Natural England Joint Publication JP016

Developing a coherent framework for assessing priority freshwater habitats in England

First published 11 April 2018

www.gov.uk/natural-england

Authors

Chris Mainstone (NE), Ruth Hall (NE), Francois Edwards (CEH), , Pete Scarlett (CEH), Laurence Carvalho (CEH), Gearoid Webb (CEH), Philip Taylor (CEH) and Cedric Laize (CEH)

Acknowledgements

The authors would like to thank other members of the project steering group for their contributions to discussions: Helen Michell (Natural England) and Dominic Coath (Environment Agency). Thanks are also due to the Rivers and Lakes stakeholder groups who provide feedback and support for work on priority river and lake habitats – specific feedback on this project was provided by Jon Bass (retired from the Freshwater Biological Association), Patrick Armitage (Fellow, Freshwater Biological Association), Jo-Anne Pitt (Environment Agency), Judy England (Environment Agency), Carl Sayer (UCL), Rick Battarbee (UCL), Penny Williams (Freshwater Habitats Trust), Jeremy Biggs (Freshwater Habitats Trust), Martyn Kelly (Bowburn Consultants) and Lee Brown (Leeds University). The report also benefited from feedback from Jess Durkota (Environment Agency).

Further information

Natural England evidence can be downloaded from our **Access to Evidence Catalogue**. For more information about Natural England and our work see **Gov.UK**. For any queries contact the Natural England Enquiry Service on 0300 060 3900 or e-mail **enquiries@naturalengland.org.uk**

ISBN 978-1-78354-479-0

Executive summary

This report summarises work undertaken by Natural England and the Centre for Ecology and Hydrology, in collaboration with the Environment Agency, to develop proposals for a framework to monitor and assess the status of priority freshwater habitats in England. It forms part of a series of actions arising from Biodiversity 2020 to refine the strategy for conserving priority freshwater habitats.

The work takes as its foundation the concept of natural ecosystem function (described in detail in the 'freshwater and wetland habitat narrative', Mainstone *et al*. 2016), which underpins the health of all freshwater habitats whether they are specially protected sites, priority freshwater habitats, waterbodies designated under the EU Water Framework Directive, or any combination of these. The report seeks to provide a framework for assessing key aspects of natural ecosystem function, harmonising with recent work to map priority freshwater habitats and bring greater clarity to the conservation strategy for the freshwater SSSI series.

Freshwater habitats have benefited from an extensive monitoring and assessment programme under the Water Framework Directive. Further relevant data are provided by Countryside Survey and other programmes. The project has developed a framework for making best use of available data, only proposing additional elements of data collection and processing where needed to provide a coherent picture of the naturalness of ecosystem function across the freshwater habitat resource.

The work covers rivers and streams, lakes and ponds and proposes a series of attributes for each. These attributes seek to characterise the main elements of natural ecosystem function, including hydrological, physical, chemical and biological integrity. A holistic approach is proposed involving the whole of the habitat resource, not just those sites on the priority habitat maps produced for England. This is because sites that will not meet the criteria for inclusion on freshwater priority habitat maps in the future can still contribute to the achievement of priority habitat objectives through various degrees of restoration of natural habitat function.

For rivers and lakes, the proposed reporting framework divides the habitat resource into the following components:

1) sites on the priority habitat map;

2) sites that are not on that map but are prioritised for some level of restoration; and

3) all remaining sites.

In addition, small water bodies (headwater streams and smaller lakes) are considered separately to larger water bodies, to allow explicit reporting on these neglected habitats and recognise the different monitoring and data circumstances surrounding them. The extent to which it has been possible to illustrate this framework with real data has varied.

The proposed sampling design is mixed, reflecting existing monitoring programmes on which the framework is based. Elements relating to small waterbodies necessarily use representative sampling, and this has important consequences for how the data can be used in biodiversity reporting. Data are categorised according to a five-class classification, allowing improvements in habitat condition to be followed through time, building on the ecological status classification used for the Water Framework Directive.

Overall, the proposals are considered to be an important step forward in building greater understanding of natural ecosystem function into freshwater monitoring and assessment.

This in turn should promote better consideration of natural processes in management decision-making and provide the priority habitat driver with an important role in protecting and restoring freshwater habitats.

The proposals are largely based on exploiting data from existing monitoring activities. But there is a need for additional monitoring in some parts of the habitat resource to generate a sufficiently representative picture of condition. The need for additional data is greatest for headwaters, smaller lakes and ponds. This is challenging, given the downward pressure on monitoring budgets which means that even the continuation of existing monitoring effort cannot be guaranteed. However, the proposed framework provides a supplementary use for existing data, adding value to them. Recommendations are made for rationalising existing monitoring programmes in a way that provides a more coherent and reliable basis for priority habitat assessment in the future. There are also considerable similarities between parts of the proposed framework and the river basin characterisation (RBC) exercise undertaken by the Environment Agency on a 6-yearly basis. Some of the proposals in this report could be harmonised with RBC processes to maximise cost-effectiveness.

Much of the required conceptual thinking has been done in this project, and illustrated with sample data where these are available, Further work is needed across all habitat types to refine the data processing procedures, but it is suggested that this is done if and when the framework is operationalised and England-level data sets are brought together for analysis.

There is considerable potential for citizen science to make an increasingly important contribution to the proposed framework, particularly in relation to small water bodies where the largest data gaps are evident. This will require further consideration of how different data types can come together in a unified assessment, and what level of data reliability is needed. Remote sensing also has potential for monitoring some condition attributes, particularly for extrapolating field data from representative sites to the wider habitat resource.

The work should be seen as a contribution to the wider reviews of environmental monitoring in progress in England, which are giving particular consideration to the role of innovative monitoring approaches. The report provides a basis for testing the extent to which such technologies can replace existing monitoring approaches in the assessment of priority freshwater habitat condition.

These proposals are independent from the condition assessment of protected freshwater sites (domestic Sites of Specialist Scientific Interest and Special Areas of Conservation designated under the EU Habitats Directive). These sites are governed by UK Common Standards that are designed to provide a level of resolution of impacts that is appropriate to protected site legislation. That said, the principles of the assessment are the same and there is potential for innovative elements of the priority habitat assessment framework to inform future refinements of UK Common Standards.

Contents

List of Figures

List of Tables

List of boxes

Appendices

1. Introduction

Priority habitats are habitats that were identified as being the most threatened and requiring conservation action under the UK Biodiversity Action Plan, the UK's response to commitments under the International Convention on Biological Diversity. The UK lists of priority habitats have been used to draw up country-level lists, in England under Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006.

The UK priority habitat list (JNCC 2011) includes one priority habitat for rivers and five for standing waters, all of which are included as listed priority habitats in England under the NERC Act. The priority habitat definition for rivers essentially covers the full range of natural habitat variation, including the following specifically named river types: chalk rivers, headwater streams, active shingle rivers and Habitats Directive Annex I rivers. Priority habitat types for standing waters are: 1) oligotrophic and dystrophic lakes, 2) mesotrophic lakes, 3) eutrophic standing waters, 4) aquifer-fed naturally fluctuating waterbodies, and 5) ponds.

There is a requirement to assess the condition of priority freshwater habitats as part of reporting under Defra's Biodiversity 2020 strategy (Defra 2011). There is a related requirement to assess the condition of European protected habitats under Article 17 of the EC Habitats Directive. The work reported here was aimed at generating proposals for a coherent assessment framework for England covering rivers and streams, lakes and ponds. It forms part of refinement work identified for priority freshwater habitats within the Biodiversity 2020 process (see Section 3).

Dynamic environmental processes play a fundamental role in freshwater habitats (Mainstone *et al.* 2016), and biological assemblages are variable and unpredictable as a result. There is an existing major national monitoring programme associated with the freshwater environment, driven by the EC Water Framework Directive (WFD). The approach to priority freshwater habitat assessment has to both recognise these technical monitoring challenges and the need for integration with WFD monitoring, assessment and reporting.

Work has recently been undertaken to map priority river and lake habitats in England, based on a unifying conceptual framework for freshwater habitat conservation that focuses on natural habitat function (Mainstone *et al*. 2016). The mapping process seeks to identify the most natural remaining examples of river and lake habitat, as the best and most sustainable expressions of freshwater habitats and their characteristic biological assemblages.

Preliminary national analyses of data have resulted in new river and lake priority habitat maps (PHMs, Mainstone *et al*. 2014, Hall *et al.* 2014), which are being subject to a process of refinement through the use of more site-specific information and local knowledge (e.g. Mainstone *et al.* 2015). In addition to the priority habitat maps themselves, maps of restoration priorities have also been produced to help direct restoration activity in the wider habitat resource (see the mapping reports above).

Indicators of habitat condition are needed that characterise natural habitat function across key components of habitat integrity (hydrological, physical, chemical and biological). Initial thinking on this was provided in Mainstone *et al*. (2016) and has been developed further in this project. Such indicators have a great deal in common with the principles of the Water Framework Directive, where assessments of ecological status are based on the magnitude of deviations from reference or minimally impacted conditions. However, WFD monitoring, assessment and reporting is designed to meet the legal requirements of the Directive (including the detail in its technical annexes) and is limited in its characterisation of natural habitat function as a result. In particular:

- critical environmental (abiotic) indicators of natural habitat function (such as the naturalness of the hydrological regime and impacts on physical habitat condition) are only included in WFD assessment and reporting at high ecological status, which applies to very few waterbodies in England;

- headwater streams (with catchments of less than $10km^2$), smaller lakes (generally less than 50 hectares if not in a SAC/SSSI or used for drinking water) and ponds are generally not assessed under the WFD, but together they constitute a large proportion of the habitat resource (headwater streams have been estimated to constitute 70% of total river length in Great Britain - Smith and Lyle 1979);

- marginal habitats (riparian corridors, lake hydroseres and other ephemeral habitats such as intermittent streams and exposed riverine sediments) are not assessed;

- WFD biological metrics are limited in various respects

    - they only deal with certain fully aquatic components of freshwater habitats (fish, macrophytes, benthic macroinvertebrates, phytoplankton and benthic diatoms);

    - there are serious challenges associated with adequately characterising reference communities;

    - metrics do not measure changes in community composition from putative unimpacted conditions, but rather changes in indices that are ***based on*** community composition (for invertebrates, not at species-level taxonomic resolution);

    - most of the biological metrics used in WFD reporting are geared towards particular anthropogenic pressures, all relating to water quality issues (eutrophication, acidification and organic pollution), leaving problems with the detection of other impacts on natural habitat function including physical habitat condition, hydrological modification and non-native species;

    - the monitoring strategy associated with these biological metrics further limits their ability to characterise impacts on natural habitat function and characteristic biological communities, particularly in relation to impacts on physical and hydrological integrity and habitat extent.

Ancillary data collected to support WFD implementation fill at least some of these gaps, or have the potential to do so. An approach to priority freshwater habitat assessment is needed that makes full use of WFD monitoring and assessment and draws in additional elements and resources that add value in characterising natural habitat function. Whilst this approach is already in place in the protected site network (through the UK Common Standards Monitoring, CSM, framework for freshwater habitats (JNCC 2016), no parallel assessment framework exists in the wider habitat resource. Constructed in the right way, a priority freshwater habitat assessment framework can provide the basis for demonstrating that the

WFD is being implemented in the spirit of the Directive, protecting and restoring natural ecosystem function as far as is reasonable, rather than simply to achieve target values of particular biological indicators.

With limited resources available for monitoring, best use needs to be made of information that is already collected for other purposes, and of representative sampling that can be used to make inferences about the state of the wider habitat resource. Various data sources are of potential value, such as Countryside Survey, the Upland Waters Monitoring Network, remote sensing programmes and citizen science. All potential data sources need to be considered in the context of a monitoring rationale that allows unbiased assessment of the habitat resource.

The development of a coherent monitoring and assessment framework for freshwater habitats not only addresses the needs of priority freshwater habitats, but would also contribute greatly to the reporting of favourable conservation status of freshwater habitats and species listed under the EC Habitats Directive.

Importantly, this report does not seek to justify the concept of natural ecosystem function as a basis for a monitoring and assessment framework for priority freshwater habitat assessment. This justification can be found in Mainstone *et al.* (2016), and an understanding of that document is necessary to appreciate the ecological rationale for the approach adopted here.

2. Objectives

The overall aim of the project was to provide proposals for a workable monitoring and assessment framework for priority freshwater habitats, encompassing rivers, lakes and ponds. Detailed objectives were:

1. to evaluate possible high-level monitoring strategies for generating data on the habitat resource (considering changes in condition within and outside of priority habitat maps) and propose the most suitable approach;
2. to characterise the usefulness of current monitoring programmes in relation to assessing priority river, lake and pond habitat condition;
3. to confirm/identify condition attributes of potential use in adding value to WFD assessment/reporting in relation to priority habitat condition;
4. to evaluate available datasets and existing monitoring programmes for providing an assessment of these attributes, and propose any necessary additional activity;
5. to illustrate potential reporting of priority habitat condition using real data, as far as existing data allow.

3. Priority habitat assessment and Biodiversity 2020 objectives

The monitoring and assessment framework needs to be capable of reporting results against Biodiversity 2020 targets and similarly framed targets beyond Biodiversity 2020. Box 1 outlines the key Biodiversity 2020 targets of relevance to priority habitats; the main ones relate to achieving favourable condition of mapped priority habitat (part of Outcome 1A), restoring or re-creating areas of priority habitat (Outcome 1B), and restoring degraded ecosystems (Outcome1D).

At the outset of Biodiversity 2020, interim arrangements were agreed for targets relating to priority freshwater habitats, based on broad linkages between ecological status objectives under the Water Framework Directive and condition status of priority habitat (TBG 2012). Under these arrangements, achieving WFD good ecological status on a WFD water body is seen as *progress towards* favourable condition of priority freshwater habitat; whilst WFD high ecological status is broadly seen as equivalent to favourable condition of the priority habitat (recognising that the extent to which this condition can be approached will depend on site-specific circumstances including socioeconomic constraints). At that time work was identified to refine the arrangements for priority freshwater habitats, by mapping priority river and lake habitats and developing a fit-for-purpose assessment framework.

Box 1 Summary of relevant Biodiversity 2020 targets.

Outcome 1A

This is divided into 3 key components:

- ***SSSIs*** **–** 50% in favourable condition by 2020
- ***SSSIs -*** 95% in favourable or unfavourable recovering condition by 2020
- ***Priority habitat*** – 90% of area in favourable or unfavourable recovering condition by 2020

These three components are separately reported. The SSSI target is reported through assessment of SSSI units using Natural England’s SSSI reporting database. The priority habitat (PH) target is reported through a combination of SSSI data and other available information on non-SSSI area.

Outcome 1B

An increase in the overall extent of priority habitats by at least 200,000 ha by 2020. This has elements that relate to 1) restoring degraded non-priority habitat and 2) re-creating new habitat.

Outcomes 1C and 1D

These are also relevant to freshwater systems:

- **1C** – At least 17% of land and inland water safeguarded by joined up approaches to biodiversity and ecosystem services.
- **1D** – At least 15% of degraded ecosystems restored as a contribution to climate change mitigation and adaptation.

Since that time maps of priority river and lake habitat have been developed (see Section 1). Because these maps are intended to encapsulate only the most naturally functioning remaining examples of freshwater habitats, much of the work of restoring the freshwater habitat resource falls under Outcomes 1B and 1D. This is a different situation to most terrestrial priority habitats, which have been dramatically reduced in extent by agricultural intensification. Given the limited remaining resource of many priority terrestrial habitats, most extant examples (even quite degraded ones) tend to be included on PHMs. In contrast, the majority of the natural freshwater habitat resource remains as freshwater habitat, albeit impacted in various ways and to varying degrees.

Another difference from terrestrial priority habitats is that many SSSIs notified for freshwater habitat are not captured by the new priority habitat maps. This is because SSSIs are notified to capture representative examples of the full natural variation in freshwater habitats, and due to widespread modifications to the habitat resource this often requires that significantly modified examples of parts of that habitat variation (not suitable for inclusion on the PHMs) are selected for notification.

The consequence of this situation is that Outcomes 1B and 1D are very important in capturing the full extent of relevant restoration work on the freshwater habitat resource, recognising that much of that work under the WFD will only generate limited improvements in habitat condition, constrained by socioeconomic activity in catchments. This leads to the following approach to Biodiversity 2020 outcomes for freshwater habitats:

- **1A: SSSI targets** – Covers all SSSIs notified for their freshwater habitat, whether on the priority habitat maps or not;
- **1A: Priority habitat condition target** – Covers all sites on the PHMs whether SSSI or not;
- **1B: Priority habitat restoration** – Covers non-SSSIs that are on the river and lake restoration priorities maps;
- **1C: Ecosystem services** - Can include any site from 1A, B or D where non-biodiversity ecosystem services are restored as a result of action under 1A, B or D;
- **1D: Restoration of degraded ecosystems** - Can include any other sites in the wider habitat resource where significant measures are being taken to restore natural processes and natural habitat function;

Note that Outcome 1C is not directly relevant to the priority habitat assessment framework, but is aimed at identifying added value of Biodiversity 2020 in sustaining and improving ecosystem services beyond biodiversity outcomes.

4. Monitoring and assessment rationale and framework

The approach to Biodiversity 2020 targets outlined in the last section, coupled with the focus of WFD monitoring and assessment on larger waterbodies, suggests a high-level structure for the assessment framework as illustrated in Table 1. Within this broad framework, additional scope will be required to report on individual habitat types included in UK priority habitat definitions (see Section 1).

Within this basic structure, attributes for natural habitat function need to be provided for running and standing waters, drawing on existing monitoring activities and, where necessary, potential enhanced activities.

Table 4.1 Basic assessment structure for priority freshwater habitats.

Waterbody types	Sites on the PH map	Sites on the restoration priorities map	Sites in the wider habitat resource
Small waterbodies (i.e. WFD data generally not available)	Habitat resource zone 1a	Habitat resource zone 2a	Habitat resource zone 3a
Larger waterbodies (i.e. WFD data available)	Habitat resource zone 1b	Habitat resource zone 2b	Habitat resource zone 3b

Working within this basic structure, a 5-class classification of habitat condition is deemed sensible to allow different levels of natural function to be characterised and help show progressive improvement and deterioration. Where WFD assessment is undertaken, this is conceptually compatible with the 5-class classification of ecological status, requiring only that consideration is made of how additional attributes and targets for priority habitat condition best fit with the WFD classification to provide an 'added value' assessment. At WFD ecological status classes of less than good (i.e. moderate, poor and bad), WFD class boundaries can be used directly because there is no need for a particularly refined assessment at these degraded levels of natural function. At high ecological status, a reasonable range of environmental (abiotic) indicators of natural habitat function are used, and there is less need to consider added-value elements. The classification of good ecological status is where greatest attention is needed to provide a full assessment of habitat condition based on natural habitat function.

Figure 4.1 attempts to illustrate how WFD assessment, CSM assessment of protected sites, and the freshwater priority habitat assessment framework need to come together to deliver the information required for key reporting processes. The term 'WFD plus' is used to describe the added-value assessment needed where WFD monitoring and assessment is undertaken, whereas in small waterbodies not subject to WFD monitoring an approach is needed that is independent of WFD monitoring data.

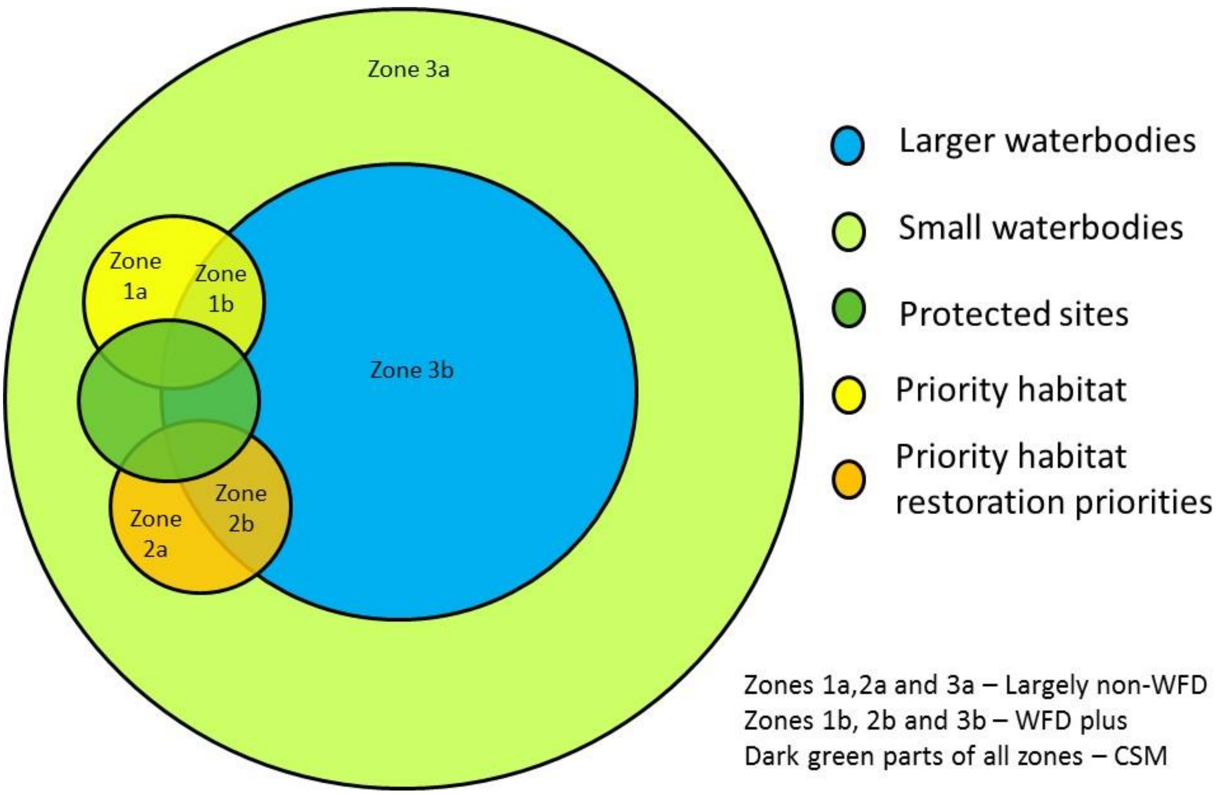

Figure 4.1 Relationship between components (zones) of the habitat resource and key monitoring regimes within the envisaged priority habitat assessment framework.

Temporal considerations are as important as these spatial considerations. The monitoring and assessment framework needs to be able to provide regular assessments of changes in habitat condition. Pragmatism is needed to avoid important datasets being excluded from the framework - repeat assessments on the scale of 5 years allows 3 assessments within a typical 10 year lifespan of biodiversity targets. This would allow a baseline assessment, an interim assessment and a final assessment within a 10-year period. WFD monitoring operates at a much finer temporal resolution than this, allowing annual reporting if necessary (although for many indicators only a subset of sites is monitored in any one year). Other monitoring initiatives, such as Countryside Survey, are only undertaken in one year every 7 to 10 years, which limits their current value for a more coherent priority habitat assessment framework.

There are also important considerations relating to sampling strategy and the management of sampling bias. To a large extent the framework being developed has to work with the sampling strategies adopted within the various monitoring activities it will draw on. These vary from risk-based strategies (used in WFD operational monitoring), fixed-site representative sampling (such as that used in Countryside Survey and WFD surveillance monitoring), and stratified random sampling (such as that used in national River Habitat Survey baseline assessments). A hybrid strategy is inevitable, and control over design is only possible on any proposals for additional monitoring beyond existing activities. Sub-sampling of available datasets can potentially be used to reduce any significant sampling bias in data, for instance the removal of any data derived from sampling targeted at sites with known impacts that may not be representative of the condition of the wider habitat resource.

A major consideration is the level of site-specificity of the data and any resulting assessment that can be made from it. This issue has implications for how directly assessments feed into Biodiversity 2020 targets, which are traditionally framed around identifying and reporting on the condition of individual sites. Representative sampling, where it is used, implies that the condition of individual sites is not known (except for those sites that are monitored as representative examples).This reduces certainty over whether biodiversity targets are met and in the relationship between applied measures and site-level biodiversity outcomes. Representative sampling can show the approximate spread of different components of the habitat resource across the 5-class classification of habitat condition, by simply extrapolating results from monitored sites to the habitat resource. Using such data to help assess the achievement of specific Biodiversity programme targets is a different matter, however, and requires recognition of the limitations of representative sampling for this purpose.

The processes for spatially aggregating scores for individual attributes are an important consideration. Whilst flexibility in the framing of different attributes and condition targets is good in some senses, when assessments need to be aggregated it can generate incompatibility problems. An attribute that is subject to a 5-class condition classification at the monitoring site level is not obviously compatible with an attribute where data are averaged across monitoring sites within a habitat resource component (to generate a single condition value for the whole resource component). Aggregation issues need to be considered at the same time that individual attributes are framed to avoid difficulties with the final assessment.

A strongly related issue, which also affects the framing of assessments and targets, concerns addressing problems with reference conditions. This is a particular problem with biological data (where few extant examples of reference communities exist in England) but also applies to some aspects of environmental data as well. Upscaling of assessments and associated condition targets from site-scale to habitat resource-scale reduces the immediacy of this problem, allowing high uncertainty in site-level reference conditions to be dissipated in broader uncertainties about the levels of improvement in habitat condition that we should be aiming to achieve in the habitat resource. Whilst this does not resolve the problem of reference conditions, it does at least provide a means by which the issue can be pragmatically managed. The resulting information, however, is something that might be regarded more as a broad-scale indicator rather than a condition target *per se*.

5. The case for monitoring small waterbodies

Small standing waters and (to a large degree) headwater streams are not normally monitored under the Water Framework because of their small size, the sheer numbers of sites involved and the lack of specific requirement under the WFD to do so. This leaves a major information gap in our understanding of the status of the freshwater habitat resource. Small waterbodies are a critical element of our freshwater ecosystems and their assessment needs to be integral to priority habitat condition assessment.

5.1 Headwater streams

Headwater streams (identified in the UK BAP definition as streams <2.5km from source) form an ecologically critical part of the river network. They typically account for most of the total river length in catchments. They occur across a wide range of geological, biogeographic and riparian settings, so exhibit a wide range of conditions which dictates the nature of their biodiversity. This includes both perennially flowing sections and intermittently flowing sections of varying flow durations, within a complex continuum of longitudinal change in wetland/aquatic character (e.g. Stubbington *et al*. 2017, Mainstone *et al*, 1999, 2016). They route precipitation to downstream water bodies, supporting these larger ecosystems as well as key societal services such as potable water, water for industry and agriculture. The biota of headwaters makes a significant contribution to biodiversity at a national level, with many plants and animals geographically restricted to the characteristic hydrological and physicochemical conditions of these habitats - other species use them seasonally or intermittently and this contributes to their populations in downstream sections.

Headwater streams are strongly connected with the adjacent landscape and therefore vulnerable to non-point and small point sources of pollution, groundwater and direct abstraction and physical habitat loss/modification. Their low thermal inertia makes them particularly vulnerable to climate change, and the low buffering capacity of acidic streams (in both upland and lowland areas) makes them highly susceptible to acid deposition from atmospheric pollution. Conversely, headwaters are typically less impacted by non-native species invasions because of constraints on dispersal, so can provide important refugia for native species. Some upland headwaters are also naturally free of fish and provide rare habitats for invertebrates where predation pressure is low. More generally, headwater streams are recognised as refugia for species that have been extirpated downstream.

Agricultural practices such as livestock grazing and tilling can lead to soil erosion and run-off of fine sediments, nutrients and pesticides into headwaters. This has direct effects on the biota and habitat integrity, for example causing a replacement of sensitive macroinvertebrate fauna by pollution-tolerant types. Cumulative impacts across headwaters can be reflected further down the river network, decreasing the water quality of larger waterbodies, with clear ecological consequence for their biota, and for ecosystem services such as the provision of clean water for human consumption, fish farming and recreation. However, in many cases impacts are not so noticeable downstream, and they can go largely undetected because of a general monitoring focus on larger rivers. For instance:

- physical habitat degradation in headwater streams is often not detectable in the physical habitat condition of downstream river sections;

- water abstracted from headwater streams is often returned to the river network further downstream; and
- acidification impacts apparent in streams are often buffered out downstream by the mixed geologies of the larger catchments in which they sit.

Much of the available information on headwaters comes from a project undertaken in the early 1990's by the Institute of Freshwater Ecology (predecessor of the CEH, Furse *et al*. 1991). The project estimated that headwaters accounted for 70% of the river network, but only 8% of the routine water quality monitoring network at that time. It assessed their biodiversity and condition based on macroinvertebrate communities at over 800 sites. The project revealed that headwaters had characteristic assemblages, with some species unique to these systems and some of conservation importance. The project also revealed impacts of agriculture on the ecological condition of headwaters, as well as a lack of streamside buffers, so that only 26% were considered in good condition based on macroinvertebrates only. Moreover, the major conclusions of the project were that there was a pressing need for better monitoring of headwaters, better baselines for headwaters, more species-level macroinvertebrate information and better habitat information based on RHS (this technique emerged during the lifetime of the project).

5.2 Small standing waters

In England, monitoring of standing waters under the WFD is focused on water bodies with an area greater than 50 ha (0.5 km^2) unless they are covered by other legislation (e.g. they are SSSI) or are drinking waters. No water body <5 ha is monitored (see Section 6.2). This leaves the vast majority of the standing water habitat resource (small lakes and ponds) unassessed by WFD monitoring. For the purpose of UK BAP priority habitat classification, lakes are generally defined as water bodies greater than 2 ha in area (i.e. 0.02 km^2), whilst water bodies smaller than this are considered ponds. According to the lake inventory (Bennion *et al*. 2001) there are 2956 lakes (i.e. larger than 2 ha) in England, of which 96% are less than 50 ha and 59% are 2-5ha in size.

Both permanent and seasonal standing water bodies are considered as pond priority habitat. Ponds are a significant wildlife habitat, supporting populations of at least two-thirds of Britain's freshwater plant and animal species. The bare mud, which is exposed when water levels fall (the drawdown zone) or created by poaching around the edge of ponds, is a particularly important habitat for a range of plants and invertebrates. The diversity of species in these drawdown zones can be large in comparison with truly aquatic habitat. They include a range of flies (such a dance flies and shore flies) whose larvae live in the mud, and a range of predatory beetles, such as ground beetles (Carabidae) and rove beetles (Staphylinidae). Many of the plants which grow on the bare mud do not compete well with the taller emergent vegetation that often occurs in margins with less disturbance or stress.

The biodiversity value of ponds is particularly significant when considered collectively. Ponds are physically and biologically heterogeneous habitats and consequently support many different species amongst them. Thus, at regional level they have been shown to support more plant and invertebrate species and more uncommon species than other freshwater habitat types including streams, rivers, ditches and lakes (Williams *et al*. 2004).

At a national level it is estimated that pond numbers in England and Wales decreased by around three quarters during the 20th Century from a maximum of about 800,000 estimated from map counts in the late 19th century to around 200,000 by the 1980s (Rackham 1986, Barr *et al.* 1994, Biggs *et al.* 2005). There is evidence that since the 1980’s this trend has been reversed, with CS 2007 estimating a net increase of approximately 33,400 ponds between 1998 and 2007 as pond creation exceeded pond losses. This resulted in an estimate of 234,000 ponds in England in 2007, the majority (68 %) of which were small 0.0025-0.04ha. Despite the overall increase in pond numbers it is estimated that approximately 14,900 ponds were lost in this time frame.

6. General characterisation of contributions from existing monitoring programmes

6.1 Preamble

This section provides an account of the relevance of a range of monitoring programmes and systems to a priority freshwater assessment framework. A series of tables is provides key statistics on these monitoring programmes, in terms of the types of information they generate and the numbers of sites they involve. Table 6.1 compares key river and lake monitoring programmes in terms of their principal monitoring components, whilst Table 6.2 summarises their compatibility in terms of principal monitoring methods. Table 6.3 outlines the spatial coverage of each river monitoring programme in terms of the six habitat resource zones defined in Section 4. The equivalent spatial coverage of lake monitoring programmes in Table 6.4 has had to be portrayed somewhat differently due to lack of information in relation to habitat resources zones – it uses coverage across lake priority habitat types. Table 6.5 shows the spread of pond monitoring sites in different programmes, whilst Table 6.6 compares the monitoring components used in the various pond monitoring schemes.

It should be noted that the figures for WFD monitoring are highly summarised and combine both surveillance and operational monitoring. Note that the figures for WFD monitoring are those available in 2013, and since this time there has been (and continues to be) considerable downward pressure on EA monitoring resources and hence numbers of sites (particularly in relation to operational monitoring). That said, the age of the WFD data used does not affect the general monitoring picture or the nature of the proposals made later in this document. Similarly, the data on the Upland Waters Monitoring Network were correct at the time of this analysis (2015), but the network has suffered from resourcing difficulties and the picture is subject to change.

These tables indicate the complexity of the task of using different monitoring programmes in a combined assessment of priority freshwater habitat condition that covers all components of the habitat resource. Key monitoring programmes are discussed in more detail in the following sub-sections.

Table 6.1 Survey elements in the main monitoring networks discussed in this document.

Colour key shows the typical sampling frequency - samples are often considered together over longer time scales for assessments. Note that information on EA WFD monitoring combines surveillance and operational monitoring.

EA – Environment Agency; WFD – Water Framework Directive; RSA – Restoring Sustainable Abstraction; CS – Countryside Survey; UWMN – Upland Waters Monitoring Network; ECN –Environmental Change Network

a) Rivers

	EA WFD	EA - other drivers (RSA + specific investigations)	CS	UWMN	ECN
River Habitat Survey	no	yes	yes	no	no
CHEMICAL (N,P & ALK)	yes	yes	yes	yes	yes
CHEMICAL (not nutrients)	yes	yes	no	yes	yes
FLOW	yes	yes	no	subset	yes
MACROINVERTEBRATES	yes	yes	yes	yes	yes
MACROPHYTES	yes	yes	yes	yes	yes
DIATOMS	yes	yes	no	yes	yes
FISH	yes	yes	no	yes	no

Colour key to sampling frequency
ad hoc
monthly
seasonal
annual
multiannual
continuous

b) Lakes

	EA monitoring WFD + other drivers	UWMN	ECN
Lake Habitat Survey	yes*	No	no
CHEM (N,P & ALK)	yes	Yes	yes
CHEM (not nutrients)	yes	Yes	yes
Hydrology: Water Level	no	No	no
PHYTOPLANKTON (including Chlorophyll)	yes	No	yes
MACROINVERTEBRATES	yes**	Yes	yes
MACROPHYTES	yes	Yes	yes
DIATOMS	yes	Yes	no

* Note LHS is no longer undertaken for WFD purposes
**Lake Acidification Macroinvertebrate Metric annual, Chironomid Pupal Exuviae Technique seasonal

Table 6.2 Compatibility of survey methodologies with WFD monitoring.

EA – Environment Agency; WFD – Water Framework Directive; CS – Countryside Survey; UWMN – Upland Waters Monitoring Network; ECN –Environmental Change Network; RHS – River Habitat Survey

a) Rivers

	Compatibility of methods with EA WFD methods				
	Macroinvertebrates	**Macrophytes**	**Diatoms**	**Fish**	**RHS**
CS	yes	yes	n/a	n/a	yes
UWMN	no	with manipulation	yes	yes	n/a
ECN	yes	with manipulation	yes	n/a	n/a

b) Lakes

	Compatibility of methods with EA WFD methods			
	Macroinvertebrates	**Macrophytes**	**Diatoms**	**Phytoplankton**
UWMN	no	yes	Yes	No
ECN	no	yes	Yes	Chlorophyll concentration only

Table 6.3 Number of riverine monitoring sites in England within each habitat resource zone (2013 data).

According to the original version of the priority river habitat map (Mainstone *et al*. 2014).

EA – Environment Agency; WFD – Water Framework Directive; CS – Countryside Survey; UWMN – Upland Waters Monitoring Network; ECN –Environmental Change Network; RHS – River Habitat Survey

Monitoring programme	**Habitat resource zone (see Figure 4.1)**					
	1a	**2a**	**3a**	**1b**	**2b**	**3b**
ECN	0	0	0	2	5	7
UWMN	4	0	0	0	0	1
RHS baseline 1	102	78	336	219	510	1439
RHS baseline 2	308	274	1662	245	391	1349
CS1998	23	10	95	13	9	47
CS2007	23	7	74	12	8	44
WFD chemistry	136	144	1646	735	1383	3382
WFD biology	92	91	1242	534	1148	2824

Table 6.4 Number of lake water bodies of each priority habitat type in England where the different components of EA monitoring are undertaken (2013 data).

LHS – Lake Habitat Survey; LAMM – Lake Acidification Macroinvertebrate Metric; CPET – Chironomid Pupal Exuviae Technique

Habitat type	Oligotrophic-dystrophic		Mesotrophic		Eutrophic		Marl		Aquifer-fed naturally fluctuating waterbodies	
Monitoring	SSSI	non-SSSI	SSSI	non-SSSI	SSSI	non-SSSI	SSSI	non-SSSI	SSSI	non-SSSI
LHS	9	8	6	4	14	5	5	0	0	0
Total monitored	17		10		19		5		0	
CHEM (N,P & ALK)	15	105	13	47	52	116	7	2	0	0
Total monitored	120		60		168		9		0	
Phytoplankton taxon	11	16	9	15	28	38	6	0	0	0
Total monitored	27		24		66		6		0	
PHYTOPLANKTON (Chlorophyll)	4	89	4	32	24	79	1	2	0	0
Total monitored	93		36		103		3		0	
MACROINVERTEBRATES-LAMM*	9	8	0	0	0	0	0	0	0	0
Total monitored	17		0		0		0		0	
MACROINVERTEBRATES-CPET	9	8	6	4	14	5	5	0	0	0
Total monitored	17		10		19		5		0	
MACROPHYTES	11	16	9	15	28	38	6	0	0	0
Total monitored	27		24		66		6		0	
DIATOMS	9	8	6	4	14	5	5	0	0	0
Total monitored	17		10		19		5		0	
Number of waterbodies in priority habitat type	488		406		2111				5	

* In lakes the macroinvertebrate LAMM metric is used to reflect the impacts of acidification so is only monitored in oligotrophic lakes.

Table 6.5 Main pond survey schemes with numbers of sites and sampling biases.

CS – Countryside Survey; NPS – National Pond Survey; LPS – Lowland Pond Survey; NARRS – National Amphibian and Reptile Recording Scheme

Survey	CS 84	CS 90	NPS	LPS	CS 00	CS 07	NARRS (Phase 1)
Temporal extent	1984	1990	1990 - 1994	1996	1998	2007	2007 - 2012
# 1km squares	384	507	n/a	150	569	591	722
# ponds sampled	0	0	200	377	0	259	412
sampling strategy	counts only	counts only	targeted	all ponds in square	counts only	counts + 1 pond in square	1 pond in square
Spatial extent	UK wide	UK wide	UK wide	UK lowlands	UK wide	UK wide	UK wide + IoM
Sampling bias	n/a	n/a	semi natural habitats	lowlands only, CS squares, excludes urban and curtilage, garden ponds, farm ponds	n/a	n/a	volunteer selection of square and pond
dry ponds	excluded	excluded	excluded	counted	counted	counted	excluded
woodlands & golf courses	excluded	excluded	woodlands yes golf courses no	included	lowland subset only	included	included
Size definition	not defined	not defined	$1m^2$ to 2ha	$25m^2$ to 2ha	$25m^2$ to 2ha	$25m^2$ to 2ha	$1m^2$ to 2ha

Table 6.6 Comparison of the relevant variables monitored in various pond monitoring schemes.

CS – Countryside Survey; NPS – National Pond Survey; LPS – Lowland Pond Survey; NARRS – National Amphibian and Reptile Recording Scheme; PSYM – Predictive System for Multimetrics

	CS84/90/00	CS07	PondNet Plant and invertebrate assemblage surveys and PSYM	NPS	LPS	NARRS
pond density[3]	yes (field)	yes (field)	yes (map)	no	yes (field)	yes (map)
distance to nearest pond	no	no	no	no	no	no
Land cover 1990	yes	yes	no	no	no	no
Land cover 2000	yes	yes	no	no	no	no
land use <5m	no	yes	yes	yes	yes	no
land use <100m	no	yes	yes	yes	yes	no
marginal complexity	no	no	no	yes	yes	no
Bank type	no	no	no	yes	yes	no
inflows	no	yes	yes	yes	yes	no
outflows	no	yes	yes	yes	yes	no
pond base substrate	no	yes	yes	yes	yes	no
sediment type	no	no	no	yes	yes	no
Major sources of pollution	no	yes	no	yes	yes	no
Pond management	no	yes	yes	yes	yes	no
extent of perimeter grazed	no	yes	yes	yes	yes	no
Amenity use	no	no	no	yes	yes	no
turbidity	no	yes	yes	yes	yes	no
pH	no	yes	yes	yes	yes	no
conductivity	no	yes	yes	yes	yes	no
alkalinity	no	yes	no	yes	yes	no
TDN	no	yes	no	yes	no	no
Nitrate[4]	no	no	yes (kit)	no	no	no
PO4P[4]	no	yes (lab)	yes (kit)	yes (lab)	no	no
calcium	no	no	no	yes	yes	no
% margin shaded	no	no	yes	yes	yes	yes
% tree cover	no	yes	yes	yes	yes	no
Macrophytes species ID/cover	no	yes	yes	yes	yes	no
Macrophytes % cover - All	no	yes	yes	yes	yes	yes
Macrophyte % cover submerged	no	yes	no	yes	yes	no
Macrophyte % cover floating	no	yes	no	yes	yes	no
Macrophyte % cover emergent	no	yes	yes	yes	yes	no
Macroinvertebrates species ID	no	no	no	yes	yes	no
Macroinvertebrate family ID	no	no	yes	yes	yes	no

6.2 Water Framework Directive monitoring

The WFD is concerned with controlling and reducing anthropogenic impacts on surface and ground waters. Since the ethos of the WFD is about controlling impacts to reach targets which are set in relation to a 'nearly unimpacted' reference condition, its aims are broadly aligned with that of priority freshwater habitat objectives as outlined in this report.

A bespoke WFD monitoring programme is used to assess the chemical (good/fail) and ecological status (high, good, moderate, poor, bad) of surface waters, with the aim of bringing all surface waters to good chemical status and at least good ecological status (various derogations apply and are used extensively in England). As a part of this system, several biological components are assessed (potentially including macroinvertebrates, phytoplankton, benthic algae, macrophytes and fish) using stressor-specific community metrics that are compared against expected values derived from a reference network of putative unimpacted sites using predictive models. The deviation from a reference value is then used to assign ecological status.

The running water WFD monitoring network in England (itself evolved from the preceding General Quality Assessment monitoring network) is spatially extensive with thousands of sites across England, and the seasonal, annual or multi-annual sampling frequency of different elements provides insight into change. Thus this monitoring network forms, in theory, one of the most 'obvious' resources that could feed into priority habitat condition assessment.

For lakes there was little monitoring before WFD so the monitoring programme reflects what is deemed to be required to satisfy the requirements of this Directive specifically. The following lakes (including reservoirs) are classified as WFD water bodies:

- all lakes > 50 ha surface area
- lakes with Protected Area status under the Directive, i.e.
  - SAC/SPA lakes, & Drinking water protected areas, 5 – 50 ha in area;
  - a number of drinking water sites of any size;
  - all Freshwater Fish Directive lakes - no minimum size;
  - lakes notified as wetlands of internal importance under the Ramsar Convention
- lakes on the EU Intercalibration register
- the majority of SSSI lakes specifically notified for lake habitat and some other SSSIs lakes notified for other features (e.g. particular species only)
- lakes in the Upland Waters Monitoring Network lakes (to ensure inclusion of upland waters)
- *Ad hoc* additions of small numbers of lakes deemed important in their catchments/river basins and not captured above

Not all WFD water bodies are monitored. Waterbodies deemed to be at low risk of failing their ecological status (or potential) objectives are much less likely to be monitored than those at high risk (unless they form part of the fixed surveillance monitoring network). Lake water bodies < 5ha are not included in the WFD monitoring programme, as there are questions about the applicability of the WFD tools to such small water bodies, and there are cost implications of doing so. In some instances where lake water bodies are clustered a single water body was chosen for monitoring on the presumption that this will reflect the condition of the cluster as a whole, (although the assessed status of these water bodies has never been conferred to their neighbours). Amongst the lake water bodies less than 50ha that are monitored, many are either SSSI/SAC or drinking water reservoirs. Most reservoirs have the WFD objective of good ecological potential rather than good ecological status; these water bodies are often only monitored for water quality and chlorophyll as the other metrics would be highly impacted by reservoir use which results in large drawdown. The high number of lake sites monitored only for water quality and chlorophyll in Table 6.4 reflects the high number of reservoirs monitored. Due to their highly artificial nature and lack of natural functioning, reservoirs are unlikely to be considered as lake priority habitat, so this monitoring contributes little to the monitoring of the priority habitat resource. The majority of the rest of the monitoring of lake water bodies less than 50ha is on SSSI and SAC sites, so WFD monitoring does not provide a great deal of information about the wider priority habitat resource of lakes <50 ha.

There are important limitations to the usefulness of WFD monitoring for assessing the integrity of key ecological processes and the naturalness of habitats and their species assemblages. Though the WFD drives policy and decision-making in freshwater environments, it is not concerned with biodiversity and habitat conservation *per se*, which is governed by the EU Habitats Directive and Birds Directive, international conventions, domestic SSSI legislation, and priority habitat and species objectives laid out within England‘s sequential biodiversity initiatives (currently Biodiversity 2020).

The ‘competent authority’ for the WFD (in England, the EA) prioritises monitoring relating to achieving GES and drinking/bathing water quality standards, with few resources left for assessments that go beyond the essential requirements of WFD legislation. A skeletal network of fixed surveillance sites is augmented by flexible operational monitoring that is targeted at waterbodies deemed to be at risk of failing their ecological status objectives. The prevailing economic conditions are forcing reductions in WFD monitoring, which makes the picture very dynamic and unstable. Critically, perceptions of risk depend on the objectives and attributes being monitored – a focus on ecological status does not provide a full picture in relation to priority habitat objectives (which are based on broader considerations of natural habitat function).

A consequence of a risk-based bias is that monitoring does not cover different water body types equally, with lowland systems over-represented as these are often where anthropogenic impacts are the most apparent. Eutrophication for example is expected to increase in lowland water bodies because of the higher density and size of sewage treatment works (STWs) as well as the accumulation of the impacts of multiple stressors throughout the catchment. The trend towards risk-based monitoring by the EA is set to continue in the coming years, meaning that the number of monitoring sites is likely to decrease. It is not clear what this will mean in terms of sampling bias within the programme as a whole.

Although risk-based monitoring does imply sampling bias, it is founded on the likelihood of change (positive or negative) in conditions, implying that older data on sites that have not been monitored recently are still valid. Representativeness in assessments may therefore still be gained from evaluating a longer time series of data, as long as there is sufficient faith in the underlying risk assessment to detect all relevant types of change.

Other operational aspects of WFD monitoring may pose problems when assessing naturalness. Representative sites for a water body are to some extent chosen, like in any survey, on the basis of access rights, ease of access and health and safety. Different survey types are rarely integrated spatially so that hydrology, water chemistry, biota and habitat quality come from different specific locations, and have to be linked to one another with inherent assumptions about their representativeness. Time series also differ between different sites, even on the same water body, so that some sites are surveyed yearly and others less frequently. At a site, WFD monitoring assesses principally fully aquatic habitats, and thus does not include important parts of the habitat mosaic such as exposed riverine sediments and other ephemeral habitat patches that host unique biotic assemblages. Furthermore, WFD monitoring does not include reporting the condition of marginal zones, distinct components of the freshwater habitat mosaic in themselves, despite their inherent conservation value and profound influence on open water habitats and ecological processes (e.g. via shading of open water, the input of organic matter, and the routing of run-off).

For WFD classification purposes, hydromorphology (hydrological regime and physical habitat status) is only considered at HES. At all other sites reliance is placed on biological classification tools to determine whether there is a problem with ecological status, and the biological tools and associated monitoring regimes used for reporting ecological status are not geared towards detecting hydromorphological problems. Nutrient status is also generally not directly considered in the reporting of ecological status other than at HES – again, biological classification tools are relied upon, although these tools are somewhat more able to reflect water quality impacts.

WFD monitoring of some biological elements does not yield enough detailed species-level information for assessments of biodiversity and community structure. All of the biological assessments used in WFD reporting for both rivers and lakes are based on derived (mainly stressor-specific) metrics rather than direct comparison of data on observed and reference community. Macroinvertebrate diversity is reported as the 'number of scoring taxa' related to different metrics and often refers to family-level diversity rather than species diversity (although improvements to taxonomic resolution are being made).

The presence of invasive non-native species (INNS) at a site is an important conservation issues, contributing to a loss of naturalness of the characteristic assemblage. However, under WFD monitoring INNS are only directly considered when assessing waterbodies at HES, and there is no wider WFD reporting of their spatial extent and distribution related to the assessment of ecological status. The effects of INNS on WFD biological metrics can be idiosyncratic (Schlaepfer *et al*, 2011), with potential for metric scores to improve following invasion; for instance, signal crayfish can elevate WFD invertebrate metric scores by predating on soft-bodied invertebrate species that are relatively pollution-tolerant (Tablado *et al*., 2010). Zebra mussels can initially benefit algal and plant communities as they reduce water turbidity (Caraco *et al.* 1997; Kirsch and Dzialowski, 2012). Reliance on these metrics to detect impacts from non-native species is therefore of concern in the context of biodiversity objectives.

Though the reference condition concept underpins WFD assessments, it is an arbitrary concept, derived in different ways for different targets, and it is unclear how well WFD reference condition and the concept of naturalness correspond. For example, the defined WFD reference conditions derived by the macroinvertebrate RIvPACS model (Wright *et al.*

1993) do not represent well the unimpacted macroinvertebrate communities in some habitats, such as deep rivers, headwater streams, chalk rivers, and very small catchments (e.g. coastal streams). Such difficulties in adequately defining unimpacted biological communities make reliance on WFD ecological status reporting (itself totally reliant on biological assessment) even more problematic for biodiversity reporting.

WFD monitoring and assessment, and routine freshwater monitoring generally in many countries, is often criticised for focusing on structural indicators over functional indicators. Within the context of structural indicators, WFD monitoring (at least at good ecological status) is further restricted to biological structure. This issue is discussed in a wider context in Section 7.1.

In looking at what existing EA monitoring regimes can provide, it is important to remember that there is a considerable difference between what is monitored by the EA and what is used for WFD ecological status reporting. A great deal more information is available on the biology, pressures and impacts on freshwater habitats than is used in headline WFD reporting, and it is important that in developing a priority habitat assessment this ancillary information is exploited to its fullest extent.

This potential is exemplified by RHS, data from which are used by the EA to help characterise river water bodies, assign artificial/heavily modified water body status, and support HES designation. RHS is not used in WFD ecological status reporting (except perhaps to help confirm no physical deterioration at the few sites in England which are at HES), However, RHS has been deployed widely across the UK and collects key channel and riparian information about habitat condition which resides in a wide range of 'sub scores'. RHS is discussed in more detail in Section 7.2. In the lake environment, the standard lake macrophyte survey for WFD records information on shoreline vegetation, land cover in the riparian zone and pressures. None of this information is presently used in WFD assessments, but has potential for use in priority habitat monitoring. Other EA sources of data include the water resources management system, flood risk management data gathering and information on fish stocking.

6.3 Common standards monitoring

Common Standards Monitoring (CSM) is the recognised UK protocol for condition assessment of specially protected sites (Natura 2000 sites and SSSIs); detailed guidance is provided by JNCC (2016). Its strength is that all key components of habitat quality are explicitly assessed. CSM is driven by habitat integrity, which in turn is based on deviation from natural conditions (e.g. hydrological targets based on deviation from natural conditions, physical condition targets based on levels of habitat modification away from the natural state). Moreover the marginal zone of freshwater habitats is also explicitly considered, while this habitat is not directly assessed in WFD reporting.

In practice, a considerable component of CSM assessment relies on available EA monitoring data (e.g. chemistry, macrophytes, phytoplankton, fish, macroinvertebrates, diatoms), from routine WFD monitoring, other operational data gathering processes (e.g. connected to permitting processes), or arising from EA responsibilities to contribute to the management of SSSIs and SACs. Although CSM is more explicit about impacts on habitat integrity, the use of WFD data means that some of the limitations of WFD monitoring are inherited by CSM assessments, particularly in relation to biological assessment.

Despite these limitations, CSM provides a broader assessment of natural habitat function than WFD reporting of ecological status. It cannot however be practically or financially deployed in the wider priority habitat resource. The way forward for assessing the wider habitat resource needs to make use of existing monitoring networks such as the WFD programme, draw on CSM concepts to improve the power to assess deviation from natural habitat function, and identify any additional measures in site monitoring or data interpretation.

6.4 Countryside Survey

Countryside Survey (CS) consists of a field survey of 591 1km x 1km sample squares spread across England, Scotland and Wales, undertaken approximately every eight years.

Around 60% of these squares contain at least one stream. Surveys of headwater stream sites have been undertaken as part of Countryside Survey in 1990, 1998 and 2007. Since 1998, the survey has consisted of three elements: macroinvertebrates, macrophytes and habitats (channel and riparian zone). A single water chemistry sample is taken for supporting information. In 1990, only the macroinvertebrate component of the survey was undertaken. Survey methods are aligned to recognised biomonitoring protocols i.e. the macroinvertebrate survey follows the RIvPACS/RICT protocol, the macrophyte survey follows MTR/LEAFPACS protocol and habitats are surveyed using RHS. The CS does not monitor fish, or diatoms. Methods are therefore comparable to that used by the EA for WFD monitoring, and for the WFD Plus approach suggested in this report.

The CS has mapped and counted the ponds that occur in the 1x1 km survey squares since 1984. Presence of new ponds, lost ponds and changes in pond shape or size are all logged. A detailed description of methods used to map ponds can be found in the CS Field Mapping Handbook (CS Technical Report No.1/07).

The first CS survey of pond quality was undertaken in 1996 as part of the Lowland Pond Survey (LPS96). It assessed pond condition using physico-chemical attributes and plant assemblages of ponds. LPS96 was the first survey to introduce a definition of CS ponds, and to specifically distinguish seasonal ponds, which naturally dry out in summer, from ponds which have been drained and are permanently dry, and which can be regarded as 'lost' (these definitions were used in all subsequent CS surveys). The LPS96 was restricted to the lowlands of England, Scotland and Wales. The survey strategy was designed to maximise compatibility between LPS96 and earlier CS data gathered in 1984 and 1990. Pond quality was assessed relative to high quality National Pond Survey reference sites. In total, surveys were undertaken at 150 1 km x 1 km lowland squares; this included 136 squares which contained ponds and 14 "non-pond" squares. In each square, all ponds that were present (n=377) were surveyed in detail to provide ecological data.

CS2000 reported the number and size of ponds in all squares but did not include assessments of pond condition or quality. CS2007 was the first to assess both pond numbers and pond quality across the whole of the British countryside including upland areas. A detailed assessment of pond condition was made for one randomly selected pond in each square containing a pond. Detailed condition assessments were made for a total of 149 ponds in England.

Lakes are not monitored as part of the CS, although they are mapped when included (or part included) in a square.

The current CS site network has the potential to provide a critical source of data for the assessment of priority river and pond habitat:

- CS specifically targets headwaters and ponds, which are not included in WFD monitoring.
- CS uses several hundred sites and is the largest survey of its kind in the UK, with a national coverage of sites across England (divided into three environmental zones: Western lowlands, Eastern lowlands, and uplands);
- CS is repeated every ~ 7 to 10 years, providing a measure of change on suitable timescales because the same sites are revisited;
- Site location is confidential so sites cannot be targeted for remediation, which would negate the aims of genuine condition assessment based on representative sampling.

6.5 The Environmental Change Network

The Environmental Change Network (ECN) is a long-term environmental monitoring programme, involving the collection, analysis and interpretation of data from a network of sites. ECN was launched in 1992 and the collection of data started formally in 1993 at terrestrial sites and 1994 at freshwater sites. There are currently 14 river sites and 6 lake sites in the network in England (ponds are not monitored in the ECN). Sites range from small to large, from lowland to upland, from minimally disturbed to those impacted by water quality issues. The ECN collects very detailed chemistry data, and river sites benefit from continuous flow gauging. Macrophytes, diatoms and macroinvertebrates are sampled in rivers, whilst phytoplankton, zooplankton, macrophytes and invertebrates are sampled in lakes. The compatibility of these metrics with WFD methodology is summarised in Table 6.2. The ECN does not monitor fish, and does not provide RHS data.

6.6 The Upland Waters Monitoring Network (UWMN)

The Upland Waters Monitoring Network (UWMN) emerged in 2013 from the previous Acid Waters Monitoring Network (AWMN), which was established in 1988 to monitor the impact and recovery from acid deposition. The UWMN includes 5 river sites and 2 lake sites in England, with the aim of tracking changes in water quality and freshwater biodiversity (Battarbee *et al*. 2014). The UWMN site network provides an alkalinity gradient rather than focusing solely on acid sensitive sites. Like the ECN, water chemistry is very detailed and flow gauging is available at most stream sites. The network surveys macroinvertebrates, macrophytes and diatoms; the compatibility of these metrics with the WFD are shown in Table 6.2. The network was originally designed to survey fish, but fish surveys have now discontinued due to funding cuts. There are no RHS data for the stream sites or habitat data for the lakes sites. Ponds are not surveyed.

The importance of this network is that it gives an insight into upland lakes and streams which are generally small and are not impacted by point sources of pollution, so are generally not monitored in EA and other monitoring networks. Its strategic value is in monitoring long-term change, in the face of changing land-use, atmospheric pollution and climate change which is vital for informing catchment management and environmental policy at local, national and

European scales. However, it contains few sites and would make only a small contribution to monitoring the condition of the habitat resource as a whole. Since sites have been chosen to factor out agricultural influences, there is also bias in site selection that would influence their contribution to assessing the overall condition of the habitat resource.

6.7 Agri-environment scheme monitoring

Monitoring of agri-environment schemes is a significant activity. However, it is mainly focused on terrestrial and wetland habitats where measures are applied, rather than open water habitats. Where this occurs on waterside land this may provide usable information on the physical condition of the marginal component of freshwater habitats. However, the survey methods used to assess condition are rudimental compared to freshwater methods such as the River Habitat Survey and Lake Habitat Survey (see Section 7 for further detail).

Some monitoring of headwater streams is undertaken to monitor the effect of ‘Resource Protection’ measures in selected small catchments, and the attributes assessed are aligned with WFD waterbody monitoring. However, such monitoring is generally biased towards agriculturally impacted areas and is time- and spatially limited.

6.8 Citizen science monitoring schemes

These hold great promise for enhancing data collection and collation while controlling costs, and will be increasingly facilitated by innovations such as mobile ‘apps’. A range of schemes has emerged in recent years, with varying levels of stakeholder engagement and core funding. Schemes in England include:

- PondNet
- the Riverfly Partnership
- Fisheries walkover surveys
- People, Ponds and Water
- Flagship Ponds
- Clean water for wildlife

Further details are provided in Appendix A.

The use of such schemes for formal assessment and reporting is hampered by the technical capabilities of the volunteer workforce, the lack of data quality control, the lack of central repositories, and by the fact that ‘uptake’ is not guaranteed. They tend to be focused on individual types of water body and often on narrow elements of the biological assemblage rather than components of natural habitat function. Such schemes require a significant amount of facilitation and guidance to ensure volunteers remain enthused, and considerable quality assurance if results are to be useful for incorporation into national scale assessments.

This means that the required data from these schemes may not always be guaranteed, but where they are relevant, available and reliable they can help to fill information gaps.

6.9 Innovations in monitoring

Although not currently central to monitoring freshwater habitats, some alternative approaches to monitoring are currently attracting considerable interest because of their potential in transforming environmental monitoring programmes. The most relevant ones to consider in this report are remote sensing and DNA techniques ('e-DNA' using water samples and 'community DNA' using biological samples).

6.9.1 Remote sensing methods

Several remote sensing methods were specifically investigated (see Table 6.7) and show promise for assessments of riparian zone vegetation, lake chlorophyll concentration and possibly some river channel features. Generally the methods are limited by their current cost, lack of national coverage, current frequency of data updates (many methods could not contribute to assessments repeated at 5 yearly or even 10 yearly intervals at the moment), and difficulties in interpreting the data. However, this is a fast–moving field, with new technologies developing rapidly.

One long-standing issue with remote sensing of freshwater habitats is that it can potentially do some things well but cannot address certain types of information requirement. Whilst data on some useful attributes could be collected by remote sensing, other attributes would still require data to be collected in the field. When in the field those attributes that can be surveyed by remote sensing could be included in field survey, thereby reducing the benefits of a remote sensing approach. This said, with a monitoring design strategy that is based on representative sampling, remote sensing data has a major potential role to play in helping extrapolate field data to unmonitored locations in an informed way. This can be done through stratifying the habitat resource to better match unmonitored with monitored locations.

Table 6.7 Potential remote sensing applications of relevance to priority habitat condition assessment.

Application	Platform	Ability to detect change	Possible uses	Technical limitations	UK coverage	Data cost
Aerial photography	Planes, satellites or UAV*	National data updated ~ 5 years. Ad Hoc local surveys possible with UAV*	Rivers: Riparian condition, channel condition. Low on detail but can cover full catchment.	Cannot see waterbody and riparian features through vegetation at some times of year, difficult to quantify riparian vegetation other than present/absent. Surveying limited by cloud cover and flying conditions.	Full	Main national dataset free
			Ponds/Lakes: counts and sizes, littoral condition	Will miss ponds hidden by overhanging vegetation at some times of year.		
Multispectral sensing	Satellite	Sentinel 2 updated every 10 days, sentinel 3 updated every 2-3 days. Need to correct for phenology	Rivers/ponds/lakes: artificial structures, channel features, turbidity, depth (penetrates water)	Overhanging vegetation cannot be penetrated.	Full	Expensive for high resolution, 30 m and above free
			Lakes: chlorophyll concentration, algal blooms	Sentinel 3 is suited to large lakes (>5 km^2) and sentinel 2 could contribute to data on small eutrophic lakes. Sentinel 2 is needed for small lakes as it has higher spatial resolution ($10m^2$) but it has the lowest chlorophyll detection ability so it is not suitable for small oligotrophic lakes or lakes with high DOC.		
				Cloud cover prevents suitable data capture (affects all RS techniques) but will have greater impact on		

Application	**Platform**	**Ability to detect change**	**Possible uses**	**Technical limitations**	**UK coverage**	**Data cost**
				Sentinel 2 datasets as refreshed every 10 days only (may miss blooms etc.)		
Radar X band	Satellite	updated every few days, need to correct for phenology	Rivers/ponds/lakes: artificial structures, channel features, areas of aquatic vegetation, depth, turbidity	Overhanging vegetation cannot be penetrated. Surveying limited by cloud cover	Full	Expensive, cm to m available to order, but archive data cheaper
Airborne LIDAR**	Planes, more recently UAV*	currently none as ad hoc surveying	Rivers/lakes/ponds: vegetation in the riparian zone	Surveying limited by cloud cover and flying conditions.	2m most of UK, better resolution is ad hoc	Expensive, but some datasets free e.g. EA shading maps
Multispectral LIDAR**	Satellites and more recently planes	none, new technology	Rivers/lakes/ponds: vegetation in riparian zone, artificial structures, channel features, depth, turbidity (penetrates water)	Surveying limited by cloud cover and flying conditions.	None, new technology	Expensive
Hyperspectral sensing	Satellite, planes	none, new technology	Rivers/lakes/ponds: artificial structures, channel features, depth, turbidity, algal blooms (penetrates water)	Surveying limited by cloud cover and flying conditions.	None, new technology	Expensive

* Unmanned aerial vehicles; **LIght Detection and Ranging

6.9.2 DNA techniques

DNA techniques are rapidly increasing in importance, with new tests becoming available for species all the time. A key application of these techniques will be better characterisation of individual species distributions (rare species and non-native species), which is less relevant to priority habitat condition assessment. However, it is clear that it will in the future become increasingly reliable, increasingly affordable and able to cover a wide range of taxa, including the assemblage level of analysis. This would make DNA a possibility for assisting in biological components of priority habitat condition assessment, as long as assemblage results could be related to reference (unimpacted) assemblages with sufficient resolution and reliability. For instance, a community DNA method has now been developed for WFD diatom assessment and one on lake fish assemblages is nearing completion.

7. Potential attributes

7.1 General

Before embarking on an evaluation of possible attributes for different types of freshwater habitat, it is useful to explore the differences between structural and functional indicators, as it is a live debate in the freshwater scientific community around which more clarity is required. Indicators of ecological processes come into this debate, as a primary means of characterising function.

A number of scientific studies have assessed under what circumstances functional variables are better than structural ones for assessing ecosystem health and whether there are good indicators of change in ecological function along perturbation gradients (Sandin and Solemini, 2009). In many cases the measures of choice are leaf litter breakdown rates, algal production and grazing rates, and stream metabolism approaches. However, no consensus has been achieved on which indicators could be used as part of wide-spread monitoring.

A functional approach to river biomonitoring was trialled in New Zealand using leaf litter breakdown and ecosystem metabolism (Young *et al*, 2004, Young 2006). Although relatively easy to set up and carry out, the pilot study found that the approach was limited without a well-developed understanding of what the processes should be in a healthy river. Thus some kind of reference baseline would be necessary, but this implies a clear understanding of controlling and confounding factors, and these appeared to be extensive in the pilot study. It is likely that these approaches would face similar challenges in the UK. There is growing interest in microbial ecology, its relationship to ecosystem function, and application biomonitoring, but no method has been established yet and the usefulness of microbes for functional condition assessments is limited to 'future potential'.

These rather narrow interpretations of functional indicators, based around key ecological processes, ignore the capacity for other forms of attribute to inform our understanding of habitat function. Indicators of biological structure are arguably most distant from the assessment of habitat function, whilst indicators of different aspects of environmental (abiotic) integrity are arguably closer. An attribute that assesses the extent of physical modifications on a habitat tells us something about the ability of the habitat to function naturally. An indicator of the naturalness of the physical habitat mosaic is essentially a structural indicator but is strongly related to impacts on physical habitat function. Nutrient levels in a habitat do not inform our understanding of nutrient fluxes but do provide some understanding of the nutrient regime and its likely effect on natural trophic function.

Recent approaches have seen biological structure used as a proxy of function, whereby biological community data is interpreted in terms of the diversity of functional traits present, rather than taxonomic structure *per se.* This so-called functional diversity, and by extension its sister concept of functional redundancy, have been linked to the resilience of natural communities to disturbance. The concept has been explored in a range of studies examining traits/species responses to stressors such as hydromorphological change (Walters, 2011; Feld *et al,* 2014), agricultural diffuse pollution (Lange *et al*, 2014) and climate extremes (Conti *et al,* 2014). Though structure, traits, function and resilience can clearly be linked to one another in individual studies, a suitable framework is yet to emerge by which functional traits can be used to assess the integrity of ecosystem functioning. This might involve, for example, reanalysing ‘reference condition’ biological data in terms of species traits to establish baseline trait composition within communities.

The distinction between what is a structural indicator and what is a functional indicator is therefore not a simple one, and it is perhaps better to think in terms of what each indicator can say about natural habitat function rather than try and categorise potential attributes in a binary way. This is important because we are constrained in what we can consider in a monitoring and assessment framework for priority habitat. We have to choose from the attributes for which we have some reasonable hope of securing data in an affordable way.

7.2 Rivers and streams

A list of potential attributes for river habitat is provided in Table 7.1, together with notes on their practicality for use in a priority habitat assessment framework. The attributes provide insights into key aspects of natural habitat function, but with a variety of types of attribute including assessment of physical habitat provision, assessment of artificial modifications (of physical habitat structure, water quality, flow regimes and by non-native species), and assessment of the naturalness of the biological community. Whilst there is no consistent structure/function theme running through these attributes, they all provide a different window on natural habitat function and all relate to existing data collection activities at some level.

Data on these different attributes can potentially come from a variety of sources, which are briefly outlined in the table. Some are relatively simple to draw into a proposed framework – these have existing datasets that have a good spatial coverage and are amenable to the classification of habitat condition. Some are pre-classified for WFD purposes. Others constitute important descriptors of natural habitat function but data are not currently collected in sufficient quantity, or if they are collected they are not currently collated in a useable form.

Potential attributes in Table 7.1 that relate to physical habitat condition are mainly based on RHS and it is sensible to provide some background to the method. RHS is an assessment of the habitat quality of rivers based on their physical structure (Raven *et al*., 1997). It consists of (i) a standard field survey method; (ii) a database for data entry and calculations (EA and CEH have the most extensive databases); (iii) a protocol for assessing habitat quality; and (iv) a protocol for describing the extent of artificial channel modification.

RHS data collection is based on a standard 500 m length of river channel. Map information is collected for each site and includes grid reference, altitude, slope, geology, height of source and distance from source. During the field survey, features of the channel (both in-stream and banks) and adjacent river corridor are recorded. Channel substrate, habitat features, aquatic vegetation types, the complexity of bank vegetation structure and the type of artificial modification to the channel and banks are all recorded at each of 10 ‘spot-checks’ located at 50 m intervals. A ‘sweep-up’ checklist is also completed to ensure that features and modifications not occurring at the spot-checks are recorded. Cross-section measurements of water and bank full width, bank height and water depth are made at one representative location to provide information about geomorphological processes acting on the channel.

The number of riffles, pools and point bars found in the site is also recorded. A full description and rationale for the survey method can be found in Fox *et al*. (1998). Current technical guidelines can be found in Environment Agency (2003).

Table 7.1 Potential river attributes.

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
Longitudinal connectivity	There are known to be around 26,000 artificial impounding structures (weirs, dams) segmenting the river network in the UK, of which a disproportionate amount are in England. They have a range of effects, including damaging natural habitat mosaics, interrupting coarse sediment supply, altering flow patterns downstream, and blocking the movement of a wide range of species (not only long-distance migratory fish). Removal of structures is a major river restoration objective for protected sites, priority habitat and WFD objectives.	Number and height of in-channel structures	Defined numerical reduction in the total number and total height of permanent structures.	**Non-headwaters** - EA River Obstructions dataset provides the number and head height of structures, EA fisheries update this dataset 'regularly', probably several times within any five year period. The River Restoration Centre is currently developing a database - this may be a useful source of data in due course. **Headwaters**- The above sources include headwaters but are unlikely to cover them as comprehensively as non-headwaters. The EA is rolling out an 'app' for weir logging which should increase the number of headwater records in the databases. RHS surveys record structures so may hold information on headwater obstructions that is not in the above datasets.	Based on a full data inventory (although patchy in headwaters) and on-going update to that inventory as structures are removed. Local logging of weir removals for national collation against the national inventory of in-channel structures. Drive to increase weir recording in headwaters Database regularly updated, so can report every 5 years
Lateral connectivity	Historical loss of river-floodplain connectivity is linked to habitat simplification by river channelization and to the construction of land drainage infrastructure and flood defences, preventing natural processes such as seasonal flooding and affecting nutrient and sediment dynamics, as well as wetland biodiversity in river and floodplain ecosystems. Where semi-natural floodplain habitat still occurs, there has typically been loss of floodplain microtopography through agricultural practices,	Floodplain connectivity	Defined percentage increase in total channel length associated with functional floodplain. Defined percentage increase in the area of natural	**Non-headwaters & headwaters** – The national flood risk assessment (NaFRA) provides probabilities of inundation exceeding specific depths for the whole UK river network, but simpler shapefiles are available from the EA Geostore for quick assessments, although these do not provide information on short return periods. These can be	Logging changes in flood defence structures and floodplain extent (natural floodplains with short return periods) and extent of semi-natural vegetation in floodplain. Datasets are updated regularly within a 5 year

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
	simplifying and reducing wetland habitat provision.		floodplain that is inundated, and defined percentage of this under semi-natural habitat.	used to map the floodplain, and also the amount of floodplain protected by flood defences for specific flood return periods.	period and are of national coverage. Through modelling this could potentially be based on full data inventory.
	Historical loss of riparian wetlands has major implications for biodiversity - as above. Linked to both river channelization and simplification, and land use change. Key ecotone between two types of PH.	Number of riparian wetlands	Defined percentage increase in total channel length associated with riparian wetlands.	**Non-headwaters** - EA RHS survey data. Biased towards WFD waterbodies, but RHS baseline surveys provide national data with unbiased site selection. RHS database is constantly updated but no clear plans for any further EA RHS baselines **Headwaters** - CS & EA RHS survey data. CS is on headwaters but few in EA data except for second baseline. No clear plans for further CS (and would not add many new sites) or EA baseline.	Use representative sampling design as per RHS national baseline assessments and CS surveys. May be possible to extract other data from the RHS database in an unbiased way. May be possible to record land use within 50m of each bank for all sites even if no RHS RHS database is updated regularly so may be possible to assess on 5 yearly basis.
Vertical connectivity	The hyporheic zone has characteristic fauna and provides refugia from extreme flows. It can provide key hydrological connectivity with riparian wetlands. Upwelling and downwelling zones and upper hyporheic are important for the reproductive cycles of salmonid fish. The hyporheic zone is impacted by channel deepening/clearing works, and by the deposition of fine sediments.	Hyporheic zone degradation	Defined decrease in proportion of river length with hyporheic zone at risk	**Non-headwaters** - Geology maps are widely available. ADAS & Rothamsted have national level sediment models and EA has access to national WQ models. Overlay these to identify risk of sediment occlusion, and pollution of hyporheos. **Headwaters** - As above although sediment models do not apply if the headwater is not on the 'blue line'.	Risk based approach combining geology maps, sediment delivery models and water quality models. Need to map the outcomes of recent sediment delivery models against vulnerable areas. One-off exercise repeated every 5 or 10 years.
Naturalness of flow regime	Natural flow regimes are fundamental to healthy river ecosystems. Flow regimes are under severe stress and are under further threat from development pressure and climate change.	Deviation from naturalised flow	Defined decrease in proportion of waterbodies exceeding the flow thresholds	**Non-headwaters** - EA water resource assessment points as they have modelled Qn and flow gauging. Data are constantly	Percentage deviation from Qn values and compliance with UKTAG flow thresholds for status classes.

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
			for good and high status.	updated and available for most waterbodies **<u>Headwaters</u>** - As above however data coverage sparse and will vary with EA region according to abstraction management in that area.	Data are continuously logged so, a five year reporting cycle is possible.
Naturalness of water quality regime	High water quality is a critical requirement for protecting and restoring characteristic biological communities including priority species such as freshwater pearl mussel. Nutrient status is a key factor, and nutrient enrichment is implicated in a range of ecosystem effects.	hemical status based on WFD classification	Defined proportion of habitat at good chemical status	**<u>Non-headwaters</u>** - EA WFD chemical data. On-going monitoring bias towards impacted sites and sites at risk. **<u>Headwaters</u>** - Limited coverage by WFD. Best data available from Countryside Survey.	**Non-headwaters** - All WFD water bodies are reported on regularly even if not monitored on a risk basis. Full inventory is therefore possible, on a 5-yearly reporting basis. **Headwaters** - Need representative approach for headwaters with better coverage of sites than currently. CS currently reports on 7-10 cycle so provides restricted reporting capacity...
Characteristic assemblages	Characteristic species assemblages are generated by naturally functioning river habitat. A characteristic assemblage is an indicator that the habitat/ecosystem is functioning naturally	Deviation in community composition from that of community expected under unimpacted conditions	Defined reduction in lower classes of assessment	**<u>Non-headwaters</u>** - EA WFD data, yearly to three yearly update, biased towards sites failing or at risk of failing GES. Suitable predictive system only available for macoinvertebrates (RIVPACS). **<u>Headwaters</u>** - EA WFD data, plus CS, ECN, UWMN. RIVPACS not developed for use in headwater streams (reference data set is limited)	**Non-headwaters** – Use species-level (pragmatically EA's mixed level). Need to generate a representative sample of sites from current-risk-based monitoring and past monitoring of sites not at risk of WFD failure. EA database continuously updated, reporting every five years. **Headwaters – As above for relevant EA data.** Countryside Survey data is species-level but reporting is every 7 to 10 years, so provides restricted reporting capacity.

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
		WFD biological metrics observed: expected scores	Defined proportion of habitat with scores consistent with good and high status	Data sources as above but WFD metrics can be predicted for macroinvertebrates, macrophytes, fish and diatoms. However, these metrics do not indicate change from characteristic community composition directly.	**Non-headwaters** – Use WFD data as per chemical status above to generate full inventory. **Headwaters** - Use WFD as per characteristic assemblages, plus CS data to generate representative data.
Non-native species	Non-native species can have physical effects on riverine habitats and can also directly alter characteristic assemblages to a considerable degree. Invasive plants can have strong influence on the condition of the riparian zone.	Presence of in-channel non-native plants and animals	Defined reduction in proportion of habitat with non-natives	**Non-headwaters** - NBN records. Updated regularly **Headwaters** -NBN records but less coverage as fewer EA surveys etc.	Database continuously updated, reporting every 5 years Need to extract recent data for condition assessment, but this may be patchy in coverage. May need a more consistent method for ensuring comparative data.
		Presence and extent of key riparian invasive plants (Japanese knotweed, Himalayan balsam and giant hogweed)	Defined reduction in proportion of habitat with these species	**Non-headwaters** -EA RHS survey data can provide presence and extent. Supplement with information from NBN **Headwaters** -As above but less coverage, supplement with Countryside Survey	Mine existing RHS database for presence and extent of each species. Database regularly updated so can generate 5-yearly reporting. May need to restrict to RHS national baseline assessments to ensure presentative approach.
Naturalness of physical habitat mosaic	Diverse physical habitat mosaics are a product of a naturally functioning river. However, they can potentially be created by physical habitat modifications in ways that work against natural habitat function. We need to evaluate the diversity of river habitat mosaics whilst ensuring that we recognise and value where this is a product of natural function.	Habitat Modification Score	Defined increases in proportion of sites in upper condition classes for each of these elements	RHS provides the data necessary to generate assessments of all of the physical attributes listed in Column 6. **Non-headwaters** - RHS database, particularly data from national baseline surveys. **Headwaters** - As above but less coverage, Countryside Survey provides more headwater data.	Use representative sampling design as per RHS national baseline assessments and CS surveys. May be possible to extract other data from the RHS database in an unbiased way. RHS database is updated regularly so may be possible to assess on 5 yearly basis, but future of national
	A diverse range of flow habitats increases the range of habitats for characteristic communities. Diverse flow habitat patches also promote	Flow biotope diversity - Flow Habitat Mosaic			

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
	resilience to hydrological events. Flow type diversity has been reduced through changes to flow regimes, and channel simplification (channelization, dredging etc.).	Score (see Section 8.1)			baselines assessments is unclear.
	Riparian habitat has intrinsic conservation value as part of the river habitat mosaic, supporting a range of characteristic species. Riparian vegetation complexity has been reduced through flood prevention and habitat loss.	Riparian vegetation structural complexity - Riparian vegetation complexity score (see Section 8.1)			
	Trees influence the channel structure through exposed and underwater roots, as well as channel shading and the input of woody debris. Riparian tree density has been reduced through flood prevention, habitat loss and historical exploitation of timber.	Riparian trees - Riparian tree condition assessment (see Section 8.1)			
	Exposed riverine sediments host unique biological assemblages within the river ecosystem but are impacted by dredging, water level stabilisation and flow regulation/low flow augmentation.	Exposed riverine sediments - Exposed sediments condition assessment (Section 8.1)			
	Woody material is a vital component of a healthy river ecosystem but has been cleaned out of rivers due to flood risk concerns There is an improving trend of leaving some material in river channels but much more needs to be done.	In channel woody material - Woody material condition assessment (Section 8.1)			
	Natural berms are a rare geomorphological unit. They are an indicator of natural planform processes. They provide a means of flood control and can be associated with unique semi aquatic flora. They have been lost through flood control measures, water level control and abstraction.	Prevalence of natural berms	No decrease in number of known sites which have berms		

Overall habitat quality is determined by the occurrence and diversity of habitat features of known value for wildlife, expressed as the Habitat Quality Assessment (HQA) score. HQA score increases linearly with increasing habitat heterogeneity, and since there is no simple relationship between habitat heterogeneity and natural habitat function it does not necessarily follow that a higher HQA score means higher levels of natural function (although this is typically the case). Attempts have been made to derive a form of reference condition to correct for natural variation in habitat heterogeneity (through 'nearest-neighbour' analysis), but HQA remains a difficult index to interpret in the context of natural habitat function.

An alternative approach to assessing naturalness and natural habitat function using RHS data is through indicators of habitat modification. RHS assesses the presence and extent of artificial features associated with the banks and channel, such as re-sectioning, reinforcement, poaching, weirs, culverts, bridges etc. These modifications are aggregated into an index called the Habitat Modification Score (HMS). Unlike the HQA, HMS values are resolved into a 5-class classification.

In addition to these two indices, data are available on individual aspects of physical habitat and modifications to it, which provide greater resolution of critical factors contributing to natural habitat function. Some of these data are used in the list of potential attributes in Table 7.1.

RHS has been used extensively by various organisations and for various purposes in recent years, which has generated an extensive database that is readily accessible. Representative assessments of England and Wales have been conducted to generate a balanced picture of physical habitat quality, and more targeted survey work has been done for local purposes. It is a core survey method for Countryside Survey and for CSM assessment of protected rivers. A detailed account of RHS data availability is provided in Appendix B.

Table 7.1 also includes the possibility of an attribute that directly measures the level of naturalness of the characteristic biological community. Although restricted to benthic macroinvertebrate assemblages, it would constitute a major step forward in freshwater biodiversity assessment. The suggested metric is already in use in Countryside Survey but with changes being made to the taxonomic resolution of WFD monitoring it is feasible to reprocess future WFD data to generate the suggested similarity index. Macroinvertebrate samples have until recently been analysed predominantly to family-level for WFD reporting purposes, despite the fact that many samples are adequate for species-level analysis. However, from 2014, the EA has switched to 'mixed taxon' sample analysis involving sub-family-level resolution, which will improve the resolution of assessments.

Standard WFD biological metrics are also included in Table 7.1. Despite being a crude surrogate measure for impacts on characteristic biological assemblages, they do allow detection of the effects of certain stressors. Given that these metrics do not measure the naturalness of the biological assemblage *per se*, and that the metrics used for WFD classification are geared towards detecting pollution stress, they would arguably better sit under water quality metrics. Some new macroinvertebrate metrics have been developed to detect hydrological and morphological impacts on river habitat, but these are not used in routine WFD classification of waterbodies. Rather, they are used in a targeted way to investigate failures to reach ecological status objectives, so available data would show a heavy bias towards impacted sites. WFD monitoring design also restricts the ability to detect impacts using these metrics, since the low density of monitoring sites (and the aggregated nature of biotope sampling within each sampling site) is not capable of characterising the high spatial variation in physical modifications to river habitat.

7.3 Lakes

A list of potential attributes for lake habitat is provided in Table 7.2, together with notes on their practicality for use in a priority habitat assessment framework. Data on these different attributes can potentially come from a variety of sources, which are briefly outlined in the table. Some are relatively simple to draw into a proposed framework – these have existing datasets and are amenable to classification. Some are pre-classified for WFD purposes. Others constitute important descriptors of natural habitat function, but data are not currently collected in sufficient quantity, or if they are collected they are not currently collated in a useable form.

Lake habitat surveys (LHS) (Rowan *et al*. 2006) collect a range of data which would be useful for assessing the physical attributes of lakes, but although a number of surveys have been undertaken there are no plans for further surveys. A database exists containing data on 66 sites surveyed using LHS. The sites included in the database were not selected as a representative sample of English lakes reflecting the condition of the habitat resource as a whole. Some sites had been chosen specifically to trial the LHS method, representing the full range of naturalness from artificial to natural lakes including the extremes. Consequently it is difficult to extrapolate from existing LHS sites to the whole habitat resource.

Unlike RHS there has been no accreditation for LHS so inter-surveyor variation may be expected to be higher. There are also no reference sites, and consequently no method of assessing what could naturally be expected at a site. Despite these drawbacks it is the most comprehensive dataset and most worked-up method for assessing lake physical habitat.

Because the LHS method has been peer-reviewed and it is the most comprehensive data set available it has been used for the data illustrations in Section 8. These give an indication of what could be done and some idea of current lake condition, but the above limitations must be born in mind. As no further LHS surveys are planned, alternative ways or gaining information on the physical habitat are explored below.

The only current alternative source of data on lake physical habitat comes from the WFD lake macrophyte surveys. When these surveys have been undertaken some limited data on pressures, morphology and riparian land use have been recorded and this may provide an alternative data source for WFD-monitored water bodies. In many cases this information could be made more useful if the methodology was slightly amended and the capacity to do this needs to be explored.

WFD lake sampling is also not necessarily a representative sample of the lake habitat resource as a whole, including many SSSIs and reservoirs, so potentially over-emphasising those sites where measures are implemented to improve water quality, but it is the most comprehensive data set available on water quality. The biological metrics do not measure the naturalness of the biological assemblage per se, and instead are geared towards detecting pollution stress, so they are included with the other water quality metrics.

Outside of protected sites and WFD monitoring there is little other data to draw on, making assessments difficult without further monitoring.

Table 7.2 Potential lake attributes.

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
Longitudinal connectivity	Longitudinal connectivity describes the natural connectivity up/down stream in standing water bodies connected to a river system. This allows movement of all species to complete their life cycles (e.g. migration and spawning in inflows and outflows), and dispersal of all species to maintain resilience to change. This also ensures the natural residence times and flushing rates, which enables the natural movement of substances through the system. Impounding structures such as weirs and dams are the main structures which prevent this.	Number of permanent structures interrupting longitudinal connectivity.	Defined numerical reduction in the total number of permanent structures.	**WFD lakes** - EA 'river obstructions' dataset provides the number and head height of structures, EA fisheries update this dataset 'regularly', probably several times within any five year period. LHS also records the number of hydrological structures on a lake, but no further LHS surveys are planned **Non-WFD lakes**- The above sources include non-wfd lakes, but are unlikely to cover them as comprehensively as wfd lakes. The EA is rolling out an 'app' for weir logging which should increase the number of records in the databases.	Based on full data inventory (although recording is likely to be somewhat sparse at present) Local logging of weir and dam removals for national collation against the national inventory of in-channel structures. Drive to increase obstruction recording on standing waters Database regularly updated, so can report every 5 years.
Lateral connectivity with surrounding land and wetlands	Shore zone: An artificial shoreline may result in a barrier between the lake and the riparian zone and prevents the development of a natural hydrosere and can prevent the movement of species.	Lateral connectivity	Defined percentage increase in sites with natural shorelines	**WFD lakes** - EA WFD macrophyte surveys/ LHS surveys **Non WFD lakes** – No information currently available – requires either additional survey or use of remote sensing. BEHTA survey may yield a few results	LHS surveys can be used as a baseline, but there are no further LHS surveys planned. An alternative is to use data collected during macrophyte surveys. Macrophyte surveys are undertaken every 3 years, on selected sites. Drive to record lake shorelines
	Loss of natural fringing wetlands has major implications for biodiversity and can also result in a lack of natural functioning, as natural marginal vegetation can contribute to the alleviation of water quality issues.	Number of sites with natural marginal fringe	Defined percentage increase in number of lakes with natural marginal fringe	**WFD lakes** - EA WFD macrophyte surveys **Non-WFD lakes** - No information currently available – requires either additional survey or use of remote sensing. BEHTA survey may yield a few results	Mining of EA lake macrophyte database - as this data is not currently used. Macrophyte surveys are undertaken every 3 years, on selected sites.

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
					Drive to increase recording of marginal vegetation on non-WFD lakes.
Naturalness of hydrological regime	Natural hydrological regimes are fundamental to healthy lake ecosystems. Both extreme fluctuations and loss of fluctuations can potentially cause the loss of species. Residence times and flushing rates also influence water quality.	Deviation from naturalised flow in the outflow.	Defined decrease in proportion of waterbodies exceeding the flow threshold for good and high status.	**<u>WFD lakes</u>** - EA water resource assessment points as they have modelled Qn and flow gauging. Data is constantly updated and available for most waterbodies **<u>Non-WFD lakes</u>** - As above however data coverage sparse and will vary with EA region according to abstraction management in that area.	Percentage deviation from Qn values and compliance with UKTAG flow thresholds for status class. Data are continuously logged, five year reporting cycle is possible.
Naturalness of water quality regime	High water quality is a critical requirement for protecting and restoring characteristic biological communities including priority species. Nutrient status is a key factor, and nutrient enrichment is implicated in a range of ecosystem effects. Other water quality issues include acidification, and toxic pollution	Chemical and ecological status based on WFD classification	Defined proportion of waterbodies at good chemical and ecological status	**<u>WFD lakes</u>** - Use EA WFD chemical and biological monitoring. **<u>Non-WFD lakes</u>** - Potential use of citizen science using kits, although accuracy and limits of detection are not as good and only measure soluble nutrients. No scheme presently available. Supplement with ECN, UWMN, Broads Authority and other regional surveys. Earth observation developments may enable chlorophyll concentration observations to be used to infer nutrient levels – this is still in development stages, but moving fast	Sample and analysis of water quality that covers seasonal fluctuations. Expand chemical monitoring to include more smaller water bodies Biomonitoring In practice, macrophytes are the most frequently surveyed biological element Invertebrates are only monitored at sites at-risk of acidification and there is currently no WFD lake fish monitoring or fish tool, although DNA methods may have a role to play in the future. EA database continuously updated. Broads monitoring is annual and is mostly limited to macrophytes only.
	Non-native species can have physico-chemical effects on lake	Presence of in-lake invasive	Defined reduction on number of		Utilise existing biological surveys and reporting on NBN, DNA

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
Non-native species	habitats and can also directly alter characteristic assemblages to a considerable degree. Invasive plants can have strong influence on the condition of the riparian zone.	plants and animals	lakes with invasives.	**<u>WFD lakes</u>** – Macrophyte surveys/ LHS/ NBN records. Updated regularly **<u>Non-WFD lakes</u>** -Use NBN records, but less coverage as fewer EA surveys etc.	methods may have a role to play in the future. NBN is regularly updated.
		Presence and extent of riparian invasive plants	Defined reduction in number of sites with invasive riparian plants.		
Naturalness of physical habitat	The littoral zone substrate is essential for fish spawning, invertebrate diversity and abundance and macrophyte anchorage and nutrition. It is impacted by sedimentation and reduction in substrate heterogeneity due to water level manipulations, as well as the introduction of artificial substrates for various reasons.	Presence of a natural littoral substrate	Defined increases in proportion of sites with a natural littoral substrate	**<u>WFD lakes</u>** - EA LHS surveys/ EA macrophyte surveys contain limited information, **<u>Non-WFD lakes</u>** No data available	Little data available.
Naturalness of physical habitat	Riparian habitat has intrinsic conservation value as part of the lake habitat, supporting a range of characteristic species. Riparian vegetation has been lost and reduced through drainage of riparian land and alternative land use in land adjacent to lakes.	Presence of semi-natural riparian land use	Defined increase in proportion of sites with natural riparian land use	**<u>WFD lakes</u>** - EA LHS/macrophyte surveys, remote sensing data. **<u>Non-WFD lakes</u>** remote sensing data	LHS and WFD macrophyte surveys contain some information, but this is not currently used. Macrophyte surveys are undertaken every 3 years on selected sites. Possibilities for remote sensing outside of WFD sites
	Riparian trees have a role to play in providing habitat and food source to in-lake assemblages.	Number of sites with riparian trees	Presently unclear whether an increase or decrease is required or whether the status quo should be maintained.	**<u>WFD lakes</u>** - LHS surveys **<u>Non-WFD lakes</u>** - No information currently available – requires either additional survey or use of remote sensing.	As no further LHS surveys are planned need to encourage future recording of this attribute. Possibilities for remote sensing.

7.4 Ponds

A list of potential attributes for pond habitat is provided in Table 7.3, together with notes on their practicality for use in a priority habitat assessment framework. Much of the monitoring to date has been focused on priority species, for which ponds are important. However, a broader assemblage approach using a standard pond survey method and an associated predictive model PSYM (Biggs *et al*. 1998 and Pond Action, 2002) is available and has been used consistently across various pond surveys. PSYM is similar in design to the RIVPACS model used to predict river invertebrate assemblages as part of assessing biological condition. Similar to RIVPACS, PSYM is based on a database of biological data from ponds deemed to be in an unimpacted state. Unlike RIVPACS, it is based on both invertebrate and plant data. Observed assemblages are compared with those predicted under unimpacted conditions by PSYM, to provide a biological measure of habitat condition.

The baseline dataset used to develop the metrics for ponds came from surveys with broad coverage of England and Wales from a wide range of altitudes (0-550m), and land types (representative coverage of ITE land classes), so the resulting model is suitable for sites across England and Wales.

Ideally, PSYM should use information from both the plant and animal assemblages present in a water body. This is because, together, plants and animal groups span a complementary range of sensitivities to potential degradation factors. Combining plant and animal assemblages gives a range of taxa which span a number of trophic levels, occupy a variety of waterbody habitats and are long-lived, so that they can provide a temporally and spatially integrated measure of the current ecosystem state.

Although PSYM pond quality assessments should be made using both plant and invertebrate assemblages, a partial assessment can be made using just one assemblage if necessary. If this is the case, macroinvertebrates are likely to be the best single choice of organisms for assessing overall water body quality. Macrophytes have the advantage of being very quick to survey and can be used, if necessary, as a rapid bio-assessment method.

The metrics used in PSYM for the condition assessment of ponds are:

- **Invertebrates**: Average Score per Taxon (the BMWP score divided by the number of scoring taxa), the number of odonates and megalopterans, and the number of coleopteran families.
- **Plants**: the number of submerged and emergent plants, the trophic ranking score, and the number of uncommon plant species.

The predictions of unimpaired water body quality are made using physico-chemical data gathered from the water body. The main predictor variables fall into nine major categories. Of these, three are invariant (e.g. grid reference, altitude, base geology) and need only be assessed once. The remaining six categories of variables require on-site field measurement when each assessment is made. These are area, pH, shading, livestock littoral grazing, presence of an inflow and emergent plant cover. Further technical details on the NPS and PSYM methodologies can be found in Biggs *et al.* (1998) and Pond Action (2002) respectively.

The standard pond survey and associated PSYM approach are used in Countryside Survey and they currently constitute the only biological tool for pond quality assessment. It parallels biological assessments used in WFD reporting for lake and river water bodies. However, as explained in earlier sections, this type of approach has a range of limitations when seeking to characterise impacts on natural habitat function. As with rivers and lakes, this approach in ponds is focused on specific pressures related to water quality, particularly organic enrichment and eutrophication. This is somewhat understandable given the wide range of natural environmental conditions in ponds, but it does generate problems in using the approach to detect undesirable impacts on hydrology and physical habitat condition, as well as from non-native species. For this reason, PSYM needs to be seen as part of a suite of tools providing a holistic picture of priority pond habitat condition, rather than a single solution to monitoring pond condition.

Direct measurements of the environment are undertaken in CS and PondNet although in some cases these need to be modified to make them more appropriate for priority habitat condition assessment; these are generally the attributes which describe hydrology and morphology. Recording observations of this type is not onerous and could be incorporated relatively easily, to improve the ability of these schemes to meet this reporting need. These possibilities need to be explored further. The data illustrations in Section 8 rely on data already collected in CS2007, so it has not been possible to produce data illustrations of all attributes where data has not currently been collected in a suitable form.

Water quality analysis has previously been undertaken for CS2007 and volunteers are monitoring water quality with kits through the People, Ponds and Wildlife project, which is lottery-funded. When this funding comes to an end the water quality recording beyond water clarity is unlikely to be undertaken, unless further funding can be found; illustrating the need for funds even for citizen science monitoring.

Table 7.3 Potential pond attributes.

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
Water quality	Water quality is a fundamental characteristic that supports natural biological communities and ecological processes. Potential pollutants include nutrients, sediment and chemical contaminants.	Number of ponds below nutrient threshold 0.069 mg L^{-1} PO4P and 0.5 mg L^{-1} TON	Semi-natural concentrations from Clean Water for Wildlife report (2016) are used as thresholds. Defined increase in number of ponds reaching this target	NPS, LPS, CS, Clean Water for Wildlife, PondNet	The use of kits now allows easy measurements. Deploy these at as many sites as possible and encourage repeat monitoring.
		Turbidity	Defined increase in number of ponds with low turbidity.	NPS, LPS, CS07, PondNet Current data sources allow 4 class classification only.	Record turbidity at all survey sites, PondNet provide the necessary accessories to volunteers.
Acidity	The pH of the water is fundamental for sustaining key biological processes and characteristic assemblages. It varies naturally with geology, some landscape have characteristically acidic or alkaline ponds. This natural state must be distinguished from acidification which is an anthropogenic pressure. Some ponds have good buffering capacity, others have none and therefore are more sensitive to changes in pH. Therefore ANC is the best assessment of acidification.	ANC	Increase in ponds with ANC > 40 µeq	None	Promote water quality analysis for ANC in low alkalinity areas as part of the next Countryside Survey
Landscape connectivity	Pond numbers have declined historically. Sufficient pond density is needed to provide a network of characteristic habitat in its own right, but also to provide landscape scale refugia and stepping stones for a range of aquatic and terrestrial biota that are associated with ponds and other freshwaters.	Pond numbers	Increase in pond numbers (Bio2020 target of 30,000 new ponds created)	CS	Record all ponds in survey squares.

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
Hydrology	Naturally fluctuating water levels support distinctive biological communities with traits adapted to these conditions. Water levels influence hydrological connectivity. Though water levels are contextual in themselves, the naturalness of the hydrological regime is important.	Naturalness of hydrological regime	Defined increase in number of ponds with a natural hydrological regime (i.e. artificial inflows, outflows and water level control structures are absent)	None at present. Monitoring schemes would need to be adapted. CS, PondNet data available on number of inflows/outflows, but not other structures. In/outflows classified as wet or dry, but not natural/artificial	Record artificial inflows and outflows, and other structures
Hydrosere/Littoral	A natural hydrosere displays a natural transition from aquatic to terrestrial plants, so supports biodiveristy directly, but also provides important wetland habitat types for fauna. Hydroseres play a role in water quality and wave dissipation. A natural hydrosere promotes vertical and lateral connectivity.	Naturalness of shoreline	Defined increase in proportion of ponds with a natural shoreline	CS, PondNet, NPS, LPS	CS, PondNet, NPS, LPS all record pond management which should capture modified shoreline, but it is not clear cut. NPS/LPS recorded bank type explicitly. CS records bank management and states type in notes Current monitoring schemes would need to be amended to record this directly.
		Naturalness of substrate	Defined increase in proportion of ponds with natural substrate	CS, PondNet, NPS, LPS	Pond net records pondbase as geology, no obvious space for natural/artificial. Record at all ponds if possible, CS07 records indicate it can be difficult. Current monitoring schemes would need to be amended to record this directly.
		Presence of natural land use at 5m	Defined increase in proportion of ponds with natural land use at 5m from pond	CS07, PondNet	Record at all ponds surveyed

Element	Rationale	Possible attribute	Possible form of target	Existing datasets	Monitoring approach
		Presence of natural land use at 100m	Defined increase in proportion of ponds with natural land use at 100m from pond	CS07, PondNet	Record at all ponds surveyed
Shading	Over-shading of ponds has led to a loss of early successional ponds and pond species at the landscape scale. However, shaded ponds in woodland landscapes are also of value.	% perimeter overhung or percentage perimeter shaded	Pond habitat resource displaying full spectrum of shading from open ponds to woodland ponds.	CS, PondNet, NPS, LPS	Record at all ponds using % perimeter overhung or percentage perimeter shaded
Grazing	Grazing leads to areas of open habitat and even bare mud where there is poaching, whilst this is not necessarily desirable across the whole of the habitat resource it is a natural and essential element for many species.	Intensity of grazing	Pond habitat resource displaying full spectrum of grazing intensity from heavily grazed and poached to no evidence of grazing	CS, PondNet	Record at all ponds surveyed
Characteristic assemblages	Distinct habitats have characteristic species assemblages that contribute to overall biodiversity. A characteristic assemblage is an indicator that the habitat/ecosystem is functioning naturally	Biological quality (PSYM)	Defined increase in number of ponds in top quality categories.	NPS, LPS, CS07, PondNet	Monitor plants and macoinvertebrates and collect necessary variables to run PSYM.
Non-native invasive species	INNS can have strong effects on natural communities by altering competition for food and habitat, and altering food webs. INNS can also modify habitats directly.	Presence of INNS	Fewer ponds with invasive species	NBN is a central repository, includes data from CS and PondNet	1. Ensure all recording schemes and surveys submit their data to NBN 2. Examine NBN data at set time intervals
Fish	Fish can occur naturally in ponds, but many are stocked for angling. Angling related activities, including overstocking, can have negative effects on water quality and clarity, can introduce new species and diseases and can cause degradation of the shoreline. The impacts of angling should be picked up by the attributes above.	Natural fish assemblage	Increase in ponds with a natural fish assemblage	CS07, PondNet, NPS, LPS and NARRS. All record evidence of fish or of angling, in slightly different ways particularly regarding the impact of angling. None use dedicated fish surveys.	A lack of any fish surveys makes this difficult unless there is progress with DNA monitoring.

8. Illustrating the use of selected attributes and data sources

8.1 Rivers and streams

8.1.1 Preamble on data aggregation across attributes

Complications in data aggregation arise in the river network because, unlike lakes and ponds, rivers and streams are not discrete functional entities – they form part of wider river and stream networks. The national river network is divided up in different ways for different purposes, the most prominent being the division into WFD waterbodies. WFD monitoring and data processing is designed to report on these waterbodies, on the assumption that each is relatively internally homogeneous in terms of human impacts and natural function. However, there is variation within these waterbodies, and the recognition of impacts on headwater streams associated with each waterbody is particularly poor. As a result, the division of habitat resource zones used in this report (Table 4.1) does not map onto the WFD waterbody framework, and WFD data that are aggregated to waterbody-level are difficult to accommodate in the reporting of priority habitat condition. All this means that, although WFD-related data are very important to the assessment of priority habitat condition assessment, the spatial framework of WFD waterbodies is difficult to apply in a simple way.

The only viable way in which WFD data pre-aggregated to WFD waterbody-level might be used for priority habitat condition assessment is through assigning individual WFD waterbodies to the most appropriate habitat resource zone that is present. This is unlikely to generate much information on the headwater stream resource zones, since whilst many WFD waterbodies have associated headwater streams the status of the waterbody is typically assessed by monitoring of its larger river sections. It would yield more information for non-headwater resource zones, but even here we know that the level of patchiness of impacts within waterbodies will limit the resolution of the assessment (for instance, the priority river habitat map contains rivers and streams that occupy part of a WFD waterbody, with other parts of the waterbody excluded on naturalness grounds).

It is clear from this discussion that data aggregation into habitat resource zones needs to be primarily conducted using raw data at the monitoring site level, rather than pre-processed data aggregated to WFD waterbody level. Following aggregation into habitat resource zones, it would be possible to re-aggregate the data at WFD waterbody-scale (sensibly using WFD waterbody catchments rather than the waterbodies themselves) if this was deemed to be useful for planning protection and restoration of priority habitat at the local scale. However, this would need to recognise that some of the attribute assessments (particularly for headwater streams) would be based on the extrapolation of representative data and are therefore of low reliability at local scale.

8.1.2 Longitudinal connectivity

The EA River Obstructions point shapefile is available from the Environment Agency's Geostore data repository. Each point in the shapefile corresponds to the location of in-river obstructions (both natural and artificial, with the difference indicated); in addition, the attribute table holds information on the maximum hydraulic head (in metres) at each obstruction. This shapefile was used to assess longitudinal connectivity as part of the filtering process for the national mapping of priority river habitat (Mainstone *et al*. 2014). However, the assessment was crude in that it was only possible to classify whole WFD waterbodies, so there is no resolution of within-waterbody variation. Obstructions were spatially linked to each WFD waterbody, filtering out natural obstructions such as waterfalls because these are part of natural habitat function. Two sets of naturalness scores were then derived by aggregating data at WFD waterbody scale into a 5-class classification (Table 8.1). Maps of the two assessments, from the recent review of the river SSSI series, are shown in Figures 8.1 and 8.2.

Table 8.1 Class boundaries for assessing in-channel structures in rivers (as used in Mainstone et al. 2014).

Attribute	1	2	3	4	5
Number of structures in WFD waterbody	0-2	3-5	6-10	11-20	>20
Total vertical drop (metres) of structures in WFD waterbody	0-2	3-5	6-10	11-20	>20

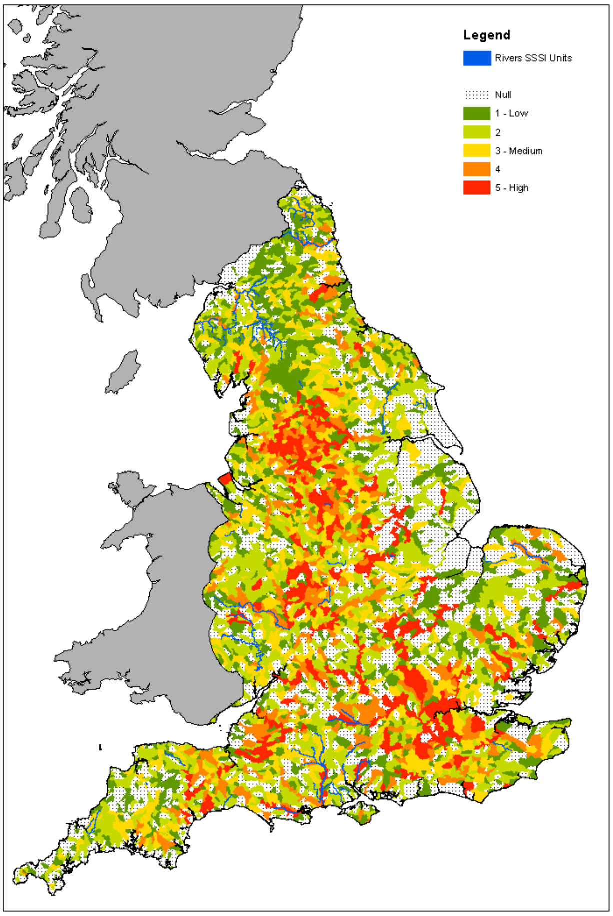

Figure 8.1 Classification of numbers of in-channel structures in WFD waterbody catchments (from Mainstone *et al*. Awaiting Publication).

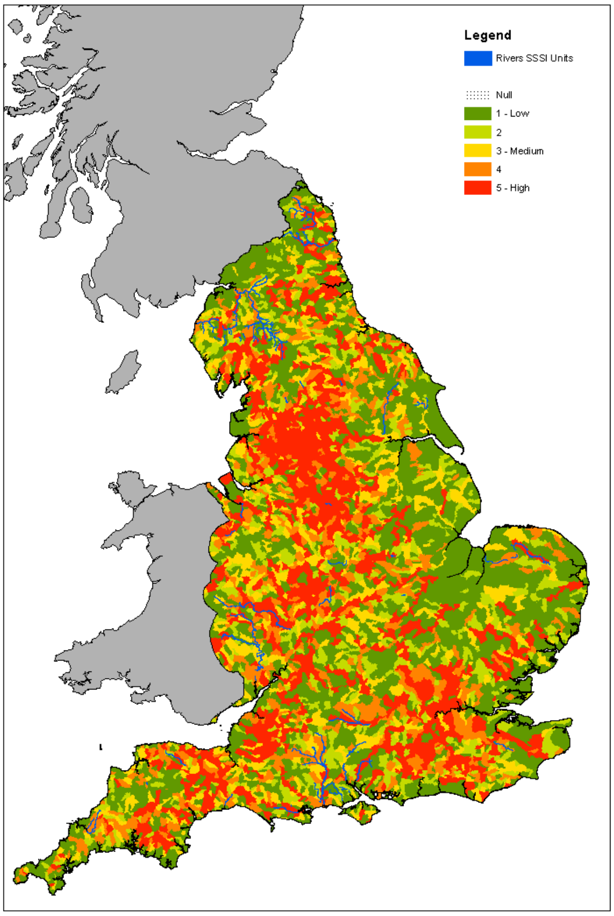

Figure 8.2 Classification of cumulative head of in-channel structures in WFD waterbody catchments
(from Mainstone *et al*. Awaiting Publication).

It has not been possible to re-aggregate all of the data by habitat resource zones for this report. However, all WFD waterbodies with artificial structures that contain some river/stream on the priority habitat map or restoration priorities map have been assigned to habitat resource zones (Table 8.2), and their class values (according to Table 8.1) are shown. Where a waterbody contains river/stream length in more than one habitat resource zone, it appears under each of those resource zones, i.e. there is double-counting in the figures. It has not been possible to assign waterbodies without any structures to habitat resource zones, so these are shown in a separate column for information.

Table 8.2 In-channel structures assessment for rivers
(values are numbers of WFD waterbodies which contain a given resource zone).

Zone		1a	2a	3a	1b	2b	3b	Unassigned
Number of WFD waterbodies	Class 5	7	0	6	22	36	33	3071
	Class 4	8	0	16	40	73	101	
	Class 3	28	3	23	73	147	234	
	Class 2	82	35	57	119	308	366	
	Class 1	211	209	156	142	749	782	

The numbers are difficult to interpret in this form because of the large number of unassigned waterbodies that contain no records of artificial structures. Waterbodies containing mapped priority habitat have considerable numbers of structures, but these are likely to be located on parts of the waterbody that are not on the priority habitat map. If nothing else the data illustrate the difficulty of using pre-aggregated WFD data in priority habitat condition assessment.

For a proper assessment, the classification in Table 8.1 would need to be modified to remove the explicit link to WFD waterbodies as a measure of spatial intensity of impact. An alternative measure based on a standard length of river/stream and compatible with the 6 habitat resource zones would be appropriate.

8.1.3 Lateral connectivity

During 2008-2010, CEH led a project for the EA on the ecological consequences of floods (Old *et al*., 2010), which investigated river-floodplain connectivity. It provides some useful examples of how lateral connectivity can be taken into account for priority habitat assessment purposes.

Frequency and depth of flooding were obtained from the National Flood Risk Assessment (NaFRA) dataset. NaFRA can be used to provide annual probabilities of inundation exceeding specific depths (for example 0, 25 and 45 cm). As NaFRA is designed to assess social and economic impacts of flooding, it is most suited to assessing infrequent extreme events - the resolution of frequent events is coarse. Channel-floodplain connectivity at catchment-level was assessed by considering the area inundated within a 5-year return period (corresponding approximately to NaFRA cells with inundation probability of 0.2). The project also looked at habitat and floodplain; for example, an empirical analysis of the inundation frequency of all priority BAP habitats throughout England and Wales was performed.

Using the NaFRA dataset is taxing (large dataset requiring advanced GIS pre-processing) but simpler shapefiles available from the EA Geostore can be used for quick assessments. Figure 8.3 below illustrates the concept. It is based on the flood map geodatasets forming part of the EA Flood Map project (Environment Agency 2011). On this figure, the river network is shown as blue lines, while the light blue polygons represent the natural 100-year return period floodplain (i.e. without flood defences). Flood defences are indicated as purple lines, and the area that is protected by flood defences is showed as transparent red polygons. This red area is not currently within the 100-year floodplain but would be if flood defences were removed. These shapefiles can be used at a national scale to show the proportion of land that floods naturally. When the EA dataset on flood defences is updated, repeat analyses can show changes in this proportion, with an increase in this proportion indicating an increase in natural lateral connectivity.

An increase in connectivity is only of ecological benefit if the use of the inundated land is receptive to wetland biodiversity. It is therefore also important to evaluate the extent of inundated land that is under semi-natural vegetation and how this is changing. The flood datasets can easily be superimposed on habitat geodatasets to determine this. Further thought is needed on which land cover datasets would be best to use for this purpose – remote sensing data is a possibility but currently has limitations in terms of the frequency of repeat assessments (see Section 6.9). Priority habitat inventories could be used – this would have the advantage of allowing the identification of any incompatibilities between the restoration of natural flooding and the location of existing priority habitat that may not benefit from that flooding. It would also be useful to including consideration of floodplain microtopography in these semi-natural habitats (using LIDAR) - those sites that retain natural microtopography (e.g. from old river courses and ox-bow lakes that have succeeded to terrestrialised wetland, and river terracing), or at least mimic this variation (Armitage *et al.* 2012) through sensitive restoration, provide the best and most holistic expression of floodplain wetland habitat mosaics.

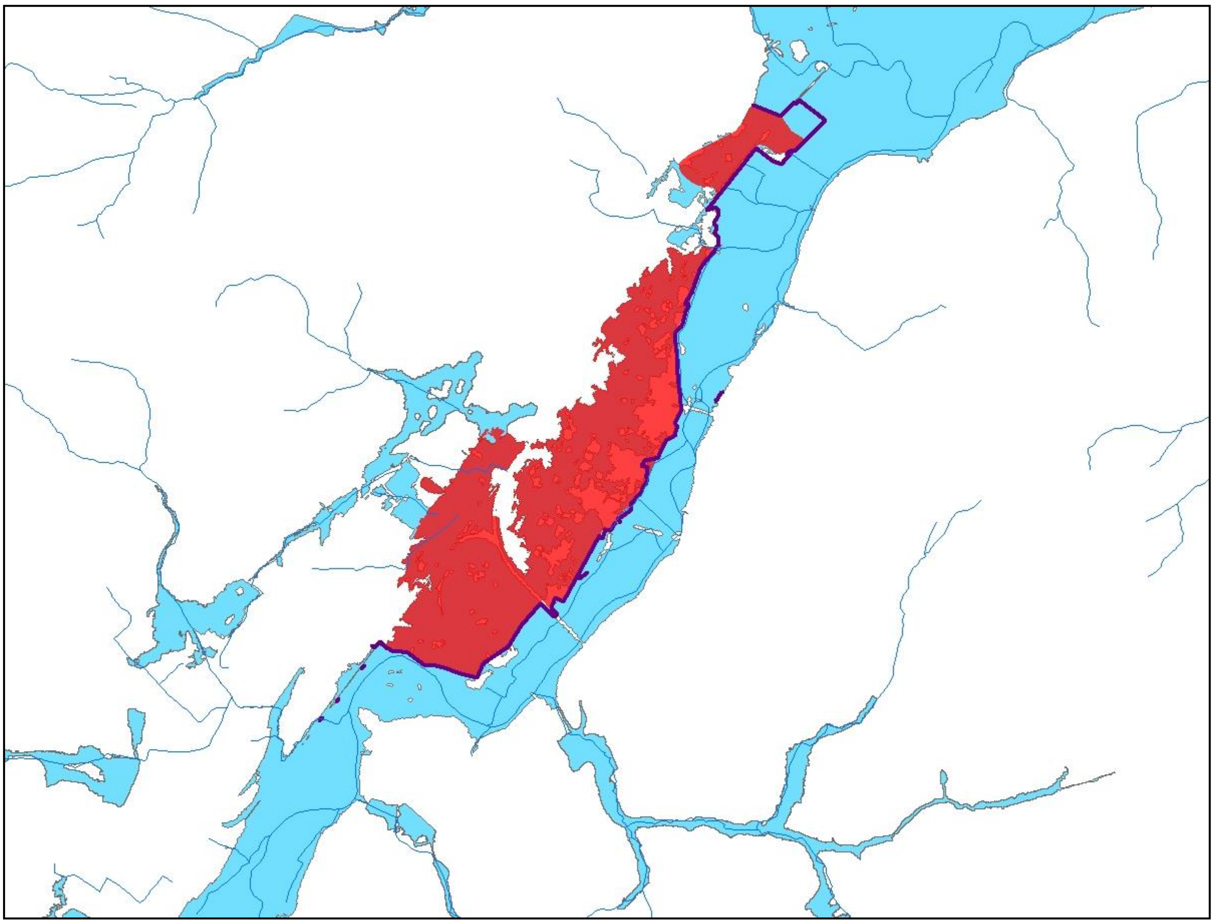

Figure 8.3 An illustration of how EA Flood Map datasets can be used to assess lateral connectivity of rivers.

Blue lines = rivers; light blue polygons = natural 100-year return period floodplain; purple = flood defences; transparent red polygons = areas protected by flood defences.

In terms of classifying the data for priority river habitat assessment purposes, Table 8.3 provides some nominal values that might form a starting point. Unfortunately the analyses necessary to illustrate what the results would look like for the 6 different habitat resource zones are too complex to undertake for this report, but at least the basis of the methodology has been clarified. In practice, the EA flood map does not have the functionality to evaluate shorter return periods – NaFRA would be needed to do this and it would take longer. It would be sensible to use the EA flood map to pinpoint where it would be most relevant to apply NaFRA.

Table 8.3 Suggested class boundaries for lateral connectivity of rivers.

Individual columns relate to different scales of flooding. The condition class of a site is given by the worst class value from all columns.

Condition class	% of natural floodplain inundated			% of inundated land under semi-natural vegetation		
	1-in-5	1-in-50	1-in-100	1-in-5	1-in-50	1-in-100
5	<30	<20	<10	<30	<20	<10
4	30-<50	20-<40	10-<30	30-<50	20-<40	10-<30
3	50-<70	40-<60	30-<50	50-<70	40-<60	30-<50
2	70-<90	60-<80	50-<70	70-<90	60-<80	50-<70
1	>90	>80	>70	>90	>80	>70

8.1.4 Naturalness of flow regime

The EA maintains a Water Resources GIS which contains a considerable amount of hydrological data that can be used for this element of the assessment. The GIS holds data on recent actual (observed or modelled) and naturalised river flows at numerous assessment points around England, which allows data to be generated on a WFD waterbody basis. The system has a standardised output structure which can be used for the purposes of priority habitat assessment. Modelled data values are produced at each assessment point for naturalised Q30 (higher flows), Q50, Q70 and Q95 flows (typical low summer flows) and these reference values can be compared with recent actual flow data to generate estimates of artificial deviations from the natural flow regime at various flow conditions.

The data that are generated only relate to the specific assessment points and waterbody outflow points, hence cannot indicate spatial variation in modifications to the natural flow regime within a WFD waterbody. Nevertheless, the system does provide a broad indication of flow modifications that is suited to priority habitat assessment, at least for larger rivers.

The standard output (Figure 8.4) indicates compliance with the Environment Agency's Environmental Flow Indicators (EFIs). The EFI flow standard is adapted from flow standards proposed by the Water Framework Directive (WFD) UKTAG required to support good ecological status (Table 8.4). This adaptation was made by the Environment Agency to use UKTAG recommendations within the existing abstraction regulatory regime in England. For the EFI compliance assessment, each river water body is allocated an Abstraction Sensitivity Band (ASB), indicating the sensitivity of ecology expected given the physical character of the river reach and upstream catchment. The EFI flow standards are based on percentage deviation from naturalised flows under different flow conditions (see Table 8.5), in accordance with UK TAG recommendations.

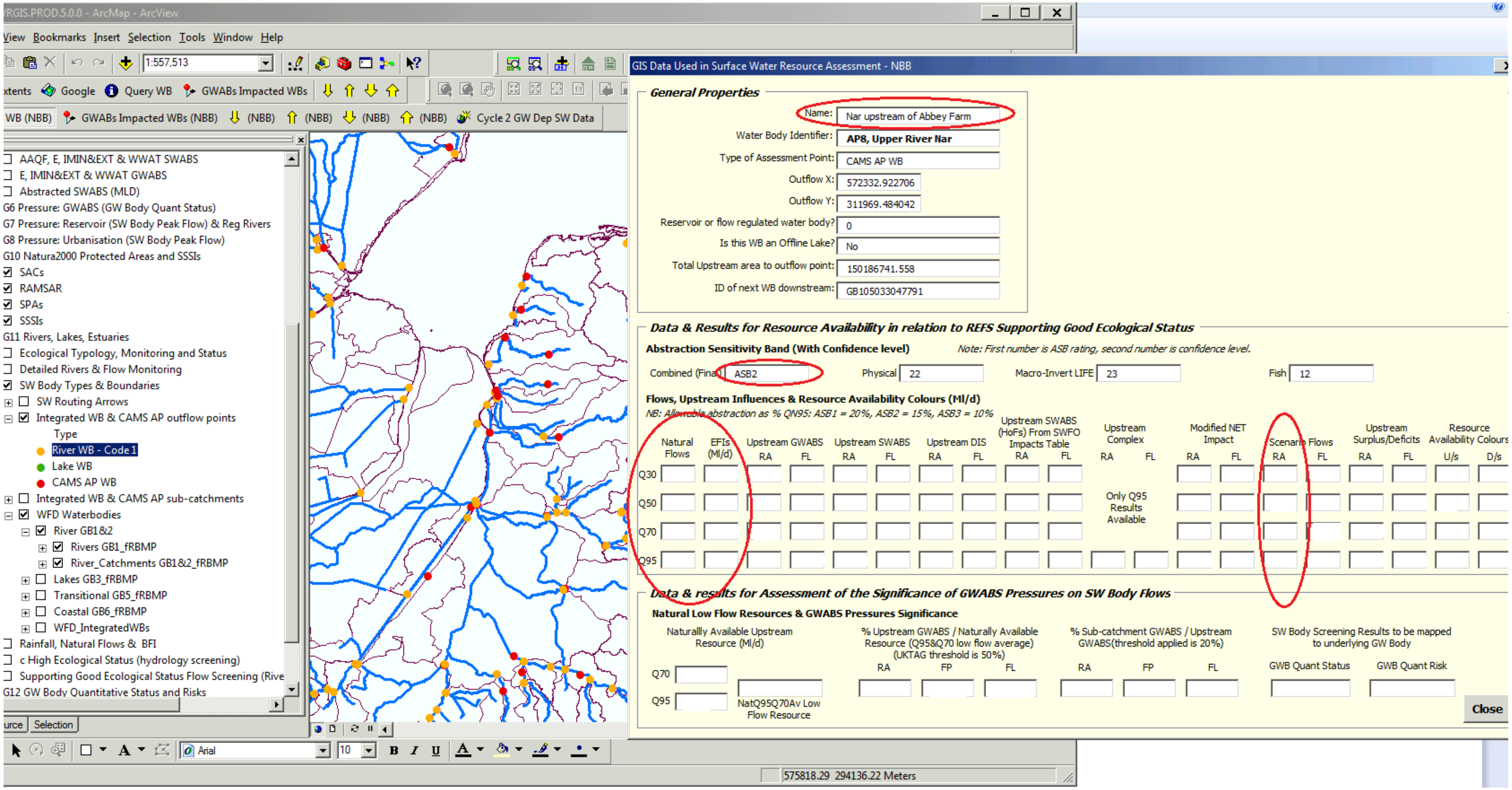

Figure 8.4 Standard output from the EA's Water Resources GIS.

Table 8.4 Flow standards to protect good ecological status of rivers
(from UKTAG 2008).
Values are % deviations from naturalised flows.

River types	Season	flow > Q60	flow > Q70	flow > Q95	flow < Q95
A1 (Clay rivers)	Mar – Jun	25	20	15	7.5
	Jul – Feb	35	30	25	15
A2 (Chalk rivers)	Mar – Jun	20	15	10	7.5
	Jul – Feb	25	20	15	10
B1, B2, C1, D1 (Low-medium altitude, hard geologies)	Mar – Jun	25	20	15	10
	Jul – Feb	30	25	20	15
C2, D2 (High gradient, hard geologies)	Mar – Jun	20	15	10	7.5
	Jul – Feb	25	20	15	10
Salmonid spawning & nursery areas (not Chalk rivers)	May – Sep	25	20	15	10
	Oct – Apr	20	15	flow > Q80 10	flow < Q80 7.5

Table 8.5 Environmental Flow Indicator (EFI) compliance level by Abstraction Sensitivity Band (ASB) and flow percentile.

	Q30	Q50	Q70	Q95
ASB1	30%	26%	24%	20%
ASB2	26%	24%	20%	15%
ASB3	24%	20%	15%	10%

The method of classifying deviations from naturalised flows into a 5-class system suitable for priority habitat condition assessment still requires some work. The method used as part of the filtering process for mapping priority river habitat could be used (Table 8.6). This would provide greater sensitivity to flow modifications than is possible with the EFI or UKTAG standards. The EFIs are additionally reliant on an expert judgement of ecological sensitivity, the appropriateness of which is unclear in relation to priority habitat condition.

For the purposes of the priority habitat assessment framework, the worst class for a waterbody at any Q value would sensibly be used to generate an overall class for flow regime. Since the outputs of the WRGIS only relate to either a single assessment point or a WFD waterbody outflow point, at the downstream end of the waterbody, there is no scope for generating data for headwaters using this system. The results could therefore only be applied to non-headwater parts of each WFD waterbody (i.e. Zones 1b, 2b and 3b). The assessment of headwaters in respect of flow regime will remain difficult, although there is potential to use other EA data sources such as the status of defined aquifers (which indicates over-licensed or over-abstracted situations). This would have to be given further consideration.

Table 8.6 Class boundaries for flow deviations used in mapping priority river habitat.

Flow condition (Qn value)	% Deviation				
	Class 1	Class 2	Class 3	Class 4	Class 5
a) Flows <Qn95	<5%	5-10%	10-25%	25-40%	>40
b) Flows Qn95-50	<5%	5-10%	10-25%	25-40%	>40
c) Flows Qn50-5	<5%	5-10%	10-25%	25-40%	>40
d) Flows >Qn5	<5%	5-10%	10-25%	25-40%	>40

Acquiring the data for priority habitat assessment purposes is complicated by data ownership and licensing issues. Some of the naturalised flow data are generated using a third party model (Low Flows Enterprise), part-owned by Wallingford Hydro Solutions (WHS). A licence would be required from WHS, detailing the precise data required and time period over which they would be used. WHS would also want a copy of the data generated, which would require an EA licence for them to formalise their access to EA-owned parts of the resulting dataset. These complications can be overcome but they do add a further resource burden to the assessment. Owing to these licensing difficulties, it was decided not to attempt an illustration of the assessment using real data for this report.

8.1.5 Attributes using River Habitat Survey (RHS) data

The following attributes and classifications were derived, unless otherwise indicated, solely using RHS baseline data (95/96 and 07/08) and CS survey data (CS 2000 and CS 2007). Note that RHS baseline data from 1994 were excluded because 1994 constituted a trial of the method and inconsistencies occurred in recording habitat features.

The habitat resource was divided into the 6 mutually exclusive zones as described in Section 4 (i.e. the priority river habitat map, the restoration priorities map and the wider habitat resource, distinguishing headwaters from larger rivers). Headwaters were defined using the UKBAP river priority habitat descriptions (JNCC, 2011), as waterbodies of first or second Strahler order, within 2.5 km of the source. Note that this division of data was performed for illustrative purposes only, since the priority river habitat map and restoration priorities map are subject to on-going refinement (note only the 2014 version of the maps were available for use at the time of the analysis).

Flow habitat mosaic attribute (FHMA)

At the reach scale, natural rivers have a diversity of flow types which arise from a combination of water quantity, slope and the patch-scale channel morphology. A diverse range of flow habitats arising from natural river function sustains habitats for characteristic biota and hence promotes biodiversity. Diverse flow habitat patches also promote resilience to hydrological events. Flow type diversity has been reduced through changes to flow regimes and channel simplification. The Flow Habitat Mosaic Score is a site-level measure of the river habitat mosaic, although restricted to submerged in-channel habitats.

The FHMA uses the 'flow subscore' that forms part of deriving the HQA. The data are a combination of the spot check and sweep up stages. The flow types are recorded at each of the ten spot checks (free fall, chute flow, broken standing wave, rippled flow, upwelling, smooth flow, no flow, dry channel, not visible). Each flow type scores 1 if recorded in the reach, 2 if recorded at 2 or 3 spot checks, 3 if 4 or more spot checks. Dry river beds and 'not visible' occurrences score 0. Then, at the sweep up stage, 1 is added to the score for each flow type recorded that was not recorded in the spot checks, and another 1 is added for the occurrence of marginal dead-water. The maximum possible value of the score is 14 (max from spot checks is 10, max from sweep up is 4).

The FHMA ranges from 0 to 14, and has been banded equally into 5 classes, with class 1 representing the highest flow diversity and class 5 the lowest (Table 8.7). The rationale for this is that higher habitat complexity is generally associated with natural processes and habitat function, although this is not always the case and care needs to be taken in interpreting data (high values associated with low Habitat Modification Scores are a good indication that habitat diversity is a result of natural processes). Table 8.8 shows how the available data classify across the six zones of the habitat resource. Generally the pattern is as expected, with more consistently diverse mosaics in sites falling within the priority habitat map (Zones 1a and 1b) and less diverse mosaics in sites falling within the wider habitat resource. On-going refinements to the priority habitat map should accentuate the pattern.

Table 8.7 Values of the FHMA and corresponding condition classification for rivers.

Values of the FHMA	Condition class
0	5
1	
2	
3	4
4	
5	
6	3
7	
8	
9	2
10	
11	
12	1
13	
14	

Table 8.8 Classification of sample riverine sites according to FHMA.
See Figure 4.1 for an explanation of zones.

Zone		Headwater streams			Non-headwaters		
		1a	2a	3a	1b	2b	3b
Number of sites	Class 5	18	18	171	6	20	57
	Class 4	47	58	713	48	224	988
	Class 3	132	157	909	180	400	1243
	Class 2	208	127	355	226	265	553
	Class 1	51	9	19	29	9	38
	TOTAL	456	369	2167	489	918	2879
% of sites	Class 5	1.2	2.2	2.0	3.9	4.9	7.9
	Class 4	9.8	24.4	34.3	10.3	15.7	32.9
	Class 3	36.8	43.6	43.2	28.9	42.5	41.9
	Class 2	46.2	28.9	19.2	45.6	34.4	16.4
	Class 1	5.9	1.0	1.3	11.2	2.4	0.9

Riparian vegetation complexity attribute (RVCA)

Riparian habitat is a vital component of the river ecosystem. It supports characteristic water-associated flora and fauna, including wetland plants, birds, mammals, and the aerial stages of many aquatic invertebrates. It supports key processes such as the input of natural organic matter to the channel, provides shading and woody material, and interacts with the channel to generate characteristic habitat mosaics. Riparian vegetation complexity has been reduced through flood defence and land drainage measures and intensive land management.

RVCA is a measure of the structural integrity of the riparian zone. It is derived from the spot check stage of RHS. At each spot check the vegetation structure of both bank tops is assessed as bare (scores 0), uniform (scores 1), simple (scores 2) or complex (scores 3). The maximum possible value of the score is 60 (equivalent to complex vegetation on both banks at all 10 spot checks).

The RVCA ranges from 0 to 60, and was banded equally into 5 classes, with class 1 representing the highest bank vegetation complexity and class 5 the lowest (Table 8.9). The rationale for this is that riparian habitat complexity is generally associated with natural processes and habitat function, although this is not always the case and care needs to be taken in interpreting data (high RVCA scores associated with low Habitat Modification Scores are a good indication that habitat diversity is a result of natural processes).

Available data are classified across the six zones of the habitat resource in Table 8.10. There is no clear pattern across the zones, and sites on the priority habitat map (Zones 1a and 1b) are generally not scoring higher than those outside of the map. This may partly be a function of the need for refinements to the map, or the existence of sites on the map that require some physical restoration, or limitations of the available data in characterising the different zones. However, it may also reflect the scope for river sections which are not functioning naturally in many respects to exhibit reasonable levels of habitat complexity through sympathetic riparian management.

Table 8.9 Values of the RVCA and corresponding condition classification for rivers.

Values of the RVCA	Condition class
0-12	5
12-24	4
24-36	3
36-48	2
48-60	1

Table 8.10 Classification of sample riverine sites according to RVCA.

See Figure 4.1 for an explanation of zones.

Zone		Headwater streams			Non-headwaters		
		1a	2a	3a	1b	2b	3b
Number of sites	Class 5	4	4	32	0	10	45
	Class 4	93	53	496	97	186	772
	Class 3	149	124	835	189	378	1157
	Class 2	181	134	680	152	267	756
	Class 1	29	54	124	51	77	149
	TOTAL	456	369	2167	489	918	2879
% of sites	Class 5	0.9	1.1	1.5	0.0	1.1	1.6
	Class 4	20.4	14.4	22.9	19.8	20.3	26.8
	Class 3	32.7	33.6	38.5	38.7	41.2	40.2
	Class 2	39.7	36.3	31.4	31.1	29.1	26.3
	Class 1	6.4	14.6	5.7	10.4	8.4	5.2

Riparian tree attribute (RTA)

Trees constitute a vital component of riparian habitat, providing direct habitat for species exploiting the riparian zone. However, they are also critical for the full expression of the in-channel habitat mosaic, providing direct habitat through exposed and underwater root systems and the supply of woody material and leaf litter, and also helping to generate lateral channel movement (critical for characteristic habitat mosaics) and providing shade. Riparian tree density has been reduced through flood prevention, land drainage and intensive land management. The RTA is a measure of the prevalence of trees in the riparian zone. It is derived from the sweep-up stage of RHS, specifically the ‘trees’ section. The RTA is based on the presence and extent of 4 elements: shading of the channel, boughs overhanging the channel, bankside roots and submerged roots. Each is recorded as absent, present or extensive. The RTA classifies sites according whether the 4 tree-related elements are present or not at the site, and if present, how many are extensive. Class 5 sites show none of the elements whilst in class 1 at least 3 of the 4 elements are extensive (Table 8.11).

The relationship between riparian tree cover and habitat condition is not simple. Patchy tree cover (such as would be provided naturally by tree fall and the action of herbivorous animals) provides the best opportunities to cater for the full characteristic community of a river. Whilst higher levels of tree cover than this are desirable to combat rising water temperatures caused by climate change, they may or may not be desirable from a conservation perspective – in woodland higher cover would be expected and desirable whilst in more open landscapes the reverse is the case. However, since the highest cover level used in RHS is only >33% (‘Extensive’), even the highest RTA class can be achieved with only patchy tree cover. This means that the classification can be used with confidence in characterising habitat condition, since it considers a wide range of tree cover values as being of high conservation value and consistent with natural function.

Available data are classified across the six zones of the habitat resource in Table 8.12. Paradoxically, results imply fewer riparian trees in sites on non-headwaters on the priority habitat map (Zone 1b) compared to the rest of the non-headwater habitat resource (Zones 2b and 3b). This may be a genuine result, since the original mapping exercise used RHS data on physical habitat modifications rather than direct data on physical habitat provision such as derived from riparian trees. The picture may change as the priority habitat map is subject to refinement, but it may well be the case that riparian tree cover and their interactions with the channel will need to be increased significantly in sites on the priority habitat map as part of measures to improve condition.

Table 8.11 Condition classification for rivers using RTA.

RTA	Condition class
All 4 elements absent	5
1 or more elements present	4
1 element extensive	3
2 elements extensive	2
3 or 4 elements extensive	1

Table 8.12 Classification of sample riverine sites according to RTA.

See Figure 4.1 for an explanation of zones.

Zone		Headwater streams			Non-headwaters		
		1a	**2a**	**3a**	**1b**	**2b**	**3b**
Number of sites	Class 5	201	25	395	99	124	593
	Class 4	130	106	784	173	440	1323
	Class 3	77	148	615	131	208	539
	Class 2	33	64	289	62	83	280
	Class 1	15	26	84	24	63	144
	TOTAL	456	369	2167	489	918	2879
% of sites	Class 5	20.2	13.5	20.6	44.1	6.8	18.2
	Class 4	35.4	47.9	46.0	28.5	28.7	36.2
	Class 3	26.8	22.7	18.7	16.9	40.1	28.4
	Class 2	12.7	9.0	9.7	7.2	17.3	13.3
	Class 1	4.9	6.9	5.0	3.3	7.0	3.9

Woody material attribute (WMA)

Woody material in river channels varies in size from small twigs to whole trunks, and is a vital natural component of a healthy river ecosystem. It falls from bankside trees and lodges in the channel or is carried by flow until it settles. Woody material in the channel: provides shelter, attachment substrate and food for an array of fauna; contributes to water levels and provides drought refugia; generates patchy scouring of the bed that is critical to a diverse habitat mosaic; retains coarse sediments and inhibits channel incision; and deflects flows in ways that encourage channel movement and hence additional habitat diversity. The prevalence of woody material has been reduced through channel clearing for flood prevention and fishing access, and also through the loss of riparian trees.

The WMA is a measure of the prevalence of woody material in the channel and is derived from the sweep-up stage of RHS, specifically the 'trees' and 'special features' section. The WMA is based on the presence and extent of 3 elements: fallen trees, large woody material and debris dams. Each is recorded as absent, present or extensive. The WMA classifies sites according to whether the 3 elements are present or not at the site, and if present, how many are extensive. Class 5 sites show none of the elements whilst in class 1 all 3 elements are extensive (Table 8.13).

Available data are classified across the six zones of the habitat resource in Table 8.14. All zones of the habitat resource score poorly according to this attribute, which reflects a combination of low levels of riparian tree cover in the habitat resource and a strong management focus on removal of woody material from channels. Interestingly, headwaters on the priority habitat map score worst of any zone when they might be expected to score highest, although the differences between zones are relatively minor. Again, this probably reflects the lack of explicit consideration of riparian trees and woody material in the derivation of the original priority habitat map, and the need to put in place restoration measures to restore the presence of both.

Table 8.13 Condition classification for rivers using WMA classification.

WMA	Condition class
All 3 elements absent	5
1 or more elements present	4
I element extensive	3
2 elements extensive	2
3 elements extensive	1

Table 8.14 Classification of sample riverine sites according to WMA.

See Figure 4.1 for an explanation of zones.

Zone		Headwater streams			Non-headwaters		
		1a	2a	3a	1b	2b	3b
Number of sites	Class 5	313	161	1389	253	506	1750
	Class 4	132	187	712	221	399	1071
	Class 3	8	16	48	11	9	38
	Class 2	2	3	16	3	4	19
	Class 1	1	2	2	1	0	1
	TOTAL	456	369	2167	489	918	2879
% of sites	Class 5	68.6	43.6	64.1	51.7	55.1	60.8
	Class 4	28.9	50.7	32.9	45.2	43.5	37.2
	Class 3	1.8	4.3	2.2	2.2	1.0	1.3
	Class 2	0.4	0.8	0.7	0.6	0.4	0.7
	Class 1	0.2	0.5	0.1	0.2	0.0	0.0

Exposed sediments attribute (ESA)

Exposed riverine sediments arise from natural hydromorphological processes. Their size and extent vary over time with water levels. They provide microhabitats with unique biological assemblages. They influence local hydraulics and the deposition of fine sediments and organic material. The occurrence of exposed riverine sediment has been reduced by dredging and flood risk prevention, water abstraction and flow regulation (which permanently submerges them).

ESA is a measure of the prevalence of unvegetated geomorphic mid-channel bars, side bars and point bars. It was derived from the spot check and sweep up stages of RHS. Mid-channel bars and side bars are recorded at the sweep up stage as absent, present or extensive. Point bars are also recorded in this way but only since ~2007 - previously they were enumerated at the spot check stage only. To be able to apply the same absent/present/extensive framework to the 3 elements, pre-2007 counts had to be converted to present/extensive categories. This was achieved by using the 2007 EA RHS baseline and the CS2007 results to directly compare the number of point bars recorded in the field and the sweep up categorisation applied at the site level. This indicated that the threshold at which point bars were considered to be extensive was 7.

The ESA classifies sites according whether the 3 elements are present or not at the site, and if present, how many are extensive. Class 5 sites show none of the elements whilst in class 1 all 3 elements are extensive (Table 8.15).

Available data are classified across the six zones of the habitat resource in Table 8.16. Scores are low across all zones of the habitat resource. Some rivers have greater natural propensity to generate exposed sediments (i.e. those with high coarse sediment supply and high flow variability), and so relatively low scores might be expected in some rivers. It is possible that the class boundaries used here are too stringent – it is difficult to achieve ‘extensive’ coverage of exposed sediments, and the RHS categorisation of feature cover might therefore not be that helpful in this context. However, exposed sediments have declined considerably in many rivers as a result of channel engineering, maintenance and flow regulation, and a high proportion of low scores might be expected as a result of this.

This attribute should generate higher scores when applied to ‘active shingle rivers’, which are specifically included in the UK definition of priority river habitat. Scores for lower energy rivers with less flow variation, such as chalk streams, would be expected to be lower naturally (Davies and Bass 2006 usefully describe dynamic biotope variation in an English chalk stream). However, exposed sediments are an important component of the habitat mosaic wherever they would naturally occur (and they do naturally occur on chalk streams, albeit often under encroaching marginal vegetation). This implies a reference condition may be needed to address natural variation – alternatively, the variation could be addressed by the way we frame restoration/improvement targets for the habitat resource (see Section 10).

Table 8.15 Condition classification for rivers using ESA.

ESA	Condition class
All 3 elements absent	5
1 or more elements present	4
1 element extensive	3
2 elements extensive	2
3 elements extensive	1

Table 8.16 Classification of sample riverine sites according to ESA.

Zone		Headwater streams			Non-headwaters		
		1a	2a	3a	1b	2b	3b
Number of sites	Class 5	226	161	1506	163	458	1855
	Class 4	225	198	646	304	435	1004
	Class 3	29	49	41	67	75	58
	Class 2	2	6	4	6	8	0
	Class 1	0	0	0	0	0	0
	TOTAL	482	414	2197	540	976	2917
% of sites	Class 5	30.2	46.9	63.6	46.9	38.9	68.5
	Class 4	56.3	44.6	34.4	46.7	47.8	29.4
	Class 3	12.4	7.7	2.0	6.0	11.8	1.9
	Class 2	1.1	0.8	0.0	0.4	1.4	0.2
	Class 1	0.0	0.0	0.0	0.0	0.0	0.0

Riparian invasives attribute (RIA)

Non-native plant species can have a strong influence on the structure and functioning of riparian zones, and can alter characteristic assemblages to a considerable degree. Three invasive plants in particular are widespread across England and are associated with degradation of the riparian zone and wider river habitat: Japanese knotweed (*Fallopia japonica*), giant hogweed (*Heracleum mantegazzianum*) and Himalayan balsam (*Impatiens glandulifera*).

RIA classifies sites according to the presence and the extent of the 3 main invasive plants. It is derived from the sweep-up stage of RHS. Each of the three main riparian invasive plants is recorded as absent, present or extensive. It classifies sites according to whether invasives are present or not at the site, and if present, how many of the invasive species are extensively established. Class 5 sites are the most afflicted by the main 3 riparian invasives, whilst class 1 sites are free of them (Table 8.17).

Available data are classified across the six zones of the habitat resource in Table 8.18. Whilst classification results are strongly skewed towards absence of these species across all zones, the species are less conspicuous at sites on the priority habitat map (Zones 1a and 1b) relative to other zones. This is likely to be a result of non-native species being explicitly considered in the original priority habitat mapping report.

Table 8.17 Condition classification for rivers using RIA.

RIA	Condition class
3 species extensive	5
2 species extensive	4
I species extensive	3
1 or more species present	2
All 3 species absent	1

Table 8.18 Classification of sample riverine sites according to RIA.

See Figure 4.1 for an explanation of zones.

Zone		Headwater streams			Non-headwaters		
		1a	2a	3a	1b	2b	3b
Number of sites	Class 5	0	0	0	0	1	1
	Class 4	0	0	0	0	1	2
	Class 3	0	5	9	3	19	92
	Class 2	2	22	51	27	135	374
	Class 1	454	343	2108	460	766	2433
	TOTAL	456	370	2168	490	922	2902
% of sites	Class 5	0.0	0.0	0.0	0.0	0.1	0.0
	Class 4	0.0	0.0	0.0	0.0	0.1	0.1
	Class 3	0.0	1.4	0.4	0.6	2.1	3.2
	Class 2	0.4	5.9	2.4	5.5	14.6	12.9
	Class 1	99.6	92.7	97.2	93.9	83.1	83.8

8.1.6 Characteristic assemblages

Similarity indices can be used to compare the taxonomic composition of a biological assemblage to a reference biological community. In theory these indices can provide a true biodiversity-based measure of impacts on biological communities, which should be capable of broadly reflecting the full range of impacts on aquatic biota whilst allowing targets to be directly related to levels of acceptable biodiversity disturbance. Such an approach contrasts with current WFD classification methods and reporting, which use metrics that aggregate taxonomic information into an index which is then compared with a predicted reference (unimpacted) index value. With these latter methods it is possible to artificially disturb a community but register no change in a metric's score, or even register an increase in score which might be interpreted as indicative of a less disturbed community.

There are many challenges associated with the use of similarity indices in this way, not least of which are the difficulties in generating a robust prediction of a reference community at a given site. This can be achieved through the use of local reference sites, although in practice this is a difficult approach to standardise and report on in a consistent way at national-scale. An alternative approach is to use a robust predictive model of reference communities, which is currently only available for the benthic macroinvertebrate community - in the form of RIVPACS.

RIVPACS provides the predictive data for the application of WFD macroinvertebrate metrics, and a great deal of effort has been expended by the UK environment agencies to make the process statistically robust. Whilst WFD processes only use the RIVPACS model to generate reference WFD metric values, the model actually generates a complete taxonomic prediction of the reference community for a site, together with an estimate of the confidence of the prediction. This can be used to make a direct comparison with the observed community at a monitoring site using a similarity index, which assesses the number of taxa the observed and predicted assemblages have in common and the number that are unique to each.

The Bray-Curtis index is one of the most common similarity indices and the adaptation by Van Sickle (2008), termed the BC index, and has been used in this data illustration.

$$BC = \Sigma|O_k - P_k| / \Sigma(O_k + P_k)$$

Where O_k is the presence (1) or absence (0) of each of the taxa predicted to occur at the site by RIVPACS and Pk is the probability of occurrence of each of the k taxa. It ranges from zero where the observed community is exactly the same as the reference community, to a value of 1 where there are no species in common.

In this data illustration the index has been applied to species-level Countryside Survey data (mainly from headwater streams) using RIVPACS predictions for each site. We only used samples where RIVPACS could generate a reliable prediction of the expected community; many of the Countryside Survey stream sites are on small headwater streams that are not well-represented in the reference site dataset upon which the RIVPACS model bases its predictions. The model provides a warning where it judges the prediction to be unreliable. We applied the BC index only to those sites that had a >1% chance of being of a type represented within the RIVPACS predictive model. We calculated the BC index based on the full list of species with a probability of occurrence >0. We also calculated the O/E Taxa value for each of the samples based on the full list of species predicted to occur (not based on the BMWP-families predicted to occur, i.e. not O/E Ntaxa). The distribution of values generated is shown in Figure 8.5. It is strongly skewed towards the lower similarity end, with no sites exhibiting particularly strong similarity with predicted reference assemblages (i.e. values towards zero). This is problematic since the data have to be classified but it is not clear whether the relatively low levels of similarity are primarily a result of impacts or limitations in generating a contemporary and robust prediction of the reference assemblage.

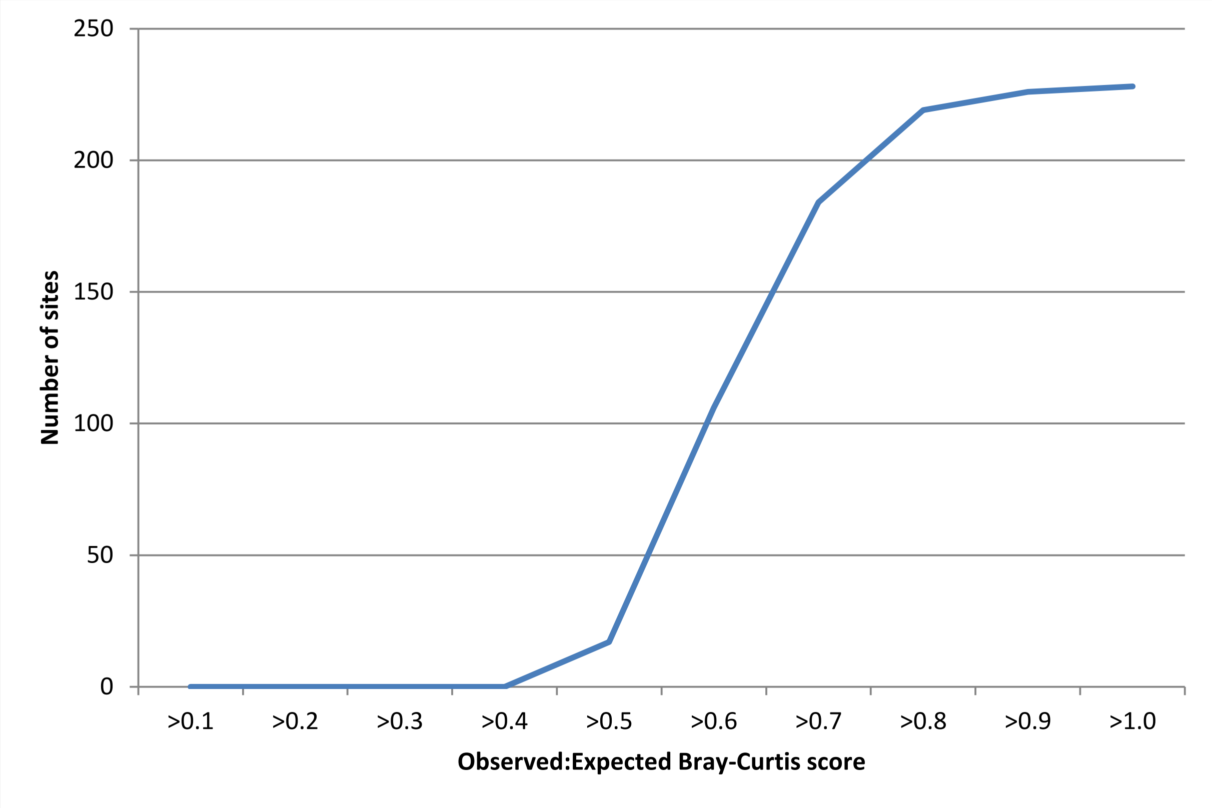

Figure 8.5 Cumulative frequency distribution of similarity (BC) index scores from the Countryside Survey stream dataset.

Whilst significant impacts on similarity scores would be expected given the widespread and multiple impacts on English rivers and streams, it is also known that the coverage of the RIVPACS reference site network (on which predictions are based) is limited, particularly in relation to headwater streams and also certain river types such as chalk streams. In addition, the RIVPACS model uses historical data on reference sites, but assemblages undergo natural change over time in response to a range of factors including year-to-year variation in weather (e.g. rainfall) and longer term climate change. RIVPACS addresses the limitations of reference sites by providing a 'suitability' score for each prediction, indicating the confidence of the prediction. Data with low suitability scores have been removed to generate Figure 8.5, so the lack of high similarity scores would appear to be for other reasons, either real impacts or natural temporal variation/change in assemblages, or a combination of both.

For the purposes of this data illustration, class boundaries have been chosen to dampen down the skew in the distribution of values (Table 8.19), so that the best performing sites can be classed at least as Class 2. However, further investigations are needed to determine whether this is appropriate. This generates a distribution of class values across habitat resource zones as shown in Table 8.20. The low number of sites available in Countryside Survey makes it much more difficult to draw meaningful conclusions from the data than for RHS-generated attributes. There is no relationship between the priority habitat map and classification results that suggest more characteristic (less modified) communities. This could be a function of low sample sizes or problems with characterising reference assemblages.

Table 8.19 Condition classification for rivers using the BC index.

BC values	Condition class
0-0.3	1
0.3-0.5	2
0.5-0.7	3
0.7-0.85	4
0.85-1.0	5

Table 8.20 Classification of sample riverine sites according to the BC index (using Countryside Survey data from 2007 only).

See Figure 4.1 for an explanation of zones.

Zone		Headwater streams			Non-headwaters		
		1a	2a	3a	1b	2b	3b
Number of sites	CLASS 1	0	0	0	0	0	0
	CLASS 2	0	0	3	1	2	4
	CLASS 3	2	3	11	5	2	11
	CLASS 4	0	0	4	1	0	5
	CLASS 5	0	0	0	0	0	0
	TOTAL	2	3	18	7	4	20
% of sites	CLASS 1	0.0	0.0	0.0	0.0	0.0	0.0
	CLASS 2	0.0	0.0	16.7	14.3	50.0	20.0
	CLASS 3	100.0	100.0	61.1	71.4	50.0	55.0
	CLASS 4	0.0	0.0	22.2	14.3	0.0	25.0
	CLASS 5	0.0	0.0	0.0	0.0	0.0	0.0

8.2 Lakes

8.2.1 Preamble

Due to a lack of data on many lakes there are large uncertainties about whether sites should be located on the PHM, on the restoration priorities map, or neither map. Consequently no attempt has been made to differentiate between the habitat resource zones in Table 4.1 for the following data illustrations. However, it is still important that sufficient monitoring is undertaken in these different zones as uncertainties reduce, and that ultimately assessments are made in this way. Separate assessment is also needed by lake type, because there are four different lake priority habitats based on lake type (this is different to the situation with priority river habitat, where there is one priority habitat containing a wide range of river types). Presently there are only five known aquifer-fed naturally fluctuating meres, all of which are designated sites and have no other monitoring undertaken on them. Therefore, no data illustrations are provided for them in this section.

The lake inventory characterises sites according to alkalinity types not priority habitat types, so alkalinity types have been used as a surrogate for priority habitat types in the data illustrations here. It is acknowledged that these are different methods of discrimination, which will not always be equivalent, but it is the best that can be done with the available data. In the following data illustrations eutrophic lakes are those typed as high alkalinity, mesotrophic lakes are those typed moderate alkalinity or marl lakes, and oligotrophic and dystrophic lakes are those typed as low alkalinity in line with previous priority habitat work (JNCC, 2011).

8.2.2 Longitudinal connectivity

This refers to the natural connectivity up- and downstream in lakes connected to a river system. Natural connectivity enables all species to complete their lifecycles and enables natural flushing rates and residence times that allow the movement of substances through the system. As the most common forms of obstructions to longitudinal connectivity are weirs, dams and sluices, their absence also allows natural water level fluctuations (discussed further under hydrological regime).

Some impounding structures are the reason for a lake's existence, as well as the reason for impacts on the river or stream that is being impounded. The decision at the site level as to what to do in these situations will be dependent on a range of factors discussed further in Mainstone *et al* (2016). Regardless of this issue a target for increasing the natural longitudinal connectivity of lakes across the habitat resource is desirable, even though all lakes being free of all obstructions is neither possible, due to socio-economic constraints, or desirable in all situations.

The number of obstructions up- and downstream of a lake was analysed. At the time of this analysis the lake inventory and the intelligent river network were not integrated, so it was not possible to be clear whether the obstructions were up- or downstream and how far they were from the lake. Instead the number of obstructions within the river stretch to which the lake is attached was counted. The river stretches between digital 'nodes' are discrete units in the intelligent river network and it is these units that were used in the analysis. Consequently the river stretches are not a uniform length and not all the obstructions that could impact a lake will have been captured, since obstructions further up- and downstream in adjoining stretches also have the capacity to influence water level fluctuations, flushing rates and the movement of species. Consequently, this should be seen as a first attempt at understanding the extent of impacts on the longitudinal connectivity of lakes, which may be improved as further data and tools become available.

Table 8.21 shows that the number of obstructions is relatively constant across all lake types and many lakes are recorded as having no obstructions. This may in part reflect current datasets, because, as with many of the lake attributes, there has been little data collection specifically for this purpose. Many lakes used for recreation and amenity have small sluices to maintain more uniform water levels and these are likely to be under-recorded; in contrast the larger weirs and dams found on lakes used for water supply are expected to have been captured. This picture may change with the introduction of the EA 'app' to record obstructions, but the recording of structures on lakes will need to be actively encouraged to ensure this.

Table 8.21 Analysis of the number of obstructions near lakes.

	Class	Number of obstructions	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	0	2573	436	478
	Class 2	1-2	448	98	95
	Class 3	3-5	226	36	46
	Class 4	6-20	283	60	70
	Class 5	20+	242	39	39
% of lakes	Class 1	0	68.21	65.17	65.66
	Class 2	1-2	11.88	14.65	13.05
	Class 3	3-5	5.99	5.38	6.32
	Class 4	6-20	7.50	8.97	9.62
	Class 5	20+	6.42	5.83	5.36

8.2.3 Lateral connectivity with surrounding land and wetlands

A natural shoreline enables the development of a natural transition from fully aquatic to fully terrestrial conditions. This ecotone provides important habitat and ecosystem functions. The LHS lake habitat modification score includes a shoreline modification score (see Table 8.22). This has been calculated for 66 lakes from the 2012 LHS database. A number of these lakes have been surveyed a number of times, usually in 2004/5 and 2008/9. The most recent survey was used in the data analysis as the later surveys tended to include a greater number of hab-plots (these are 15m wide survey plots extending from the riparian to the littoral zone) and the most up-to date information was deemed preferable. However, it was noted that many sites had quite different scores across the surveys, with more recent surveys having lower shoreline modification scores than earlier surveys, despite there being no change on the ground. Although thorough quality assurance of the results is outside of the scope of this work, it was noted that these surveys were often undertaken by different surveyors. The disparity in the surveys illustrates the difficulty in assessing some modifications in the field. This also reflects a lack of training and accreditation in using this method, potentially making future comparisons unreliable due to inter-surveyor variation. If LHS were continued a classification based on the shoreline modification score by lake type could be used as seen in Table 8.23.

Table 8.22 Lake shoreline modification score derived from LHS surveys.

Shoreline modification score	Shore zone modification
0	<10% shoreline affected by hard engineering AND Shore re-enforcement recorded at 0-1 hab-plots (0 for core)
2	≥10% - <30% shoreline affected by hard engineering OR Shore re-enforcement recorded at 2 hab-plots (1 for core) OR Poaching recorded at 3 or more hab-plots (2 for core)
4	≥30% - <50% shoreline affected by hard engineering OR Shore re-enforcement recorded at 3-4 hab-plots (2 for core)
6	≥50% - <75% shoreline affected by hard engineering OR Shore re-enforcement recorded at 5-7 hab-plots (3 for core)
8	≥75% - shoreline affected by hard engineering OR Shore re-enforcement recorded at 8 or more hab-plots (4 for core)

Table 8.23 Classification of lake sample sites according to shoreline modifications (using the LHS 2012 database).

	Class	Shoreline modification score	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	0	11	12	5
	Class 2	2	12	5	3
	Class 3	4	3	2	4
	Class 4	6	4	0	0
	Class 5	8	1	2	2
% of lakes	Class 1	0	35	57	36
	Class 2	2	39	24	21
	Class 3	4	10	10	29
	Class 4	6	13	0	0
	Class 5	8	3	10	14

When undertaking macrophyte surveys for the EA for WFD purposes the contractors have assessed the shoreline where a macrophyte transect is undertaken (generally 4 or 8 transects are undertaken depending on lake size), thus producing an assessment of a limited sample of the lake perimeter. The sample shoreline characteristics are currently assessed using a 5-point scale (see Table 8.24). Unfortunately this, does not represent a useable 5-class system moving from best to worst since it includes 'denuded' as the descriptor for Class 2, and there is no further information on precisely how these classes are assigned. However, it illustrates how a 5-class system of shoreline modification could easily be incorporated into a routine macrophyte survey. These waterbodies are re-surveyed every 3 years.

An alternative class system is proposed in Table 8.25 which should be used to assess the entire of the lake shoreline- the use of this could be encouraged whenever a lake survey is undertaken. Remote sensing could also be used to help assess modifications on large lakes, although this may be limited if the banks are shrouded in woodland. No data are currently collected outside of WFD monitoring - such monitoring (and associated recording) would need to be encouraged.

Table 8.24 Shoreline characteristic classes currently recorded during EA WFD lake macrophyte monitoring.

Class	Description
1	Natural
2	Denuded
3	Minor
4	Major
5	Entire

Table 8.25 Proposed alternative 5-class system for assessing shoreline modifications during EA WFD lake macrophyte monitoring.

Class	Description	Comment
1	≤5% shoreline modified	This is the equivalent to favourable condition in lake CSM
2	>5% ≤ 30%	30% is the cut-off for a water body to support GES under the WFD
3	>30% ≤ 50%	This is in line with LHS
4	>50% ≤ 75%	This is in line with LHS
5	>75%	This is in line with LHS

If a new class system cannot be incorporated into macrophyte surveys, the existing data could be used in an alternative manner. Since the aspiration is to increase the number of lakes with natural shorelines, the number of lakes with only natural shorelines (Class 1 in

Table 8.24) in all sampled areas could be assessed. The target would then be to increase the proportion of the lakes where all sampled areas had natural shorelines. Such an assessment is less desirable than the 5-class system proposed in Table 8.25 as it does not cover the entire lake shoreline and will not capture improvements in a lakes shoreline until it is natural in all sample areas, but it is all that can be done with currently collected data. The results of such an analysis are shown in Table 8.26.

The results of this analysis suggest that shoreline modification is not a widespread problem, but this is in contrast to the results from LHS surveys. The differences are likely to be due to the sampling approach undertaken during macrophyte surveys (transects are unlikely to be positioned where macrophytes will be absent due to physical modifications), as well as the differences in the sites where the surveys were undertaken. Generally WFD macrophyte surveys are not undertaken on highly artificial sites where the artificiality will affect the macrophyte assessment, whilst LHS sites were chosen specifically to incorporate the range of artificiality that can be found in lakes. This is a good illustration of why surveying beyond existing WFD macrophyte survey sites is required to illustrate the condition of lakes across England.

Table 8.26 Analysis of naturalness of lake shoreline using available data.

	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes with only natural shorelines recorded	60	25	17
Number of lakes surveyed	74	26	19
% of lakes with only natural shorelines recorded	81	96	89

8.2.4 Natural fringing wetlands

The natural morphology, hydrology and geology will determine the underlying capacity of a lake to support a wetland fringe. Although the extent to which this capacity is realised can be influenced by a range of factors including: water quality, shore-reinforcement, siltation, shading by trees, increased wave action and direct disturbance due to increased use, the impacts of herbivory (grazing from both land and water based animals e.g. cattle and Canada geese respectively) and direct vegetation management. The extent to which a wetland fringe can be expected is also influenced by water body type; for example, whilst a natural eutrophic water body may be expected to be surrounded by a dense reed bed, more nutrient poor lakes are unlikely to support this (although emergents such as *Eleocharis*, *Equisetum*, *Carex* or *Juncus* may be present).

Any distinction between wetland fringe and a larger scale wetland adjacent to a lake will be arbitrary. Whilst accepting this, the natural fringing wetland attribute is ensuring the ecotone between aquatic and terrestrial habitats, often dominated by emergent vegetation, is not neglected. The wetlands adjacent to lakes are dealt with under natural riparian land use below.

Within LHS the percentage cover of narrow-leaved and broad-leaved emergent vegetation is recorded in each hab-plot, on a five point abundance scale (0=0, 1>0-1, 2>10-40, 3>40-75, 4>75). To summarise this across a lake, a mean abundance class has been calculated from all the hab-plots and the results assigned to a 5-class scale. The results from this analysis for broad-leaved and narrow-leaved emergent vegetation can be seen in Table 8.27-8.30. As expected, more eutrophic lakes support a high abundance of narrow-leaved emergent vegetation than the other lake types, illustrating the requirement for a target that accepts their natural variation. Broad-leaved emergent species are found at lower abundance at a few sites in all habitat types.

Table 8.27 Lake sites with broad leaved emergent vegetation using LHS data.

	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Broad leaved emergent vegetation present	3	6	3
Number of lakes surveyed	10	12	9
Percentage of lakes with broad leaved emergent vegetation present	30	50	33

Table 8.28 Classification of lake sites using broad leaved emergent vegetation data.

	Class	Average abundance	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	0.8-1	0	0	0
	Class 2	0.6-0.8	0	1	0
	Class 3	0.4-0.6	2	0	0
	Class 4	0.2-0.4	0	1	1
	Class 5	0-0.2	8	10	8
% of lakes	Class 1	0.8-1	0	0	0
	Class 2	0.6-0.8	0	8	0
	Class 3	0.4-0.6	20	0	0
	Class 4	0.2-0.4	0	8	11.
	Class 5	0-0.2	80	83	89

Table 8.29 Lake sites with narrow-leaved-emergent vegetation using LHS data.

	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Narrow leaved emergent vegetation present	9	10	7
Number of lakes surveyed	10	12	9
Percentage of lakes with narrow leaved emergent vegetation present	90	83	78

Table 8.30 Classification of lake sites using narrow-leaved emergent vegetation data.

	Class	Average abundance class	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	2+	5	1	0
	Class 2	1.5-2.0	1	4	0
	Class 3	1.0-1.5	1	2	0
	Class 4	0.5-1.0	1	2	4
	Class 5	0-0.5	2	3	5
% of lakes	Class 1	2+	50	8	0
	Class 2	1.5-2.0	10	33	0
	Class 3	1.0-1.5	10	17	0
	Class 4	0.5-1.0	10	17	44
	Class 5	0-0.5	20	25	56

Although species-level botanical data is presently collected from the lake and the shore for WFD botanical surveys, the data on plants growing on the shore are not used and data on species such as *Phragmites australis* are not included in the WFD Leafpacs metric. This is because the metric is designed to reflect the impacts of nutrient enrichment and species of the shoreline are not good indicators of this, as they are influenced by the many factors described above. It is beyond the scope of this work to design a metric utilizing these species data and it would be difficult to apply without knowledge of what could be expected under natural conditions at each site. However, the presence or absence of a wetland fringe is recorded at each site where a transect is undertaken during the macrophyte survey. For the purpose of this analysis a frequency of occurrence in the survey areas across the lake has been calculated (i.e. if it occurs in 1 out of 4 survey plots it is assigned a frequency of 0.25) and these have been assigned to a 5-class scale. The results are shown in Table 8.31.

Table 8.31 Frequency of the presence of a marginal fringe as recorded during WFD lake macrophyte surveys.

	Class	Frequency	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	>0.75-1	15	3	0
	Class 2	>0.5-0.75	4	3	0
	Class 3	>0.25-0.5	8	4	0
	Class 4	>0-0.25	7	4	2
	Class 5	0	40	12	17
% of lakes	Class 1	>0.75-1	20	12	0
	Class 2	>0.5-0.75	5	12	0
	Class 3	>0.25-0.5	11	15	0
	Class 4	>0-0.25	9	15	11
	Class 5	0	54	46	89

In contrast to the results from the LHS survey (which showed that narrow leaved emergent vegetation was present in all lake types but at a smaller percentage cover in oligotrophic and dystrophic lakes), the above analysis suggests there is no wetland fringe in most oligotrophic and dystrophic lakes, despite the latter analysis containing more natural lakes. This is likely to be due to the definition of the wetland fringe as well as the methods of survey. An improvement would be to collect an estimation of the proportion of the lake perimeter with a wetland fringe and to provide a better definition of wetland fringe (i.e. to include all emergent vegetation not just reed beds).

This is also an aspect where remote sensing may have a role to play particularly to help fill the gap for water bodies not monitored for the WFD, as currently there is no information available.

Loss of fringing wetlands is known to be an issue, although they may not be expected at every site due to the natural conditions. Consequently a target needs to be set that promotes the recovery of fringing wetlands, but acknowledges that they can be naturally absent.

8.2.5 Natural substrate

The LHS lake habitat modification score includes an erosion and deposition score which has potential for use for this attribute. However, absence of a future LHS monitoring programme makes its future use doubtful. The WFD lake macrophyte surveys record substrate type, but without a reference to what would be expected in unimpacted conditions for each lake it is difficult to use for these purposes. No monitoring is carried out on non-WFD water bodies. It is accepted that without data on reference conditions for lakes this attribute cannot currently be used or taken forward at present.

8.2.6 Riparian land and trees

The LHS Lake Habitat Quality Assessment score includes an element on riparian habitat, which is further divided into complex vegetation structure, vegetation longevity (occurrence of trees), natural land cover types, number of land cover types and number of bank top features. Consequently a high score is reliant on a particularly diverse riparian zone with respect to features, land cover types, and vegetation structure. However, there are no reference sites to compare this to and naturalness does not necessarily correlate with diversity of riparian habitat. Consequently the most useful elements are the occurrence of riparian trees and natural land cover types.

Natural land cover types are also recorded during the EA WFD macrophyte surveys, although extent is not recorded. Alternatively remote sensing could be used for this attribute and this would extend coverage beyond WFD lakes to those in the wider habitat resource. The presence of semi-natural land cover types in a 50m zone around a water body was analysed using the 2007 land cover map (25 m resolution). The results can be seen in Table 8.32.

The data illustrate that oligotrophic and dystrophic lakes are more likely to have semi-natural land use in the riparian zone than eutrophic lakes, with mesotrophic lakes somewhere in between the two.

Table 8.32 Lakes with semi-natural habitats in a 50m riparian zone.

	Class	% semi-natural riparian habitat	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	100	482	172	205
	Class 2	90<100	599	138	106
	Class 3	80<90	590	132	92
	Class 4	70<80	546	81	68
	Class 5	0<70	1676	230	132
% of lakes	Class 1	100	12.4	22.8	34.0
	Class 2	90<100	15.4	18.3	17.6
	Class 3	80<90	15.2	17.5	15.3
	Class 4	70<80	14.0	10.8	11.3
	Class 5	0<70	43.1	30.5	21.9

Tables 8.33-35 illustrate the mean number of trees present in the three lake types. These data come from the LHS database so the issues around whether this is a representative sample of English lakes apply. Additionally the data are collected on the hab-plot scale so there is also an issue as to how representative this is of the entire lake riparian zone. The data suggest that there are fewer trees around oligotrophic and dystrophic lakes than eutrophic lakes, as might be expected because oligotrophic and dystrophic lakes often have rocky unvegetated shorelines and are often found in grazed upland areas. The presence of

woody debris less than 30cm in diameter (Table 8.36) reflects the presence of trees in the riparian zone, suggesting that this is often left where it falls. However very little large woody debris was found (Table 8.37) - it is unclear whether this is due to removal or large woody debris, or that the surveys were at such a scale that they failed to detect it.

Table 8.33 Presence of riparian trees (>30 cm diameter) around lakes using LHS data.

	Class	Mean number of trees > 30cm in diameter within a hab plot	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	0-0.5	4	3	4
	Class 2	>0.5- 1.0	1	3	3
	Class 3	>1-1.5	2	4	2
	Class 4	>1.5-2	1	2	0
	Class 5	>2	2	0	0
% of lakes	Class 1	0-0.5	40	25	44
	Class 2	>0.5- 1.0	10	25	33
	Class 3	>1-1.5	20	33	22
	Class 4	>1.5-2	10	17	0
	Class 5	>2	20	0	0

Table 8.34 Presence of riparian trees (<30cm diameter) around lakes using LHS data.

	Class	Mean number of trees <30cm in diameter in a hab-plot	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	0-0.5	3	2	3
	Class 2	>0.5-1	2	4	3
	Class 3	>1-1.5	2	1	3
	Class 4	>1.5-2.0	1	4	0
	Class 5	>2	2	1	0
% of lakes	Class 1	0-0.5	30	17	33
	Class 2	>0.5-1	20	33	33
	Class 3	>1-1.5	20	8	33
	Class 4	>1.5-2.0	10	33	0
	Class 5	>2	20	8	0

Table 8.35 Presence of riparian woody shrubs and saplings around lakes using LHS data.

	Class	Mean woody shrubs/saplings	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	0-0.5	1	2	2
	Class 2	>0.5-1	3	2	3
	Class 3	>1-1.5	3	2	3
	Class 4	>1.5-2.0	2	5	1
	Class 5	>2	1	1	0
% of lakes	Class 1	0-0.5	10	17	22
	Class 2	>0.5-1	30	17	33
	Class 3	>1-1.5	30	17	33
	Class 4	>1.5-2.0	20	42	11
	Class 5	>2	10	8	0

Table 8.36 Presence of woody debris (< 30cm) in lakes using LHS data.

	Class	Mean woody debris	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	0-0.25	3	5	4
	Class 2	>0.25-0.5	4	2	3
	Class 3	>0.5-0.75	0	1	1
	Class 4	>0.75-1	2	4	1
	Class 5	>1	1	0	0
% of lakes	Class 1	0-0.25	30	42	44
	Class 2	>0.25-0.5	40	17	33
	Class 3	>0.5-0.75	0	8	11
	Class 4	>0.75-1	20	33	11
	Class 5	>1	10	0	0

Table 8.37 Presence of large woody debris (> 30cm diameter) in lakes using LHS data.

	Class	Mean of large (>30cm diameter) woody debris	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	Class 1	0-0.25	10	12	9
	Class 2	>0.25-0.5	0	0	0
	Class 3	>0.5-0.75	0	0	0
	Class 4	>0.75-1	0	0	0
	Class 5	>1	0	0	0
% of lakes	Class 1	0-0.25	100	100	100
	Class 2	0.25-0.5	0	0	0
	Class 3	0.5-0.75	0	0	0
	Class 4	0.75-1	0	0	0
	Class 5	1+	0	0	0

Whilst the occurrence of woodland habitats in the riparian zone could be pulled out of the riparian land use analysis, riparian trees (as opposed to woodland habitats) would be missed. There is a growing recognition of the importance of riparian trees, but a mix of wooded and un-wooded riparian land is desirable. Unlike the situation with ponds there is currently no information or consensus on whether lake riparian zones need more or fewer trees in England so target-setting is difficult, even if information were available. Consequently whilst the recording of the percentage of the lake perimeter which is tree lined should be encouraged to expand understanding of this issue, at present no target could be proposed.

8.2.7 Hydrology

Data on lake hydrology are only available for natural WFD water bodies. These are not monitored directly, but data will be collected downstream of some lakes. Where this is the case deviation from the modelled naturalised flow can be used in the same way as is proposed for rivers (see Section 8.1.4). Non-WFD water bodies and those which are predominantly ground water fed are not monitored for hydrology and no alternatives are available.

8.2.8 Water quality

Tables 8.38-8.44 show the range of water quality conditions reported in 2015 for WFD. The overall status (Table 8.38) shows that no lake reached high ecological status in England, although a similar number of lakes in all three habitat types reached good ecological status, and a greater proportion of eutrophic lakes were in poor condition than the other two lake types. WFD looks across a suite of metrics and uses the ‘one out all out’ rule to assess overall status. The importance of this approach is seen by looking at the various attributes below, all of which have the capacity to reflect eutrophication (with the exception of ANC), and yet different proportions of the habitat resource are assigned to each ecological status depending on the attribute being considered. Part of the reason for this is that different lakes are monitored for different suites of attributes, but it is also because each lake is different and experiencing multiple pressures and so the response of each lake is different. A particular response to a pressure e.g. algal blooms or low dissolved oxygen concentrations are often only evident at a particular time of year and this may be missed by some monitoring regimes. Dissolved oxygen concentration is generally only measured once a year, so confidence in the extent to which this reflects the true conditions of a lake is relatively low. It is therefore important that all attributes for water quality are monitored to allow the condition of the lake to be assessed.

Upland low alkalinity lakes are more often impacted by acidification, but only a small number of upland lakes are monitored under WFD (partly due to their size). Despite the small number of at-risk lakes monitored, this still reveals some oligotrophic and dystrophic lakes as suffering from acidification. This illustrates that this is still a pressure that needs to be considered in any priority habitat condition assessment. The data on ANC for lakes of higher alkalinity lake types are included for completeness, but acidification is not considered a risk at these sites.

The results on water clarity shown in Table 8.45 represent the water clarity observed when a macrophyte survey was undertaken. This information is not used for WFD classification purposes, but is included here to illustrate how woefully insufficient such a measure is at reflecting water quality in a lake. These results give a deceptively positive picture, with many lakes having clear water at the time of the macrophyte survey. This further illustrates the importance of looking at all facets of eutrophication to gain a proper picture of the condition of a lake. It is not recommended that water clarity on a single monitoring occasion is a suitable method for assessing water quality.

Table 8.38 Overall WFD ecological status of lakes using 2015 data.

	Overall ecological status	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	High	0	0	0
	Good	53	32	29
	Moderate	126	110	106
	Poor	68	13	6
	Bad	6	0	1
% of lakes	High	0	0	0
	Good	21	21	20
	Moderate	50	71	75
	Poor	27	8	4
	Bad	2	0	1

Table 8.39 WFD lake macrophyte status using 2015 data.

	Macrophytes	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	High	2	5	0
	Good	26	13	16
	Moderate	37	14	7
	Poor	17	7	2
	Bad	5	1	3
% of lakes	High	2	13	0
	Good	30	33	57
	Moderate	43	35	25
	Poor	20	18	7
	Bad	6	3	11

Table 8.40 WFD Total Phosphorus status in lakes using 2015 data.

	TP	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	High	16	8	16
	Good	21	32	6
	Moderate	48	44	26
	Poor	44	15	17
	Bad	50	4	1
% of lakes	High	9	8	24
	Good	12	31	9
	Moderate	27	43	39
	Poor	25	15	26
	Bad	28	4	2

Table 8.41 WFD phytoplankton status in lakes using 2015 data.

	Phytoplankton	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	High	16	40	39
	Good	47	30	12
	Moderate	56	22	7
	Poor	55	12	4
	Bad	3	0	1
% of lakes	High	9	38	62
	Good	27	29	19
	Moderate	32	21	11
	Poor	31	12	6
	Bad	2	0	2

Table 8.42 WFD phytobenthos status in lakes using 2015 data.

	Phytobenthos	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	High	1	8	5
	Good	2	13	11
	Moderate	12	4	1
	Poor	24	0	1
	Bad	0	0	0
% of lakes	High	3	32	28
	Good	5	52	61
	Moderate	31	16	6
	Poor	62	0	6
	Bad	0	0	0

Table 8.43 WFD dissolved oxygen status in lakes using 2015 data.

	DO	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	High	46	18	9
	Good	9	13	9
	Moderate	6	1	1
	Poor	6	1	3
	Bad	4	2	0
% of lakes	High	65	51	41
	Good	13	37	41
	Moderate	8	3	5
	Poor	8	3	14
	Bad	6	6	0

Table 8.44 WFD ANC status in lakes using 2015 data.

	ANC	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes	High	50	27	23
	Good	0	0	1
	Moderate	0	0	1
	Poor	0	0	0
	Bad	0	0	0
% of lakes	High	100	100	92
	Good	0	0	4
	Moderate	0	0	4
	Poor	0	0	0
	Bad	0	0	0

Table 8.45 Observations of water clarity when macrophyte surveys have been undertaken.

	Eutrophic lakes	Mesotrophic lakes	Oligotrophic and dystrophic lakes
Number of lakes with clear water	24	16	16
Number of lakes surveyed	74	26	19
Percentage with clear water	32	62	84

8.2.9 Invasive non-native species

WFD macrophyte surveys record all plant species encountered using the survey method and these will include invasive non-native plant species where they occur. Other INNS, such as fish and invertebrates, are not covered by routine monitoring. Consequently the NBN is likely to be the best source of data for INNS, although there are issues relating species occurrence within a 10 km^2 to a particular lake. A class of 1 should be assigned to lakes with INNS and a declining class for every additional species found, with a class of 5 for lakes containing 4 or more INNS.

8.3 Ponds

Owing to the lack of a pond inventory or pond priority habitat map, the following data illustrations cannot be presented using the habitat resource zones in Figure 4.1. It is still important that sufficient monitoring is undertaken in these different zones, but at present this cannot be assessed. Instead in order to illustrate the range of pond types and their geographic spread the data are presented for three relevant Countryside Survey Environmental Zones (EZ)[1]. These are:

1. Easterly Lowlands, England EZ1
2. Westerly Lowlands, England EZ2
3. Uplands, England EZ3

8.3.1 Water quality assessment

Good water quality is a fundamental characteristic that supports natural biological communities and ecological processes. Recent and current pond surveys principally measure nutrients (N and P) and turbidity. Previously only CS and NPS had studied water quality as these required laboratory analyses, but field kits now allow rapid measurement of nutrients. Turbidity is easily recorded into categories using a transparency tool and provides additional information with respect to suspended solids, it is not suggested that this is a

---

[1] The Environmental Zones were created for the purpose of reporting results of the Countryside Survey (Carey et al., 2008) and are aggregations of ITE Land Classes. Classes are derived from multivariate analysis of environmental data collected for each 1km square in the country. Thus the classes, and hence the zones, are determined by combinations of environmental characteristics. Their names have been derived from an analysis of their average environmental characteristics (Wood, 2013).

substitute for measuring nutrient concentrations. The proposed Water Quality Assessment (WQA) combines data on all of these to produce a single water quality indicator.

The WQA uses measured values of N and P and compares them to thresholds reported in Biggs *et al*. (2016) for minimally impacted ponds (0.069mgL^{-1} PO_4P and 0.5 mg L-1 TON). Turbidity in CS was classified on a 1- 4 scale with 4 the most turbid. Data were reclassified as low turbidity (original scores of 1 and 2) or high turbidity (original scores of 3 and 4). The WQA classifies sites into 5 classes according to whether they exceed the nutrient thresholds and have high or low turbidity (Table 8.46). It can be stratified by biogeographic region, e.g. using CS environmental zones (Table 8.47). This shows that more ponds than lakes are reaching class 1 for water quality, but as to be expected, lowland ponds are faring worse than upland ponds.

Table 8.46 Classification of water quality parameters for ponds.

Nutrient Status	Turbidity	Condition class
Below both nutrient thresholds	Low	1
Below one nutrient threshold	Low	2
Below both nutrient thresholds	High	3
Below one nutrient threshold	High	4
Above both nutrient thresholds	Low or High	5

Table 8.47 Classification of CS07 pond sites according to WQA, stratified by Environmental Zones.

	Class	England	EZ1	EZ2	EZ3
Number of ponds	Class 1	66	30	28	8
	Class 2	30	14	14	2
	Class 3	60	29	25	6
	Class 4	30	14	15	1
	Class 5	3	3	0	0
	Total	189	90	82	17
% of ponds	Class 1	34.9	33.3	34.1	47.1
	Class 2	31.7	32.2	30.5	35.3
	Class 3	15.9	15.6	17.1	11.8
	Class 4	15.9	15.6	18.3	5.9
	Class 5	1.6	3.3	0.0	0.0

No data are currently collected on acidification for ponds. The sites most at risk are likely to be upland pools. It is recommended that ANC is recorded at such sites where possible, on a geographically representative basis. The classification system used for lakes could then be applied to ponds.

8.3.2 Landscape connectivity: assessment of pond numbers (APN)

Pond numbers have declined historically. They need to provide a network of characteristic habitat in their own right, but also need to provide landscape-scale refugia and stepping stones for a range of aquatic and terrestrial biota that are associated with ponds and other freshwaters. The APN consists of the CS pond number estimate which is the only current reliable source of data. Here we use data from CS2000 (1998) and CS2007 (Table 8.48).

There is no scoring system associated with this indicator as it only applies to the whole habitat resource. At present the target is to create 30,000 additional ponds by 2020. CS allows changes in pond number to be tracked over time.

Table 8.48 CS98 and CS07 pond numbers by environmental zone.

	1998 number (x 1000)	95% confidence limits	2007 number (x 1000)	95% confidence limits
England	197	(165, 230)	234	(195, 272)
EZ1	114	(87, 143)	141	(108, 176)
EZ2	75	(57, 92)	83	(64, 103)
EZ3	9	(5, 14)	10	(5, 15)

8.3.3 Hydrological condition assessment (HCA)

A natural hydrological regime is important as it allows for natural water level fluctuations which support distinctive biological communities with traits adapted to these conditions. Artificial hydrological regimes which alter hydrological connectivity affect the movement of sediment, nutrients and pollutants as well as the movement of organisms and their propagules, both native and non-native, through the freshwater environment. Consequently natural hydrological regimes are desirable. At present there are no suitable metrics recorded to assess this in any of the pond survey programmes. The presence of inflows and outflows and the water level at the time of survey in relation to the high water mark are recorded, and these provide context, but alone are not indicators of pond quality and could be artificial or natural. It is suggested that pond surveys are modified to include the presence of water control structures and any drainage ditches connected to the pond. This would be relatively easy for surveyors to record, but without an indication of the magnitude of the modification it would be difficult to assess the hydrological condition using a five-class system. Instead the proportion of the resource with a natural hydrological regime could form the classification, but in the absence of any current data the thresholds for the various classes are difficult to assign at this time.

8.3.4 Hydrosere condition score (HCS)

A natural hydrosere displays a natural transition from aquatic to terrestrial habitat, so supports biodiversity directly. It is essential for fauna that use both the terrestrial and freshwater habitat as it enables them to access these different habitats. Hydroseres also play a role in water quality and wave dissipation. A natural hydrosere promotes vertical and lateral connectivity allowing species and substances to move across it.

The HCS measures the naturalness of the hydrosere, based on shoreline modification, pond base, and land use at 5m and at 100m.

Element 1: naturalness of the shoreline

At present the naturalness of the shoreline is not directly recorded in any of the pond surveys. Many ponds are of artificial or unknown origin and consequently naturalness of the shoreline is difficult to assess. What is important is that there are no artificial barriers to a fully functioning hydrosere - such barriers often take the form of artificial/reinforced banks. It is suggested that the presence of artificial/reinforced banks is recorded in pond surveys using a 5 class scale of 0, 1-25%, 26-50%, 51-75% and 76-100% to allow the assessment of this part of habitat functioning.

In the absence of the data described above, to give an indication of how the HCS may work, the ‘management measures’ part of CS 07 ponds was used. This identifies the categories relevant to shoreline management (trees planted, trees felled, trees partly cut back, pond change in size and shape, bank plants mown, structural work). The category ‘other management’ was checked for surveyor notes to identify *ad hoc* measures not recorded in the previous categories. All this information was summarised as shoreline natural (= 0) or shoreline modified (=1).

Element 2: naturalness of pond base

This used the pond base section of CS07, but was simplified by ignoring details of the substrate type so that the base is either natural (=0) or artificial (=1). Again the surveyor notes were consulted to identify missed occurrences.

Elements 3 & 4: semi-natural land use at 5m and 100m

This was derived by the land use categories recorded in CS07, although these data are also available from PondNet. Ponds with semi-natural land use at the appropriate distance are assigned the value ‘0’, whilst ponds without are assigned the value ‘1’.

PondNet includes the habitats in Table 8.49, which can broadly be separated into semi-natural or not semi-natural.

Table 8.49 Habitat types recorded in PondNet.

Semi-natural	Not semi-natural
Rank vegetation	Arable
Trees - woodland	Improved grassland
Unimproved grassland	Roads tracks paths
Fen - marsh - flush	Urban - buildings - garden
Heathland -moorland	Orchard
Bracken	
Montane	
Ponds – lakes	
Streams - ditches	
Rock -stone - gravel	
Ocean	

The 4 elements were combined into the HCS (Table 8.50), where natural is Class 1, then each modified element lowers the Class by 1 until all 4 elements are modified/managed and the pond falls into the worst class (5). The data presented in Table 8.51 show that, as may be expected, more upland ponds can be considered natural with respect to the hydrosere condition score. No ponds surveyed had all 4 elements modified, such ponds are more likely to be found in urban settings, which are not included the Countryside Survey. The two elements that considered surrounding land use were the most commonly modified, with relatively few ponds recorded as having artificial bases or shorelines. As neither of these questions were asked directly in CS 2007, this may change if incorporated directly in future surveys.

Table 8.50 HCS classification for ponds.

	Condition class
No element modified/managed	1
1 element modified/managed	2
2 elements modified/managed	3
3 elements modified/managed	4
4 elements modified/managed	5

Table 8.51 Classification of sample pond sites according to HCS.

		England	EZ1	EZ2	EZ3
Number of ponds	Total	128	62	54	12
	Class 1	31	16	10	5
	Class 2	50	26	19	5
	Class 3	37	17	18	2
	Class 4	10	3	7	0
	Class 5	0	0	0	0
% of ponds	Class 1	24.2	25.8	18.5	41.7
	Class 2	39.1	41.9	35.2	41.7
	Class 3	28.9	27.4	33.3	16.7
	Class 4	7.8	4.8	13.0	0.0
	Class 5	0.0	0.0	0.0	0.0

8.3.5 Shading

An increase in the shading of ponds has been found to lead to a decrease in the biological diversity of ponds (Williams *et al*., 2010, Sayer *et al*., 2012). However, shaded ponds and ponds within woodland can support their own characteristic range of species and are also an important component of naturally functioning landscapes. It is important that any condition assessment of priority pond habitat monitors this pressure without suggesting that all ponds should be open or that trees around ponds are automatically detrimental. Instead the goal should be for the pond habitat resource to support a range of pond types, shaded, partially shaded and unshaded.

Percentage pond overhang is recorded in PondNet and percentage perimeter shaded is recorded in CS. Either attribute could be used, but consistency is required - this is one of the few attributes which differs between the survey methodologies. When interpreting these data it is important to acknowledge the ability of a relatively limited number of perimeter trees to cast shade over a large area of the pond, even when they are only present along a small proportion of the margin, and that they do not need to directly overhang the pond to cast shade. Whilst the proportion of the pond that is shaded may appear a better metric, this is very difficult to assess in the field and the above surrogates are used instead. Consequently the shading classification (Table 8.52) is not split into equal proportions, acknowledging that a small number of trees can have a relatively large effect.

On a site basis a class of 5 should not be automatically be considered as an indicator of poor quality. Due to the recent decreases in pond quality due to shading a target of increasing the number of unshaded ponds in the habitat resource as a whole is appropriate, although a guide of the proportion of open ponds which could be thought of as sufficient for conservation purposes remains undetermined.

The data presented in Table 8.53 illustrate that, as expected. Upland sites (in EZ3) are generally not shaded, but the proportion of the resource that is shaded is higher in EZ1 and EZ2.

Table 8.52 Shading classification for ponds.

Percentage pond overhang or percentage perimeter shaded	Condition class
0-	1
1-10%	2
11-20%	3
21-60%	4
61-100%	5

Table 8.53 Classification of sample pond sites according to level of shading.

		England	EZ1	EZ2	EZ3
Number of ponds	Total	131	64	55	12
	Class 1	33	8	15	10
	Class 2	41	22	17	2
	Class 3	14	7	7	0
	Class 4	20	12	8	0
	Class 5	23	15	8	0
% of ponds	Class 1	25.2	12.5	27.3	83.3
	Class 2	31.3	34.4	30.9	16.7
	Class 3	10.7	10.9	12.7	0.0
	Class 4	15.3	18.8	14.5	0.0
	Class 5	17.6	23.4	14.5	0.0

8.3.6 Grazing

Grazing not only results in less shading, but also acts as a disturbance that at high levels can result in bare ground, providing early successional habitat for a range of species. It can also lead to an increase in turbidity and nutrients where animals congregate. Grazing and the congregation of animals in and around ponds would always have occurred naturally, although the intensity at individual sites would vary. As with shading a range of grazing intensities is required across the pond resource as a whole, to provide the niches for the full range of pond biodiversity. Consequently neither grazed nor ungrazed ponds are automatically good or bad, but we still need to understand whether the balance is right across the whole habitat resource.

In CS and PondNet the intensity of grazing is ranked from 1 ('infrequent') to 5 ('heavily poached'). Although in CS an additional score of 0 is used for ungrazed ponds (creating 6 categories). Grazing levels ranked 1 are described as ponds which can be accessed by animals but the surrounding grassland or other vegetation is tall and shows little signs of grazing - in the analysis here this ranking has been combined with the 0 score from CS to form a 5 class system (Table 8.54). Where grazing intensity is not uniform across a pond the grazing intensity is averaged out, so the grazing intensity score also incorporates an element of extent of grazing.

The data in Table 8.55 illustrates that most of the resource is currently ungrazed, so an increase in the number of ponds subject to some level of grazing is desirable.

Table 8.54 Grazing intensity classification for ponds.

Grazing intensity rank	Condition class
0 or 1	1
2	2
3	3
4	4
5	5

Table 8.55 Classification of sample pond sites according to grazing intensity.

		England	EZ1	EZ2	EZ3
Number of Ponds	Total	131	64	55	12
	Class 1	109	55	46	8
	Class 2	7	3	2	2
	Class 3	9	2	5	2
	Class 4	1	0	1	0
	Class 5	5	4	1	0
% of ponds	Class 1	83.2	85.9	83.6	66.7
	Class 2	5.3	4.7	3.6	16.7
	Class 3	6.9	3.1	9.1	16.7
	Class 4	0.8	0.0	1.8	0.0
	Class 5	3.8	6.3	1.8	0.0

8.3.7 Biological status assessment

The PSYM provides a multimetric assessment of pond condition based on its assemblages. A PSYM score is assigned to each pond by comparing the pond surveyed to ponds of a similar nature in pristine condition. The score is expressed as a percentage similarity, the higher the percentage the closer it is to pristine condition. PSYM scores have previously been split into 4 condition classes (good, moderate, poor and very poor) with good status representing close to reference biological assemblages for a particular pond type. There is already a general acceptance that scores above 75% are good and the desired status for ponds, but there are always more ponds in the very poor category than any other group, As 5 classes are required for our assessment, it is suggested that an additional class of ‘bad’ is introduced (see Table 8.56). PSYM results for CS07 ponds have been used as example data (Table 8.57). This suggests that few ponds are at good status and, contrary to the water quality results, upland ponds fared the worst.

Table 8.56 Classification of PSYM results for ponds.

PSYM status	% similarity	Condition class
Good	75 or above	1
Moderate	50 <75	2
Poor	25<50	3
Very poor	12<25	4
Bad s	0<12	5

Table 8.57 Classification of CS07 pond sites according to PSYM.

		England	EZ1	EZ2	EZ3
Number of ponds	Total	128	62	52	14
	Class 1	5	4	1	0
	Class 2	14	8	6	0
	Class 3	37	24	9	4
	Class 4	24	8	13	3
	Class 5	48	18	23	7
% of ponds	Class 1	3.9	6.5	1.9	0
	Class 2	10.9	12.9	11.5	0
	Class 3	28.9	38.7	17.3	28.6
	Class 4	18.8	12.9	25	21.4
	Class 5	37.5	29	44.2	50

8.3.7 Invasive non-native species assessment (INNSA)

Invasive non-native species can have strong negative effects on natural communities and habitats. The invasive non-native species status assessment provides a measure of the extent to which a pond is colonised by non-native species; it does not assess the impact of non-native species on native assemblages. A classification is proposed in Table 8.58.

Results for CS07 ponds were used for our data illustration (Table 8.59), with the addition of two records of invasive non-native plant species that were not included in the original analyses. Only plant species were considered as data were not available on invasive fauna. The overall approach could easily be adapted to include these species although data availability may be more limited, particularly because data from NBN is attributed to a 10km square which may contain many ponds. The CS2007 data suggests relatively few ponds had invasive non-native species at the time of survey.

Table 8.58 Classification of INNSA for ponds.

	Condition class
No invasive non-native species present	1
1 invasive non-native species present	2
2 invasive non-native species present	3
3 invasive non-native species present	4
>3 invasive non-native species present	5

Table 8.59 Classification of CS07 pond sites according to INNSA.

		England	EZ1	EZ2	EZ3
Number of ponds	Total	149	68	65	16
	Class 1	126	50	61	15
	Class 2	12	11	0	1
	Class 3	8	5	3	0
	Class 4	3	2	1	0
	Class 5	0	0	0	0
% of ponds	Class 1	84.6	73.5	93.8	93.8
	Class 2	8.1	16.2	0.0	6.3
	Class 3	5.4	7.4	4.6	0.0
	Class 4	2.0	2.9	1.5	0.0
	Class 5	0.0	0.0	0.0	0.0

9. Some key points to consider in making proposals

It is vitally important to make distinct assessments of the different aspects of natural habitat function (physical, hydrological, chemical and biological stressors), since attributes for each do not act as surrogates for the others. No attribute or indicator is designed to provide a holistic indicator of natural habitat function, and none are capable of performing this role. This highlights the importance of existing monitoring programmes such as River Habitat Survey baseline assessments and Countryside Survey, which evaluate elements of natural habitat function that are not monitored by routine WFD programmes.

Indicators of biological integrity (such as WFD classification metrics and other biological indices) provide useful insights into some aspects of natural function, but again are not capable of providing a holistic assessment of natural function. The raw data on biological assemblages from which WFD metrics generated are potentially of greater value to assessing natural habitat function than the WFD metrics themselves.

Data availability varies greatly between rivers, lakes and ponds, and within rivers and lakes between small and large waterbodies. This has a fundamental bearing on what is achievable in a monitoring and assessment framework, and where to focus effort to plug key data gaps. This said, even for some small waterbodies we have existing monitoring programmes on which we can build, whilst providing those programmes with a further important rationale for their existence.

The lack of monitoring data is most acute for lakes and ponds, despite the increase in lake monitoring since the implementation of the WFD. The majority of WFD lake monitoring is for nutrients and chlorophyll, which mainly occurs in reservoirs, and whilst there is some monitoring of biological metrics, for the reasons described above this is limited in the context of the national lake priority habitat resource. Algal blooms are often brief and sporadic and are therefore not always detected unless sampling is sufficiently frequent - they are not a substitute for other monitoring of attributes of natural habitat function. Currently there are no biological metrics that adequately reflect lake hydrological or morphological pressures and no direct monitoring of these pressures is planned under any existing programme.

In developing an assessment framework we need to be careful to avoid seeing physical habitat complexity, or its biological counterpart species richness, as necessarily indicative of natural habitat function. Natural habitat function in freshwater systems does generally produce physical habitat complexity, and this generally translates into speciose communities. However, habitat diversity can potentially be increased by engineered means without underlying natural environmental processes, and at the expense of natural habitat function and characteristic assemblages. Equally, natural biological assemblages can be relatively species-poor if natural environmental conditions are hostile. Artificially modified systems can generate high levels of habitat complexity but it is not the norm and should not be valued in the same way as habitat complexity from naturally functioning systems. Separating the two circumstances with available attributes and datasets is not necessarily simple.

This means that we need to be careful with the assessment of some attributes that we wish to use, to avoid characterising impacts on natural habitat function as beneficial. This largely applies to physical habitat attributes, although it can relate to biological metrics that treat increases in species richness as beneficial under any circumstances, or where non-native species impacts create changes in species composition that spuriously imply improved water quality conditions (for instance, the effects arising from selective predation by signal crayfish).

Data illustrations that compare the condition of sites inside and outside of the priority habitat maps have only been possible for river habitat. These data illustrations do not provide a clear picture of the higher naturalness of sites on the PHMs compared to the rest of the habitat resource. This is likely to be due to a variety of reasons including:

- scaling issues – data illustrations were undertaken on individual sites whereas the river PHM was developed using data aggregated to WFD waterbody level;
- the coarseness of the existing PHM – the original map used nationally available data and considerable anomalies have been identified at local level (some initial refinement of the river PHM has now been undertaken and an on-going process of refinement is being developed);
- the patchiness of data available for illustration – data have been used that were not collected for this task.

All this said, the illustrative analyses undertaken do provide a feel for the nature of the assessment needed and how it can be done.

This work has been undertaken at a time when great changes are being considered to environmental monitoring programmes, and has been firmly based on making the best use of existing monitoring activities. There has been consideration of where monitoring might go in the future, in terms of earth observation, DNA techniques and citizen science. These activities all have potential to play a more significant role in future, but it is important to understand their limitations in the context of assessing natural habitat function in freshwater systems. They need to be deployed in accordance with their strengths and weaknesses, informed by the points made above, to ensure that an appropriate resolution of impacts on natural ecosystem function is maintained.

10. Proposed monitoring and assessment framework

10.1 Preamble

The following sub-sections contain information on the attributes deemed most useable for rivers, lakes and ponds, based on the evaluations made within this project. The lists of attributes should not be considered definitive, but they do provide a reasonable platform for further refinement. Such refinements could be made as part of operationalising the framework.

Note that this information relates solely to non-SSSI assessment. As outlined in this report, an established programme of condition assessment exists for protected sites, which provides a level of resolution of condition issues that is commensurate with their special status.

10.2 Rivers

The proposed list of attributes for rivers is shown in Table 10.1, along with information about how the assessment would be done and where the data would come from. Most of the proposals are based on data that are already collected, assuming that Countryside Survey and Environment Agency baseline RHS assessments continue to be funded. However, the assessment of headwaters for a number of key attributes requires a review of both Countryside Survey and EA baseline RHS assessment to ensure that there is sufficient spatial coverage of sites and sufficiently short return periods to inform priority habitat assessment. Whilst both the Upland Waters Monitoring Network and the Environmental Change network are considered critical programmes for assessing long-term ecological trends in detail, they are not suited to the broad scale assessment of the river habitat resource. However, they should be considered as critical in factoring in natural temporal variation and broader climate change trends to the priority habitat assessment.

We can adopt (or at least aspire to) a 'full data inventory' approach (i.e. evaluating the whole habitat resource) with a surprisingly large proportion of attributes. However, some of these evaluations may prove problematic when undertaken on a national scale and we may have to adopt a representative sampling approach.

Whilst the physical habitat indicators developed in this project are considered to be fit for purpose, it is known that similar indicators have been generated by others with a view to informing future UK WFD assessments and local investigations (Naura *et al.* 2016). There may be scope for collaborative working to agree a common set of indicators that addresses both needs, to facilitate information sharing and reduce the costs of data processing.

It is worth noting that WFD biological metrics have been included under the water quality element in Table 10.1. It is considered misleading to place them under 'natural biological assemblages', since their ability to characterise impacts on natural assemblages is not clear. They are designed to detect certain types of (mainly water quality) impact and so fit better under the water quality element.

The EA's RHS baseline surveys are based on random sampling within each 10 km grid square in England, selecting 3 sites per grid square and new sites in each baseline survey.

There are 1307 10 km grid squares, generating nearly 4000 sites per baseline survey. This is likely to be adequate to provide a suitably representative picture of the physical state of the habitat resource, in terms of both headwaters and larger rivers (Table 6.3 shows these sites to be distributed evenly across headwaters and larger rivers in the last survey). Some adjustments to site selection may be needed to capture a sufficient sample of sites on the priority habitat map (although the last survey looks adequate in this regard – see Table 6.3), and sites on individual river types (such as chalk rivers).

Headwater monitoring sites in Countryside Survey are far fewer in number and are selected to be representative, but locations are fixed across surveys. This places greater reliance on the representativeness of the sites chosen but increases the robustness of detecting real changes over time. Invertebrate sampling within CS is ideally suited to priority river habitat assessment but chemical sampling is one-off and so does not provide high reliability.

WFD monitoring of chemistry and invertebrates includes a significant proportion of headwater streams, though currently these data are not reported in this way (they are subsumed into WFD water-body-level reporting). It has not been possible to evaluate the representativeness of this monitoring, either in terms of stream size (they may be largely located near the boundary of the headwater definition), habitat integrity, spatial distribution, or stream type.

It has been estimated that there are around 62,000 headwater streams in England (from estimates made in Wright and Symes 1997). The numbers of sites sampled in the programmes mentioned above constitute only 1 – 3% of the habitat resource, depending on the element of condition considered. This is far lower than the proportion of larger rivers that are monitored. Headwater streams also tend to be highly variable in condition because each is influenced by its own small catchment, implying that a greater proportion of sites may need to be monitored than for larger rivers, rather than a smaller proportion.

Taken together, the baseline RHS survey, Countryside Survey and WFD monitoring of headwater streams seem to provide at least a basic coverage of sites in the headwater habitat resource zones to evaluate physical, chemical and biological (invertebrates) elements of condition. However, RHS baseline survey and Countryside Survey need to be coordinated to deliver data in time to match the need for priority habitat assessment and reporting. A rolling programme of monitoring within the RHS baseline survey and Countryside Survey would regularise the sampling effort across years and thereby simplify budgeting and the scheduling of monitoring resource. A 5-yearly rolling programme would fit the timelines for priority habitat reporting.

Leaving aside the different motivations and objectives for current field monitoring, a practical field monitoring programme for assessing progress with priority habitat objectives (over and above routine WFD monitoring) might be considered to be one randomly selected site per 10km grid square across England, using RHS, species-level macroinvertebrate monitoring and a standard suite of chemical determinands. Ideally each site would be visited quarterly over the course of one year in a 5-year reporting period (for water quality purposes, with macroinvertebrate sampling twice a year), but this is likely to be considered prohibitively expensive and a single visit may need to be the compromise for providing a reasonable spatial picture of condition across the whole habitat resource. This would however place much greater reliance on a skeletal framework of sites that are monitored more frequently, so that we can understand temporal variation in condition and interpret the broader spatial picture accordingly.

As outlined above, this level of monitoring effort across these elements has been in place in recent years, but would need to be rationalised so it delivers for priority habitat assessment in a timely way. Other elements of condition outlined in Table 10.1 would carry additional costs for their assessment that are not easy to quantify, but would be expected to be relatively minor in comparison and largely relate to data processing.

It is envisaged that, for those elements of condition reliant on representative sampling outlined above, remote sensing data on land use and GIS data on the river network (e.g. stream order) could be used to help improve the extrapolation of field data to the wider habitat resource. For instance, any relationships between elements of condition and land use or river characteristics could be used to weight the extrapolation of results.

Citizen science may become a more influential activity in the headwater stream resource over time, particularly in relation to physical habitat assessment and chemical quality. Equally, improvements in remote sensing may provide an effective means of generating some of the data currently derived from field data. Data from these source can be analysed alongside the data outlined in Table 10.1 and, if found to be sufficiently reliable, may be factored into the assessment in the future. In relation to citizen science, this may be as a supplement to or partial replacement for professionally collected data, depending on its reliability.

Table 10.1 Proposed river attributes.

Element	Attribute		Existing data sources	Method	New data required (if any)	Statistical approach to sampling
Longitudinal connectivity	Number and total height of structures	Headwaters	EA River Obstructions dataset.	Aggregate data by habitat resource zones and classify into 5-class classification	Knowledge of structures is patchy for headwaters but new obstructions app will improve coverage.	Full data inventory but recognising that the baseline will change as new structures are added to the GIS layer.
		Non-headwaters	EA River Obstructions dataset	Aggregate data into habitat resource zones and classify into 5-class classification	The layer will be updated regularly so suitable for 5-yearly assessment No need for additional bespoke resource.	Full data inventory. The baseline should not change significantly
Lateral connectivity	Proportion of natural floodplain free to inundate at all return periods Proportion of inundated land under semi-natural vegetation Level of microtopographic variation in inundated semi-natural vegetation.	Headwaters	Not appropriate	Not appropriate	Not appropriate	Not appropriate
		Non-headwaters	National EA 1-in-100 year flood map. National EA flood defence asset map. National land cover map National priority habitat inventory map	GIS overlay.to generate classification results for each habitat resource zone	None as long as the flood defence assets GIS layer is regularly updated or there is some other way of logging changes in extant flood defence structures that can be used.	Full data inventory
Vertical connectivity	None proposed at this time	Headwaters				
		Non-headwaters				
Naturalness of flow regime	% deviation from naturalised flows at a defined range of flow conditions	Headwaters	EA Water Resources information on aquifer status	Expert judgement on each habitat resource zone by WFD waterbody based on water resource status of relevant aquifer.	None	Aim for full data inventory
		Non-headwaters	EA Water Resources GIS	Processing of observed and naturalised flow data at all Assessment Points in the WRGIS,	None	Full data inventory

Element	Attribute		Existing data sources	Method	New data required (if any)	Statistical approach to sampling
				to generate classification results for each habitat resource zone in each WFD waterbody		
Naturalness of physical habitat mosaic	Flow habitat mosaic (FHMA) Riparian vegetation complexity (RVCA) Riparian trees (RTA) Woody material (WMA) Exposed sediments (ESA) Habitat Modification Score (HMS)	Headwaters	River Habitat Survey – Countryside Survey and baseline EA assessments	Process relevant RHS data to generate score for individual sites, and aggregate site scores to habitat resource level	Coverage of Countryside Survey and baseline EA assessments needs to be reviewed, in terms of spatial coverage of sites and return period of assessments.	Representative sampling*. Statistical design differs between Countryside Survey and EA baseline assessments
		Non-headwaters	River Habitat Survey – Countryside Survey, baseline EA assessments	As above	Baseline EA assessments provide sufficient coverage of representative sites. There is other RHS surveying undertaken on the main river network but generally focused on impacted reaches so carries sampling bias.	Representative sampling*
Naturalness of water quality regime	WFD chemical status WFD ecological status	Headwaters	Countryside survey, EA WFD data	Classify data at monitoring site level within each habitat resource zone. Countryside Survey is a one-off survey repeated ever few years, so does not generate robust water quality assessments that take account of short-term temporal variation. However, one-off water quality samples taken can be used to generate low-confidence assessments of chemical status. Macroinvertebrate samples can be converted into ecological status assessments	WFD monitoring programme contains significant numbers of headwater sites. Coverage of Countryside Survey needs to be reviewed, in terms of spatial coverage of sites and return period of assessments.	Representative sampling*
		Non-headwaters	EA WFD data	Classify data at monitoring site level within each habitat resource zone. Chemical status includes nutrient and organic pollution status as well as compliance with EQSs of a range of toxins. Ecological status includes WFD	None	Full data inventory although some data will be based on historical status assessment and lack of known risk that

Element	Attribute		Existing data sources	Method	New data required (if any)	Statistical approach to sampling
				classification metrics for macroinvertebrates, plants, diatoms and fish.		would alter that assessment.
Characteristic assemblages	Benthic macroinvertebrate similarity index	Headwaters	Countryside Survey, EA WFD monitoring – raw data	This is a standard metric generated at Countryside Survey sites. EA WFD data would need to be analysed along with assemblage predictions from RIVPACS to generate index values	Coverage of Countryside Survey needs to be reviewed, in terms of spatial coverage of sites and return period of assessments. WFD monitoring programme contains significant numbers of headwater sites	Representative sampling*
		Non-headwaters	EA WFD monitoring – raw data	EA raw data would need to be analysed along with assemblage predictions from RIVPACS to generate index values, which could then be classified and used to generate a result per WFD waterbody. It is anticipated that there would be sufficient data of mixed-taxon resolution to avoid the need to use family-level data.	None.	Representative sampling from the EA macroinvertebrate database. Stratified random sampling of WFD monitoring sites likely to be most appropriate.
Non-native species	Number of non-native species present	Headwaters	NBN data	Resolve tetrad data from previous 5 years onto the river network and sum the number of species within the relevant part of each WFD waterbody that are on the UKTAG high-impact list.	None. Encouragement can be given to recorders to generate more data for submission to NBN.	Full spatial coverage but recognising the patchiness of available data.
		Non-headwaters	NBN data	As above	As above	As above

* Representative sampling requires that there are sufficient sites to adequately capture variation in habitat condition within the six habitat resources zones defined in this report, as well as the different river types listed in the UK definition of priority river habitat - Habitats Directive Annex II H3260 (watercourses with Ranunculion vegetation, chalk rivers, active shingle rivers and headwater streams.

Blue-shaded boxes – WFD Plus elements. Note that some of these make use of EA data that are not used for WFD classification purposes, or use EA data collected for WFD classification purposes but in a different way.

10.3 Lakes

The proposed list of attributes for lakes is shown in Table 10.2. Critical field-based elements requiring representative monitoring are water quality, macrophytes and physical habitat condition. Whilst reference is made to Lake Habitat Survey, it is possible that a simplified physical habitat assessment could be devised and attached to macrophyte surveys to reduce costs. However, this depends on wider objectives for the use of LHS (e.g. monitoring in relation to WFD ecological status). There is also considerable uncertainty over the future role of remote sensing of chlorophyll a in water quality monitoring (see Section 7), which is touched on later in this section.

Proposals for lake monitoring need to be approached in a somewhat different way to rivers due to their patchy and relatively sparse spatial distribution in the landscape and the considerably lower levels of monitoring undertaken on them. There is also greater clarity on their typological divisions, which helps to construct a representative monitoring design.

Data on the number of standing waters in England in different categories are provided in Table 10.3. Sites that are less than 2 ha are not relevant to this section as they are defined as ponds and will be dealt with in Section 10.4. Sites of between 2 and 5 ha are of particular concern as these are not monitored at all by the EA as part of the WFD programme, but constitute a large proportion of the lake resource in England (see Table 10.3). Sites between 5 and 50 ha that are WFD-monitored are mainly SSSIs (including SACs, SPAs and Ramsar sites) and/or reservoirs, the latter are largely artificial or heavily modified waterbodies monitored for drinking water purposes and so not relevant to priority habitat objectives.

Table 10.2 Proposed lake attributes

Element	Attribute		Existing data sources	Method	New data required (if any)	Statistical approach
Longitudinal connectivity	Number of permanent structures	WFD lakes Non-WFD lakes	EA River Obstructions dataset.	Number within a river node of the lake and classified into 5-class classification This could be improved when intelligent rivers network and lake inventory are combined to check obstructions are online to the lake.	Knowledge of structures is not complete but new obstructions 'app' will improve coverage. Structures on lakes can be recorded alongside any additional lake shoreline recording	Full data inventory, but recognising that the baseline will change as new structures are added to the GIS layer.
Lateral connectivity	Proportion of shorelines which are natural	WFD lakes	LHS, WFD macrophyte surveys	Shorelines classified into a 5 class classification	Record % of entire shoreline monitored during WFD macrophyte surveys	WFD monitored water bodies only, non-statistical approach to selection of water bodies monitored
		Non-WFD lakes	None	Shorelines classified into a 5 class classification	Record % of entire shoreline modified, when surveying lakes and/or using remote sensing	Requires a stratified random sampling regime
	Proportion of lakes with emergent vegetation	WFD lakes	EA WFD macrophyte surveys, LHS	% shoreline with emergent vegetation needs to be classified into a 5 class system	Need to record % of lake circumference with emergent vegetation Definition of marginal fringe needs to be altered or an additional metric needs to be added for EA WFD macrophyte surveys	WFD monitored water bodies only, non-statistical approach to selection of water bodies monitored
		Non-WFD lakes	None	% shoreline with emergent vegetation needs to be classified into a 5 class system, records could potentially include site observations and remote sensing data although the latter has not yet been trialled.	Need to record % of lake circumference with emergent vegetation	Requires a stratified random sampling regime
Naturalness of hydrological regime		WFD lakes	EA data	Deviation from naturalised flow on the lake outflow	It has not been possible to undertake data illustrations on this data and the extent of data availability is unclear.	Non-statistical approach to water body selection depends on where data is available. Does not cover ground water fed lakes.
	Non-available at this time	Non-WFD lakes	EA data	Deviation from naturalised flow on the lake outflow	It has not been possible to undertake data illustrations on this data and the extent of data availability is unclear.	Non-statistical approach to water body selection depends on where data is available. Does not cover ground water fed lakes.

Element	Attribute		Existing data sources	Method	New data required (if any)	Statistical approach
Naturalness of physical habitat	Presence of natural substrate (none proposed at present) Semi- natural riparian habitat % shoreline tree lined	WFD lakes	Earth observation of riparian land use LHS trees	Process Land class data within a 50 m riparian zone of the lake Percentage of perimeter which is tree lined, earth observation and direct observation could be used.	Process earth observation data Need to record % of perimeter which is tree lined, (could be done as part of macrophyte surveys) earth observation and direct observation could be used.	Earth observation data would represent a full inventory No direct observations at present could be introduce to macrophyte surveys.
		Non-WFD lakes	Earth observation of riparian land use	% of riparian land which is semi natural	Process earth observation data Need to record % of perimeter which is tree lined, earth observation and direct observation could be used.	Earth observation data would represent a full inventory Requires a stratified random sampling regime
Naturalness of water quality regime	Number of lakes reaching good and high status overall for the suite of water quality and biological monitoring	WFD lakes	EA WFD reporting database	Data are already pre-processed and classified by WFD waterbody. Chemical status includes water quality status as well as compliance with EQSs of a range of toxins. Ecological status includes WFD classification metrics for plants, phytobenthos and phytoplankton.	Dependent on the continued monitoring of WFD lakes	WFD monitored water bodies only, non-statistical approach to selection of water bodies monitored
		Non-WFD lakes	None	Could potentially encourage citizen science (see pond section). Earth observation of lake chlorophyll concentration may be beneficial but would not give a full picture.	Additional survey required	Requires a stratified random sampling regime
Non-native species	Number of non-native species present	WFD lakes	NBN data	Resolve tetrad data from previous 5 years onto the lake inventory GIS layer and sum the number of species within each WFD waterbody that are on the UKTAG high-impact list.	None. Encouragement can be given to recorders to generate more data for submission to NBN.	Full spatial coverage but recognising the patchiness of available data.
		Non-WFD lakes	NBN data	As above	As above	As above

Table 10.3 Numbers of waterbodies in the GB lakes inventory.

GB lake inventory type	Equivalent priority lake habitat type*	Total number of sites	Water bodies >2 ha	Waterbodies > 5ha
High alkalinity	Naturally eutrophic	3827	2117	845
Low alkalinity	Oligotrophic, Dystrophic	598	368	148
Moderate alkalinity	Mesotrophic	582	378	195
Marl	'Mesotrophic'	159	93	28
Unclassified	Unknown	9594	0	0
Grand Total		**14760**	**2956**	**1216**

*This is a very simplistic read-across but is acceptable for this purpose.

A geographically stratified approach based on a scale larger than 10km^2 grid squares is proposed for lake priority habitat assessment purposes, due to their relatively sparse spatial distribution in the landscape. The GB lake inventory indicates in which OS Landranger map sheet (~40km^2) each lake is located. This is useful for getting a feel for the scale of a suitable monitoring programme, although a more consistent spatial framework would be better for implementation purposes (there is some overlap in map sheets and they are not all the same shape and size). The distribution of different lake habitat types in OS map sheets is summarised in Table 10.4. Lake alkalinity type has been used in the presentation of these data, but marl lakes have also been brought out as a separate category to ensure that this rare and distinctive habitat type is properly addressed. Taking a random selection of one site of each lake type in every sheet where they occur generates a sampling programme of 231 lakes. As some of these lakes will already be monitored through WFD the actual number required may be smaller. Of course the site selection proposed should not be entirely random because SSSI lakes would be excluded from the assessment since these are monitored by SSSI condition assessment processes (the programme of assessment outlined aims to provide information on the non-designated component of the lake habitat resource).

Table 10.4 Numbers of lakes selected for monitoring by using random sampling within OS Landranger map sheets.

	High alkalinity	Low alkalinity	Moderate alkalinity	Marl
Total number of lakes greater than 2ha	2117	368	378	93
Total number of map sheets in which they occur	100	40	69	22
Range in frequency in squares where they occur	1 to 75	1 to 47	1 to 29	1 to 11

Given that the number of waterbodies is relatively small compared to headwater streams, it is considered practical to undertake quarterly water quality monitoring at all sites, although monthly would be preferable. It is proposed that this sample of lakes would be monitored on a 5-yearly rolling basis, each lake being monitored/surveyed for one year within the 5-year cycle. Whilst this would not align with the WFD cycles of monitoring, any WFD monitoring within the previous 5-year period could be included (as is the case with rivers).

Improvements in remote sensing of lake chlorophyll may help to provide additional data on sites not currently monitored, however the limitations of the approach in terms of lake size and trophic type explained in Table 6.7 should be considered, as well as inconsistencies in the nature of the eutrophication picture it provides (see Section 8).

10.4 Ponds

Proposed pond attributes are shown in Table 10.5. Overall, the extent of pond sampling undertaken in CS 2007 is thought to be suitable for priority habitat assessment. CS2007 provided a detailed assessment of pond condition for one randomly selected pond in each survey square containing a pond. Detailed condition assessments were made for a total of 149 ponds in England, including both upland and lowland ponds. As CS and PondNet are essentially very similar, data from either could provide data on many of the attributes (the exception is change in pond number, which only CS records). Work for PondNet suggested an additional 50 ponds needed to be surveyed beyond their species surveys in order to gain a picture of environmental pond condition. This relies on sufficient volunteers being willing to undertake this work and future funding for the provision of water quality testing kits.

There are a number of physical attributes listed in Table 10.5 which are not well monitored by PondNet or CS, and recommendations have been made in Section 8 on what these are. It would be relatively easy to incorporate these into either monitoring scheme as the suggestions would not be expensive or onerous to undertake.

Table 10.5 Proposed pond attributes.

Element	Attribute	Existing data sources	Method	New data required (if any)	Statistical approach
Landscape connectivity	Number of ponds	Countryside Survey	Counts in $1km^2$ survey squares are extrapolated to national scale. Losses and gains in pond numbers between surveys can be similarly extrapolated. Data can be stratified by pond size and land use. Urban areas not included.	Countryside Survey needs to be continued	Representative sampling
Naturalness of water quality regime	Nitrate and phosphate concentration	Countryside Survey, PondNet	Sites are classified into 5 classes according to whether they exceed the NPS nutrient thresholds and have high or low turbidity.	Countryside Survey and/ or PondNet need to be continued. Turbidity scales should be aligned. The use of nutrient field test kits may allow more frequent sampling in a representative subset of ponds in either network.	Representative sampling
	Turbidity				
	ANC		There are no ANC data from either network, currently limited to alkalinity and pH measurements.	ANC should be added to any future Countryside Survey pond water quality analysis particularly those in low alkalinity areas	
Naturalness of hydrological regime	Presence of ditches and water control structures	None, Countryside survey and PondNet record some hydrological features but they are not adequate to assess naturalness.	Presence of artificial inflows, outflows and any water level control structures need to be recorded	Discussions are underway to introduce this to PondNet, it should also be included in any future Countryside Survey	Representative sampling
Naturalness of the hydrosere	Natural pond base	Partially covered in Countryside Survey and PondNet	Individual ponds are classified into 5 classes according to how many of the 4 components are modified/managed.	Countryside survey and/ orPondNet need to be continued. Both surveys need to clearly report on shoreline modifications and naturalness of the pond base.	Representative sampling
	Natural shoreline				
	Semi natural land use 5m from pond edge	PondNet, Countryside Survey			

Element	Attribute	Existing data sources	Method	New data required (if any)	Statistical approach
	Semi natural land use at 100m from pond edge				
Shading	Percentage of pond margin overhung by trees or percentage of perimeter shaded	PondNet, Countryside Survey	The percentage shading is used to classify ponds into 5 classes, with no inference to quality. The aim is to be able to report on the diversity of the extent of shading across the whole habitat resource.	Countryside Survey and/ or PondNet need to be continued	Representative sampling
Grazing	Grazing intensity score	PondNet, Countryside Survey	The intensity of grazing score is used to classify ponds into 5 classes, with no inference to quality. The aim is to be able to report on the diversity of the intensity of grazing across the whole habitat resource.	Countryside Survey and/ or PondNet need to be continued	Representative sampling
Characteristic assemblages	PSYM score	PondNet, Countryside survey	The PSYM score is used to classify individual ponds into 5 quality classes.	Countryside Survey and/ or PondNet need to be continued, ideally to include pond macroinvertebrate survey	Representative sampling
Non-native species	Number of non-native species	PondNet, Countryside survey	The number of invasive species (0,1,2,3,>3) is used to classify individual ponds into 5 classes.	Countryside Survey and/ or PondNet need to be continued. Currently mostly relevant to plants, but should include fauna	Representative sampling

10.5 Reporting

The reporting process needs to be capable of conveying information on individual attributes as well as some overall impression of habitat condition. Reporting on individual elements of habitat function is particularly important since none can act as a surrogate for another. Depending on the nature of the aggregation, aggregating data across attributes provides the potential for some attributes to exhibit low levels of natural function whilst overall condition appears reasonable. The same risk applies when aggregating from individual elements to some overall assessment of condition.

A hierarchical presentational format is proposed, in which the condition of each attribute within each habitat resource zone is clear and can be linked to the overall condition of each zone (Figure 10.1). An illustration of how the different levels of the hierarchy could be reported is given in Figures 10.2 (by attribute), 10.3 (by natural function element) and 10.4 (overall classification). The detailed format would be different for rivers, lake and ponds, depending on the number of attributes and elements proposed. For ponds, the assessment would be undertaken by the 3 environmental zones outlined in Section 8, rather than the habitat resources zones applicable to rivers and lakes.

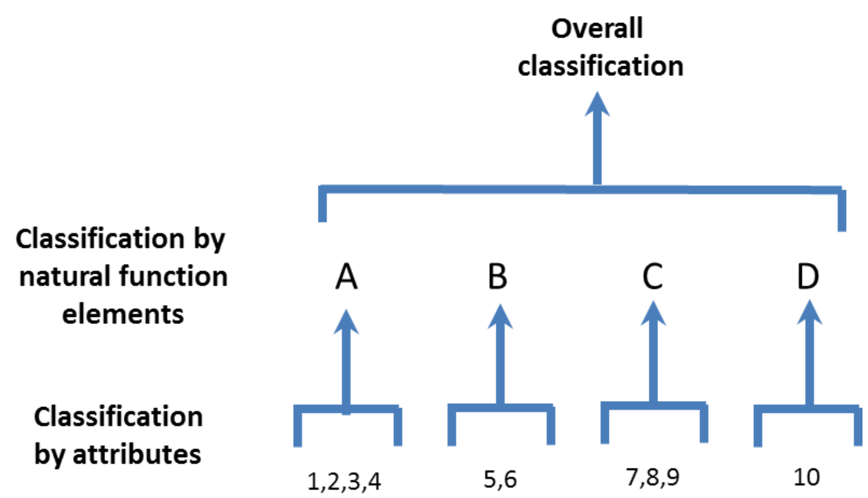

Figure 10.1 Hierarchical reporting of condition within individual habitat resource zones.

The exact nature of aggregating classification results up the hierarchy will need further thought when a full evaluation is attempted using the proposed framework. The traditional method in environmental assessment is that the worst class value from the group of classifications being aggregated is adopted as the aggregated value. However, this can lead to progressive downgrading moving up the hierarchy, with a preponderance of values in the lower classes at the top of the hierarchy. This does reflect real problems with components of condition that need to be addressed (which is why the 'worst class' approach is normally adopted in environmental reporting), but can paint an overly pessimistic picture of the condition of the habitat resource. Using worst class becomes more important to use at higher levels in the hierarchy where information about individual natural function elements is lost – some measure of averaging can be more justifiable at the attribute level within each natural function element, but it does come down to the specific circumstances surrounding each attribute.

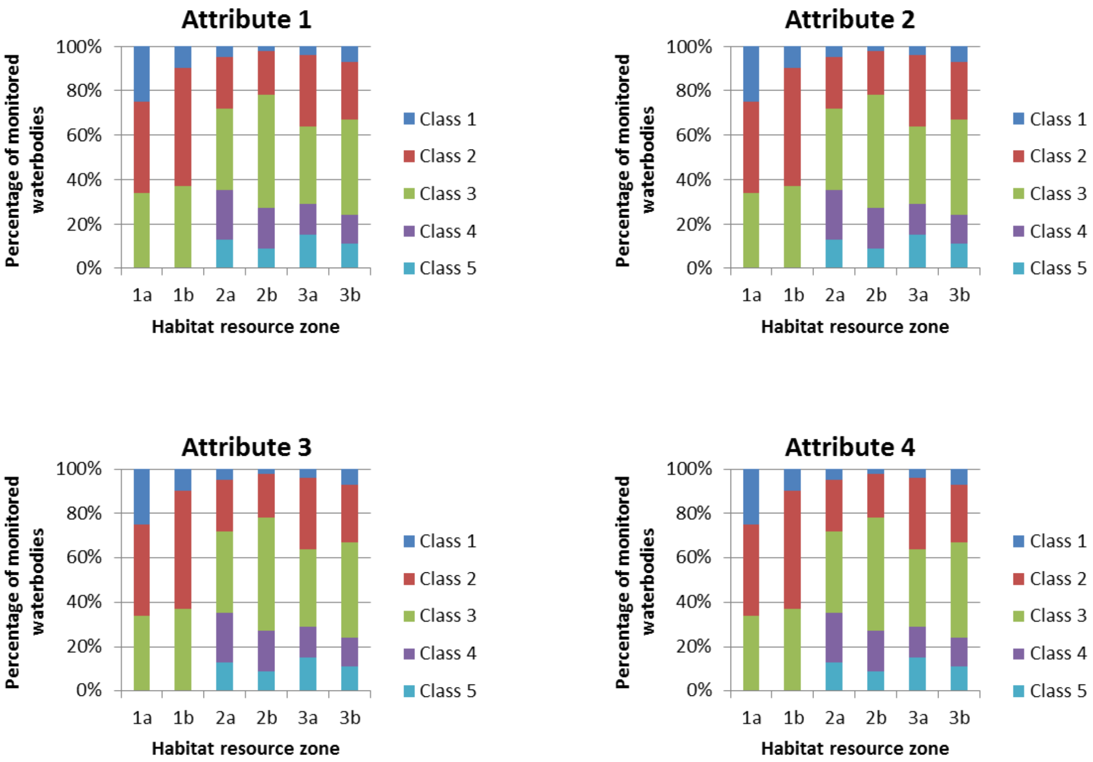

Figure 10.2 Illustration of reporting by attributes for an individual element of natural function.

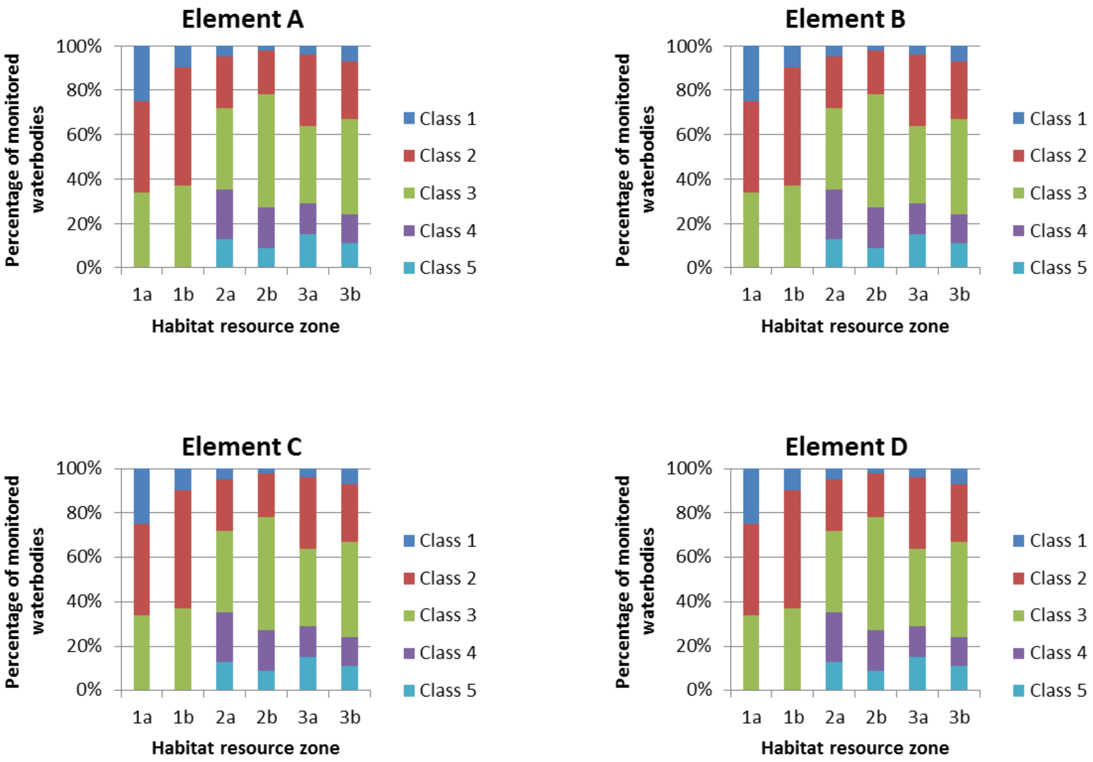

Figure 10.3 Illustration of reporting by natural function elements.

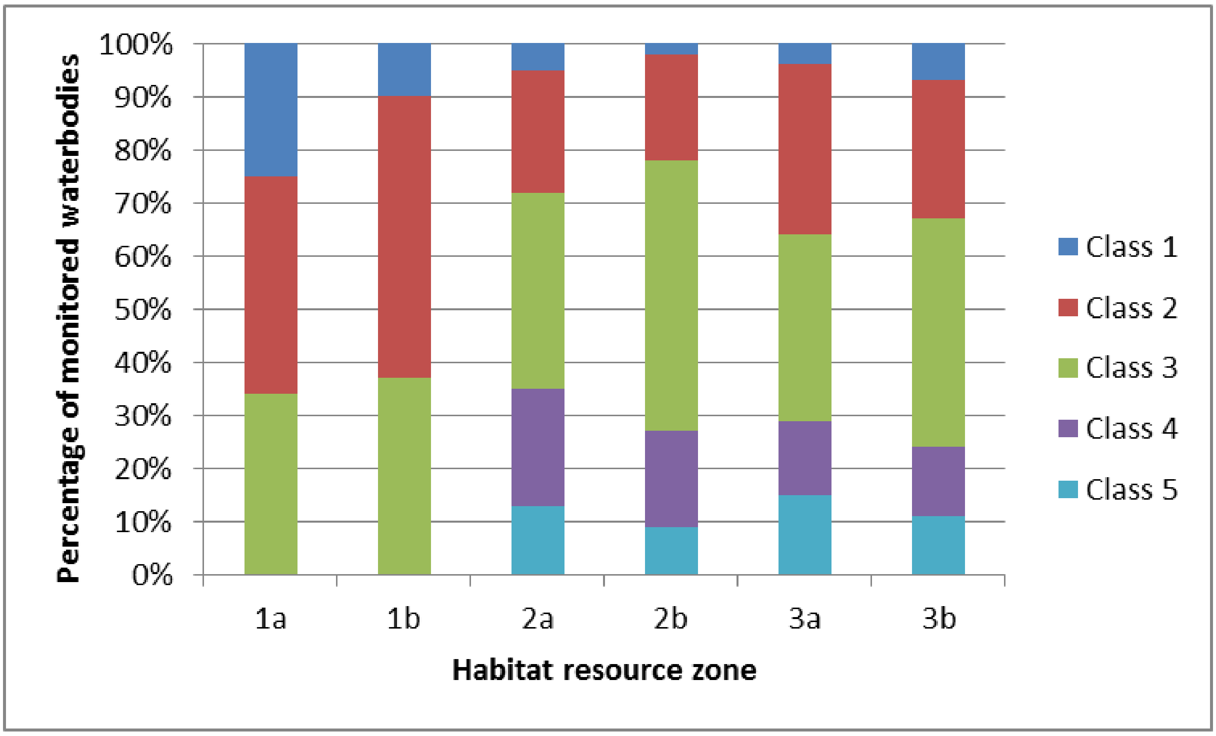

Figure 10.4 Illustration of reporting by overall condition.

10.6 Setting targets for improvement

It is not clear how the current condition of the habitat resource would look when this framework is applied in earnest, so it is currently difficult to set targets that carry an appropriate level of ambition and feasibility. However, these proposals do provide a basis for framing these targets, based on defined levels of change in the distribution of classification results within each habitat resource zone. So, for instance, for rivers it might be considered that we should be looking for an increase in the percentage of waterbodies in habitat resource zone 1b at overall Class 2 or above to x%, which should be achieved by action across the different natural function elements (not just due to water quality improvements, for instance). Targets could be framed for each component of the habitat resource in this way.

The proposals as framed would not provide reporting on changes in lake or river habitat **extent**, which is a common feature of habitat targets in biodiversity reporting. Less emphasis is generally placed on restoration of spatial extent in freshwater habitats, because (where it is needed) it tends to follow restoration of key aspects of natural habitat function (e.g. hydrological regime and the lateral river movement required to sustain natural habitat mosaics). The situation is different for ponds where habitat loss/creation is a major issue. At present the pond proposals in this report are reliant on representative sampling, but it is advisable to use an additional logging system for pond creation.

11. Other recommendations

1. These proposals need to be considered as a contribution to the wider reviews currently being undertaken on environmental monitoring in England. These wider reviews need to test how innovative technologies (earth observation, DNA techniques and citizen science) can reliably provide the type of assessment that is needed for priority freshwater habitats, as laid out in this report.

2. Consideration needs to be given to greater formalisation and alignment of the existing separate monitoring processes that are critical to the proposed framework, particularly the freshwater component of the Countryside Survey and EA monitoring activities (for instance, baseline RHS assessments). Scheduling and then fixing these processes to better align with biodiversity reporting processes (i.e. 2020, 2030, 2040 etc. and interim assessments at 2025, 2035 etc.) would provide certainty over the availability and timeliness of data. Decoupling the freshwater and terrestrial components of Countryside Survey may help to achieve this. WFD reporting is fixed on a 6-yearly reporting cycle so cannot be completely aligned, but WFD monitoring data are collected throughout that 6-year period on a rolling programme so can be processed to provide data to suitable timescales.

3. The attributes considered in this report have strong linkages to the type of assessment undertaken by the EA for river basin characterisation under the WFD, which is repeated every 6 years and uses a wider range of data on pressures and impacts than used in the reporting of ecological status. There may be potential for building some of the data processing required for priority habitat assessment into the process of river basin characterisation to make the two assessments as cost-effective as possible. However, detailed consideration needs to be given to issues relating to the spatial aggregation of data.

4. Further work is needed to consider the relationship between the proposals made here for priority freshwater habitats and condition assessment of specially protected freshwater sites. This includes the potential for including certain attributes and methods proposed for priority habitat assessment in future assessments of protected sites. Also relevant is the nature of connections between the highest condition class used for priority habitat assessment and favourable condition of SSSI/SAC habitat features.

5. At a more detailed technical level, it is recommended that attention is given to the work areas listed below:

   - the development of trait analysis of biological data, which can provide fresh insights into impacts on natural ecosystem function;

   - the wider and more coherent application of citizen science to small waterbodies, including headwater streams and small lakes alongside ponds (where such science is more mainstream);

   - the incorporation of slightly different or new recording of some hydromorphological/ riparian features when undertaking lake macrophyte surveys for WFD (this would help to implement the proposals in the last section without adding significant amounts of monitoring effort);

- incorporation of hydromorphological attributes of naturalness into PondNet and CS pond monitoring along with continued pond water quality monitoring by PondNet;
- the extension of the RIVPACS prediction system to headwater streams so that the macroinvertebrate element of the assessment proposals for rivers can be robustly implemented.

6. Work is needed to rationalise the relationship between the proposals made here and the web-based initiative currently being developed for refining the river and lake priority habitat maps. This initiative involves generating simple naturalness assessment systems for rivers and lakes that are capable of informing decisions about whether to include sites on these maps. These systems need to be broadly compatible with the assessment of habitat condition outlined here.
7. As has been highlighted, biological samples (invertebrates, diatoms etc.) from routine monitoring programmes have considerably more potential value than their current use in assessment and reporting processes. Lack of systematic storage of samples means that the potential for constructing historical time series of novel forms of information (including DNA sequencing) are being lost. Greater consideration of the value of systematic sample storage from routine monitoring programmes is required.

References

ARMITAGE,P.D., HAWCZAK, A. AND BLACKBURN, J.H. (2012) Tyre track pools and puddles - anthropogenic contributors to aquatic biodiversity. *Limnologica,* **42**, 254– 263

BATTARBEE, R.W., SHILLAND, E.M., KERNAN, M., MONTEITH, D.T. AND CURTIS, C.J. (2014) Recovery of acidified surface waters from acidification in the United Kingdom after twenty years of chemical and biological monitoring (1988–2008). *Ecological Indicators*, **37**, Part B, 267-273, doi:http://dx.doi.org/10.1016/j.ecolind.2013.10.011.

BARR, C.J., HOWARD, D.C. AND BENEFIELD, C.B. (1994). *Countryside Survey 1990. Inland water bodies.* Countryside 1990 Series Volume 6. Department of the Environment, London.

BENNION, H, HILTON, J, CARVALHO, L, CLARK, J, CURTIS, C, HUGHES, M, PHILLIPS, G AND REYNOLDS, C (2001) Development of a georeferenced based inventory of standing waters for England and Wales, together with a risk based prioritisation protocol – Phase 1. R&D Interim Technical Report P2-239/TR1, pp 40.

BIGGS, J., FOX, G., NICOLET, P., WALKER, D., WHITFIELD, M. AND WILLIAMS, P. (1998) A guide to the methods of the national pond survey. Pond Action (Freshwater Habitats Trust), Oxford, UK. pp 22. Available from: http://freshwaterhabitats.org.uk/wp-content/uploads/2013/09/National-Pond-Survey-Methods.pdf (Accessed 11/01/18).

BIGGS, J., WILLIAMS, P., WHITFIELD, M., NICOLET, P. AND WEATHERBY, A. (2005). 15 years of pond assessment in Britain: results and lessons learned from the work of Pond Conservation*. Aquatic Conservation: Marine and Freshwater Ecosystems*, **15**, 693-714.

BIGGS, J., MCGOFF, E., EWALD, N., WILLIAMS, P., DUNN, F. AND NICOLET, P. (2016) Clean Water for Wildlife technical manual. Evaluating Pack Test nitrate and phosphate test kits to find clean water and assess the extent of pollution. Freshwater Habitats Trust, Oxford.

BROWN, L.E., RAMCHUNDER, S.J., BEADLE, J.M. AND HOLDEN, J. (2016) Macroinvertebrate community assembly in pools created during peatland restoration. Science of the Total Environment, 569-70, 361-372.

CARACO, N.F., COLE, J.J., RAYMOND, P.A., STRAYER, D.L., PACE, M.L., FINDLAY, S.E.G. AND FISCHER, D.T. (1997) Zebra mussel invasion in a large turbid river: phytoplankton response to increased grazing. *Ecology,* **78,** 588-602.

CAREY, P.D., WALLIS, S., CHAMBERLAIN, P.M., COOPER, A., EMMETT, B.A., MASKELL, L.C., MCCANN, T., MURPHY, J., NORTON, L.R., REYNOLDS, B., SCOTT, W.A., SIMPSON, I.C., SMART, S.M. AND ULLYETT, J.M. (2008) Countryside Survey: UK Results from 2007. NERC/Centre for Ecology & Hydrology, 105pp. (CEH Project Number: C03259).

CONTI, L., SCHMIDT-KLOIBER, A., GRENOUILLET, G. AND GRAF, W. (2014) A trait-based approach to assess the vulnerability of European aquatic insects to climate change. *Hydrobiologia,* **721,** 297-315.

DAVIES, G.R. AND BASS, J.A.R. (2006) Structure and dynamics of within-river landscape, as illustrated by chalk streams. In: *Water and the Landscape: The Landscape Ecology of Freshwater Ecosystems.* Proceedings of the fourteenth annual IALE (UK) conference, held at Oxford Brookes University, 5th-8th September 2006. International Association for Landscape Ecology. Available at: http://iale.uk/conference2006/proceedings (Accessed 10/10/17).

DEFRA (2011) Biodiversity 2020: A strategy for England's wildlife and ecosystem services. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69446/pb13583-biodiversity-strategy-2020-111111.pdf (Accessed 15/02/17).

ENVIRONMENT AGENCY (2003) *River Habitat Survey in Britain and Ireland. Field Survey Guidance Manual: 2003 version* Environment Agency, Bristol, UK.

ENVIRONMENT AGENCY (2010) *Our river habitats. River habitat in England and Wales: current state and changes since 1995-1996*. Environment Agency, Bristol, UK. pp 30.

ENVIRONMENT AGENCY (2011) Flood Map Guidance for professional partners v3.0. Bristol, 12pp. Retrieved online September 2012.

FELD, C.K., DE BELLO, F. AND DOLÉDEC, S. (2014) Biodiversity of traits and species both show weak responses to hydromorphological alteration in lowland river macroinvertebrates. *Freshwater Biology,* **59,** 233-248.

FOX, P. J. A., NAURA, M. AND SCARLETT, P. (1998) An account of the derivation and testing of a standard field method, River Habitat Survey. *Aquatic Conservation: Marine and Freshwater Ecosystems,* **8,** 455-475.

FURSE, M.T., WINDER, J. M., SYMES, K.L. AND CLARKE, R.T. (1991) The faunal richness of headwater streams: a review of existing information. Institute of Freshwater Ecology report to the National Rivers Authority, R&D Project 242, publication reference P-96.

HALL, R., SKINNER, A., PHILLIPS, G. AND PITT, J. (2014) Priority lake habitat in England – mapping and targeting measures. Natural England joint publication JP0088. Available at: http://publications.naturalengland.org.uk/publication/5630174502584320?category=430388 (Accessed 10/10/17).

JNCC (2011) UK Biodiversity Action Plan Priority Habitat Descriptions. Available at: http://jncc.defra.gov.uk/PDF/UKBAP_PriorityHabitatDesc-Rev2011.pdf (Accessed 10/10/17).

JNCC (2016) Common standards monitoring guidance for freshwater habitats and species. Available at: http://jncc.defra.gov.uk/page-2232 (Accessed 10/1017).

KIRSCH, K. AND DZIALOWSKI, A. (2012) Effects of invasive zebra mussels on phytoplankton, turbidity, and dissolved nutrients in reservoirs. *Hydrobiologia,* **686,** 169-179.

LANGE, K., TOWNSEND, C.R. AND MATTHAEI, C.D. (2014) Can biological traits of stream invertebrates help disentangle the effects of multiple stressors in an agricultural catchment? *Freshwater Biology,* **59,** 2431-2446.

MAINSTONE, C.P., HOLMES, N.T., ARMITAGE, P.D., WILSON, A.M., SOLOMON, D AND WESTLAKE, D. (1999) Chalk rivers: nature conservation and management. English Nature, Peterborough. 184pp. Available at: http://publications.naturalengland.org.uk/publication/5981928 (Accessed 11/01/18).

MAINSTONE, C.P., LAIZE, C., WEBB, G. AND SKINNER, A. (2014) Priority river habitat in England – mapping and targeting measures. Natural England joint publication JP006. Available at: http://publications.naturalengland.org.uk/publication/6266338867675136?category=432368 (Accessed 10/1017).

MAINSTONE, C.P., SKINNER, A., PETERS, S. AND ROGERS, M. (2015) Refining the priority river habitat map for England: a report on recent revisions and proposals for on-going refinement. Natural England joint publication JP012. Available at:

http://publications.naturalengland.org.uk/publication/5104941191397376?category=432368 (Accessed 10/1017).

MAINSTONE, C.P., HALL, R. AND DIACK, I. (2016) A narrative for conserving freshwater and wetland habitats in England. Natural England Research Reports, Number 064. Available at: http://publications.naturalengland.org.uk/publication/6524433387749376?category=429415 (Accessed 10/1017).

MAINSTONE, C.P., LAIZE, C. AND WEBB, G. (Awaiting Publication) Review of the river SSSI series in England. To be published as a Natural England Research Report.

NAURA, M., CLARK, M.J., SEAR, D.A., ATKINSON, P.M., HORNBY, KEMP, P., ENGLAND, J., PEIRSON, G., BROMLEY, C. AND CARTER, M.G. (2016) Mapping habitat indices across river networks using spatial statistical modelling of River Habitat Survey data. *Ecological Indicators*, **70**, 209-221. doi:10.1016/j.ecolind.2016.01.019.

OLD, G., ACREMAN, M., LAIZE, C., NOTTAGE, A., OVERTON, I., MOUNTFORD, O., PACKMAN, J., WALTON, S., COWX, I., THORNE, C., THOMPSON, J., NEWMAN, J., RAMSBOTTOM, D., GOULDBY, B., LUMBROSO, D. AND GOWING, D. (2010) Ecological impact assessment tools for fluvial flooding and coastal inundation. Environment Agency, Bristol, 114pp.

POND ACTION. (2002) A guide to monitoring the ecological quality of ponds using PSYM. Oxford, UK. pp16. Available at: http://freshwaterhabitats.org.uk/wp-content/uploads/2013/09/NPMN_PSYM_MANUAL_July09.pdf (Accessed 12/10/17).

RACKHAM, O. (1986). *The History of the Countryside*. Weidenfeld & Nicholson, London.

RAVEN, P.J., FOX, P.J.A., EVERARD, M., HOLMES, N.T.H. AND DAWSON, F.H. (1997) River Habitat Survey: a new system for classifying rivers according to their habitat quality. In *Freshwater Quality: Defining the Indefinable?* (ed P. J. D. L. H. Boon), pp. 215-234. The Stationery Office, Edinburgh.

RAVEN, P.J., HOLMES, N.T.H., DAWSON, F.H., EVERARD, M., FOZZARD, I.R. AND ROUEN, K.J. (1998) *River Habitat Quality: the physical character of rivers and streams in the UK and Isle of Man*. Environment Agency, Bristol, UK. pp 85.

ROWAN, J.S., CARWARDINE, J., DUCK, R.W., BRAGG, O.M., BLACK, A.R., CUTLER, M.E.J., SOUTAR, I. AND BOON, P.J. (2006) Development of a technique for Lake Habitat Survey (LHS) with applications for the European Union Water Framework Directive. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **16**, 637-657.

TERRESTRIAL BIODIVERSITY Group (2012) Task & Finish Group 2: Definitions of Outcomes 1A, 1B and 3. Paper TBG 5-5a. Natural England, Peterborough.

UKTAG (2008) UK environmental standards and conditions. UK Technical Advisory Group on the Water Framework Directive. Available at: https://www.wfduk.org/sites/default/files/Media/Environmental%20standards/Environmental%20standards%20phase%201_Finalv2_010408.pdf (Accessed 11/01/18).

SAYER, C.D., ANDREWS, K., SHILLAND, E., EDMONDS, N., EDMONDS-BROWN, R., PATMORE, I., EMSON, D. AND AXMACHER, J.A. (2012) The role of pond management for biodiversity conservation in an agricultural landscape. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **22** (5), 626-638.

SANDIN, L. AND SOLIMINI, A.G. (2009) Freshwater ecosystem structure-function relationships: from theory to application. *Freshwater Biology*, **54**, 2017-2024.

SCHLAEPFER, M.A., SAX, D.F. AND OLDEN, J.D. (2011) The potential conservation value of non-native species. *Conservation Biology,* **25,** 428-437.

SMITH, I. AND LYLE, A. (1979) *Distribution of freshwaters in Great Britain*. Institute of Terrestrial Ecology, Cambridge, 44pp.

STUBBINGTON, R., ENGLAND, J., WOOD, P. AND SEFTON, C. (2017) Temporary streams in temperate zones: recognizing, monitoring and restoring transitional aquatic-terrestrial ecosystems. *WIRES Water, **4**, 4*. DOI 10.1002/wat2.1223

TABLADO, Z., TELLA, J.L., SANCHEZ-ZAPATA, J.A. AND HIRALDO, F. (2010) The Paradox of the Long-Term Positive Effects of a North American Crayfish on a European Community of Predators. *Conservation Biology,* **24,** 1230-1238.

VAN SICKLE, J. (2008) An index of compositional dissimilarity between observed and expected assemblages. *Journal of the North American Benthological Society,* **27**, 227-235.

WALTERS, A.W. (2011) Resistance of aquatic insects to a low-flow disturbance: exploring a trait-based approach. *Journal of the North American Benthological Society,* **30,** 346-356.

WILLIAMS, P., WHITFIELD, M., BIGGS, J., BRAY, S., FOX, G., NICOLET, P. AND SEAR, D. (2004) Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. *Biological Conservation* **115**, 329-341.

WILLIAMS, P., BIGGS, J., CROWE, A., MURPHY, J., NICOLET, P., WEATHERBY, A. AND DUNBAR, M. (2010) Ponds Report from 2007, CS Technical Report No. 7/07.

WOOD, C.M. (2013) Countryside survey environmental zones. Dataset documentation. Document version 1:1-6-2013. Centre for Ecology and Hydrology, Lancaster. https://catalogue.ceh.ac.uk/documents/0cfd454a-d035-416c-80dc-803c65470ea2 (Accessed 01/10/16).

WRIGHT, J.F. AND SYMES, K.L. (1997) Operational mechanisms for the protection and enhancement of headwaters. Scoping study. R&D technical report E25. Environment Agency, Bristol, UK. pp 138.

WRIGHT, J.F., FURSE, M. AND ARMITAGE, P. (1993) RIVPACS - a technique for evaluating the biological quality of rivers in the UK. *European Water Pollution Control*, **3**, 15-25.

YOUNG, R., TOWNSEND, C.R. AND MATTHAEI, C.D. (2004) Functional indicators of river ecosystem health – an interim guide for use in New Zealand. Prepared for the Ministry of the Environment, sustainable management fund, contract 2208. pp 54.

YOUNG, R. (2006) Functional indicators of river ecosystem health - Results from regional case studies of leaf decomposition. Prepared for the Ministry of the Environment, sustainable management fund, contract 2208.31. Cawthron Report No. 1054. 35 pages. Avqailable at: http://www.cawthron.org.nz/publication/science-reports/functional-indicators-river-ecosystem-health-results-regional-case-studies-leaf-decomposition/ (Accessed 12/10/17).

Appendix A

Citizen science programmes

PondNet aims to deliver a nationwide assessment of ponds through its volunteer network and is currently the only tangible survey of ponds where data are collected regularly. It is therefore the most likely source to inform pond habitat condition assessments. The network has a robust design spatially and temporally, and the volunteers provide a prodigious workforce, which is well supported by the FHT.

The survey approach is modular, so that volunteers can chose to survey one, several or all wildlife groups according to their skills, time availability and experience. FHT provide volunteers with a starter pack (health and safety etc.) as well as recording forms for each survey module. Nutrient test kits can also be provided through the CWfW initiative and eDNA test kits are made available for the great crested newt eDNA module, to be returned to FHT for analyses. The FHT website contains guidance for collecting environmental data and this forms a stand-alone module of PondNet, though all modules also collect some baseline environmental data. PondNet data are open access, and contribute to the WaterNet portal. Data are also shared with local record centres and national species groups.

The shaping of the PondNet network has been very much influenced by the ability to detect change in widespread or localised Section 41 and Annex II species. The final recommendations for the design of the PondNet surveillance network are:

- The network will comprise approximately 700 1 km squares divided into overlapping sub-networks.
- The largest proportion of the network will be a core of c.550 1 km grid squares used to detect stock and change in widespread amphibians (e.g. Great Crested Newt, Common Toad, Common Frog). Of the 550 squares, 50% are sites known for GCN or Common Toad and 50% are a random selection of sites from which these species are unknown. All (or a significant proportion of) ponds in each survey square must be surveyed for amphibians. Great Crested Newt Habitat Suitability Index values, and other environmental data, will also be collected.
- A proportion (c 200 sites) of the 550 grid square amphibian network can be used be used as a fully random network for the surveillance of very widespread pond species (e.g. widespread dragonflies, common wetland plants) and, more significantly, to assess and explore change in pond quality using biological and environmental metrics.
- Additional ponds will be surveyed for localised BAP species, based on species abundance, and Habitat Directive habitat types, using the occurrence of indicator taxa. The number of sites required to show change is not yet known, and gathering abundance data to investigate this will form part of the project's regional trials. However provisional analysis for BAP species suggests a total of c.220 sites could be adequate to monitor change in most species including: Marsh Stitchwort, Flat-sedge, Yellow Centaury, Marsh Clubmoss, Mud Snail, Pill wort, and the more widespread Tubular Water-dropwort. Random selection of these sites showed that, because of overlap in the 1 km squares in which localised species occur, these 220 BAP species ponds occurred in 134 1 km squares.

- A small number of additional ponds will be selected randomly, stratified to include a proportion of designated sites, using the range of criteria used to identify Priority pond habitat. Preliminary assessment suggests that this would need no more than 50 additional ponds.

The main constraint to the national roll-out of PondNet is the ability to maintain and extend the network in the long term. An organisational structure is required to manage the project at national and local levels and this is likely to require further funding. National coordination by FHT and other national recording groups is likely to be necessary to maintain some of the key project aspects highlighted by the trials: methodological and site selection standards, delivery of quality assurance, provision of web-tools and project guidance, and analyses and reporting of results against statutory or other targets. This would allow local/regional coordination (local recording centres and species groups) to focus on the important issues highlighted by the volunteers: recruitment and training, retention of species experts and mentors, arrangements for site access and access to equipment, and day to day volunteer queries.

There are some limitations to how much PondNet can currently contribute to condition assessments:

- There are inherent limitations to using volunteers for data quality and consistency, in particular regarding the completeness of the survey. The collection of environmental variables is required for all ponds, and needs to be comparable. There has been much focus on the success of the volunteers with different biological surveys, but is unclear how well environmental data are recorded.
- Some aspects of recording could be improved to better describe habitats, e.g. clear questions such as is the pond fenced off? Does it have a buffer? Does it have a natural or artificial base?
- The main type of data currently collected is priority species data, and this information does not clearly link to natural habitat function as required for priority habitat assessment. However, in the future a greater element of habitat assessment may be the best approach, considering the difficulties that PondNet has faced with accurately record the presence and abundance of priority species by volunteers.

The Riverfly Partnership is an extensive network of volunteer recorders on rivers around the country, who are trained in the identification of certain common river flies (species of mayfly, caddis-fly and stonefly. Monitoring and reporting is undertaken to highlight impacts that are not detected by the core surveillance monitoring undertaken by statutory agencies, either due to the sparsity of surveillance sites or the resolution of the monitoring methods used.

People, Ponds and Water (PPW) is a citizen science scheme worth particular consideration as a source of pond data. Work on this project can also give some insights into what makes such schemes successful. It is a national project delivered by the FHT and is funded by the Heritage Lottery Fund (HLF). Its principal aim is to promote the monitoring and protection of ponds and other small water bodies through public engagement. The project has three complementary initiatives: Flagship Ponds, PondNet and Clean Water for Wildlife (CWfW). These initiatives will feed into a data sharing portal called ‘WaterNet’ where data can be freely viewed and analysed from January 2016 onwards.

Flagship ponds is aimed at protecting 70 of the UK’s very best ponds together with their rare and endangered freshwater plant and animal species. They can be individual ponds or a complex of ponds within a site. Though they represent some of the least impacted most diverse pond habitat remaining in England, many of these sites are at risk from degradation, although the causes vary widely.

The flagship ponds are selected from sites classified as pond priority habitat and account for ~1% of these. The Flagship Ponds Project aims to ensure that the Flagship sites are supported with regular monitoring of key species and pond quality. Monitoring data from the Flagship Ponds contributes to PondNet.

Clean Water for Wildlife is a community-based survey which aims to identify clean freshwater habitats, capable of supporting rich wildlife. The survey also aims to discover the extent of nutrient pollution nationally. The project uses reliable field rapid water testing kits. These provide people with a quick, simple and accurate means of assessing water quality on the basis of nitrate and phosphate concentrations using a colour chart system. The test kits are provided for free by the FHT and are accompanied by a recording form to note location, waterbody type, and test kit results. Nutrients are recorded in 6 categories: up to 0.2, 0.5, 1, 2, 5 and 10ppm for nitrate and likewise for phosphate: up to 0.02, 0.05, 0.1, 0.2, 0.5, 1 ppm. Whilst the CWfW targets all freshwater habitats, it also specifically supports PondNet through the provision of test kits.

The accuracy of the kits has been tested by checking the results for some sites against formal laboratory analyses (Mike Bowes, CEH, personal communication). The test kit data were found to be consistent with those generated by laboratory analyses (Figure A1), with the exact laboratory-derived values falling within the corrected ranges indicated by the text kit.

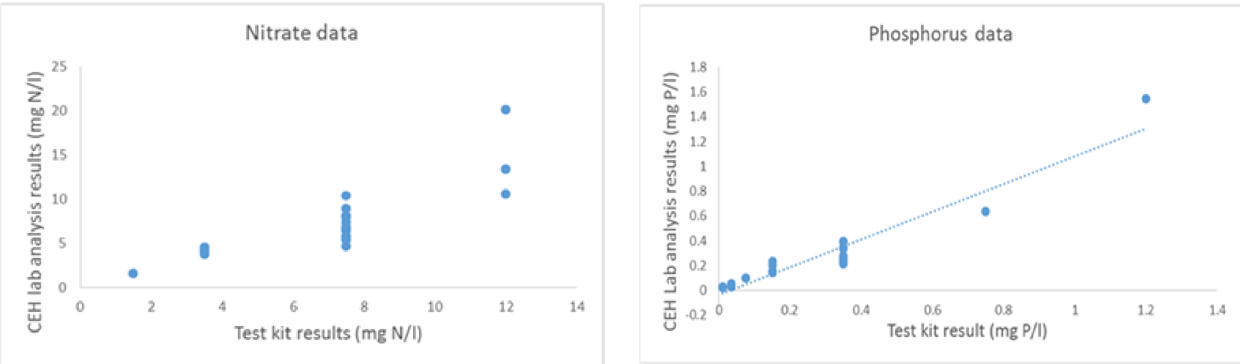

Figure A1 Comparison of test kit results and laboratory analysis of nutrient levels (M. Bowes, unpublished data).

National Amphibian and Reptile Recording Scheme (NARRS) - This scheme is led by Amphibian and Reptile Conservation in partnership with other partners. It brings under the same umbrella surveys for rarer herpetofauna and volunteer surveys for more widespread amphibians and reptiles. The volunteer surveys share the modular approach of PondNet as surveyors may choose between a widespread amphibian species survey, a widespread reptile species survey, an adder survey or alien species survey (the latter forms a distinct subset of NARRS under the auspices of *Alien Encounters*). So far (to 2015), the scheme has surveyed 738 1 km squares for either reptiles or amphibians or both. The scheme reports fully in 6 year cycles, while phase 1 was principally levelled at determining occupancy, phase 2 is targeted to tracking population size. Reptile surveys are square based but amphibian surveys are focused on ponds, thus their relevance to this report. To date, 412 ponds have been sampled by the scheme

NARRS phase 1 surveys have been running since 2007 and the first full survey cycle was completed in 2012. The results set baseline occupancy rates for widespread amphibians and reptiles and were made available in 2013 through a website. **NARRS phase 1** surveyors were allocated a different survey square each year, near where they live (based on their postcode) and which they surveyed for amphibians, reptiles or both. For amphibians, 1 pond was selected and surveyed per square.

NARRS phase 2 began in 2012 and opened to volunteers from 2013. The methods are the same as for **phase 1**, but survey squares are targeted on known locations containing amphibian and/or reptile populations (i.e. known ponds for amphibians). The aim of phase 2 is to obtain population data, so squares/ponds are revisited every year with the emphasis on obtaining estimates of species abundances. Volunteers are allowed to select any local site/pond with an amphibian and/or reptile population, however, volunteers must be able to visit their chosen site(s) **at least 4 times each year in suitable survey conditions** so that data are comparable. The chosen square(s) are added to a register of PHASE 2 sites that can be used to assess population trends over time.

The variables recorded by NARRS are also recorded in PondNet and CS, albeit much fewer and in less detail. They are principally aimed at the quality of the habitat for amphibians but do include some of the fundamental characteristics e.g. pond area, pond permanence, shading and macrophyte cover. Unsurprisingly only amphibians are recorded (other than fish/waterfowl impacts). Unlike in PondNet amphibian surveys where all ponds in a square are surveyed, the NARRS amphibian surveys only target one pond per square, which confers PondNet greater power to detect change over time. However NARRS because less biased towards the detection of S41 species (GCN, common toad) and the common frog, it collects more information than PondNet on some other amphibians (smooth and palmate newts). Similarly to PondNet, NARRS runs training events and provides training materials on the scheme website. In contrast to PondNet there is less structure to the scheme and less mentoring of the volunteers. For example volunteers arrange their own landowner access.

The Open Air Laboratories network (OPAL) - OPAL is a UK wide citizen science initiative with the broad remit of bringing people and the environment together while collecting scientific data. It is funded by the Big Lottery Fund and led by Imperial College London. Two OPAL surveys are relevant to UK ponds.

The *metals* survey targeted sediment in ponds and lakes. Volunteers chose their own sample sites, and were sent sampling kits which were then returned to UCL for analysis. 395 kits were sent out, 120 returned with only 5 unusable. Imperial College did additional sampling, building the dataset up to 296 distinct water bodies, principally ponds. Results were made available through a dedicated website. The network of sites is very biased towards urban areas and very little environmental information was collected other than pond location.

The *water* survey targets water quality in ponds and lakes and has been running since 2010. It includes basic variables such as location, land use, turbidity, visible impacts and pH. The presence of a number of main invertebrate groups are recorded to provide a rapid assessment of ecological status via a ‘pond health score’. Optionally, volunteers can further record amphibian species, odonate species and duckweed species. Volunteers select their own sites. Again most sites consist of ponds in urban and peri-urban areas. Results are made available through a dedicated interactive website.

The Big Pond Dip is a public engagement project run by FHT that deploys a very basic pond survey. The data do not support full condition assessments, but the scheme provides valuable insight into garden and school ponds while promoting interest in ponds and encouraging creation of new private ponds.

Wetland Bird Survey, and the Waterways Breeding Bird Survey – These are run by the British Trust for Ornithology, taking place around various freshwater habitats (including ponds) and collecting some environmental data as well as occupancy by wading birds. Neither provide enough data on habitat integrity to allow condition assessment.

Appendix B – Key data sources for River Habitat Survey

RHS baselines (Environment Agency)

An early requirement for RHS was to establish a representative baseline sample of river habitat features, collected in a consistent and repeatable fashion. This was achieved by surveying a network of reference sites based on a stratified random sample of those rivers classified for water quality purposes. As a result, any length of river surveyed in the UK using RHS can be categorised and its habitat quality assessed, by comparing it with other sites of similar physical character.

The RHS reference sites were selected independently of existing chemical and biological sampling points, because the latter are located, for practical reasons, in a non-random manner. Ordnance Survey 10 km grid squares were used as a sampling framework. For convenience, however, all coastal squares with less than 50% of land area above high water mark were omitted from the baseline reference sample. The original focus for RHS development was England and Wales, and a 3-year sampling period was planned. Three individual RHS sites in each of the 1523 qualifying 10 km squares were sampled during 1994, one in each square in successive years (95-96), giving 4569 sites in all. Rivers indicated on 1:250000 scale topographical maps qualified for inclusion, but tidal reaches and canals were specifically excluded.

Sites were located on the basis of random selection of tetrads (2 km) within each qualifying 10 km square. The main qualifying criterion was that the watercourse had been classified for water quality, as indicated by the 1985 River Quality Map based on the National Water Council classification (National Water Council, 1981). Where no such classified watercourses existed within a 10 km square, any watercourse qualified. In the three cases in England where a 10 km square did not contain a watercourse shown on the 1:250000 scale map, the 1:50000 scale Ordnance Survey map was used to determine site location. In 1995–96, Scotland and Northern Ireland sites were added. In Scotland, one site in each of 779 qualifying squares was sampled over a 2 year period in 1995 and 1996. Because some 10 km squares were inaccessible by road, site selection had the added practical requirement of being within 2 km of a vehicle track. In Northern Ireland, one site in each of 133 qualifying squares was sampled in both 1995 and 1996, giving 266 sites in all. To extend the picture, three RHS sites in each of six qualifying squares on the Isle of Man were sampled in 1997. A first report on the state of river habitats was produced in 1998 (Raven et al, 1998).

A second survey in England, Isle of Man and Wales was carried out during 2007 and 2008 similarly to the first baseline, with a random sampling design that used 10km OS map grid squares to stratify the sample. Three survey points were randomly selected in each of those grid squares. In 2007-08, two of these were selected from larger rivers (which only appear on the 1:250,000 scale river network), selecting the third from smaller rivers (which only appear on the 1:50,000 scale network). This ensured the baseline was representative not only of larger rivers, but also of smaller streams, many of which are headwaters. Summary information, including changes since the original baseline, was published in October 2010 (Environment Agency, 2010).

Data from the two RHS baselines are held by both the EA and the CEH. They are freely available upon request to the EA.

RHS in the Countryside Survey (CEH)

The CEH was heavily involved in shaping the RHS protocol, and deployed it as one of the standard methods for the countryside surveys of 1998 (referred to as ‘CS2000’) and 2007 (and more recently to the Wales GMEP survey).

The CS protocol divides the UK into 1km squares and these are selected for survey using a random method stratified by land classes (591 squares were surveyed in 2007). Squares which are 90% sea or 75% urban are not included. It is principally a survey of the terrestrial habitat, but included one headwater stream survey per square where possible in 1990, 1998 and 2007. From CS2000 onwards, RHS was deployed at the stream sites. Headwater streams were defined as Strahler order 3 or less, and in some squares drains and ditches were used as a substitute.

Because CS revisits the same squares whenever possible, the RHS data are unique in their ability to track change at the site level for a large population of sites (the second EA RHS baseline used different sites to the first). The RHS dataset is also unique due to the focus on headwater streams, which are otherwise poorly studied. This uniqueness however is also a form of constraint because the data are only relevant to these types of water bodies. A further bias may lie in the site selection within the square. Usually this has been selected to maximize the amount of the upstream catchment that lies within the square, as well as ensuring the RHS 500m falls within the square, using maps, so that the site is usually placed near the edge of the square. This means the site is chosen because it is representative of the square, rather than because it is representative of the stream, and this may have implications for assessing the naturalness of the water body for the purpose of this project.

CS data are held solely by the CEH. They are freely available but site location is anonymized.

Other RHS data

RHS is routinely deployed by the EA and its contractors for water body characterization, and, for example, data are used to identify HMWB’s, confirm HES and calibrate hydro-ecological models. By their nature these data are biased towards water bodies included in the WFD monitoring network and therefore towards larger lowland rivers and sites that are either degraded or at risk of degradation.

CEH routinely deploys RHS in riverine ecology research projects for site descriptions and the interpretation of ecological data, as well as the calibration of hydro-ecological models. Though there is less of a bias towards larger lowland water bodies, with some CEH data sets specific to smaller headwater streams, site selection is usually dictated by the aims of the research project that the data were collected for, and thus the majority of sites are also degraded or at risk of degradation (particularly relating to water abstraction and agri-environmental diffuse pollution).