Appendix 5 Defining reference conditions for chalk stream and Fenland natural channels

Chalk stream geomorphology is poorly understood, and under-researched. What studies exist appear to confirm that the majority of UK and European chalk streams have been modified in form and hydraulics by a long history of river management (Sear and others 1999, WRc 2000). The overriding control these modifications exert on the geomorphology and processes operating within the channel, make it difficult to establish what features and physical habitat diversity a natural, unmodified chalk stream should display. In the absence of semi-natural chalk stream habitats from which reference conditions can be determined, the Water Framework Directive specifies the use of palaeoecological information (Logan and Furze 2002). However much of this research is focussed on interpretations of human activity or climatic reconstruction rather than on the specific determination of river form and associated habitats (Davies and Griffiths 2005; French and Lewis 2002). Despite this, it is possible to reconstruct some information of relevance to characterising the floodplain habitats associated with relatively undisturbed chalk streams and rivers.

French and others 2005 report a complex suite of landscape changes in the Dry valley and upper reaches of a chalk stream in Dorset. Their results suggest the presence of a relatively wide shallow low sinuosity meandering channel throughout the Holocene into the early historic period, between 30 - 50m in width and 1.5 – 3m in depth with a width:depth ratio of between 10 and 33. The authors stress that the development of each chalk valley is best considered individually rather than to expect a common history of landscape evolution hence the precise form of the channel system and floodplain habitats is also likely to be valley specific. Davies and Griffiths (2005) report on the alluvial history of the lower reaches of the River Test. These reveal extensive deposits of calcareous tufa, associated with upwelling groundwater in the Early to Mid Holocene (6050-9500 BP) and again a large palaeochannel (50-80m width and up to 5m depth with high width:depth ratio of 13-16. The accumulation of fine inorganic sediments is relatively low at both sites compared to other valley systems. Instead the deposits are dominated by Pleistocene river gravels, overlain by a sequence of peat and tufa capped by more recent silt-clay alluvium.

The evolution of floodplain habitats at both sites share some commonalities with incursions of open woodland (Willow, Alder) into a wet floodplain with freshwater flooding and groundwater upwelling. The complexity of the habitat is noted by both studies, suggesting that local groundwater upwelling is associated with standing pools on the floodplain surface, interspersed by more alluvial flooding and drier areas colonised by wet woodland. Phases of drier and wetter floodplain conditions extend throughout the Holocene record the precise causes being uncertain but attributed to climatically driven changes in the extent of groundwater upwelling and fluvial flooding as well as potential influences from floodplain land management designed to keep the floodplain:valley margin open. A recent review of spring-dominated river ecosystems in relatively undisturbed catchments in Oregon also highlights the relative lack of woodland and the dominance of herbaceous species in the floodplain.

A review of the few studies that have focussed on semi-natural groundwater-dominated streams, describe the following features together with those detailed in Table A1:

- Low drainage density (limited tributary network).

- Low stream power per unit catchment area.
- Relatively large width:depth ratios (shallow and wide channel cross-sections with little variability).
- Irregular – straight channel planforms with variable sinuosity accordingly.
- Limited in-channel coarse sediment storage (bars).
- High residence time of Large Organic Matter (Woody Debris).
- Presence of woody debris islands but few debris dams.
- High floodplain water tables leading to organic rich floodplain soils.
- Low rates of lateral channel adjustment.
- Limited accumulation of fine sediments on bed surface in undisturbed catchments.
- Armouring of the bed surface (but not as well developed as runoff-dominated gravel streams).
- Tufa deposition and concretion of gravels at points of groundwater upwelling.
- Higher duration of flows at bankfull or overbank discharge compared to runoff-dominated streams.
- High density of aquatic macrophytes that facilitate flushing of fines (Francis & Bjorn 1979).
- Relatively open woodland development with dominance of herbaceous plants due to high floodplain water tables.
- Marsh habitat with open groundwater pools in floodplain where strong coupling with groundwater is evident.

Table A1: Geomorphological features associated with main UK aquifer and impermeable catchment lithologies (data from River Habitat Survey **Semi-Natural** sites (Sear and others 1999)).

Aquifer/Lithology	***Power (W/km^2)***	***Bankfull width (m)***	***Width: depth ratio***	**Riffle spacing/ bankfull width**	**Mean number VSSF / 500m**	**Mean number DSSF / 500m**	***Sinuosity***	***n***
Chalk	**6.1 (17.8)**	**8.7 (4.4)**	**18.4 (14.0)**	**51.0**	**0.1**	**0.1**	**1.29 (0.47)**	**21**
Soft Limestones	15.6 (31.6)	7.7 (4.5)	11.0 (7.1)	27.2	0.8	1.0	1.24 (0.41)	15
Permo-Triassic Sandstone	6.8 (13.9)	10.8 (8.3)	9.2 (6.3)	20.9	0.6	0.6	1.25 (0.24)	24
Clay	6.3 (19.3)	6.1 (3.8)	7.8 (5.4)	31.0	0.4	0.5	1.31 (0.33)	29
Hard limestones	72.1 (236)	9.2 (7.9)	11.7 (8.5)	15.4	0.7	1.2	1.22 (0.26)	35
Impermeable lithology	25.4 (81.8)	10.3 (10.6)	10.0 (9.3)	15.1	1.4	1.5	1.20 (0.25)	352

Figures in brackets are standard deviations of the sample population.
VSSF = Vegetated sediment storage features (point bars, mid channel bars and side bars)
DSSF = Dynamic sediment storage features (point bars, mid channel bars and side bars)

There is an intuitive discrepancy between the presence of high width depth ratios, and a lack of sediment storage and high sinuosity, since both create conditions for sediment accumulation. Whiting & Moog (2001), associate this condition with an absence of sediment available for transport, largely arising from limited headwater catchments (their streams largely rose from discrete springs) and a lack of active bank erosion. However, another explanation could be the lack of available energy for bedload transport. In many chalk rivers, a combination of relatively low bankfull discharge capacity and shallow valley gradients results in low bankfull stream power. Stream power is a measure of the energy expenditure per unit area of river bed, available to transport sediment. Low stream power relative to the size and packing of the bed material results in a static bed, and therefore limited opportunity for the development of bars. In chalk rivers (and in other Spring-dominated systems), a armouring of the gravel bed, and concretion of the substrate by calcareous deposition (tufa) may further constrain bedload transport. Instead, sediment storage is dominated by the passage of fine silts and sands that are stored in zones of relatively low stream power; for example, the long reaches of glide/pool that characterise existing chalk river geomorphology, or in marginal deadwater areas. A final constraint on sediment transport in groundwater dominated streams arises from the relatively high flow resistance associated with the presence of in-channel vegetation and woody debris. The effect of this resistance is to reduce the energy available in the flow for sediment transport.

The emerging picture of both a sediment supply limited and sediment transport limited geomorphology in groundwater dominated rivers, is corroborated by the reported (and observed) lack of bank erosion and associated lateral channel activity (Sear and others 1999, Whiting & Moog 2001). However, observed planform sinuosity appears to contradict this observation. Brown (1996) outlines a model for lowland river evolution that commences with relatively high energy systems during the last deglaciation (10 – 11kBP) with braided and meandering planforms, that subsequently become fossilised in the early Holocene by fine sediment accumulation – in part the product of land clearance. Thus one interpretation of the sinuous planform of chalk streams is that they are "fossils"; remnants developed under higher energy (increased discharge) conditions in the early Holocene.

The high width:depth ratios reported for semi-natural groundwater-dominated and chalk streams requires explanation. In theory, high width:depth ratios are typically associated with channels that are capable of lateral erosion relative to bed erosion, the situation for example in braided rivers where there is a high rate of sediment supply as bedload. This is clearly not the situation in groundwater dominated and chalk rivers. Instead it is possible to advance a model whereby the relatively long duration of near bankfull flows has sufficient capacity to progressively erode the organic rich and moist bank sediments, while lacking the ability to erode the bed substrate. Channel widening, in such conditions, is progressive over time, not episodic such as one observes in runoff dominated rivers. The high w:d ratios reported from semi-natural groundwater-dominated rivers in the US and recorded for the UK River Habitat Survey is not supported by Dangerfield (1999). This study surveyed bankfull cross-sections for a range of channels with different hydrology and bank materials. The data demonstrates that in the presence of cohesive silt/clay bank material chalk streams are characterised by low w:d ratios (Figure A1). This latter observation can be explained since the presence of a bank of low erodibility in a channel of low erosivity will result in minimum bank erosion and hence limited capacity for channel widening. The model for channel morphology is clearly dependant on the nature of the confining bank materials – with peaty sandy banks being associated with higher width:depth ratios and clay/silt cohesive banks being associated with lower width:depth ratios.

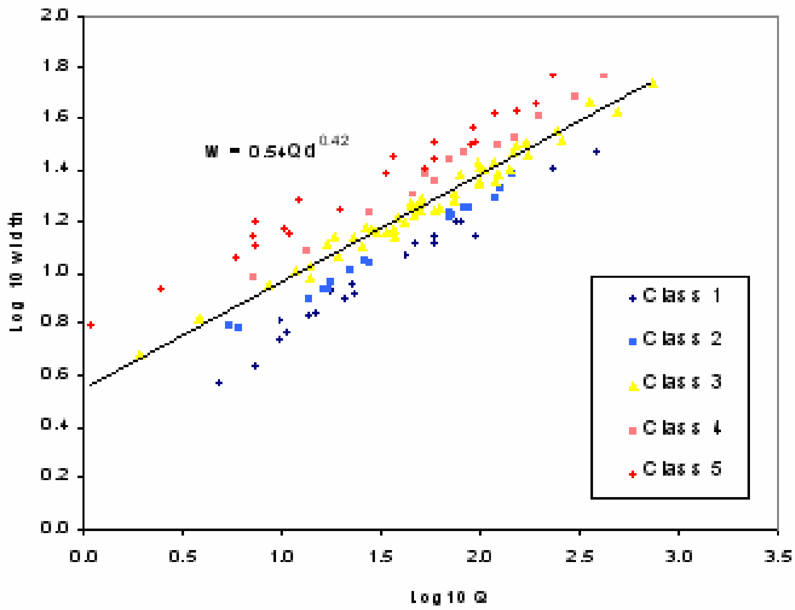

Figure A1: Comparison between chalk streams with cohesive banks and other channel types indicating the relatively narrow channels associated with limited erodibility of the banks in the presence of a groundwater dominated flow regime. Class 5 silt/sand bank materials – slumping, Class 4. bedrock dominated bed, fine materials in banks, Class 3 mixed bed or cobble bed, Class 2. sand/gravel banks dominant, Class 1. chalk streams; clay/silt banks dominate (after Dangerfield 1999).

In semi-natural groundwater dominated rivers, the presence and persistence of large woody debris from riparian tree fall, provides additional opportunities for local channel widening and channel adjustment. In fact, the presence of woody debris in a sediment supply and transport limited system probably provides the greatest opportunity for the development of diverse physical habitat. Given the limited bank erosion reported for these types of rivers, tree-fall most likely arises from wind-throw. The accumulation of woody debris in natural chalk streams is therefore likely to be episodic – a function of the frequency of high winds. However, the reported persistence of woody debris in groundwater dominated rivers, and corroborated by studies of the Bere Stream, semi-natural chalk river, results in progressive accumulation of large quantities of organic material over time (Whiting & Mood 2001) with little mobility of the large woody debris (Reiser and others 2004).

Hydrological differences between chalk streams and other run-off dominated systems are characterised by relatively shallow flow duration curves, that arise from the relatively small range of discharge. Furthermore, Sear and others (1999) have shown how chalk streams can be classified according to their Base Flow index (a measure of the groundwater contribution to the total flow regime), and the ratio of Mean Discharge: Mean Annual Flood, which is a measure of the range of flows. Chalk streams have a high BFI (>0.8 where 1.0 is a theoretical 100% baseflow contribution) and a low flashiness index. Bankfull discharge can occur for up to 20% of the time, and overbank flows in spring dominated rivers occur up to 13% of the time (Whiting and Moog 2001). This compares with more impermeable catchments where run-off is dominated by precipitation and bankfull or over occurs for around 5% of the time.

In semi-natural groundwater dominated rivers, the stage:discharge regime can be heavily influenced by seasonal macrophyte growth, which tends to result in prolonged periods of relatively high stage (Gurnell & Midgeley 1994; Reiser and others 2004). The effect of these high stages and prolonged periods of stable high discharges, is the observed saturation of floodplain soils and river banks, and the development of organic rich floodplain soils and bank material (Whiting & Moog 2001; Whiting & Stamm 1995, Reiser and others 2004). Watson, (1986) reports the effects of *Ranunculus* growth on channel roughness and unit stream power. He concluded that there was considerable local variability in the effects that *Ranunculus* growth has on the local flow regime. Watson (1986) concluded that vegetation growth tended to reduce unit stream power through a local reduction in water surface slope and current velocity. This is corroborated by detailed velocity profiling within beds of *Ranunculus* that record reductions in velocity with the plants leading to deposition and trapping of fine sediments (Clarke 2002). Macrophyte bed structure can also result in local patches of high velocity between beds of macrophytes in which the surface of the substrate is scoured of fines leaving cleaner gravels. It should be noted that this generally only affects the surface layer and fine sediments are still to be found within the gravels.

The sediment deposits within semi-natural chalk streams are presently unquantified, however general observations and theoretical assumptions suggest four broad types:

TYPE 1: those which receive few fine sediment inputs and have partially mobile gravel beds are characterised by clean surface gravel substrates and the development of weak armouring (coarser particles at the bed surface).

TYPE 2: those which lack bed mobilising flows and receive some fine sediment inputs are characterised by extensive fine sediment accumulation on the surface and within the gravel beds. Flushing of fines is limited by low stream power. Armouring is poorly developed.

TYPE 3: Theoretically but not reported, those which have low stream power and flushing but little fine sediment input would have clean stable gravel beds with little armouring.

TYPE 4: Any of the above but with strong upwelling of calcium carbonate rich groundwater have the additional characteristic of tufa concretion of the gravel bed and a fine – coarse low density tufa oncoid and fragment load that accumulates on the bed surface and within the gravels.

Milan and others (2000), Beaumont (1994), Acornley & Sear (1999) and Sear (pers obs.) report on the grainsize characteristics of disturbed chalk stream bed sediments. These are associated with among the highest levels of fine sediment within the gravels of any river type and are strongly correlated with low stream power and hence flushing capability.

In summary, the geomorphology of chalk streams would appear to be associated with:

1) Relatively low drainage density reduces the opportunity for sediment delivery from the catchment, but also makes new routes (eg drainage channels, ditches, roads, tracks) more important.
2) Inherited planform, gravel bed and bed morphology creates a system that is highly sensitive to modification, since in the absence of coarse sediment supply, once lost, morphology cannot be easily regained through natural erosion:deposition processes.

3) Supply limited and transport limited coarse sediment loads results in a relatively impoverished (but natural) geomorphology, with few riffles and bars forms typical of more dynamic sediment systems.

4) Stable, armoured bed sediments often with concretion further limits the transport of bed material and results in a shallow, open-work gravel framework for salmonid spawning that is sensitive to siltation.

5) Absence of high magnitude flood events of sufficient stream power to modify the bed and bank morphology. Chalk streams are most sensitive to rain on frozen ground to generate geomorphologically effective floods.

6) Relatively wide:shallow channels associated with organic rich floodplain soils, narrower channels where bank materials are of cohesive nature.

7) High and stable flow regime, influenced locally, by hatches, diversions, abstraction and macrophyte growth – this results in locally high water tables in the floodplains, and channel dimensions that relate to higher frequency flows than other run-off dominated channels.

8) Persistent accumulations of large woody debris, with low rates of mobility leading to isolated tree falls and island accumulations of smaller mobile coarse woody debris.

The river management implications of these characteristics are summarised below:

1) Chalk rivers will be highly sensitive to relatively small increases in sediment loads. Catchment scale evidence for fine sediment sources and the relative absence of bank erosion suggests these will be mostly fine sediments derived from the land**. Routes from the land into the river network are prime targets for reducing sediment delivery**.

2) Fine silts and clay sediments are conveyed readily throughout the system by the relatively long duration of high in-bank flows. This results in strong coupling between the upper catchment and the rest of the river system. **Local catchment sources will therefore have widespread impact and reductions in channel flows through climatic or human abstraction will increase the residence time of fine sediments within the river network**.

3) The geomorphology and physical habitat diversity of chalk streams will be highly localised and sensitive to local controls (ie hatches, weirs, debris fall, planform variation etc**.). This creates a system that is best managed for sediment supply at the catchment scale, and for physical habitat at the local scale**.

4) Fine sediments will be a feature of contemporary chalk streams because of increased catchment sources, and will occupy areas of relatively low velocity – bank margins (berms), weed beds, upstream of hatches etc. Removing these opportunities will encourage flushing of fines through the system. **Manipulation of channel structure is a sustainable way of manipulating the location of fine sediment in the system**.

5) Aquatic macrophytes increase flow resistance and decrease energy available for sediment transport. They trap and temporarily store fine sediments and associated nutrients. Manipulation of macrophytes may therefore prove to be the most successful method of managing the physical habitat of chalk rivers.

6) Bank side trees, and associated in-channel woody debris is the most important missing element of chalk stream geomorphology and the main driver of physical habitat (and substrate) diversity. Woody debris has a high residence time in groundwater-dominated rivers and tends therefore to control flow and geomorphological processes over long timescales. Woody debris, locally creates scour and coarse sediment transport (as well as encouraging fine sediment storage) and is responsible for creating and maintaining riffle, pool and bar geomorphology. The stochastic nature of debris recruitment in a transport limited system means rhythmic spacing of features is highly unlikely.

Characteristics of semi-natural chalk streams

The literature review and analysis of existing data from River Habitat Survey provides some generic guidance on the most likely semi-natural conditions of chalk streams and rivers. It is however important to emphasize that local controls on bank erodibility, sediment delivery from the catchment, hydrology and in particular strength of groundwater coupling, will result in highly localised combinations of floodplain habitat and channel form. Echoing French and others 2005) each chalk river valley is best viewed as an individual case, although broad commonalities exist. This caution should be extended to the history and form of past modifications, which when layered on top of a highly localised river and floodplain habitat results in a reduction in habitat diversity that makes the specific elements of semi-natural chalk ecosystem difficult to predict.

The physical summary points 1-8 above, summarise the main characteristics of semi-natural chalk rivers that might form the basis of an assessment of the naturalness of the existing river network and a template on which to assess the need for physical habitat restoration should the target be taken as the semi-natural.

Tidal fenland rivers

In terms of the natural reference condition, the lower Nar should be recognised as a tidal influenced system with associated physical processes and habitats. Tidal rivers can be defined as the part of a river through which the tide ebbs and floods, which begins upstream at the upper limit of tidal influence, and ends where the river enters the estuary or where the channel enters into a mouth or bay (Clark and Hill 2000). Such reaches are characterised by temporal variability in salinity (ranging from 0.5 – 5 ppt at the tidal head to 30 ppt at the estuary), water depth, velocity (downstream and upstream) and sediment transport (downstream, upstream). Morphological characteristics are dependant on the power of the reach (derived from tidal and fluvial discharges) and the type and availability of sediments. Typically the bank morphology is associated with fine sediment accumulation and the exposure of silt and mud banks at the bank toe, giving a two-stage profile to the bank margins. Table A2 gives potential candidate features associated with naturalness in tidal rivers.

Table A2: Candidate elements of natural tidal rivers, after Clark and Hill (2000)

Valley Form	Channel/riparian features	Adjacent Land use
Low-lying, unmodified floodplain	Un-modified littoral zone Natural channel banks	Extensive native woodlands (broadleaved or native conifer) on both banks
Natural transition to riparian and bank zone	Natural abandoned channels Natural bank levees Riparian trees/wetlands on both banks	Extensive wetland on both banks Extensive combinations of wetland and native woodlands on both banks.

The progression downstream along a tidal river depends on the relative influence of marine and fluvial conditions which in turn determine the vegetation communities. An additional controlling element is the sediment type in transport. Cohesive clay and silt dominated river or tidal inputs generally result in narrower deeper tidal channels with more confined inter-tidal habitats (Bird 2000), whilst sand dominated tidal rivers have wider shallower cross-sections. Wetland habitats adjacent to tidal rivers have extensive reedbeds, backed by marshes with woodland developing alongside. Transitional tidal river reaches of the lower broad land rivers may be a suitable analogues in terms of major communities.

Deriving reference conditions from river habitat surveys

RHS Site Selection – Wensum and Upper Nar reference conditions

- RHS database supplied (1994-2002) = 15600 sites.
- Extracted sites where river name = Wensum or Nar and a HMI class of 1 (pristine and semi-natural) or 2 (predominantly unmodified) = 15 sites (14 on Wensum and 1 upper Nar).
- Using the standard RHS PCA1 and PCA2 scores (based on altitude, height of source, distance from source and slope) the Wensum and Nar sites were plotted over the whole RHS dataset.
- The Wensum and Nar sites produced two clear groups in the PCA plot predominantly based on a difference in slope (and as expected their distance from source). The groups were thus labelled as 'Upstream' (sites with slopes 0.8-1.5) and 'Downstream' (slopes 0.5-0.79).
- A square selection tool centred on each group extracted ~1200 sites around the upstream group and ~730 sites around the downstream group.
- These two datasets were then filtered on solid geology (code 106 = chalk), a HMI class of 1 and slopes in the ranges of the upstream and downstream Wensum and Nar sites = 40 upstream reference sites and 28 downstream reference sites.

The characteristics of the sites within these resultant datasets provide an insight into the reference condition of the Wensum and Upper Nar. The sites were analysed to characterise their geomorphology using the fields available within the RHS database.

Outputs:

1) PCA plot – distribution of filtered sites within PCA plot (Figure A2).
2) Location Map – distribution of filtered sites within the UK (Figure A3).
3) Table of filtered sites characteristics from RHS database fields (Table A2).

RHS Site Selection – Lower Nar reference conditions

- RHS database supplied (1994-2002) = 15600 sites.
- Extracted sites where river name = Nar (2 sites located on Lower Nar with a HMI class of 4 – significantly modified).
- Using the standard RHS PCA1 and PCA2 scores (based on altitude, height of source, distance from source and slope) the Nar sites were plotted over the whole RHS dataset.
- A square selection tool centred on the two sites extracted ~480 sites.
- These data were then filtered on a clay solid geology (codes 97, 98, 99, 103, 108 = Oxford, Ampthill, Kimmeridge, Weald, London Clays), a HMI class of 1 and slopes < 0.5 = 6 sites.

Outputs:

1) PCA plot – distribution of filtered sites within PCA plot (Figure A4).
2) Location Map – distribution of filtered sites within the UK (Figure A5)
3) Table of filtered sites characteristics from RHS database fields (Table A2)

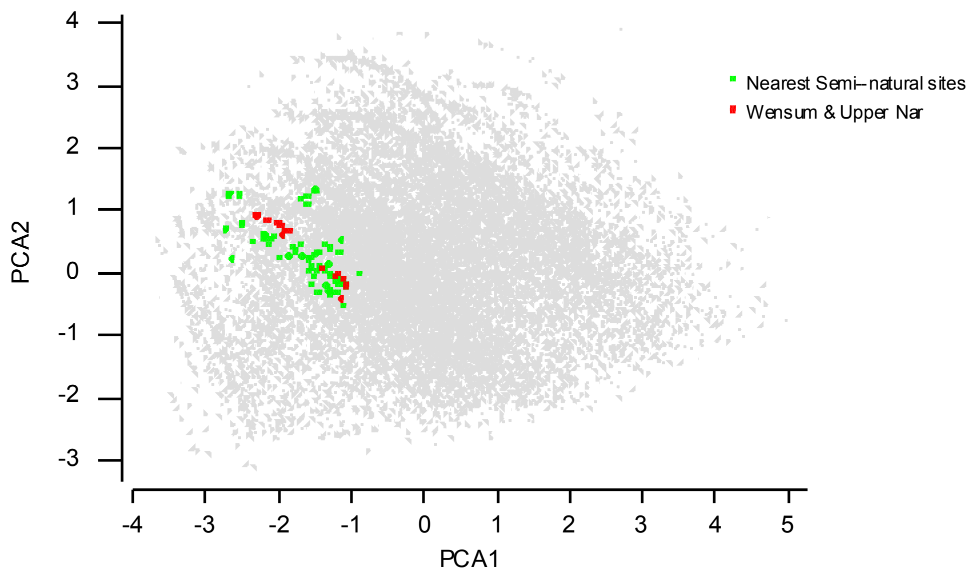

Figure A2 PCA plot – distribution of filtered sites within PCA plot (Upper Nar)

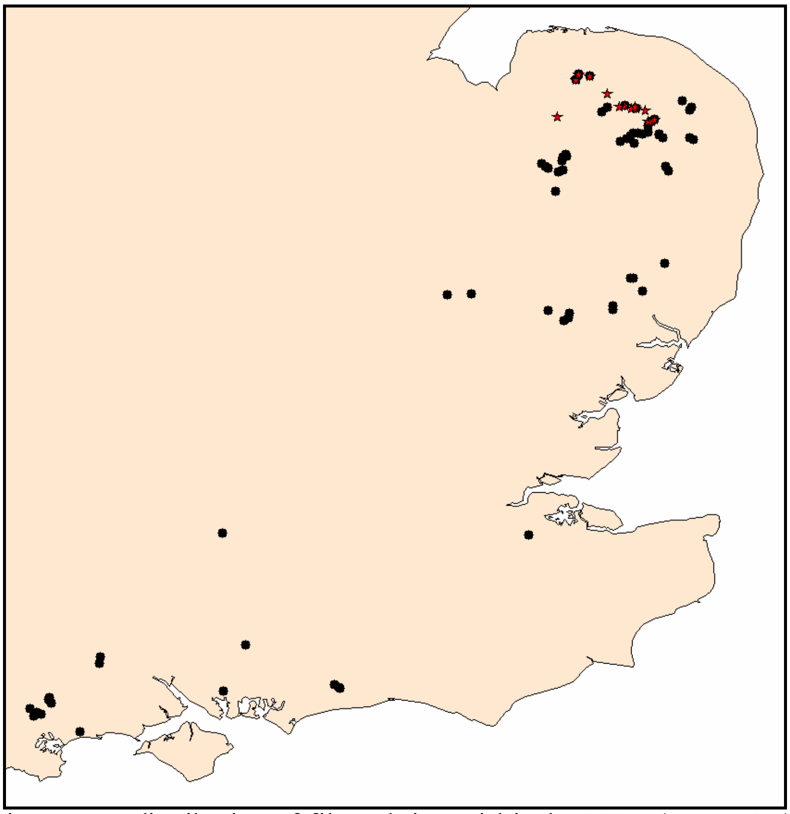

Figure A 3 Location Map – distribution of filtered sites within the UK – (upper Nar)

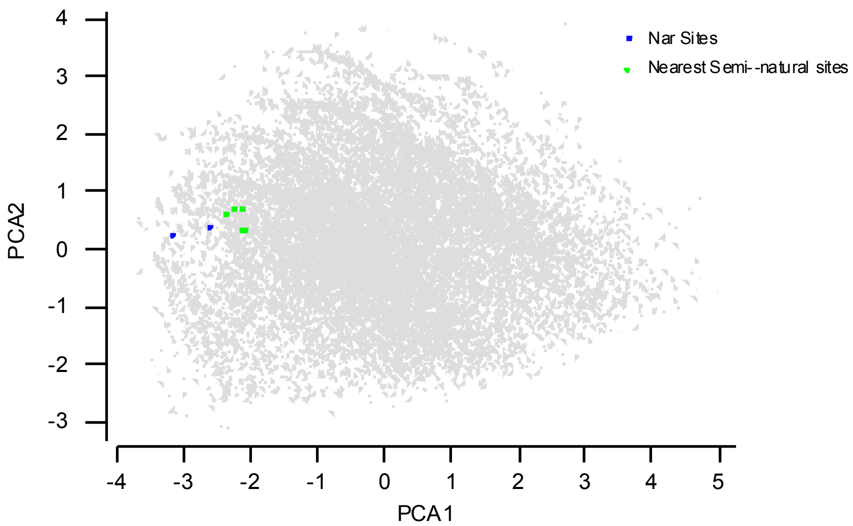

Figure A4 PCA plot – distribution of filtered sites within PCA plot (lower Nar conditions)

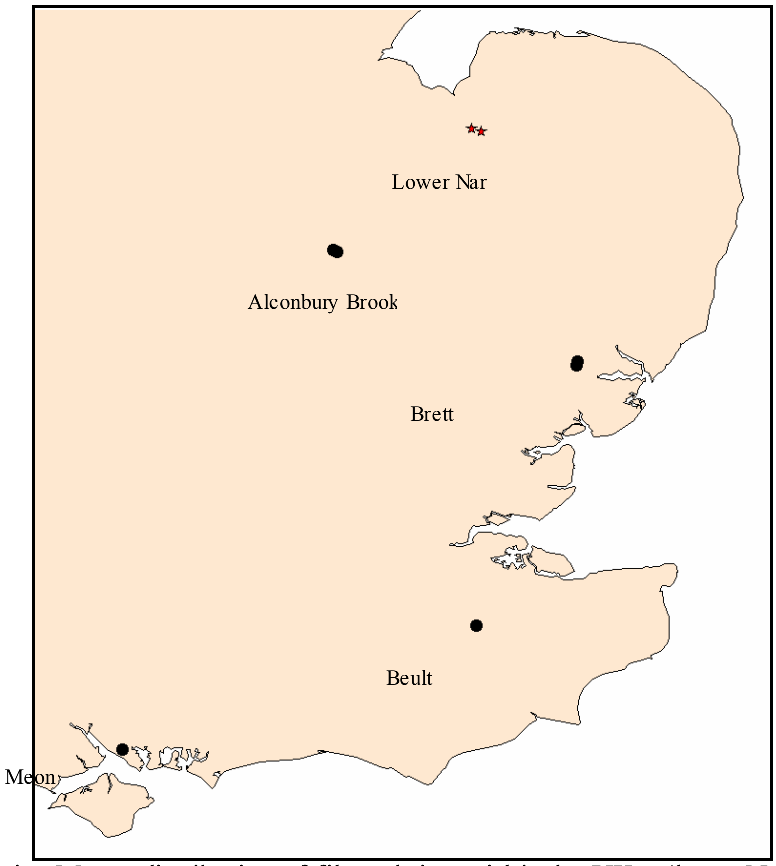

Figure A 5 Location Map – distribution of filtered sites within the UK – (lower Nar conditions)

Table A2: Physical characteristics of natural chalk streams.

CHALK RIVER	Planform	W:d ratio	Cross-section form	Substrate	Pool-Riffle Features	Dominant Flow Types	LWD accumulations	Depositional features	Erosional Features	Macrophyte structure	Floodplain Community
Cohesive silt/clay banks (UPPER NAR)	Irregular meandering Local sinuosity up to 1.3.	<10	Rectangular – steep shallow banks with wide gravely bed	Weakly armoured gravels with fine sediment abundance determined by geology and ability to mobilise bed sediment	Few No rhythmic spacing except on steeper slopes. Location controlled by scour around large woody debris and tight meander bends.	Run/Glide	YES – persistent, – isolated trees perpendicular to flow and smaller CWD accumulations as islands and small dams	Few – isolated fine gravel and sand as point bars and mid channel accumulations downstream of large woody debris islands.	Limited erosion of out banks in bends and opposite large woody debris.	Locally abundant and strongly controlled by shading. Can block channel in summer.	High floodplain water table with dominance of herbaceous wet tolerant communities. Patchy wet woodland. Standing pools of groundwater where springs upwell.
Non-cohesive peat/sandy banks **(Middle & Lower NAR)**	Irregular meandering Local sinuosity 1.2-1.3	10-18	Rectangular – steep shallow banks with wide gravely bed.	Weakly armoured gravels with fine sediment abundance determined by geology and ability to mobilise bed sediment. Fine sediment likely to be more abundant in higher w:d ratio streams	Few - no rhythmic spacing except on steeper slopes. Location controlled by scour around large woody debris and tight meander bends.	Run/Glide	Yes persistent, no dams – isolated trees perpendicular to flow and smaller CWD as islands and small dams	Few – isolated gravel and sand point bars and mid channel accumulations downstream of large woody debris islands	Limited erosion of out banks in bends and opposite large woody debris.	Locally abundant and strongly controlled by shading. Can block channel in summer	High floodplain water table with dominance of herbaceous wet tolerant communities. Patchy wet woodland. Standing pools of groundwater where springs upwell.

Appendix 6 River Nar: geomorphological audit survey form

Catchment		River		Reach Code	
Date		Surveyor		Survey conditions	

Photo code	Orientation (°)	Description

Reason for reach change	BK	BD	XS	PL	GR	AR	VG	CF	EM	TR
Description: -										

Bankfull height (m)	L		R		**FP width (m)**	L		R		**FP connected (Y/N)**	
Flow condition	Low flow		Med flow		High flow					**Riffle/run water depth (m)**	
Planform	Straight		Wandering		Meandering		Braided			**Bankfull width (m)**	
Modification	Realigned		Impounded		Over-deep		Over-widened		Resectioned	**Water width (m)**	

Dominant Bank Features

	L	R		L	R		L	R		L	R
Bank vegetation cover (%)			**Woody (%)**			**EM Length (%)**			EM Height (m)		

		L	R		L	R		L	R		L	R		L	R
Dominant bank material (D/✓)	Clay			Earth/alluvium			Sand			F. gravel			C. gravel		
	Cobble			Boulder			Bedrock								
	S. piling			W. piling			Brick/laid stone			Concrete			Gabion		
	Rip-rap			Fabric			Bioengineer			T' debris					

		L	R		L	R		L	R		L	R
Bank cohesiveness (D/✓)	Artificial			Cohesive (clay/bedrock)			Moderate (clay loam)			Poor (sandy loam)		
Bank sorting & structure (D/✓)	Sorted			Unsorted			**Composite (D/✓)**			**Uniform**		
Dominant erosion process (D/✓)	Fluvial			Geotechnical			Subaerial			Burrowing		
	Poaching			Structural Failure			Human cause			Stable		

		L	R		L	R		L	R		L	R
Condition of Toe	Accumulating			Steady			Undercutting			Unknown		
Veg at toe	None			Sparse			Dense					
Age of veg at toe	Young			Mature			Old					

Acceleration of process Y/N	Footpath		Bank/bed manage't		Fishing		Woody debris	

Evidence of Incision Y/N	Exposed tree roots		Undermined structures		Deep gravel layer at base of bank		Bare armoured bed		Terraces		Old Channels	
Evidence of Aggradation Y/N	Floodplain dep'n		Buried Structures		Buried toes of vegetation		Recent channel dep'n		Large uncompacted & unvegetated bars			
Evidence of Stability Y/N	Vegetated bars & banks		Weed covered bed									

In-channel Features / Bed

Dominant bed material (%)	Fines		Sand		F.Gravel		C.Gravel		F. Cobble		C.Cobble		Boulder		Bedrock	
Channel margin silt deposits (APE)			**Silt >20cm deep**		**Water Depth (m)**								Artificial		NotVis	

Berms (% length)	L		R		**Average Width (m)**		**Berm Veg. Cover (B/U/S/C)**		**Islands** (tally)	
Bed veg. type (D/✓)	Mosses etc		Emergent BL		Emerg NL		Floating Leaved (rooted)		Free Floating	
Bed veg. cover (% chart)			Amphibious		Submerged BL		Sub LL		Sub FL	Filamentous algae

Ranunculus comm. cover (D/✓)	NV		None		Isolated		Regular		Semi-continuous		Continuous	
Dom. species in community (D/✓)	Callitriche		Ranunculus		Potomogeton		Bryophyte					

Crayfish: Boulder / C. Cobble clusters overlying finer substrate (A/P/E)		**Submerged refuges in steep stable banks (nat. or art.) (A/P/E)**	

Deposition:

BARS	**Boulder & C. Cobble**		**F. Cobble & C. Gravel**		**F. Gravel**		**Sands**		**Silt**	
	Stable	*Unstable*	*Stable*	*Unstable*	*Stable*	*Unstable*	*Stable*	*Unstable*	*Stable*	*Unstable*
Meso (1-10 m^2)										
Meso (10-50 m^2)										
Macro (>50 m^2)										
Macro (>150 m^2)										

Flow Types:	**D/✓**	**U/NU**		**D/✓**	**U/NU**
Waterfall (FF)			**Pool /Riffle (UW)**		
Cascade (CH)			**Glide (SM)**		
Rapid (BW)			**Ponded (NF)**		
Run (RI)			**Marginal Waters**		
No. Riffles or Rapids					

Hydraulic controls:	**No impact**	**Scour d/s**	**Pond u/s**
Weir			
Bridge			
Gauging station			
Outfall			
Sluices			
Groynes / deflector			
Mill streams			
Other			

Significant woody debris accumulations (tally):

Partial			

Invasive Species Y/N	Giant Hogweed		Himalayan Balsam		Japanese Knotweed		Other	

Catchment Influences

Sedi't source B/C/G/S/F	Bed		Bank		Tributary		Ditch / drain		Farm tr'k/gate		Ford		Urban		River cliff	
Rank order																

Floodplain land use (Record dominant and other uses within 50 metres of bank top (D/✓))

	L	R		L	R		L	R		L	R		L	R
Improved Pasture			Rough Pasture			Amenity Grassland			BL/M Woodland			Coniferous plantation		
Arable			Moor/Heath			Scrub			Wetland			Urban		
Road, track, path			Rock and Scree			Quarrying/mining			Other					

		L	R		L	R
Floodplain channels / drains	Number			Av. distance from Bk top (m)		

Riparian vegetation (Within 2 metres of bank top (D/✓))

	L	R		L	R		L	R		L	R		L	R		L	R
Bare (nat. or art.)			Sedge dominated			Light grazing			Heavy grazing			Mown			Trees/scrub		

Evidence of Management (Channel and banks Y/N)

Channel weed clearance		Desilting		**Fencing – buffer zone**			% Length		Av. Width (m)	
Other (e.g. restoration site?)										

Research Information Note

English Nature Research Reports, No 684

Geomorphological appraisal of the River Nar Site of Special Scientific Interest

Report Authors: Sear, D.A. Newson, M. Old, J.C. and Hill, C. 2006
Keywords: fluvial audit, geodynamic assessment, multi-criteria analysis.

Introduction

The River Nar was notified as a Site of Special Scientific Interest for its chalk river to fenland river transitions, but like many river systems in lowland England, has been heavily modified.

The upper river supports chalk river habitats and flows through a predominantly semi-natural floodplain. However, interventions include canalisation of the headwaters, construction of ornamental lakes, over-deepening and over-widening, and the presence of a series of weirs and mills. In recent decades, elevated levels of silt ingress have resulted from the intensive arable farming in the wider catchment.

In contrast, the lower river occupies an entirely artificial channel, having been diverted from its original course. It flows through a landscape dominated by intensive agriculture and is characterised by high flood-banks, low river gradients, and a lack of connectivity with its floodplain. As a high level carrier, there are significant issues in relation to the balance between flood-risk management, and impacts of this management on the special interest.

Upstream of its outfall, the Nar flows through King's Lynn and an industrial hinterland which is currently under redevelopment by the Nar Ouse Regeneration Area (NORA) Project. In addition, there are also proposals to develop a marina on the outfall of the river and to reopen navigation upstream to the Flood Diversion Channel.

What was done

A geomorphological appraisal was jointly funded by English Nature, the Environment Agency, King's Lynn Consortium of Internal Drainage Boards, and the Borough Council of King's Lynn & West Norfolk (the latter on behalf of EEDA and English Partnerships). The objectives of this appraisal were to provide a holistic overview of the river, to identify appropriate solutions to environmental issues, and to consider impacts and mitigation in relation to the NORA project and proposed navigation. The appraisal involved a detailed fluvial audit to establish the physical nature of the river channel, and geodynamics assessments to understand how the river functions within this channel. The report also details a new methodology designed to integrate scientific evaluation of natural geomorphological conditions with data on channel modifications. This multi-criteria analysis is used to extract a set of indices of geomorphic function and morphological condition relative to natural conditions. To assist decision making in relation to the NORA Project and the proposal to reopen navigation, the report also provides an assessment of the proposed landscaping, and the potential for compensatory enhancement work between King's Lynn and Narborough.

Results and conclusions

A reach classification is presented with comparisons against geomorphological reference conditions. This information is used to derive a set of suggested management approaches to move each reach back towards a more favourable geomorphological condition. Reach-by-reach information is summarised in the report and accompanying maps, and Geographical Information System (GIS) database. Key conclusions are:

- The geomorphology and gravel bed substrate on the upper river are a relic of past geomorphological processes.
- Once gravel beds have been removed, there is an insufficient supply of gravel to replenish these through natural processes.
- Fine sediment is mostly derived from catchment sources, with a limited contribution from bank erosion. The sand load is mobile throughout the river under flood conditions.
- The road and ditch network should be viewed as an extension to the naturally low density drainage network and managed to reduce sediment ingress.
- The perched nature of the channel on the lower river precludes embankment set back except in the reach upstream of Marham flume.
- The transition from the upper to the lower river should be regarded as a valuable ecological gradient.

English Nature's viewpoint

The Geomorphological Assessment of the River Nar Site of Special Scientific Interest is a useful baseline and gives us new insights into the form and function of the river. It gives us a valuable new tool in order to develop a strategic approach to river restoration on the upper river, but also to evaluate proposals on the lower river with regard to flood risk management and proposed developments associated with the regeneration of King's Lynn.

Selected references

SEAR, D.A., NEWSON, M.D. & THORNE, C.R. 2004. *Guidebook of applied fluvial geomorphology.* Defra/Environment Agency Flood and Coastal Defence R&D Programme. R&D Technical Report FK1914.

Further information

English Nature Research Reports and their *Research Information Notes* are available to download from our website: www.english-nature.org.uk

For a printed copy of the full report, or for information on other publications on this subject, please contact the Enquiry Service on 01733 455100/101/102 or e-mail enquiries@english-nature.org.uk

English Nature is the Government agency that champions the conservation of wildlife and geology throughout England.

This is one of a range of publications published by:
External Relations Team
English Nature
Northminster House
Peterborough PE1 1UA

www.english-nature.org.uk

Cover printed on Character Express, post consumer waste paper, ECF.

ISSN 0967-876X

Cover designed and printed by Status Design & Advertising, 2M, 5M, 5M.

Front cover photographs:
Top left: Using a home-made moth trap.
Peter Wakely/English Nature 17,396
Middle left: Co_2 experiment at Roudsea Wood and Mosses NNR, Lancashire.
Peter Wakely/English Nature 21,792
Bottom left: Radio tracking a hare on Pawlett Hams, Somerset.
Paul Glendell/English Nature 23,020
Main: Identifying moths caught in a moth trap at Ham Wall NNR, Somerset.
Paul Glendell/English Nature 24,888

CHARTER MARK
Awarded for excellence