UK Centre for Ecology & Hydrology

An example application of the CEN Water quality — Guidance standard for assessing the hydromorphological features of rivers to the River Frome, Dorset, Southern England

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Contents

1 Introduction

1.1 Rationale

The River Frome case study is a comprehensive application of the framework proposed in CEN Standard CEN/ TC 230/ WG 25/ EN14614 and so needs to be read with reference to that Standard. This framework was first developed in REFORM, a European Union Framework 7 project (Grant Agreement 282656), established to improve the success of hydromorphological restoration.

The hierarchical and multiscale nature of the analysis (Figure 1) provides causative links between catchment processes and local scale hydromorphological conditions; for example, how catchment scale issues influence fine sediment erosion, transfer and deposition. In this way it can facilitate the application of a DPSIR (Drivers, Pressures, State, Impact, Response) model of management intervention, illustrate causes and consequences, and help target sustainable management solutions.

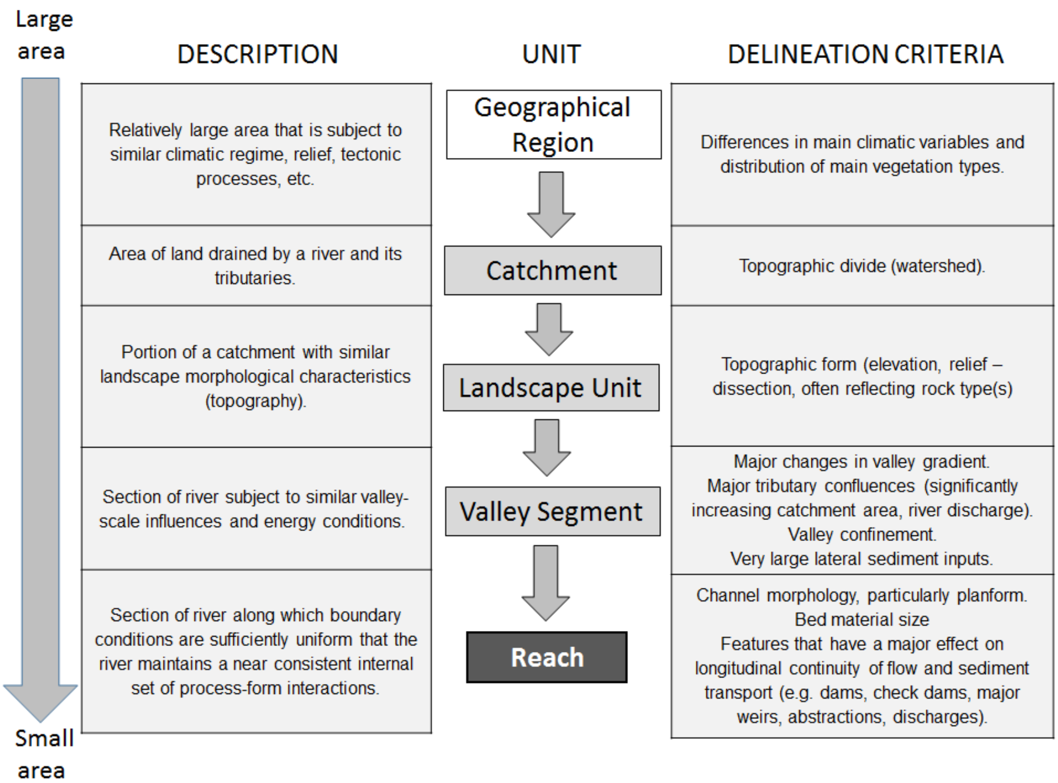

Figure 1: The spatial units that govern the processes affecting the hydromorphology of river reaches and the criteria that can be used to delineate them.

The standard determines the natural hydromorphological condition of rivers for many applications. It is appropriate for long-term, catchment-scale management, e.g. river basin planning and implementation. It is also able to support assessments for site-scale, project delivery, e.g. flood management schemes, channel maintenance and channel restoration.

The method can be applied to support both local, national and European policy. The River Frome, for example, is subject to the Water Framework Directive and is also designated as a Special Area of Conservation, under the EU Habitats Directive, and a Site of Special Scientific Interest in England, which require river status or condition to be assessed and restoration and management plans developed.

1.2 Case Study Structure

This case study example follows the investigative structure described in sections 6 to 8 of the CEN Standard:

Standard section 6: Delineation
Standard section 7: Characterisation
Standard section 8: Reference conditions

It focuses on the catchment and main stem of the River Frome (catchment area of 459 km^2), Dorset, southern England.

Delineation (summarised in section 2 and Tables 1 to 3) was extended across the whole catchment to the landscape unit scale and thereafter it focussed only on the main stem of the river (Figure 2).

Characterisation (summarised in section 3 and Tables 4 to 9) followed the lists of 'Key Processes or Features' presented in Tables 1 to 6 of the CEN Standard. However, some fields had to be omitted where information was not available, and others were evaluated at a coarser spatial scale where the resolution of the information was insufficient for a more detailed spatial analysis.

By referring to the components of reference conditions listed in Table 7 of the Standard, section 4 provides a brief integration of the information gathered during delineation and characterisation (sections 2 and 3).

The analysis was based entirely on secondary sources (global, European, national and local). Field observations from subreaches of reaches 3, 4 and 5 were then used to check the likely validity of the analysis outcomes and to support their interpretation.

This case study example illustrates a baseline application of the CEN guidance. Some additional data were collected where the baseline information on specific 'Key Processes or Features' indicated their potential local importance for characterising the hydromorphology of this case study catchment. It is recommended that such a two-stage approach should be applied to other catchments, whereby additional information is assembled to characterise aspects that appear to be particularly important in the local hydromorphological context.

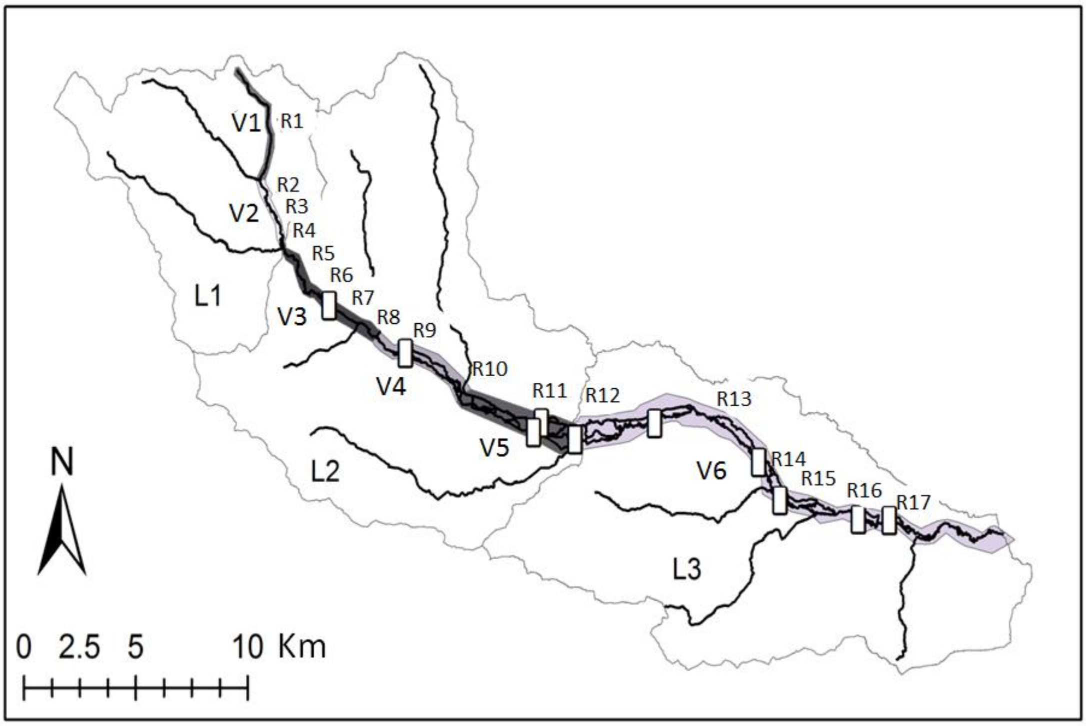

Figure 2: The main river Frome (Dorset, UK), subdivided into three landscape units (L1 to L3), 6 valley segments (V1 to V6), and 17 reach units (R1 to R17). White rectangles = weirs.

2 Delineation

2.1 Catchment and Landscape Units

The catchment was delineated based on topography (Ordnance Survey Profile DTM) in ArcGIS using the watershed tool. Landscape units were delineated by considering the predominant elevation range, geology and land cover. The junctions between landscape units were positioned at major tributary junctions with the main stem so that each landscape unit was comprised of whole subcatchments.

Table 1: Landscape Unit delineation

	Landscape Unit 1	2	3
Area (km^2)	82	190	187
Mean Elevation (m)	170	131	56
Dominant Geology	Calcareous / Siliceous	Calcareous	Siliceous
Dominant Land Cover	Pasture	Arable	Arable

2.2 Valley segments and reaches

Only the main stem was considered when delineating valley segments and reaches.

Because the main stem is unconfined from source to mouth, degree of confinement could not contribute to defining valley segments. Therefore, 6 segments were delineated using the landscape unit boundaries, the locations of important tributary junctions (in this example, those resulting in >20% increase in catchment area) and changes in valley gradient.

Table 2: Landscape Unit delineation

Landscape Unit	Segment	Catchment Area Upstream Of Tributary Junction (km^2)	Tributary Catchment Area (km^2)3	% Increase in Catchment Area due to Tributary	Gradient	Valley Confinement
1	1		13.59		0.011	Unconfined
1	2	13.59	19.57	144%	0.005	Unconfined
2	3	41.67	40.00	96%	0.003	Unconfined
2	4	111.54	26.77	24%	0.003	Unconfined
2	5	158.20	39.55	25%	0.002	Unconfined
3	6	213.38	55.48	26%	0.002	Unconfined

The valley segments were further divided into 17 reaches. The reaches were delineated first using the valley segment boundaries. Then, they were divided at the locations of major weirs that were likely to significantly modify the flow of water and sediment. Finally, reaches were further divided where channel planform changed between the three broad types found in the river system (sinuous, meandering, anabranching).

Table 3: Reach delineation

Segment	Reach	Channel Threads	Planform	Structure At Downstream End
1	1	Single thread	Sinuous	
2	2	Single thread	Sinuous	
2	3	Single thread	Meandering	
2	4	Single thread	Sinuous	
3	5	Single thread	Sinuous	Weir
3	6	Multi-thread	Anabranching	
3	7	Single thread	Sinuous	
4	8	Single thread	Sinuous	Weir
4	9	Multi-thread	Anabranching	
5	10	Multi-thread	Anabranching	Weir
5	11	Multi-thread	Anabranching	Weir
6	12	Multi-thread	Anabranching	Weir
6	13	Multi-thread	Anabranching	Weir
6	14	Multi-thread	Anabranching	Weir
6	15	Multi-thread	Anabranching	Weir
6	16	Multi-thread	Anabranching	Weir
6	17	Single thread	Meandering	

3 Characterisation

In this section, Tables 1 to 6 in the Standard are completed with information for the River Frome to produce Tables 4 to 9. These tables give contemporary estimates of each process or feature and indications of change over a period of between 10 and 100 years (time period depends on available information). Change is recorded either in a 'Significant change?' column (catchment, landscape unit and valley segment units) or in relation to change-specific 'Key processes or features' (reach units).

3.1 Catchment and Landscape Units

Catchment and landscape unit characteristics are listed in Table 4. The main data sources were national records and maps, aerial imagery, CORINE and PESERA map data, and other data downloaded from the JRC European Soil Portal.

At the catchment and landscape scales, the main characteristic that is likely to change significantly through time is land cover, with potential impacts on soil erosion. The estimates in Table 4 for three broad land cover types (A. Lightly managed, B. Agriculture, C. Artificial) represent a single point in time and were estimated from the CORINE land cover map for 2006. They are presented in this example at landscape unit scale, partly because land cover was one of the key determinants for delineation of these landscape units, but also because of the rather coarse spatial resolution of the data. The soil erosion estimates are based on PESERA modelled data, where the modelling incorporated CORINE 1996 land cover data.

To provide a more detailed temporal assessment of changes in land cover types A, B and C within the Frome catchment since 1940, estimates were extracted from national land utilisation and countryside surveys (Figure 3a). More detailed temporal changes in agriculture over 100 years were explored using agricultural statistics for the county of Dorset (2653 km^2, in which the Frome is centrally located) (Figure 3 b, c, d) and national data on crop yields (Figure 3e).

The catchment and valley segment characteristics indicate:

(i) The runoff ratio of 52% and average runoff of 507mm reflect the relatively low precipitation and high evapotranspiration regime of this area.

(ii) The catchment is extremely permeable and underlain by extensive aquifers.

(iii) There are no major coarse sediment sources.

(iv) Land cover is predominantly agricultural with little change over 60 years in the proportion of A - Lightly managed, B - Agriculture, C - Artificial. However, there has been a notable increase over 100 years in the proportion of agricultural land under arable crops, the proportion of grain production on arable land, the yield of grain crops and the number of livestock on the decreasing area of pasture (i.e. intensification of animal husbandry).

(v) PESERA-based estimates of soil erosion are not particularly large, but they are significant when estimated for the subdued topography of a lowland catchment. Land use and management changes over the last 100 years are likely to have resulted in a steady increase in soil erosion and sediment delivery to the river network over this period.

Table 4: Characteristics of the catchment and its landscape units

Key Processes or Features	Characteristics	Landscape Unit	Value	Significant Change?
CATCHMENT				
Water Production	Average runoff (mm)		507	No
	Average runoff ratio (average runoff / average precipitation)		0.52	No
LANDSCAPE UNIT				
Runoff Production / Retention	Geology (% cover): Siliceous, Calcareous, Mixed.	1 2 3	47, 53, 0 5, 95, 0 73, 26, 1	No
	Exposed aquifers (% cover)	1 2 3	98 85 26	No
	Permanent snow and ice cover	1 2 3	0 0 0	No
	Area of permeable soil / parent material (% cover) (Note that areas of low permeability are largely caused by high water table)	1 2 3	73 98 77	No
	Large surface water bodies (% cover)	1 2 3	0 0 0	No
Fine Sediment Production	Land Cover[1] A (%): Lightly managed: Forest, Scrub/herbs/grass	1 2 3	2, 0 2, 0 13, 10	Minimal change
	Land Cover B[1] (%): Agricultural: Arable, Pasture	1 2 3	26, 72 55, 39 44, 29	Minimal change in area but increase in arable
	Land Cover C[1] (%): Artificial: Urban-suburban, Industrial-commercial, Open spaces	1 2 3	0, 0, 0 3, 0, 1 2, 2, 0	Minimal change
	Estimated average erosion[1] (t ha^{-1} $year^{-1}$)	1 2 3	0.09 0.28 0.17	Probable increase
Coarse Sediment Production	Potential coarse sediment source areas (% cover)	1 2 3	0 0 0	No

[1] estimated from CORINE 2006 land cover data
[2] estimated from PESERA data (modelled estimates which used 1996 CORINE land cover data)

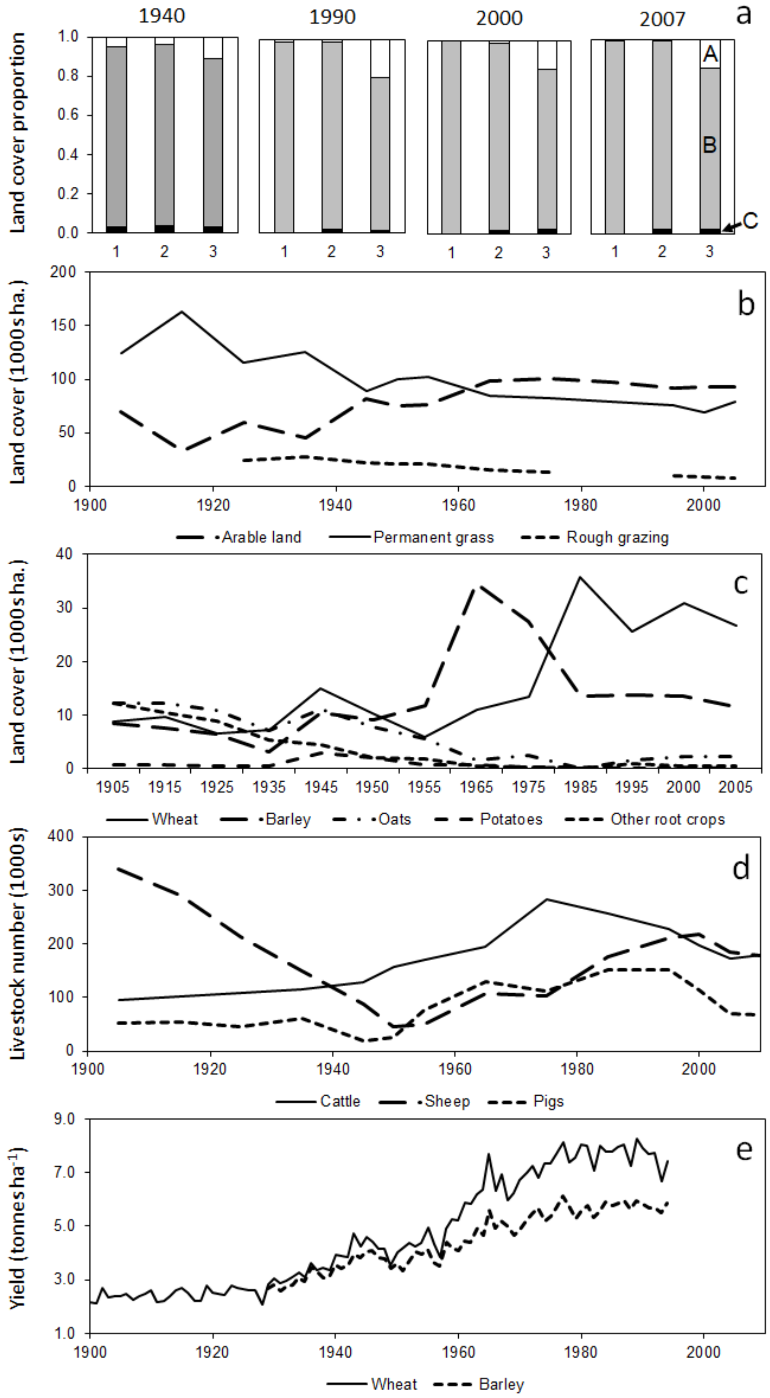

Figure 3

(a) Proportion of the Frome catchment's landscape units (1, 2, 3) under land cover A (Lightly managed), B (Agriculture), C (Artificial) in 1940 (First Land Utilisation survey), 1990, 2000, 2007 (Countryside surveys).

(b) to (e) Changes in agricultural land use, 1900-2010: (b) arable and grazing land (Dorset), (c) cover of major crops (Dorset), (d) livestock numbers (Dorset), (e) wheat and barley yield (national)

3.2 Valley Segment Units

Valley segment characteristics are listed in Table 5. The main data sources were aerial images, national maps, national digital data, and agency records.

In addition to the standard segment characteristics listed in Table 1 of the Standard, river flow and sediment delivery and transport were investigated at the segment rather than the reach scale. This difference was because there was insufficient data on these processes for reliable analysis at a higher spatial resolution.

Gauged river flow data were available for two sites on the main stem (Segment 5 at Dorchester from 1971, Segment 6 at East Stoke from 1965). Flow properties were estimated for each of these gauging sites and were combined with information from gauging sites on two tributaries to estimate some flow properties at the downstream end of each valley segment.

There is no routine monitoring of sediment transport for the River Frome, only monthly water quality measurements (which include turbidity in ntu) were available. Monthly sampling, although indicative of average suspended sediment concentration, grossly underestimates annual loads because it does not capture high flow events when most sediment is transported. However, an indicative sediment budget was estimated at the valley segment scale using the Sediment Impact Assessment Method (SIAM) that is available within the hydraulic modelling package HEC-RAS. The simple sediment transport and sediment budget modelling approach estimates indicative sediment transport and retention within the channel network by applying a 1-D sediment continuity model based on reach-averaged hydraulic and sediment information. Modelling represented the River Frome as a single (main) channel with sand-gravel bed. River discharge was based on the monitored flow duration curve and fine sediment input was interpreted from PESERA soil erosion within a 500m zone bordering the main river channel. Sediment transport was estimated using the Yang transport equation (a stream power-based model that is suitable for sand and gravel), which indicated predominantly sand and finer transport. The simple sediment budget estimates were translated into whether each segment was gaining or losing sediment or in equilibrium under the modelled flow and sediment delivery inputs. Because of these major simplifications, this application of the SIAM model only provides indicative outputs capable of defining broad spatial trends in fine sediment transport and in the typical annual sediment budget (under 1996 CORINE land cover). It was not possible to take advantage of more advanced sediment transport modelling capability in HEC-RAS, because the data required for calibration and validation were not available.

The estimated valley segment characteristics indicate:

(i) An unconfined river with a floodplain that is almost completely accessible to flood waters.

(ii) A riparian corridor (30-70m wide) extending over much of the floodplain that encloses small patches of functioning riparian vegetation within a generally agricultural landscape.

(iii) Limited longitudinal continuity of riparian trees. When present, trees are frequently located in a narrow line or as individuals along the main channel bank tops. Tree continuity is particularly poor in segments 4, 5 and 6

(iv) There are no major surface water abstractions, although groundwater is abstracted, and no significant sediment removal from the channel.

(v) Longitudinal continuity of flows and sediment transport is interrupted by numerous weirs (although only 3 are large structures) and bridges.

(vi) There has been little change in the valley-bottom and floodplain features listed above in (i) to (v) over recent decades, although there have been significant changes in agricultural land cover and management that have already been identified at the landscape unit scale.

(vii) In relation to river flows, the river has a stable, baseflow-dominated flow regime. Analysis of the > 60 year East Stoke record (comparison of flows in two 20 year periods: 1966-1985, 1992-2011), indicates a tendency towards an increase in the baseflow index (from 40 to 59, using the method described by Rinaldi et al., 2016) with the flow regime type changing from perennial stable to perennial super-stable.

(viii) In relation to sediment transport and storage, despite the relatively modest (but likely increasing) delivery of (finer) sediment to the river, all segments apart from 1 are probably gaining sediment. Overall the river appears to be receiving more sediment than it is able to transfer downstream and this trend is intensifying through time.

Table 5: Valley Segment Characteristics

Key Processes or Features	Characteristics	Valley Segment	Value	Significant Change?
Valley Features	Valley confinement e.g. confined, partly confined, unconfined	All	See Table 2	No
	Valley gradient	All	See Table 2	No
Valley Bottom – Floodplain Features	Floodplain accessible by flood water	All	Close to 100% of 100 year flood plain accessible (small areas in segments 1 and 6 not accessible)	No
	Average floodplain and riparian corridor width (m) Note that all the area of the floodplain accessible by floodwater (virtually 100%) has the potential to support patches of riparian vegetation	1 2 3 4 5 6	70 122 227 345 603 585	No
	Average total width of riparian vegetation within the riparian corridor (m, % corridor width)	1 2 3 4 5 6	31, 44% 74, 61% 43, 19% 32, 9% 59, 10% 71, 12%	Minimal
	Longitudinal continuity of riparian vegetation (% river bank length)	1 2 3 4 5 6	42 30 27 9 18 21	Minimal
	River channel edges bordered by mature trees (non-coniferous trees and tree/scrub that can contribute to wood delivery, coniferous stands are excluded because they are managed plantations) (% river bank length)	1 2 3 4 5 6	32 14 24 8 13 13	Minimal
Major Disruptions to Longitudinal Continuity	Number of blocking structures structures (weirs) and impeding spanning structures (bridges): high weirs, intermediate weirs, low weirs, high impact bridges, medium impact bridges	1 2 3 4 5 6	0, 0, 1, 0, 0 0, 3, 2, 2, 3 0, 3, 6, 3, 3 0, 4, 9, 3, 5 0, 7, 21, 9, 17 3, 12, 21, 4, 19	No
	Number of major sites of sediment removal from the river bed	All	0	No
	Major abstractions and discharges (locations, magnitude)	All	No major abstractions from river. Data on discharges not obtained but unlikely to be large	No

Key Processes or Features	Characteristics	Valley Segment	Value	Significant Change?
River Flow Regime and Extremes	Flow regime type	Dorchester (5) East Stoke (6)	Perennial stable Perennial superstable	More stable*
(* changes inferred from analysis of 1966-present record from East Stoke gauge)[3]	Annual floods (from daily flows) of hydromorphological significance ($m^3 s^{-1}$): Q_{median}, Q_{2year}, Q_{10year},	1 2 3 4 5 6	0.85, 0.84, 1.19 2.59, 2.54, 3.56 6.56, 6.41, 8.82 9.13, 8.91, 12.08 12.17, 11.84, 15.73 22.24, 21.32, 25.46	No*
	Base flow index (%)[3]	Dorchester (5) East Stoke (6)	50 56	Increase*
	Timing of maximum flows (Julian day)	Dorchester (5) East Stoke (6)	335 1	No*
	Month of short and prolonged extreme flows: 1-day min, 30-day min, 1-day max, 30-day max	Dorchester (5) East Stoke (6)	Sep, Sep, Jan, Jan Sep, Aug, Jan, Jan	No*
Sediment Delivery and Transport Regime	Eroded soil delivery (estimated for a 500m buffer using PESERA data) in $t\ year^{-1}$ and $t\ year^{-1}\ km^{-1}$ main channel length	1 2 3 4 5 6	0, 0 14, 4 32, 4 151, 26 314, 39 65, 2	Probable increase
	Estimated suspended sediment load ($t.y^{-1}$)[2]	1 2 3 4 5 6	1 20 90 400 1300 1500	Minimal change?
	Sediment delivery from bank erosion[1]: Gravel delivery ($t.km^{-1}.yr^{-1}$) (a)1889-1960s, (b) 1970s-2013 Sand and finer delivery ($t.km^{-1}.yr^{-1}$) (c) 1889-1960s, (d)1970s-2013	1 2 3 4 5 6	a 1, b 4, c 19 d 56 a 2, b 4, c 37 d 77 a 3, b 3, c 57 d 59 a 4, b 5, c 59 d 78 a 2, b 4, c 30 d 58 a 4, b 8, c 67 d 132	Minimal change?
	Sediment budget[2]: gain-equilibrium-loss	1 2 3 4 5 6	Loss Gain Gain Gain Gain Gain	Probable increasing gain

[1] bank erosion estimated from bank position change on Ordnance Survey topographic maps (1889, 1960), typical bank heights from habitat surveys, and likely ratio of sand and finer to gravel and coarser bank materials.
[2] modelled using SIAM – HEC-RAS with Yang sediment transport equation.
[3] estimated using the method described in Rinaldi et al. (2016)

3.3 Reach Units

Hydromorphological characteristics indicative of flow and sediment transport were estimated at the valley segment scale (Table 5). From these data, reach unit estimates of specific stream power for annual maximum daily flows with different return periods (Q_{median}, Q_{2year}, Q_{10year}) were estimated tentatively for all reaches (Table 6), because specific stream power is often used as an indicator of the likely naturally-formed river channel types that may be found at a site. Other contemporary characteristics of reach units were extracted from aerial images, lidar data, large scale topographic maps and, where available, national river habitat and macrophyte survey data.

The following tables summarise reach-scale characteristics indicative of river channel size and type (Table 6), the river bed (Table 7), river channel and large island margins (Table 8), and floodplain (Table 9).

Typical bed sediment size has been added to Table 6, but detailed data on bed sediments are retained in Table 7. The estimated river channel size and type characteristics (Table 6) indicate:

(i) A main channel that is typically <14 m wide, represents between 35% and 100% of the total channel width (including side channels), is <1.5 m deep and is of low gradient (all reaches $\leq$ 0.004).

(ii) Specific stream power estimated from Q_{median}, Q_{2year}, Q_{10year} discharges and bankfull channel width reveals a low energy flow regime. Although specific stream power has an estimated maximum value of 39 W m^{-2} (Q_{10year}, reach 1), most estimates are < 20 W m^{-2}, which represents the lower end of the range typically associated with laterally migrating rivers. Many estimates fall below 10 W m^{-2}, which is thought to be typically indicative of laterally stable rivers. Thus the river Frome main stem has a low potential for lateral movement.

(iii) Low lateral dynamics is also indicated in the river types initially identified, although at this stage the degree of natural form and function of these types is not established. All are unconfined types with nine reaches showing anabranching channels, six reaches showing low sinuosity, single-thread channels, and only two having a single-thread meandering channel pattern. Most reaches show a mixed gravel-sand bed with silt present throughout (see Table 7 for more details of bed sediments).

The hydromorphological characteristics of the river bed (Table 7) indicate:

(i) The more detailed characterisation of bed material from macrophyte surveys, which provide aerial cover estimates of different sediment size classes within the surveyed reach, illustrates that sand and finer sediment is present with at least 50% cover in all reaches apart from 1 and 6. Furthermore, 1 and 6 are the only reaches with any cover coarser than gravel (8% and 2% cobble cover in reaches 1 and 6, respectively), and all reaches contain areas of silt, with a maximum recorded cover of 25%.

(ii) Recorded bed sediment features include pools, riffles, point / side and mid-channel bars. The recorded numbers are likely to be significant underestimates because of their constrained definition in existing surveys or restricted visibility in aerial images.

(iii) There is a sizeable aquatic vegetation cover (up to 69% cover of submerged/floating and 17% emergent plants), which increases markedly downstream.

(iv) Vegetation stabilised features are widespread. The numbers extracted from air photographs are likely to be underestimates because of their dependence on visibility. The abundances extracted from lidar data are more reliable for those reaches (3 to 7, 14, 15, 17) for which data were available. Vegetated side / point bars and berms increase in number downstream and represent the majority of the total bar/berm features that are present (see bed sediment features). In addition, islands, identified from air photos as mid-channel features with well-developed (shrubs / trees) vegetation, are widespread along the river with a tendency for numbers to decrease downstream. Island numbers are also likely to be underestimates because they have been extracted from air photographs. Information from lidar data focussed on the degree to which vegetated point bars were observable on bends, revealing that they were present on many bends. In addition, subdued scrolls were observable across the upper bank (and adjacent floodplain margins). From the limited lidar coverage analysed, these channel edge features appear to increase in abundance downstream.

(v) Large wood is recorded as present in some habitat surveys conducted in reaches 1 to 10 but is not observed downstream from reach 10. A similar pattern is observed for fallen trees. No habitat surveys record extensive large wood or extensive fallen trees, and a record of ‘present’ can refer to any cover between 1% and 33%. It is likely that these data indicate a generally modest cover of wood and fallen trees.

(vi) Bed reinforcement is negligible and, based on habitat survey transect observations, is largely confined to reaches 1 and 2. The main disruption to longitudinal continuity is offered by weirs distributed throughout the length of the river. Weirs are only absent in reach 2, and 12 reaches contain at least 1 weir of intermediate size.

(vii) A lack of data prevents any quantification of bed incision or aggradation, although bed armouring and siltation are known to occur at many locations along the river.

The hydromorphological characteristics of the river channel and large island margins (Table 8) indicate:

(i) River banks are dominated by vertical bank profiles. Modest active bank erosion is observed in most reaches, but its spatial extent is difficult to assess accurately from the available data. Bank erosion is likely to be underestimated by habitat survey transect data.

(ii) Bridges disrupt longitudinal continuity in most reaches, with reaches 9, 10, 13, 15, 17 particularly heavily affected. Bridges not only constrict flow and moderate sediment and large wood transfer but also provide local areas of bank reinforcement that limit sediment inputs from bank erosion.

(iii) The full extent of non-erodible banks (reinforced, embanked, infrastructure within 0.5 channel widths) is low, typically 10% bank length or less, apart from reach 10.

(iv) Lateral change in the main river channel is estimated over ca. 70 years (1889-1960s) and ca. 40 years (1970s-2013) from large-scale (1:2500) Ordnance Survey maps, which have a standard convention for recording river edges. Lateral changes have been generally small given the multi-decadal timescales over which the river has moved laterally at a rate of 0.13 m yr^{-1} (the maximum estimate). Changes in channel width, sinuosity and area were highly variable in magnitude and direction in the earlier period, but there has been an overall trend of decreasing channel width and area, and increasing sinuosity in the later period.

The hydromorphological characteristics of floodplains (Table 9) indicate:

(i) The presence of a few floodplain features / units, mainly water- or wetland-filled oxbow lakes and other ponds and abandoned channels, were identified from aerial imagery and so may be under-estimates. Analysis of lidar data revealed greater detail on the extent of apparently-functioning wetlands, drained and degraded backswamp areas and abandoned channels. Degraded backswamps and abandoned channels, which were difficult to see on aerial images and are probably difficult to identify in the field, are widespread within the lidar images, with abandoned channels occupying significant (P or E) areas of the riparian corridor along most of the analysed reaches. In addition, scrolls (recorded in Table 7), where they occur, often extend beyond the channel across bank tops and nearby floodplain edges.

(ii) The observed floodplain features indicate the presence of hydromorphological floodplain types that are appropriate to the river types but are degraded forms of these floodplain types. This reflects the degradation or complete removal of natural floodplain features by agricultural activities such as ploughing and draining, including the construction of networks of drainage undulations and ditches.

(iii) Lateral continuity is high in terms of the spatial extent of the erodible floodplain (here expressed for each reach in reach-averaged channel widths).

(iv) Previous tables have indicated the lack of obstructions to floodplain inundation. However, lateral continuity across the floodplain is also disrupted by channel realignment, which was most clearly identified from lidar data. The lidar coverage indicates that realignment is not widespread but is notable locally in some reaches. In addition, agricultural activities disrupt lateral connectivity of water and sediment. Evidence of land drainage activities is widespread on lidar images. Land drainage, observed as surface undulations and deeper ditches on lidar images, modifies water and sediment flow pathways and its installation degrades the natural morphology of floodplains by smoothing or completely removing their geomorphic features.

Table 6: Hydromorphological characteristics indicative of river channel size and type

Key Processes or Features	Characteristics	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Specific Stream Power	Q_{median} (W m^{-2})	28	18	16	19	13	16	10	13	14	9	8	10	15	16	11	12	13
(estimated from daily flow series)	Q_{2year} (W m^{-2})	27	17	16	18	13	15	10	13	14	9	8	9	15	15	10	12	12
	Q_{10year} (W m^{-2})	39	24	22	26	18	21	14	17	18	12	10	12	19	19	13	14	15
Average Channel Dimensions	All channels width (m)	3.1	4.8	5.5	7.7	10.0	14.1	14.7	12.6	17.2	20.9	29.4	23.7	21.1	23.7	20.1	17.5	15.5
	Main channel bankfull width (m)	3.1	4.5	5.0	6.5	9.1	13.9	11.7	11.0	9.8	12.0	10.3	11.6	13.9	11.8	13.1	12.2	14.2
	Main channel bankfull depth (m)	1.0	1.4	1.2	1.2	1.5	1.0	1.5	1.1	0.9	0.9	1.1	1.1	1.2	1.0	1.2	1.4	1.1
	Bankfull slope (m m^{-1})	.010	.004	.003	.006	.002	.004	.002	.002	.003	.002	.002	.002	.002	.002	.001	.001	.001
River Hydromorph-ological Type	Sinuosity index	1.12	1.13	1.51	1.06	1.28	1.03	1.20	1.28	1.21	1.21	1.30	1.45	1.34	1.18	1.39	2.11	1.59
(note – all unconfined)	Braiding index (no major bars present)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Anabranching index	1.00	1.00	1.04	1.41	1.06	1.75	1.00	1.43	2.39	2.93	4.67	2.87	2.00	3.00	2.23	2.00	1.20
	Typical bed sediment size[1,2] (all > 30% cover)	GR	SA-GR	SA-GR	SA-GR	SA-GR	GR	GR-SA	SA-GR	SA-GR	GR-SA	GR	GR-SA	GR-SA	GR-SA	GR	SA-GR	SA-GR
	Type[3]	17	17	18	17	17	19	17	17	19	19	19	19	19	19	19	19	18

[1] GR = gravel (predominantly fine), GR-SA = gravel-sand/silt, SA-GR = sand/silt-gravel, SA = sand/silt (silt present in all reaches – 5-25% cover)
[2] estimated from macrophyte survey data (includes aerial coverage of different sediment sizes within a surveyed reach) apart from reaches 7, 11, 15 where habitat survey transect data (10 per 500m reach) are used. [3] river type – see Informative Annex 3 in the Standard, Rinaldi et al. (2016)

Table 7: Hydromorphological characteristics indicative of river main-channel bed

Key Processes or Features	Characteristics	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Bed Sediment	Bed sediment size (% cover)[1]:																	
	cobble	8	0	0	0	6	2	nd	5	0	0	nd	0	0	0	nd	0	0
	gravel	62	45	42	40	49	72	nd	33	42	50	nd	60	45	45	nd	43	45
	sand	19	40	38	40	31	22	nd	55	33	36	nd	30	45	43	nd	43	40
	silt/clay	11	15	20	20	13	5	nd	8	25	14	nd	10	10	13	nd	14	15
	Bed sediment features/units per km:																	
	large pool[2]	0.5	0	1	0.2	0.5	0.2	0.2	0.1	0.2	0.1	0.2	0	0.1	0.1	0.2	0.3	0.2
	riffle[2]	3.7	1.3	1.5	0.5	0.9	1.1	0.3	0.1	0.6	0.3	0.2	0.1	0.4	0.4	0.1	0.1	0.2
	side-point.bar/berm[3]	nd	0	0	nd	2.5	0.3	0.9	0	0.1	0.3	0.4	0.7	1.5	3.4	1.1	0.4	2.0
	mid bar[3]	nd	0	1.1	nd	1.3	0.3	0	0.4	0.9	0.1	0	0.1	0.2	0	0.1	0	0.1
Vegetation Units	Aquatic vegetation cover (%)[2]:																	
	emergents	1	1	1	13	1	4	1	6	6	4	1	10	6	3	11	3	17
	submerged/floating	0	2	6	3	6	2	4	41	6	29	20	69	42	3	62	45	42
	Vegetation-stabilised features emergent at low flow per km:																	
	veg. side-point.bar/ berm[3]	nd	0	0	nd	1.8	0	0.9	0	0	0.3	0.4	0.7	1.5	3.4	1.0	0.4	1.4
	veg. mid bar[3]	nd	0	1.1	nd	1.3	0.3	0	0.4	0.8	0.1	0	0	0.1	0	0.1	0	0.1
	island[3]	nd	1.1	1.7	nd	1.1	0	0.8	1.5	0.1	0.1	0.1	0.1	0.2	0	0	0.2	0.2
	point bars[4]	nd	nd	O	A	P	P	O	nd	nd	nd	nd	nd	nd	O	P	nd	P
	scrolls[4]	nd	nd	A	A	O	O	O	nd	nd	nd	nd	nd	nd	O	P	nd	E
	Wood[5]:																	
	Large wood P	75	100	80	33	37	67	25	20	13	11	0	0	0	0	0	0	0
	Large wood E	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fallen trees P	53	100	60	68	9	33	25	0	13	0	0	11	19	0	0	0	0
	Fallen trees E	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Key Processes or Features	Characteristics	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Disruption of Longitudinal Continuity[7]	Bed reinforcement %[6]	2	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	No. of artificial barriers:																	
	high weirs,	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0
	intermed. weirs,	0	0	0	3	3	0	0	1	3	5	2	2	3	2	1	2	2
	low weirs	1	0	1	1	2	2	2	2	7	19	3	5	4	3	4	0	5
Evidence of Contemporary / Recent Changes	Bed incision	No exposed bedrock, stressed or dying riparian trees or recent disconnection of side channels																
	Bed aggradation	Bed armouring and siltation occur but no records are available																
		No monumented, repeat channel cross section topographic surveys available to quantify bed incision or aggradation																

[1] estimated from macrophyte surveys (nd = no data)
[2] estimated from habitat survey transect data (absolute values too low but relative values informative)
[3] estimated from aerial imagery (nd = not visible)
[4] estimated from lidar data and extend across banks into the floodplain margins at some sites - : nd (no data), A (absent), O (<5% main channel length), P (5-33% length), E (> 33% length)
[5] estimated from habitat survey reach-cumulative measurements (% surveys reporting large wood/fallen trees present (P=<33%cover, E=>33%cover). No channel-spanning wood jams recorded
[6] % habitat survey transects recording bed reinforcement
[7] aquatic vegetation management occurs but no records available

Table 8: Hydromorphological characteristics indicative of river channel (and large island) margins

Key Processes / Features	Character-istics	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Bank Sediments	Sediment size	Banks are predominantly comprised of < 2mm diameter particles (sand and finer) with some gravel, particularly near the base of banks.																
Bank Morphol-ogy	Extensive bank profiles[1]																	
	Vertical	87	100	80	67	91	100	75	60	94	94	100	56	72	83	91	90	100
	Steep	20	0	10	34	19	0	25	40	6	6	0	33	28	17	18	10	0
	Gentle	0	0	0	0	0	0	25	0	0	0	0	0	3	0	9	0	0
	Active bank erosion[2]	2	0	4	4	5	0	3	0	1	1	2	1	3	0	3	4	3
Disruption of Longitud-inal Continuity	No. artificial barriers encroaching from banks (bridges)																	
	High impact,	0	0	0	2	1	1	1	1	2	7	2	0	2	0	1	0	1
	Inter. impact,	0	0	1	2	1	0	2	1	4	12	5	5	3	1	4	0	6
	Low impact.	3	5	0	12	4	3	0	1	20	28	5	14	17	7	17	4	18
Disruption of Lateral Continuity	Non-erodible banks (% bank length)[3]	+0.3	+0.2	-0.5	-0.6	+0.5	+0.4	+3.3	+1.3	+0.5	-0.7	+1.2	-1.5	+3.1	+1.5	+0.9	+0.9	+0.5
		+0.1	+0.4	-0.3	-0.2	-1.1	-1.8	-2.2	-1.3	-1.2	-1.4	-0.5	-2.1	-2.0	+1.4	+0.3	-2.1	+0.1
Evidence of Lateral Channel Change[5]	Channel width[4] (m) 1889-1960s,	+0.01	-0.01	+0.04	-0.01	+0.03	0.00	+0.02	-0.02	+0.02	0.00	0.00	+0.02	-0.05	+0.02	+0.01	0.00	-0.02
	1970s-2013	+0.02	+0.01	+0.06	+0.04	+0.02	+0.01	0.00	+0.04	+0.04	+0.01	-0.07	+0.02	+0.05	-0.03	+0.01	+0.01	+0.06
	Sinuosity[4] 1889-1960s, 1970s-2013	+8	-4	-11	-19	+2	-21	+8	+10	+2	-5	+5	-14	-7	-5	-9	0	-10
		+11	+9	+4	-2	-4	-10	-6	-8	-14	-8	-2	-11	-6	+11	+3	-9	-1
	Channel area[4] (%) 1889-1960s,	+0.3	+0.2	-0.5	-0.6	+0.5	+0.4	+3.3	+1.3	+0.5	-0.7	+1.2	-1.5	+3.1	+1.5	+0.9	+0.9	+0.5
	1970s-2013	+0.1	+0.4	-0.3	-0.2	-1.1	-1.8	-2.2	-1.3	-1.2	-1.4	-0.5	-2.1	-2.0	+1.4	+0.3	-2.1	+0.1

[1] % habitat survey 500m reaches with > 33% bank length of the given bank profiles.
[2] % habitat survey transects with eroding, vertical bank faces.
[3] % bank length with reinforcement and/or embanking (from habitat surveys) and/or infrastructure set back < 0.5 channel width (from aerial imagery)
[4] changes between dates interpreted from bank line positions on Ordnance Survey 1:2500 maps

[5] No data on bed material exposed in banks, burial of soil layers or vegetation, tree features (leaning, falling, root exposure) on opposing banks

Table 9: Hydromorphological characteristics of floodplains

Key Processes or Features	Characteristics	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Floodplain Morphology	Number of floodplain features / units																	
	oxbow lakes[1]	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	other abandoned channel lakes[1]	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	1
	oxbow wetlands[1]	0	0	2	0	0	0	0	0	2	0	0	1	3	1	1	1	6
	other abandoned. channel wetlands[1]	0	0	0	0	0	0	0	1	3	2	2	2	3	2	5	1	4
	degraded backswamps[2]	nd	nd	O	O	O	O	nd	nd	nd	nd	nd	nd	nd	P	A	nd	E
	abandoned. channels[2]	nd	nd	P	O	E	P	nd	nd	nd	nd	nd	nd	nd	E	P	nd	P
	Floodplain hydromorphological type[3]	A	A	A	A	A	A/B	A	A	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A
Lateral Continuity[3]	Width of erodible floodplain corridor (in reach-average main channel widths)	22	15	11	14	22	17	18	20	17	25	29	38	31	21	19	20	28
Disruption to Lateral Continuity	Measures designed to disrupt flood plain inundation - erosion	Entire channel is virtually entirely free of embankments, and non-erodible bank length (includes infrastructure within 0.5 channel widths of bank tops) is less than 10% in all reaches apart from 9 (10.6%) and 10 (23.1)%.																
	Channel realignment (straightening, artificial cut-offs)[2]	nd	nd	A	P	A	E	Nd	nd	nd	nd	nd	nd	nd	A	P	nd	A
	Flood plain under drainage undulations / ditches[2]	nd	nd	P	E	E	E	Nd	nd	nd	nd	nd	nd	nd	E	E	nd	E
	Artificial land cover along river margin[4] (% riparian corridor area)	56	39 (reaches 2-4)			81 (reaches 5-7)			91 (reaches 8-9)		90 (reaches 10-11)		88 (reaches 12-17)					

[1] extracted from air photographs – because of intense agriculture, these were the only features that could be extracted reliably
[2] interpreted from lidar data: - abundance across the accessible floodplain / riparian corridor: nd – no data, A (absent), O (<5% floodplain area), P (5-33% area), E (> 33% area)
[3] interpreted from lidar data and air photos: A = degraded lateral migration, backswamp; B = degraded organic anabranching
[4] since the floodplain is mainly accessible by floodwater and is either under natural riparian vegetation or agriculture, these valley segment-scale percentages represent the proportion of the accessible floodplain – riparian corridor that is not recorded as riparian vegetation in Table 5 and is thus largely under agriculture

3.4 Field Checking of Reach Characteristics

Subreaches of reach 4, reach 5 and reach 6 were subject to brief field survey to check the likely validity of the assessments made from secondary sources and to identify additional relevant processes and features. The visited subreaches consisted of single channels selected to represent a channel length with a predominantly naturally-functioning riparian corridor (4) or with a sinuous (reach 5) or meandering (reach 6) channel planform coupled with a predominantly agricultural floodplain.

Evidence from field observations indicate the following:

(i) In relation to hydromorphological characteristics indicative of channel size and type (Table 6):
   a. Channel dimensions from secondary sources are a good approximation to those observed in the field
   b. Estimates of river hydromorphological type accurately represent those observed in the field (but see (iia) for comments on bed material)

(ii) In relation to hydromorphological characteristics of the river main-channel bed (Table 7):
   a. Bed sediment size estimated from macrophyte survey data is a good representation of field conditions, whereas information extracted from habitat survey transects underestimates the sand and finer fractions. Finer sediment was an important component of the gravel-dominated bed in all visited reaches, reaching 100% in some parts of the visited subreach of reach 4, where it covers a gravel bed.
   b. Bed sediment features (bare and stabilised by vegetation) identified from habitat surveys and air photographs were all present in the field, but their frequencies were underestimated. In relation to pools and riffles, only the most prominent ones are recorded in habitat surveys or are recognisable in aerial images. As indicated by habitat survey data, few exposed features were unvegetated. Islands, which were discriminated from vegetated bars on air photos by their vegetation development, proved to be mainly vegetated bars rather than true islands in the field. Major vegetated point bars identified from lidar data matched field observations and scrolls identified along the channel margins were observed as extremely subdued features that graded into side and point bars in the field. In the field, aggraded, vegetated features (bars, islands, scrolls) were all constructed mainly from sand and finer sediment. In the visited meandering subreach of reach 5, pools, riffles, mid channel, side and point bars were all developed in the expected longitudinal pattern and frequency for a meandering and laterally migrating river. In the sinuous subreach of reach 6, such features were more widely spaced with one large vegetated point bar present at a bend marking the downstream end of the subreach. In the subreach of reach 4, geomorphic features were mainly forced by trees and large wood, with aggraded units all comprised of sand and finer sediments.
   c. Aquatic vegetation cover varies greatly through the year, but habitat survey data reliably reflected its spatial distribution. It was widely

observed in the visited subreaches of reaches 5 and 6, with emergent aquatic vegetation often present along the inundated edge of developing bars and berms. Aquatic vegetation was rare in the visited subreach of reach 4, which is heavily shaded by riparian trees.

d. The spatial distribution of large wood and fallen trees estimated from habitat surveys was confirmed in the field, with 'present' usually representing rather small quantities. The visited subreach of reach 4, retains much more wood than is indicated from habitat survey data available for the reach. Numerous tree-related features were observed in the visited subreach, including wood- and tree- induced jams, islands, berms, benches, scrolls and bank buttresses, all of which retained or were constructed from sand and finer sediment.

e. Bed siltation was observed in all visited subreaches in addition to that retained in aggrading geomorphic units. It was most marked within the subreach of reach 4.

f. The importance of weirs for disrupting longitudinal continuity was confirmed in the field as was the rarity of river bed reinforcement.

(iii) In relation to hydromorphological characteristics of the river channel (and large island) margins (Table 8):

a. Banks were confirmed to be predominantly comprised of < 2mm particles, although gravel particles often also occurred, particularly towards the base of some banks.

b. Bank profiles were confirmed to be predominantly near-vertical and vegetated, although actively eroding near-vertical banks were widespread on the outer bank of bends and steep to gently sloping vegetated banks were widespread on the inner banks of river bends. Thus the presence of active bank erosion is correctly identified by habitat survey data but its extent is underestimated, particularly in the most sinuous reaches.

c. Interruption of longitudinal and lateral continuity by bridges and the presence of non-erodible banks is quite accurately characterised from secondary sources.

d. Based on field observations of eroding banks, vegetated side-point bars and scroll features along the channel margins, the evidence of lateral change from topographic maps appears to be accurate. Indeed coupling of feature identification from lidar data, and channel margin movements from 1:2500 scale topographic maps provides a robust perspective on where change has occurred and how it has been achieved mainly by lateral migration and side-point-scroll bar building over the last 100 years.

(iv) In relation to the hydromorphological characteristics of floodplains (Table 9):

a. Air photo interpretation has reliably identified most of the floodplain features present, but their abundance is underestimated. Where available, lidar data can provide more accurate assessments of floodplain features and is particularly effective in identifying subdued features such as degraded (drained and silted) wetland patches, backswamps and abandoned channels. These subtle features are not easily identified in the field but can be interpreted from lidar data, in some cases even through later land drainage works. In these cases, the geomorphic features can be interpreted to pre-date land drainage and, with channel margin features, support the existence of degraded floodplain types appropriate to the observed river types

b. Disruption of lateral continuity by embankments, bank reinforcement, presence of infrastructure and the presence of agriculture are all reliably estimated from secondary sources. However, lidar data is needed to reliably identify channel realignment, which is often difficult to detect from aerial photographs unless it has been undertaken with little regard for sustainability. Furthermore, lidar data provides the only means for reliably characterising the full extent of land surface modification by land drainage.

4 Reference Conditions

The Frome catchment analysis indicates that reference conditions are not achieved, but there are some elements that can be interpreted as indicating reference processes or forms, albeit under the influence of a variety of human pressures and interventions. It also identifies the ways in which human pressures and interventions from catchment to reach scales have and are influencing the hydromorphological characteristics of the main stem of the river.

(i) Hydrological and sediment regime: Despite groundwater abstraction and other minor water abstraction activities, the hydrological regime appears to be close to reference conditions. However, land cover changes across the catchment and its floodplains suggest a likely increase in fine sediment delivery to the river network that reflects human pressures, particularly from agriculture, and has important impacts on hydromorphology across all spatial units.

(ii) Longitudinal connectivity of water, sediment and other materials and organisms: Longitudinal connectivity is disrupted by numerous weirs and bridges, with increasing disruptions as these become more frequent and also larger downstream. The predominantly gaining sediment budget and observations of siltation of the river bed confirm poor longitudinal connectivity of sediment transport.

(iii) Lateral connectivity is heavily disrupted throughout the main stem, particularly by agricultural development and intensification and related land drainage activities on the floodplain. Although some functioning riparian areas exist, these are mainly confined to the upper reaches of the river and are indicated by higher continuity of riparian vegetation and presence of trees bordering the river in valley segments 1, 2 and 3 than 4, 5 and 6, and by the decreasing presence of large wood and fallen trees in river reaches in a downstream direction, with negligible quantities recorded downstream of reach 10. However, bank modification and protection are both relatively limited, so that lateral river movement is rarely controlled.

(iv) The river long profile is heavily affected by weirs.

(v) The river cross profile is not greatly affected by human activities, although some planform straightening has occurred locally.

(vi) River bed and bank characteristics are free to adjust throughout most of the main stem length and their character is largely appropriate to the river and floodplain types that are present. In the long term (from lidar evidence) channel movements have included both channel switching-splitting-avulsion and migration. Degraded floodplain units illustrate how the floodplain might have looked and functioned prior to intensive, widespread agriculture. However recent (last 100 years) channel movements have mainly occurred through lateral migration along the margins of the main channel, with increasing recent evidence (last 40-50 years) of fine sediment retention in vegetation-stabilised geomorphic features coupled with channel narrowing and increasing sinuosity within a previously wider channel. The nearest to a reference reach is provided by part of reach 4, where the presence of near-natural riparian vegetation is inducing channel characteristics driven by trees and large wood (which in the past would have promoted channel blockage and avulsion processes). However, even here, high fine sediment delivery is reflected in bed smothering and aggradation, and the rapid building of channel features composed of fine sediments and negligible gravel.

(vii) Overall the channel, margins and floodplain all exhibit features appropriate for their hydromorphological type. However, floodplain features are heavily degraded by agricultural activities, and channel-margin features are being constructed from excess fine sediments and stabilised by aquatic plants and riparian herbs and grasses because of the lack of riparian woodland along much of the river network.

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