides a measure of whether the prevalence of silt is greater than expected. To assess whether an observed difference in observed v. expected was likely to be due to sampling variation, the magnitude of this different for a waterbody was compared to the standard deviation of the difference between the predictions and observations at the 500m reaches within the waterbody. If the water-body level difference exceeded two standard deviations, this was taken to be evidence of elevated silt prevalence.

The second part of the fine sediment assessment was to focus upon the percentage cover of fines in the Fluvial Audit, as this measure has been used widely in the scientific literature concerning the ecological impacts of fine sediments (e.g. Larsen *et al*., 2009; Jones *et al*., 2012; Burdon *et al*., 2013). Whilst there is some variation in methodology, many studies seem to identify impacts upon macroinvertebrates and other taxa (albeit fewer studies are available) appearing in the approximate range of 10–15% cover. It should be noted, however, that there is evidence of some sensitive taxa appearing to respond at <5% cover (e.g. Larsen *et al*.'s study in the Usk catchment). For the current assessment, 10% was used as a threshold to identify possible impacts based on the percent fines cover.

The overall assessment rule for fine sediment was that a potential impact was identified when at least one of the two individual assessment rules suggested elevated prevalence/abundance of silt.

Assessment results

Across the 44 waterbodies, only two were judged to be in favourable condition by passing all criteria: Bachell Brook (GB109055042120) and the Nantmel Dulas (GB109055042080; Table 5). Four showed no evidence of a failure, but lacked data on aspects such as siltation, whilst a further four showed some weak evidence of failure, based on a small sample size.

The most frequent reason for failure was a lack of CWD, with 69% of waterbodies (for which sufficient data were available) failing on this criterion. No coarse wood was detected in the 500m reaches on many waterbodies, with several others having a prevalence of 20–30%. In the Welsh RHS Baseline sites, the mean prevalence was 57%, suggesting that the majority of river reaches in Wales would fail the 75% criterion. Conversely, very few waterbodies failed on SERCON/riparian vegetation, reflecting how well wooded most tributaries of the Wye are. The exceptions were Gwenlas and Llaethdy Brooks, and the main Wye between the Tarenig and Bidno confluences.

There is some overlap between the three criteria assessing direct physical modifications to the channel (planform, HMC, in-channel structures) and cumulatively these were responsible for many failures. Considering the planform, 41% of waterbodies failed due to >5% of channel length modified, although this would drop to 25% if only re-alignment and embankments were considered i.e. excluding bank protection. The wording of the CSM guidelines is such that this is open to some interpretation, and further guidance about what to include would be helpful. A similar proportion (43%) failed because they had structures thought to be interrupting the continuity – at least at a local scale. Over half of the waterbodies failed on the HMC criterion, seemingly as relatively little bank reinforcement or re-alignment of the channel is required to achieve HMC3 or above, and only one reach ≥HMC3 is needed per waterbody to fail (cf. using the mean HMS). Despite this, on average the Wye has a relatively low level of modification compared to Wales more generally: for 38 waterbodies where HMC data were available, the mean rank of Wye reaches in the RHS Baseline was 76 – indicating that on average, Wye waterbodies were in the 25% of least modified reaches. Only Howey Brook had a mean rank above 50, indicating that it was in the top 50% of modified sites in Wales for similar channels.

Excess fine sediment led to a 49% failure rate amongst waterbodies where sufficient data were available. The mean prevalence of fines in 500m reaches was 33%, compared to a predicted prevalence of 9%. The precise magnitude of this difference should be treated with some caution, however, due to the difficulty of testing a model that predicts 'pristine' conditions, which rarely – if ever – occur.

Considering the distribution across the Wye of waterbodies passing and failing the different criteria (Fig. 5), a few patterns emerge. Notably, there are similarities in the pattern of failures due to direct channel modifications or fine sediment issues: large parts of the Ithon (especially western tributaries) and some of the tributaries lower down the Wye (Fig. 5). At the same time, the few waterbodies that passed the CWD rule were also in this area.

Combining the waterbody-level data to assess complete SSSIs indicated that seven out of the eight were not in favourable condition (Table 6). The exception was the Upper Wye Tributaries, but the data were limited for this unit. All but Colwyn Brook failed due to a lack of CWD, and all seven failures included at least one of the direct modification categories (planform, HMS or in-channel structures; Table 6).

Table 5. Summary of the results of SAC assessments based on WFD waterbodies. The results of the six individual tests are included, along with a summary of the overall assessment and a note of any data limitations. In the six assessment columns, 1 = pass, 0 = fail, 'Low' indicates an insufficient sample size for a reliable assessment and 'NA' = no data available.

Waterbody code	Waterbody name	Planform	HMC	SERCON	CWD	Structures	Siltation	Summary of assessment	Data limitations
GB109055037050	Duhonw - source to conf R Wye	0	0	1	**Low**	0	1	Fail: planform (if bank protection is included), HMC, 1 weir	No major limitations
GB109055041870	Afon Gwesyn - source to conf R Irfon	1	NA	**Low**	NA	1	NA	Fail: SERCON (limited tree cover)	No Fluvial Audit or RHS
GB109055036680	Cledan - source to conf R Irfon	1	NA	1	NA	1	NA	No evidence of failure, but limited data	No Fluvial Audit or RHS
GB109055041880	Afon Cammarch - source to conf R Irfon	1	NA	1	NA	**Low**	NA	Possible fail: no direct evidence of failure, 2 weirs + large number of bridges (expect impacts to continuity based on average across Fluv. Aud)	No Fluvial Audit or RHS
GB109055042190	Afon Chwefru - source to conf R Irfon	1	0	**Low**	**Low**	0	NA	Fail: weir	Only data = 1 RHS
GB109055036690	Tirabad Dulas - source to conf R Irfon	1	0	**Low**	**Low**	1	NA	Fail (low confidence): HMC, SERCON, CWD	Only data = 1 RHS
GB109055041890	Afon Garth Dulas - source to conf R Irfon	1	0	**Low**	**Low**	0	NA	Fail: weir	Only data = 1 RHS
GB109055037090	Irfon - conf Cledan to conf R Wye	1	0	**Low**	**Low**	0	NA	Fail (low confidence): HMC and CWD	Only data = 1 RHS
GB109055036760	Irfon - conf Afon Gwesyn to conf Cledan	1	1	**Low**	**Low**	**Low**	NA	Fail: in-channel structures (weir)	Only data = 3 RHS
GB109055042070	Clywedog Bk - conf Bachell Bk to conf R Ithon	1	1	1	0	1	0	Fail: CWD, evidence of siltation	Only four 500m reaches
GB109055042090	Clywedog Bk - source to conf Bachell Bk	1	0	1	1	0	1	Fail: HMC + weir	No major limitations
GB109055042170	Gwenlas Bk - source to conf R Ithon	0	0	0	0	1	0	Fail: re-alignment, HMC, SERCON, CWD, evidence of siltation	No major limitations
GB109055042160	Llaethdy Bk - source to conf R Ithon	1	1	0	**Low**	1	0	Fail: SERCON (less tree cover), evidence of siltation	No major limitations
GB109055042120	Bachell Bk - source to conf Clywedog Bk	1	1	1	1	1	1	Pass	No major limitations
GB109055042180	Ithon - source to conf Llaethdy Bk	1	0	1	0	0	1	Fail: HMC, CWD, weir	No major limitations
GB109055042150	Ithon - conf Llaethdy Bk to conf Gwenlas Bk	1	1	1	0	1	1	Fail: CWD	No major limitations
GB109055041960	Mithil Bk - source to conf R Ithon	0	0	1	**Low**	0	0	Fail: direct modification of the channel (incl. re-aligment) and weir, potential siltation	No major limitations
GB109055042080	Nantmel Dulas - source to conf R Ithon	1	1	1	1	1	1	Pass	No major limitations
GB109055042130	Camddwr Bk - source to conf R Ithon	1	1	1	0	1	0	Fail: CWD + evidence of siltation	No major limitations
GB109055041900	Howey Bk - source to conf R Ithon	0	0	1	**Low**	1	1	Fail: planform, HMC	No major limitations
GB109055042110	Aran - source to conf R Ithon	0	0	1	1	0	0	Fail: planform (if bank protection is included), HMC, bridge with evidence of impeding flow, evidence of siltation	No major limitations
GB109055042140	Ithon - conf Gwenlas Bk to conf Camddwr Bk	0	0	1	0	0	0	Fail: nearly 10% re-aligned, bridge that appears to	No major limitations

								affect continuity, insufficient CWD and evidence of siltation	
GB109055042270	Ithon - conf Camddwr Bk to conf R Wye	0	0	1	0	0	0	Fail: planform (if bank protection is included), HMC, CWD, 1 weir, evidence of siltation	No major limitations
GB109055036920	Dulas Bk - source to conf Afon Llynfi	0	0	1	1	1	0	Fail: planform, HMC, evidence of siltation	Only four 500m reaches
GB109055036950	Afon Llynfi - conf Dulas Bk to conf R Wye	0	0	1	0	1	0	Fail: 12% re-aligned, insufficient CWD, evidence of siltation	No major limitations
GB109055036970	Triffrwd - source to Dulas	0	0	1	0	1	1	Fail: planform, HMC, CWD	No major limitations
GB109055042280	Wye - conf to conf Afon Marteg to conf Afon Elan	0	1	1	0	1	1	Fail: CWD, modification to planform (if bank protection is included)	No major limitations
GB109055042330	Wye - conf Afon Tarenig to conf Afon Bidno	0	0	0	0	0	1	Fail: large proportion of channel length constrained by embankments, with re-alignment and bank protection also present. Failures for SERCON and CWD too	No major limitations
GB109055037150	Wye (Avon Gwy) - conf R Ithon to conf R Irfon	0	1	1	0	0	0	Fail: planform (if bank protection is included), no CWD, 2 weirs, evidence of siltation	No major limitations
GB109055042320	Wye - conf Afon Bidno to conf Afon Marteg	0	1	1	0	1	1	Fail: CWD + planform (if bank protection is included)	No major limitations
GB109055042250	Wye - conf Afon Elan to conf R Ithon	1	0	1	0	0	1	Fail: bank protection (HMC), no CWD, weirs	No major limitations
GB109055037115	Wye - conf R Irfon to Scithwen Bk	0	1	1	0	0	1	Fail: 6 weirs, CWD, extensive bank protection	No major limitations
GB109055037116	Wye - Scithwen Bk to Brewardine Br	1	0	1	0	1	1	Fail: bank protection (HMC) and no CWD	No major limitations
GB109055042310	Afon Marteg - source to conf R Wye	1	NA	1	NA	1	NA	No evidence of failure, but limited data	No Fluvial Audit or RHS
GB109055042260	Afon Elan - Caban-coch Rsvr to conf R Wye	1	NA	1	NA	1	NA	No evidence of failure, but limited data	No Fluvial Audit or RHS
GB109055042340	Afon Bidno - source to conf R Wye	1	NA	1	NA	1	NA	No evidence of failure, but limited data	No Fluvial Audit or RHS
GB109055037060	Bach Howey Bk - source to conf R Wye	1	1	1	**Low**	1	1	Fail (low confidence): CWD	Only two 500m reaches
GB109055042200	Edw - source to conf Colwyn Bk	1	1	1	1	0	0	Fail: weir + evidence of siltation	No major limitations
GB109055037130	Edw - conf Camnant Bk to conf Clas Bk	1	1	1	**Low**	1	0	Fail: evidence of siltation	No major limitations
GB109055037080	Edw - conf Clas Bk to conf R Wye	1	1	1	**Low**	1	1	Fail (low confidence): CWD	No major limitations
GB109055042370	Camnant Brook - source to confluence R Edw	0	0	1	1	1	1	Fail: extensive modification to planform (re-alignment, embankments and bank protection)	No major limitations
GB109055037160	Builth Dulas Bk - source to conf R Wye	0	0	1	0	0	0	Fail: nearly 14% re-aligned and 2 weirs, insufficient CWD, evidence of siltation	No major limitations
GB109055036990	Scithwen Bk - source to conf R Wye	0	0	1	1	0	0	Fail: planform (if bank protection is included), HMC, several weirs, evidence of siltation	No major limitations
GB109055037030	Clettwr Bk - source to conf R Wye	1	0	1	0	0	0	Fail: HMC, CWD, culvert, evidence of siltation	No major limitations

Figure 5. Results of the SAC assessment plotted for WFD waterbodies. The top left panel plots the overall assessment, while plots in columns 2-4 plot the distribution of waterbodies assessed for the six component tests. Black = pass; white = fail; grey = limited/no evidence (lack of data or wide confidence intervals). All WFD waterbodies overlapping with the SAC are plotted in the bottom left panel for reference.

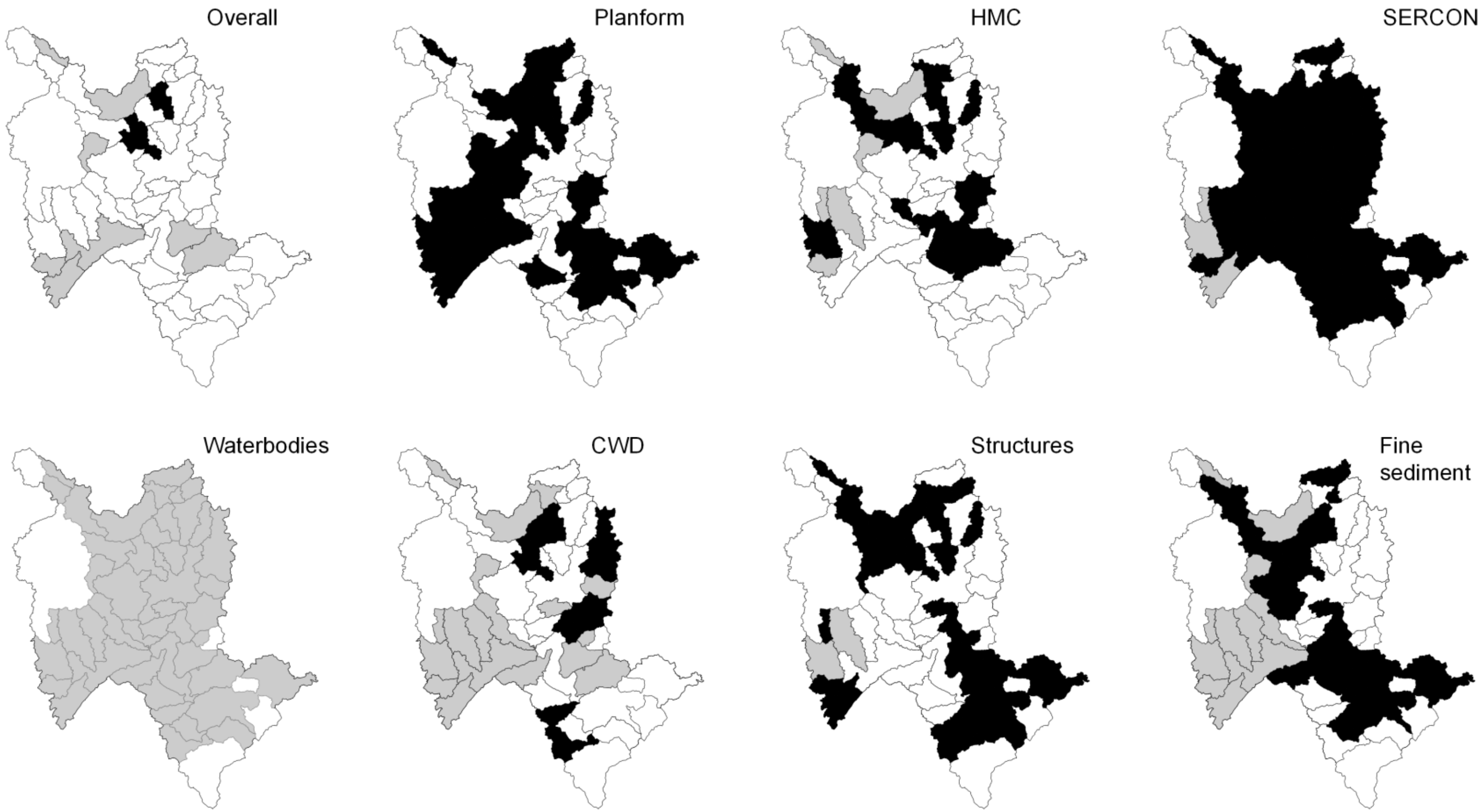


Table 6. Summary of the results of SAC assessments based on constituent SSSIs. The results of the six individual tests are included, along with a summary of the overall assessment and a note of any data limitations. In the six assessment columns, 1 = pass, 0 = fail, 'Low' indicates an insufficient sample size for a reliable assessment and 'NA' = no data available.

Waterbody name	Planform	HMC	SERCON	CWD	Structures	Siltation	Summary of assessment	Data limitations
Ithon	0	0	1	0	0	0	Fail: modifications to channel/planform, CWD and evidence of siltation	No major limitations
Wye tribs	0	0	1	0	0	0	Fail: modifications to channel/planform, CWD and evidence of siltation	No major limitations
Colwyn Brook	0	0	1	1	1	1	Fail: >6% re-aligned	No major limitations
Upper Wye tribs	Low	NA	1	NA	Low	NA	No evidence of failure, but limited data	No Fluvial Audit or RHS
Duhonw	0	0	1	0	0	1	Fail: modification to channel/planform, CWD	No major limitations
Llynfi	0	0	1	0	0	0	Fail: modifications to channel/planform, CWD and evidence of siltation	No major limitations
Upper Wye	0	0	1	0	0	1	Fail: modification to channel/planform, CWD	No major limitations
Irfon	Low	0	1	0	0	NA	Fail: modification to channel/planform, CWD (limited data)	Only 7 RHS
Ithon	0	0	1	0	0	0	Fail: modifications to channel/planform, CWD and evidence of siltation	No major limitations

3. WFD assessment

The guidelines for classifying hydromophology at WFD High Status used in the current report comprise six main rules (Table 7; Environment Agency, 2010). The first two require analysis of the landcover within waterbody catchments, the third examines the riparian zone, the fourth uses HMC, the fifth considers the potential impacts of railway embankments on connectivity between the channel and its floodplain, and the final rule considers direct modifications to the channel. Several of the rules share similarities with those for CSM, but the approach often differs in using rules to assign a degree of confidence, rather than a pass/fail. Each will be described in turn.

Catchment land cover

The two rules for land cover relate to the percentage of the catchment with artificial or intensive land cover (pass/fail) and the percentage of the catchment with low intensity agriculture (level of confidence in a High Status assessment; Table 7). Land cover assessments were based on the 2007 CEH Land Cover Map (LCM2007). The 25m resolution raster version was used because this was available for the whole of Great Britain, allowing models that predict physical habitat based on the RHS Baseline survey (above) to be applied directly in the Wye. The High Status guidelines were developed with the 2000 Land Cover Map (Environment Agency, 2010), and so this was updated for LCM2007 (Table 8).

Assessments were made of the land cover within the WFD waterbody catchments, but also for the complete area estimated to drain to each point on the river network at which RHS data were recorded from Fluvial Audit/aerial photographs (n = 598). These hydrological catchments were estimated using Arc HydroTools (v. 9; Center for Research in Water Resources, University of Texas). This latter analysis made it possible to see whether significant areas of WFD catchments might pass the ‘intensive or artificial’ land cover criterion when the complete WFD catchment did not. Land cover was also examined within a 50m wide buffer strip along the upstream river network, but the results were nearly identical to the catchment wide results, so are not presented.

Condition of the riparian zone

The condition of the riparian zone is used primarily to assign a degree of confidence to a High Status assessment, although it does not specify thresholds at which different levels of confidence are attained (cf. low intensity agriculture), and can be used as a basis for rejecting waterbodies (Table 7; Environment Agency, 2010). Condition was based upon the 5m land cover estimated from the aerial photographs, as for the CSM SERCON assessment, allowing complete coverage of the WFD channels.

Table 7. WFD High Status criteria (Environment Agency, 2010)

Category	Criterion	Possible in Upper Wye?
Catchment land cover 'artificial or intensive' (arable agriculture, improved grassland, suburban/urban, coniferous woodland)	Pass/Fail High Status: Reject waterbodies from High Status category where >10% of catchment	Yes
Catchment land cover 'low intensity agriculture'	Confidence in High Status: <30% - passes High Status test with high confidence 30% - 60% - pass with moderate confidence >60% - pass with low confidence	Yes
Condition of the riparian zone	Confidence in High Status: Absence/presence of riparian zone vegetation, along with its structural complexity – looking for '*adjacent natural vegetation appropriate to the type and geographical location of the river*'	Partially – a combination of aerial photos and limited RHS/Fluvial Audit information
Morphological alteration using River Habitat Survey (RHS) Habitat Modification Score class (HMC)	Pass/Fail: Not High Status if >20% of RHS 500m reaches in a waterbody are in HMC 3-5	Yes – HMC can be predicted with a reasonable degree of accuracy from the data collected
Floodplain disruption by the rail network	Confidence in High Status: Flag up waterbodies where railways run for ≥20% of river length within 250m of the channel and within the 1-in-100 year floodplain	Yes
Direct physical modifications to the channel	Pass/fail: Assess the cumulative impacts of soft and hard channel engineering. One possible criterion: fail if >10% of the watebody is affected	Yes – where Fluvial Audit or RHS data are available

One of the main impacts of changing land cover in the riparian zone is increased fine sediment delivery to the channel, and such impacts may provide a basis for deciding when the riparian zone is degraded to a point where the hydromorphology and ecology may be affected. Recent work by Larsen *et al*. (2009), based on the Fluvial Audit of the River Usk, found a clear relationship between the extent of broad-leaved woodland in the riparian zone and the coverage of fine sediment in the channel (and ultimately impacts upon organisms). Once riparian woodland fell below approximately 30% of the bank length, the percentage cover of fine sediments increased. For the current study, this 30% threshold was adopted for the riparian zone assessment: if broad-leaved woodland covered <30% of the bank length in a waterbody, it was denoted 'Low confidence', 30-50% 'Medium' confidence and >50% 'High' confidence.

More generally, the High Status guidelines specify that the riparian zone should be: 'appropriate to the type and geographical location of the river', suggesting that open moorland in the uplands may also qualify as a riparian zone in good condition. To reflect this, if broad-leaved woodland was sparse, but the majority of the bank length (>50%) was 'moorland/heath' or 'rough pasture' land cover types, the confidence was upgraded to 'Medium'. 'High' confidence was not assigned based purely on these land cover categories because of the lack of evidence describing the link between riparian vegetation cover and in-channel effects on the hydromorphology (cf. broad-leaved woodland) and because fringing trees are less effective at stabilising the banks.

Morphological alteration using HMC

The guidelines provide a pass/fail criterion, where a prevalence of >20% of 500m reaches having an HMC of 3 or above leads to a failure (Environment Agency, 2010). As for the CSM HMC rule, 90% confidence intervals were calculated around the mean values for WFD waterbodies to provide a measure of confidence in the pass or failure of a waterbody. Where the 90% confidence limit spanned the 20% threshold for HMC3 prevalence, or the sample size was <5, confidence was considered to be 'low', whereas a confidence limit entirely above or below 20% was assigned 'high' confidence.

Railway infrastructure on the floodplain

The railway line between Craven Arms and Llanelli runs broadly north-east to south-west through the Wye catchment, crossing from the Ithon to the Irfon, and passing through Llandrindod Wells, Llangammarch Wells and Llanwrtyd Wells. The High Status guidance uses railway infrastructure to adjust the level of confidence in potential High Status, based on the lateral or longitudinal constraints that embankments running parallel to the river, or crossing the floodplain, may enforce on the channel. The guidance focuses specifically on railway lines that fall within the 1 in 100 year floodplain and are within 250m of the channel (Environment Agency, 2010). Sections of the railway line that qualify for these criteria were identified using the GIS method described by Jacobs (2007). Where an impact on latitudinal connectivity was suspected (railway running parallel to the river), the length of railway that passed through the selection rule (100 year floodplain and within 250m) was divided by the total channel length to estimate the percentage of the waterbody that was affected: the High Status guidelines flag 20% as a threshold above which confidence of a High Status conclusion might be reduced.

Table 8. Categorisation of land cover categories from CEH land cover maps used to define 'Artificial or Intensive' and 'Low intensity agriculture' land cover types according to Environment Agency guidelines using LCM 2000 (Environment Agency 2010) and the equivalent classification used in the current report based upon LCM2007.

EA High status guidelines	LCM2007 classification
'Artificial or intensive'	
Arable cereals	Arable & Horticulture
Arable horticulture	
Arable non-rotational	
Improved grassland	Improved grassland
Suburban/urban development	Suburban
Continuous urban	Urban
Coniferous woodland	Coniferous woodland
'Low intensity agriculture'	
Fen, marsh, swamp	Fen, marsh, swamp
Bog (deep peat)	Bog
Setaside grass	No longer a separate category – could be within Neutral or Improved grassland
Neutral grassland	Neutral grassland
Calcareous grassland	Calcareous grassland
Acid grassland	Acid grassland (incorporates Bracken)
Bracken	
Dense dwarf shrub heath	Heather
Open dwarf shrub heath	Heather grassland
Inland bare ground	Inland rock (incorporates both natural and degraded land e.g. quarries)

Direct physical modifications to the channel

Similarly to the CSM guidelines, the High Status guidance provides general principles for this part of the assessment, but generally eschews specific rules due to the diversity of modifications and the complex responses of the hydromorphology to impacts (Environment Agency, 2010). A simple default position could be the Central-Baltic Geographical Intercalibration Group suggestion of 10% of the waterbody affected (Environment Agency, 2010). In consideration of this suggestion, and using similar methods to the CSM assessment, the extent of potential impacts was addressed in three ways:

1. The simple footprint of re-alignment, embankments and bank protection, leading to a total percentage of the waterbody length that is affected. This was calculated as described for the SAC assessment and compared to the 10% criterion.
2. As (1), but calculating the footprint of modifications where there appeared to be evidence of impact in the Fluvial Audit data, using the approach described above for the SAC assessment. This was only possible within the Fluvial Audit area, and so was calculated as a percentage of the Fluvial Audit and compared to the 10% criterion. Despite the restricted coverage, the quality of the data meant that this assessment should be more reliable.
3. Structures were assessed as for impacts on connectivity (i.e. impoundments) as described for the SAC assessment.

The overall assessment relied primarily upon (2) and (3), with a failure of either leading to an overall failure on the basis of direct channel modifications.

Table 9. Results of the WFD waterbody assessment, with the results of the six tests for each waterbody with the result (pass/fail, or low/mod/high confidence) and an overall summary of the assessment, with a description of the data availability.

Waterbody code	Waterbody name	Intensive or artificial LC	Low intensity agriculture	Riparian zone	HMC3+	Railway infrastructure	Direct modifications	Summary of assessment	Data limitations
GB109055042270	Ithon - conf Camddwr Bk to conf R Wye	Fail	High	High	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055036950	Afon Llynfi - conf Dulas Bk to conf R Wye	Fail	High	High	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055036970	Triffrwd - source to Dulas	Fail	High	High	Fail	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055036980	Digedi Bk - source to conf R Wye	Fail	Mod	High	Fail	High	Fail	Fail: land cover + HMC/direct modification	Only data = 1 RHS
GB109055036990	Scithwen Bk - source to conf R Wye	Fail	High	High	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055037010	Hay Dulas Bk - source to conf R Wye	Fail	Mod	High	NA	High	Pass	Fail: land cover	No Fluvial Audit or RHS
GB109055037020	Clyro Bk - source to conf R Wye	Fail	High	High	Fail	High	Pass	Fail: land cover + HMC	Only data = 1 RHS
GB109055037030	Clettwr Bk - source to conf R Wye	Fail	Mod	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055037050	Duhonw - source to conf R Wye	Fail	Mod	High	Fail	High	Fail	Fail: land cover	No major limitations
GB109055037060	Bach Howey Bk - source to conf R Wye	Fail	Mod	High	Pass	High	Pass	Fail: land cover	Only data = 1 RHS
GB109055037080	Edw - conf Clas Bk to conf R Wye	Fail	Mod	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055037090	Irfon - conf Cledan to conf R Wye	Fail	High	High	Pass	Low	Fail	Fail: land cover + direct modification	Only data = 1 RHS
GB109055037116	Wye - Scithwen Bk to Brewardine Br	Fail	High	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055037140	Clas Bk - source to conf R Edw	Fail	Low	High	Fail	High	Pass	Fail: land cover + HMC	Only data = 1 RHS
GB109055037150	Wye (Avon Gwy) - conf R Ithon to conf R Irfon	Fail	High	High	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055037160	Builth Dulas Bk - source to conf R Wye	Fail	High	High	Fail	High	Fail	Fail: land cover + HMC/direct modification	No major limitations
GB109055041870	Afon Gwesyn - source to conf R Irfon	Fail	Low	Mod	NA	High	Pass	Fail: land cover	No Fluvial Audit or RHS
GB109055041880	Afon Cammarch - source to conf R Irfon	Fail	Mod	High	NA	High	Fail	Fail: land cover + direct modification	No Fluvial Audit or RHS
GB109055041890	Afon Garth Dulas - source to conf R Irfon	Fail	Mod	High	Pass	High	Fail	Fail: land cover + direct modification	Only data = 1 RHS
GB109055041900	Howey Bk - source to conf R Ithon	Fail	High	High	Fail	High	Fail	Fail: land cover + HMC/direct modification	No major limitations

GB109055041910	Irfon - source to conf Afon Gwesyn	Fail	Low	Mod	Fail	High	Pass	Fail: land cover + HMC	Only data = 1 RHS
GB109055037115	Wye - conf R Irfon to Scithwen Bk	Fail	High	High	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055041960	Mithil Bk - source to conf R Ithon	Fail	Mod	High	Fail	High	Fail	Fail: land cover + HMC/direct modification	No major limitations
GB109055042070	Clywedog Bk - conf Bachell Bk to conf R Ithon	Fail	High	High	Pass	High	Pass	Fail: land cover	Small sample
GB109055042080	Nantmel Dulas - source to conf R Ithon	Fail	High	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055042090	Clywedog Bk - source to conf Bachell Bk	Fail	Mod	High	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055042110	Aran - source to conf R Ithon	Fail	Mod	High	Pass	Low	Fail	Fail: land cover + direct modification	No major limitations
GB109055042120	Bachell Bk - source to conf Clywedog Bk	Fail	Mod	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055042070	Clywedog Bk - conf Bachell Bk to conf R Ithon	Fail	High	High	Pass	High	Pass	Fail: land cover	Small sample
GB109055042130	Camddwr Bk - source to conf R Ithon	Fail	Mod	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055042140	Ithon - conf Gwenlas Bk to conf Camddwr Bk	Fail	Mod	Mod	Fail	High	Fail	Fail: land cover + HMC/direct modification	No major limitations
GB109055042160	Llaethdy Bk - source to conf R Ithon	Fail	Mod	Mod	Pass	High	Pass	Fail: land cover	No major limitations
GB109055042170	Gwenlas Bk - source to conf R Ithon	Fail	High	Mod	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055037130	Edw - conf Camnant Bk to conf Clas Bk	Fail	Mod	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055042180	Ithon - source to conf Llaethdy Bk	Fail	Mod	High	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055042190	Afon Chwefru - source to conf R Irfon	Fail	Mod	High	Pass	High	Fail	Fail: land cover + direct modification	Only data = 1 RHS
GB109055042200	Edw - source to conf Colwyn Bk	Fail	High	High	Pass	High	Fail	Fail: land cover + direct modification	Small sample
GB109055036680	Cledan - source to conf R Irfon	Fail	High	High	NA	High	Pass	Fail: land cover	No Fluvial Audit or RHS
GB109055036690	Tirabad Dulas - source to conf R Irfon	Fail	Mod	Mod	Pass	High	Pass	Fail: land cover	Only data = 1 RHS
GB109055042250	Wye - conf Afon Elan to conf R Ithon	Fail	Mod	High	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055042260	Afon Elan - Caban-coch Rsvr to conf R Wye	Fail	Mod	High	Pass	High	Fail	Fail: land cover + direct modification	Only data = 1 RHS
GB109055042280	Wye - conf to conf Afon Marteg to conf Afon Elan	Fail	Mod	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055036760	Irfon - conf Afon Gwesyn to conf Cledan	Fail	Mod	Low	Pass	High	Pass	Fail: land cover	Small sample
GB109055036900	Afon Llynfi - source to conf Dulas Bk	Fail	High	High	Pass	High	Pass	Fail: land cover	Only data = 1 RHS
GB109055036910	Ennig - source to conf Afon Llynfi	Fail	Mod	High	NA	High	Fail	Fail: land cover + direct modification	No Fluvial Audit or RHS
GB109055036920	Dulas Bk - source to conf Afon Llynfi	Fail	High	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055042310	Afon Marteg - source to conf R Wye	Fail	Mod	Low	Pass	High	Fail	Fail: land cover + direct modification	Small sample

GB109055042320	Wye - conf Afon Bidno to conf Afon Marteg	Fail	Mod	High	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055042330	Wye - conf Afon Tarenig to conf Afon Bidno	Fail	Mod	Low	Pass	High	Fail	Fail: land cover + direct modification	No major limitations
GB109055042340	Afon Bidno - source to conf R Wye	Fail	Low	Low	NA	High	Pass	Fail: land cover	Only data = 1 RHS
GB109055042350	Afon Tarenig - source to conf R Wye	Fail	Low	Mod	NA	High	Fail	Fail: land cover + direct modification	No Fluvial Audit or RHS
GB109055042370	Camnant Brook - source to confluence R Edw	Fail	Mod	High	Fail	High	Fail	Fail: land cover + HMC/direct modification	No major limitations
GB109055042150	Ithon - conf Llaethdy Bk to conf Gwenlas Bk	Fail	Mod	High	Pass	High	Pass	Fail: land cover	No major limitations
GB109055042210	Rhiwnant - source to conf Afon Claerwen	Pass	Low	Mod	Pass	High	Pass	Pass (low confidence)	Only data = 1 RHS
GB109055042230	Afon Claerwen - conf Afon Arban to Caban-coch	Pass	Low	High	NA	High	Fail	Fail: direct modification	No Fluvial Audit or RHS
GB109055042240	Afon Arban - source to conf Afon Claerwen	Pass	Low	Mod	NA	High	Pass	Pass (low confidence)	No Fluvial Audit or RHS
GB109055042290	Afon Claerwen - source to conf Afon Arban	Pass	Low	Low	NA	High	Fail	Fail: direct modification	No Fluvial Audit or RHS
GB109055042300	Afon Elan - source to Pont ar Elan	Pass	Low	Mod	Pass	High	Fail	Fail: direct modification	Small sample

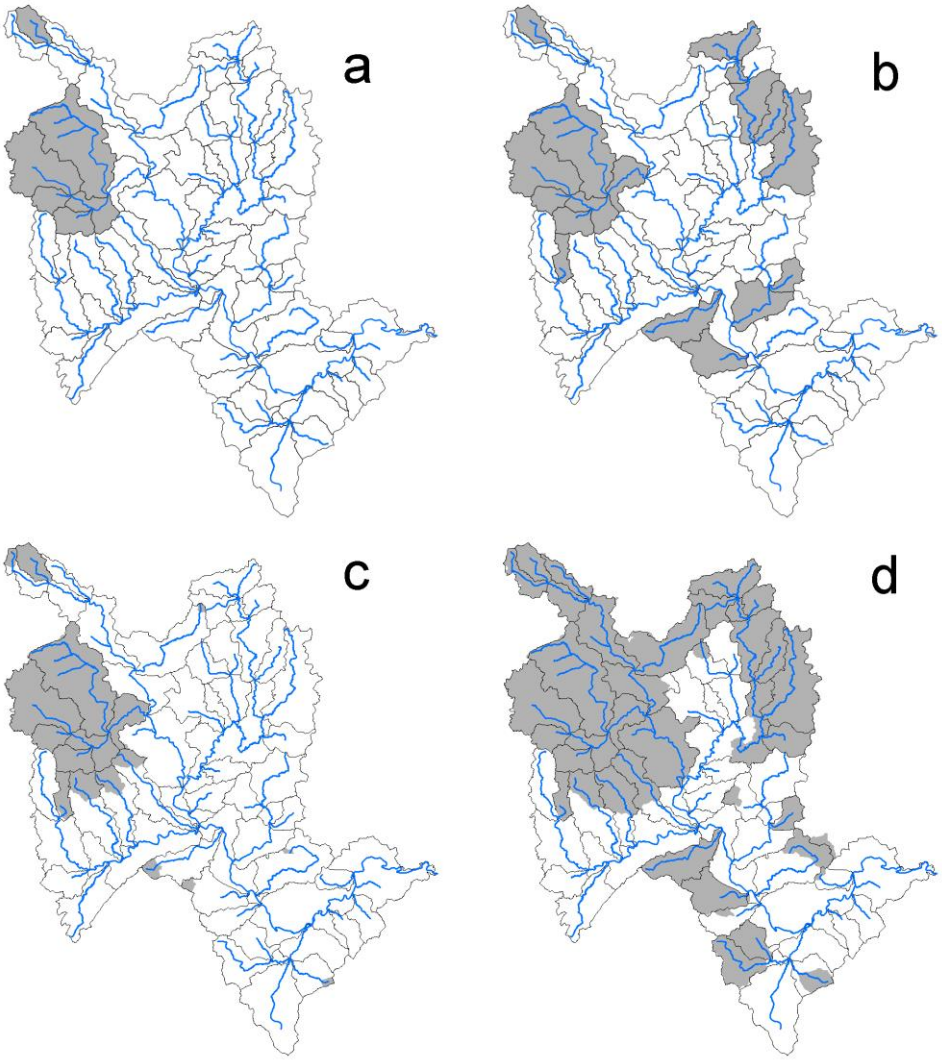
Outline results

All but two of the 58 WFD waterbodies failed the High Status assessment (Table 9). Only the Rhiwnant (GB109055042210) and Afon Arban (GB109055042240) did not show clear evidence of failure, but only sparse data were available. Out of the 58 waterbodies, 52 failed on the first land cover rule (<10% intensive or artificial). Most waterbodies passed the HMC3 rule, although data were limited for many catchments. The rules devised for direct modifications to the channel, were more stringent, with the majority of waterbodies failing on that basis: as with the SAC assessment, this rule could be revisited following further investigation.

Failure to meet the artificial/intensive land cover rule for High Status resulted primarily from improved grassland in the catchment (31% of the Upper Wye catchment according to LCM 2007). Whilst this may be accurate, the reliability with which ‘improved’ can be separated from less intensively-managed acid/calcareous/neutral grassland is a known challenge with LCM2007 (Morton *et al*., 2011). These current assessments may therefore represent a worst case scenario. For comparison, if all of the improved grass is re-classified to acid/neutral/calcareous (i.e. low-intensity agriculture), the results change substantially, resulting in a very different ‘best case’ scenario (Fig. 6b v. 6a). This illustrates the need for cautious interpretation of the land cover data. Further investigation may be warranted – waterbodies may in some instances be rejected unnecessarily if a significant proportion of the ‘improved grassland’ category is not intensively managed.

Re-examining the assessment at a smaller spatial scale by using the hydrological catchments of individual 500m reaches within WFD waterbodies, rather than the complete waterbodies themselves, suggests that there may be regions that could qualify as High Status for hydromorphology, even where the waterbody does not (Fig. 6). An initial assessment based solely on the land use assessment – the main cause of failure to reach High Status in the current assessment – suggests that several additional areas could qualify for High Status. This needs some further work to screen these candidate catchments through the remainder of the WFD High Status criteria.

Figure 6. Catchments passing the <10% artificial or intensive land cover rule based on LCM2007 (grey shading). The left hand column shows the results of applying the current rule to (a) WFD waterbody catchments and (c) hydrological catchments of each of the 598, 500m reaches, whilst the right hand column illustrates the extreme case of re-classifying all improved grass to a lower intensity (acid/neutral), for the WFD catchments (b) and hydrological catchments (d).



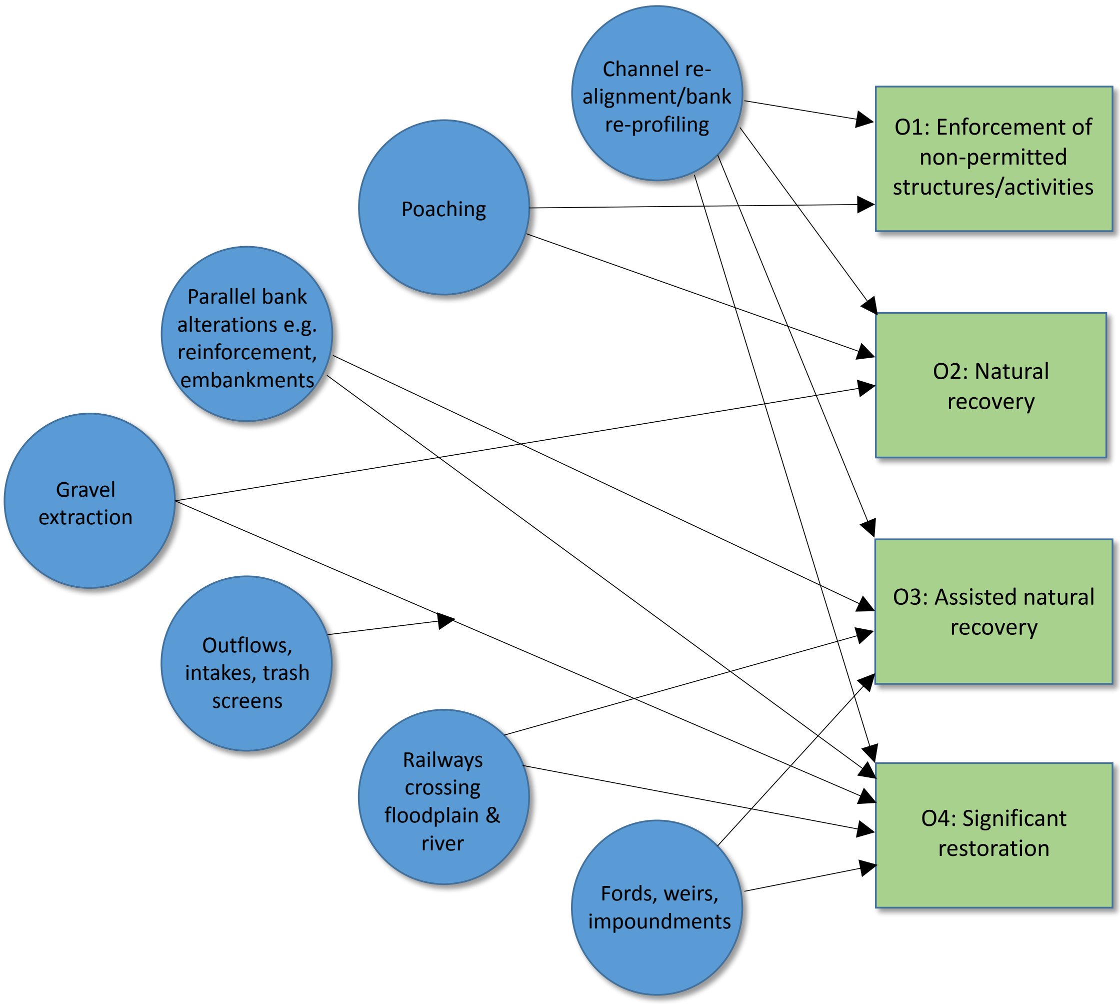
4. Devising restoration options

The Wye Vision presents four general approaches to restoration (Halcrow, 2012):

1. Enforcement of non-permitted structures or gravel management activities.
2. Natural recovery.
3. Assisted natural recovery
4. Significant restoration

From this starting point, we mapped the seven broad categories of modification identified in Table 2 onto these four options (Figure 7). This represents the complete 'restoration space' i.e. the range of possible approaches. The choice among these general approaches was largely dictated by the properties of the waterbody/reach involved. In general, it is considered that much of the Wye is capable of some form of natural recovery if maintenance of structures is withdraw (Halcrow, 2012).

Figure 7. Four general approaches to river restoration (right hand column; Halcrow 2012), with the seven broad categories of modification seen in the Wye mapped onto them.



Two stages/spatial scales were involved in the decision: the ability of a waterbody to re-work its bed material and local factors (sediment availability, woody bank vegetation) that may influence restoration planning for individual reaches.

Stream power

The ability of channels to re-work their bed was assessed by comparing the mean specific stream power of different tributaries to the critical stream power required to mobilise sediment particles of different sizes (Parker *et al*., 2011). For each of the 44 WFD waterbodies that overlap with part of the SAC, the mean specific stream power was calculated for the channels within the SAC boundary from the estimates at each of the 500m reaches used for the SAC assessments. Power was calculated for the median annual flood discharge, which approximates bankfull discharge and has a typical frequency of about once every 1-2 years (Wharton, 1995), using the method of Vaughan *et al*. (2013). The waterbody means were then compared to the critical power required to mobilise particles ranging from silt to boulders, using the mid-point in the size range for each class (Table 10). Critical power was calculated from the work of Parker *et al*. (2011).

This analysis confirmed that the SAC channels in all 44 WFD catchments should be able to mobilise particles up to at least fine gravel (9 mm) at bankfull discharge, and 41 out of the 44 are expected to be able to mobilise coarse gravel (40mm) too. This supports the idea that these channels would be able to recover from many physical modifications with minimal intervention. The exceptions were the River Aran, and Mithil and Camnant Brooks, where the modest mean estimated powers (41.6, 50.8 and 35 W m^{-2} respectively) appear insufficient to move coarser gravels. This suggests that a greater degree of intervention may need to be considered when designing restoration options in these catchments.

Two important caveats should be noted with this analysis. The first is that although specific power estimates derived from GIS have been used widely in studying fluvial geomorphology (e.g. van den Berg, 1995; Knighton, 1999; Bizzi & Lerner, 2014), and the specific method used here has proven predictive ability across the RHS Baseline (Vaughan *et al*., 2013), the precision of the estimates (compared to detailed site-specific measurements) is unknown. As such, the power estimates should be treated as a general guide. The second caveat is that the mean estimates for the waterbodies disguises variation in transport ability among their constituent reaches. This could easily be added at a future date.

Table 10. The ability of channels in the different waterbodies to mobilise different sizes of sediment at bankfull discharge. Boulders and cobbles would not be mobilised at bankfull flow.

Waterbody code	Waterbody name	Mean slope / m km-1	Mean SSP / W m-2	Silt	Sand	Fine gravel	Coarse gravel
			D_{50} / mm =	0.03	1.03	9.00	40.00
			Critical SSP / W m^{-2} =	<0.01	0.22	5.56	52.10
GB109055041870	Afon Gwesyn - source to conf R Irfon	13.8	127.0	✓	✓	✓	✓
GB109055036690	Tirabad Dulas - source to conf R Irfon	7.4	91.5	✓	✓	✓	✓
GB109055042170	Gwenlas Bk - source to conf R Ithon	12.0	74.9	✓	✓	✓	✓
GB109055042310	Afon Marteg - source to conf R Wye	13.6	221.3	✓	✓	✓	✓
GB109055042260	Afon Elan - Caban-coch Rsvr to conf R Wye	2.7	96.1	✓	✓	✓	✓
GB109055042340	Afon Bidno - source to conf R Wye	11.9	124.3	✓	✓	✓	✓
GB109055036680	Cledan - source to conf R Irfon	7.8	60.9	✓	✓	✓	✓
GB109055041880	Afon Cammarch - source to conf R Irfon	7.4	90.8	✓	✓	✓	✓
GB109055037090	Irfon - conf Cledan to conf R Wye	3.9	79.7	✓	✓	✓	✓
GB109055036760	Irfon - conf Afon Gwesyn to conf Cledan	4.9	100.6	✓	✓	✓	✓
GB109055041960	Mithil Bk - source to conf R Ithon	7.0	50.8	✓	✓	✓	×
GB109055042330	Wye - conf Afon Tarenig to conf Afon Bidno	4.4	82.0	✓	✓	✓	✓
GB109055036950	Afon Llynfi - conf Dulas Bk to conf R Wye	3.8	67.6	✓	✓	✓	✓
GB109055037160	Builth Dulas Bk - source to conf R Wye	13.4	71.4	✓	✓	✓	✓
GB109055042140	Ithon - conf Gwenlas Bk to conf Camddwr Bk	7.1	58.9	✓	✓	✓	✓
GB109055042270	Ithon - conf Camddwr Bk to conf R Wye	2.3	62.8	✓	✓	✓	✓
GB109055036920	Dulas Bk - source to conf Afon Llynfi	5.1	53.6	✓	✓	✓	✓
GB109055042160	Llaethdy Bk - source to conf R Ithon	10.4	82.3	✓	✓	✓	✓
GB109055037050	Duhonw - source to conf R Wye	18.6	188.2	✓	✓	✓	✓
GB109055037150	Wye (Avon Gwy) - conf R Ithon to conf R Irfon	2.5	147.5	✓	✓	✓	✓
GB109055041900	Howey Bk - source to conf R Ithon	14.4	92.7	✓	✓	✓	✓
GB109055042110	Aran - source to conf R Ithon	4.5	41.6	✓	✓	✓	×
GB109055036970	Triffrwd - source to Dulas	14.2	101.1	✓	✓	✓	✓
GB109055036990	Scithwen Bk - source to conf R Wye	36.7	181.3	✓	✓	✓	✓
GB109055037030	Clettwr Bk - source to conf R Wye	29.2	102.5	✓	✓	✓	✓
GB109055042190	Afon Chwefru - source to conf R Irfon	8.2	97.5	✓	✓	✓	✓
GB109055041890	Afon Garth Dulas - source to conf R Irfon	13.4	122.3	✓	✓	✓	✓
GB109055042070	Clywedog Bk - conf Bachell Bk to conf R Ithon	5.9	82.3	✓	✓	✓	✓
GB109055042280	Wye - conf Afon Marteg to conf Afon Elan	5.1	166.6	✓	✓	✓	✓
GB109055037130	Edw - conf Camnant Bk to conf Clas Bk	4.3	56.4	✓	✓	✓	✓
GB109055042180	Ithon - source to conf Llaethdy Bk	9.7	70.2	✓	✓	✓	✓
GB109055042130	Camddwr Bk - source to conf R Ithon	7.9	57.5	✓	✓	✓	✓
GB109055042320	Wye - conf Afon Bidno to conf Afon Marteg	7.2	110.8	✓	✓	✓	✓
GB109055042250	Wye - conf Afon Elan to conf R Ithon	11.2	199.4	✓	✓	✓	✓
GB109055037115	Wye - conf R Irfon to Scithwen Bk	1.6	113.3	✓	✓	✓	✓
GB109055037116	Wye - Scithwen Bk to Brewardine Br	1.3	95.8	✓	✓	✓	✓
GB109055042370	Camnant Brook - source to confluence R Edw	6.4	35.0	✓	✓	✓	×
GB109055037060	Bach Howey Bk - source to conf R Wye	23.1	294.3	✓	✓	✓	✓
GB109055042090	Clywedog Bk - source to conf Bachell Bk	9.6	84.5	✓	✓	✓	✓
GB109055042200	Edw - source to conf Colwyn Bk	6.3	62.6	✓	✓	✓	✓
GB109055037080	Edw - conf Clas Bk to conf R Wye	6.8	111.5	✓	✓	✓	✓
GB109055042150	Ithon - conf Llaethdy Bk to conf Gwenlas Bk	4.7	61.8	✓	✓	✓	✓
GB109055042120	Bachell Bk - source to conf Clywedog Bk	6.5	56.1	✓	✓	✓	✓
GB109055042080	Nantmel Dulas - source to conf R Ithon	4.9	57.3	✓	✓	✓	✓

Reach scale

Two additional factors influenced the restoration options at the individual Fluvial Audit reach scale. The first was the presence of gravel/pebble material within the reach and the reach immediately upstream that the channel could potentially re-work as part of recovery from restoration. This was considered important in the potential recovery from weirs, bank protection and channel re-alignment. Using the data in the 'Sediment_Storage' GIS layer, the extent of stable and unstable gravel/pebble bars in each reach was estimated as a percentage of the reach area, multiplying the count of bars within the five size categories by their mid-points (<1m^2 assumed to be 0.5m^2; 1–10m^2 as 5.5m^2; 10–50m^2 as 30m^2; 50–150m^2 as 100m^2; >150m^2 as 200m^2) and dividing by the area of the reach. Overall, 56 out of the 362 (15.5%) Fluvial Audit reaches had no gravel/pebble bars, whilst 164 (45%) had less than 1% coverage. In lieu of an evidence-based threshold for deciding when there could be local sediment limitations, we used a 1% threshold to flag up situations where sediment supply may be limited, raising the possibility of including bed material augmentation in the restoration plans.

The second factor was the extent of woody vegetation within the Fluvial Audit reach, helping to stabilise the banks. This was a particular concern for weir removal, where dramatic changes in width with associated bank de-stabilisation are possible. Similar to bars, there is no clear threshold for deciding when the woody vegetation coverage was insufficient, so reaches below 50% woody vegetation cover (104 out of 363 reaches) were flagged up, and bank stabilisation measures were included as a possibility in the restoration plans.

Restoration options

The following pages present outline restoration plans for 31 catchments judged to be in 'unfavourable' condition (Table 11). Plans have not been devised where a lack of data (no Fluvial Audit, no/few RHS) means that the overall confidence in the site assessment was low.

<table>
<tr><td rowspan="3">Waterbody Name: Scithwen Brook (source to Wye Confluence)</td><td>EA Waterbody ID: GB109055036990</td><td>Channel length: 14.14 km</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Fluvial Audit reaches: SGI002 – SGI007, SGI1001 – SGI1012, RHI001 – RHI005, RHI1006 – RHI1008</td><td>Number of 500m sampling reaches: 21

Number of 500m sampling reaches with Fl. Aud. or RHS data: 16</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
1 reach with re-alignment
5 reaches with bank protection, totalling 241m (concrete, loose stones, others)
3 bridges, 3 footbridges
2 reaches with poaching, totalling 55m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Bridges in reaches SGI1002
Culvert in reach RHI1008
Rock dams in reaches SGI006 and SGI007
Fords in reach SGI1006
Weirs in reach SGI1009
Bank protection in reaches SGI005, SGI007, SGI1001 and SGI1006
Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove rock dams, fords and weirs to minimise disruption to continuity</td><td colspan="2">Reach appears to have sufficient stream power to rework streambed once obstructions are removed.
SGI1006 and SGI1007: banks have extensive woody vegetation cover, so should be stable if dams are removed/breached, and both reaches have numerous bars that the channel could re-work.
SGI1009: limited woody vegetation cover on banks, so notching – rather than removing – weirs could be considered, or some local bank re-profiling and bioengineering to help stabilise the banks. Relatively little sediment storage, so some augmentation of the bed might be considered</td></tr>
</table>

Remove bank protection/re-enforcement and allow natural recovery, where possible	Waterbody appears to have sufficient stream power to rework channel where bank protection is removed: • SGI007: nearly 175m of protection in total, protecting A470 bridge and adjacent buildings. Possible limited sediment supply for channel to re-work (bars cover <1%) • SGI005 & SGI1001: plentiful supply of sediment to re-work • SGI1006: reinforcement protects farm buildings. Limited sediment in the reach to re-work
Fence channel to exclude stock in poached sections	Lower catchment has large amounts of tree cover; upper tributaries have bare banks in many areas, particularly in association with farms, and may benefit from fencing.
Consider modifying design or structure of bridges and culverts that are causing impacts, or remove altogether, if feasible.	Site appears to have sufficient stream power to rework bank and bed material once impacts have been rectified.

<table>
<tr><td rowspan="2">Waterbody Name: Wye (Afon Tarenig confluence to Afon Bidno confluence)</td><td>EA Waterbody ID: GB109055042330</td><td>Channel length: 7.21 km</td></tr>
<tr><td>Fluvial Audit reaches: WYE001 – WYE014</td><td>Number of 500m sampling reaches: 7

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 2 reaches with re-alignment, totalling 215m
• 8 reaches with bank protection, totalling 578m (gabions, loose stones, others)
• 7 reaches with embankments, totalling 5501m
• 3 bridges, 4 fords, 2 weirs
• 4 reaches with poaching, totalling 144m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• 2 hand-built rock weirs in Fl. Aud. reach WYE009
• Instances of bank protection in WYE001, WYE003, WYE004, WYE007, WYE008, WYE009, WYE010, WYE014
• Embankments
• Re-alignments
• Too little coarse woody debris (CWD)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove rock weirs to minimise disruption to continuity</td><td colspan="2">Site appears to have sufficient stream power to rework streambed</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible</td><td colspan="2">Site appears to have sufficient stream power to rework channel:
• WYE001: reinforcement of bank to protect forestry track. Aerial photos suggest bars upstream
• WYE003, WYE004 & WYE007: limited sediment to re-work.
• WYE008 & WYE009: abundance sediment for the channel re-work (bar cover >6%).
• WYE010: sediment available to re-work. Top section at the upstream end (total length 25m) protect farm buildings
• WYE014: little sediment available within-reach, but bar coverage (>8% coverage) upstream.</td></tr>
</table>

Cease removal of CWD	Lower reaches have little CWD, but riparian tree cover appears sufficient to re-supply this area.
Fence channel to exclude stock in poached sections	Lower catchment has large amounts of tree cover; upper tributaries have bare banks in many areas, particularly in association with farms, and may benefit from fencing.
Breach or remove embankments, where possible	Embankments are protecting low-lying agricultural land with few, if any, buildings. Setting-back embankments could be considered where complete removal/breaching is deemed unacceptable.
Do not maintain re-alignments to allow natural recovery	WYE010 & WYE009: bars present in the channel upstream of both re-aligned sections that could be re-worked by the channel

<table>
<tr><td rowspan="2">Waterbody Name: Clywedog Brook (source to confluence Bachell Brook)</td><td>EA Waterbody ID: GB109055042090</td><td>Channel length: 2.36km</td></tr>
<tr><td>Fluvial Audit reaches: CLW005 – CLW007</td><td>Number of 500m sampling reaches: 5

Number of 500m sampling reaches with Fl. Aud. or RHS data: 5</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 1 reach with re-alignment
• 1 weir
• 2 reaches with poaching , totalling 130m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Weir with associated ponding (CLW007)
• Too little CWD</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove weir and allow natural recovery, where possible</td><td colspan="2">Site appears to have sufficient stream power to rework streambed. Limited Fluvial Audit data available in this region, but woody vegetation cover is limited immediately downstream, so consider bioengineering to accompany weir removal</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Lower reaches have relatively extensive tree cover, probably sufficient to resupply CWD stocks. Upper reach has comparably less tree cover, and could possibly benefit from fencing to allow for recovery.</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to resupply CWD stocks, and ensure potential impacts of poaching are limited</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Wye (confluence Afon Marteg to confluence Afon Elan)</td><td>EA Waterbody ID: GB109055042280</td><td>Channel length: 9.06km</td></tr>
<tr><td>Fluvial Audit reaches: WYE039 – WYE034</td><td>Number of 500m sampling reaches: 5

Number of 500m sampling reaches with Fl. Aud. or RHS data: 5</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 1 reach with re-alignment
• 4 reaches with bank protection, totalling 793 m (concrete, others)
• 1 weir, 1 pipe (Elan Valley pipeline), 3 bridge, 2 FB, 4 outfalls, 2 fords
• 3 reaches with poaching, totalling 351m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Modified planform due to extensive bank protection (WYE036, WYE037, WYE038, WYE039)
• Too little CWD</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible</td><td colspan="2">Site appears to have sufficient stream power to rework channel:
• WYE036: reinforcement of bank to protect former railway line. No bars within reach, but extensive bars in reach c. 250m upstream.
• WYE037: presence of bars to re-work channel. Close proximity to A470 may limit opportunities
• WYE038: extensive bars. Some reinforcement likely to be protecting roads/buildings
• WYE039: extensive bars. Some reinforcement likely to be protecting roads/buildings</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Waterbody has relatively substantial riparian tree cover, likely sufficient to resupply CWD stocks if left undisturbed.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Builth Dulas Brook (source to confluence river Wye)</td><td>EA Waterbody ID: GB109055037160</td><td>Channel length: 8.08km</td></tr>
<tr><td>Fluvial Audit reaches: DULB001 –DULB005, DULB1000 – DULB1007</td><td>Number of 500m sampling reaches: 15

Number of 500m sampling reaches with Fl. Aud. or RHS data: 15</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
2 bridges, 2 weirs
3 reaches with re-alignment totalling 1195m
4 reaches with poaching, totalling 244m
6 reaches with footpath erosion, totalling 199m
1 reach with fishing related erosion, totalling 35m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Extensive re-alignment (DULB1003, DULB1004, DULB1005)
2 weirs (both in DULB001)
Too little CWD
Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove weirs and allow natural recovery, where possible</td><td colspan="2">Site appears to have sufficient stream power to rework bed material. High degree of woody vegetation cover in DULB001 and downstream, but next reach upstream (DULB1007) has no woody vegetation, so bank stabilisation/re-profiling may need to be considered. DULB1007 also has no bars, but there is extensive bar cover in DULB1006 upstream.</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Lower reaches have relatively extensive tree cover, probably sufficient to resupply CWD stocks. Middle and upper reach have comparably less tree cover, and could possibly benefit from fencing to allow for recovery.</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to resupply CWD stocks, and ensure potential impacts of poaching are limited, reducing siltation</td></tr>
</table>

Allow natural recovery of re-aligned planform	Site appears to have sufficient stream power to rework bank and bed material. Re-aligned sections (DULB1003, DULB1004, DULB1005) all have sediment available to re-work and well-vegetated banks, so should natural recovery should be feasible

<table>
<tr><td rowspan="2">Waterbody Name: Ithon (confluence Camddwr Brook to confluence river Wye)</td><td>EA Waterbody ID: GB109055042270</td><td>Channel length: 37.9 km</td></tr>
<tr><td>Fluvial Audit reaches: ITH105 – ITH109, ITH209 – ITH212, ITH309 – ITH328, ITH208, ITH330 – ITH333, ITH301 – ITH308</td><td>Number of 500m sampling reaches: 20

Number of 500m sampling reaches with Fl. Aud. or RHS data: 20</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 2 reaches with re-alignment, totalling 840m
• 1 reach with embankments, totalling 270m
• 19 reaches with poaching, totalling 1879m
• 2 reaches with footpath erosion 26m
• 15 reaches with bank protection, totalling 2567m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Bridge causing ponding (ITH212)
• Too little CWD
• Evidence of siltation
• Modified planform in ITH208 and ITH209
• Extensive bank protection (ITH323, ITH333, ITH320, ITH325, ITH327, ITH304, ITH305, ITH309, ITH311, ITH209, ITH210, ITH212, ITH105, ITH108, ITH109, ITH208)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Consider modifying design or structure of bridge that is causing impacts, or remove altogether, if feasible.</td><td colspan="2"></td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Lower reaches have relatively extensive tree cover, probably sufficient to resupply CWD stocks. Middle and upper reaches have comparably less tree cover, and could possibly benefit from fencing of various to allow for recovery.</td></tr>
</table>

Consider fencing channel to exclude livestock	Could allow regeneration of riparian tree cover, to resupply CWD stocks and stablise banks to reduce siltation.
Remove bank protection/re-enforcement and allow natural recovery of planform, where possible	Site appears to have sufficient stream power to rework channel: • Bank protection in ITH108 and ITH109: limited sediment available to re-work. Some reinforcement associated with roads and disused railway line • ITH105: sediment available to re-work. One stretch of reinforcement relates to a minor road • ITH212: limited sediment, although some bars present. Protects A4081 road bridge • ITH210: no GP bars, but extensive sediment storage in next reach upstream (ITH209) • ITH209: sediment available to re-work. • ITH327: limited sediment available. Protects the railway line. • ITH323, ITH320: sediment available within the reach and upstream • ITH311: sediment available • ITH309: limited sediment, largely urban reach. Weir upstream would reduce ability to re-work channel • ITH208: sediment available • ITH333: limited sediment, but large stores in ITH332 upstream • ITH305: limited sediment, but stores in ITH304 • ITH304: sediment available. Protection associated with A483 road bridge
Allow natural recovery of re-aligned planform	Re-aligned sections at Penybont – associated with the Flood Alleviation Scheme?

<table>
<tr><td rowspan="2">Waterbody Name: Ithon (confluence Gwenlas Brook to confluence Camddwr Brook)</td><td>EA Waterbody ID:
GB109055042140</td><td>Channel length: 18.88km</td></tr>
<tr><td>Fluvial Audit reaches: ITH201 –ITH207, ITH100 – ITH103, ITH011 – ITH012, MIG1000, MIG001 – MIG005, LYM103 – LYM104, LYM101, LYM002</td><td>Number of 500m sampling reaches: 18

Number of 500m sampling reaches with Fl. Aud. or RHS data: 18</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
4 bridges
3 reaches with re-alignment, totalling 828m
13 reaches with bank protection, totalling 1195m
5 reaches with poaching, totalling 232m
1 reach with footpath erosion, totalling 35m
2 reaches with fishing related erosion, totalling 75m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Extensive re-alignment in several reaches (ITH207, LYM101, LYM104)
1 bridge disrupting continuity (ITH201)
Too little CWD
Evidence of siltation
Bank protection in (LYM103, LYM104, ITH100, ITH101, ITH103, ITH202, ITH203, ITH204, IH205, ITH207, MIG001, MIG005)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Consider modifying design or structure of bridge that is causing impacts, or remove altogether, if feasible.</td><td colspan="2">Site appears to have sufficient stream power to rework channel</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Lower reaches have relatively extensive tree cover, probably sufficient to resupply CWD stocks. Upper reach has comparably less tree cover, and could possibly benefit from fencing to allow for recovery.</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to resupply CWD stocks, and ensure potential impacts of poaching are limited, reducing siltation</td></tr>
</table>

Remove bank protection/re-enforcement and allow natural recovery of planform, where possible	Waterbody appears to have sufficient stream power to rework bank and bed material once impacts have been rectified. Llymwynt and Migram's Brooks have extensive supplies of sediment available to re-work. Some reaches of main Ithon have limited GP sediment stores (e.g. ITH102, ITH203) that may restrict the channel's ability to adjust
Allow natural recovery of re-aligned planform	Site appears to have sufficient stream power to rework channel: • ITH207: limited bed material to re-work, suggesting a greater degree of intervention may be required • LYM101 & LYM104: extensive bed material to re-work

<table>
<tr><td rowspan="2">Waterbody Name: Camnant Brook (source to confluence River Edw)</td><td>EA Waterbody ID: GB109055042370</td><td>Channel length: 6.53km</td></tr>
<tr><td>Fluvial Audit reaches: COL100 – COL111</td><td>Number of 500m sampling reaches: 12

Number of 500m sampling reaches with Fl. Aud. or RHS data: 12</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 5 reaches with bank protection, totalling 267m (concrete, block stone, others)
• 2 reaches with embankments, totalling 233m
• 7 reaches with poaching, totalling 379m
• 3 reaches with re-alignment</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Extensive re-alignment (above COL100, COL105, COL109)
• Extensive bank protection (COL103, COL104, COL105, COL108, COL109)
• Extensive embankments (COL103, COL107)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove bank protection</td><td colspan="2">Mean stream power is low in this waterbody, limiting the capacity of the stream to recover without greater intervention</td></tr>
<tr><td>Breach or remove embankments, where possible</td><td colspan="2">Where breaching or removal is not feasible, consider setting embankments back to reduce the constraints on the channel.</td></tr>
</table>

Assisted recovery of re-aligned planform; consider actively re-shaping the planform	Mean stream power is low in this waterbody, raising doubts over whether it could readily re-work the stream bed. Active re-shaping of the channel and/or local augmentation of the stream bed with gravel may need to be considered.

<table>
<tr><td rowspan="2">Waterbody Name: Wye (Scithwen Brook to Brewardine Brook)</td><td>EA Waterbody ID: GB109055037116</td><td>Channel length: 27.52km</td></tr>
<tr><td>Fluvial Audit reaches: WYE072 – WYE088</td><td>Number of 500m sampling reaches: 14

Number of 500m sampling reaches with Fl. Aud. or RHS data: 11</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 7 reaches with bank protection, totalling 1380m (concrete, brick wall, others)
• 3 bridges
• 5 reaches with poaching, totalling 858m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Extensive bank protection WYE075, WYE077, WYE078, WYE079, WYE086, WYE088)
• Too little CWD</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible.</td><td colspan="2">Site appears to have sufficient stream power to re-work channel, but relatively limited sediment supply (cover of GP bars <<1% throughout the waterbody) may limit the capacity for recovery
WYE079: extensive bank protection for Glasbury and A438 road bridge</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Waterbody has relatively substantial riparian tree cover, likely sufficient to resupply CWD stocks if left undisturbed.</td></tr>
</table>

Waterbody Name: Wye (confluence Irfon to Scithwen Brook)	EA Waterbody ID: GB109055037115	Channel length: 16.83km
	Fluvial Audit reaches: WYE065 – WYE071	Number of 500m sampling reaches: 8 Number of 500m sampling reaches with Fl. Aud. or RHS data: 8
Location of catchment within the upper Wye: 	All habitat modifications within waterbody: • 4 reaches with bank modifications, totalling 1271m • 1 reach with embankments • 3 bridges, 3 weirs • 3 reaches with poaching, totalling 1014m Issues with hydromorphological impacts: • 3 weirs (in reaches WYE068, WYE071) • Too little CWD • Extensive bank protection (WYE069)	
Potential restoration actions	Site specific details	
Remove weirs to minimise disruption to continuity	Waterbody appears to have sufficient stream power to rework streambed: • WYE068: banks with 60% woody vegetation cover should be relatively stable, but limited sediment for the channel to re-work (<1% bar cover in WYE068 and upstream) • WYE071: similar – woody vegetation, but limited sediment	
Remove bank protection/re-enforcement and allow natural recovery, where possible	Site appears to have sufficient stream power to rework channel, but limited GP sediment (most reaches <<1% cover)	
Cease removal of CWD	Lower and middle reaches relatively extensive tree cover, but tree cover is lower in the upper waterbody, and this may be insufficient to resupply the most upstream reaches.	

<table>
<tr><td rowspan="2">Waterbody Name: Triffrwd (source to Dulas)</td><td>EA Waterbody ID:
GB109055036970</td><td>Channel length: 4.16km</td></tr>
<tr><td>Fluvial Audit reaches:
TRI001 – TRI007</td><td>Number of 500m sampling reaches: 8

Number of 500m sampling reaches with Fl. Aud. or RHS data: 8</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
4 reaches with bank protection, totalling 259m (concrete, brick wall, others)
1 reach re-aligned
6 reaches with poaching, totalling 426m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Extensive bank protection (TRI002, TRI005, TRI006, TRI007)
Too little CWD
Modified planform</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible.</td><td colspan="2">River appears to have sufficient stream power to re-work channel, and >1% bar cover in all but one reach, suggesting natural recovery should be possible. Some of the protection in TRI005 is associated with the road bridges for the A470 and nearby minor road</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Waterbody has relatively substantial riparian tree cover, likely sufficient to resupply CWD stocks if left undisturbed, though some bare banks near farms.</td></tr>
<tr><td>Do not maintain re-alignments to allow natural recovery</td><td colspan="2">Site appears to have sufficient stream power to re-work channel. Re-aligned reach (TRI004) has sediment available to re-work. Limited sediment upstream in TRI003/TRI002.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Aran (source to confluence Ithon)</td><td>EA Waterbody ID: GB109055042110</td><td>Channel length: 15.94km</td></tr>
<tr><td>Fluvial Audit reaches: ARA201 – ARA206, ARA100 – ARA111</td><td>Number of 500m sampling reaches: 8

Number of 500m sampling reaches with Fl. Aud. or RHS data: 8</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
2 reaches re-aligned
12 reaches with bank protection, totalling 1291m (concrete, wood, others)
1 reach with embankments, totalling 137m
4 bridges
10 reaches with poaching, totalling 479m
1 reach with footpath erosion, totalling 8m
4 reaches with fishing-related erosion, totalling 50m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
1 bridge with impacts in ARA202 (ponding upstream)
Extensive bank protection (ARA100, ARA102, ARA107, ARA108, ARA110, ARA111, ARA201, ARA202, ARA203, ARA204, ARA205, ARA206)
Modified planform (ARA100, ARA202)
Evidence of siltation
Embankments (ARA106)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Consider modifying design or structure of bridges that is causing impacts, or remove altogether, if feasible.</td><td colspan="2"></td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible</td><td colspan="2">Site does not appear to have sufficient stream power to rework channel, so active removal of protection may be required along with possible local bed augmentation and/or local channel re-shaping. Stored sediment is abundant (>5% GP bar cover) throughout most of the channel length. ARA206 is an exception (<0.5% cover), but sediment is abundance upstream</td></tr>
<tr><td>Fence channel to exclude stock in poached sections</td><td colspan="2">May limit further inputs of silts, river should have sufficient power to remove fine particles once rectified.</td></tr>
<tr><td>Breach or remove embankments, where possible</td><td colspan="2">Embankments are protecting low-lying agricultural land.</td></tr>
</table>

Reinstate a more natural planform	Site does not appear to have sufficient stream power to re-work channel, so may need active restoration of channel planform. A more detailed study of the affected reaches (ARA100, ARA202) is needed to assess this fully.

<table>
<tr><td rowspan="2">Waterbody Name: Wye (confluence Afon Elan to confluence Ithon)</td><td>EA Waterbody ID: GB109055042250</td><td>Channel length: 22.41km</td></tr>
<tr><td>Fluvial Audit reaches: WYE040 – WYE051</td><td>Number of 500m sampling reaches: 22

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 4 reaches with bank protection, totalling 537m (block stone, concrete, others)
• 10 bridges, 2 fords, 1 weir
• 4 reaches with poaching, totalling 208m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Rock weir causing ponding in WYE040
• Extensive bank protection (WYE040, WYE044, WYE050, WYE051)
• Too little coarse woody debris (CWD)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove rock weir to minimise disruption to continuity</td><td colspan="2">River appears to have sufficient stream power to rework streambed. Limited sediment within WYE040 (<0.5%), but greater supply upstream (c. 5% cover). 50% woody vegetation cover suggests that the banks should be reasonable stable following weir removal, but a local site survey would be important</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible</td><td colspan="2">Site appears to have sufficient stream power to rework channel once protection is removed, but sediment supplies are limited (bar cover <<1%) in most reaches.</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Riparian tree cover appears sufficient to resupply CWD stocks in waterbody once removal is halted.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Wye (confluence Afon Bidno to confluence Afon Marteg)</td><td>EA Waterbody ID: GB109055042320</td><td>Channel length: 17.17km</td></tr>
<tr><td>Fluvial Audit reaches: WYE014–WYE033</td><td>Number of 500m sampling reaches: 14

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
1 reach with re-alignment
6 reaches with bank protection, totalling 1403m (block stone, concrete, others)
2 reaches with embankments, totalling 9m
7 bridges, 4 fords
6 reaches with poaching, totalling 461m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Extensive bank protection (WYE015, WYE016, WYE017, WYE022, WE025, WYE032)
2 fallen footbridges causing ponding in WYE025
Too little coarse woody debris (CWD)
Modified planform (WYE017)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove fallen footbridges to minimise disruption to continuity</td><td colspan="2"></td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible</td><td colspan="2">Site appears to have sufficient stream power to rework channel once bank protection is removed, but limited limited sediment stores (most reaches with bar cover <1%) may restrict channel recovery. One of the most heavily modified reaches (WYE017) has >5% cover.</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Riparian tree cover appears sufficient to resupply CWD stocks in waterbody once removal is halted.</td></tr>
</table>

Do not maintain re-alignments to allow natural recovery	Site appears to have sufficient stream power to re-work channel over time and WYE017 has extensive sediment stores.

<table>
<tr><td rowspan="2">Waterbody Name: Camddwr Brook (source to confluence Ithon)</td><td>EA Waterbody ID: GB109055042130</td><td>Channel length: 7.08km</td></tr>
<tr><td>Fluvial Audit reaches: CAM1000 – CAM1007</td><td>Number of 500m sampling reaches: 7

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
1 reach with poaching, totalling 14m
3 reaches with footpath erosion, totalling 310m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Too little coarse woody debris (CWD)
Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Riparian tree cover appears sufficient to resupply CWD stocks in waterbody once removal is halted.</td></tr>
<tr><td>Fence channel to exclude stock in poached sections</td><td colspan="2">Lower and upper waterbody has relatively extensive tree cover; middle reaches have grass/bare banks, particularly in association with farms, and may benefit from fencing.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Gwenlas Brook (source to confluence Ithon)</td><td>EA Waterbody ID: GB109055042170</td><td>Channel length: 2.46km</td></tr>
<tr><td>Fluvial Audit reaches: GWE1000 – GWE1002</td><td>Number of 500m sampling reaches: 5

Number of 500m sampling reaches with Fl. Aud. or RHS data: 5</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 1 reach re-aligned</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Re-alignment (GWE1002)
• Too little coarse woody debris (CWD)
• Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Current amount of riparian tree cover appears insufficient to resupply CWD stocks in waterbody.</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to resupply CWD stocks, and ensure potential impacts of poaching are limited. Little riparian tree cover in catchment at present.</td></tr>
<tr><td>Do not maintain re-alignments to allow natural recovery</td><td colspan="2">Site appears to have sufficient stream power to re-work channel over time, but GWE1002 has no stores of GP. Upstream, GWE1001 has bar cover >3%.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Ithon (source to Llaethdy Brook)</td><td>EA Waterbody ID: GB109055042180</td><td>Channel length: 4.04km</td></tr>
<tr><td>Fluvial Audit reaches: ITH001 – ITH004</td><td>Number of 500m sampling reaches: 8

Number of 500m sampling reaches with Fl. Aud. or RHS data: 6</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
• 2 reaches with poaching, totalling 60m
• 2 outfalls</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
• Too little coarse woody debris (CWD)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Current amount of riparian tree cover appears insufficient to resupply CWD stocks in waterbody.</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to resupply CWD stocks, and ensure potential impacts of poaching are limited. Very little riparian tree cover in catchment at present.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Wye (Ithon confluence to Irfon confluence)</td><td>EA Waterbody ID: GB109055037150</td><td>Channel length: 7.41km</td></tr>
<tr><td>Fluvial Audit reaches: WYE052 – WYE064</td><td>Number of 500m sampling reaches: 7

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
1 reach re-aligned
4 reaches with bank protection, totalling 279m (concrete, brick/wall)
6 reaches with poaching, totalling 538m
4 reaches with footpath erosion, 173m
1 weir, 1 bridge</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Extensive bank protection (in WYE057, WYE058, WYE062, WYE063)
Re-alignment modifying planform (WYE056)
Too little coarse woody debris (CWD)
Evidence of siltation
Weir (WYE063)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove weir and re-instate river continuity</td><td colspan="2">Waterbody appears to have sufficient stream power to rework streambed once obstructions are removed, but may be sediment limited (bar cover in WYE063 and WYE062 <0.3%). >90% woody vegetation cover in both reaches suggests that banks should be stable if weir is removed.</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible.</td><td colspan="2">Site appears to have sufficient stream power to rework channel, but has little stored sediment (bar cover <<1% in all reaches). Protection in WYE062 is associated with the railway line and in WYE063 with the A470.</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Waterbody has relatively substantial riparian tree cover, likely sufficient to resupply CWD stocks if left undisturbed, though some bare banks near farms.</td></tr>
<tr><td>Do not maintain re-alignments to allow natural recovery</td><td colspan="2">Site appears to have sufficient stream power to re-work channel over time, but limited sediment.</td></tr>
</table>

Fence channel to exclude stock in poached sections	Waterbody has relatively extensive tree cover, though some areas have grass/bare banks, and may benefit from fencing.

<table>
<tr><td rowspan="2">Waterbody Name: Edw (source to confluence Colwyn Brook)</td><td>EA Waterbody ID: GB109055042200</td><td>Channel length: 5.93km</td></tr>
<tr><td>Fluvial Audit reaches: EDW201 – EDW204</td><td>Number of 500m sampling reaches: 5

Number of 500m sampling reaches with Fl. Aud. or RHS data: 5</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
• 3 reaches with bank protection, totalling 215m
• 4 bridges, 1 weir
• 4 reaches with poaching, totalling 352m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
• Bridge in EDW202 causing upstream ponding
• Weir with ponding in EDW204 causing upstream ponding
• Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Consider modifying design or structure of bridge that is causing impacts, or remove altogether, if feasible.</td><td colspan="2"></td></tr>
<tr><td>Remove weir and allow natural recovery, where possible</td><td colspan="2">Waterbody appears to have sufficient stream power to rework bank material, and stored sediment is available. Woody vegetation cover within reach EDW204 is 40% (70% in upstream reach), suggesting that bank stability may be an issue following weir removal. Bioengineering approaches to bank stabilisation could be considered</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to ensure potential impacts of poaching are limited. Lower waterbody, in particular, has several areas with exposed banks.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Clywedog Brook (confluence Bachell Brook to confluence Ithon)</td><td>EA Waterbody ID:
GB109055042070</td><td>Channel length: 8.34km</td></tr>
<tr><td>Fluvial Audit reaches: CLW050, CLW1000 – CLW1001</td><td>Number of 500m sampling reaches: 4

Number of 500m sampling reaches with Fl. Aud. or RHS data: 4</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 2 reaches with poaching, totalling 256m
• 1 reach with footpath erosion, totalling 14m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Too little CWD
• Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Lower reaches have relatively extensive tree cover, probably sufficient to resupply CWD stocks. Upper reach has comparably less tree cover, and could possibly benefit from fencing to allow for recovery.</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to ensure potential impacts of poaching are limited, and to resupply CWD. Several areas throughout waterbody with exposed banks.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Dulas Brook (source to confluence Afon Llynfi)</td><td>EA Waterbody ID: GB109055036920</td><td>Channel length: 8.34km</td></tr>
<tr><td>Fluvial Audit reaches: DUL1000, DUL001 – DUL006</td><td>Number of 500m sampling reaches: 4

Number of 500m sampling reaches with Fl. Aud. or RHS data: 4</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
• 4 reaches re-aligned
• 2 bridges, 3 outfalls
• 6 reaches with poaching, totalling 467m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
• Extensive re-alignment causing modification to planform (DUL001, DUL002, DUL005, DUL1000)
• Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Do not maintain re-alignments to allow natural recovery</td><td colspan="2">Waterbody appears to have sufficient stream power to re-work channel and most reaches have stored sediment available:
• DUL001: sediment available to re-work (>3% cover)
• DUL002: GP bar cover nearly 1%, with more extensive cover in DUL001 upstream
• DUL005 (section near Trebarried Mill): bar cover >1%
• DUL1000: bar cover >1%</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to ensure potential impacts of poaching are limited. Several areas with exposed banks throughout waterbody.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Howey Brook (source to confluence Ithon)</td><td>EA Waterbody ID: GB109055041900</td><td>Channel length: 3.87km</td></tr>
<tr><td>Fluvial Audit reaches: HOW001 – HOW007</td><td>Number of 500m sampling reaches: 7

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
4 reaches re-aligned
4 reaches with bank protection, totalling 201m (loose stones, brick/wall, others)
4 reaches with poaching, totalling 114m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Extensive re-alignment (HOW001, HOW005, HOW04, HOW06) and bank protection (HOW002, HOW04, HOW005, HOW007)
Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Do not maintain re-alignments to allow natural recovery</td><td colspan="2">Waterbody appears to have sufficient stream power to re-work channel over time:
HOW001, HOW005, and HOW04 all appear to have sediment available to re-work the channel
HOW06: may be sediment limited (cover <1%), but greater coverage (>3%) immediately upstream</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible</td><td colspan="2">Site appears to have sufficient stream power and sediment supply to rework channel once protection is removed. Parts of HOW04 and HOW005 protect buildings and a road bridge</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to ensure potential impacts of poaching are limited. Several areas with exposed banks.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Mithil Brook (source to confluence Ithon)</td><td>EA Waterbody ID:
GB109055041960</td><td>Channel length: 3.6km</td></tr>
<tr><td>Fluvial Audit reaches: MIT52, MIT050, MIT301 – MIT306</td><td>Number of 500m sampling reaches: 7

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper

Wye:</td><td colspan="2">All habitat modifications within waterbody:
• 1 reach re-aligned
• 3 reaches with bank protection, totalling 213m (concrete, others)
• 3 bridges, 2 outfalls, 1 weir
• 6 reaches with poaching, totalling 331m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
• Weir in MIT306
• Extensive re-alignment modification to planform (MIT050)
• Extensive bank protection (MIT301, MIT303, MIT306)
• Potential evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Do not maintain re-alignments to allow natural recovery</td><td colspan="2">Waterbody appears to have sufficient stream power to re-work channel over time and MIT050 has extensive GP bars (near 5% coverage)</td></tr>
<tr><td>Remove weir to minimise scouring and disruption to continuity</td><td colspan="2">Waterbody appears to have sufficient stream power to rework streambed following weir removal, and there is a supply of sediment (>5% cover of bars) and woody vegetation cover is 50% (70% upstream), suggesting stable banks.</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible</td><td colspan="2">Waterbody appears to have sufficient stream power and a supply of sediment to rework the channel once structures are removed. The exception in MIT301, where sediment is less abundant (<0.2% coverage of bars)</td></tr>
<tr><td>Consider fencing channel to exclude livestock</td><td colspan="2">Could allow regeneration of riparian tree cover, to ensure potential impacts of poaching are limited. Several areas with exposed banks, particularly in lower waterbody.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Duhonw (source to confluence Wye)</td><td>EA Waterbody ID: GB109055037050</td><td>Channel length: 9.69km</td></tr>
<tr><td>Fluvial Audit reaches: DUH105, DUH201 – DUH209, DUH100 – DUH104, NANB100 – NANB101</td><td>Number of 500m sampling reaches: 7

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
• 2 reaches with re-alignment
• 4 reaches with bank protection, totalling 242m (rubbish, others)
• 2 bridges, 1 weir
• 7 reaches with poaching, totalling 397m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
• Weir causing ponding and scour in DUH201
• Extensive bank protection (DUH102, DUH201, DUH202, DUH209)
• Re-alignments causing modification to planform (DUH103, DUH209)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Remove weir and allow natural recovery, where possible</td><td colspan="2">Waterbody appears to have sufficient stream power to rework channel. Little sediment available in DUH201, but DUH104 upstream has extensive cover of GP bars, Woody vegetation cover is 85%, suggesting banks would be stable if weir was removed</td></tr>
<tr><td>Do not maintain re-alignments to allow natural recovery</td><td colspan="2">Waterbody appears to have sufficient stream power to re-work channel over time:
• DUH103: sediment available to rework
• DUH209: limited sediment (<<1%) in this reach and reaches upstream, potentially limiting channel adjustment</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible</td><td colspan="2">Waterbody appears to have sufficient stream power to re-work channel over time:
once impacts have been removed, but little sediment to re-work the channel in the lower reaches of the river. Only DUH102 has extensive sediment available.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Edw (confluence Camnant Brook to confluence Clas Brook)</td><td>EA Waterbody ID: GB109055037130</td><td>Channel length: 3.51km</td></tr>
<tr><td>Fluvial Audit reaches: EDW301 – EDW302, EDW205 – EDW206</td><td>Number of 500m sampling reaches: 6

Number of 500m sampling reaches with Fl. Aud. or RHS data: 6</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 1 reach with bank protection, totalling 46m (block stone)
• 2 bridges
• 1 reach with poaching, totalling 187m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Fence channel to exclude stock in poached sections to reduce silt inputs</td><td colspan="2">Waterbody has relatively extensive riparian tree cover, though some areas have grass/bare banks, and may benefit from fencing.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Llaethdy Brook (source to Ithon)</td><td>EA Waterbody ID: GB109055042160</td><td>Channel length: 2.58 km</td></tr>
<tr><td>Fluvial Audit reaches: LLA1000</td><td>Number of 500m sampling reaches: 5

Number of 500m sampling reaches with Fl. Aud. or RHS data: 5</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:

</td><td colspan="2">All habitat modifications within waterbody:

• 1 reach with poaching, totalling 90m
• 1 reach with footpath erosion, totalling 118m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Evidence of siltation
• Too little riparian tree cover (failing SERCON score)</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Fence channel to exclude stock in poached sections to reduce silt inputs and allow regrowth of riparian tree cover</td><td colspan="2">Very little riparian tree cover in whole waterbody; most banks exposed.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Edw (confluence Clas Brook to confluence Wye)</td><td>EA Waterbody ID: GB109055037080</td><td>Channel length: 9.32km</td></tr>
<tr><td>Fluvial Audit reaches: EDW100, EDW303 – EDW311</td><td>Number of 500m sampling reaches: 6

Number of 500m sampling reaches with Fl. Aud. or RHS data: 6</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 6 bridges
• 1 reach with bank protection (blockstone)
• 2 reaches with poaching, totalling 105m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Too little CWD</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Waterbody has relatively substantial riparian tree cover, likely sufficient to resupply CWD stocks if left undisturbed.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Bach Howey Brook (source to confluence Wye)</td><td>EA Waterbody ID: GB109055037060</td><td>Channel length: 1.74km</td></tr>
<tr><td>Fluvial Audit reaches: BAC001 – BAC002</td><td>Number of 500m sampling reaches: 3

Number of 500m sampling reaches with Fl. Aud. or RHS data: 2</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 1 bridge
• 1 reaches with poaching, totalling 11m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Too little CWD</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Waterbody has relatively substantial riparian tree cover, likely sufficient to resupply CWD stocks if left undisturbed.</td></tr>
</table>

<table>
<tr><td rowspan="2">Waterbody Name: Afon Llynfi – conf Dulas Bk to conf R Wye</td><td>EA Waterbody ID: GB109055036950</td><td>Channel length: 6.76km</td></tr>
<tr><td>Fluvial Audit reaches: DUL1001–DUL1004</td><td>Number of 500m sampling reaches: 7

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
Channel re-aligned, totalling 821m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Extensive re-alignment (DUL1001)
Too little CWD
Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Allow natural recovery of re-aligned planform</td><td colspan="2">Site appears to have sufficient stream power to rework bank and bed material. Re-aligned section in DUL1001 has limited sediment availability to re-work, but sediment is also available in DUL1000 upstream</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Relatively extensive tree cover throughout, probably sufficient to resupply CWD stocks.</td></tr>
</table>

Consider fencing channel to exclude livestock	Could allow regeneration of riparian tree cover, to resupply CWD stocks, and ensure potential impacts of poaching are limited, reducing siltation

<table>
<tr><td rowspan="2">Waterbody Name: Clettwr Brook</td><td>EA Waterbody ID:
GB109055037030</td><td>Channel length: 15.56km</td></tr>
<tr><td>Fluvial Audit reaches:
CLE002–CLE016, NYO1001–NYO1012</td><td>Number of 500m sampling reaches: 21

Number of 500m sampling reaches with Fl. Aud. or RHS data: 21</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:
5 bridges, 2 culverts, 2 fords
Bank protection totalling 163m
Re-alignment of channel, totalling 250m</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:
Channel re-alignment in CLE002
1 culvert with impact in NYO1001 (ponding upstream, scour downstream)
Too little CWD
Evidence of siltation</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Allow natural recovery of re-aligned planform</td><td colspan="2">Site appears to have sufficient stream power to rework channel:
CLE002: limited bed material to re-work, suggesting a greater degree of intervention may be required</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Lower reaches have relatively extensive tree cover, probably sufficient to resupply CWD stocks.</td></tr>
</table>

Consider modifying design or structure of bridges and culvert that is causing impacts, or remove altogether, if feasible.	Site appears to have sufficient stream power to rework bank and bed material once impacts have been rectified.
Consider fencing channel to exclude livestock	Could allow regeneration of riparian tree cover, to resupply CWD stocks, and ensure potential impacts of poaching are limited, reducing siltation

<table>
<tr><td rowspan="2">Waterbody Name: Ithon – conf Llaethdy Bk to conf Gwenlas Bk</td><td>EA Waterbody ID: GB109055042150</td><td>Channel length: 4.3km</td></tr>
<tr><td>Fluvial Audit reaches: ITH005–ITH009</td><td>Number of 500m sampling reaches: 7

Number of 500m sampling reaches with Fl. Aud. or RHS data: 7</td></tr>
<tr><td rowspan="2">Location of catchment within the upper Wye:
</td><td colspan="2">All habitat modifications within waterbody:

• 2 bridges</td></tr>
<tr><td colspan="2">Issues with hydromorphological impacts:

• Too little CWD</td></tr>
<tr><td>Potential restoration actions</td><td colspan="2">Site specific details</td></tr>
<tr><td>Cease removal of CWD</td><td colspan="2">Catchment has a reasonable amount of tree cover, should be able to resupply CWD given time, if removal is halted.</td></tr>
</table>

5. Cost-benefit/multi-criteria analysis

The restoration options were subjected to a cost-benefit analysis to identify some the key risks and benefits, and more generally to explore the range of possible issues that could be evaluated. This was done in two stages:

1. An initial screening of all candidate restoration options, to flag major risks and benefits at the waterbody scale.
2. A more detailed analysis, drawing in a wider range of issues and multiple data sets to explore the potential risks and benefits more widely. This is illustrated with four waterbodies, ranging in the degree and types of impacts identified.

Initial screening cost-benefit analysis

The initial analysis drew on a simple judgements of the risks of different restoration options to: i) travel infrastructure (roads and railways), ii) increased flood risk to buildings, iii) increased flood risk to farmland, iv) erosion of farmland and v) risk to buildings from increased erosion. Scoring was similar to Jacobs (2011), using low/no change, some/moderate level of increase, and large increase in risk. Potential ecological benefits of different restoration options were summarised in terms of the potential benefits of the restoration actions to the SAC designated features: nine species and the *Ranunculion fluitantis and Callitricho-Batrachion* vegetation community (Dyson, 2008). The potential benefits to these taxa were obtained from recent reviews of their habitat preferences (Jeffries *et al*., 2008; Dyson, 2008). Taxa only scored where they are present in the SAC management unit (Dyson, 2008). In lieu of detailed costings, the simple bandings suggested by Jacobs (2011) were used.

Potential risks were considered to be ‘High’ if risks to infrastructure or buildings were rated ‘High’. Where a restoration option would apply at multiple locations within a reach or waterbody, this flagged up the worst case situation: the more detailed cost-benefit analysis provides a more nuanced analysis. Ecological benefits scored ‘High’ if five or more SAC features could benefit from the proposed restoration work.

Table 12. Initial cost-benefit screening of the proposed restoration options. Risks to infrastructure, property and farmland are given simple three points ratings. The potential benefits to SAC designated features (species/habitats) are shown (see text for details): 1=potential benefit and 'Total' = number of features that could benefit.

Name	Restoration option	Impact to travel infrastructure	Increasing flood risk to properties	Increasing flood risk to farmland	Buildings affected by erosion	Farmland affected by erosion	Bullhead	Shad	Lampreys	Atlantic salmon	Otter	White-clawed crayfish	Macrophyte community	Total	Cost banding	Potential risks	Potential benefits
Duhonw – source to conf R Wye	Remove bank protection and allow natural recovery	High	Low	Low	Low	Low	1	0	1	0	1	1	1	5	Medium	High	Medium
Duhonw – source to conf R Wye	Allow natural recovery of re-aligned planform	Low	Low	Low	Low	Low	0	0	1	0	1	0	1	3	Low	Low	Medium
Duhonw – source to conf R Wye	Remove dams/weirs	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Medium	Low	High
Tirabad Dulas - source to conf R Irfon	Minimise CWD removal	Low	Low	Low	Low	Low	1	1	0	1	1	0	0	4	Low	Low	Medium
Tirabad Dulas - source to conf R Irfon	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	1	1	1	1	1	1	7	Low	Low	High
Irfon - conf Cledan to conf R Wye	Minimise CWD removal	Med	Med	Med	Low	Low	1	1	0	1	1	0	0	4	Low	Medium	Medium
Howey Bk - source to conf R Ithon	Remove bank protection and allow natural recovery	Low	Low	Low	Low	Low	1	0	1	0	1	1	1	5	Medium	Low	Medium
Howey Bk - source to conf R Ithon	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Howey Bk - source to conf R Ithon	Allow natural recovery of re-aligned planform	Med	Low	Low	Med	Med	0	0	1	0	1	0	1	3	Low	Medium	Medium
Mithil Bk - source to conf R	Remove bank protection and allow natural recovery	High	Low	Low	Med	Med	1	0	1	0	1	1	1	5	Medium	High	Medium

Ithon																
Mithil Bk - source to conf R Ithon	Allow natural recovery of re-aligned planform	Low	Low	Low	Low	Low	0	0	1	0	1	0	1	3	Low	Low	Medium
Mithil Bk - source to conf R Ithon	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Mithil Bk - source to conf R Ithon	Remove dams/weirs	Low	Low	Low	Low	Med	1	0	1	1	1	1	1	6	Medium	Medium	High
Clywedog Bk - conf Bachell Bk to conf R Ithon	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Clywedog Bk - conf Bachell Bk to conf R Ithon	Minimise CWD removal	Med	Low	Med	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Clywedog Bk - source to conf Bachell Bk	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Clywedog Bk - source to conf Bachell Bk	Remove dams/weirs	Low	Low	Low	Low	Med	1	0	1	1	1	1	1	6	Medium	Medium	High
Clywedog Bk - source to conf Bachell Bk	Minimise CWD removal	Med	Med	Med	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Aran - source to conf R Ithon	Remove bank protection and allow natural recovery	High	Low	Low	Low	Med	1	0	1	0	1	1	1	5	Medium	High	Medium
Aran - source to conf R Ithon	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Aran - source to conf R Ithon	Breach or remove embankments, where possible	Med	Low	High	Low	Low	0	0	0	0	1	0	0	1	Medium	Medium	Low
Aran - source to conf R Ithon	Reinstate a more natural planform	Med	Low	Low	Low	Med	0	0	1	0	1	0	1	3	High	Medium	Medium
Aran - source to conf R Ithon	Consider modifying design or structure of bridges that is causing impacts, or remove altogether, if feasible.	Med	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Medium	Medium	High
Camddwr Bk - source to conf R Ithon	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Camddwr Bk - source to conf R Ithon	Minimise CWD removal	Med	Low	Low	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium

Ithon - conf Gwenlas Bk to conf Camddwr Bk	Remove bank protection and allow natural recovery	High	Low	Low	Low	Med	1	0	1	0	1	1	1	5	Medium	High	Medium
Ithon - conf Gwenlas Bk to conf Camddwr Bk	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Ithon - conf Gwenlas Bk to conf Camddwr Bk	Allow natural recovery of re-aligned planform	Med	Low	Low	Low	Med	0	0	1	0	1	0	1	3	Low	Medium	Medium
Ithon - conf Gwenlas Bk to conf Camddwr Bk	Minimise CWD removal	Med	Low	Med	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Ithon - conf Gwenlas Bk to conf Camddwr Bk	Consider modifying design or structure of bridge that is causing impacts, or remove altogether, if feasible.	Med	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Medium	Medium	High
Llaethdy Bk - source to conf R Ithon	Increase tree cover	Low	Low	Low	Low	Low	1	0	0	1	1	0	0	3	Low	Low	Medium
Llaethdy Bk - source to conf R Ithon	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Gwenlas Bk - source to conf R Ithon	Minimise CWD removal	Low	Low	Low	Low	Low	1	0	0	1	1	0	0	3	Low	Low	Medium
Gwenlas Bk - source to conf R Ithon	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Gwenlas Bk - source to conf R Ithon	Allow natural recovery of re-aligned planform	Med	Low	Low	Med	High	0	0	1	0	1	0	1	3	Low	Medium	Medium
Ithon - source to conf Llaethdy Bk	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Ithon - source to conf Llaethdy Bk	Minimise CWD removal	Med	Low	Low	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Ithon - conf Camddwr Bk to conf R Wye	Allow natural recovery of re-aligned planform	High	Low	Low	Med	Med	0	0	1	0	1	0	1	3	Low	High	Medium
Ithon - conf	Remove bank protection and allow	High	Low	Low	Med	Med	1	0	1	0	1	1	1	5	Medium	High	Medium

Camddwr Bk to conf R Wye	natural recovery																
Ithon - conf Camddwr Bk to conf R Wye	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Ithon - conf Camddwr Bk to conf R Wye	Minimise CWD removal	Med	Med	Med	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Ithon - conf Camddwr Bk to conf R Wye	Consider modifying design or structure of bridge that is causing impacts, or remove altogether, if feasible.	Med	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Medium	Medium	High
Dulas Bk - source to conf Afon Llynfi	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Dulas Bk - source to conf Afon Llynfi	Allow natural recovery of re-aligned planform	Med	Low	Low	Med	Med	0	0	1	0	1	0	1	3	Low	Medium	Medium
Triffrwd - source to Dulas	Remove bank protection and allow natural recovery	High	Low	Low	Low	Low	1	0	1	0	1	1	1	5	Medium	High	Medium
Triffrwd - source to Dulas	Allow natural recovery of re-aligned planform	Low	Low	Low	Low	Low	0	0	1	0	1	0	1	3	Low	Low	Medium
Triffrwd - source to Dulas	Minimise CWD removal	Med	Med	Med	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Wye - conf R Irfon to Scithwen Bk	Remove bank protection and allow natural recovery	High	Low	Low	High	High	1	1	1	0	1	1	1	6	Medium	High	High
Wye - conf R Irfon to Scithwen Bk	Remove dams/weirs	Low	Low	Low	Low	Med	1	1	1	1	1	1	1	7	Medium	Medium	High
Wye - conf R Irfon to Scithwen Bk	Minimise CWD removal	Med	Med	Med	Low	Low	1	1	0	1	1	0	0	4	Low	Medium	Medium
Wye - Scithwen Bk to Brewardine Br	Remove bank protection and allow natural recovery	High	Low	Low	Med	High	1	1	1	0	1	1	1	6	Medium	High	High
Wye - Scithwen Bk to Brewardine Br	Minimise CWD removal	Med	Med	Med	Low	Low	1	1	0	1	1	0	0	4	Low	Medium	Medium
Wye (Avon Gwy) - conf R Ithon to conf R Irfon	Remove bank protection and allow natural recovery	High	Low	Low	Med	Med	1	1	1	0	1	1	1	6	Medium	High	High
Wye (Avon	Allow natural recovery of re-aligned	Low	Low	Low	Low	Low	0	0	1	0	1	0	1	3	Low	Low	Medium

Gwy) - conf R Ithon to conf R Irfon	planform																
Wye (Avon Gwy) - conf R Ithon to conf R Irfon	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	1	1	1	1	1	1	7	Low	Low	High
Wye (Avon Gwy) - conf R Ithon to conf R Irfon	Minimise CWD removal	Med	Low	Med	Low	Low	1	1	0	1	1	0	0	4	Low	Medium	Medium
Wye (Avon Gwy) - conf R Ithon to conf R Irfon	Remove dams/weirs	Med	Low	Low	Low	Low	1	1	1	1	1	1	1	7	Medium	Medium	High
Wye - conf Afon Elan to conf R Ithon	Remove bank protection and allow natural recovery	High	Low	Low	Low	Med	1	0	1	0	1	0	1	4	Medium	High	Medium
Wye - conf Afon Elan to conf R Ithon	Remove dams/weirs	Low	Low	Low	Med	Med	1	0	1	1	1	0	1	5	Medium	Medium	Medium
Wye - conf Afon Elan to conf R Ithon	Minimise CWD removal	Med	Med	Low	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Wye - conf to conf Afon Marteg to conf Afon Elan	Remove bank protection and allow natural recovery	High	Low	Low	Med	High	1	0	1	0	1	0	1	4	Medium	High	Medium
Wye - conf to conf Afon Marteg to conf Afon Elan	Minimise CWD removal	Med	Med	Low	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Wye - conf Afon Bidno to conf Afon Marteg	Remove bank protection and allow natural recovery	High	Low	Low	Low	High	1	0	1	0	1	0	1	4	Medium	High	Medium
Wye - conf Afon Bidno to conf Afon Marteg	Allow natural recovery of re-aligned planform	Low	Low	Low	Low	High	0	0	1	0	1	0	1	3	Low	Low	Medium
Wye - conf Afon Bidno to conf Afon Marteg	Remove fallen footbridges to minimise disruption to continuity	Low	Low	Low	Low	Low	1	0	1	1	1	0	1	5	Low	Low	Medium
Wye - conf Afon Bidno to conf	Minimise CWD removal	Med	Low	Med	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium

Afon Marteg																		
Wye - conf Afon Tarenig to conf Afon Bidno	Breach or remove embankments, where possible	Low	Med	High	Low	Low	0	0	0	0	1	0	0	1	Medium	Medium	Low
Wye - conf Afon Tarenig to conf Afon Bidno	Allow natural recovery of re-aligned planform	Low	Low	Low	Low	High	0	0	1	0	1	0	1	3	Low	Medium	Medium
Wye - conf Afon Tarenig to conf Afon Bidno	Minimise CWD removal	Low	Low	Low	Low	Low	1	0	0	1	1	0	0	3	Low	Low	Medium
Wye - conf Afon Tarenig to conf Afon Bidno	Remove bank protection and allow natural recovery	Low	Low	Low	Med	Med	1	0	1	0	1	0	1	4	Medium	Medium	Medium
Wye - conf Afon Tarenig to conf Afon Bidno	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	0	1	5	Low	Low	Medium
Wye - conf Afon Tarenig to conf Afon Bidno	Remove dams/weirs	Low	Low	Low	Low	Med	1	0	1	1	1	0	1	5	Medium	Medium	Medium
Scithwen Bk - source to conf R Wye	Remove bank protection and allow natural recovery	High	Low	Low	Med	Low	1	0	1	0	1	1	1	5	Medium	High	Medium
Scithwen Bk - source to conf R Wye	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Scithwen Bk - source to conf R Wye	Remove dams/weirs	Low	Low	Low	Low	Med	1	0	1	1	1	1	1	6	Medium	Medium	High
Scithwen Bk - source to conf R Wye	Bridge/culvert modification to reduce impoundment	Med	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Medium	Medium	High
Bach Howey Bk - source to conf R Wye	Minimise CWD removal	Med	Low	Low	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Edw - conf Clas Bk to conf R Wye	Minimise CWD removal	Med	Med	Med	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Edw - conf Camnant Bk to conf Clas Bk	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Builth Dulas Bk - source to conf R Wye	Allow natural recovery of re-aligned planform	Low	Low	Low	Low	High	0	0	1	0	1	0	1	3	Low	Medium	Medium

Builth Dulas Bk - source to conf R Wye	Minimise CWD removal	Low	Low	Med	Low	Low	1	0	0	1	1	0	0	3	Low	Medium	Medium
Builth Dulas Bk - source to conf R Wye	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Builth Dulas Bk - source to conf R Wye	Remove dams/weirs	Low	Low	Low	Med	Med	1	0	1	1	1	1	1	6	Medium	Medium	High
Edw - source to conf Colwyn Bk	Fence channel to reduce poaching/fine sediment delivery	Low	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Low	Low	High
Edw - source to conf Colwyn Bk	Remove dams/weirs	Low	Low	Low	Low	Med	1	0	1	1	1	1	1	6	Medium	Medium	High
Edw - source to conf Colwyn Bk	Consider modifying design or structure of bridge that is causing impacts, or remove altogether, if feasible.	Med	Low	Low	Low	Low	1	0	1	1	1	1	1	6	Medium	Medium	High
Camnant Brook - source to confluence R Edw	Remove bank protection and allow natural recovery	High	Low	Low	Low	Low	1	0	1	0	1	1	1	5	Medium	High	Medium
Camnant Brook - source to confluence R Edw	Breach or remove embankments, where possible	Low	Low	High	Low	Low	0	0	0	0	1	0	0	1	Medium	Medium	Low
Camnant Brook - source to confluence R Edw	Assisted recovery of re-aligned planform	Med	Low	Low	Low	Med	0	0	1	0	1	0	1	3	High	Medium	Medium

Multi-criteria analysis of restoration options

In considering the likely risks and constraints associated with different restoration options there is a need to link the potential expenditures on the upland river restoration with an understanding of where increased risks may occur, and potentially where there could be benefits associated with the new management options. Given the time-scales of the project and the large number of water bodies concerned, we provide a 'scoping' of these issues at a catchment level and on the basis of available evidence, provide an assessment in terms of whether potential management options will increase risks to a series of economic and social services provided by the river catchment.

A desk based scoping study of the different types of economic and social/cultural benefits the river contributes towards and the likely constraints were considered for four river catchments:

- Scithwen Brook – source to the River Wye confluence (GB109055036990).
- River Wye – confluence of Afon Tarenig to the confluence of the Afon Bidno (GB109055042330).
- Wye – confluence of Afon Marteg to the confluence of the Afon Elan (GB109055042280).
- Clywedog brook – source to the Bachell Brook confluence (GB10955042090).

Desk based method and data sources

This scoping study has used a combination of existing information, literature from previous desk studies, web searches and experienced judgement to evaluate the constraints of the proposed restoration options outlined earlier in this report.

This study involved interpreting spatial data which has been made available for the river catchments. Much of the data has been provided by Natural Resources Wales or obtained from the Office for National Statistics (ONS). Spatial data and official government statistics were used to gain an insight into the socio-economic characteristics of the river catchments and how these characteristics have been influenced by land management and other human modifications. These data included land cover, aerial photography, River Wye Fluvial Audit, Fluvial flood zone, designated sites, WFD catchment boundaries and river reaches. Table 13 sets out the main data sets used and what information has been inferred from them.

Table 13. Main data sources and information inferred.

Data	Information Inferred
WFD river catchments	To identify the location of the river catchments and to set the context for analysis.
WFD river reaches	To identify the location of the river channels.
Ordnance Survey base mapping	To describe constraints within the catchment e.g. access routes (e.g. Public Rights of Way and road infrastructure). Important historical sites
Infoterra Aerial photography	Interpret land use and other socio-economic activity within the catchments.
Land Cover Map 2007 (Vector)	To describe the land cover characteristics, particularly those which may have agricultural value.
Provisional Agricultural Land Classification (ALC)	To identify the agricultural land grade for the catchments.

Data	Information Inferred
Flood Zone 3 Map (≥1 in 100 per year chance of flooding)	Identify habitats and infrastructure which fall within the fluvial flood risk zone.
Designated sites (SSSI, SAC)	To describe important designations and conservation areas within the catchments.
Sustran national cycle network (Sustran web viewer)	To describe access via cycle routes.
River Wye river audit	To describe catchment characteristics and detailing modifications that influence morphological pressures.
Census ward spatial boundaries (2011)	Describing socio-economic composition e.g. industry type
Lower super output area boundaries (2011)	Describing socio-economic composition e.g. industry type
Welsh Index of Multiple Deprivation (WIMD) rankings for 2011.	Describing socio-economic composition e.g. education, economic opportunity, access to services etc.

Approach

Higher level scoping framework

The nature of this scoping analytical framework is to outline the initial steps in considering an indicative cost-benefit analysis. Criteria for the framework were initially selected from the information and data assimilated during the desk study and GIS analysis. Following this, indicators and criteria applicable to the four catchments were scoped out, such indicators for the social and economic aspects are outlined in Table 14.

Table 14. Higher level scoping framework

Economic	
Indicator	**Description**
Impacts on Tourism	Economic activity directly and indirectly supported by river in tourism and other sectors. Will the restoration options impact on recreation and tourism activity?
Impact on employment and business	Economic activity associated directly and indirectly with the river in agriculture, fisheries and forestry. For instance will there be any long term costs to land owners (e.g. farmers) e.g. reduced land values or agricultural yields?
Flood risk	Upland river as currently managed influences flood risk to non-agricultural businesses and homes. What is the risk of flooding to agricultural, residential and industrial land within the catchments?
Social	
Indicator	**Description**
Impact on recreational access	Recreation facility: the river provides an important recreation facility, river environment provides access, and health benefits. Will the restoration options hinder access to recreation provision e.g. removal of weirs could contribute to the loss of a fishing location?
Impact on education provision	The river provides an education resource in terms of habitat access and learning. Will the restoration option hinder access to areas for education learning?
Impact on community networks	The river provides an opportunity to get involved with conservation management and volunteering opportunities, a basis for social networks.

Tables 15 and 16, illustrate a summarised scoping framework for both the economic and social aspects. For example, in terms of economic benefits and services (Table 15), the upland river may support agricultural yields, might support employment locally in other ways, or it might reduce flood risks on businesses etc. In this scoping exercise we assess broadly how specific restoration options might affect the flow of economic services and at what spatial scale the benefit is likely to be most important. For example, in terms of the restoration options affecting agricultural prospects the impacts are considered important in more local terms (i.e. within the river catchment).

Tables 15 and 16 therefore reveal selected socio-economic benefits, and then how these might be affected by management options. This permits an initial judgement of how changes in restoration options might be associated with increased risk to the service involved. For example, in the case of economic benefits the analysis seeks to highlight the level of economic activity close to a water body that could be affected by changes to the management of the water course. Similarly, if a potential economic benefit is in terms of supporting tourism revenues, economic data might be used to assess the significance of revenues supported, and the level of tourism facing activity in the given area. It is accepted here that there are problems collecting appropriate data at the levels of water catchment areas, and with these boundaries not always fitting with boundaries over which socio-economic data is typically reported for small areas.

The final element is to use the evidence derived to make a judgement on how a given restoration plan might affect the flow of socio-economic or other services. This could be in terms of a high, medium or low risk to the flow of services. However, we note in each case where there may be some potential for an improvement in the level of benefits.

Economic benefits and constraints

Table 15 reveals that we rate the risk of restoration options to economic benefits as low in each river body case. Important in the analysis of the economic activity supported by the river catchment was an analysis of the productive land close to water bodies where restoration works could occur. In each river body case employment and self-employment provided by farming is small and it is difficult to see how revised management options could provide a risk to jobs and incomes given the expected ground areas likely to be affected by the management options. Indeed in some of the river catchments very little agricultural activity occurs. Moreover, we suspect that given the diverse factors that affect agricultural yields and farm incomes it would be difficult to isolate the impacts of elements such as reduced yield caused by necessary fencing etc. Note here that no account is taken of any increase in economic opportunity associated with the capital works and maintenance for the restoration options which could provide an additional income stream for local farmers.

The second issue covered is in terms of whether restoration options might affect other economic activity both directly and indirectly, and this includes tourism levered to the river catchment areas. Again this was informed by examining tourism activity that might be linked to the presence of the river, and a scoping of the tourism facing infrastructure in each river catchment. It is accepted that the individual river catchments might support tourism facing infrastructure outside of the immediate catchment area, but we focus here on the tourism demand and supply side that might be associated with the presence of the water body. There is also a requirement here to examine whether restoration options might increase flood risks to businesses and with this having a knock on effect to the ability of local businesses to capitalise on infrastructure investment. The conclusion here from the four river catchment areas is of low risk caused by any restoration option. One caveat in the Wye-Marteg case is the presence of camp sites close to rivers where there could a partial increase in the risk of flooding. While tourism is an important contributor to the local economy of Powys and these small river catchment areas it is difficult to see how restoration options could affect tourism sector incomes, or those of other industries in each area. Indeed, it is more likely here that management options might improve prospects for angling by residents and tourists, and improve prospects for other water born recreation such as canoeing provided that access is not overly impeded by the removal of structures.

Finally, there is the fact that the management of the upland river affects the probability of flooding in areas downstream of the river catchment area. While the GIS analysis undertaken identified flood zones within the river catchment, and downstream, it was not possible to make comments on how far events upstream affected the probability of an increase in flood zones downstream. This analysis would require a modelled framework.

Social benefits and constraints

Four separate sets of benefits provided by the river are identified with respect to social services (see Table 16). The first is that the river provides an educational resource. Here the presence of the river provides a potential learning resource, and with the potential for restoration options to affect access to the resource. Against this 'cost' is the potential for improvement options to increase the scope of benefits as an education resource i.e. as the river runs with less built impediments. The evidence base examined here was the degree of public access offered to the reference water courses, and then whether there was evidence of education use of the environmental assets. The conclusion across each of the four water bodies was that educational access was unlikely to be seriously impeded by restoration options so the risk to these services was low, and again with some expectation in the context of the restoration improvements that the flow of services could increase.

A very similar set of conclusions relate to the services that the river provides in terms of volunteering and conservation opportunities. The scoping found little evidence of extensive volunteering and conservation activity in connection with the river areas concerned and were such activity to be occurring it is unlikely that restoration options would impact on the services the river provides in this respect.

The next set of services refers to role of the river in supporting a sense of local place. While this is undoubtedly important it is very difficult to assess risks to this service without speaking to local residents in each river catchment case. It is recommended that this could be subject to focus group analysis while noting that three of the river catchment areas contain no real centres of population.

Finally here is reference to the role of the river in providing a recreation facility for residents and tourists, and in providing health benefits. Several areas of recreation require access and with the potential of selected management options to decrease access. However, the GIS analysis provides little evidence of public access routes close to the reference water courses that would be affected by management options. Moreover, there is currently limited information on recreational use outside of fishing. So the risks to this class of services have been rated as low.

Ideally, a comprehensive welfare assessment would seek to cost each of the benefit flows but this would be very difficult in the case of the many of services outlined, and the time available to complete the project. However, such an approach to scoping the services that might be affected by restoration plans against a series of criteria, can help to inform any public consultation process, and would possibly alert NRW to where the main cost-benefit issues in management options might be. Moreover, we have in the analysis highlighted where public consultation might be most useful in further developing the evidence base.

Table 15. Selected Economic Benefits

Economic benefits and services	Issue	Key spatial scale	Factors considered in and around water catchment area	Would restoration options increase risks to flow of benefits and services?
1.Economic activity associated directly and indirectly with the river in agriculture, fisheries and forestry	• Restoration options could reduce economic and employment opportunities through reduction in yields, or loss of productive land. • Where sedimentation is occurring due to agricultural runoff and poaching, erosion and soil loss could impact on crop yields and availability of land for livestock rearing. Soil loss affects future viability of the land for economic activity.	Local	• Employment in primary sectors in wards encompassing the water catchment area using ONS NOMISWEB and Business Register and Employment Survey • Audit of land cover in terms of improved grass land , arable etc in water catchment area, and extent to which this land is subject to flood risk; GIS analysis • Extent to which employment in primary sectors likely to be replaceable with employment in other local sectors • Analysis of Welsh Index of Multiple Deprivation for wards encompassing the river catchment area	• Scithwen Brook GB109055036990: LOW • Wye/Marteg GB 109055042090: LOW • Wye Afon Tavenig GB109055042330: LOW • Wye Marteg Elan GB109055042280: LOW Limited land areas subject to increased risk; low levels of employment supported in agriculture in 4 river catchments.
2.Economic activity directly and indirectly supported by river in tourism and other sectors	• Restoration options could reduce economic and employment opportunities in tourism • Risks could include flood risks to tourism sites, reduction in opportunities for tourists to use river resources because of access issues • Restoration options could also serve to improve economic prospects for tourism	Local	• Employment in tourism facing sectors such as accommodation and restaurants in wards encompassing the water catchment area using ONS NOMISWEB and Business Register of Employment Survey • Audit of tourism facilities in the river catchment including camp sites, B&B, bunkhouses, hotels and other visitor facing facilities • Extent to which employment in sectors that might be affected by restoration options could be replaced elsewhere in local economy. • Web based search of leisure activities currently undertaken along river including canoe runs, trout and salmon fishing • Current flood risk to tourism facing infrastructure close to rivers using GIS software	• Scithwen Brook GB109055036990: LOW • Wye/Marteg GB 109055042090: LOW • Wye Afon Tavenig GB109055042330: LOW • Wye Marteg Elan GB109055042280: LOW Several of the river catchments lever tourism activity; little evidence in any of the cases that likely restoration options would affect tourism employment, but noted that some tourism infrastructure (campsites) might see marginal increase in probability of flooding. In some cases restoration options could improve prospects for canoeing activity and fishing.
3.Upland river as currently managed influences flood risk to business and homes	• Restoration options could increase flood risks to businesses and homes outside of the reference water catchment area • Restoration options might impose other externalities on areas downstream.	Regional	• GIS analysis of current flood risk in areas downstream of the river catchment area	No conclusions made due to inadequate information on how far reference river catchment currently contribute to flood risk downstream.

Table 16. Selected Social Benefits

Social & cultural benefits and services	Issue	Key spatial scale	Factors considered in and around water catchment area	Would restoration options increase risks to flow of benefits and services?
4. Education: river provides an education resource in terms of habitat access and learning	• Upland river system provides a learning resource • Restoration options could reduce access to river system • Restoration options potentially improve quality of upland river as a learning and education resource	Local Regional	• Current education and learning resources within river catchment • Presence of various nature reserves and SSSIs in the river catchment area • Presence of access routes such as bridleways and footpaths which could be affected by restoration options and increased flood risk	• Scithwen Brook GB109055036990: LOW • Clywedog/Bachell GB 109055042090: LOW • Wye Afon Tavenig GB109055042330: LOW • Wye Marteg Elan GB109055042280: LOW Little evidence to support that restoration options would reduce level of services here other than slightly increased risk to access in some cases. Some expectation of options leading to marginal improvement in flow of services here.
5. The river provides an opportunity to get involved with conservation management and volunteering opportunities.	• Upland river provides an opportunity for local and regional volunteers to improve skills • Restoration options could result in increased opportunities for volunteering	Local Regional	• Presence of nature reserves within the catchment (Ordnance Survey and web search of conservation bodies operating in and around catchment) • Presence of other natural managed sites within the water catchment which offer opportunities for volunteering and conservation work • Evidence of current volunteering activity in the water catchment linked to river (web search)	• Scithwen Brook GB109055036990: LOW • Clywedog/Bachell GB 109055042090: LOW • Wye Afon Tavenig GB109055042330: LOW • Wye Marteg Elan GB109055042280: LOW Only marginal effects expected in some cases, and potential for increase in services here.
6. The river catchment provide a basis for social networks; the natural capital and associated infrastructure provides impetus to social networks, encourages networking.	• The river provides community/sense of place; the river give a sense of place to the community, defines the reference area • Restoration options could change sense of place	Local	• Difficult to assess and recommend focus groups to examine this range of benefits	Not possible to assess. Generally small populations around the river areas with exception of Wye-Marteg which runs adjacent to Rhayader and potential for focus group here.
7. Recreation facility: the river provides an important recreation facility, river environment provides	• River situates recreation activity for residents and tourists which could be affected by restoration options	Local Regional	• Access routes proximate to rivers, using OS resources; bridleways, footpaths, forestry access roads etc. • Evidence of recreational use in terms of fishing, canoeing, bird watching from	• Scithwen Brook GB109055036990: LOW • Clywedog/Bachell GB 109055042090: LOW • Wye Afon Tavenig GB109055042330: LOW

access, and health benefits	• Access to river area levers health benefits • Recreation benefits could be improved through restoration options		web search. • Potential to follow up with focus groups at local level to establish residential use	• Wye Marteg Elan GB109055042280: LOW Limited evidence that there are significant public access routes close to water body which would be affected. Limited evidence relating to extensive recreational use.

Impacts, constraints and cost bandings

The scoping assessment was taken a stage further by looking at the likely impacts, constraints and indicative costs for each restoration option on a catchment by catchment basis for four Wye catchments (Tables 18a-d).

Each restoration option was considered in terms of both the geomorphological (short/long term morphological changes to the river channel) and socio-economic (including financial implications to the landowner e.g. reduced extent in grazing land for agriculture) impacts and options which could potentially increase or decrease the likelihood of flooding on adjacent land e.g. agricultural or urban have been mentioned.

The constraints considered in Tables 18a-d focus on the likely social constraints the restoration action may face, for example, land owners or a particular group of users (e.g. angling clubs). Physical and environmental constraints include aspects such as access, cultural heritage features and flood risk (Environment Agency, 2008). The proposed restoration actions should not be undertaken without further consultation through feasibility and geomorphological studies and agreement with the appropriate landowners and other relevant stakeholders.

The cost bandings associated with the restoration actions listed in tables 18a-d are based on the experiences of previous river restoration studies and are indicative estimates (Environment Agency, 2008; JBA consulting, 2013; Jacobs, 2012). Collecting raw costing information on proposed restoration actions was beyond the scope of this work and therefore information from Environment Agency (2008) and JBA consulting (2013) have been used to create the cost bandings which have been grouped as high, high/medium, medium, medium/low and low. The associated restoration actions linked to these bands are outlined in Table 17.

Table 17. Cost bandings for restoration actions (Environment Agency, 2008; JBA consulting, 2013).

Cost band	Related costs from literature
High	Re-meandering ~£1603k/km
Medium/high	Structure modification / weir removal ~£210k/km
Medium	Remove bank protection/re-enforcement ~ 77k/km
Medium/low	
Low	Fencing ~£18k/km

The costs associated will be determined by site specific characteristics and will vary according to a number of variables which include, the sensitivity of the site, the need for further investigations (such as feasibility studies, environmental impact assessments), external contractors, funding opportunities, access provision and the re-use or disposal of extracted material. To determine these site specific characteristics it is important that the process is inclusive and local stakeholders are involved in the decision making process, by providing local knowledge and insight to understanding the problem. Stakeholders can also impart valuable information on the likely social and environmental difficulties and help assess the cost effectiveness of any proposed river restoration programmes.

Table 18a. Impacts, constraints and indicative costs - Scithwen Brook (GB109055036990).

<table>
<tr><td colspan="7">Scithwen Brook</td></tr>
<tr><td colspan="7">Socio-economic characteristics</td></tr>
<tr><td colspan="7">- Evidence of a farming community with farm holdings spread across the catchment. Evidence of hay bailing/ silage making in fields. In addition, there is evidence of livestock grazing and other ploughed fields. The land within this catchment is grade 4 and 5.
- Evidence of coniferous plantations. There is evidence to suggest the plantations are being managed due to areas of felled plantation being identified.
- Sparsely populated catchment but there is a small hamlet and additional housing.
- Evidence of tourism within the catchment e.g. campsite, bunkhouse and Bed and Breakfasts.
- The A470 intersects Scithwen Brook at the point where it meets the River Wye. There are additional minor roads intersecting the catchment.</td></tr>
<tr><td colspan="7">Agricultural and forestry Land use characteristics</td></tr>
<tr><td colspan="7">Catchment Land Cover (Agricultural, forestry and urban) characteristics (figures derived from Land Cover Map 2007 ©CEH and the provisional agricultural land classification © NAW).</td></tr>
<tr><td colspan="2">- Arable and horticulture: 51ha.
- Improved grassland: 747ha.
- Low productivity rough grassland: 118ha.
- Acid grassland: 257ha</td><td>- Grade 4 agricultural land: 877ha
- Grade 5 agricultural land: 359ha</td><td colspan="4">- Coniferous woodland: 533ha
- Urban: 9ha</td></tr>
<tr><td colspan="7">Habitat modifications within the Scithwen Brook Catchment:</td></tr>
<tr><td colspan="7">- 1 reach with re-alignment
- 5 reaches with bank protection (concrete, loose stones, others)
- 3 bridges, 3 footbridges
- 2 reaches with poaching</td></tr>
<tr><td colspan="7">Impacts, constraints and indicative costs of restoration option</td></tr>
<tr><td>Proposed restoration actions</td><td>Description of restoration action</td><td>Geomorphological impacts of restoration</td><td>Socio-economic impacts of restoration</td><td>Ecological benefits of restoration</td><td>Constraints</td><td>Indicative cost banding</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible.</td><td>Removal of bank protection/re-enforcement may also involve a second step of re-profiling the channel to increase the overall channel capacity during flood events.</td><td>- Will require work within the river channel and could cause a period of disturbance to the channel and surrounding riparian areas.
- Potential impact on protected species from construction works.
- Connectivity</td><td>- Land owners may lose agricultural land.
- Removal of bank protection may increase the risk of flood inundation.</td><td>- Allows natural bank materials to be exposed.
- River channel undergoes natural morphological change in response to changes in flow and sediment</td><td>- Social constraints include private landowners and user groups.

- Physical and Environmental constraints include; access, flood</td><td>Medium cost[1]*

Costs will vary depending on how much effort is needed to remove the modification and whether re-profiling of the channel will be needed.</td></tr>
</table>

[1] Medium cost activities like removing bank protection falls within a similar cost banding as cross section enhancement (Environment Agency, 2008). *However, if further modification is needed this action may be graded as medium/high.

		between channel and floodplain.		supply.	risk	
Fence channel to exclude stock in poached sections	Fencing is a simple and effective non in-river method to protect river corridors from bank erosion caused by cattle. This action will allow vegetation to recover and colonise river banks.	- Fencing will reduce bank erosion caused by livestock poaching.	- Reduced availability for stock watering. - Reduced extent of grazed land. - Reduction in economic opportunities through reduction in yields or area of productive land.	- Reduced sedimentation in the river.	- Social constraints include private landowners and user groups due to changes in land management. - Physical and environmental constraints include access.	**Low cost[2]** Costs will vary depending on the fence type required and whether any access arrangements need to be maintained (gates, styles etc).
Remove rock dams, fords and weirs to minimise disruption to continuity	Weirs can have two primary effects: 1) Alterations to the geomorphology and hydraulics of the channel through impoundment. 2) Alterations to flow regime. The impacts weirs have include changes in river flow velocities, sediment transport rates and water levels[3]. Over time rivers become adjusted to these structures being in place and their removal requires careful planning to mitigate the disturbances which will occur once the structure has been removed.	- Removal of weir could contribute to change in river flow i.e. a natural water flow level upstream. - Reduced impoundment. - Uninterrupted sediment transport. - Modifying a weir instead of removal would reduce interruptions in sediment transport. - Localised impact to species and habitats during restoration	- Loss of weir pools may have an impact on angling activities - Weirs can be seen as a historic and cultural heritage feature and their removal may not be favourable.	- Barriers to fish migration are removed	- Social constraints include user groups and private landowners - Physical and environmental constraints include local heritage features, access and flood risk.	**Medium/High cost[4]** Cost of removal and whether access arrangements need to be maintained (road connections, foot paths). Further assessments would be required as there are many unknowns e.g. amount of structure which needs to be removed, the amount of profiling which needs to be done.

[2] Low cost relates to the fencing and large woody debris restoration actions listed in Environment Agency (2008).

[3] JBA Consulting (2013).

[4] Medium/high cost relates to structure modification and weir removal as stated in Environment Agency (2008). Structure modification is a fairly severe in-river intervention activity. The costs of these actions may increase if further feasibility assessments or an Environmental Impact Assessment needs to be carried out.

Consider modifying the design or structure of bridges and culverts that are causing impacts, or remove altogether, if feasible.	Structures present in the river channel have an impact on the geomorphological diversity and processes and influence river flow. Culverts can severely degrade the ecological value of the river and restrict options for future recovery of the river channel. Poorly installed culverts can become impassable for freshwater species, particularly if they become blocked with wooded debris which also increases the flood risk.	- Riparian access may cause disturbance - Reduction in upstream or downstream bank and bed erosion.	- Bridges and culverts may have an important function and/or hold an aesthetic/ cultural heritage significance and their modification may not be favourable. - Any alterations to be carefully planned when designing restoration work. - Reduction in flood risk if removed	- River channel undergoes natural morphological change.	- Social constraints include private land owners and user groups. - Physical and environmental constraints include access.	**Medium/High cost**[4] The cost to modify a structure will vary depending on the work required to reduce upstream water levels during the period of restoration work. Costs associated often include the physical removal of structure and any material trapped behind it in addition to maintaining/diverting access (road connections and/or rights of way).

Table 18b. Impacts, constraints and indicative costs - River Wye – confluence of Afon Tarenig to the confluence of the Afon Bidno (GB109055042330).

<table>
<tr><td colspan="7">River Wye – Afon Tarenig confluence to Afon Bidno confluence</td></tr>
<tr><td colspan="7">Socio-economic characteristics</td></tr>
<tr><td colspan="7">- Evidence of a farming community with farm holdings spread across the catchment. Evidence of livestock grazing and ploughed land. The agricultural land within the catchment is grade 4 and 5.
- Extensive coniferous plantation coverage in the catchment. There is evidence of re-planting in areas which have been previously felled.
- Sparsely populated catchment. There are a few small residential dwellings within the catchment but particularly along the A44.
- The A44 trunk road (Llangurig to Aberystwyth) cuts through the catchment.
- The Sweet Lamb rally complex is situated at the top of the catchment.</td></tr>
<tr><td colspan="7">Agricultural and forestry Land use characteristics</td></tr>
<tr><td colspan="7">Catchment Land Cover (Agricultural, forestry and urban) characteristics (figures derived from Land Cover Map 2007 ©CEH and the provisional agricultural land classification © NAW).</td></tr>
<tr><td colspan="2">- Arable and horticulture: 28ha.
- Improved grassland: 146ha.
- Low productivity rough grassland: 56ha.
- Acid grassland: 359ha.</td><td>- Grade 4 agricultural land: 134ha
- Grade 5 agricultural land: 924ha</td><td colspan="4">- Coniferous woodland: 783ha
- Urban: 2ha</td></tr>
<tr><td colspan="7">Habitat modifications within the Afon Tarenig confluence to Afon Bidno confluence:</td></tr>
<tr><td colspan="7">- 2 reaches with re-alignment, totalling 215m
- 8 reaches with bank protection, totalling 578m (gabions, loose stones, others)
- 7 reaches with embankments, totalling 5501m
- 3 bridges, 4 fords, 2 weirs
- 4 reaches with poaching, totalling 144m</td></tr>
<tr><td colspan="7">Impacts, constraints and indicative costs of restoration option</td></tr>
<tr><td>Proposed restoration actions</td><td>Description of restoration action</td><td>Geomorphological impacts of restoration</td><td>Socio-economic impacts of restoration</td><td>Ecological benefits of restoration</td><td>Constraints</td><td>Indicative cost banding</td></tr>
<tr><td>Remove rock weirs to minimise disruption to continuity</td><td>Weirs have two primary effects to the river channel:
1) Changes to the geomorphology and hydraulics of the channel through impoundment.
2) Changes to the flow regime within the channel.
Weirs impact on the speed of the flowing water, sediment transport rates and water levels[3]. Over time rivers become adjusted to these</td><td>- Removal of weir could contribute to changes in river flow i.e. the flow level upstream/downstream.
- Reduced impoundment.
- Uninterrupted sediment transport.
- Localised impact to species and habitats during restoration.</td><td>- Loss of weir pools may have an impact on angling or other recreational activities.
- Weirs are often seen to have an important historic and cultural heritage significance. Their removal</td><td>- Barriers to fish migration are removed.</td><td>- Social constraints include user groups and private land owners.
- Physical and environmental constraints include local heritage features, access and flood risk.</td><td>Medium/High cost[4]
Costs would need to cover further assessments due to the unknowns linked with weir removal e.g. amount of structure which needs to be removed, the amount of re-profiling (if any) needed.</td></tr>
</table>

	structures being in place. Their removal requires careful planning to mitigate the disturbances which may occur within the channel if the structure is removed.		may not be favourable. Each weir should be looked at in a case by case basis.			
Remove bank protection/re-enforcement and allow natural recovery, where possible	Removal of bank protection/re-enforcement may also involve a second step of re-profiling the channel to increase the overall channel capacity during flood events.	- Will require work within the river channel and could cause a period of disturbance to the channel and surrounding riparian areas. - Potential impact on protected species from construction works. - Connectivity between channel and floodplain.	- Land owners may lose agricultural land. - Removal of bank protection may increase the risk of flood inundation.	- Allows natural bank materials to be exposed. - River channel undergoes natural morphological change in response to changes in flow and sediment supply.	- Social constraints include private landowners and user groups. Physical and environmental constraints include; access, flood risk	**Medium cost[1*]** Costs will vary depending on how much effort is needed to remove the modification. These costs could subsequently increase depending on whether re-profiling of the channel is needed.
Cease removal of CWD	Coarse woody debris is a natural feature of rivers where adjacent trees fall into the channel and provide a variety of important ecological and geomorphological functions[5]. Debris input encourages and increases the diversity of flow and sediment movement. However, historically woody debris has been removed due to both flood risk and access reasons.	- Woody debris contributes towards the regulation of sediments and water quality by temporary trapping mobile silts and reduces siltation. - Woody debris improves bed structure. - Increased debris loads can become lodged on structures and if not monitored created blockages. To reduce this, planning considerations should factor in how to prevent debris collecting on structures and should also assess the risk of debris accumulation in narrow channels.	- Ceasing the activity may face resistance from local land/property owners or user groups. Particularly as historically, fallen trees and associated branches are seen as a flood risk (e.g. due to blockages). - Woody debris is also historically removed to facilitate angling/other	- Ceasing woody debris removal will increase variations in flow velocity enhancing the provision of slow flow sheltered areas and small pools that act as fish refuges and nursery sites. - Creates cover that reduces predation of fish. - Increases food provision for fish.	- Social constraints include private landowners and user groups. - Physical and environmental constraints included access and flood risk.	**Low cost[2]** Costs initially associated with debris removal will be avoided due to the activity ceasing. However, there may be low costs associated with assessing the risks of completely ceasing the activity i.e. debris blockages, the risk of debris accumulation on structures and associated flood risk. Furthermore, any intervening activities which need to be carried out by land owners to reduce any flood risk will need to be factored in.

[5] JBA Consulting (2013).

			water recreation access.	- Provides foraging sites for terrestrial species.		
Fence channel to exclude stock in poached sections	Fencing is a simple and effective non in-channel way to protect riparian river corridors from bank erosion caused predominantly by cattle but also other livestock. This action will allow vegetation to recover and colonise river banks.	- Fencing protects those areas excessively poached and will reduce bank erosion caused by livestock poaching.	- Reduced availability for stock watering. - Reduced extent of grazed land. - Reduction in economic opportunities through reduction in yields or area of productive land.	- Reduced sedimentation in the river.	- Social constraints include private landowners and user groups due to changes in land management. - Physical and environmental constraints include access.	**Low cost[2]** Costs will vary depending on the fence type required and whether any access arrangements need to be maintained (gates, styles etc).
Breach or remove embankments, where possible	Removing embankments allows the natural inter-relationship between the river channel and the floodplain to be reinstated[6]. Whereby natural channel morphology is encouraged and over time will adapt to changes in river flow and sediment supply.	- Embankment removal improves drainage of the floodplain by allowing surface water to drain freely back into the river channel. - Limits the impact of flood flows by allowing the water to dissipate across the flood plain. - Provides connectivity between the river channel and the wider surrounding floodplain.	- Land owners may lose land and see a reduction in the amount of land which can be grazed. Thereby, opposition for their removal may increase. - Increased risk of floodplain inundation and could result in a change of management practices.	- Enhancing natural bank profiles will increase the connectivity and associated diversity of supporting habitats both in the river channel and surrounding flood plain in the long term.	- Social constraints include private land owners. - Physical and environmental constraints include flood risk.	**Medium cost[1*]** Costs will be associated with infrastructure removal and associated in channel works. Long term costs could potentially include those to the landowner which are associated with floodplain inundation, loss in grazed land and changes in management practices.
Do not maintain re-alignments to allow natural recovery	Re-alignment is where the river channel is straightened, the meanders are removed and subsequently the channel is shortened. Not maintaining the	- The river channel may face natural morphological change in response to changes in flow and sediment	- Channel migration may impact on infrastructure across the	- Variations in flow velocity enhancing the provision of slow flow	- Social constraints include private land owners	The costs of the restoration will be dependent on the level of intervention to assist natural recovery.

[6] JBA Consulting (2013).

	re-aligned channels will result in these structures disintegrating overtime, allowing the channel to develop a more natural morphology and encourage the re-meandering of the channel	supply. - Potentially, increased channel migration over time due to natural meander development within the river channel. - Changes in flow and sediment supply.	floodplain e.g. electricity cables, footpaths and roads/tracks. - Loss of suitable grazing land.	sheltered areas.	- Physical and environmental constraints include flood risk.	**Low cost[2]** The costs will be lower if the re-alignments are abandoned and there is no intervention to convert the channel to a more natural state. **High cost[7]** Cost relates to the necessary geomorphological assessments needed prior to any re-meandering works. The costs are also related to the removal of excavated material. If the material excavated can be re-used locally the cost potentially reduces.

[7] High costs relate to activities similar to re-meandering which is documented in Environment Agency (2008). However, this restoration action does not state explicitly that re-meandering is a key feature. If there is a high level of intervention and the meanders are encouraged this may warrant a high cost. If the intervention is lower, this action could be demoted to a lower cost band.

Table 18c. Impacts, constraints and indicative costs - River Wye confluence of Afon Marteg to confluence of Afon Elan (GB109055042280).

<table>
<tr><td colspan="7">Wye – confluence Afon Marteg to confluence Afon Elan</td></tr>
<tr><td colspan="7">Socio-economic characteristics</td></tr>
<tr><td colspan="7">- Evidence of a farming community with farm holdings spread across the catchment. Evidence of livestock grazing and ploughing of fields.
- Grade 4 and 5 agricultural land.
- Largest settlement is the market town of Rhayader with the remainder of the catchment sparsely populated.
- Rhayader has many shops, restaurants, pubs, schools, a leisure centre and other local amenities.
- Evidence of tourism within the catchment e.g. campsites, hotels, B&Bs, Red kite feeding station.
- The national cycling routes 8, 81 and 25 connect the catchment to other parts of Wales.
- Gateway to the Elan Valley via the scenic minor road.
- The A470 (connecting North and South Wales) runs through the catchment. The A44 and the B4518 also intersect the catchment.
- Disused quarry.</td></tr>
<tr><td colspan="7">Agricultural and forestry Land use characteristics</td></tr>
<tr><td colspan="7">Catchment Land Cover (Agricultural, forestry and urban) characteristics (figures derived from Land Cover Map 2007 ©CEH and the provisional agricultural land classification © NAW).</td></tr>
<tr><td colspan="2">- Arable and horticulture: 218ha.
- Improved grassland: 914ha.
- Low productivity rough grassland: 288ha.
- Acid grassland: 1234ha.</td><td>- Grade 4 agricultural land: 1675ha
- Grade 5 agricultural land: 1587ha</td><td colspan="4">- Coniferous woodland: 89ha
- Urban: 70ha</td></tr>
<tr><td colspan="7">Habitat modifications within the Wye (confluence to Afon Marteg to confluence Afon Elan):</td></tr>
<tr><td colspan="7">- 1 reach with re-alignment
- 4 reaches with bank protection, totalling 793 m (concrete, others)
- 1 weir, 1 pipe (Elan Valley pipeline), 3 bridge, 2 FB, 4 outfalls, 2 fords
- 3 reaches with poaching, totalling 351m</td></tr>
<tr><td colspan="7">Impacts, constraints and indicative costs of restoration option</td></tr>
<tr><td>Proposed restoration actions</td><td>Description of restoration action</td><td>Geomorphological impacts of restoration</td><td>Socio-economic impacts of restoration</td><td>Ecological benefits of restoration</td><td>Constraints</td><td>Indicative cost banding</td></tr>
<tr><td>Remove bank protection/re-enforcement and allow natural recovery, where possible</td><td>Removal of bank protection/re-enforcement may also involve a second step of re-profiling the channel to increase the overall channel capacity during flood events.</td><td>- Will require work within the river channel and could cause a period of disturbance to the channel and surrounding riparian areas.
- Potential impact on protected species from construction works.
- Connectivity between channel and floodplain.</td><td>- Land owners may lose agricultural land.
- Removal of bank protection may increase the risk of flood inundation.
- A470 trunk road is in close proximity.</td><td>- Allows natural bank materials to be exposed.
- River channel undergoes natural morphological change in response to changes in flow and sediment supply.</td><td>- Social constraints include private landowners and user groups.

- Physical and environmental constraints</td><td>Medium cost[1*]
Costs will vary depending on how much effort is needed to remove the modification. These costs could subsequently increase depending on whether re-profiling of the channel is needed.</td></tr>
</table>

					include; access, flood risk	
Cease removal of CWD	Coarse woody debris is a natural feature of rivers where adjacent trees fall into the channel and provide a variety of important ecological and geomorphological functions[5]. Debris input encourages and increases the diversity of flow and sediment movement. However, historically woody debris has been removed due to both flood risk and access reasons.	- Woody debris contributes towards the regulation of sediments and water quality by temporary trapping mobile silts and reduces siltation. - Woody debris improves bed structure. - Increased debris loads can become lodged on structures and if not monitored created blockages. To reduce this, planning considerations should factor in how to prevent debris collecting on structures and should also assess the risk of debris accumulation in narrow channels.	- Ceasing the activity may face resistance from local land/property owners or user groups. Particularly as historically, fallen trees and associated branches are seen as a flood risk (e.g. due to blockages). - Woody debris is also historically removed to facilitate angling/other water recreation access.	- Ceasing woody debris removal will increase variations in flow velocity enhancing the provision of slow flow sheltered areas and small pools that act as fish refuges and nursery sites. - Creates cover that reduces predation of fish. - Increases food provision for fish. - Provides foraging sites for terrestrial species.	- Social constraints include private landowners and user groups. - Physical and environmental constraints included access and flood risk.	**Low cost[2]** Costs initially associated with debris removal will be avoided due to the activity ceasing. However, there may be low costs associated with assessing the risks of completely ceasing the activity i.e. debris blockages, the risk of debris accumulation on structures and associated flood risk. Furthermore, any intervening activities which need to be carried out by land owners to reduce any flood risk will need to be factored in.

Table 18d. Impacts, constraints and indicative costs – Clywedog brook source to the Bachell Brook confluence (GB10955042090).

<table>
<tr><td colspan="7">Clywedog Brook (source to confluence Bachell Brook)</td></tr>
<tr><td colspan="7">Socio-economic characteristics</td></tr>
<tr><td colspan="7">- Evidence of a farming community with farm holdings spread across the catchment. There is evidence of livestock grazing and ploughed land.
- Grade 4 and 5 agricultural land.
- Evidence of coniferous plantations being managed, different succession stages of plantation. There is evidence of felling in both sets of aerial photography.
- Main village within the catchment is Abbeycwmhir. However, much of the catchment is sparsely populated but is connected by a minor road network.
- Evidence of tourism within the catchment e.g. the Hall at Abbeycwmhir, Abbey ruins (historical interest), the Inn, self-catering cottages and a B&B.</td></tr>
<tr><td colspan="7">Agricultural and forestry Land use characteristics</td></tr>
<tr><td colspan="7">Catchment Land Cover (Agricultural, forestry and urban) characteristics (figures derived from Land Cover Map 2007 ©CEH and the provisional agricultural land classification © NAW).</td></tr>
<tr><td colspan="2">- Arable and horticulture: 68ha
- Improved grassland: 403ha.
- Low productivity rough grassland: 54ha.
- Acid grassland: 425ha</td><td>- Grade 4 agricultural land: 526ha
- Grade 5 agricultural land: 769ha</td><td colspan="4">- Coniferous woodland: 674ha
- Urban: 0ha</td></tr>
<tr><td colspan="7">Habitat modifications within the Clywedog Brook (source to confluence to Bachell Brook):</td></tr>
<tr><td colspan="7">- 1 reach with re-alignment
- 1 weir
- 2 reaches with poaching , totalling 130m</td></tr>
<tr><td colspan="7">Impacts, constraints and indicative costs of restoration option</td></tr>
<tr><td>Proposed restoration actions</td><td>Description of restoration action</td><td>Geomorphological impacts of restoration</td><td>Socio-economic impacts of restoration</td><td>Ecological benefits of restoration</td><td>Constraints</td><td>Indicative cost banding</td></tr>
<tr><td>Remove weir and allow natural recovery, where possible</td><td>Weirs have two primary effects to the river channel:
3) Changes to the geomorphology and hydraulics of the channel through impoundment.
4) Changes to the flow regime within the channel.
Weirs impact on the speed of the flowing water, sediment transport rates and water levels[3]. Over time rivers become adjusted to these structures being in place. Their removal requires careful planning to mitigate the disturbances which may occur within the channel if the structure is removed.</td><td>- Removal of weir could contribute to changes in river flow i.e. the flow level upstream/downstream.
- Reduced impoundment.
- Uninterrupted sediment transport.
- Localised impact to species and habitats during restoration</td><td>- Loss of weir pools may have an impact on angling or other recreational activities.
- Weirs are often seen to have an important historic and cultural heritage significance. Their removal may not be favourable. Each weir should be looked at in a case by case</td><td>- Barriers to fish migration are removed.</td><td>- Social constraints include user groups and private land owners.

- Physical and environmental constraints include local heritage features, access and flood risk.</td><td>Medium/High cost[4]
Costs would need to cover further assessments due to the unknowns linked with weir removal e.g. amount of structure which needs to be removed, the amount of re-profiling (if any) needed.</td></tr>
</table>

			basis.			
Cease removal of CWD	Coarse woody debris is a natural feature of rivers where adjacent trees fall into the channel and provide a variety of important ecological and geomorphological functions[5]. Debris input encourages and increases the diversity of flow and sediment movement. However, historically woody debris has been removed due to both flood risk and access reasons.	- Woody debris contributes towards the regulation of sediments and water quality by temporary trapping mobile silts and reduces siltation. - Woody debris improves bed structure. - Increased debris loads can become lodged on structures and if not monitored created blockages. To reduce this, planning considerations should factor in how to prevent debris collecting on structures and should also assess the risk of debris accumulation in narrow channels.	- Ceasing the activity may face resistance from local land/property owners or user groups. Particularly as historically, fallen trees and associated branches are seen as a flood risk (e.g. due to blockages). - Woody debris is also historically removed to facilitate angling/other water recreation access.	- Ceasing woody debris removal will increase variations in flow velocity enhancing the provision of slow flow sheltered areas and small pools that act as fish refuges and nursery sites. - Creates cover that reduces predation of fish. - Increases food provision for fish. - Provides foraging sites for terrestrial species.	- Social constraints include private landowners and user groups. - Physical and environmental constraints included access and flood risk.	**Low cost[2]** Costs initially associated with debris removal will be avoided due to the activity ceasing. However, there may be low costs associated with assessing the risks of completely ceasing the activity i.e. debris blockages, the risk of debris accumulation on structures and associated flood risk. Furthermore, any intervening activities which need to be carried out by land owners to reduce any flood risk will need to be factored in.
Consider fencing channel to exclude livestock	Fencing is a simple and effective non in-channel way to protect riparian river corridors from bank erosion caused predominantly by cattle but also other livestock. This action will allow vegetation to recover and colonise river banks.	- Fencing protects those areas excessively poached and will reduce bank erosion caused by livestock poaching.	- Reduced availability for stock watering. - Reduced extent of grazed land. - Reduction in economic opportunities through reduction in yields or area of productive land.	- Reduced sedimentation in the river.	Social constraints include private landowners and user groups due to changes in land management. - Physical and environmental constraints include access.	**Low cost[2]** Costs will vary depending on the fence type required and whether any access arrangements need to be maintained (gates, styles etc).

Recommendations

The scoping reveals factors that should be considered when developing a more comprehensive cost benefit framework. Of necessity it is important to realise that not all categories of costs and benefits have been considered here and to some extent the approach is illustrative. However, by examining the likely impacts, constraints and indicative costs it becomes apparent that further work involving local land owners and other key stakeholders through consultation could be beneficial. Their feedback is useful, particularly as it can raise and identify issues on social and environmental obstacles to delivering the proposed actions and it provides an opportunity for knowledge sharing, contributing towards enhancing the understanding of the issues within the river catchment. Set against this we are mindful that the costs in developing a more detailed evidence base of socio-economic benefits and costs can be high, and these costs need to be carefully weighed against the marginal benefits of more detailed information and consultation.

All restoration actions within SSSI's will need to have appropriate planning, design and construction in place and will require land owners and agency staff working together to produce a strategy, costed action and plan and when needed to secure funding to progress the most appropriate restoration actions.

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Appendix 1. Data collection in RHS format from Fluvial Audit and aerial photographs.

Fluvial Audit data were manually resampled to provide a modified version of that recorded during a standard River Habitat Survey (RHS). This was achieved using Fluvial Audit (FA) data available in supplied GIS files, aerial photographs and the accompanying 2007 CCW report. Despite this conversion method proving generally straightforward, and providing directly comparable data on many habitat features, several variables recorded as part of FA could not be easily converted to RHS data, largely due to the disparity in reach assignment methodologies between the two survey techniques (the former having variable length units, and the latter having set 500m reaches). This difference resulted in some longer FA units covering several individual RHS reaches, and some RHS reaches overlapping the boundaries between one or more FA units. As a result, several habitat features could not be directly converted between the two data formats; in particular, those recorded in the ‘G_Reach’ GIS Layer, such as flow types, channel features and channel substratum, which were recorded as counts for FA units as a whole, could not be assigned to discrete spatial locations. In contrast, other GIS layers, such as those mapping the locations of embankments, coarse wood or in-channel structures were directly compatible with RHS.

The overall set of RHS data that could be could be obtained from FA/aerial photographs provided a reasonable level of information about the major physical modifications of each reach, allowing for identification of major features likely to impair the hydromorphological status of each waterbody. A list of all FA data provided, their RHS equivalents (where available) and information about the subset of data used in subsequent assessments are given in Table 1.
Where available, supplementary information available from aerial photographs was used to support data resampling from the relevant Fluvial Audit layers. The channel was often obscured by riparian tree cover over much of the Wye catchment, however, somewhat limiting the utility of aerial photographs for assessing the presence, extent or type of some features, such as bankface vegetation structure, cliffs, and mid-channel or side bars. Where FA GIS data were not available (i.e. all sampling reaches located outside the SAC boundary) only aerial photograph data could be used in initial assessments. This generally only provided information on riparian land use, and major modifications easily visible at this scale, such as road bridges, fords and large weirs. As a consequence, the data on modifications outside the FA (except where an RHS was available) will almost certainly under-estimate the extent and prevalence of modifications.

General Scoring Methodology

This section outlines the general procedure used to score each habitat feature assessed from subset of usable Fluvial Audit data, and explains the different data types subsequently generated. Data were scored differently for each habitat feature, with this dependent on whether features were associated with bank or channel, and if data were recorded as part of the spot-check or sweep-up phase of the RHS survey. The differences between the spot-check and sweep-up sections of the survey are described below.

Spot checks

Habitat features associated with the bank-top and 5m riparian strip (materials, features, modifications, type and structure of vegetation within 5m of the bank-top) were scored out of 20, with both left and right banks considered separately, with the summed total recorded for each surveyed reach. Individual scores out of 10 for each bank were recorded for bank-top vegetation type, in order to allow for calculation of SERCON scores. Features associated with the channel were scored one at each spot check location, out of a total of 10.

Sweep-up
Habitat features recorded during the sweep phase of each survey were either recorded as absent, present or dominant (e.g. 50m riparian land use), or as the total number of occurrences of each features present within a given reach (e.g. counts of weirs or bridges).

Re-sampled variables

Given below are the habitat features for which data were ultimately recorded in RHS format, from the provided Fluvial Audit information, along with the type of data collected and collection protocol for each of these:

Bank Features
(Spot Check, score out of 20)

The only ‘Bank Feature’ directly recordable in RHS format from available FA data was the presence of Eroding Cliffs on either bank, at each spot check location (giving a total possible score out of 20 for each reach). Relevant data on the extent of eroding cliffs were recorded in the Erosion FA GIS layer, as Erosion Type 8.

Bank Materials
(Spot Check, score out of 20)

Though RHS considers both natural and artificial bank materials together, FA records data on natural bank materials and bank reinforcements separately, and in different formats. As such, natural bank materials could not be recorded for individual RHS sampling reaches. Data on the type and spatial extent of artificial bank materials were available in the Bank Protection layer, however, and these were therefore recorded, and score out of a possible total of 20 for each reach.

Bank Modification
(Spot Check, score out of 20)

The major bank modifications recorded as part of Fluvial Audit surveys, which were also assessed by RHS, were the presence and extent of poaching and embankments. Poaching was recorded in the Erosion GIS layer: both Erosion Type 5, poaching, and Erosion Type 7, footpath erosion, were considered to be examples of this kind of bank modification. Embankments were assessed using the Embankments GIS layer. The presence of both these kinds of modification was recorded on each bank at each spot location.

Channel Modification
(*Spot Check, score out of 10 for each modification type****)***

The presence of each type of channel modification at each spot check location within a reach was assessed using data recorded in the Structures layer where FA data were available. In addition to this, supplementary information from aerial photographs was used where FA data were not present. Channel modifications that were present within a reach, but not at any spot check location, were recorded in the ‘Sweep’ section for the survey.

Riparian Land Use
(5m: Spot Check, scored recorded separately out of 10 for each bank; 50m: Sweep, all land uses present recorded)

Although data on riparian land use were present within the G_Reach GIS layer, these data could not be accurately assigned to individual spot check locations or individual RHS reaches. Moreover, eight land use categories recorded as part of RHS were not recorded in FA GIS data, and in some cases several RHS land use categories were amalgamated under a single FA category, and vice versa (Table 1), making direct conversion of these data problematic. For these reasons, available aerial photographs were used to assess land use within each 500m reach. Data were recoded as spot checks for the 5m within the bank-top at each section, with only one vegetation type recorded per spot check per bank. Data on riparian land use within 50m of the bank-top were recorded as part of the sweep section, with all land use types present recorded. Land use types were recorded as either ‘Present’ or ‘Extensive’ (the latter used where a single land use type spanned >33% of the bank length within a reach). Separate scores for each bank were recoded for both the spot check and sweep data, to allow for calculation of relevant SERCON scores

Bank-top Vegetation Structure
(*Spot Check, score out of 20***)**

River habitat surveys record data on both bank-face and bank-top vegetation. However, as aerial photographs were used for assessing riparian vegetation, and as the bank-face was typically not visible, only bank-top vegetation structure data were estimated. As a detailed appraisal of the vegetation structure could not be carried out using aerial photographs, assumptions were generally made about the vegetation structure based on the dominant vegetation types. For example, semi-natural broadleaf cover was considered to be ‘Complex’, conifer forest and tall herbs (bracken) were considered to be ‘Simple’, rough and improved grassland were considered to ‘Uniform’, and urban cover, including roads, were assumed to be ‘Bare’.

Tree Features
(Sweep, Presence-Absence)

The only RHS tree feature routinely recorded by FA was the presence of Coarse Woody Debris. Separating situations where woody debris was ‘present’ from situations where it would be judged ‘extensive’ by RHS surveyors in the field was considered problematic, and so this was simply recorded as present or absent – actual RHS data were simplified in the same way by combining the present and extensive categories.

Artificial Bank Profiles
(Sweep)

The presence of artificial bank profiles was assessed using data on resectioning, reinforcement, poaching and embankments from the relevant GIS layers, and followed standard RHS absent/present/extensive coding.

Table 1: Habitat components assessed and scored as part of a standard River Habitat Survey (RHS), their corresponding equivalents in Fluvial Audit (FA) and the relevant FA GIS layer containing data on each component. Habitat features recorded in RHS with no directly translatable equivalent in Fluvial Audit are indicated with a dash. Data collected during the sweep phase of RHS, rather than via spot checks, are indicated with an asterisk (*). Variables ultimately recorded during data collection are highlighted in red. Datasheet codes for each RHS category are given in brackets.

Habitat Component	RHS Categories	Fluvial Audit Equivalent	Relevant GIS Layers
Bank Features			Erosion Sediment Storage Area
	Eroding Cliff (**EC**)	Eroding Cliff (Erosion Type = 8)	
	Stable Cliff (**SC**)	–	
	Unvegetated Point Bar (**PB**)	Sediment Storage Area (Unstable)	
	Vegetated Point Bar (**VP**)	Sediment Storage Area (Stable)	
	Unvegetated Side Bar (**SB**)	Sediment Storage Area (Unstable)	
	Vegetated Side Bar (**VS**)	Sediment Storage Area (Stable)	
	Natural Berm (**NB**)	–	
Bank Material			G_Reach Bank Protection
	Bedrock (**BE**)	Bedrock	
	Boulder (**BO**)	–	
	Cobble (**CO**)		
	Gravel/Sand (**GS**)	Sand, Fine Gravel, Coarse Gravel	
	Earth (**EA**)	–	
	Peat (**PE**)	–	
	Sticky Clay (**CL**)	Clay	
	–	Fines (**FI**)	
	Concrete (**CC**)	Concrete (Type 1)	
	Sheet Piling (**SP**)	Sheet Piling (Type 3)	
	Wood Piling (**WP**)	Wood (Type 10)	
	Gabion (**GA**)	Gabion (Type 5)	
	Brick/Laid Stone (**BR**)	Brick/Wall (Type 9); Blockstone (Type 2)	
	Rip-Rap (**RR**)	Loose Stone (Type 4)	
	Tipped Debris (**TD**)	Rubbish (Type 7)	
	Fabric (**FA**)	–	
	Bio-Engineering Materials (**BI**)	Laid Vegetation (Type 6)	
			Erosion

Bank Modification			
	Not Known (**NK**)	–	G_Reach
	None (**NO**)	None	
	Resectioned (**RS**)	Resectioned	Embankments
	Reinforced (**RI**)	Reinforced	
	Poached (**PC**)	Poaching (Erosion Type = 5; Footpath Erosion: Type = 7)	Bank Protection
	Artificial Berm (**BM**)	–	
	Embankment (**EM**)	Embankments	
Channel Features			
	Not Known (**NK**)	–	
	None (**NO**)	None	
	Exposed Bedrock (**EB**)	–	
	Exposed Boulders (**RO**)	–	Sediment Storage Area
	Vegetated Rock (**VR**)	–	
	Unvegetated Mid-Channel Bar (**MB**)	Sediment Storage Area (Unstable)	Aerial Photographs
	Vegetated Mid-Channel Bar (**VB**)	Sediment Storage Area (Stable)	
	Mature Island (**MI**)	–	
	Trash (**TR**)	–	
Channel Modifications			
	Not Known (**NK**)	–	
	None (**NO**)	None	
	Culverted (**CV**)	Culvert	Structures
	Resectioned (**RS**)	–	
	Reinforced (**RI**)	–	CCW Report
	Dam/Weir/Sluice (**DA**)	Weir	
	Ford (**FO**)	Ford	
	–	Bridge (**BR**)	
	–	Outfall (**OU**)	
Channel Substratum			
	Bedrock (**BE**)	Bedrock	
	Boulder (**BO**)	Boulder	
	Cobble (**CO**)	Coarse Pebble	
	Pebble (**P**)	Fine Pebble	
	Gravel (**G**)	Fine Gravel, Coarse Gravel	G_Reach
	Sand (**SA**)	Sand	
	Clay (**CL**)	Clay	
	Silt (**SI**)	–	
	Peat (**PE**)	–	
	Earth (**EA**)	–	
	Artificial (**AR**)	Artificial	
	–	Fines (**FI**)	
Flow Type			
	Free Fall (**FF**)	Waterfall	
	Chute (**CH**)	Cascade	
	Broken Standing Waves (**BW**)	Rapids	
	Unbroken Standing Waves (**UW**)	Riffle	G_Reach
	Chaotic Flow (**CF**)	–	
	Rippled (**RP**)	Run	
	Upwelling (**UP**)	Boil	

	Smooth (**SM**) No Perceptible Flow (**NP**) No Flow (**DR**)	Glide Pool, Ponded Reach, Deadwater –	
Riparian Land Use (5 m and 50 m)*	Broadleaf/Mixed Woodland (**BL**) Broadleaf/Mixed Plantation (**BP**) Coniferous Woodland (**CW**) Coniferous Plantation (**CP**) Scrub and Shrubs (**SH**) Orchard (**OR**) Wetland (**WL**) Moorland/Heath (**MH**) Artificial Open Water (**AW**) Natural Open Water (**OW**) Rough Pasture (**RP**) Improved Pasture (**IP**) Tall Herb/Rank Vegetation (**TH**) Rock, Scree, Sand Dunes (**RD**) Suburban/Urban (**SU**) Tilled Land (**TL**) Irrigated Land (**IL**) Parklands or Gardens (**PG**)	Mixed Woodland – – Coniferous Plantation Scrub – Wetland Moor/Heath – – Rough Pasture Improved Pasture – Rock and Scree Urban (Commercial/Industrial, Residential) – – Amenity Grassland?	G_Reach Aerial Photographs
Banktop and Bankface Vegetation Structure	Bare (**B**) Uniform (**U**; Predominantly 1 Type) Simple (**S**; 2 or 3 Types) Complex (**C**; 4 or More Types)	Percentage Cover Recorded for Whole Reach	G_Reach Aerial Photographs
Macrophytes	Bryophytes	Percentage Bryophyte Cover in the Whole Reach	G_Reach
	Emergent Broad-Leaved Herbs Emergent Reeds Floating-Leaved Amphibious Submerged Broad-Leaved Submerged Linear-Leaved Submerged Fine-Leaved Filamentous Algae	Percentage Macrophyte Cover in the Whole Reach	
*Tree Features**	Presence and Extent (None, Occasional,	_	G_Reach

	Continuous) Shading of Channel Overhanging Boughs Exposed Bankside Roots Underwater Tree Roots Fallen Trees Large Woody Debris	 – – – – Coarse Woody Debris	Coarse Woody Debris
Counts of Riffles, Pools and Bars	Recorded within 500m section	Recorded within the whole fluvial audit unit	G_Reach
Channel Dimensions	Banktop Height (Both) Bankfull Width Water Width Water Depth	Bank Height Overtop Width Water Width –	G_Reach
Alien Species Bankface and Banktop	Giant Hogweed Japanese Knotweed Himalayan Balsam	Alien species are occasionally detailed in individual tributary reports. Check for these.	CCW Report
Natural Bank Profiles	Vertical Undercut Vertical with Toe Steep Gentle Composite Natural Berm	– – – – – –	
*Artificial Bank Profiles**	Resectioned Reinforced (Whole) Reinforced (Top Only) Reinforced (Toe Only) Artifical Two-Stage Poached Bank Embankment Set-Back Embankment	– – – – – – – –	

Appendix 2: Potential consequences of hydromorphological modifications for SAC target species.

Modification	Major impacts	SAC Target Species	Potential detrimental consequences
Bank re-profiling and re-sectioning	Width or depth change and change in bed surface composition, leading to: • Larger dominant substratum type • Reduced prevalence of silt/sand substrata, increased prevalence of gravel/pebble/cobble • Reduced coverage of fines/silt • Reduced prevalence of bars • Increased prevalence of fine sediments downstream • Increased prevalence of bars downstream • Narrowing of channel downstream	Bullhead	• Downstream increases in fine sediments may inhibit spawning
		Allis shad and Twaite shad	• Downstream increases in fine sediments may inhibit spawning • Downstream channel narrowing may decrease habitat suitability
		River lamprey, Brook lamprey and Sea lamprey	• Downstream increases in fine sediments may inhibit spawning • Within reach reductions of fine sediments may reduce available larval habitat
		Atlantic salmon	• Downstream increases in fine sediments may inhibit spawning
		Otter	• Heavily modified channel may provide no cover or limited holt habitat
		White-clawed crayfish	• Reductions in available marginal habitat
Floodplain embankments parallel to river	Increased specific stream power, coarsening of riverbed and reduction in alluvial bars, leading to: • Larger dominant substratum type • Reduced prevalence of silt/sand substrata, increased prevalence of gravel/pebble/cobble • Reduced coverage of fines/silt • Reduced prevalence of bars • Increased prevalence/extent of unstable banks • Increased probabilities of fine sediments	Bullhead	• Downstream increases in fine sediments may inhibit spawning
		Allis shad and Twaite shad	• Downstream increases in fine sediments may inhibit spawning • Increased stream power may impede upstream migration
		River lamprey, Brook lamprey and Sea lamprey	• Within reach reductions of fine sediments may reduce available larval habitat

	downstream • Increased prevalence of bars downstream	Atlantic salmon	• Downstream increases in fine sediments may inhibit spawning
		Otter	• Heavily modified channel may provide no cover or limited holt habitat
		White-clawed crayfish	• Reductions in available marginal habitat
Floodplain embankments perpendicular to river	• Increased flood risk upstream • Widening upstream, narrowing downstream	Bullhead	• –
		Allis shad and Twaite shad	• Downstream channel narrowing may decrease habitat suitability
		River lamprey, Brook lamprey and Sea lamprey	• –
		Atlantic salmon	• –
		Otter	• Heavily modified channel may provide no cover or limited holt habitat
		White-clawed crayfish	• –
Bank defences and reinforcement	Local channel deepening, increased specific stream power and increased bank erosion in reaches immediately upstream or downstream, leading to: • Larger dominant substratum type • Reduced probability of silt and/or sand substrata, increased probability of gravel/pebble/cobble • Reduced coverage of fines/silt • Reduced prevalence of bars • Increased prevalence/extent of unstable banks downstream • Reduced prevalence of fine sediments/increased prevalence of coarse	Bullhead	• –
		Allis shad and Twaite shad	• Increased stream power may impede upstream migration
		River lamprey, Brook lamprey and Sea lamprey	• Within reach reductions of fine sediments may reduce available larval habitat
		Atlantic salmon	• –
		Otter	• Heavily modified channel may provide no cover or limited holt habitat

	sediments downstream • Reduced prevalence of bars downstream • Widening of channel downstream • Increased probability/extent of unstable banks upstream	White-clawed crayfish	• Reductions in available marginal habitat
Poaching (livestock, footpaths/access points)	Local loss of natural bed forms, local coarsening of the riverbed, fining of the riverbed downstream of impacted reach and river bank instability, leading to: • Possible larger dominant substratum type (locally) • Increased prevalence of silt/sand substrata, • Increased coverage of fines/silt • Increased prevalence/extent of bars • Increased prevalence of fine sediments/increased prevalence of coarse sediments downstream • Increased prevalence/extent of bars downstream	Bullhead	• Increases in fine sediments within reach may inhibit spawning
		Allis shad and Twaite shad	• Increases in fine sediments within reach may inhibit spawning
		River lamprey, Brook lamprey and Sea lamprey	• Increases in fine sediments within reach may inhibit spawning
		Atlantic salmon	• Increases in fine sediments within reach may inhibit spawning
		Otter	• Heavily modified channel may provide no cover or limited holt habitat
		White-clawed crayfish	• Reductions in available marginal habitat
Bridges	Local channel deepening, increased specific stream power, local channel coarsening, downstream aggradation, bar growth and bank erosion, upstream incision and upstream flooding, leading to: • Local increase in prevalence of larger substrata • Local increase in prevalence of bars and unstable banks	Bullhead	• –
		Allis shad and Twaite shad	• Increased stream power may impede upstream migration
		River lamprey, Brook lamprey and Sea lamprey	• –
		Atlantic salmon	• –
		Otter	• Heavily modified channel may provide no cover or limited holt habitat
		White-clawed crayfish	• Reductions in available marginal habitat
Outfalls and intakes	Bed and bank erosion downstream of outfalls,	Bullhead	• Increases in fine sediments downstream of

with reinforcement	coarsening of the bed downstream of outfalls and aggradation and fining downstream of intakes.		intakes may inhibit spawning
		Allis shad and Twaite shad	• Increases in fine sediments downstream of intakes may inhibit spawning
		River lamprey, Brook lamprey and Sea lamprey	• Increases in fine sediments downstream of intakes may inhibit spawning
		Atlantic salmon	• Increases in fine sediments downstream of intakes may inhibit spawning
		Otter	• –
		White-clawed crayfish	• –
Fords	Local loss of natural bed forms, local coarsening of the riverbed and fining of the riverbed downstream of impacted reach, leading to: • Local increase in prevalence of largest substrata • Increased prevalence of silt/sand substrata, • Increased coverage of fines/silt • Increased prevalence/extent of bars • Increased prevalence of fine sediment/bars downstream	Bullhead	• Increases in fine sediments within reach may inhibit spawning
		Allis shad and Twaite shad	• Increases in fine sediments within reach may inhibit spawning
		River lamprey, Brook lamprey and Sea lamprey	• Increases in fine sediments within reach may inhibit spawning
		Atlantic salmon	• Increases in fine sediments within reach may inhibit spawning
		Otter	• –
		White-clawed crayfish	• –
Gravel extraction	Local channel deepening, potential coarsening at location and upstream and channel widening upstream, leading to: • Larger dominant substratum type • Reduced prevalence of silt/sand substrata, increased prevalence of gravel/pebble/cobble • Reduced prevalence of bars • Downstream channel incision and narrowing due to reduced sediment supplies from upstream	Bullhead	• –
		Allis shad and Twaite shad	• Downstream channel narrowing may decrease habitat suitability
		River lamprey, Brook lamprey and Sea lamprey	• Within reach reductions of fine sediments may reduce available larval habitat

	• Larger dominant substratum type upstream • Reduced prevalence of silt/sand substrata, increased prevalence of gravel/pebble/cobble upstream	Atlantic salmon	• –
		Otter	• –
		White-clawed crayfish	• Downstream reductions in available marginal habitat
Groynes and croys	Local channel narrowing and coarsening of thalweg, downstream widening and fining of bed, leading to: • Local increase in prevalence of largest substrata • Marginal silt deposits • Increased prevalence/coverage of fine sediments downstream	Bullhead	• Increases in fine sediments downstream may inhibit spawning
		Allis shad and Twaite shad	• Downstream channel narrowing may decrease habitat suitability
		River lamprey, Brook lamprey and Sea lamprey	• Increases in fine sediments downstream may inhibit spawning
		Atlantic salmon	• Increases in fine sediments downstream may inhibit spawning
		Otter	•
		White-clawed crayfish	•
Weirs	Upstream channel widening and fining, downstream channel narrowing and coarsening and reduction in alluvial bars downstream, leading to: • Increased prevalence/extent of impounded/no-perceptible flow • Increased prevalence/coverage of fine sediments and marginal silt deposits • Increased prevalence/coverage of coarse sediments downstream • Reduced prevalence of fine sediments downstream • Reduced prevalence of bars downstream	Bullhead	• May limit upstream-downstream movements of individuals, resulting isolated and/or fragmented populations • Increases in fine sediments within reach and upstream may inhibit spawning
		Allis shad and Twaite shad	• Downstream channel narrowing may decrease habitat suitability • May limit upstream-downstream movements of individuals, resulting isolated and/or fragmented populations – not easy to offset, as shad species do not respond well to fish passes or other areas of confined turbulent flow • Increases in fine sediments within reach and upstream may inhibit spawning

	• Increased prevalence/coverage of fine sediments and marginal silt deposits upstream	River lamprey, Brook lamprey and Sea lamprey	• May limit upstream-downstream movements of individuals, resulting isolated and/or fragmented populations • Increases in fine sediments within reach and upstream may inhibit spawning
		Atlantic salmon	• Very large weirs (> 3m high) may limit upstream-downstream movements of individuals and limiting access to spawning habitat • Increases in fine sediments within reach and upstream may inhibit spawning
		Otter	• May impede upstream-downstream movement, forcing individuals to leave the water and travel terrestrially, potentially putting them in contact with roads/urban areas.
		White-clawed crayfish	• May limit upstream-downstream movements of individuals, resulting isolated and/or fragmented populations • May favour rival American signal crayfish populations, which are better able to traverse in-stream barriers
Trash screens	Local channel coarsening leading to: • Local increase in prevalence of larger substrata • Local increase in prevalence of bars and unstable banks • Reduced prevalence of coarse wood downstream	Bullhead	• Reduced woody debris availability downstream may decrease habitat suitability
		Allis shad and Twaite shad	• –
		River lamprey, Brook lamprey and Sea lamprey	• –
		Atlantic salmon	• Reduced woody debris availability downstream may decrease habitat suitability
		Otter	• Reduced woody debris availability downstream may decrease habitat suitability
		White-clawed crayfish	• Reductions in available marginal habitat

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