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This is the peer reviewed version of the following article: Shuker, L., Moggridge, H.L., Gurnell, A.M. 2015. Assessment of hydromorphology following restoration measures in heavily modified rivers: illustrating the potential contribution of the Urban River Survey to Water Framework Directive investigations. Area 47.4, 396-407, which has been published in final form at DOI: 10.1111/area.12185. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Self-Archiving.

Assessment of hydromorphology following restoration measures in heavily modified rivers: illustrating the potential contribution of the Urban River Survey to Water Framework Directive investigations

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Abstract

This paper explores the potential application of the Urban River Survey (URS) method for assessment of the hydromorphological condition of a heavily modified waterbody pre- and post-implementation of mitigation measures. The findings of a case study are used to demonstrate the utilisation of URS for monitoring hydromorphological response to restoration and assessing hydromorphological quality, particularly in relation to ecological potential and the European Water Framework Directive (2000/60/EC).

Key words: urban river, hydromorphology, Water Framework Directive, restoration, good ecological potential, sustainable river management

Introduction

Worldwide, rivers have been extensively modified to serve societal needs, including agricultural, industrial, navigation and flood risk management services. As a consequence, many rivers have fundamentally altered morphology, with straightened planforms, reinforced banks and in-channel structures (Paul and Meyer 2001; Gurnell *et al.* 2007). Such modifications are particularly prevalent in urban centres, where rivers are also affected by altered flow regimes and elevated levels of nutrients and pollutants, described by Walsh *et al.* (2005) as the 'urban river syndrome'. There is a well established negative biotic response to these modifications (Wenger *et al.* 2009), with observed declines in the abundance and diversity of fish (Wang and Kanehl 2003; Roy *et al.* 2006), invertebrates (Beavan *et al.* 2001; Chadwick *et al.* 2006) and macrophytes (Suren 2009; Vermonden *et al.* 2010).

In recent years, the drive to reverse these declines and 'restore' rivers back to a 'pre-modified' state (Bernhardt *et al.* 2005; Skinner and Bruce-Burgess 2005), has seen an evolution of restoration measures from the simple reinstatement of features for single species, towards improving physical habitat by increasing in-channel and riparian heterogeneity (Woolsey *et al.* 2007; Roni *et al.* 2008), often on the assumption that creating habitat diversity alone will promote ecological recovery and morphological sustainability (Palmer *et al.* 2010). However, understanding of the physical and ecological responses to such measures is limited by the lack of post-project monitoring (Bernhardt *et al.* 2005; Hering *et al.* 2010) and the absence of pre-restoration baseline data for comparison (Skinner and Bruce-Burgess 2005).

Although not currently a legal obligation, information on the physical outcomes of restoration schemes is vital for lesson learning to understand effective river rehabilitation and fundamental to achieving more sustainable river management, therefore it is imperative that schemes are appraised using standard methodologies and disseminated information is widely accessible (Kondolf *et al.* 2007; England *et al.* 2008).

River restoration within Europe has received impetus from the EU Water Framework Directive (WFD, 2000/60/EC) through its requirements for improved ecological quality of surface waters and the sustainable management and protection of freshwater resources. The Directive requires that bodies of surface water (WFD water bodies), defined by their hydromorphological (i.e. hydrological and morphological) and chemical characteristics, achieve 'good' status for biological (macro-invertebrates, macrophytes and fish) and chemical elements by 2015, or where derogations are applied through successive river basin planning cycles, until 2027 (Kallis and Butler 2001). An exception to the WFD requirement for overall 'good ecological status' (GES) is made for heavily modified water bodies (HMWBs) that provide important services to society and where the changes required to achieve GES would carry high social or economic cost (Hering *et al.* 2010). The aspiration for these systems is 'good ecological potential' (GEP), which requires that appropriate and reasonable measures are taken to mitigate the impact of use-related modifications on a range of hydromorphological indicators or 'quality elements' e.g. channel substrate or connectivity. Meeting WFD targets will require extensive restoration measures, which need to be monitored and the findings disseminated (Collins *et al.* 2012).

Assessing Ecological Potential within the UK

Variation and uncertainty in the assessment of 'ecological potential' across EU Member States is reported by Hering *et al.* (2010). Within the UK, the WFD Technical Advisory Group outlines a recommended stepwise procedure (UKTAG 2008).

Following the 'Prague approach' to GEP assessment (Kampa and Kranz 2005), the UKTAG procedure begins with an appraisal of how many of the mitigation measures associated with its designated use have been implemented within an individual HMWB. Without all of these mitigation measures 'in place' a HMWB automatically fails to meet GEP, unless those measures cause a 'significant adverse impact' upon designated use or protected sites. The UKTAG GEP assessment then considers whether an alternative objective is needed for the HMWB, such as an extended deadline, in order to achieve phased progress towards GEP.

UKTAG (2008) guidance requires mitigation measures to be implemented through WFD River Basin Planning, where feasible. However, the extent of implementation and whether those measures *adequately mitigate the identified impacts* is decided by expert judgement (UKTAG 2008). Furthermore, whilst primary biological indicators (fish, macro-invertebrates and macrophytes) are excluded from GEP assessment, the WFD recognises the importance of hydromorphological characteristics for aquatic fauna at particular life stages (i.e. fish migration and spawning) within an '*ecological continuum'*. Although a lack of clear guidance on mitigation adequacy in GEP assessment has led to uncertainty surrounding WFD implementation in HMWBs (Hering *et al.* 2010), the value of evidence to demonstrate hydromorphological responses to mitigation measures for PPA and adaptive management remains constant.

Ongoing developments in hydromorphological assessment beyond the standard UK River Habitat Survey (RHS) approach for river restoration monitoring (Clews *et al.* 2010), particularly the inclusion of flow assessment to determine which quality elements help to determine GEP (Webb, unpublished) have been informed by comparative studies of methodologies across Europe (e.g. Raven *et al.* 2002; Scheifhacken *et al.* 2012) and development of a European standard (Boon *et al.* 2010). Most significant is the lack of a hydromorphological assessment method for HMWBs which takes into account the influence of channel engineering or physical modifications.

The Urban River Survey (URS)

The URS is a semi-quantitative field method for recording the size, sediments, morphology / physical habitats and vegetation structure of rivers that are urbanised or modified for other uses, and the detailed character of any physical interventions or modifications. Thus, the URS has potential to provide much of the data required for the hydromorphological assessment of GEP. It emphasises morphology and does not incorporate flow or chemical data, since these are already recorded by other routine monitoring.

The methodology consists of a field survey, developed from the UK Environment Agency's River Habitat Survey (Raven *et al.* 1997), with additional detail concerning channel modifications from which indices are extracted that support (a) classification and (b) ordination of reaches or stretches of 'urban' river to allow comparisons of condition between different stretches and to track changes through time. The development of the URS method and its application to European rivers is well documented (Davenport *et al.* 2004; Boitsidis *et al.* 2006) with methodological guidance and data from >400 surveyed stretches publicly available at www.urbanriversurvey.org.

Whilst the URS has previously been used to understand the impact of modifications on the physical condition of rivers (Gurnell *et al.* 2007, 2012) ; for detecting physical change from large-scale enhancements, and to guide management decisions (Shuker *et al.* 2011), its use for measuring the effectiveness of in-channel rehabilitation measures has not been demonstrated before.

In this paper, we employ a case study to illustrate the potential of the URS: (i) to assess hydromorphological responses to mitigation / rehabilitation measures at both stretch and patch scales; and (ii) to provide evidence for post-project appraisal and assessment of GEP in heavily modified systems.

Application of the Urban River Survey for post-project appraisal and GEP assessment – Carshalton Case Study

Study site

URS was conducted on a rehabilitated section of the Carshalton water body on the River Wandle, a heavily urbanised chalk stream that rises in South West London, UK and flows north to join the River Thames in the London Borough of Wandsworth (Figure 1). The Wandle has a long history of use, initially for watercress production and then increasingly for industrial and domestic water supply and disposal, resulting in extensive channel modifications along its course.

The Wandle system is divided into two WFD water bodies: one extends from Croydon to Wandsworth; the other is the Carshalton Branch, a tributary of the main Wandle (Figure 1). The Carshalton water body includes a section that was restored in the 1990s as part of residential developments on adjacent, previously-industrial land (D. Webb, pers. comm.). Restoration involved extensive removal of hard bank reinforcement and naturalisation of bank profiles, although the channel remained over-widened, with a highly constrained linear planform and several weirs.

Within the first Thames River Basin Management Plan (RBMP, Environment Agency 2009), the Carshalton water body was designated as heavily modified with 'moderate ecological potential', based on its urban 'use'. In line with UKTAG guidance, the RBMP reports those mitigation measures (associated with urban use) that are 'not in place' (see Table 1, column 1) with the reason for failure to achieve GEP cited as 'hydromorphology'. Linkages between WFD hydromorphological quality elements and mitigation measures can be clearly demonstrated and used to define expected indicators of physical change where the latter are implemented (Table 1, columns 2 to 7).

This example of URS application focuses on two stretches of the Carshalton water body at Mill Lane (ML, 400m) and Butterhill (BH, 300m) for which baseline (pre-restoration) URS data were available (see Method section). The study stretches have a 130m overlap (due to unsynchronised baseline data collection, see Figure 1), altogether representing a total of 0.57km of rehabilitated river in 1.1km of open channel. In 2011, in-channel and marginal enhancements were undertaken on the stretches during two phases (Table 2, Figure 2) (Longstaff, 2011). For each study stretch, the main interventions were located beyond the overlapping section. The only enhancement work affecting both stretches was rubble removal. As the main focus of the investigation is temporal, i.e. in-channel hydromorphological changes pre- to post- implementation of WFD mitigation or rehabilitation measures, the overlap is considered to have low significance.

Method

The two stretches were each surveyed twice using URS, following the standard method (Gurnell and Shuker 2011). Baseline surveys took place in September 2009 and October 2011, with post-works surveys completed in September 2013. Since morphological adjustment depends upon a combination of direct human modifications and fluvial processes, flow records from the Carshalton Ponds gauging station were inspected to identify the timing of high flows between pre- and post-intervention URS surveys.

The baseline survey at Mill Lane (Sept. 2009) was conducted before any works were undertaken, whilst the Butterhill survey (Oct. 2011) was conducted immediately after a weir removal, but before other interventions (channel narrowing, marginal planting, gravel introduction). All but one of the surveys (Butterhill 2011) were conducted by the same URS trained surveyor, providing confidence in recording consistency.

The URS data were used to generate three different measures of habitat quality for each stretch: (i) a Stretch Habitat Quality Index (SHQI) value (Boitsidis *et al.* 2006); (ii) a comparison of the study stretches with other surveyed stretches through a Principal Components Analysis (PCA) of 48 indices, derived from URS data from >400 surveyed stretches (Gurnell *et al.,* 2007); (iii) a more detailed assessment of patch-scale physical responses, through a comparison of local values of some of the derived indices.

To achieve element (ii), PCA was applied to values of 48 indices from 406 river reaches using XLSTAT (v.2011.3.01). The analysis, which was applied to a Spearman's rank correlation matrix, identified environmental gradients and groupings within the dataset. Comparison of the plotting positions of the study stretches surveyed at different dates with respect to the first two Principal Components, allowed their character and any changes following river restoration interventions to be explored.

The three methods and outputs described above were designed primarily for research purposes. In the present case, a new application is proposed, to assess reach (stretch) to patch-scale hydromorphological responses within the two study stretches following the implementation of mitigation works as they have the potential to contribute to post-project appraisal and assessment of GEP in heavily modified systems.

Results

(i) River flows records

Flow data recorded at the Carshalton Ponds gauging station (located approximately 100m upstream of the Mill Road stretch) showed two periods of relatively higher flows between October 2009, when the first baseline survey was conducted at Mill Lane and September 2013, when both post-works surveys were completed (Figure 3).

Following, Downs and Kondolf (2002), who noted the importance of differentiating short term geomorphological-hydraulic interactions from the longer term relationships, hydrological data during the study period revealed the highest daily flow of 0.412 m^3/sec occurred on 03/06/2013, after the two baseline surveys and before the post-works survey. Based on an analysis of the annual maximum series derived from the 1956-2013 daily flow record for this site, this flow value has a return period of approximately 3.2 years, suggesting that it was sufficient to have driven some channel adjustment following the works. The peak flow between the two baseline surveys (0.374 m^3/sec) has a return period of approximately 2.3 years, indicating that post-works adjustments at Mill Lane may be greater than at Butterhill. Further change can be anticipated in the longer term and following greater magnitude events. The influence of hydrological variability upon physical adjustment time frames should not be underestimated in post-project appraisal, with a minimum of 10 years monitoring recommended by Downs and Kondolf (2002) to build understanding of longer-term geomorphological-hydrological relationships and channel dynamics within a restored reach.

(ii) Stretch Habitat Quality Index

An initial reach-scale evaluation of the Stretch Habitat Quality Index (SHQI) scores for both stretches before and after interventions (Table 3) revealed lower SHQI scores post-works, indicating higher quality and suggesting an improvement in physical habitat. As this scoring system is at the reach-scale, it does not provide information on the presence or nature of local changes to physical habitat.

(iii) Relative changes in stretch hydromorphology

Figure 4 shows the two environmental gradients identified by the first two Principal Components, which explain 33% of variation in the data. Interpreting the PCs from the loadings of the contributing indices: PC1 (20.4% variance) shows a gradient from high, solid (e.g. concrete, brick) bank protection (left of plot) to high bank form complexity and 'naturalness', high tree feature diversity (e.g. exposed roots, trailing branches, large wood), with an increasing presence of different flow types indicating a relatively complex river bed (right of plot); whereas PC2 shows a gradient from high tree cover (bottom of plot) to high aquatic vegetation cover (top of plot) with a transition through stretches characterised by the diversity of vegetation types, ranging from very low (extreme left of plot) to high (centre-right of plot). Furthermore, the count of physical habitats (indicating overall habitat diversity) has a positive loading on PC1 and a negative loading on PC2, indicating that overall physical habitat complexity increases across the plot towards the bottom right.

SHQI classes are broadly arranged along PC1 from Poor to Good, reflecting a reduction in bank protection and an increase in habitat complexity, particularly of bank, bed and tree features. The relative positions and clustering of the study stretches near the centre of the scatterplot indicates both an overall improvement in complexity but also persistence of broad hydromorphological similarities despite the restoration works. The smaller shift along PC1 between the Butterhill surveys (BH_11 to BH_13) suggests a smaller increase in the habitat complexity of bed and banks, which is explained by the timing of the 'baseline' survey (pre-gravel introduction and marginal planting but post-weir removal) and also the shorter time between surveys involving exposure to only one rather than two higher flow periods (Figure 3). The diagonal shift in position of the baseline and post-works Mill Lane surveys (ML_09 to ML_13) relative to PC2 reflects increased physical habitat diversity as well as some adjustment in the balance between riparian and aquatic vegetation.

(iv) Local patch-scale hydromorphological response

The PCA provides considerable value in demonstrating and visualising broad shifts in the plotting position of the two reaches relative to a large sample of other heavily modified reaches in Figure 4, allowing a broad link with the WFD hydromorphological indicators to be surmised. Undertaking the URS allows both integrative and single elements to be explored, thus enabling a more detailed and robust interpretation of specific changes, particularly in relation to individual quality elements. Therefore, the reach-level investigations were complemented by a more detailed exploration of the URS data to reveal specific habitat characteristics within the stretches and their relationship with the WFD quality elements (Table 4). The post-works data reveal increases in the diversity of flow and physical habitat types for both stretches, with higher proportions of riffles and gravel bar habitats. While the percentage cover of vegetation has not increased significantly, aquatic vegetation diversity is greater in both stretches, especially in the Butterhill stretch, reflecting the successful establishment of marginal macrophytes following planting works.

Table 4 also illustrates how URS indices can provide information that relates directly to the WFD hydromorphology quality elements and wider conservation objectives which can in turn be linked to the expected indicators of change associated with implementation of mitigation measures (Table 1). For example, the variety and number of flow types can be used as basic indicators of hydraulic diversity and flow dynamics; also the proportion and type of hard bank protection and presence of weirs can be used as indicators of restrictions in lateral and longitudinal connectivity or continuity, respectively. Furthermore, the counts and positions of marginal and in-channel morphological features can provide much information regarding river width and depth as well as riverbed structure and substrate. Data presented in Table 4 clearly demonstrate that empirical evidence from URS (1) provides valid indicators of morphological dynamics; and (2) demonstrates spatial and temporal adjustments that can be related to the outcome and effectiveness of restoration or mitigation measures and the river's response to these measures.

Discussion

Urban River Survey as a mechanism for determining measure-related hydromorphological change

Although the case study only considers one relatively small water body, it illustrates considerable potential for using URS outputs across larger HMWBs to demonstrate and assess change in hydromorphological indicators that can be related directly to responses to mitigation measures, thus providing evidence for their effectiveness in support of GEP assessment.

At the reach scale, URS can support hydromorphological assessment in two ways: SHQI scoring provides an easily interpreted measure of overall physical habitat quality; whilst PCA comparison of the physical characteristics and condition of individual stretches relative to broad environmental gradients in a large sample of urban rivers allows a comparison of the extent and direction of change in physical indicators that link broadly with the hydromorphological quality elements. These assessment methods provide not only useful outputs for demonstrating large scale changes associated with major restoration works (see Shuker *et al.* 2011) but with additional potential for relating underpinning indices to WFD objectives for HMWBs, particularly as data from all URS-surveyed stretches (including derived indices and SHQI scores) and guidance are freely available for trained surveyors to view or download at www.urbanriversurvey.org.

Standard reach-scale assessment methods can effectively reveal overall differences in physical habitat condition, but their outputs typically lack the sensitivity required to pick up the detail of localised habitat/patch-scale changes taking place over shorter time periods. Further exploration of the URS indices has demonstrated valuable, patch-scale insights into the nature of specific changes in hydromorphological characteristics associated with mitigation measures or other interventions. Key indicators of adjustment include: the extent and diversity of channel materials or functional habitat features, e.g. bars, pools and riffles; and evidence of dynamic fluvial processes, such as channel narrowing or incision. For example, detailed exploration of the URS indices reveals that habitat improvements are attributable to increases in the diversity of flow (proportions of riffles and runs), bar features and in-channel vegetation types; increasing presence of 'natural' bank profiles of different types; and changes in dominant bed sediment calibre (i.e. silt to gravel-pebble at Butterhill). Thus, URS data can be used to assess both the relative quality of stretches and to demonstrate morphological/ physical responses to river restoration or mitigation measures at different scales.

Whilst physical rehabilitation alone does not necessarily promote ecological recovery in rivers (Harrison *et al.* 2004; Palmer *et al.* 2010), especially if water quality remains poor (Violin *et al.* 2011), URS offers a potential contribution towards an improved integrated understanding of the effectiveness of river improvements by contributing to coordinated measurement of biological, hydrological, morphological and chemical properties.

Application of Urban River Survey for the Water Framework Directive

The comparison of URS outputs with WFD hydromorphological quality elements, and links to expected responses to mitigation measures (Tables 1, 4) clearly indicate the potential of this method for revealing the effectiveness of interventions in HMWBs aligned with WFD objectives to achieve GEP and sustainable river management. Within the UK, mitigation of the impacts of particular 'uses' is assumed where measures are implemented, but this is not supported by post-mitigation appraisal, reflecting a wider absence of monitoring, post-restoration appraisal and effective dissemination following river restoration (Bernhardt *et al.* 2005; Skinner and Bruce-Burgess 2005; England *et al.* 2008).). This case study points to further potential for developing the URS method and web interface to address this gap, disseminate outputs, advance investigation into the effectiveness of mitigation measures at a range of spatial and temporal scales, and support future evidence-based decision-making within the WFD specifically for HMWBs (Hering *et al.* 2010, Collins *et al.* 2012).

Key attributes represented within the raw data such as longitudinal connectivity, indicated by presence or absence of structures; or variation in channel width, indicated by opposing depositional or erosional features are highlighted as significant WFD quality elements, but there is currently no guidance on their implementation. Thus, ample potential exists for developing specific URS metrics to support GEP assessment and WFD objective delivery.

Conclusions

URS provides an accessible and economical method that can provide hydromorphological information in sufficient detail to show patch-scale changes in the context of broader, comparative reach-scale assessments. The 'pilot study' presented here indicates a good potential for further, regional scale testing of the method for evaluations of other HMWBs.

The pilot study also demonstrates the potential to develop further bespoke URS indices to assess the effectiveness of river restoration for beneficial and sustainable hydromorphological change and also to meet the need for evidence to demonstrate WFD measure outcomes, thus filling gaps highlighted by Skinner and Bruce-Burgess (2005), England *et al.* (2008) and Hering *et al.* (2010).

The overriding methodological principle: to assess habitat in the context of river channel modifications combined with the flexibility of the URS method provides considerable scope to test its wider application across a range of (non)urbanised modified river systems with outputs adapted to suit relevant local or regional conservation objectives, and so to inform and guide adaptive approaches to long term sustainable river management.

Acknowledgements

The authors are very grateful to Dave Webb and Dr Judy England for initiating and contributing valued comments to ongoing discussions on the development of GEP assessment and potential for URS as a tool in that context. Thanks also to Shaun Oliver and David McCutcheon for their help in the preparation of the figures.

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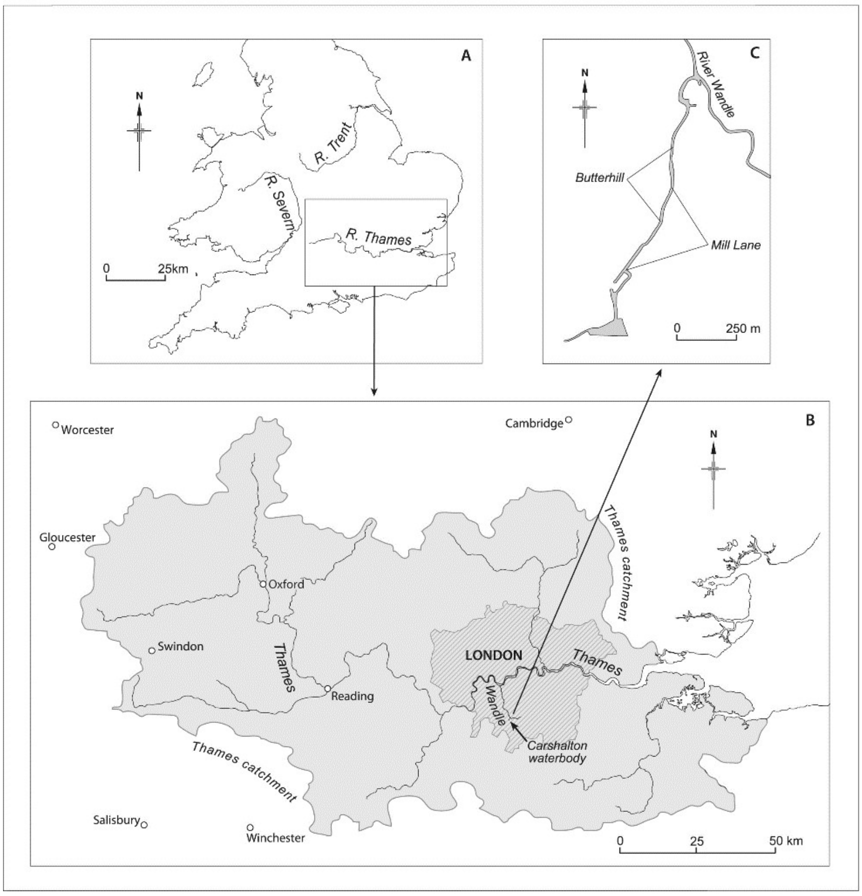

Figure 1 – Location of the study site within: (a) England and Wales, (b) the River Thames catchment and (c) Carshalton water body. Map (c) also shows location of the study stretches.

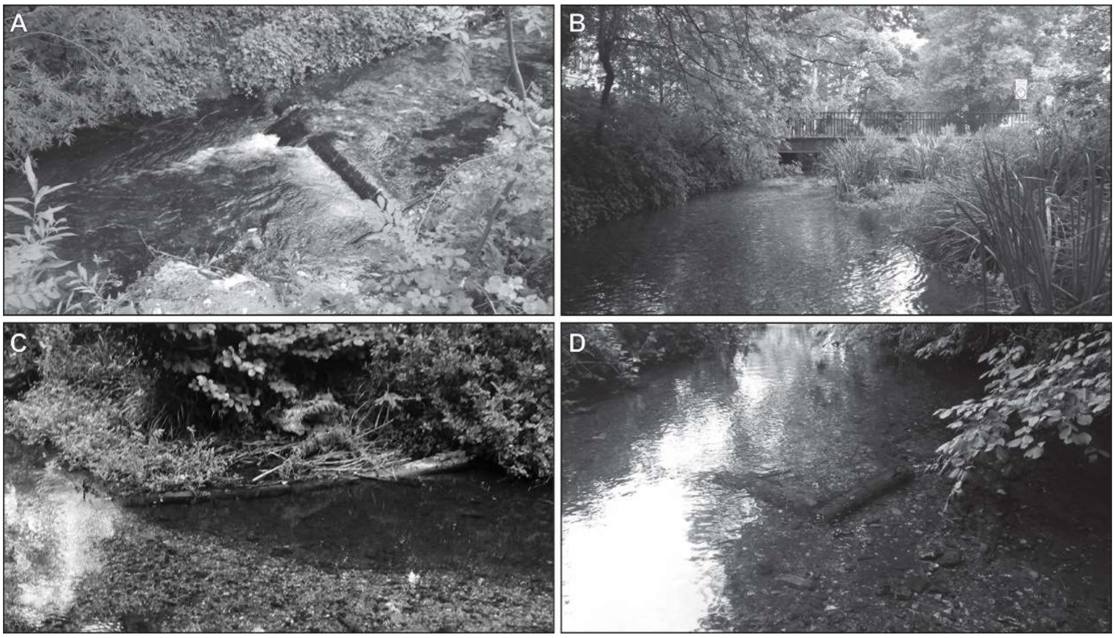

Figure 2 – Mitigation works on Carshalton water body: (a) weir notching to increase connectivity, (b) channel planting and narrowing through the development of vegetated, marginal bar/berms, and addition of wood in margin (c) and centre (d) of the channel.

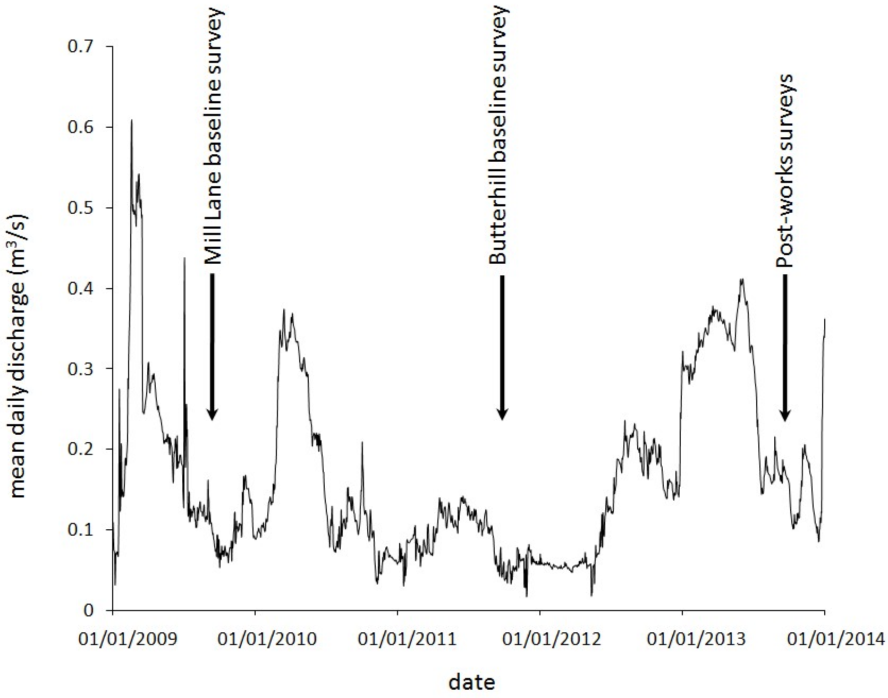

Figure 3 - Discharge time series for the River Wandle at Carshalton October 2009 - 2013

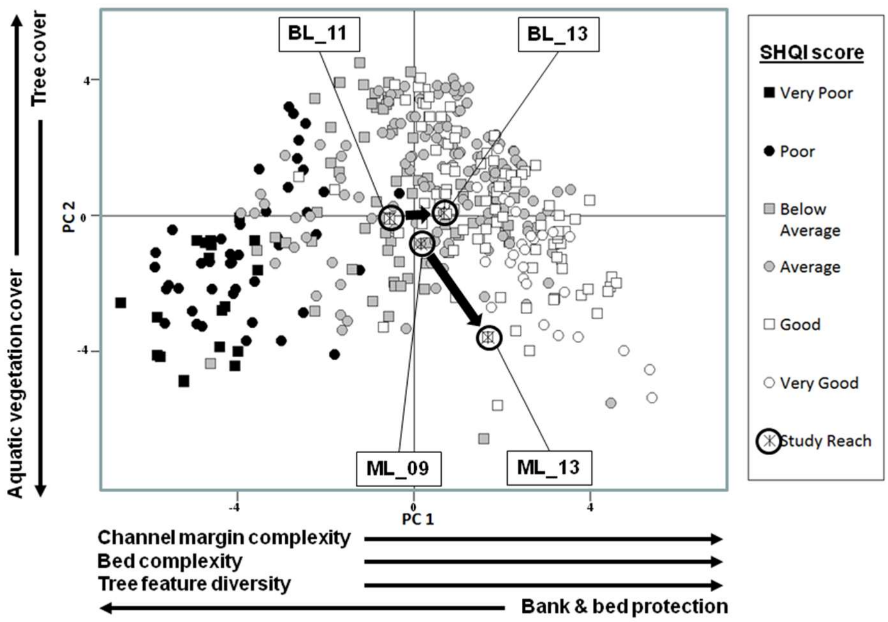

Figure 4 – Scatterplot showing the scores of all surveyed stretches on the first two axes of the PCA. The study stretches are shown as: Mill Lane pre-works in 2009 (ML_09) and post-works in 2013 (ML_13); and Butterhill post-works in 2011 (BH_11) and post-recovery in 2013 (BH_13). All stretches are distinguished by Stretch Habitat Quality Index scores, with interpretations of PC gradients taken from Gurnell *et al* (2007).

Table 1 List of mitigation measures listed as 'not in place' for the Carshalton branch of the River Wandle, resulting in Moderate Ecological Potential classification (Thames RBMP, Environment Agency 2009) with linkages to WFD hydromorphological quality elements as potential indicators of expected measure outcomes

Mitigation Measures listed as 'Not In Place' for the Carshalton Branch HMWB, River Wandle (Thames RBMP, 2009)	WFD Hydromorphological Quality Element (showing ✓/✗ as the potential of the expected measure outcome to provide a hydromorphological indicator specific to the WFD Quality Element)					
	Water flow: quantity & dynamics	Ground water connectio n	Continuity (migration & sediment transport)	River depth and width variation	River bed: structure & substrate	Riparian zone: structur e
Removal of obsolete structure	✓	✓	✓	✓	✓	✓
Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution	✗	✗	✗	✓	✗	✓
Increase in–channel morphological diversity	✓	✗	✓	✓	✓	✗
Alteration of channel bed (within culvert)	✓	✓	✓	✗	✓	✗
Structures or other mechanisms in place and managed to enable fish to access waters upstream and downstream of the impounding works.	✓	✗	✓	✗	✗	✗
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone	✗	✗	✗	✓	✗	✓
Operational and structural changes to locks, sluices, weirs, beach control, etc	✓	✗	✓	✗	✓	✓
Retain marginal aquatic and riparian habitats (channel alteration)	✓	✗	✓	✓	✓	✓
Appropriate techniques to align and attenuate flow to limit detrimental effects of these features (drainage)	✓	✗	✗	✗	✗	✗
Educate landowners on sensitive management practices (urbanisation)	✗	✗	✗	✗	✗	✗

Table 2: Summary of works within each surveyed stretch and overlapping intersection

	Mill Lane (400m)	Intersection (130m)	Butterhill (300m)
Weir notching / removal	✓		✓
Addition of large wood	✓		✓
Fish hides	✓		
Removal of rubble / silt	✓	✓	✓
River narrowing / planting			✓
Gravel introduction			✓

Table 3: URS Stretch Habitat Quality Index (SHQI) scores for Carshalton Branch, Wandle, with interpretation of SHQI categories (from Boitsidis et al. 2006)

	Butterhill Stretch (BH)		Mill Lane Stretch (ML)	
	Baseline (Sept 2011)	Post–works (Sept 2013)	Baseline (Oct 2009)	Post–works (Sept 2013)
SHQI score: from 3 (Very Good) to 18 (Very Poor)	Below Average (10)	Average (7)	Average (9)	Good (6)
SHQI category interpretation	Below average: Stretches with varying levels of modification but showing some levels of activity, combined with low bank vegetation complexity; channels often choked with macrophytes.	Average: Stretches with varying levels of engineering; displaying some level of either recovery or activity; reduced riparian vegetation complexity or excessive macrophyte growth.		Good: Semi–natural, recovering; a few uniform channels displaying some activity; good vegetation complexity and tree cover.

Table 4 –URS index values for study stretches on the Carshalton Branch, R. Wandle, highlighting links with WFD hydro–morphology quality elements and potential conservation objectives

WFD Hydro–morphology Quality Elements	Conservation objectives (e.g. features supporting salmonid life stages)	Urban River Survey (calculated indices and raw data)	Mill Lane		Butterhill	
			Baseline (Oct 2009)	Post–Works (Sept 2013)	Baseline (Sept 2011)	Post–Works (Sept 2013)
Water flow: quantity and dynamics	Flow quantity	n/a	–	–	–	–
	Flow habitat diversity	Number of flow types	4	6	2	4
		Proportion (%) of Riffles	10	27	0	5
		Proportion (%) of Runs	15	40	50	42
		Proportion (%) of Glides	70	25	50	50
Ground water connection	Baseflow (vertical) connectivity	Proportion (%) of immobile substrate	0	0	0	0
Continuity	Floodplain (lateral) & in–channel (longitudinal) connectivity	Proportion (%) of No bank protection	25	20	50	55
		Dominant Bank protection class	2(Open Matrix)	2(Open Matrix)	0(None)	0(None)
		Count of impermeable / impounding structures (Major Weirs)	4	0	0	0
River depth and width variation	Bed and marginal morphological diversity	Count of vegetated side bars	2	3	0	3
		Count of unvegetated side bars	1	3	0	0
		Count of point bars	0	0	0	0
	Channel cross–section dimensions	Channel dimensions	–	–	–	–
River bed: structure and substrate	River bed structure: Physical habitat diversity	Count of mid-channel bars	0	0	0	0
		Count of habitat types	8	14	4	8
		Number of in–channel vegetation types	7	10	1	10
		Average (%) channel vegetation cover	52	53	50	59
	Bed & bank substrate	Dominant channel substrate type	5(Gravel–pebble)	5(Gravel–pebble)	7(Silt)	5(Gravel–pebble)
		Average Bed Sediment Calibre	–2(Pebble)	–2.3(Pebble)	1.5(Silt)	–1.5(Sand)
		Average Bank Sediment Calibre	1.5(Earth)	1.5 (Earth)	1.5 (Earth)	1.5 (Earth)
		Complexity of bank face structure	3.6	3.6	3.6	3

Riparian zone: structure	Riparian habitat diversity	Number of ‘natural’ bank profile types	2	4	1	4
		Count of tree features	4	7	4	3