River Crane Hydrogeomorphology

Progress Report November 2021

Angela Gurnell and Lucy Shuker

Queen Mary University of London

Cartographer

CONTENTS

1. INTRODUCTION

In order to investigate the hydrogeomorphological characteristics of rivers and streams in the River Crane catchment, we have taken a three spatial scale approach (sections 2, 3, 4) to assembling and interpreting available data. The scales and the data associated with each are selected to be appropriate for application to an urban catchment: River network segments, Engineered reaches, River Stretches. The results of analysis of data at these three scales underpins a final discussion (section 5) concerning (i) limitations and gaps of the available data sets; (ii) the opportunities revealed by our analysis; (iii) the requirements and design for future monitoring.

1.1 Network Segments (typically several km long)

This scale of analysis attempts to establish the geomorphic types of river that may be present. We have split the river network into reasonably homogenous segments in order to estimate the likely 'natural' river type that might emerge in each segment if human interventions and pressures were to be completely removed. This uses a simple methodology that is being applied nationally to indicate a target river type to guide appropriate styles of restoration and against which river condition may be assessed (Gurnell et al., 2020). The river type is estimated for each segment by coupling data assembled through a desk study on channel planform, valley gradient and degree of valley confinement with field observations of bed material made within the segment (in this case drawn from Urban River Surveys (URS), see 1.3). Once a target river type is established, this indicates the physical habitat assemblage and dynamics that might be achievable within each segment.

1.2 Engineered Reaches (typically one to a few km long)

This scale of analysis attempts to define the broad character of human interventions across the river network. Because the River Crane catchment is heavily affected by urban development, the river network is likely to have suffered a history of human interventions and modifications. A broad overview of the extent and styles of interventions can be established through a walkover survey, which maps the broad character of channel engineering that appears to have been applied. Engineered reaches are typically shorter than network segments but in some cases a single engineered reach may occupy an entire segment. Three components of engineering modification are classified to establish the broad type of engineering that is present: modifications to the planform; modifications to the channel cross-section; the level of reinforcement of the channel bed and banks. The classes assigned for these three components are combined to subdivide the river into engineered reaches and summarise their engineering type.

1.3 River Stretches (typically 500m long)

This scale of analysis establishes the diversity and extent of physical habitats, sediments, vegetation morphological types and human interventions that are present. River stretches are selected for field survey that conform to a single engineering type (see 1.2) and thus fit within a single engineered reach. The surveyed stretches are typically 500 m long but may be shorter where an engineering type only persists over a shorter river length than 500 m. At the river stretch scale a detailed field survey called the Urban River Survey (URS, Boitsidis et al., 2006; Gurnell et al., 2012) is conducted. This captures information on the physical habitat structure, vegetation structure, sediments and human interventions within the river channel and across its bank tops / near-channel floodplain along the surveyed stretch.

Analysis of information derived from these three scales of investigation are combined to assess river characteristics; identify where opportunities exist for improving the river's condition; and identifying targets for measures aimed at condition improvement.

1.4 River modules (approximately twice as long as the channel width)

No information was available at this scale for the present analysis. However, in the future, this fourth finer scale of data-gathering will be necessary to generate sufficiently precise and local information to monitoring the changing character of the river. Such monitoring is achieved using the MoRPh survey (Shuker et al., 2017, Gurnell et al., 2019, 2020). This survey method should be applied at sites where other monitoring surveys are being conducted (e.g. Riverfly) and also at sites where restoration or other interventions are planned to track their effects (see 5.3).

PLEASE NOTE: Although every effort has been made to check the data presented in this report, data validation is an ongoing process and so this should be the context in which any of the following graphs and maps are interpreted.

2. NETWORK SEGMENTS

The river network within the Crane catchment was split into segments. Some segments represented individual headwater tributaries and the remaining network was split at major tributary confluences or diffluences. All of these segments were then inspected and further subdivided where clear changes in planform occurred. This procedure identified 16 segments of the river network (Figure 2.1).

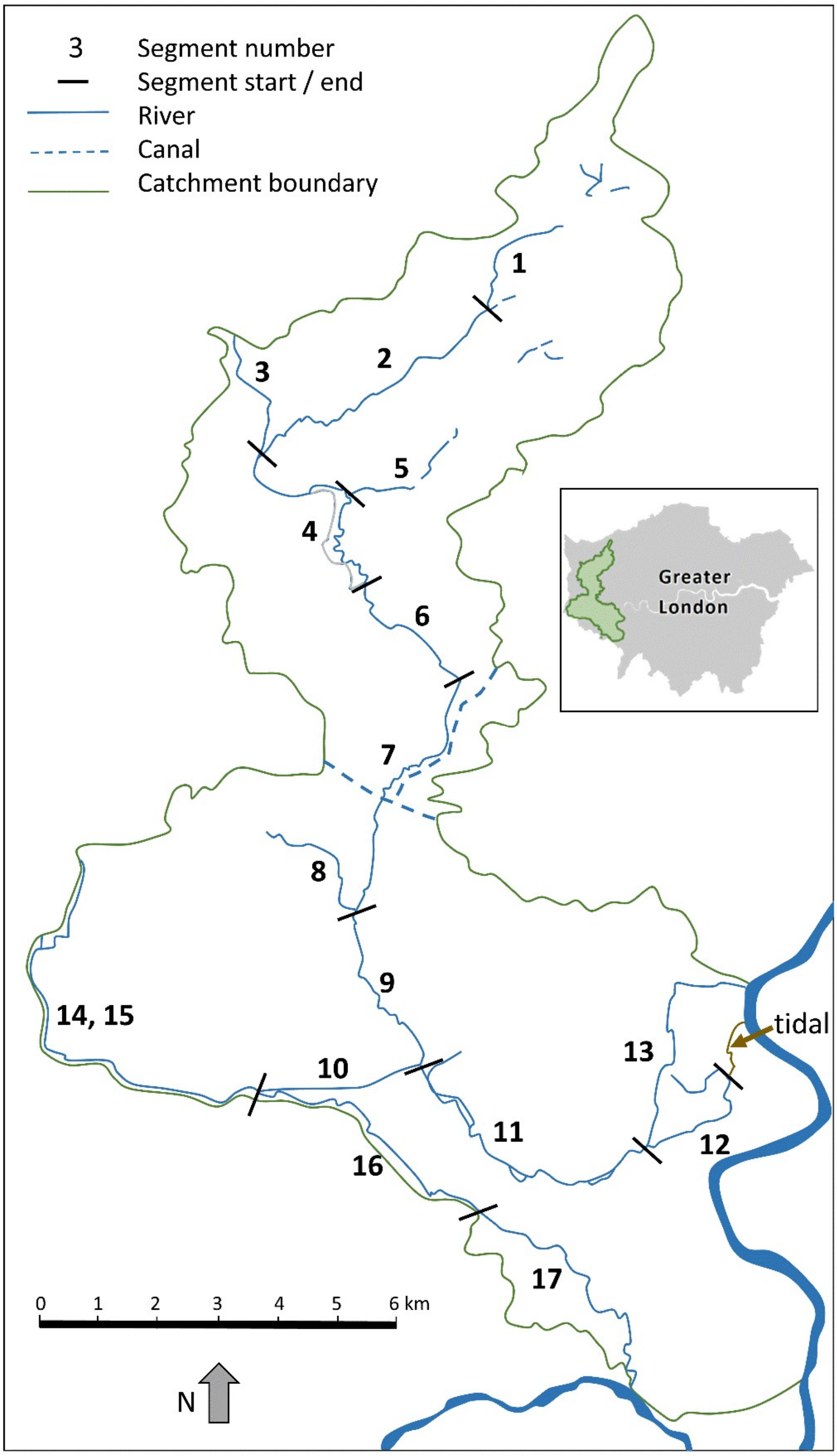

Figure 2.1: 16 segments of the Crane river network

Using the methodology described by Gurnell et al. (2020), the main river channel length, valley length, upstream and downstream elevation, and degree to which the river appeared to be confined by its valley sides were extracted from Google Earth for each segment. These measurements supported estimation of 5 indicators of river type (A1-braiding index, A2-sinuosity, A3-anabranching index, A4-valley confinement, A5-valley gradient). Using Google Earth imagery for these purposes may introduce a number of errors but these are extremely unlikely to have affected the final river type. An autumn image was selected to maximise the degree to which the centre line of the river channel could be accurately tracked and measured, but visibility remained poor in some cases. Although secondary channels can also be included in the river type assessment, this was not done in the present case because only one river channel appeared to be likely to be natural at any location and only one segment contained a sufficient length of secondary channel to achieve more than a classification as a single channel system. The DEM underlying Google Earth is only displayed to the nearest 1 m elevation and does not always match the imagery perfectly. Therefore, the lowest elevation was identified from the DEM within the vicinity of the river channel to estimate the required elevations at segment end points. Given the very subdued topography of the catchment, estimates of valley gradient based on these elevations will not be of high accuracy but are sufficient for the analysis of river type.

Where Urban River Surveys (see section 4) were available within a segment, three further indicators were estimated (A6-bedrock reach, A7-coarsest bed material size class, A8-average alluvial bed material size class).

The location, intermediate measurements and A1 to A8 indicator values for each segment are listed in Table 2.1 and the river types are mapped in Figure 2.2. Figure 2.3 illustrates the full range of river types that can be identified using indicators A1 to A8.

All 16 segments were determined to be low gradient, unconfined, single thread and sinuous, so they could not be differentiated according to any of the indicators extracted during the desk study. Only 10 segments could be assigned to a type because some bed material information was available for each of these segments. Virtually all 10 segments displayed gravel-pebble as their coarsest bed material. Four segments showed an average bed material size class of gravel-pebble (type F), four were sand – actually a result of averaging a mixture of silt and gravel (type H) and one was silt (type K). The classifications for reaches 1, 5 and 6 are extremely tentative because only one URS was available to indicate bed material characteristics for each. Although an URS was available for a spur of segment 13 and would have assigned this segment to type K, the survey was conducted under conditions of poor bed visibility and was not on the main channel. Therefore, segment 13 was not assigned to a river type.

Overall, the outcomes of the river typing exercise are what might be expected in a lowland catchment that inevitably contains low energy rivers. The river type reflects a decrease in bed material size between the upper and lower catchment segments and only single-thread stream types can be justified on the available evidence. However, it is highly likely that more sinuous types (particularly I and L but also possibly G), and also multi-thread, low energy (i.e. anabranching) types J and M may have existed before humans started to modify the river channels in this heavily urbanised catchment. Each river type is likely to display certain characteristic habitats if it is functioning completely naturally. Those most likely types of habitat to be displayed for river types F, H, K, J and M are summarised in Table 2.2.

Table 2.1: Segments of the Crane river network: Locations, sizes, elevations, river type indicators and river types
(* artificial water course or valley length indeterminate, ** some secondary channels but too modified to include in river type assessment)

Segment	URS surveys in segment	US Northing	US Easting	DS Northing	DS Easting	US elevation	DS elevation	Channel length (m)	Valley length (m)	**A1** Braiding Index	**A2** Sinuosity Index	**A3** Anabranching Index	**A4** Confinement	**A5** Valley gradient	**A6** Bedrock reach	**A7** Coarsest bed material size class	**A8** Average alluvial sediment size class	**River Type**
1	2	51.585661	-0.366585	51.574508	-0.380751	48	47	1919	1820	1	1.05	1	unconfined	0.0005	no	GP	SA	**H**
2	3,4	51.574508	-0.380751	51.551065	-0.438437	47	34	5304	4993	1	1.06	1	unconfined	0.0026	no	GP	GP	**F**
3	none	51.559877	-0.435202	51.554150	-0.434072	36	34	726	600	1	1.21	1	unconfined	0.0033				
4	5,6,7	51.551065	-0.438437	51.534110	-0.411945	34	31	4012	3430	1	1.17	1**	unconfined	0.0009	no	GP	GP	**F**
5	1	51.553941	-0.391768	51.546085	-0.415765	34	31	2072	1946	1	1.06	1	unconfined	0.0015	no	GP	GP	**F**
6	8-11	51.534110	-0.411945	51.517740	-0.390267	31	29	2711	2497	1	1.09	1	unconfined	0.0008	no	GP	SI	**K**
7	none	51.517740	-0.390267	51.483674	-0.416290	29	23	4749	4477	1	1.06	1	unconfined	0.0013				
8	none	51.493331	-0.428478	51.483674	-0.416290	25	23	1649	1479	1	1.11	1	unconfined	0.0014				
9	12-14	51.483674	-0.416290	51.459709	-0.401373	23	21	3224	2993	1	1.08	1	unconfined	0.0007	no	GP	GP	**F**
10*	none	51.456742	-0.441542	51.459709	-0.401373	22	21	2843	2843*	1	1.00	1	unconfined	0.0004				
11	15-22	51.459709	-0.401373	51.447002	-0.347286	21	11	5288	4888	1	1.08	1**	unconfined	0.0020	no	GP	SA	**H**
12	23-28	51.447002	-0.347286	51.462813	-0.325822	11	5	2906	2766	1	1.05	1	unconfined	0.00217	no	GP	SA	**H**
13*	29-42	51.447002	-0.347286	51.470431	-0.321578	11	3	4151	4151*	1	1.00	1	unconfined	0.0019	no	GP	SA	H
14,15*	none	51.492779	-0.483919	51.456742	-0.441542	24	22	7700	7700*	1	1.00	1	unconfined	0.0003				
16*	none	51.456742	-0.441542	51.439473	-0.390722	22	20	4567	4567*	1	1.00	1	unconfined	0.0004				
17*	43	51.439473	-0.390722	51.410219	-0.351565	20	9	5429	4653	1	1.17	1	unconfined	0.0024				

14,15* two parallel channels – measurements are for the eastern channel

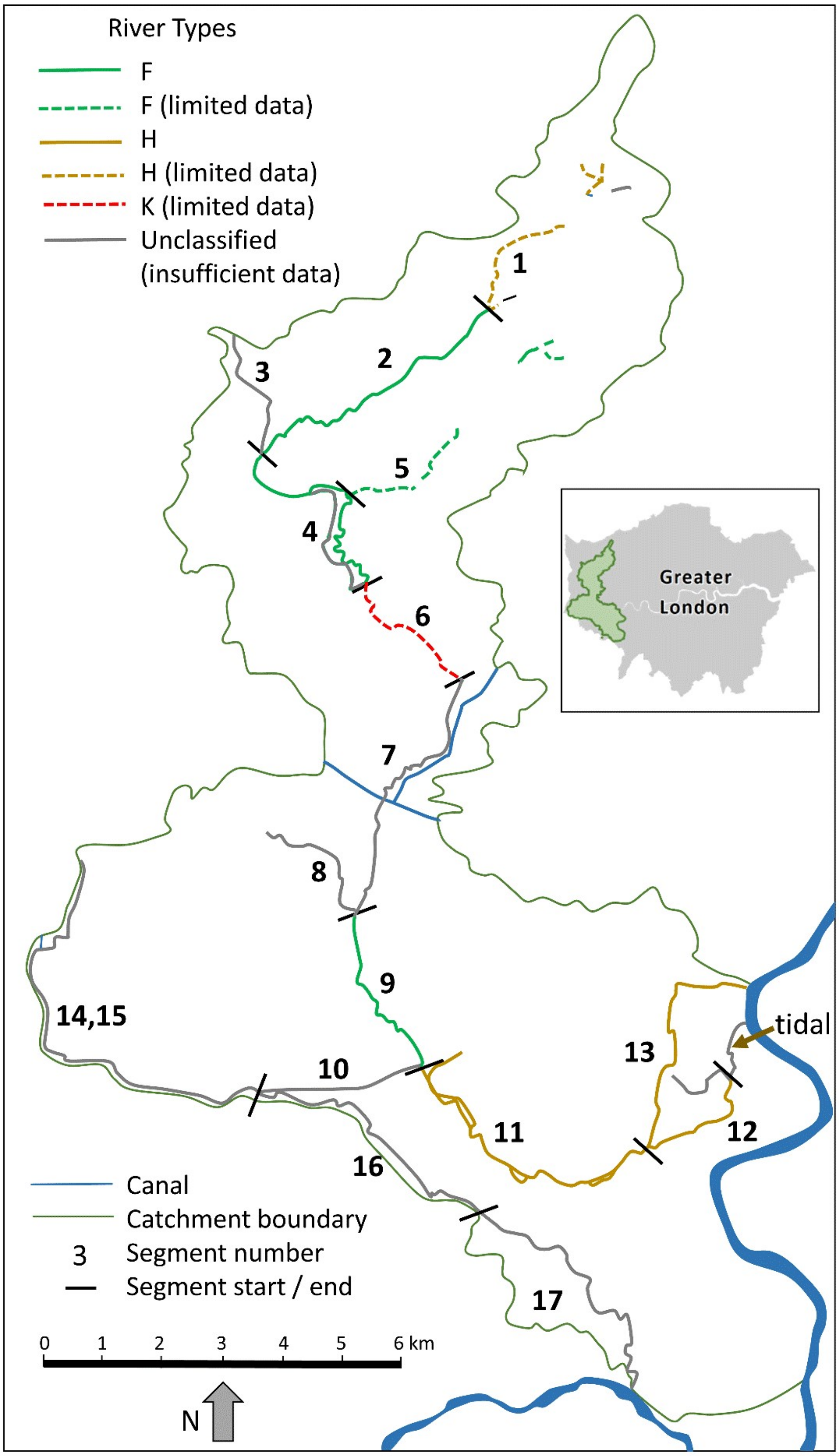

Figure 2.2: River types assigned to segments of the Crane river network

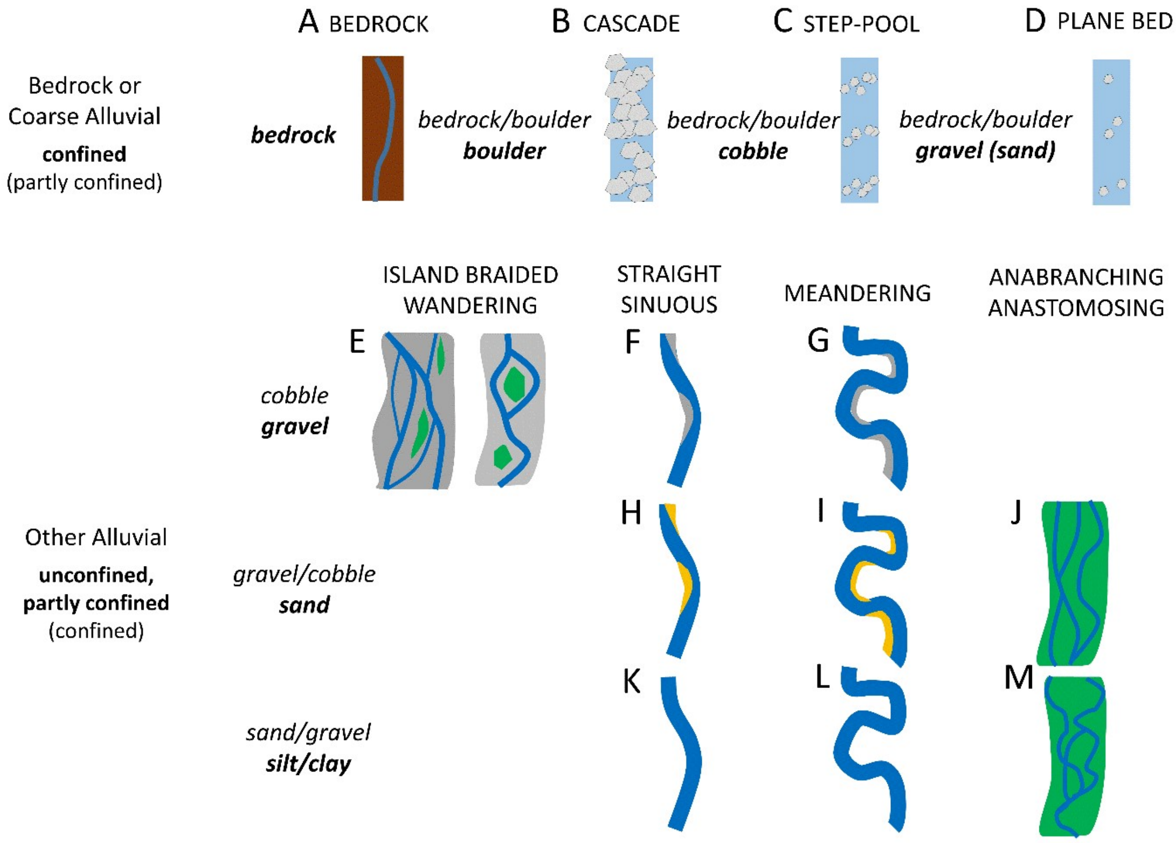

Figure 2.3: River types that can be identified using indicators A1 to A8.

Table 2.2. Key physical and vegetation features that are expected to be present (brown shading) or are typical (yellow shading) of a particular river type when it is fully functioning as that type.

RIVER TYPE	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
Channel threads	Single	Single	Single	Single	Multi	Single	Single	Multi
Planform	Straight/ sinuous	Meand ering	Straight/ sinuous	Meand ering	Anabra nching	Straight/ sinuous	Meand ering	Anabra nching
Coarsest bed material size class	Cobble /gravel	Cobble /gravel	Gravel	Gravel	Gravel	Fine gravel /sand	Fine gravel /sand	Sand
Average alluvial bed material size class	**Gravel**	**Gravel**	**Sand**	**Sand**	**Sand**	**Silt**	**Silt**	**Silt**
CHANNEL BED								
Water surface / hydraulic habitats								
Free fall								
Chute								
Broken standing waves								
Unbroken standing waves								
Physical features								
Exposed bedrock								
Boulders - unvegetated								
Boulders - vegetated								
Waterfall								
Step								
Cascade								
Riffle								
Pool								
Island								
Mid-channel bar - unveg								
Mid-channel bar - vegetated								
Aquatic vegetation morphotypes								
Emergent broad/linear leaf								
Subm. broad/linear/fine leaf								
CHANNEL BANKS AND MARGINS								
Physical features								
Active vertical bank profiles (+overhang/toe/undercut)								
Eroding cliff								
Stable cliff								
Toe								
Side bar - unvegetated								
Side bar - vegetated								
Berm / Bench								
Marginal vegetation								
Emerg. broad/linear-leaved								
BANK TOPS / FLOODPLAIN EDGE								
Physical features								
Wetlands (any types)								
Ponds and side channels								

3. ENGINEERED REACHES

We walked parts of Yeading Brook West, Lower Duke of Northumberland's River and the River Crane mainstem (Figure 3.1) in order to gain photographs depicting the current character of the river and to map the spatial extent of different river engineering types (Figure 3.1). Engineering types capture the broad nature of engineering interventions over extended reaches of river. Engineering types represent the combination of widely-occurring modifications to channel planform and channel cross section form coupled with typical levels of bank and bed reinforcement (Table 3.1). The lengths of river assigned to the three components of the engineering type are mapped in Figure 3.2.

Table 3.1: Planform, Cross profile and Reinforcement Types and Codes

Planform	Cross-Section form	Level of Reinforcement
ST = Engineered Straight (engineered to an essentially straight planform – can include bends but predominantly straight)	**EN** = Enlarged (cross section made substantially wider and/or deeper than a naturally-adjusted channel would be at the same site)	**NONE** = No reinforcement
ME = Engineered Sinuous (engineered to a notably sinuous planform)	**TS** = Two-stage (cross section includes a flood channel with an inset smaller channel to accommodate non-flood flows)	**BED** = Bed reinforced
RC = Recovering (engineered straight or sinuous but showing significant planform readjustment induced by fluvial processes)	**RS** = Resectioned (cross section reshaped to a more efficient trapezoidal form)	**ONE** = One Bank reinforced
SN = Semi-natural (no obvious sign of engineering of the planform)	**CL** = Cleaned (flow resistance reduced through removal of roughness elements such as trees and shrubs and minor morphological irregularities)	**BEDONE** = Bed and one bank reinforced
	RE = Restored (cross profile form designed as part of a restoration scheme)	**TWO** = Both banks reinforced
	SN = Semi-natural (cross profile form shows no obvious signs of engineered modification / has completely recovered from historical engineering)	**FULL** = Full reinforcement (bed and both banks)

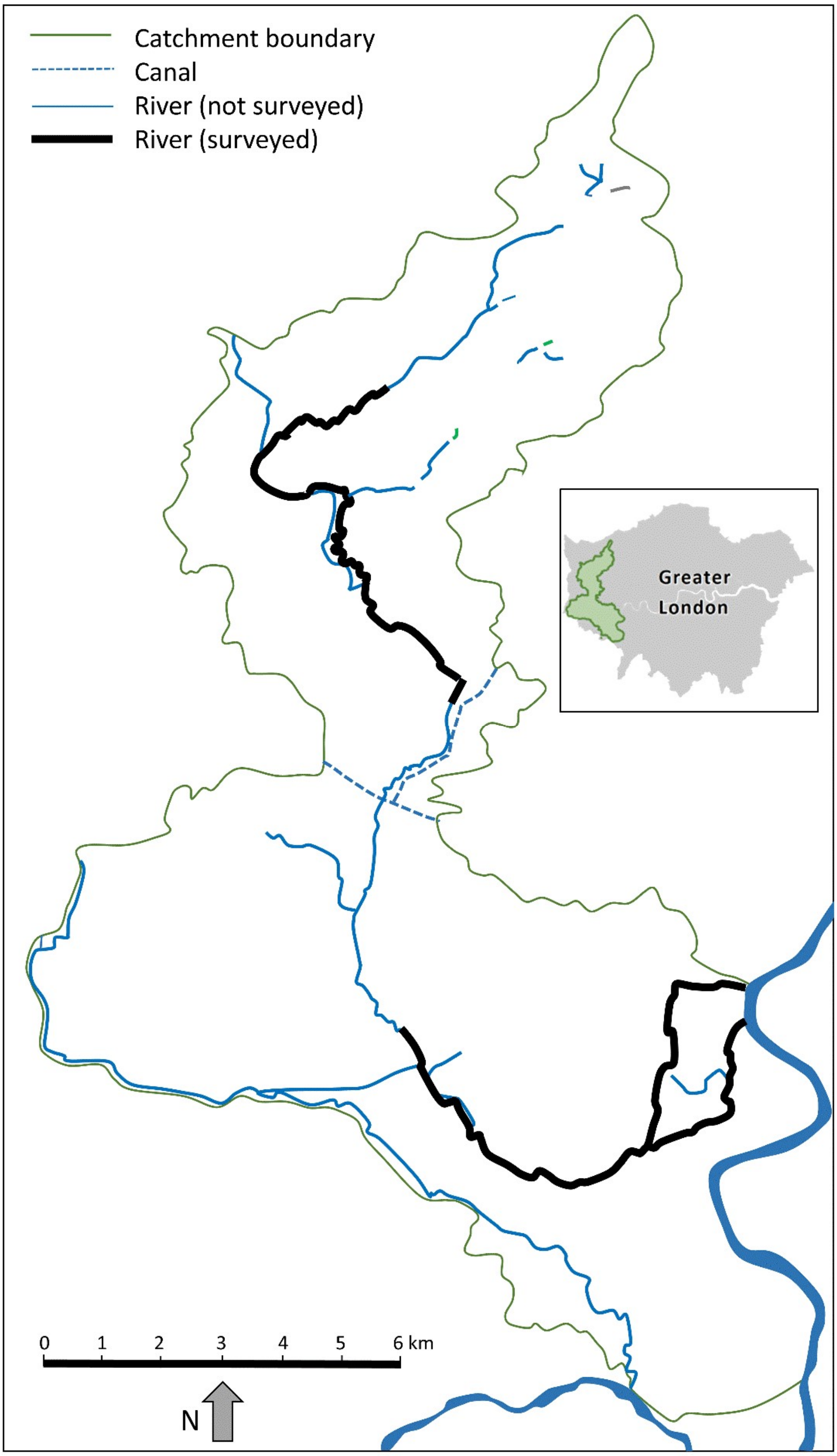

Figure 3.1: Lengths of the River Crane and tributaries assigned to engineering reaches types.

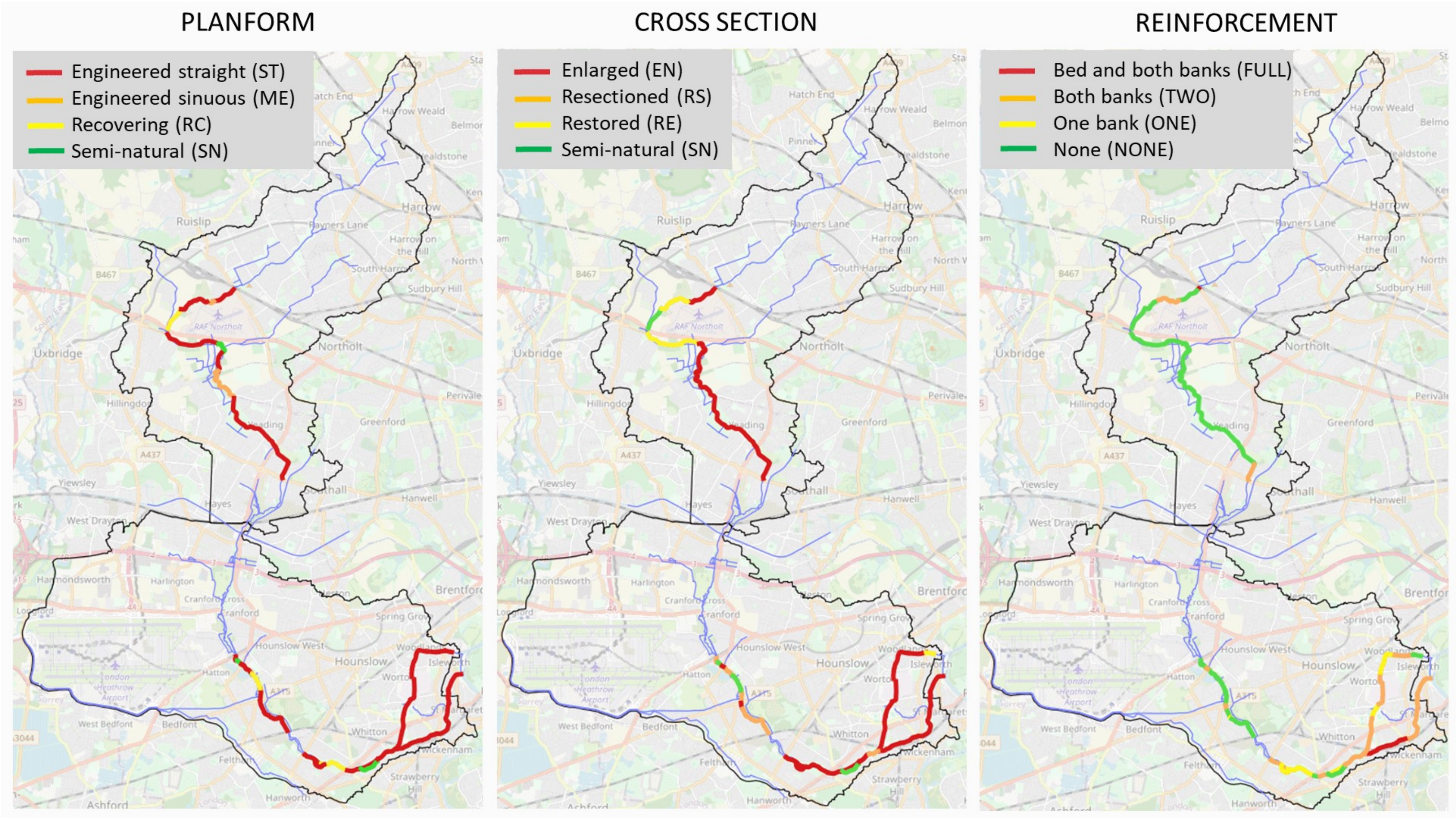

Figure 3.2: The three components of engineering type that define the style of engineered reaches within the area surveyed. (**NOTE** the types refer to the broad characteristics of extended lengths of river within which there may be notable but local changes in type that are not mapped)

4. URBAN RIVER SURVEY STRETCHES

All 55 Urban River Surveys conducted on any part of the Crane river network were downloaded from the URS data base (www.modularriversurvey.org). Of these, 10 are duplicate surveys for the same stretch (with surveys recorded at different dates), so 45 unique stretches have been surveyed. Inspection of these surveys resulted in the exclusion of 12 surveys because of inaccurate GPS data and thus difficulties in identifying precisely which sections of river were surveyed. However, none of the excluded surveys were conducted in areas where other surveys were not available. In total, 43 surveys of 33 different stretches were retained for analysis (Figure 4.1, Table 4.1).

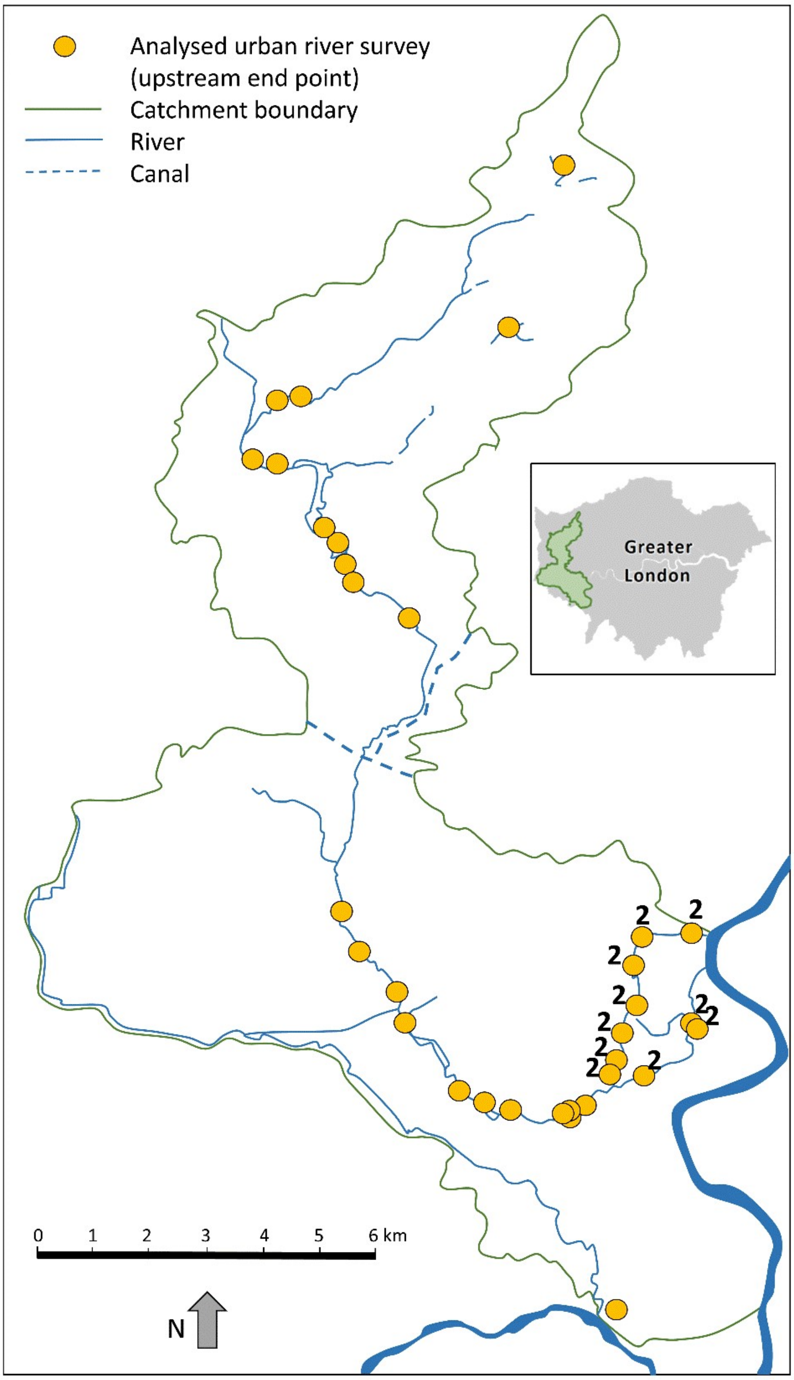

Figure 4.1: Locations of the 33 URS stretches for which survey data was analysed.

Note: the orange dots locate the upstream end of each URS stretch and '2' indicates where two of the analysed surveys were conducted on the same stretch at different dates.

Table 4.1: Number, date, location and length of the 43 Urban River Surveys analysed.

Notes:
(i). The number in the first column is used to identify surveys on graphs (Figures 4.2 to 4.7) and to identify an approximate upstream to downstream sequence of surveys.
(ii) The heavy (bold) boundaries separate groups of listed surveys that are located in different parts of the river network – stretches 1 and 43 are in isolated locations, stretches 2 to 28 run downstream along Yeading Brook west, the Yeading Brook and the Crane, stretches 29 to 42 run downstream along the Lower Duke of Northumberland's River.
(iii) Where there is more than one survey for a stretch the surveys are arranged in chronological order with the earlier survey first.
(iv) The River Name and Stretch Name are those used in the URS information system.

Survey number	**Survey date**	**River Name**	**Stretch Name**	**Stretch Length (m)**	**Northing (upstream end)**	**Easting (upstream end)**
1	04/08/2015	Yeading Brook East (The Roxbourne)	Newton Park	458	51.56810	-0.36993
2	04/08/2015	Yeading Brook West	Headstone Manor	503	51.59380	-0.35509
3	21/07/2015	Yeading Brook West	RAF Northolt Aerodrome	493	51.55772	-0.42236
4	21/07/2015	Yeading Brook West	Ickenham Marsh	498	51.55736	-0.42928
5	23/07/2015	Yeading Brook West	Cutthroat Wood	497	51.54760	-0.43411
6	23/07/2015	Yeading Brook West	Gutteridge Wood	489	51.54693	-0.42726
7	12/05/2016	Yeading Brook	Yeading Brook Meadows North	491	51.53653	-0.41713
8	12/08/2013	Yeading Brook	Yeading Meadows 01	350	51.53366	-0.41188
9	12/08/2013	Yeading Brook	Yeading Meadows 02	300	51.53053	-0.41192
10	12/08/2013	Yeading Brook	Yeading Meadows 03	300	51.52802	-0.41015
11	23/05/2016	Yeading Brook	Brookside Open Space	403	51.52129	-0.39507
12	05/08/2015	River Crane	Crane Meadows	452	51.47571	-0.41513
13	06/08/2015	River Crane	Causeway	460	51.46881	-0.41037
14	06/08/2015	River Crane	Donkey Wood	493	51.46190	-0.40140
15	06/08/2015	River Crane	Brazil Mill Wood	477	51.45724	-0.40067
16	22/05/2011	River Crane	Crane Park Island - May2011	500	51.44562	-0.38390
17	25/06/2015	River Crane	Shot Tower	471	51.44385	-0.37896
18	27/01/2015	River Crane	Main Channel, Crane Park, TQ 12988 72819	250	51.44311	-0.37564

19	02/11/2012	River Crane	Main Channel, Crane Park (Mill Road Weir) - Nov2012	470	51.44219	-0.36118
20	31/01/2015	River Crane	Main Channel, Crane park, Mill Road weir, TQ 14296 72881	250	51.44249	-0.35951
21	22/07/2015	River Crane	Mill Stream	467	51.44176	-0.36065
22	22/07/2015	River Crane	Crane Park (bottom)	470	51.44415	-0.35505
23	22/07/2015	River Crane	Craneford Playing Fields	468	51.44794	-0.34231
24	22/08/2018	River Crane	Craneford Playing Fields	468	51.44794	-0.34231
25	06/09/2017	River Crane	Coal Park Island (concrete)	364	51.45697	-0.32691
26	22/08/2018	River Crane	Coal Park Island (concrete)	364	51.45697	-0.32691
27	06/09/2017	River Crane	Coal Park Island (natural)	433	51.45712	-0.32693
28	22/08/2018	River Crane	Coal Park Island (natural)	433	51.45712	-0.32693
29	24/06/2015	Lower Duke of Northumberland's River	Stoop Memorial Ground	497	51.44733	-0.34699
30	24/08/2018	Lower Duke of Northumberland's River	Stoop Memorial Ground	497	51.44733	-0.34699
31	24/06/2015	Lower Duke of Northumberland's River	Chase Bridge	491	51.45167	-0.34485
32	24/08/2018	Lower Duke of Northumberland's River	Chase Bridge	491	51.45167	-0.34485
33	24/06/2015	Lower Duke of Northumberland's River	Rugby Football Union	421	51.45596	-0.34425
34	24/08/2018	Lower Duke of Northumberland's River	Rugby Football Union	471	51.45596	-0.34425
35	06/10/2015	Lower Duke of Northumberland's River	Mogden STW	460	51.45991	-0.34017
36	23/08/2018	Lower Duke of Northumberland's River	Mogden STW	460	51.45991	-0.34017

37	23/06/2015	Lower Duke of Northumberland's River	Riverside Walk	502	51.46695	-0.34111
38	23/08/2018	Lower Duke of Northumberland's River	Riverside Walk	502	51.46664	-0.34114
39	23/06/2015	Lower Duke of Northumberland's River	Old Brewery	519	51.47120	-0.33894
40	23/08/2018	Lower Duke of Northumberland's River	Old Brewery	500	51.47132	-0.33872
41	23/06/2015	Lower Duke of Northumberland's River	Silverhall Park Stretch	189	51.47092	-0.32543
42	23/08/2018	Lower Duke of Northumberland's River	Silverhall Park	189	51.47092	-0.32543
43	26/02/2012	Longford	Bushy Park - Feb2012	500	51.41198	-0.34498

Each URS captures an enormous number of observations relating to a wide range of properties of the river channel and bank tops along each stretch. To illustrate the types of information available that can provide insights into the condition of stretches and opportunities for condition improvements, we present Figures 4.2 to 4.7 which provide groups of line graphs illustrating various aspects of the character of the surveyed stretches. In each line graph, the individual URS surveys are represented by their survey number (Table 4.1) along the horizontal axis, and values of a property of the river environment are plotted as dots, one for each stretch, linked by lines to depict upstream to downstream sequences. Each line graph is split into separate sections by vertical solid lines to identify the groups of surveys enclosed by heavy (bold) boundaries in Table 4.1. Vertical dashed lines indicate the transitions from Yeading Brook West to Yeading Brook to the main channel of the River Crane.

Figure 4.2 summarises the degree to which the surveyed stretches have experienced characteristic human modifications (Table 3.1). Note that there may be slight differences between the engineering type assigned to a URS stretch and to the extended engineered reach in which it is located (Figure 4.3). This may be due to surveying error – for example several URS surveys identify semi-natural planforms or cross sections where this is unlikely given the classification of the engineering reach in which they are located. Nevertheless, most differences are likely to reflect the spatial scale of the survey. This is because an engineering type is assigned according to the broad engineering modifications observed across the length of river being considered (reach or stretch scale). However, all differences need to be checked to correct any genuine errors. The surveyed stretches are dominated by resectioned (20 surveys) and enlarged (15 surveys) cross sections (Figure 4.2 top graph). Semi-natural cross sections were recorded in only 7 surveys. 12 URS surveys indicate a natural river planform, with engineered straight or sinuous planforms recorded in 24 surveys and only 4 stretches showing some recovery from past planform interventions (Figure 4.2 second graph). While 17 surveys record no widespread, characteristic reinforcement, 23 stretches have both banks reinforced, including four surveys recording full reinforcement (Figure 4.2 third graph). Given the extent of the interventions indicated by these modifications of planform, cross section and reinforcement, it is not surprising that all but 15 surveys indicate river channels that are either over-deep or probably over-deep (Figure 4.2 bottom graph). Although some aspects of the river appear more natural in the upper part of the catchment, the whole river network shows significant human modifications.

Bed sediments are the building materials from which river flows construct physical habitats and generate related hydraulic habitats. Urban River Surveys provide some information on bed material size and diversity, although it is important to stress that more accurate information is collected by more local, higher resolution surveys such as MoRPh (see section 5). Nevertheless, Figure 4.4 uses URS observations to assess bed material characteristics. Figure 4.4 illustrates that although the coarsest bed material observed in most stretches is gravel-pebble, the average bed material size is typically sand or silt. Only 11 URS surveys record gravel-pebble as the average particle size. Furthermore, the richness of bed material size classes is low with 12 surveys achieving only one size class, the majority only two and a maximum of only three size classes is observed in 5 surveys. While these aspects of bed material are typical of lowland, low-gradient rivers, as is the general decrease in particle size from headwaters to the lower reaches, it is important to note that they provide clear boundary conditions for all other 'natural' aspects of the river network.

Some summary indicators of poor condition / pollution are presented in Figure 4.5. The URS is not a water quality survey, but it records four indicators of potential pollution: water odours, sediment odours, oils on the water surface, scum/foam on the water surface. It also records the extent of both smaller litter and large items of trash (e.g. traffic cones, shopping trolleys), and the number of pipes/outfalls that could deliver pollutants to the river.

The highest number of the four potential pollution indicators (Figure 4.5 top graph) are observed in the upper catchment. The highest values of a trash index combining the cover abundance of litter and large items of trash (Figure 4.5 second graph) and the highest number of pipes/outfalls (Figure 4.5 third graph) are observed in the river's headwaters and in the downstream parts of the Lower Duke of Northumberland's River.

The Urban River Survey records the abundance of seven named non-native invasive plant species (NNIPS), with the opportunity to add an eighth. An index combining the number and abundance of NNIPS can achieve a maximum value of 5 (Figure 4.5 bottom graph). This maximum value is achieved by most surveys in the upper catchment with values of 3 or more achieved in 27 surveys located throughout the surveyed parts of the river network.

Figure 4.6 provides a summary of the richness of different habitat types as well as the extent of riparian tree cover. The total count of in-channel physical habitats is plotted in the upper (first) graph (Figure 4.6). The 25 habitat types that can be recorded include both sediment-related habitats (e.g. exposed boulders, unvegetated and vegetated bars of different types, waterfalls, riffles, pools) and hydraulic habitats (e.g. cascades, rapids, runs, glides, ponded areas, backwaters). In general, there are very few of these habitat types recorded in most stretches, but the highest numbers tend to be in the river's middle reaches (the upper parts of the River Crane) (Figure 4.6 second graph). The Yeading Brook and parts of the Lower Duke of Northumberland's river show the highest number of aquatic vegetation morphotypes (Figure 4.6, second graph). Tree cover is high throughout the headwaters and most of the surveyed stretches of the River Crane (Figure 4.6 third graph). High tree cover is associated with a number of different types of tree feature (Figure 4.6 bottom graph), suggesting that 'maintenance' of riparian trees and the features they naturally produce is not severe.

Finally, Figure 4.7 indicates the cover or number of four types of physical habitat that would be expected to be observed in lowland, low-gradient rivers. Riffles (Figure 4.7 upper graph) and pools (Figure 4.7 second graph) are mainly observed in the upper part of the catchment, corresponding with the coarser bed material observed there (river type F segments), but the area occupied by pools is very small in all surveys. The high riffle coverage in surveys 39 and 40 relates to a highly artificial site and probably reflects the side effects of channel engineering. Mid-channel bars (Figure 4.7 third graph) are few in number, and are confined to the upper reaches where gravel bed material is relatively abundant. However, side bars (Figure 4.7 bottom graph) are widespread and are particularly abundant in the middle reaches, suggesting some active habitat construction that could be associated with adjustments in the width or position of the channel.

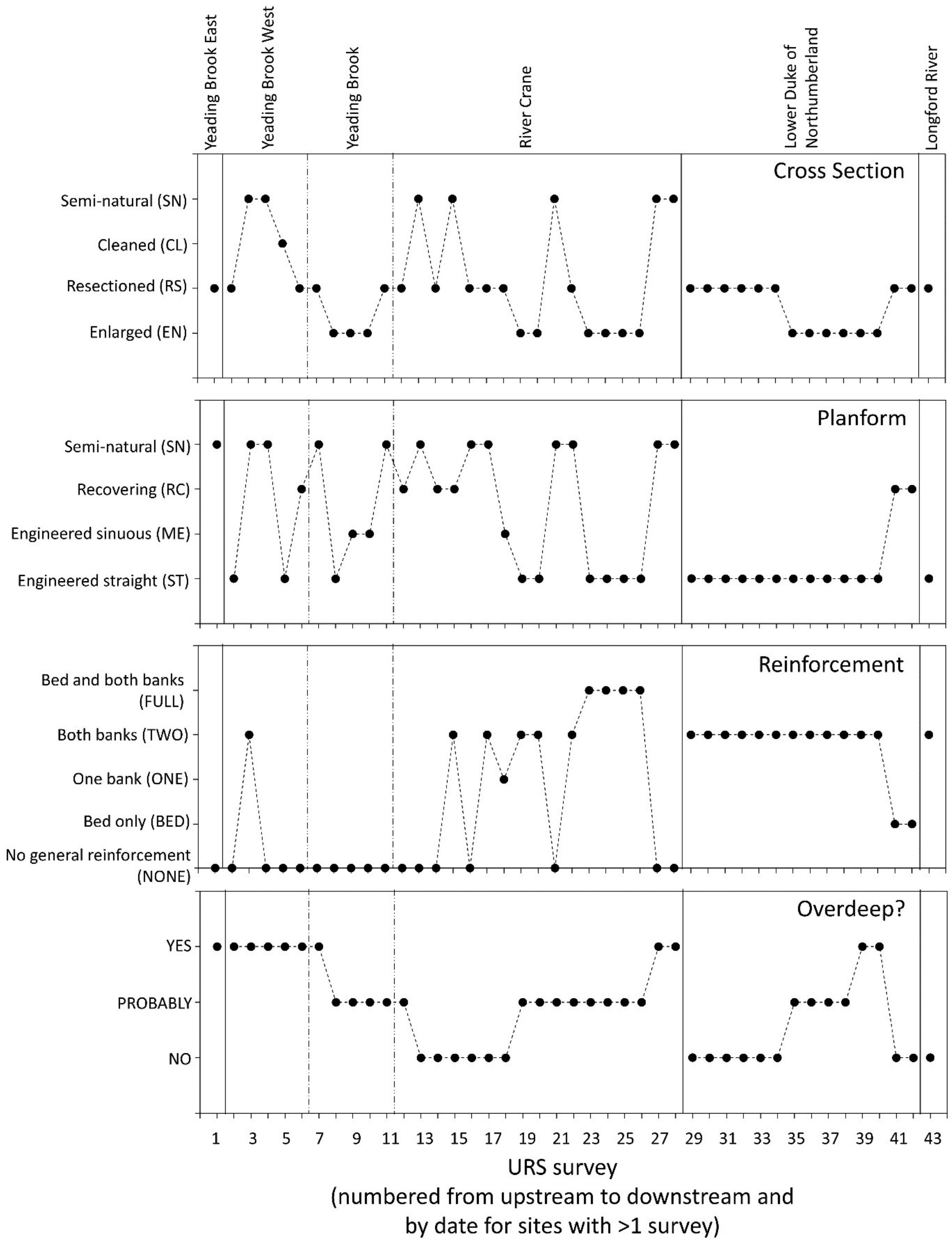

Figure 4.2: Values of the three components of the engineering type an appears to be overdeep for each of 43 URS.

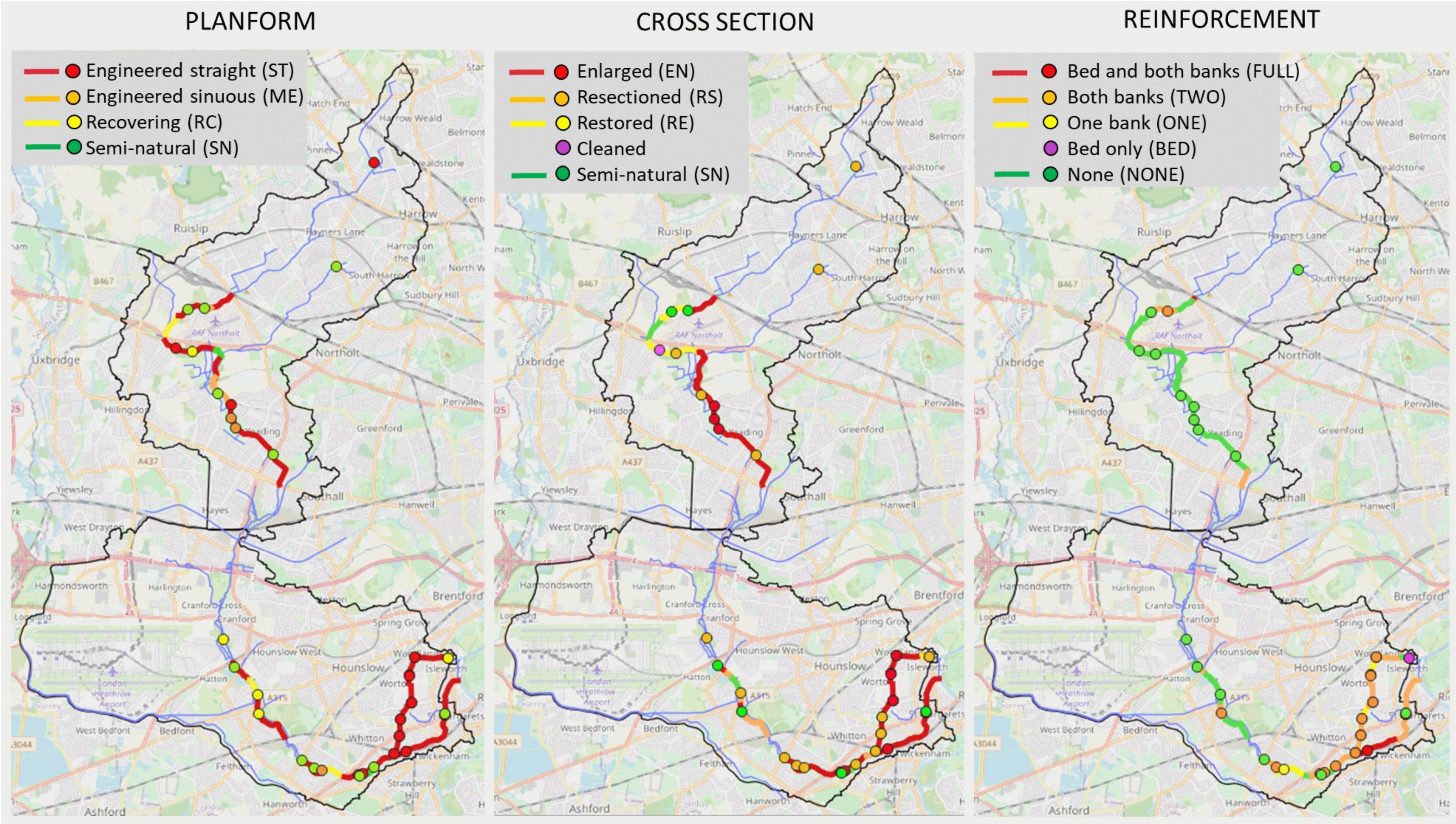

Figure 4.3 The three components of the engineering type assigned to engineering reaches (lines) and Urban River Survey stretches (dots).

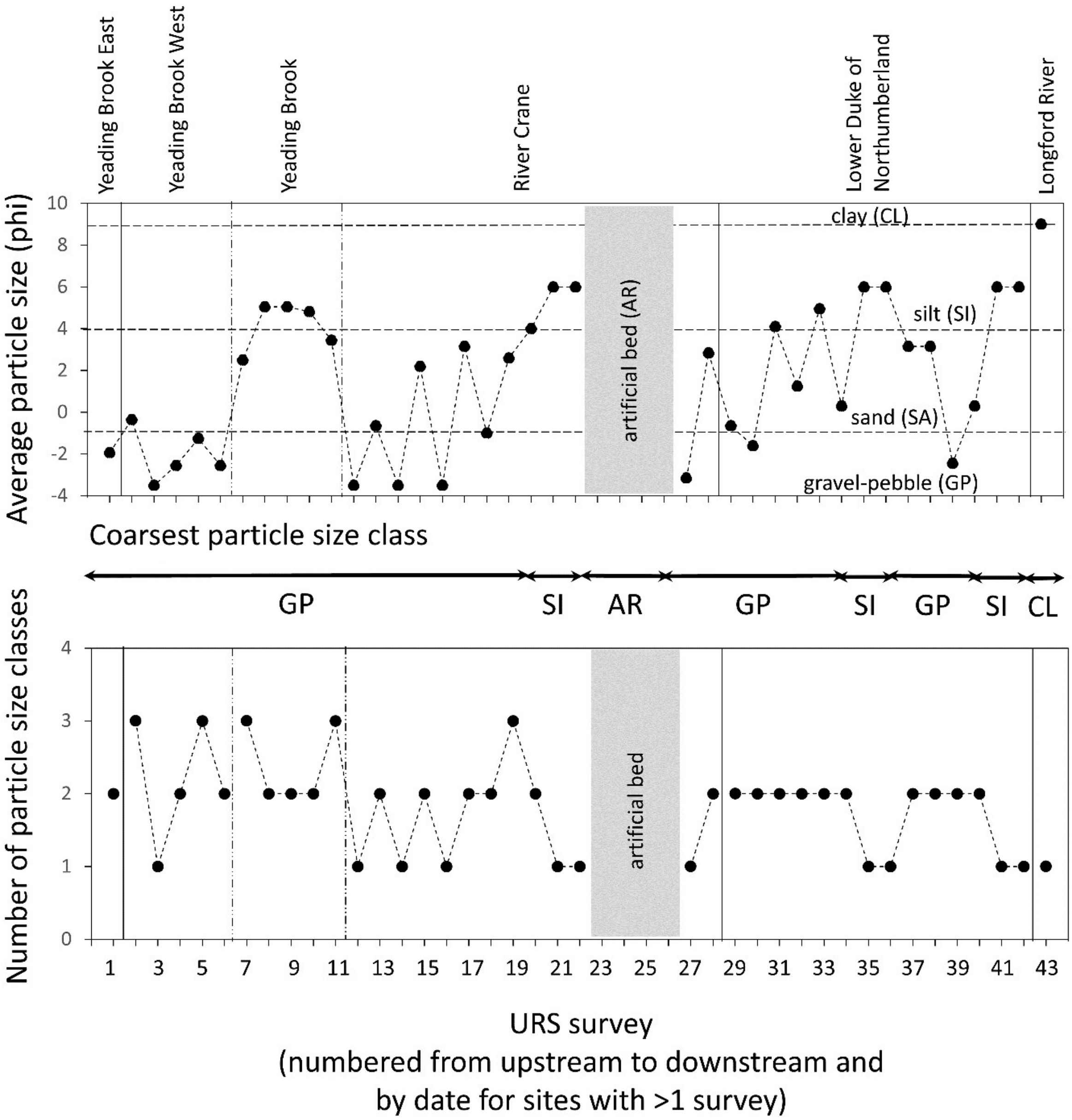

Figure 4.4: Bed material characteristics (average particle size, coarsest particle size class and the number of particle size classes) observed in each URS.

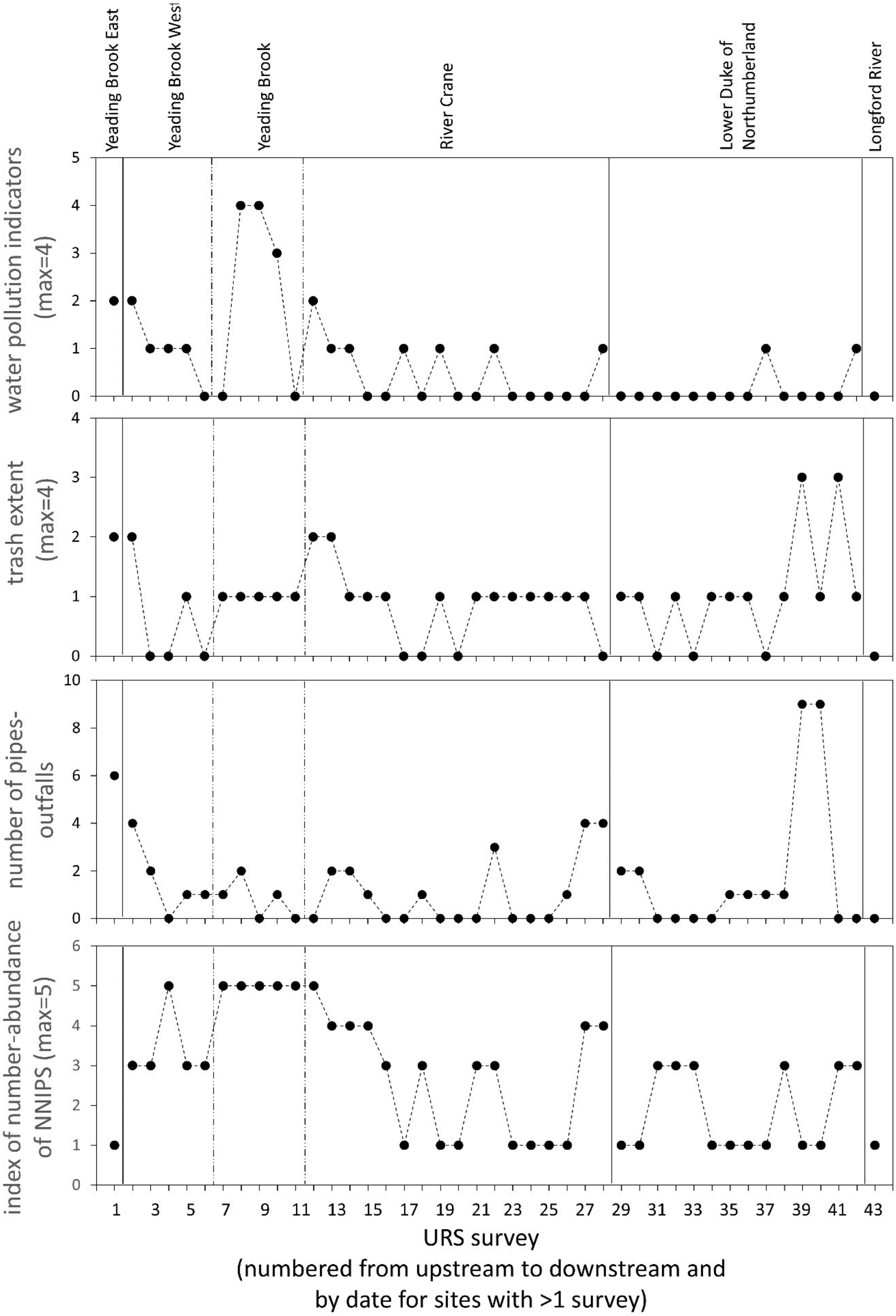

Figure 4.5: Four indicators of poor condition revealed in the 43 surveys.

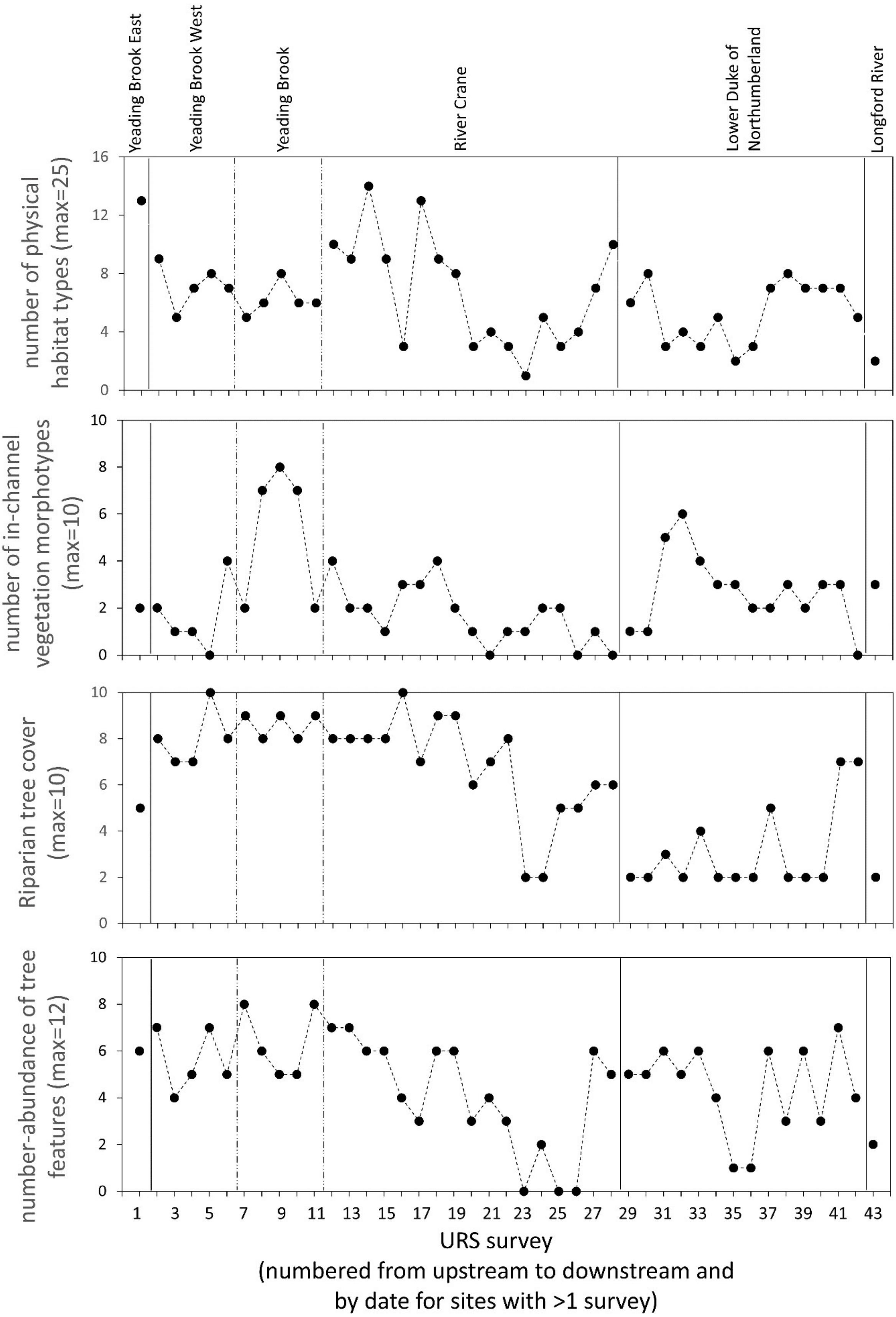

Figure 4.6: Measures of the richness or abundance of groups of physical features or vegetation morphotypes

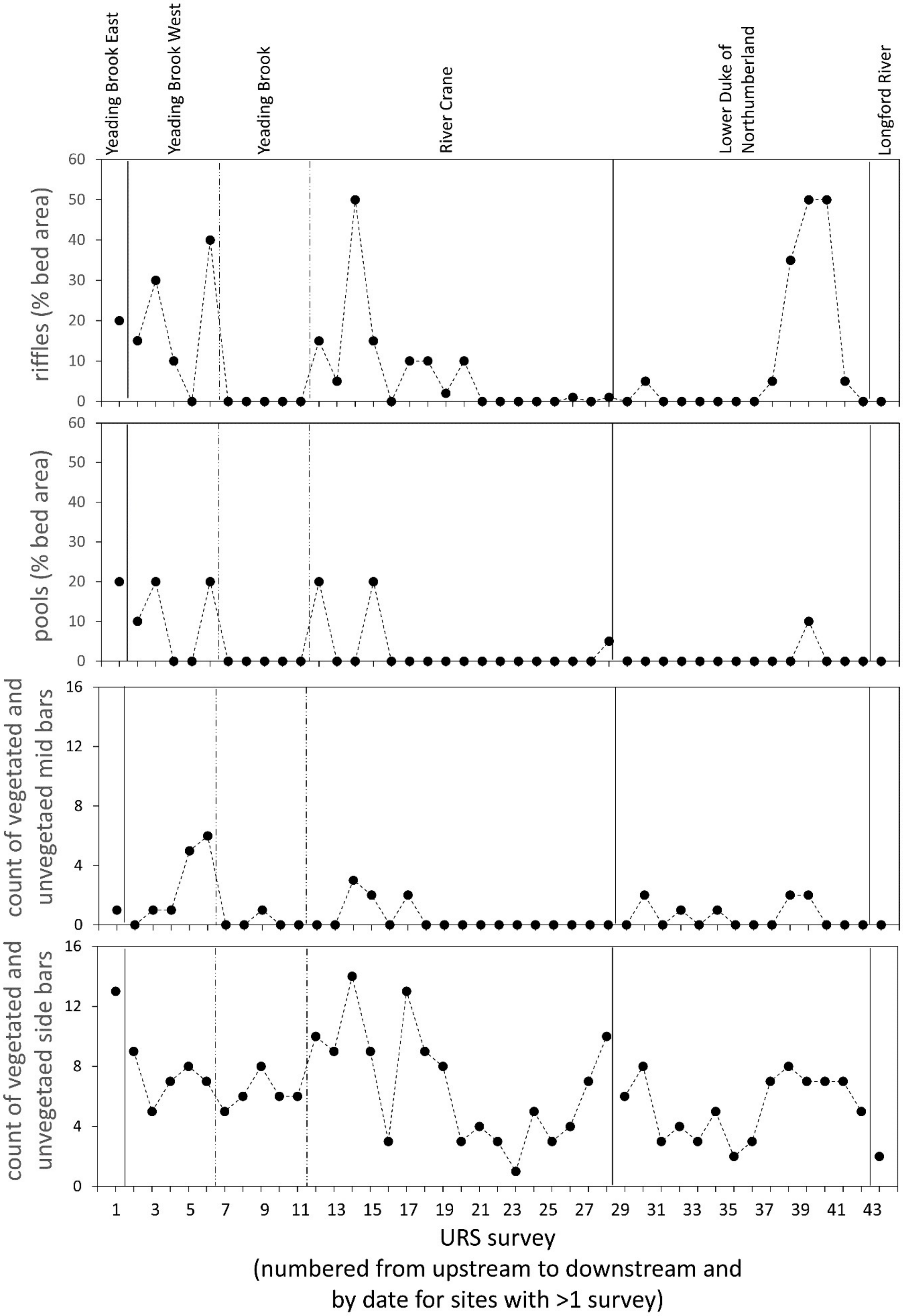

Figure 4.7: The extent or abundance of some physical habitat types that are expected to be observed in lowland rivers

5. DISCUSSION AND RECOMMENDATIONS

5.1 Limitations and gaps

As noted at the beginning of this report, although every effort has been made to check the data presented, data validation is an ongoing process and changes may be made as the project proceeds. At this stage, it is important to note the main limitations and gaps in the presented analyses.

5.1.1 Network segments.

Indicative river type identification is challenging in a heavily modified catchment, such as the Crane. Not only has there been a long history of interventions on the more naturally functioning segments of the river network, but extended segments are either entirely artificial channels or are so heavily altered that any elements of the original river character can no longer be recognised. In these extremely artificial segments, it may not be appropriate to assign an indicative river type. Nevertheless, if any 'rehabilitation' measures are considered, the river types assigned to less heavily modified segments can be used to provide a 'reference'.

Full river typing requires information on the river bed material. Such information is extremely limited or not available for several network segments. In these cases, it was impossible to assign a river type. Where bed material information was available, it is was derived from Urban River Surveys. It is important to recognise that the resolution of such data is limited. The URS records the dominant bed material inside ten 1 m wide transects of the river bed spaced evenly along the URS survey stretch. This means that for a 500 m long stretch, bed material is only recorded for a total 10 m length and thus 2% of the total bed area. Furthermore, only the dominant bed material class is recorded at each 1 m wide transect. A far higher resolution and more reliable record of bed material is collected by MoRPh surveys, where the entire river bed in each MoRPh module (typically 20 m long) is surveyed to record the abundance of all possible bed material types (bedrock, boulder, cobble, gravel-pebble, sand, silt, clay and also any superficial silt deposits). MoRPh surveys provide a fourth spatial scale of geomorphological information and so we recommend that this survey method is adopted for future monitoring of the changing character of the river (see 5.3). As these MoRPh surveys are collected, they will add to the URS surveys to provide far more accurate information to update and extend the river types displayed in Figure 2.2. The MoRPh field survey method has been developed to be suitable for citizen science volunteers, and so it also facilitates physical habitat data collection and repeat monitoring in many locations as part of a catchment-wide monitoring strategy.

5.1.2 Engineered Reaches

The engineered reaches that have been mapped were recorded during three days of rapid walkover. There remain large gaps in the mapping that need to be filled, especially for the Crane and its main true (rather than artificial) tributaries. This will provide an informative background for identifying extended river lengths where different styles of 'restoration' might be considered.

5.1.3 River Stretches

Analysis of the available Urban River Surveys has revealed many important aspects of the river environment. However, there are long lengths of river for which no URS data are available. These gaps need to be filled to achieve at least one URS survey on each sizeable engineered reach. This is likely to mean at least one URS on every artificial segment of the river network, and two or more on the remaining segments.

5.2 Opportunities

Based on our walkover surveys, which only covered a part of the river network (Figure 3.1) we list our initial suggestions concerning opportunities:

5.2.1 General comments

Many of the channels appear to be too deep – probably as a result of bed incision in straightened (and thus steepened) sections but also as a result of an initial overdeep intervention design and ongoing management that has probably included a long history of dredging and obstacle removal. While the latter are typical measures imposed to improve flood conveyance, it is important to consider whether this problem can be at least partly addressed to improve river-margin-floodplain hydrological connectivity, especially in the current context of reduced levels of channel maintenance by regulatory authorities.

Overdeepening is a problem for several reasons:

- (i) It prevents movements and exchange of water, sediment, organic material and organisms between the river and its margins/floodplain. Such movements are not only crucial ecosystem processes but they can support improvements in river water quality.
- (ii) It can lead to lowering of the near-channel water table and thus drying of marginal/floodplain wetlands.
- (iii) It slows or prevents natural recovery of the river's morphology and physical habitats because any increment of bank erosion creates enormous amounts of sediment (because the banks are so high). The river needs to transport this eroded sediment away to create room for further bank erosion.

Example (partial) solutions to overdeepening include (in order of increasing levels of intervention and requirement for space):

- (i) The deliberate introduction of naturally-functioning large wood (felled trees) to serve as naturally-functioning drop structures in the form of wood jams. It is important that these are designed to mimic nature and are introduced in appropriate locations, from a geomorphic as a well as a flood risk management perspective.
- (ii) Channel widening to introduce a 2-stage channel cross section, with the outer stage acting as a new local, well-connected flood plain for the inner channel, which conveys most river flows.
- (iii) The introduction of new, shallower but connected, side channels that can adjust more readily than the current channel and link to existing or created wetlands.
- (iv) A complete restoration of the channel to a more natural planform and cross section, wherever possible trying to re-occupy any historical channel locations identify from old maps, aerial images, lidar surveys or field observations.

The following specific suggestions relate to smaller measures that could be considered as local interventions in specific reaches. In all cases, these measures should be designed to work with nature as far as possible. For example, measures using large wood should contain the largest wood pieces achievable and should be secured as little as possible so that they can 'bed in' and adopt a natural orientation in response to local hydraulic conditions. Furthermore, at this stage, these measures are proposed only as a basis for discussion and refinement.

5.2.2 Yeading Brook: Ruislip Gardens to Yeading Brook Meadows

Downstream of Ruislip Gardens, the Yeading Brook has been historically modified with an un-natural planform and cross profile, it is mainly unreinforced and there are some signs of natural channel recovery. Opportunities exist between Stafford Open Space and Ickenham Marsh for tree works and to remove obsolete hard engineering:

- notch or remove small weirs and remove toe board, avoiding excess mobilisation of fine sediments;
- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to trap fine sediments.

South of the A40 (Western Avenue), the artificially straight channel is heavily overshaded, but is also showing signs of cross-profile recovery. Opportunities exist in Cutthroat Wood and Gutteridge Wood for tree works and habitat enhancements using large wood arisings:

- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to trap fine sediments;
- introduce large wood as ‘flood-safe fallen tree features’ to increase flow diversity, mobilise sediments, promote low flow channel sinuosity and lateral connectivity to the river margins.

Downstream of the Ten Acre Wood Flood Alleviation Scheme, the channel has greater sinuosity but its planform has been simplified and ‘smoothed’ to increase flood conveyance resulting in an ‘engineered sinuous’ planform. Overshading by riparian trees introduces the opportunity for tree works to:

- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to trap fine sediments.

At Yeading Meadows to south of the A312 (The Parkway), the channel is in part straightened (old meanders are visible on historic maps) and over deep, especially in the northern section bordered by the Greenway. Although some in channel restoration work has been carried out, the channel remains highly disconnected from the floodplain. Short- and long-term opportunities exist for tree works and habitat enhancements using large wood arisings (throughout), and for floodplain reconnection at Yeading Meadows to:

- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to trap fine sediments;
- introduce large wood, as ‘flood-safe fallen tree features’ to increase flow diversity, mobilise sediments, promote low flow channel sinuosity and lateral connectivity to the margins;
- recreate wetland habitats, intercepting ditch in-flows to improve water quality and further restore lateral connectivity to the river margins.

5.2.3 River Crane (lower-mid reaches to tidal extent)

Downstream of the A30 (Great South West Rd), although historic engineering has made the channel artificially straight and over wide, signs of recovery indicate the potential for ongoing habitat rehabilitation between the A312 (Causeway) to the A315 (Staines Rd), upstream of and adjacent to Donkey Wood. Opportunities exist to encourage rehabilitation and promote habitat recovery in the main river channel through tree works and strategic placement of large wood arisings to:

- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to trap fine sediments;

- introduce large wood, as 'flood-safe fallen tree features' to increase flow diversity, mobilise sediments, promote low flow channel sinuosity and lateral connectivity to the river margins.

Below the confluence of the Upper Duke of Northumberland's River and the A315 (Staines Rd), large scale historic engineering has modified the channel, including construction of a large weir, and further sluices controlling flows to secondary channels associated with historic mills. Short- and long-term opportunities exist for tree works and habitat enhancements using large wood arisings and for weir and sluice removal, dependent upon flood modelling and heritage considerations. For short term habitat enhancements, localised signs of recovery (including wood jams) should be left intact (with artificial litter removed and replaced by large wood where possible), and habitat rehabilitation further encouraged through selective tree works and strategic placement of large wood arisings (as listed above).

At Crane Park, a diverse mosaic of wetland habitats within the Crane Park Island reserve provides a biodiverse environment, however the secondary channel forming the perimeter is highly engineered and devoid of in-channel habitat features. Several outfalls and a small weir also contribute to the artificial pressures on this historic meander loop (visible on 1880s historic maps). Opportunities exist to remove obsolete hard engineering and to intercept flow from outfalls:

- notch or remove small weirs, avoiding excess mobilisation of fine sediments;
- introduce large wood and marginal planting at outfalls to intercept incoming fine sediments.

Downstream of Crane Park Island, previous unsuccessful attempts to form a low flow sinuous channel within the overwide reach by the introduction of large boulders has been supplemented by the addition of large wood and some sections of wood spiling. Some signs of recovery are starting to appear, with marginal vegetation increasing the capture of fine sediments and forming side bars, eventually leading to narrowing and less uniform silty bed materials. Further opportunities exist to enhance these changes through tree works that will:

- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to trap fine sediments;
- introduce large wood, as 'flood-safe fallen tree features' to increase flow diversity, mobilise sediments, promote low flow channel sinuosity and lateral connectivity to the river margins.

Downstream of the A316 (Great Chertsey Rd), initially before the A358 (Sixth Cross Rd) surprising channel recovery has occurred, between engineered road crossings with marginal vegetation and far greater diversity of bed sediments than sections upstream, although considerable quantities of large trash also present.

At Crane Park by Mill Road Weir island, the main channel is showing some recovery after removal of the main weir, and some toe board protection on the island. The historically engineered channel is over deep and options for further restoration limited by the narrow linear park and path access. However, some further enhancements to the main channel could be achieved along the right bank where the island offers fewer constraints, apart from where the allotments exist.

Along the Mill Stream, the historic channel that forms the boundary of the island is far more diverse and less heavily engineered, although the remaining weir at the downstream end, further limits recovery by impounding the water and increasing sedimentation. A long term opportunity exists to remove this weir, although would be dependent upon flood modelling, amenity and heritage considerations. As the current bed levels and flow split have been governed by many years of engineering, detailed investigations would be required to ensure the risks of bank failure, potential impacts on bridge crossing or other structures such as outfalls, and excess mobilisation of potentially contaminated silts associated with lowering the water levels are avoided.

Downstream of the Mill Road Weir island to Mereway weir and the Lower Duke of Northumberland's bifurcation, the Crane becomes more naturalised, although wooden toe board and heavy riparian shading inhibits marginal habitat diversity. Opportunities exist for treeworks and marginal habitat enhancements to:

- remove toe board, avoiding excess mobilisation of fine sediments;
- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to trap fine sediments;
- introduce large wood, as 'flood-safe fallen tree features' to increase flow diversity, mobilise sediments, promote low flow channel sinuosity and lateral connectivity to the river margins.

Downstream of Mereway weir, the Crane is heavily engineered and confined in a fully reinforced concrete channel, largely obscured from view by heavy riparian vegetation. Regulated flows limit the habitat diversity both in terms of sediment availability and flow variability. Numerous weirs are indicated on OS maps indicating control of the bed gradient throughout this section.

At Moormead Recreation Ground, a change in bed material is observed, with gravels appearing suggesting the end of the fully reinforced bed, however, weirs and hard (concrete and brick) banks are still present. Heavy shading by riparian trees also limits any in-channel recovery. Long term opportunities for habitat restoration would require substantial removal of hard reinforcement and bank reprofiling. Whilst space exists along the lower Crane corridor, other park infrastructure, heritage and amenity considerations, including a children's play area would need to be factored into wider floodplain reconnection opportunities. If landowners wished to enhance the Lower Crane in this location, substantial opportunities exist to:

- remove hard reinforcements and reprofile banks, avoiding excess mobilisation of fine sediments,
- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to establish and trap fine sediments;
- introduce large wood, as 'flood-safe fallen tree features' to increase flow diversity, mobilise sediments, promote low flow channel sinuosity and lateral connectivity to the river margins;
- if wetter 'moor-like' areas are present during wet weather, there may be additional opportunities to recreate wetland habitats, intercepting ditch in-flows to improve water quality and further restore lateral connectivity to the river margins (dependent upon services infrastructure).

North of the A316 (Great Chertsey Rd), downstream of the Whitton Brook confluence, another engineered flow split forms Coal Park Island with the historic semi-natural channel forming a loop to the east of the engineered main channel. Similar long term habitat opportunities exist to improve both channels as those at Mill Road weir island, however in this case, private properties backing onto the historic channel also limit options and accessibility. Access to main channel is also limited by the gated allotments, preventing public engagement and involvement in planning, delivering restoration works or aftercare. If access and riparian landowners were engaged and wished to restore the Crane in this location, substantial opportunities exist to remove obsolete engineering and improve in channel habitats to:

- remove hard reinforcements and/or terrace banks, avoiding excess mobilisation of fine sediments;

- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to establish and trap fine sediments;
- introduce large wood, as 'flood-safe fallen tree features' to increase flow diversity, mobilise sediments, promote low flow channel sinuosity and lateral connectivity to the river margins.

The tidal limit is just below the end of Coal Park Island.

5.2.4 Lower Duke of Northumberland's River

The Lower Duke of Northumberland's (DoN) River is an artificial channel, created to serve historic mills in Isleworth and more recently created offtakes for the Mogden sewage treatment works (STW). Although manmade, a relatively unregulated flow regime (partly influenced by the Mereway weir that controls flows to the Lower Crane)

Downstream of the Mereway split to the A316 (Great Chertsey Rd), the straight DoN channel is heavily shaded and lined with toeboard. Habitat enhancement opportunities exist for treeworks and removal of obsolete engineering to:

- remove toe board, avoiding excess mobilisation of fine sediments;
- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to trap fine sediments;
- introduce large wood, as 'flood-safe fallen tree features' to increase flow diversity, mobilise sediments, promote low flow channel sinuosity and lateral connectivity to the river margins.

Just north of the A316, a surprising short stretch of highly diverse in-channel vegetation indicates the potential for habitat rehabilitation, dependent upon light availability and channel gradient. Continuing north to Mogden STW, some sections of natural bank have begun to recover, although marginal vegetation is limited by heavy shading, in many locations opportunities exist for marginal habitat enhancements through tree works to:

- reduce over-shading, increasing light to the banks, encouraging marginal vegetation to trap fine sediments;
- introduce large wood, as 'flood-safe fallen tree features' to increase flow diversity, mobilise sediments, promote low flow channel sinuosity and lateral connectivity to the river margins.

Downstream of Mogden STW, further evidence of channel recovery exist as useful reference conditions where banks are unreinforced and marginal vegetation is thriving. Where restoration works have taken place and gradient has been restored, riffle features and some marginal and in-channel bars have formed, confirming the potential of habitat recovery in the DoN river.

Further evidence at Silverhall Park, just upstream of the historic offtake to Syon Park and tidal weir, demonstrates the potential for the DoN to sustain diverse natural riverine habitats, and potentially reference conditions for potential restorations along the Lower Crane also.

5.3 Future hydrogeomorphological work

We propose three pieces of work for next year which build on one another in the sequence (i) to (iii). In other words (ii) is not appropriate if (i) is not completed and (iii) is not appropriate if (ii) is not completed.

(i) BASELINE SURVEYS: URS surveys are needed in the gaps identified in 5.1.2. We estimate that at least 15 strategically-placed surveys are required. In addition, MoRPh surveys are needed at the key (Riverfly-Water Quality) monitoring sites. We suggest a MoRPh5 survey at each (5 contiguous surveys to give a 100 m reach length with the central survey centred on the Riverfly kick-sampling site). We recommend that these URS and initial MoRPh surveys are conducted by us to ensure good quality and a baseline on which others can build.

(ii) ADDITIONAL SURVEYS AND TRAINING: MoRPh5 or MoRPh10 surveys, as appropriate, conducted by us at sites where sizeable restoration measures are anticipated plus MoRPh survey training courses for volunteers, who may wish to participate in monitoring at specific sites for the surveys specified in (i) and (ii).

(iii) MANAGEMENT, DESIGN, GIS, ANALYSIS, REPORTING: Breadth and depth of work as appropriate to generate required outcomes

6. REFERENCES

Boitsidis, A.J., Gurnell, A.M., Scott, M., Petts, G.E., Armitage, P. A (2006) Decision support system for identifying the habitat quality and rehabilitation potential of urban rivers. *Water and Environment Journal*, 20, 130-140, DOI: 10.1111/j.1747-6593.2005.00005.x.

Gurnell, A.M., England, J., Shuker, L., Wharton, G., 2019. The contribution of volunteers to river monitoring: international and national perspectives and the example of the MoRPh survey. *River Research and Applications*, 35(8), 1359-1373.

Gurnell, A.M., Scott, S.J., England, J., Gurnell, D.J., Jeffries, R., Shuker, L., Wharton, G. 2020. Assessing river condition: A multiscale approach designed for operational application in the context of biodiversity net gain. *River Research and Applications*, 36(8): 1559-1578, https://doi.org/10.1002/rra.3673.

Gurnell, A.M., Shuker, L., Lee, M., Boitsidis, A. (2012) Gradients in the biophysical structure of urban rivers and their association with river channel engineering. *River Research and Applications,* 28, 908-925.

Shuker, L., Gurnell, A.M., Wharton, G., Gurnell, D.J., England, J., Finn Leeming, B.F., Beach, E. 2017. MoRPh: A citizen science tool for monitoring and appraising physical habitat changes in rivers. *Water and Environment Journal,* 31, 418-424, doi:10.1111/wej.12259