4 Contemporary catchment management

4.1 Catchment land use and management

The management of the River Nar is influenced by the land use and land management of the catchment surface and floodplain as well as the modifications made to the channel over time. This section of the report details the main types of land use in so far as they influence the main drivers of channel geomorphology, sediment flux and water discharge (See Section 1.2). The section also chronicles the major physical modifications made to the river channel in so far as they influence the channel morphology and sediment transport regime of the channel.

Catchment land use is known to contribute to the production and delivery of water sediment and nutrients from the land surface into the river network. Furthermore, since over 90% of a river catchment is the land surface, the management and use of this surface strongly influences the nature of the river channel. In turn, the land use and land management is strongly controlled by the soil type, topography and climatic regime of the catchment. In the River Nar catchment, the presence of generally well drained loamy-sandy soils in the upper catchment and the low-lying topography and silt/peat soils of the lower Nar valley provide a land use transition. Typically the upper catchment and valley slopes have been intensively farmed for arable crops and livestock, including more recently, pig units. In the wet valley bottoms, low intensity grazing, managed further using floating meadow systems (water meadows) have dominated. In the lower Nar valley, the low gradients and presence of silt and underlying clay and peat precluded intensive arable farming until the mid – late 20th century. Until this time, land use was predominantly grazing marsh and meadow, with areas of wet fen (Silvester 1988). Figure 4.1 shows the land use classes for the Nar catchment in the 1930's. The main differences compared with the present catchment are:

- Increase in arable agriculture and horticulture in the lower Nar floodplain since the 1930s.
- Decrease in the areas of permanent grassland and heath in the upper catchment since the 1930s.
- Increase in gravel and sand extraction along the Nar valley.
- Increase in free-range pig units on sandy soils.
- Expansion of urban land use around King's Lynn and infrastructure development associated with road improvements.

Land use within the valley of the River Nar has remained relatively low intensity with exceptions in the headwaters around Mileham where arable cropping extends down to the river, and in the gravel-workings around Narford Hall. Thus the valley floor is a mosaic of wet meadows, improved and semi-improved grasslands, secondary growth wet woodland, and lakes. Defunct water meadow systems are present between Lexham and Narford.

In the lower Nar, land drainage and economics has resulted in a change in land use to intensive arable and horticultural land use around the 1970's – 1980's. The maintenance of this land use depends on the land drainage and flood protection provided by the embankments of the River Nar and the annual maintenance of the drainage system by the IDB's.

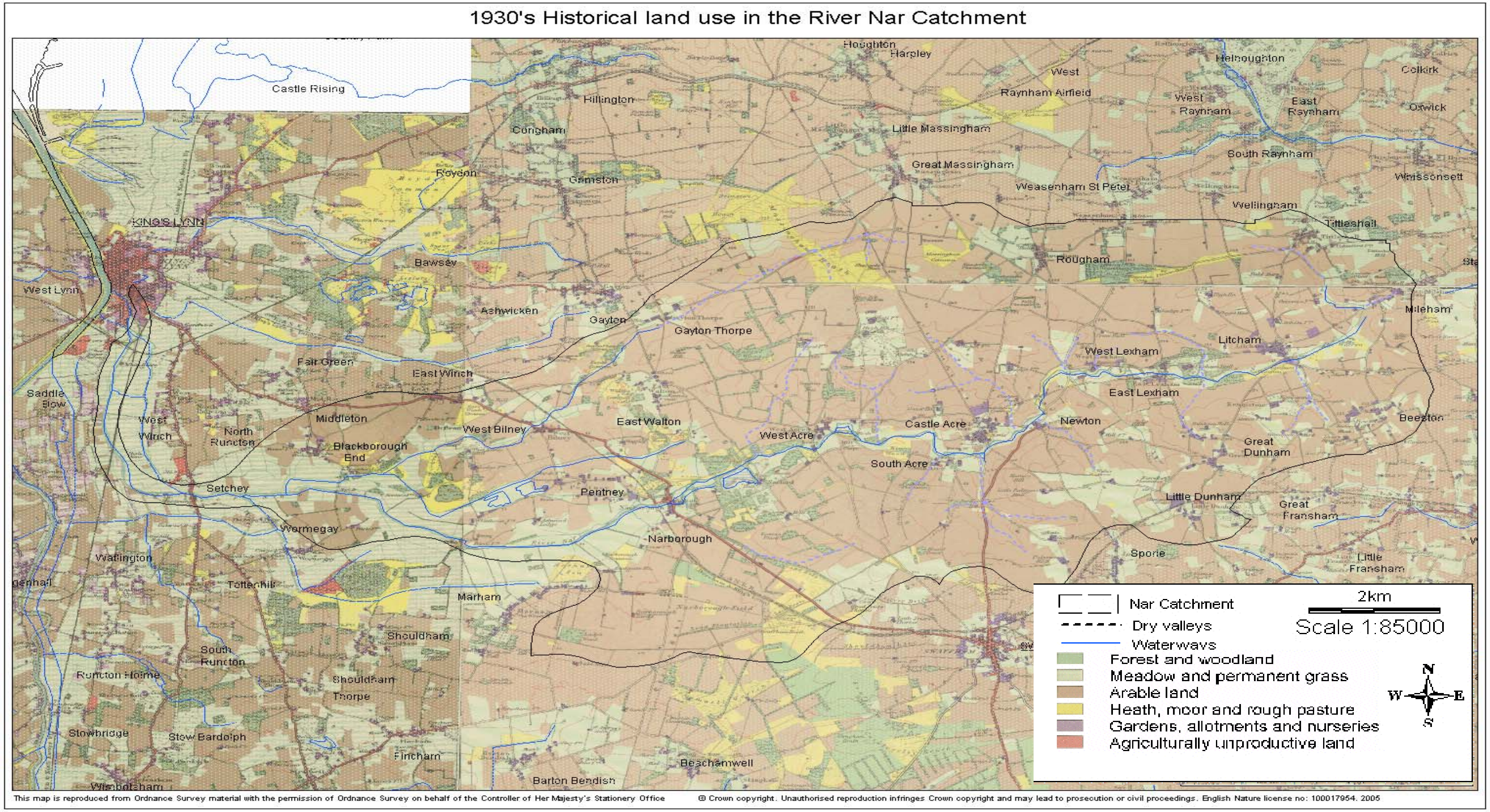


Figure 4.1: Land use in the River Nar in the 1030's (Data: Dudley Stamp land use survey of 1932).

In King's Lynn, the Nar Ouse Regeneration scheme (NORA) will affect the landscape and land use around the lower Tidal reach of the River Nar with proposed modifications to the channel bank morphology and adjacent land (Sheils Flynn 2003; Penny Anderson 2003). The implementation of the further proposal to reinstate navigation on the reaches between King's Lynn and the Flood Diversion Channel would affect the hydrology and hydraulics of the lower Nar from the Flood Relief Channel to the Tidal outfall (Environment Agency 2003).

4.2 River use and modification

An important element of any fluvial audit is the historical analysis of channel characteristics and change (Sear and others 2004, Sear and others 1995). These typically involve the use of cartographic data (Maps), long and cross-section surveys, historical documents relating to river management and photographs.

Key information derived from these sources includes:

- River planform and associated changes due to natural or human activity.
- Bankfull channel width and low flow width together with natural or human induced changes.
- Larger sediment deposits (gravel shoals and mud banks) and fords.
- Channel and floodplain structures past and present (eg water meadows, weirs).
- Location of past channels.
- Channel dimensions and slope at bankfull or other water levels.
- Broad vegetation classes in riparian and floodplain.
- Details and location of past river management.

This report attempts to link these changes to the field observations and through this process attempts to develop an understanding of the current river form and habitat. In particular, there is an assessment of the extent to which changes have resulted from anthropogenic modification or natural processes.

Assessment of the historic channel change has been conducted using historic maps dating back to 1604, OS 1st Edition maps 1:10560, and aerial photographs. The main changes occurring over that period are documented in Table 4.1 below.

Table 4.1 Spatial Data sets used in Fluvial Audit and GDA.

Documents	1604	1751	1797	1824	2000
Maps	Hayward Survey Current Course shown with more sinuous lower reaches	Kinderley Current course shown but with widened reach downstream of Setchey.	Fayden Current course shown.	OS 1st Edition Current course shown but with some meander bends in lower Nar	OS Land Line Current course shown but highlights locations of some channel realignment compared with earlier maps.

Documents	1604	1751	1797	1824	2000
Aerial Photographs	2000 Useful for corroborating land use				
Cross-Sections/Long Profiles	1967 Cross-sections between Lexham and Narford lakes. (after Harvey (1967)	2000 Lower Nar, E.A. surveyed cross-sections and long profile, Narborough Mill to Tidal flap.			

Modifications to the River Nar have been undertaken over much of the length of the river for over 1000 years (Silvester 1988). Modifications within the Nar catchment take the form of:

- Physical alteration to the course and dimensions of the river channel (eg straightening, widening).
- Changes in the connectivity between the river and the floodplain (eg embanking, water meadows).
- Removal of the bed substrate (eg gravel removal, desilting).
- Control of aquatic and riparian vegetation.
- Alterations to the water levels within the channel and downstream movement of sediment (mill weirs, sluices).

The management of the River Nar and its tributaries is under the jurisdiction of three separate bodies. The Environment Agency is responsible for the management of the 'main channel' between King's Lynn and Narborough. The Upper Nar Internal Drainage Board (a member of the King's Lynn Consortium of Internal Drainage Boards) is responsible for river maintenance from its source, down to Narborough. The East of Ouse Internal Drainage Board is responsible for the management of the Country Drain, the Black Dyke and the Trout Stream.

There are continuous rolling programmes of channel maintenance undertaken by the Upper Nar IDB and the East of Ouse IDB in the network of gravity and pumped 'main drains'. Further programmes of maintenance are undertaken by the Environment Agency in the lower Nar to maintain flood risk management and the effectiveness of the drainage schemes. These take the form of desilting operations and an annual programme of weed cutting.

Silvester (1988) suggests that the northerly course of the lower Nar might be an artificial cut made by the monastic land owners in the early medieval period. Prior to this period the River Nar flowed straight into the Great Fenland River near Wiggenhall St German. Whether this is artificial or not, the monastic houses and associated settlements are reported to have built flash locks and improved navigation of the River Nar in order to bring in building materials up as far as Castle Acre (Babtie Brown & Root 2003 – Archaeological Report Appendix 8). Prior to the late 19th century, all river modifications would have been constructed by hand.

Maps pre-dating the navigation are not accurate but they show the former course. The 1604 Haywards map shows the River Nar to follow approximately the same course as the current channel, though with some suggestion of a more sinuous planform between Setchey and King's Lynn (Figure 4.2). Similarly, the 1797 Faden map shows the former course of the River Nar as more sinuous but similar to the course shown on the 1824 OS 1st Edition survey. The main changes appear to be the artificial cut off of a large double meander bend located downstream of Setchey. Adjacent land use is referred to as "Common" or "Fen" in the 1797 Faden map, whereas by 1824 this land is depicted as a much more enclosed landscape of fields. The Puny drain is shown on both maps.

The planform of the lower Nar shown on the 1751 Kindersley map (cited in Darby 1940) shows a wider channel downstream of Setchey Bridge (Figure 4.3). This may indicate early attempts at navigation which at that time were under development, or reflect the location of the tidal limit.
An important modification to the lower Nar occurred with the creation of the River Nar navigation. http://www.norfolkmills.co.uk/Watermills/narborough.html (accessed Oct 2004) summarises the Nar Navigation:

"In 1751 an Act of Parliament authorised the "...making of the River Nar navigable, from the Town and Port of **King's Lynn, to West Acre** in the county of Norfolk." The navigation opened in 1759 and was used to bring in coal, grain and bones from King's Lynn by horse drawn lighters or barges. Return cargoes included sand and gravel from Pentney pits and bonemeal fertilizer from Narborough Bone Mill.

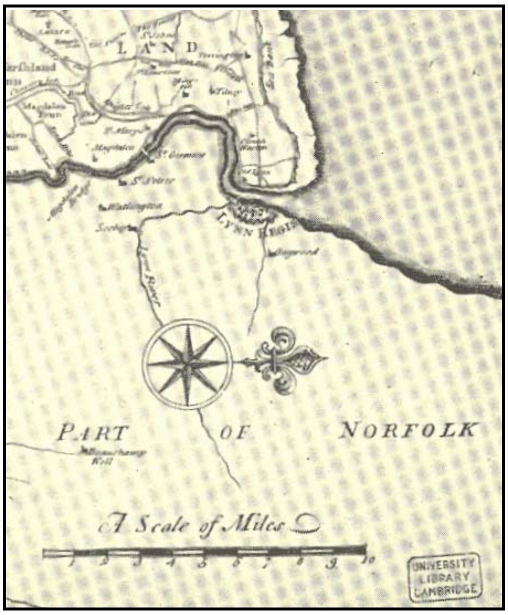


Figure 4.2: Planform of the River Nar in 1604 (Badeslade, 1725) prior to the major drainage schemes of Vermuyden and the navigation of the lower river to Narborough. The general course of the river is similar to present, suggesting that the instigation and engineering of the northerly course into King's Lynn took place at some point during the medieval period.

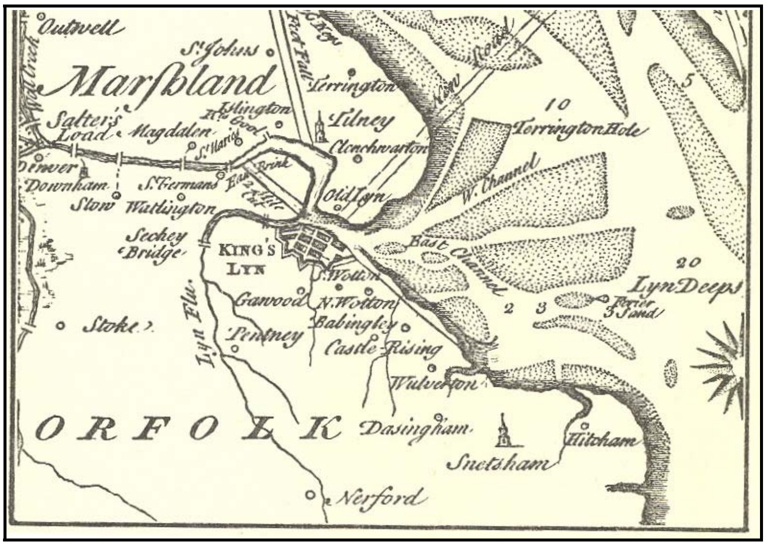


Figure 4.3: Planform of the River Nar in 1751 after the major drainage schemes of Vermuyden, the Eau brink cut and the commencement of navigation.

In http://www.norfolkbroads.com/interest/rivernar.html (accessed Oct 2004) John Worral reports that the River Nar was made navigable up to Narborough in 1759, using a system of **straightening and locks, with a basin (presumably) to supply water at West Acre**. Further reference to this navigation continues:

'Whether navigation ever actually went above Narborough is debatable but there were two short branches lower down, one to Wormegay - now empty - and another to Blackborough Priory. But the complete Nar system included only one pound-lock, still visible beneath the A47 at Narborough. Ten staunches were built in the five miles below Narborough, all but one of them apparently of the water-profligate guillotine type'.

There is some confusion as to when the Nar navigation ceased to operate. Two websites accessed suggest that the construction of the sluice at King's Lynn in 1889 closed the River Nar to navigation, but http://easyweb.easynet.co.uk/jim.shead/History18.html (Accessed Oct. 2004) report that it was still navigable up until 1932. Presumably, access from the Great Ouse ceased at the earlier date, whilst inland navigation within the "closed" channel continued until later. What is clear is that the result of the navigation was the control of water levels by artificial structures, the straightening of a series of bends, and the widening and possibly dredging of the river to receive barge traffic.

The main periods and types of modification are listed in Table 4.2. These are not comprehensive, but illustrate the extent and type of modifications made to the River Nar. Further details of the modifications are contained in the GIS database and maps accompanying this report. What is important to recognise is that although the lower Nar follows a course established in medieval times, it has been modified and continues to be maintained in a modified condition. This subdues the action of natural processes within these reaches of the river. However, the drivers on the upper river are quite different. On these sections of the river, a long history of channel and floodplain management has resulted in the modification of significant lengths of the river, either to improve drainage or to provide the head to driver the mills. Thus although the river is widely recognised as a good example of chalk river, it is in fact in a largely modified state.

Table 4.2 Channel modifications recorded on the River Nar (Brookes 1983) and Environment Agency/King's Lynn IDB Consortium updates.

Channel modification reaches	Date	Type
Setchey Bridge to King's Lynn	Post 400 - Pre 1500	Change of course to follow present northerly route to King Lynn.
Upper Nar Litcham - Narborough	1100 -	Mill channel creation. Channel straightening. Creation of water meadow systems.
West Acre – King's Lynn	1751-1884	Lower Nar Navigation: Bend straightening, widening and deepening, embanking, water level control using staunches/locks.
King's Lynn	c.1884	Creation of sluice and effective end of Ouse/Nar navigable connection.
Narford, West Lexham	c. 18th-19th Century	Creation of ornamental lakes and sluice structures for estates.
Upper Nar	C19th- C20th	Channel realignments for land drainage, embanking of isolated reaches, dredging of cross-sections (Narford reach), widening of channel.
Narford Lakes, South Acre sandpits	1940's-1990's	Gravel extraction in floodplain creates series of artificial lakes adjacent to straightened channel.
Lower Nar	1950's-90's	Embanking, regular desilting, weed cutting.
Nar/Ouse confluence at King's Lynn	1988	Nar tidal flap installed.
Lower Nar	2001	Flood Relief channel & flood storage area at High Bridge completed. Much of the embankment strengthening.
Upper Nar	- present	IDB 10 yr rolling programme of berm "turnback") and weed cut. Fisheries enhancement structures (riffle creation, hurdles and channel narrowing).
Lower Nar	- present	IDB drains maintained on annual basis – desilt. Lower Nar: 2 weed cuts downstream of Setchey bridge, 4 per year upstream of Setchey: Desilt on needs only basis since 1990. Fisheries enhancements in Narborough – Marham reach – riffle creation, groynes, narrowing.

To determine the level of modification along the Nar, a Multi-criteria assessment was carried out using all available data on modifications. First the modification data was digitised and mapped within the GIS. This included information on past modifications (eg Navigation, Mills, lakes) and current maintenance operations (eg data from the KLC IDB GIS database). Each modification was classified in terms of the severity of impact on the channel and then the total number of modifications for a reach was summed to provide a modification level (1-5 where 1 = least modified and 5 = artificial). Out of a total of 76 geomorphologically defined reaches, only 8 did not show any documented signs or minor modification. This was reduced to seven after cross-referencing with photographs of the reach giving a total of 4.79km or 11.2% of the total river length. The least modified reaches extend from the A1065 at West Lexham to the ford at Castle Acre with a short section of unmodified channel at TT852170 and a longer reach (1.035km) at Warren Farm, West Acre. Upstream of the A1065 the reaches are categorised as moderate to high modification. Downstream the reaches through Narborough to King's Lynn are classified as highly modified on the basis of channel realignments, maintenance regimes, evidence of re-sectioning and Navigation. None of the lower Nar is categorised as less than highly modified.

In summary, the River Nar is a modified watercourse with the least modified reaches occurring in the Chalk stream geomorphological Type 2 typology (see Table 3.2). All other channel types are modified with most in the moderate-highly modified classes. The status of the channel is therefore largely in less than favourable condition with regards to morphology and physical processes.

4.3 River conservation status

The River Nar, from Mileham to the Tidal sluice at King's Lynn has been notified as a Special Site of Scientific Interest. The boundary takes in the river and its banks up to the first break in slope, but also includes adjacent land where this supports semi-natural vegetation which is in hydrological continuity with the river. The river lies within the Fens and North Norfolk Natural Area and North West Norfolk and Fenland Character Area that recognise the landscape and geological controls on the environment. The Norfolk Biodiversity Action Plan (BAP) includes relevant target habitats including chalk rivers, reedbeds and floodplain/grazing marsh. The Fens are considered to be a National Priority Habitat though locally this status is degraded by intensive agriculture (Environment Agency 2000). The statutory and non-statutory drivers for river conservation and restoration of the River Nar are summarised in Table 4.3.

During the course of this contract, English Nature and the Environment Agency have been working towards the development of a national strategy for the restoration of physical and geomorphological favourable conditions on river SSSIs (Mainstone per comm. 2005). It is vital to understand this report within the context of this strategy. Under the proposed strategy a series of stages are followed leading to an agreed "Action Plan". Specifically on each river SSSI, the strategy will:

- Undertake a geomorphological assessment, using fluvial audit where necessary, to identify problem areas.
- Establish common standards monitoring sites (where RHS data will be used) on problem areas identified by Fluvial Audit.
- Set Favourable Condition targets for physical habitat.
- Map flood risk constraints to physical restoration.
- Determine the physical measures required to attain favourable condition across the whole site.
- Identify mechanisms and funding streams available/required to deliver these measures and map these spatially.
- Seek agreement with landowners and other stakeholders over willingness to accept physical changes if implementing mechanism can be secured.
- Draw up an agreed action plan according to consultation with landowners/stakeholders, secure the necessary implementing mechanisms, and schedule the works.

- Judge the action plan and schedule in the context of an assessment of "unfavourable recovering".
- Deliver the action required.
- Monitor to assess changes in condition and the effectiveness of the measures adopted.

Fluvial Audit and Geomorphological Dynamics Assessment are not designed to determine detailed restoration plans, but are the recognised method for determining the optimum channel form necessary to support the **physical habitats** of a river SSSI.

Table 4.3: Statutory and non-statutory conservation drivers of conservation and restoration for the River Nar.

Statutory/non statutory drivers	**Conservation target**
SSSI Designation	The conservation objectives for this site are, subject to natural change, to maintain the river and stream habitats in favourable condition, with particular reference to any dependent component special interest features (habitats, vegetation types, species, species assemblages etc.) for which the land was notified as an SSSI. In order to achieve this conservation objectives will need to be met in relation to the following criteria: Habitat function, including water flow and water quality; Habitat structure, including river substrate, channel and banks; Plant communities including species composition and abundance, reproduction; Negative indicators including native, alien and introduced species; In-stream barriers; and Indicators of local distinctiveness. Where artificial modifications have occurred - such as weirs and impoundments, embankment, straightening and dredging – the restoration of natural channel profiles and dynamics is desirable where appropriate. Opportunities should be taken to create additional riparian areas where flooding is acceptable, in order to reconnect the river with its floodplain. It is recognised that much of the lower River Nar has been disconnected from its floodplain; is in effect a high level carrier; and needs to be managed within certain flood-risk parameters. However, the transition from a chalk river to a fenland river is recognised as a valuable ecological gradient, and management regimes designed to achieve the necessary flood risk parameters should be implemented so as to maximise the conservation value of these river reaches. On river reaches where practical and feasible, this should include the setting back of flood banks. Terrestrial compartments should continue to support semi-natural vegetation, should be hydrologically linked to the river, and should be managed in a manner that does not compromise the special interest of the site. NB. Under Section 28G of the Wildlife and Countryside Act 1981 (as amended), public bodies must "take reasonable steps, consistent with the proper exercise of their functions, to further the conservation and enhancement of SSSIs.

Statutory/non statutory drivers	**Conservation target**
UK BAP	The objectives of the UK National Chalk Rivers Habitat Action Plan are: • Maintain the characteristic plants and animals of chalk rivers, including their winterbourne stretches. • Restore all rivers notified as SSSI to favourable condition. • Restore important non-SSSI rivers to favourable condition. There are a large number of national/Norfolk Habitat and Species Action Plans relevant to the River Nar and its floodplain, including those for chalk rivers, floodplain and coastal grazing marsh, reed-bed, fen, otter, water vole and Desmoulin's whorl-snail. All these SAP/HAPs have targets and objectives (www.norfolkbiodiversity.org)
North Norfolk Natural Area Profile (Relevant in relation to the upper River Nar).	• Identify and promote flows necessary to sustain geomorphological and ecological interest of the system. • Identify, maintain, enhance, and restore both natural and man-made riverine features which provide ecological and conservation interest. • Ensure protection, enhancement and restoration of habitat features during the design and implementation of flood risk management schemes. • Restore arable land adjacent to rivers back to pasture to reduce silt loading and improve habitats. • Manage associated dyke systems on a regular but not intensive regime.
The Fens Natural Area Profile (Relevant in relation to the lower River Nar).	• Sympathetic management of all ditches, drains and rivers for the benefit of wildlife. • Develop effective water level management for all wetland sites. • Ensure all wetland sites have sufficient water of the right quality to sustain their wildlife interest. • The restoration of at least 1 river system, with re-instatement of flood plain grasslands, meanders etc. • To ensure that water voles are present throughout their 1970's range by 2010. • The restoration of riverine habitats so as to make the area suitable for the otter to become a common sight.
Environment Agency / Internal Drainage Boards	• Sustain, and where appropriate, enhance or restore the habitat diversity within the water environment. • Provide an environmental assessment and recommendations to ensure the maintenance and enhancement of conservation interest when implementing flood risk management. • Develop and implement Water Level Management Plans.
European Water Framework Directive	• Take appropriate measures to ensure water bodies attain Good Ecological Status by 2015. • Establish a Programme of Measures to ensure water bodies attain Good Ecological Status.
UK Gov PSA Targets	• 95% of SSSIs in Favourable Condition by 2010

Statutory/non statutory drivers	Conservation target
Environmental Stewardship Targeting - Mid Norfolk	• High Level Scheme applications for environmentally sensitive farming practice. • Maintain or enhance Sites of Special Scientific Interest (SSSIs). • Improvement of water quality through reduction of soil erosion and leaching of nutrients. • Conservation of landscape and wildlife associated with arable farming; in particular maintaining locally distinctive landscapes and reversing the decline in farmland birds. • Protection of historic and archaeological sites. • Access – provide further recreational facilities to promote greater appreciation of the countryside. • Maintenance and restoration of BAP priority habitats. Conservation of BAP priority and locally important species. (Defra 2005)

5 Geomorphological processes

The geomorphology of the River Nar is composed of the processes of sediment production (sources), transport and storage (deposition) and the resulting physical form of the river channel and floodplain. Central to understanding these is to quantify the dynamics of sediment transport through the river system and to establish the sources and sinks (storage) of sediment within the channel network. Once these have been identified it becomes possible to interpret the channel morphology.

5.1 Sediment transport in the river network

A fundamental question for any morphological restoration is whether the channel boundaries are stable relative to the flow regime. If the boundary is stable under all flows, then the channel will be unable to recreate degraded morphology. Instead the channel boundary will remain stable under a given flow regime with a mobile fraction composed of finer sands and silts. Alternatively, if the channel boundary is mobile under high flows, then provided that a supply of coarse sediment is available, the river will be capable of recreating a more natural channel morphology.

The evidence required to assess this would ideally include actual measurement of sediment fluxes over the flow regime. In the absence of this data it is possible to estimate the depths of flow required to mobilise the bed material and compare these to those observed under bankfull floods. A common approach is to utilise a tractive force method based on mobilising the median diameter of the surface material in the river bed (Komar 1987; Petit 1990). The method adopted by this study utilised surveyed cross-sections (Harvey 1967; Environment Agency 2003) along the River Nar, together with measurements of bed material grainsize. These were used to determine the discharge at bankfull based on the Manning-Strickler equation (Hydraulics Research1997) and a Catchment Area based estimate (Harvey 1967). The average of these two methods was taken to represent the maximum value of flows contained within the river channel boundary.

The maximum particle mobilised can be estimated by rearranging the Shields equation:

$$d_{max} = \tau/\theta\ (\rho_s - \rho)gD_{50} \tag{1}$$

d_{max} is the maximum particle size mobilised by bankfull floods (mm), g is the gravitational acceleration in ms^{-2}, τ is the bankfull shear stress (Nm^{-2}) and is calculated from

$$\tau = \rho\ gRS \tag{2}$$

θ is the Shields entrainment function which ranges in value from 0.03 for loose gravels to 0.06 for packed gravel. ρ_s and ρ are the densities of sediment and water and are taken as 1650 and 1000 kgm^{-3} respectively.

The shear stress calculated in equation (2) is widely recognised to over-estimate that which is available for entrainment of bed material (Richards 1982; Petit 1990) since it does not account for energy losses resulting from vegetation, form roughness and internal friction between moving water bodies. Petit (1990) following Richards (1982); provides a correction factor based on the ratio between grainscale roughness and the remaining roughness contribution;

$$\tau' = \tau . K^{3/2} \tag{3}$$

Where K is a correction factor (n'/n_o) where n_o is the total Mannings roughness and n' is the grain roughness calculated from:

$$n' = 0.051D_{50}^{1/6} \tag{4}$$

Field derived values for Manning's n_o were estimated according the method outlined in HR (1997):

$$n_o = \frac{R^{0.66}\ S^{\ 0.5}}{U} \tag{5}$$

where R is the hydraulic radius, S is the water surface and U is the cross-sectional average velocity (ms^{-1}) derived from the continuity equation;

$$U = Q/A \tag{6}$$

Where Q is the morphologically defined bankfull discharge (m^3s^{-1}) and A is the wetted cross-sectional area (m^2) for that discharge.

On the basis of this analysis it can be demonstrated that in all the semi-natural sites surveyed by Harvey (1967), the majority of the bed material will be stable under bankfull flood conditions (Figure 5.1). The "loose" material, represents the conditions found in freshly cut salmonid redds or construction gravels used in rehabilitation. This is also predicted to be stable relative to bank full tractive force in the majority of sites, though Figure 5.1 suggests bed mobility increases towards Narford Lake. In fact conditions recorded in this reach suggest that the bed is frequently heavily compacted and cemented by Tufa (calcium carbonate deposits) and is therefore more representative of "packed" conditions.

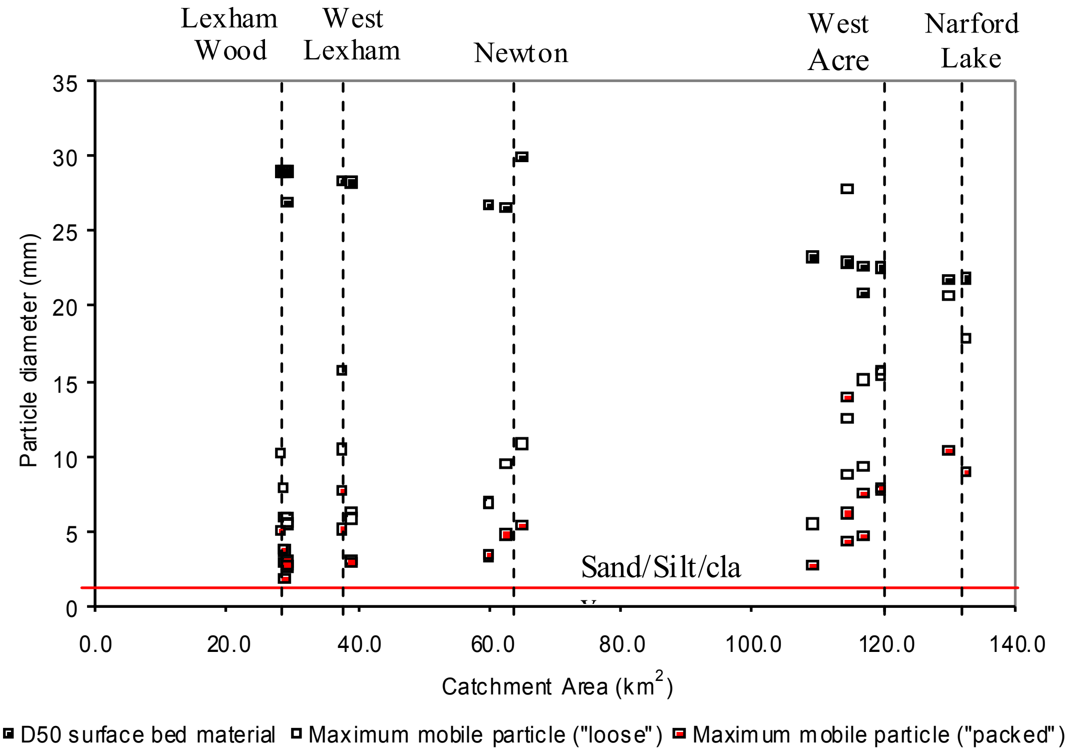


Figure 5.1: Comparison between the maximum predicted mobile particles and the median diameter of coarse surface bed material for semi-natural cross-sections of the River Nar. Conditions for "loose" and "packed" gravels are shown.

It is possible by re-arranging equation (1) to give the shear stress required to initiate motion of the median bed material and then correct this value by K to give τ, to predict the depth required at each site (assuming floodplain slope still represents S). Table 5.1 provides this analysis for all survey sites from Harvey (1967) on the upper Nar between Lexham Wood and Narford Lake. At all sites the predicted flow depths are in excess of bankfull. This means that to achieve additional increases in flow depth would require inundation of the floodplain. At this point however, increases in discharge are typically contained by increases in flow width as the floodplain is progressively inundated rather than changes in depth. At almost all sites the increased flow depth above bankfull is more than would be achieved by even the largest recorded floods. For the packed bed condition the predicted flow depths required to mobilise the coarser bed material will be generally unachievable under current hydrological conditions. The bed stability of lowland groundwater dominated rivers has been reported by German & Sear (2003) for the River Wylye, a chalk stream with greensand headwaters. Similarly, Acornley & Sear (1999) report low rates of bedload transport in the groundwater dominated River Test which were characterised by sands and tufa fragments. The coarse bed framework gravels remained immobile.

Table 5.1: Predicted depths required to generate the grain shear stress required to entrain the median diameter of the bed surface material. Comparison with bankfull depths indicates that in most cases the bed will remain stable.

Critical τ' for movement of bed D_{50} (Nm^{-2})		**τ required to generate τ' (Nm^{-2})**		**Flow Depth (m) required to generate τ**		**Bankfull Depth (m)**
"Loose"	**"Packed"**	**"Loose"**	**"Packed"**	**"Loose"**	**"Packed"**	
14.1	28.2	56.7	113.4	2.51	5.03	0.5
14.1	28.2	30.0	60.1	2.04	4.09	0.3
14.1	28.2	44.8	89.7	3.05	6.10	0.4
14.1	28.2	37.7	75.3	2.56	5.12	0.2
14.1	28.2	45.3	90.7	3.56	7.12	0.5
14.1	28.2	33.8	67.6	3.83	7.66	0.4
13.1	26.2	28.7	57.3	3.25	6.50	0.4
13.8	27.6	31.4	62.8	1.60	3.20	0.4
13.8	27.6	18.0	36.0	0.92	1.83	0.3
13.7	27.5	75.2	150.5	3.84	7.68	0.5
13.7	27.5	83.7	167.4	4.27	8.54	0.5
13.0	26.1	46.7	93.4	2.98	5.96	0.5
13.0	26.1	56.9	113.9	3.63	7.26	0.6
12.9	25.9	39.8	79.5	2.03	4.06	0.4
14.6	29.1	34.1	68.3	1.51	3.03	0.3
11.3	22.7	48.4	96.9	3.80	7.61	0.6
11.2	22.3	8.5	17.0	0.46	0.91	0.3
11.2	22.3	36.9	73.9	1.98	3.97	0.5
11.2	22.3	15.7	31.5	0.85	1.69	0.3
11.1	22.1	36.0	72.0	1.93	3.87	0.5
10.2	20.4	24.7	49.4	1.20	2.40	0.5
11.0	21.9	30.5	61.0	1.35	2.70	0.6
11.0	21.9	25.2	50.4	1.07	2.14	0.5
10.6	21.2	15.5	31.0	0.75	1.50	0.4
10.7	21.3	24.7	49.4	1.26	2.52	0.6

This analysis supports the conclusion that the gravel bed of the River Nar in a semi-natural state, is largely stable by virtue of the low gradient and discharge.

5.1.1 Fine sediment transport

As part of the Geomorphological Dynamics Assessment suspended sediment loads were monitored via a calibrated turbidity probe located at the gauging station at Marham flume. The turbidity datasets were collected by Anglia Water Services as part of the monitoring of the Public Water Supply abstraction point at the Marham Flume. To convert this data into a record of suspended solids requires joint collection of suspended sediment samples. This was undertaken by Lou Mayer, Conservation Officer with the King's Lynn Consortium of Internal Drainage Boards. Unfortunately, the number of samples was not large with only nine samples were collected, and these only ranged over 9 mgl-1. Calibration was not therefore possible, but remains as an option. Historic turbidity records are available from Anglian Water Services, though only six years of record were provided up to the point of reporting. Longer term and more recent records exist and should be analysed. These records could extend back to the inception of the Public Water Supply in the 1950s.

The data from Anglian Water Services was processed and 'cleaned' in order to remove the bias due to drifts in the calibration between turbidity and water discharge. These arise due to changes in the method of sampling or to problems with the instrumentation. The 'cleaned' dataset is shown in Figure 5.2 together with the flow record at the Marham flume. Turbidity can be used as a surrogate for sediment load. In this instance the turbidity is clearly a responce to increases in runoff generated by storm events in the upper catchment, and also demonstrates seasonal fluctuations associated with the release of groundwater. Turbidity is generally highest at the start of the increase in discharge and generally reaches its maximum before the peak in flow. This arises due to the remobilization and then exhaustion of fine deposits that have accumulated in the channel over the previous autumn. The peaks in discharge relate to peaks in turbidity which demonstrates that heavy rainfall events provoke a rapid change in turbidity.

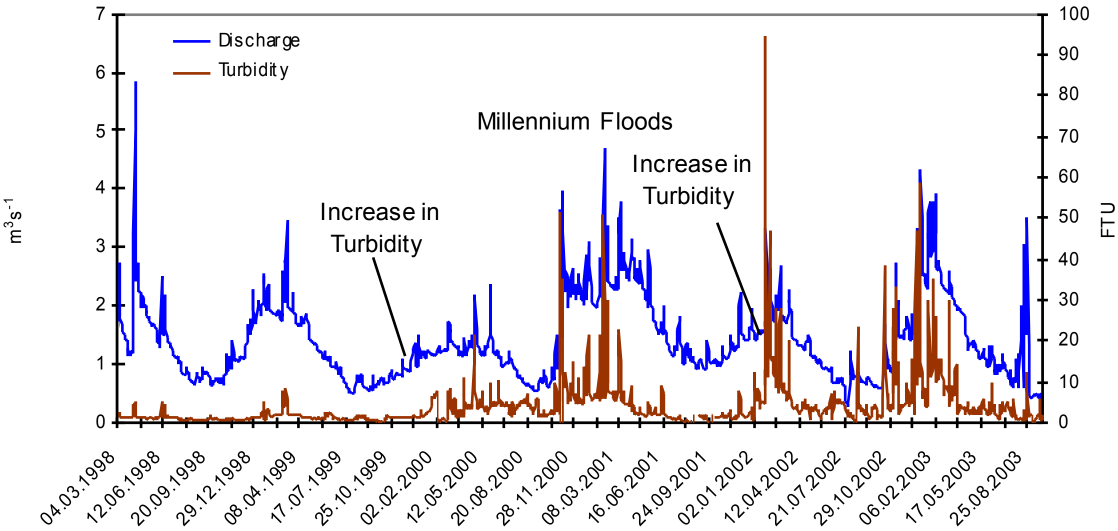


Figure 5.2: Time series of turbidity and discharge at Marham flume. Turbidity data were provided by Anglian Water. Increases in turbidity show both seasonal and event fluctuations.

The dataset also shows some increases in turbidity that is independent of flow. These may be in part an artefact of the sampling procedure even after data processing, but could also reflect changes in the catchment sediment system. Figure 5.3 shows a double-mass plot of cumulative flow and cumulative turbidity. The double mass plot is a standard approach for checking consistency in a time series, and breaks of slope show where turbidity increases or decreases above the general relationship. Two increases occur which suggest possible increases in the transport of suspended sediment from the catchment in the period around February 2000, and again in January 2002. A reduction in the rate of increase in turbidity back to pre 2000 levels occurs in March 2001. Unfortunately, it is not possible to ascertain whether these effects are real, or what the cause of these changes might be. This analysis does however demonstrate the value of this type of information and careful analysis might help determine longer term trends in the turbidity records and potentially, correlations with land use change and or changes in channel management practice.

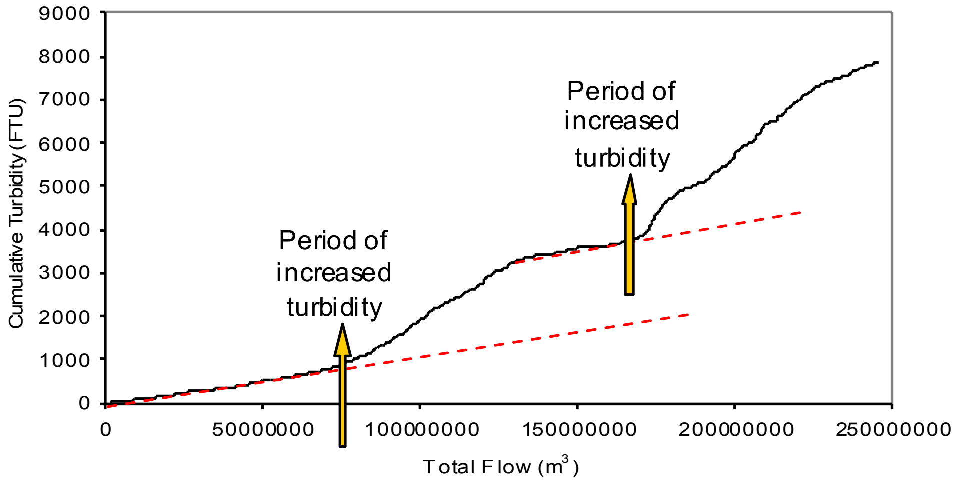


Figure 5.3: Double mass plot of flow and turbidity, indicating periods of increased turbidity independent of changes in flow.

Sand transport in the catchment occurs by two processes:

1) **bed load transport** where the coarse sand remains in contact with the river bed and moves as threads or sheets over the stable gravel bed;

2) **suspended sediment transport** where the finer sand sizes are transported in the water column, suspended by turbulent eddies.

Evidence for suspension of sand comes from the presence of this material in the floodplain while bed load transport is observed in reaches in the form of dune fields (Figure 5.4).

Figure 5.4: Sand transport as bed load moving in a series of dunes under higher flows (Reach N200, West Acre)

Figure 5.1 demonstrates that the forces generated in the River Nar under bankfull flow, while insufficient to mobilise the gravel framework, are capable of transporting coarse sand (2mm) and sizes up to fine gravels. Field evidence from the fluvial audit such as that recorded in

Figure 5.4 support the view that sand is the dominant material in motion as bedload within the upper Nar catchment.

A provisional assessment of the capacity of the River Nar to transport sand-sized sediment particles was undertaken using the cross-section data reported by Harvey (1967) for semi-natural reaches of the River Nar. Sediment transport of sand-sized material was calculated using the Ackers-White (Ackers & White 1973) bedload transport equation with a grainsize of 1.4mm to represent the sand fraction. The data used were derived from bankfull dimensions and thus represent maximum bedload transport capacities for the upper River Nar at these sites. The data is presented in Figure 5.5 where it has been plotted against catchment area. Sand transport capacity is shown to increase with catchment area, which corresponds to an increase in bankfull discharge. River reaches towards the headwaters, though slightly steeper do not have such a large bankfull discharge and are therefore less able to transport sands. This is an important consideration for management of the River Nar since reductions in discharge either due to climate change or abstraction, would result in reduced fine sediment transport and increased accumulation. Similarly, reduction in gradient through the introduction of a meandering planform would also result in a decrease in transport capacity and therefore an accumulation of fine sediments on the river bed.

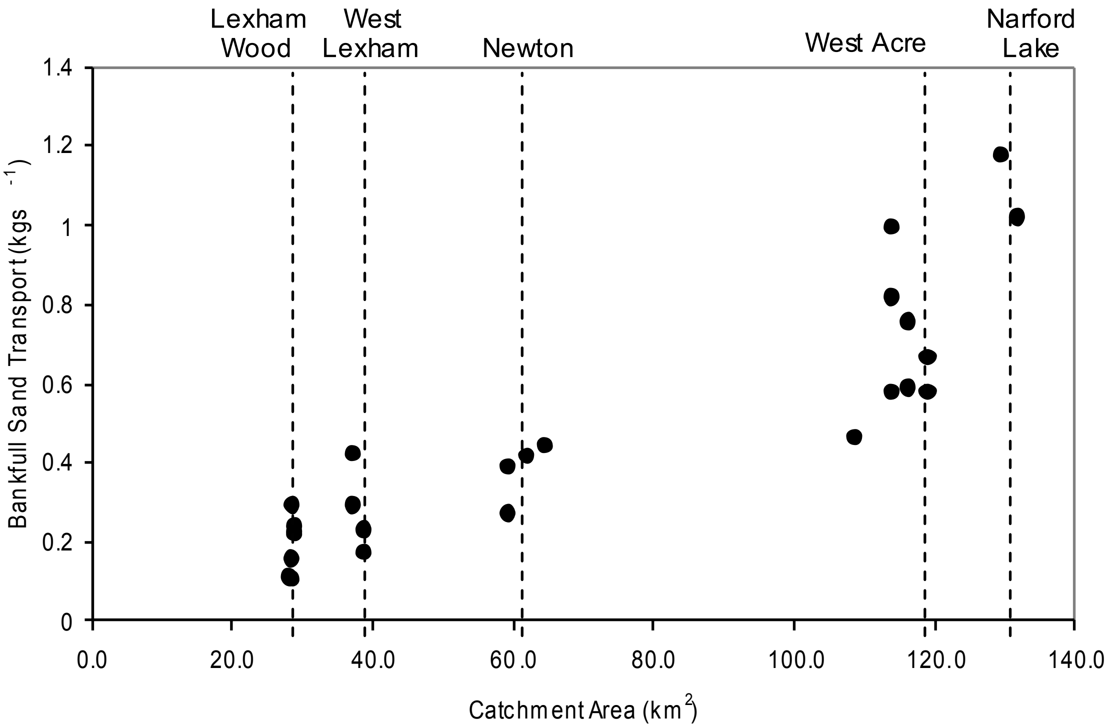


Figure 5.5: Estimated bankfull bedload transport capacity for sand sized material at sites measured by Harvey (1967) in the upper Nar. Transport capacity is shown to increase downstream (to the right of the figure) as catchment area and hence discharge increases.

Downstream of Narborough, there is a rapid reduction in gradient with little increase in discharge. The result is a reduction in transport capacity and the accumulation of fine sediment. Cross-section survey data from 2003 were available for this study. These were used to derive estimates of bed shear stress at high, within bank, flows following the approach presented above. Volumes of fine sediment accumulation were calculated using the areas of soft bed recorded on the survey and calculating the difference between the hard bed elevations for each cross-section. The values were then integrated over the reach to provide an estimate of volume of fine sediment storage. The shields entrainment formula was used to analyse the shear stress values so as to estimate the maximum size of mobile particle. This information is presented in Figure 5.6 below.

The major control on shear stress and maximum mobile particle size, is the water surface gradient. The values used in the estimates do not reflect the ponded flow conditions present during high tides. These will effectively result in further reduction in gradient and ponded flows from those already experienced on the river upstream of the tidal sluice. Instead the results show the water surface slopes associated with scouring flows in the lower Nar when the tidal outfall is open. This explains why the size of mobile particle increases towards King's Lynn, yet the silt volumes remain high (though decreasing). Figure 5.6 shows the relative mobility of sand and fine gravels in the reach between Narborough Mill and Marham weir, followed by a decrease in maximum particle mobility towards Abbey Farm weir. Downstream of Abbey Farm weir, shear stress increases slightly and this is reflected in a reduction in fine sediment accumulation shown on the 2003 surveys. A reduction in shear stress (and maximum mobile particle size) occurs on the river 6km to 12km upstream of the tidal sluice. Particle mobility in this reach falls below the coarse sand threshold of 2mm, and is associated with a large increase in fine sediment accumulation within this reach. A local increase in shear stress downstream of the A10 at Setchey appears to be correlated with a decrease in fine sediment accumulation before a further reduction occurs, with a corresponding increase in fine sedimentation.

In Figure 5.6 the locations of sediment ingress points are shown as orange arrows. These correspond with the increase in fine sediment accumulation on the bed. The upstream ingress point is associated with the confluence with the Country drain at High Bridge, which is known to receive fine sediment from the road network (see Figure 5.7 below). The downstream ingress point is associated with the discharge from the East of Ouse IDB pumping station. The north bank pumping station receives water from the Blackborough Drain and Trout Stream, both of which have known siltation problems (Mrs Jean Marriott pers. com.) (see section on catchment sediment sources below).

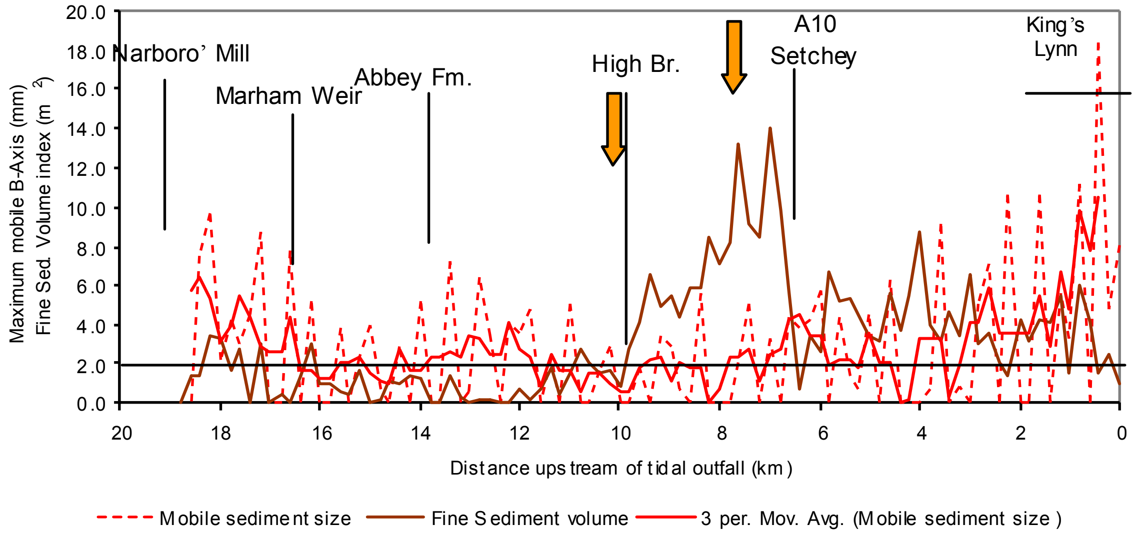


Figure 5.6: Fine sediment accumulation and bed mobility in the lower Nar showing the decrease in maximum mobile particle size which results in a gravel-sand transition, and the downstream increase in fine sediment accumulation. Orange arrows represent sediment ingress points.

The sediment transport regime in the lower Nar is therefore one which is partially controlled the transition from steeper to very low gradients, but is complicated by tidal ponding in the downstream reach and the input of fine sediment from the drainage channels maintained by the East of Ouse IDB. The tidal scouring process is capable of mobilising the finer sediment, but is only functional during low tides below the tidal sluice. However, it would appear that sand transport during ponded periods will reduce upstream delivery into the reaches through King's Lynn, resulting in a net reduction in accumulated fine sediment in this lower reach. The upper reach of the lower Nar is a transitional reach that shares similarities in terms of sediment transport, with the upper Nar. In these reaches, the flow is unable to mobilise anything above small gravels and retains some finer sediments on the margins. Progression downstream is marked by a decline in mobile particle size and transport capacity.

5.2 Sediment sources

An important aspect of the sediment system of a river is the source of the material available for transport. This material has ultimately to enter the river network, though much is simply stored within the catchment and does not make it into the network. The component of this material that enters the river network provides the supply of sediment that can be utilised by the river to create physical habitat. It is important to stress that not all of the material that enters a river as a source is able to be mobilised by the river, in which case it is deposited close to the entry point.

The River Nar has three potential sources of fine sediment – channel bed, channel banks and catchment sources. Each requires assessment in terms of contribution to the river sediment load.

5.2.1 Bank erosion sources

Bank erosion in the River Nar was assessed in two ways:

1) Analysis of lateral channel migration over long time scales through digital comparisons between the 2000 OS Land-Line depicted channel outline and a digitised First Edition OS map from 1824.
2) Through field survey of the length and type of bank erosion observed in the walk through survey.

The historical analysis revealed limited channel migration at only two locations associated with meandering profiles:

- TF817146 – Castle Acre meanders – meander apex extension into floodplain by <3m in 181 years;
- TF832166 – Meanders upstream of Newton – meander apex migration by < 3m in 181 years and initiation of meandering planform.

Accuracy of this method is limited and the rates are therefore tentative. However the values for migration are low compared to other river types (<2 cm per annum) and were recorded in less than 0.01% of the total channel length.

The contemporary field survey identified erosion processes. These are dominated by weathering of the bank face where unvegetated, poaching by livestock and fluvial scour by river processes. The total length of eroding river bank on the River Nar at the time of survey is 4.18km or 4.9% of the total bank length. Of this value some 1.3 km of eroding bank (1.5%) is in the lower Nar. The dominant bank material for the River Nar is fine sands and silt, with limited areas of gravel where the channel has been dredged below the former bed level. The bank materials are reported by Harvey (1967) as having a significant silt/clay component (23-61% by weight) that is known to increase the resistance of bank material to erosion by fluvial scour. Additional resistance to bank erosion is provided by the extensive communities of riparian vegetation and marginal emergent aquatic plants, which even in winter afford protection from scour.

Table 5.2 provides comparison with other rivers for which equivalent fluvial audits are available. The River Nar has comparable bank erosion lengths to the River Wylye chalk river, and has much less bank erosion compared to other higher energy river systems. Consideration of the low rates of bank erosion and the short length of bank erosion on the River Nar draws one to the conclusion that bank erosion is not a primary source of sediment to the river channel, although on very limited river reaches, it may provide an important contribution. Furthermore, this source is primarily fine sediment (sand, silts and clay) with organic peat and small (local) gravel contributions.

Table 5.2: Comparison of percentage of surveyed length of bank erosion for different rivers. Note the relatively low proportion of eroding banks recorded for low gradient lowland channels and chalk rivers compared to higher energy upland rivers.

River	**Relative Stream Energy**	**% River bank eroding**	**Source**
Wylye (Chalk)	Low	4.2	GeoData 2002
Nar (Chalk/Fen Basin)	Low	4.9	GeoData 2004
Britt (Greensand/Chalk)	Mod	6.0	GeoData 2003
Highland Water (New Forest)	Mod	9.4	GeoData 2003
Till	Mod	10.0	Newson and Orr 2003
Caldew	High	14.8	GeoData 2001
River Ure	High	16.1	GeoData 2000
River Lune	High	18.0	Orr 2000
Dee	High	18.2	GeoData 2004
Wharfe	High	18.7	GeoData 2001
Swale	High	25.2	GeoData 2002

5.2.2 Catchment sediment sources

In the absence of bank erosion as a major source of sediment, the other main sources are the river bed and the catchment land surface. The catchment land surface is the origin of all sediment found in river valleys. What is important for contemporary river management is the extent to which sediment sources are still active on the catchment surface and secondly, the extent to which these are connected to the river network. In the catchment of the River Nar, the land surface is covered with former glacial deposits, providing a range of mostly fine sediments in the form of soils of varying textures and grainsize composition. Gravels also outcrop on the surface. Potentially therefore the catchment surface under current land use and land management is a source of both fine and coarse sediments. However, the subdued topography and lack of drainage network results in limited erosion and transport of coarser materials. Rather, the main sediments in movement over the catchment surface are in the coarse sand-clay size range with minor quantities of fine-medium gravels washed out of fields and road verges, but generally failing to connect with the river network.

While potential sediment sources in a given catchment can be readily identified, these do not become actual sources unless they are connected to the river network. As part of the fluvial audit, a field reconnaissance of fine sediment ingress points was carried out as part of the fluvial audit and entry points for sediment and the dominant type of sediment at these points were mapped along the entire river. In addition, fine sediment sampling of active sources of sediment was carried out over a storm event in September 2004, and subsequent monitoring programme established over the study period. In the event the dry autumn/winter prevented any further assessment of sources from the catchment.

Examples of a sediment input and source recorded during a heavy rain storm on 28 September 2004 in the Nar catchment is shown in Table 5.3 and Figure 5.7. These illustrate sources derived from erosion of roadside verges by traffic associated with an aggregate works near Blackborough and soil erosion from a pig unit.

Figure 5.7: Fine sediment input from a pig unit and road routeway at West Acre Bridge showing the highly concentrated plume during the rain event and the deposit one month later. The majority of fine material had been moved downstream and was present over 1 km. The third image is a fine sediment input from road verge erosion into the River Nar via the Country Drain.

The values for sediment production over a 30 minute rain event are indicative and are not considered to be accurate. Nevertheless, the values demonstrate the potential for delivery of significant quantities of fine sediment from single fields. In the West Acre case, the estimated transport rate or 1.7 kg/s is in excess of the calculated bankfull transport rate for the river at this point of between 0.45-0.9 kg/s. Evidence from the field suggests that the channel is capable of moving the sand from the surface (Figure 5.7) but only locally, deposition occurring within the reach downstream.

Table 5.3: Examples of fine sediment runoff from land use types in the River Nar and River Wensum catchment (winter 2004/2005). Values of sediment delivery are based on measured discharges for each flow. Note these values are subject to uncertainty and error in estimation. Relative values are believed to be robust.

River	Location	Date	Source	Sediment Concentration (mgl^{-1})	Load (kg) delivered in 30 minutes (figures in brackets are rates in kg/s)
NAR	West Acre Bridge	28/09/04	Pig Unit + Road Runoff into River Nar.	9740	3103.2 (1.72)
NAR	West Acre Bridge	28/09/04	Channel upstream of input point.	28	28.4 (0.016)
WENSUM	TF964273 Gt Ryburgh	28/01/05	Arable Field Runoff	2540	91.4 (0.051)
WENSUM	TF965265 Gt Ryburgh	28/01/05	Arable Field Runoff	200	21.6 (0.012)
WENSUM	TF972248 Grately	28/01/05	Arable Field Runoff	2277	553.3 (0.312)
WENSUM	TF987267 Guist Bottom	28/01/05	Arable Field Runoff	689	310.1(0.172)

Critical conditions for catchment sediment delivery are:

1) Delivery of fine sediment at high transport rates into river reaches with low sediment transport capacity.
2) Delivery of fine sediments at high transport rates during short intense storms that do not cause significant increases in river flow (eg summer convective storms), resulting in input exceeding transport capacity.

Examples of catchment fine sediment sources identified in the Nar catchment by field survey include:

- Erosion of road side verges and deposits on the road network.
- Pig farm units.
- Runoff from arable and pasture fields including maize.
- Runoff from aggregate works.
- Erosion of unmetalled tracks and footpaths where these discharge onto road network.
- Erosion of recently cleared drainage channels.
- Bank erosion/poaching of banks.

Although UK agencies refer to silt pollution as a diffuse pollution issue (ie multiple unspecified sources distributed around the catchment), in chalk streams such as the River Nar, the lack of extensive headwater tributary networks and the presence of wide floodplains result in a naturally low connectivity between the river and the adjacent slopes. Fine sediment ingress is therefore better described as a set of point sources of sediment discharge

(German and others 2003). These points of ingress occur where runoff from the catchment surface intersects with the river and existing drainage network. Ingress points located during this survey include:

- Tributary confluences (few in chalk streams).
- Road crossings where road drains discharge into the River Nar.
- Footpath/track/fords crossing the river network.
- Points where the channel is intersected by dry valley network without the presence of a floodplain.
- Confluences with IDB main drains.
- IDB Pumping stations
- Hillslope discharges into the main river network in the absence of a floodplain
- Poor land management around springs which connect to the main river.
- Tidal silt incursion.

The lower Nar is protected from fine sediment inputs by the pattern of land drainage. Thus major sediment input points downstream of Narborough are located at the junction of IDB gravity drains and at the two IDB pumping stations. Discussions with staff of the East of Ouse IDB highlighted the following sources:

1) Gravel Pits at Blackborough drain into Trout Stream, then into the Country Drain and from there into River Nar.
2) Road runoff from Blackborough enters Country Drain then into the River Nar.
3) Some road runoff from Blackborough also enters Black Dyke then into River Nar at Nar Valley Pumping Station.
4) Silt (sand) has always been an issue in the Trout Stream and Country Drain system – land owner keeps upper Trout Stream reaches cleaned out.
5) Siltation around Nar Valley pumps (4ft silt in River Nar – see section above)
6) Siltation in the River Nar d/s Country drain system.

Upstream of Narborough silt ingress occurs in response to intense rainfall events on bare fields and where there is a routeway into the channel. The presence of a wide and shallow floodplain with low-intensity land use along most of the upper Nar buffers the river network from fine sediment delivery from the valley sides. Thus the dominant routeways appear to be via the road network and associated network of road side drains, with entry points possible where trackways intersect with the river network. The network of drains is maintained by Norfolk County Council with field drainage systems being the responsibility of the local land owner. An important key to sediment management in the upper Nar is therefore the development of an integrated approach to the management of these routeways alongside cost-effective management of the land surface in key hotspots of sediment production. An opportunity for Best Practice management exists at West Acre where runoff from a pig unit and farm track was strongly connected with the road network and roadside drainage. Joint management of the source AND the routeway into the River Nar would provide an effective control on this ingress point. The land owner has already taken steps to reduce runoff from this unit.

The main sediment ingress points for the River Nar are mapped in Figure 5.8 together with an estimate of the type of sediment delivered from these points. Three points emerge from this study:

1) There are relatively few major point sources of fine sediment into the river network.

2) These appear to be concentrated in four zones.

3) The majority of sources are fine silts and sand with only one local gravel source.

The sources in the upper Nar are derived from the catchment and are linked to field drainage systems, tributary inputs and road drainage. The sources in the lower Nar downstream of Narborough are again from the catchment and linked to the river via the East of Ouse IDB drain outfalls and pumping station. The exception is the ingress of tidal silt into the lower reach of the River Nar that is largely controlled by the operation of the tidal outfall.

Comparison with the soil map in Figure 3.4 highlights the spatial correlation between the upper Nar zones of sediment ingress and the IDB sedimentation issue at Blackborough with the presence of erodible sandy soils in the catchment. Evidence from storm runoff monitoring confirms that the loads produced off pig units and roads in these areas are substantial. **A key recommendation of this report is to further investigate ways in which these sources and ingress points can be better managed to reduce fine sediment delivery into the River Nar.**

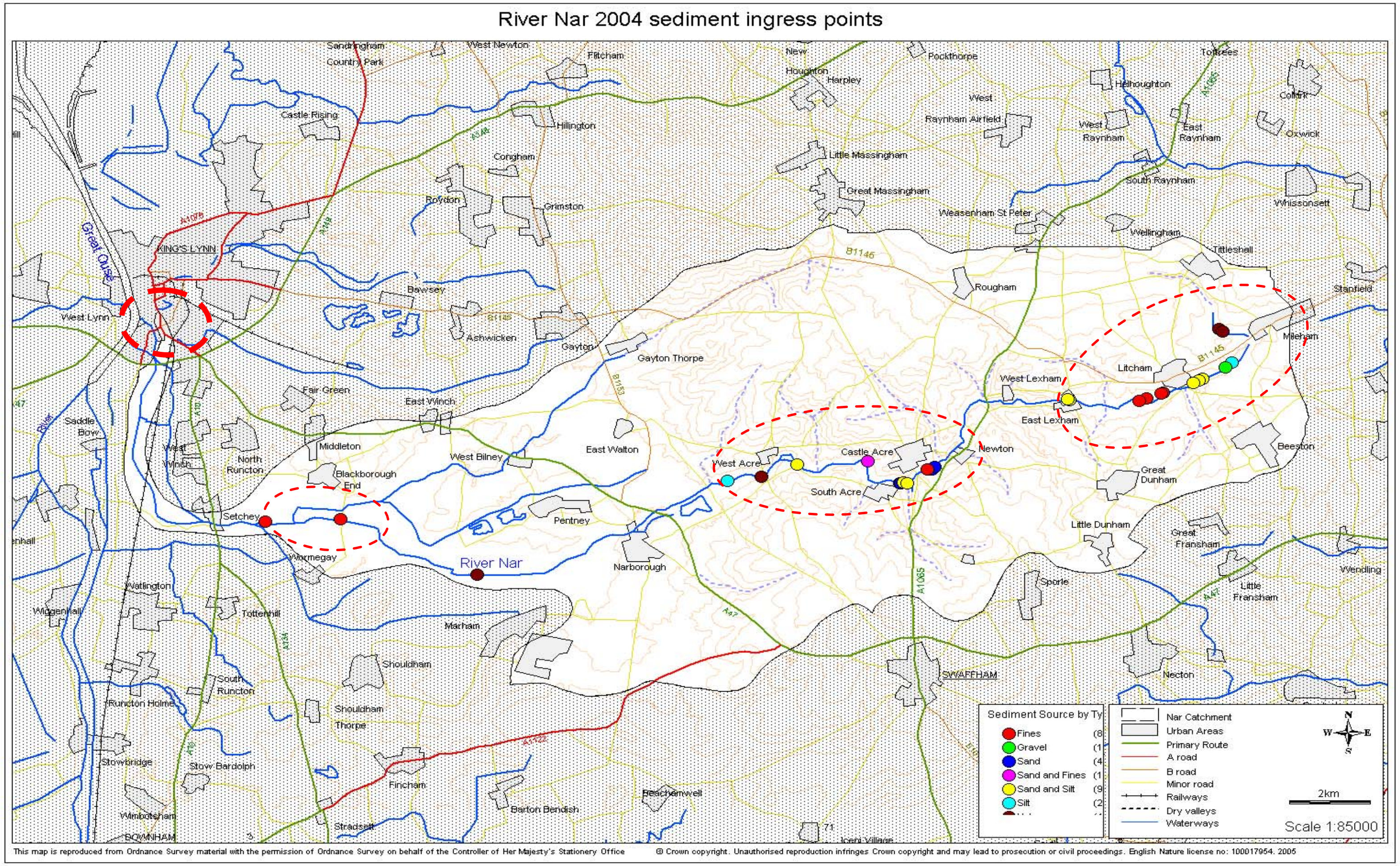


Figure 5.8 River Nar sediment ingress points.

5.2.3 River bed sediment sources

The river bed is a potential source of sediment to downstream reaches and requires consideration for two reasons: Firstly, as a source of gravels and fine sediment to downstream reaches: and secondly as a measure of fine sedimentation of the gravel bed which is an important measure of habitat quality for many instream biota. The analysis in section 5.1 has demonstrated that the bed of the River Nar is not an active mobile gravel bed and is therefore not a major source of gravel to downstream reaches. The implication of this is that the bed is stable over most flows and that each reach is disconnected from upstream supplies of gravel. The same analysis has also demonstrated that particles within the range of coarse sand to clays are both supplied from the catchment surface and are readily transported through the river until the channel gradient drops downstream of Marham flume. River reaches may therefore be said to be connected with upstream sediment supply.

Two aspects of sediment supply from the river bed are now reviewed; first the availability of sediment in terms of the proportions of silt-sand and gravel on the river's bed, and second, a measure of the fine sediment load on the surface and within the gravels at riffle/run locations.

Information on the proportions of different bed substrate types are available from:

1) The 1981 River Corridor Survey (Mileham to King's Lynn – 1km reach interval)
2) The 1990 River Corridor survey of the lower Nar (Narborough – King's Lynn 0.5km interval).
3) The 2004 Fluvial Audit survey (Mileham to King's Lynn – variable reach lengths).

The approach adopted during all three surveys was to assess the proportion of the river bed covered by the main grainsize classes silt & clay, sand, gravel, and cobble. The different sediment proportions are shown in the following sequence of figures 5.10 – 5.12.

It should be recognised that because the estimates are visually determined, there is a degree of uncertainty associated with direct comparison of the values, however the broad trends downstream are believed to be robust.

The most obvious change in bed substrate recorded in all three surveys is the gravel-sand-silt transition downstream of Narborough. As previously discussed this is a natural phenomena resulting from the decline in gravel and then sand transport capacity as the river gradient decreases as it flows into and through the Fen Basin. This condition is exacerbated by ponding of flow in the reach by weirs and tidal back watering, but should be recognised as reflecting the natural processes. The effect of tidal scour at the very downstream end of the river reveals gravel/cobbles on the channel bed. This is possibly part of the armouring of the channel introduced when the River Nar was realigned in the early 20th century. The fluvial audit survey picked out more gravel dominated substrates than the previous surveys through this reach and this reflects the presence of small patches of gravels in the upstream reach and around the area of the gravel workings. However, the survey confirms the overall conclusion of earlier surveys that the dominant substrates on these reaches are sands and fine silts.

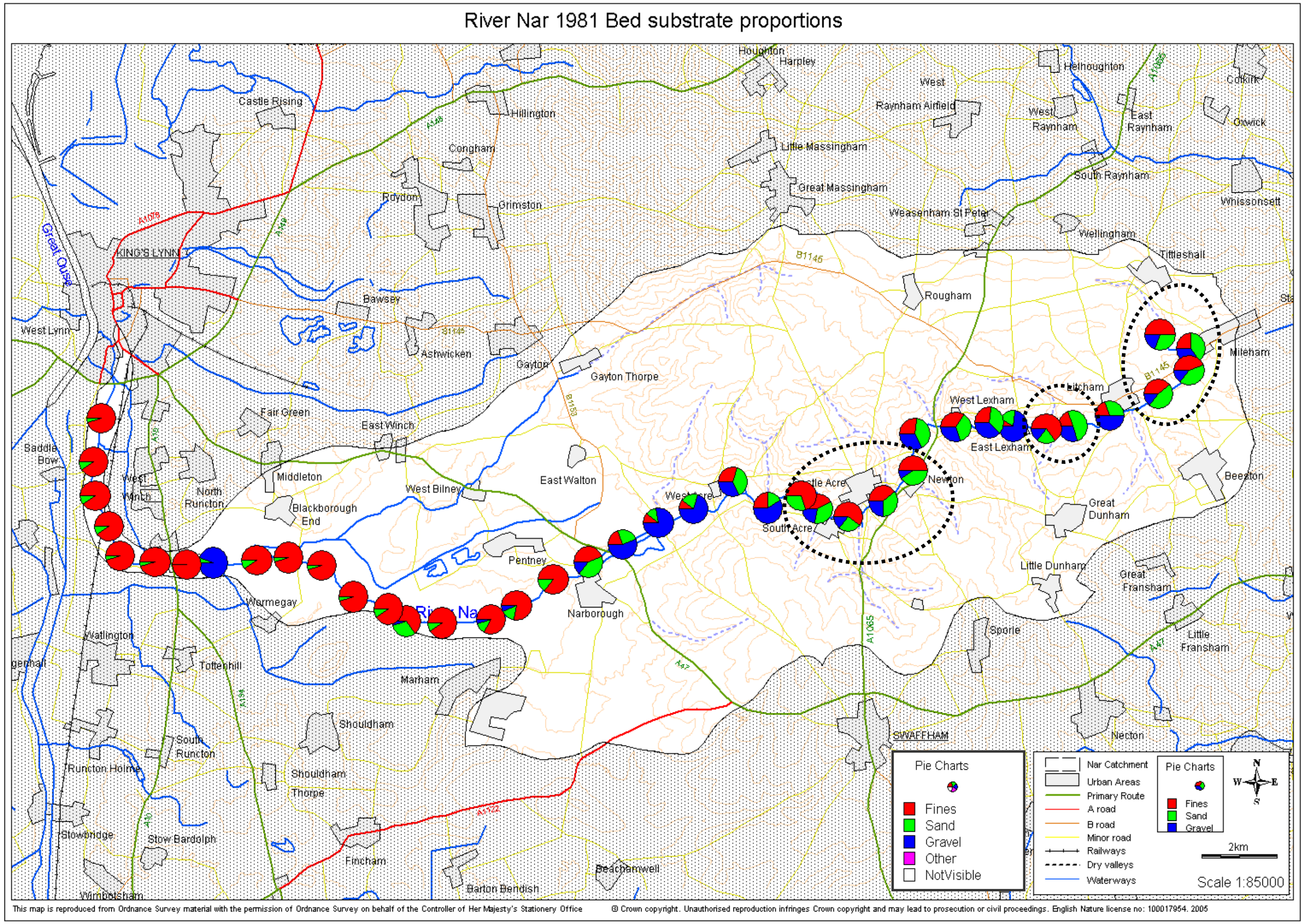


Figure 5.10: Bed substrate proportions visible in 1981. Data from the River Corridor Survey

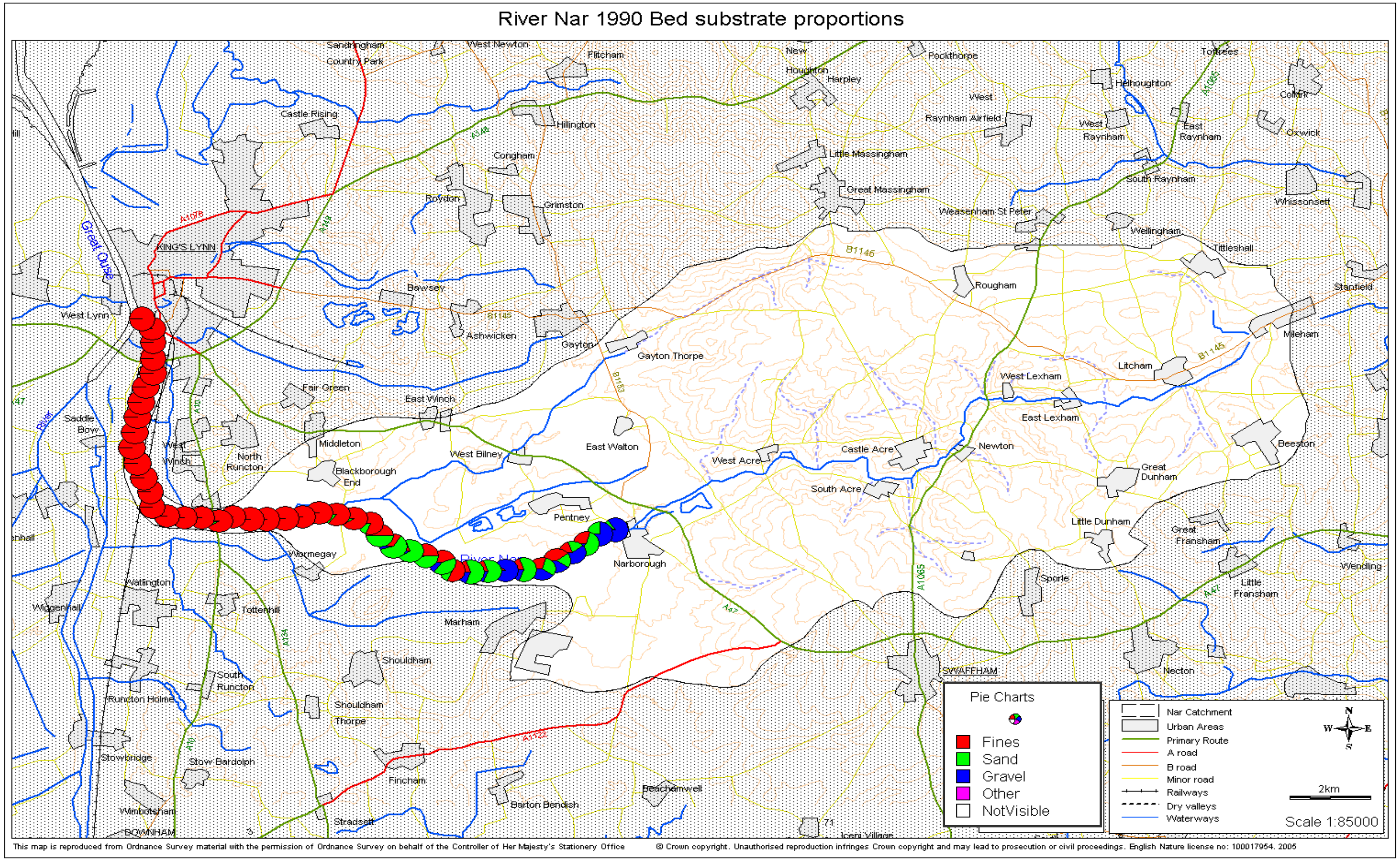


Figure 5.11: Bed substrate proportions visible in 1990 for the lower Nar. Data are from River Corridor Survey.

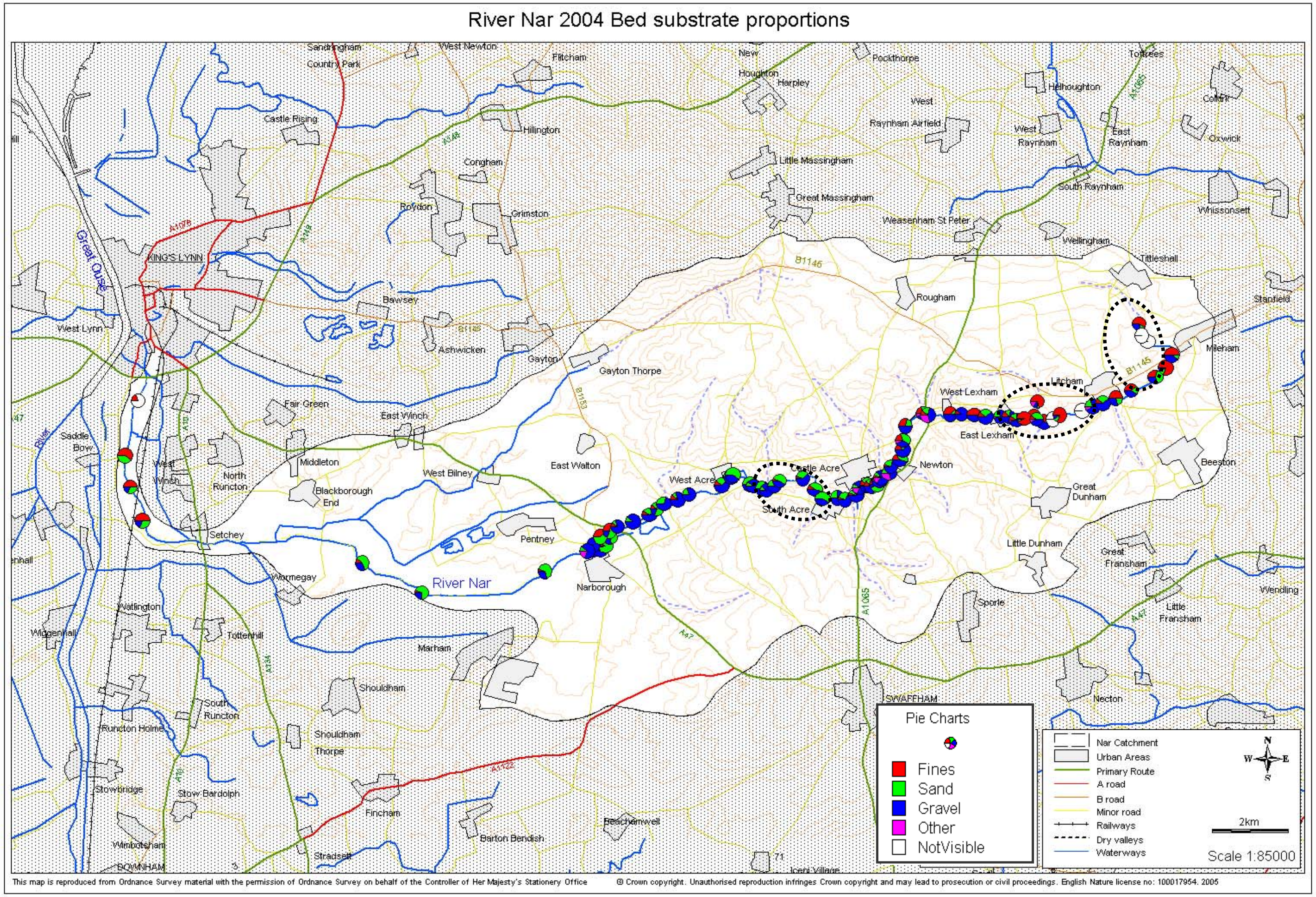


Figure 5.12: Bed substrate proportions visible in 2004. Data are from Fluvial Audit. Note reach lengths are determined by changes in geomorphology.

The survey found that on the Upper Nar, there was a more complex sequence of substrates, with no clear downstream trend in grainsize, and that the substrates reflect the existence of relict gravels in the valley floor and the presence of fine sediment accumulations from catchment sources. Channel morphology locally influences the presence of fine sediments, particularly where the channel gradient is reduced through meanders or where the channel is overwide. Good examples of these controls are in the reach through Castle Acre (Figure 5.13).

Figure 5.13: Examples of over-widened channel and meandering channels at Castle Acre. In each case fine sediment accumulation on the bed is dominated by sands (Left image – reach code N215. Right image – reach code N213).

The presence of extensive beds of emergent and submerged macrophytes has a strong influence on the storage of sediment on the river bed. Whilst a ubiquitous feature of chalk streams and lowland channels (and the main reason for the SSSI designation), the presence of fine sediment and associated nutrients, in association with low flows and degraded morphology, create conditions where these can choke the river channel and trap any incoming fines. Examples of this control are found in the upper reaches of the River Nar where the narrow open ditch is in places completely choked with emergent plants, and the bed is either not visible or else is silt covered (Figure 5.14).

Figure 5.14: Headwater channels choked with macrophytes and riparian plants, making an effective fine sediment trap. The 1981 River Corridor Survey indicates that gravel substrate was present on these reaches. However, by the time of the 2004 fluvial audit, these reaches were dominated by fine sediments. (Image on left – Reach Code N304. Image on right – Reach Code N305 - channel above Mileham).

Comparison between the 1981 and 2004 surveys demonstrate that in both surveys there are three locations on the river where fine sediments consistently dominate the bed substrates. An examination of these reaches reveals that they are located where there is a combination of both high rates of sediment ingress and over-widened channel morphology. An analysis of particle size indicates that there is a proportionately higher silt/clay content in the river bed in the headwater reaches around Mileham and downstream of High Bridge, with more sandy substrates dominating the middle reaches of the River Nar. Silts and clays become increasingly dominant components of the bed sediments in the lower reaches of the River Nar as the tidal outfall is approached. The median grain-size of the fine sediment on the bed surface of these reaches is fine sand (0.5mm). Some 10-30% by dry weight of fine sediments is composed of decayed organic matter reflecting the productive growth of macrophytes within the channel.

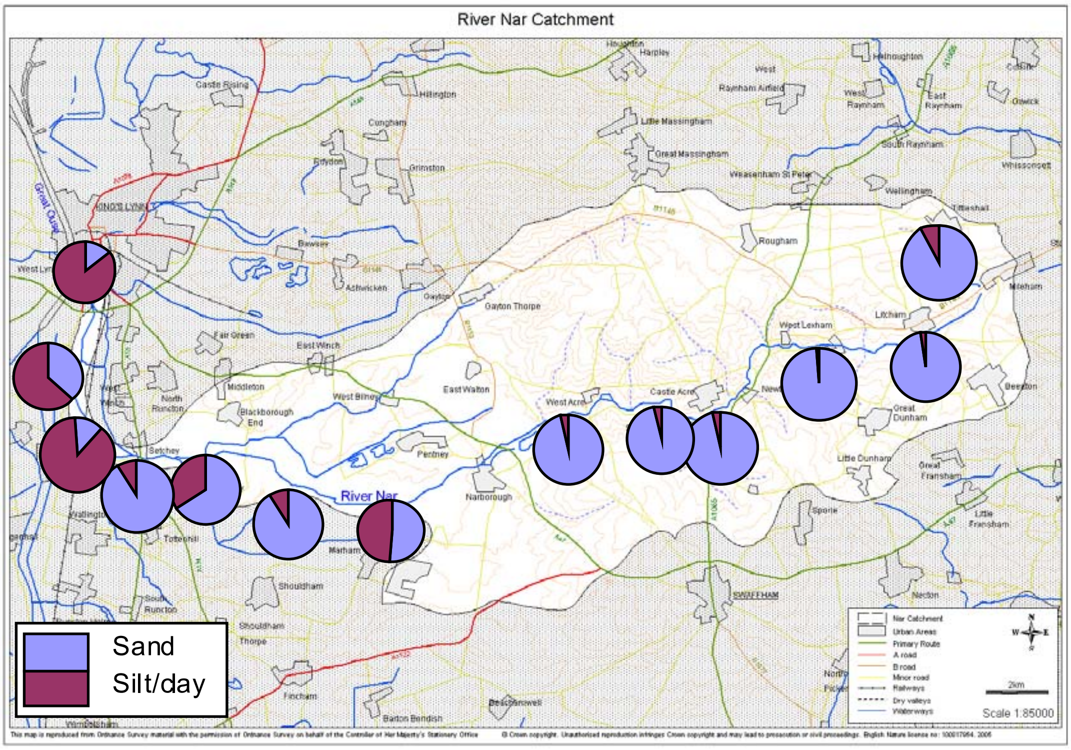


Figure 5.15: Fine sediment accumulation on the river bed and the dominant controls on sedimentation identified in the River Nar.

5.2.4 Fine sediment storage in the spawning gravel habitat

A key element of chalk stream river sediments is the relatively large quantity of fine sediments stored within the gravels (Milan and others 2000, Whiting & Moog 2001). This results from the lack of flushing of the gravel framework due to the low stream power produced in these channels. The quantity of fine sediment stored within chalk stream gravel beds is currently perceived to be of ecological significance in relation to the spawning requirements of salmonids, bullhead and lamprey. Furthermore, excessive fine sedimentation can obscure the gravel bed and create a relatively impoverished invertebrate fauna (Woods & Armitage 1999). Thus the estimation of the quantity of fine sediment stored within the gravel of the River Nar is important, both as a potential source of fines, but also as an indication of the quality of the spawning habitat.

A methodology was adopted based on that of Lambert & Walling (1987) in which a stilling basin is driven into the gravel bed; the bed surface and subsurface are agitated; and the resulting fine sediment concentration sampled. The weight of fines <1 mm) is then estimated from the concentration (g/l), volume of water in the stilling basin (l) and the area of the bed disturbed (m^2).

A total of 14 replicates were sampled at seven sites along the upper Nar. At each site gravels were selected where conditions appeared to be appropriate for salmonid spawning. Values for surface fine sediment load in kgm^{-2} were variable between sites with no clear gradients related to channel width, slope or distance from source. Average values of fine sediment surface storage are $1.0kgm^{-2}$ (s.d. = $1.7kgm^{-2}$) whilst subsurface storage down to 10cm depth are much higher at 5.6 kgm^{-2} (s.d. $4.7kgm^{-2}$). These figures compare with average values of 0.25 kgm^{-2} (s.d. 0.13 kgm^{-2}) for surface and $0.41kgm^{-2}$ (s.d. 0.22 kgm^{-2}) for subsurface for the runoff dominated River Exe (Lambert & Walling 1987). This data supports the conclusion that the River Nar has a static river bed into which fine sediment accumulates in relatively large quantities, as compared with a runoff-dominated stream with bed mobility and a large fine sediment load.

Figure 5.16 illustrates the variability in surface and subsurface fine sediment load within the upper River Nar. Generally there is good correspondence between replicates indicating that between site differences are robust. Several points emerge from the figure:

1) The lowest storage of fines on the surface are associated with the upper reaches at Mileham and in the fast riffle downstream of the road bridge at Castle Acre.

2) The highest levels of surficial fine sediment storage occur at the over-widened river reaches at Castle Acre.

3) The highest levels of subsurface fine sediment storage occur in the artificial channel at Litcham, East Lexham and in the lower course at West Acre and Narford Hall. The West Acre site is located at the point of measured pig farm runoff.

No correspondence was found between fine sediment storage on the river bed and channel width as measured at each site. Instead the proportion of fines appeares to be associated with the "looseness" of the gravels: – Looser gravels were generally free of fines whereas compacted gravels had high levels of fines stored within the bed. The channel through Litcham was sampled from a side bar, in a reach downstream of the Sewage Treatment Works and within a reach in which fine sediments are stored. The bed of the River Nar is a significant store of fine sediments. Mobility of this bed by gravel flushing will release large quantities of fines into the downstream river system.

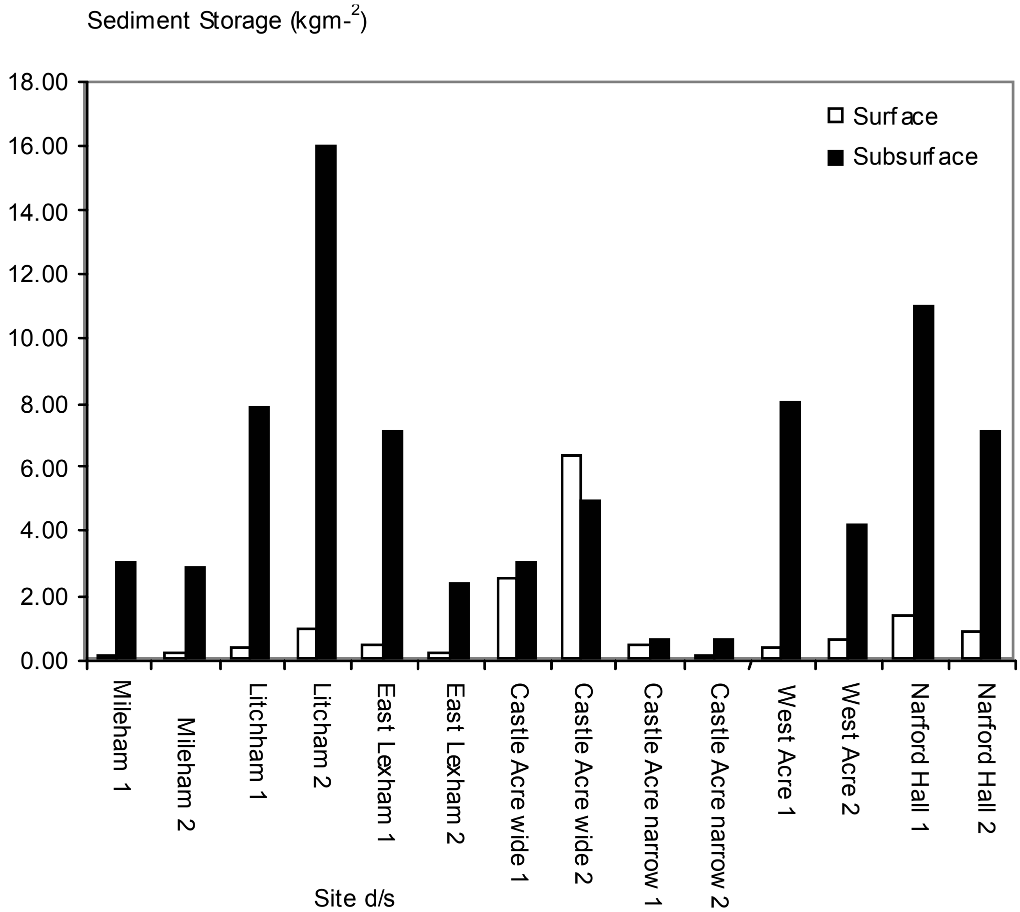


Figure 5.16: Fine sediment storage on the bed surface and within potential spawning gravels in the upper Nar. Values are typically 4 times higher than those found in steeper upland runoff dominated rivers.

5.3 Classification of River Nar sediment system

The status of the River Nar reaches identified by fluvial audit were assessed in terms of their function as either a source or storage reach for fine sediments. Note that reaches can be defined as both, in that storage of fines in one reach will provide a source of fines to downstream reaches. The criteria used in the classification of sediment source were:

- The percentage of fine sediment on the river bed surface.
- The total number of sediment ingress points in the reach.
- The proportion of bank erosion in a reach.

The criteria used in the classification of sediment storage (sinks) were:

- The percentage of fine sediment on the river bed surface.
- The proportion of each reach area occupied by fine sediment berms.

Each criterion was weighted such that a score reflects the total sum of the criteria multiplied by their weighting. The table of scores and weightings applied to all Multi-Criteria Analysis on the River Nar are given in Appendix 4.0. The MCA model was then run on the fluvial audit database and visualised in the GIS. Maps of Sediment Source Index and Sediment Storage Index are given in Sediment Source Maps 1-3 and Sediment Storage Maps 1-3 in Appendix 4.

The highest scores indicate a reach that is functioning as a sediment store (sink) or sediment source. In practice only those reaches with high scores (coloured blue) should be considered. There are also some anomalies resulting from no visible bed substrate, notably the lowest tidal scour reach (which is both a source and a sink of fine sediments), and the first yellow reach downstream from the headwaters near Mileham (which would also be classified as a sediment source and sink).

The classification identifies a sediment source reach in the headwaters and in the reaches upstream of Litcham. Further sediment source reaches occur in the reach between Castle Acre and West Acre. In these cases the cause is both the ingress points recorded on these reaches, and the high proportions of fine sediments on the river bed. Additional source reaches occur in Narborough where fines accumulate on the river bed and in berms, locally increasing the score. The largest source reaches are associated with the lower Nar downstream of Marham flume, where bank erosion, abundant fine sediment and ingress points combine to produce a high score. These reaches are also identified as sediment sinks.

Figure 5.17 provides a summary of the sediment system that functions on the River Nar. The reaches upstream of Lexham Hall are characterised as a sediment source area with a relatively high proportion of fine sediments stored in ditch-like channels. The presence of bank erosion and ingress points through this reach indicate that it is dominated by the supply of sediment. Local gradients are steep relative to other reaches and the accumulation of fines must result from supply, low flows and abundant macrophyte growth.

Downstream of Lexham Hall, the channel adopts a more natural morphology as flows increase with spring inputs, but gradients decline. Sediment ingress from the erodible sandy soils provides additional sandy substrate that increases in proportion through the Castle Acre-West Acre reach. In part this is a function of the reduction in gradient resulting from a more sinuous planform, together with locally over-widened sections. Morphology and sediment supply therefore control the movement and accumulation of fines. Downstream of West Acre, the river runs through wooded reaches with a relatively straight channel. Absence of macrophytes help reduce trapping of fines. Width:depth ratios also reduce and the channel is best characterised as a sediment transport reach. Ponding from Narborough increases fine sediment storage on the bed in the lower reaches.

Downstream of Narborough, hydraulic controls (in part natural), but also heavily controlled by tidal ponding and weirs, creates a reach that acts as both a sediment sink and sediment source. Transport of fine bedload and suspended load decreases downstream, resulting in downstream fining and siltation. Berms accumulate in the lower reaches, locally reducing water widths to 5m.

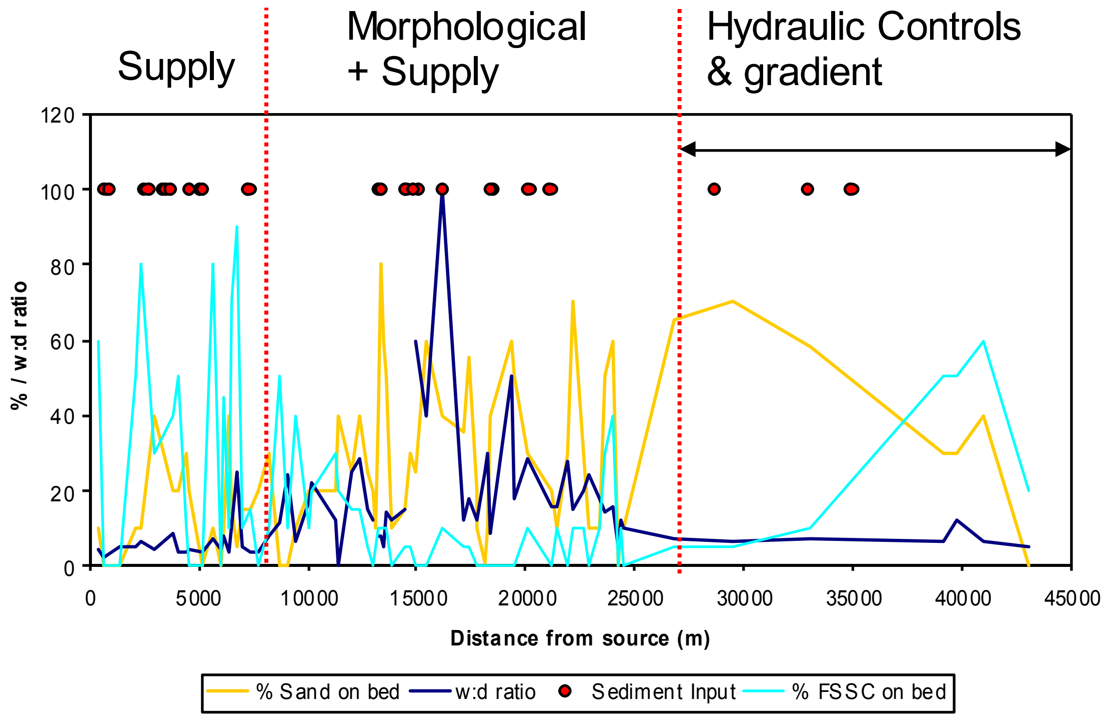


Figure 5.17: Summary of the main sediment system controls on the River Nar.

5.4 Capacity for natural recovery

The results of this analysis for the upper Nar support the view that the form and distribution of coarse gravel bed forms of the upper River Nar result from:

1) Inherited "relic" planform, gravel bed topography and sedimentology arising from glacial and postglacial river processes that were characterised by steeper valley gradients (sea level was far lower) and higher runoff compared with present conditions.

2) A long history of channel modifications that have altered the channel planform, cross-section and bed materials and which persist in the absence of coarse sediment supply and bed mobility.

3) Local scour and short-distance gravel transport is associated with: Local increases in bed and valley gradient (eg downstream of weirs, at valley constrictions): flow acceleration through channel constrictions (eg fallen debris, bridges, and narrowed channels): and strongly 3-dimensional flows that cause spatially discrete zones of scour (eg meander bends).

In turn these conditions make the upper River Nar:

- Highly sensitive to any form of channel modification since what is removed is unlikely to re-form through natural processes.
- Highly sensitive to increases in fine sediment loads, since the stable bed sediments will tend to accumulate fines without being flushed (this is confirmed to some extent by the reported high levels of fines in chalk stream sediments; Acornley & Sear 1999; Milan and others 2000).

- Unpredictable in terms of channel morphology and sedimentology with strong local control on channel form. The morphology is therefore not amenable to "textbook" restoration designs or importation of existing channel classifications, but requires local restoration vision based on understanding processes and modification history.

The gravel bed and morphology (where semi-natural) are among the highest value conservation features of the River Nar.

The Lower River Nar should be viewed as:

- A natural transitional river type of high conservation value.
- In its lower reaches, a heavily modified water course with a morphology that reflects centuries of management.
- A river where processes are largely depositional, dominated by fine sediments and strongly influenced by hydraulics.
- A river where absence of shade is one of the main factors contributing to prolific weed growth.
- A river where fine sediment ingress points are clearly identified and could be managed at source. These appear to be in part responsible for the increase in fine sediment accumulation in the High Bridge to Setchey reach.

6 River restoration vision and strategy

6.1 Introduction

The restoration vision for the river needs to be based on a set of scientifically justifiable principles. Where these are currently unable to be met the river should be recognised to be in a less favourable natural condition. These principles are:

1) Restoration of natural process rates.
2) Restoration of natural processes where these are missing.
3) Restoration of natural form where this has been damaged by past modification since the river is only able to adjust through fine sediment deposition.

It is recognised from the outset that the restoration of forms and processes should be based on those that can be sustained under current and future climate and sea level conditions. It should also be recognised that this report deals only with the functioning of the geomorphological processes; the same principles apply to hydrological, nutrient and biological processes.

The significance of the preceding sections is that it provides the scientific justification for recognising that the River Nar channel and floodplain has undergone significant transformations in morphology, process dominance and resulting physical habitat. Furthermore, many of the features of the current landscape can only be understood in relation to the sequence of past processes. It is also important to understand the large scale causation of valley and river morphology since this helps to define what is "natural" and therefore what is an appropriate definition of "reference condition" for the different river types represented within the River Nar catchment. Clearly, the importance of climatic and sea level changes in creating the larger scale morphology of the River Nar and its valley provide the context for the management of the channel into an era of predicted climate change and sea level rise.

The general implications of the geomorphological analysis of the River Nar highlight the largely relic nature of the valley sediments, planform and gravel bed topography. The inability of the current river processes to actively supply coarse material from either catchment sources, bank erosion or mobility and flux of bed material, results in a situation where the river geomorphology and coarse substrate are highly sensitive to modification. The combination of historical topographic surveys, channel maintenance records and contemporary surveys of the channel substrate and morphology support this assessment and demonstrate that the river can be viewed as an essentially static channel form with a substrate over which catchment-derived sand, silt and clay passes, accumulating only in areas of relatively low velocity. An additional proportion of the fine load is organic, with a likely source in decaying macrophytes and invertebrate faecal pellets.

The options for the restoration of natural processes and river form must be viewed within this context. Figure 3.13 provides a broad typology of the River Nar. This recognises natural transitions within the river network and extends the view of the river network out into the dry valleys and catchment surfaces. The sediment transport analysis has demonstrated how the channel is linked to the catchment surface through road, footpath and drainage networks. The assessment of modifications has demonstrated that the River Nar is largely modified, but with some reaches where the level of documented modification is low. Restoration of the River Nar must recognise the following constraints:

1) River processes will not replace dredged gravel substrates.
2) River processes will not create extensive coarse gravel features.
3) Fine sediment is the only mobile component of the sediment system.
4) The Nar is sensitive to increases in fine sediment loads due to a natural inability to flush fines.
5) Channel planform, long profile, cross-section form and connectivity with the floodplain are relics of past processes and will not recover to pre-disturbance states.
6) Natural processes of recovery will be dominated by fine sediment deposition and growth of aquatic vegetation.
7) The hydrological network of the River Nar should be viewed as including roads and associated drainage networks as well as the sequence of field drainage systems Management of these is as important to the restoration of the River Nar as is manipulation of the SSSI river network.

An important element of the restoration vision is based on assessing the extent to which the current channel diverges from the natural condition. Defining “naturalness” is therefore an important element of the restoration process since it provides an understanding of what the reference conditions should be. Reference conditions may form the basis of channel designs, and the baseline against which to monitor the effectiveness of the restoration. Reference Conditions are also relevant in defining the condition of the river in relation to the requirements of the Water Framework Directive.

6.2 Defining channel naturalness & reference condition for the River Nar

The European Committee for Standardisation (CEN 2004) lists reference conditions for hydromorphological quality in rivers as:

- Reflecting totally or nearly totally, undisturbed conditions.
- Lacking any artificial instream and bank structures that disrupt natural hydromorphological processes, and/or unaffected by any such structures outside the site.
- Bed and bank composed of natural materials.
- Planform and river profile: not modified by human activities.
- Lateral connectivity and freedom of lateral movement: lacking any structural modification that hinders the flow of water between the channel and the floodplain, or prevent the migration of a channel across the floodplain.
- Lacking any instream structural works that affect the natural movement of sediment, water and biota.
- Having adjacent natural vegetation appropriate to the type and geographical location of the channel.

When viewed against these criteria and when viewed as a whole, the River Nar is not in good hydromorphological quality. However, some reaches may be closer to these hallmarks of naturalness than others. The vision for restoration should therefore aim to move the River Nar towards this definition of condition, within the constraints of flood risk management, and progressively as funds permit. It is equally important that any restoration does not make the current status any worse.

The CEN definitions are generic. What is necessary is to define naturalness for the local conditions in the Nar catchment. Appendix 5.0 details the process through which this has been undertaken for the two broad river types on the River Nar; groundwater dominated rivers flowing from chalk geology with overlying glacial deposits; and low gradient semi-tidal channels. Two sources of information have been used to define a natural vision for these channel types;

1) Scientific literature where available from semi-natural or natural rivers of similar type.
2) River Habitat survey data for semi-natural reference sites of similar type.

The physical attributes derived from these data sources have been combined into a table for each river type. Not all values are available from existing data. Those that are available have been used according to the Naturalness Index in the MCA tables in Appendix 4. It is recognised that the attributes, scores and weights are subjective. The MCA process enables discussion and modification of these according to expert or local understanding.

The Naturalness Index was derived for each reach identified by fluvial audit. The lower the index score the higher the naturalness of the reach as defined by the attributes used. The existing modification index was enhanced by including two other categories, presence of ponded flow upstream of structures, and > 80% bed cover by macrophytes. The Naturalness Index and Modification Index were then overlaid in the GIS and both visualised. The resulting reaches are coloured according to the degree of naturalness and modification. This provides a set of potential classes for each reach – in principle similar to the River Habitat Survey Physical Quality Objectives (Walker and others 2002) only derived from science-based and locally applicable datasets. Figure 6.1 illustrates the potential classes arising from the combination of naturalness and modification indices and a reclassification matrix.

	0 Natural	**1 Predominantly natural**	**2 Partially natural**	**3 Practically Un-natural**	**4 Un-Natural**
0 Unmodified	Natural	Semi-Natural	Damaged	Damaged	Damaged
1 Predominantly Unmodified	Semi-Natural	Semi Natural	Damaged	Damaged	Damaged
2 Obviously Modified	Recovered	Recovering	Degraded	Degraded	Degraded
3 Significantly Modified	Recovered	Recovering	Degraded	Severely Degraded	Severely Degraded
4 Severely Modified	Recovered	Recovering	Degraded	Severely Degraded	Artificial

Figure 6.1: Classification of reach types arising from the combination of Modification and Naturalness Indices.

Each reach class can be allocated a management action required to move the river towards an improved condition. In the simplest case of a natural river reach the action would be to protect and monitor the status. For the artificial river reach it is most likely a case of 'do nothing' as there is very little that can be achieved. Figure 6.2 details the management options for each river class, through a separate reclassification. These form the basis for the restoration vision for the River Nar. Definitions of the terms used are given in Table 6.1. The final element of the vision is to recognise that maximum gain in terms of restoration is achieved by building out from the best sites, rather than attempting to improve the mediocre sites.

	0 Natural	1 Predominantly natural	2 Partially natural	3 Practically Un-natural	4 Un-Natural
0 Unmodified	Protect & Monitor	Protect & Monitor	Assist natural Recovery	Restoration	Restoration
1 Predominantly Unmodified	Protect & monitor	Protect & Monitor	Assist natural Recovery	Restoration	Restoration
2 Obviously Modified	Conserve & Monitor	Assist natural Recovery	Rehabilitation	Rehabilitation	Enhancement
3 Significantly Modified	Conserve & Monitor	Assist natural Recovery	Rehabilitation	Rehabilitation	Enhancement
4 Severely Modified	Conserve & Monitor	Assist natural Recovery	Rehabilitation	Rehabilitation	HMWB

Figure 6.2: Management action associated with each reach class. Definitions of the terms used are given in Table 6.1. (HMWB stands for Heavily Modified Water Body)

Table 6.1: Definition of terms used in Figure 6.2. Costs typically rise up the table.

Term	Definition
Restoration	Restoration of to a pre-disturbance state.
Rehabilitation	Physical modification to the river form to re-create physical habitats (eg re-meandering, riffle installation, bed level raising).
Enhancement	Addition of structural features to improve physical habitat diversity (eg narrowing, woody debris).
Protect & monitor	Afford legal protection to the site and monitor for change in status.
Assisted natural recovery	Amplification of existing processes to encourage recreation of physical habitats (eg encouraging berm formation to narrow channel, removal of bank revetment to create sediment supply).
Conserve	Protect site against further degradation not necessarily with legal statute.

6.3 A classification of management options for the River Nar

Table 6.2 provides a reach by reach classification according to the criteria outlined in Figures 6.1 and 6.2. Each reach was then reviewed against the database from the fluvial audit and cross-referenced against the reach codes in the Land Use Consultants report (2001). Where the classification was not accepted, the reach was given a new score and management option. This was only necessary on reaches 5 and 76. There is good agreement between the Land Use Consultant report reaches and the reach types identified by the classification. There is also excellent agreement between the reaches selected in 1962 by Prof Adrian Harvey as having a semi-natural geomorphology, and the semi-natural/natural classes identified by the MCA analysis. Modified Lakes are correctly classified as artificial. On this basis, the river classification is believed to be robust.

Possible options for river restoration are given in Table 6.2. These are based on an assessment of the main contributory indices to the naturalness scores and modification scores. Each reach was also checked against the photographs and map-based information on the GIS.

The reach status and reach management classes are provided in map formats in Maps 1-3 (Naturalness and Modification) and Maps 1-3 (Reach management type) and all the data are accessible as layers within the GIS (Appendix 4).

The prioritising of the restoration options should be guided by catchment scale requirements:

1) Establish a programme for treating the sediment ingress problems identified by this report prior to any physical habitat restoration/rehabilitation or enhancements except where these form part of the sediment source control.
2) Set in place a condition monitoring plan for all semi-natural/natural and recovering reaches.
3) Prioritise the restoration/rehabilitation/enhancement on the basis of linking existing natural/semi-natural reaches first.
4) Seek to improve those reaches closest to semi-natural conditions.

The options reported in Table 6.2 and within the GIS are given in order to return the river to a functioning chalk stream habitat characteristic of the geographical location. They do not take into account landscape/cultural aspects. Neither do they account for any particular set of biota or stakeholder interests which should be negotiated locally using the outputs of this report to guide the discussions where appropriate.

Use of the natural channel descriptions in Appendix 5.0

The two tables created from the review of scientific and RHS data may be used to support restoration design plans. However it is recommended that specific options are carefully considered and appropriate use made of expert advice on the ground.

Woody debris and wooded riparian margins

The review of natural groundwater dominated rivers with low gradients provides targets for restoration. These have been applied within the MCA analysis and are reflected in the options for management. A key missing element and a major cause of excessive weed growth in the channel is the lack of shading provided by a wooded riparian margin. Linked to this is the lack of recruitment of woody debris to the River Nar. This is known to be a major source of habitat diversity in semi-natural chalk streams, and works to suppress excessive weed growth. Coarse or large woody debris in the form of trees falling into the channel create major increases in physical habitat diversity (German & Sear 2003). However there are legitimate concerns of flood risk management. Clearly some debris management will still be necessary and limited to reaches where overbank flooding is both possible and desirable.

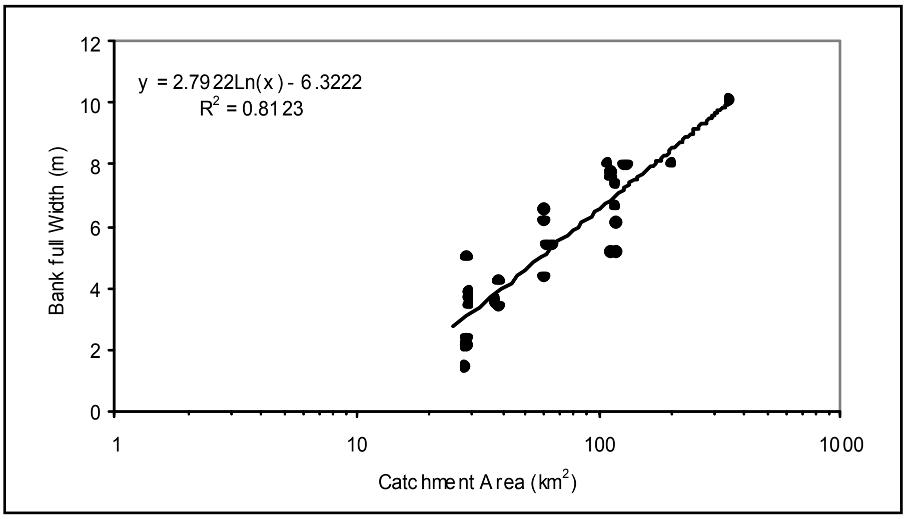
Tree-lined riparian corridors in natural chalk streams and Fenland Rivers typically have open patches created by tree fall or by locally waterlogged conditions where light can penetrate the channel (See Figure 6.3). Thus management of dense wooded sections is envisaged in order to provide a patchwork of light and shade where macrophytes can develop within the channel.

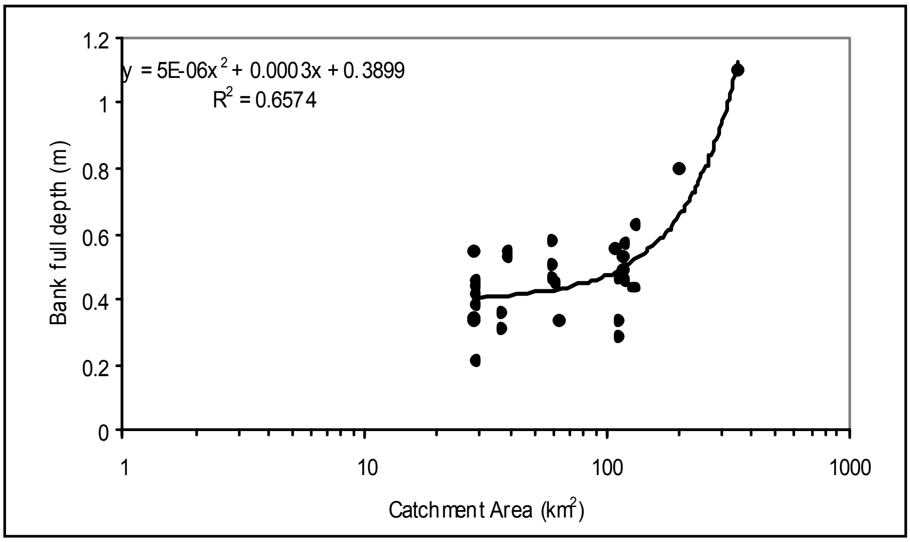
Figure 6.3: Woody debris and macrophyte patches in groundwater dominated chalk streams a) Bere stream River Wylye in Wiltshire b) Large Spring river, Oregon photo courtesy of D.Reiser.

The use of trees rather than cut timber for the enhancement of chalk streams is based on the greater diversity benefits provided by the complex structures fallen trees create. Analysis of the impacts of wood structures on the physical and hydraulic properties of chalk streams undertaken as part of the Life in UK Rivers project (German and Sear 2003; Kondolf and others 2003) demonstrated that measurements of habitat patchiness and diversity were low compared to reaches with natural debris accumulations. However, where such structures are considered inappropriate or unacceptable for flood risk management, then simpler log structures could be used.

Channel dimensions

An important aspect of restoration and rehabilitation projects is the design of the channel dimensions. A guide to these has been undertaken as part of this study, based on datasets provided by Prof Adrian Harvey (1967) and Stephanie Goff (Newson, pers comm.). The equations presented in Figure 6.4 can be used to provide design guidance for the basic dimensions of the bankfull channel.





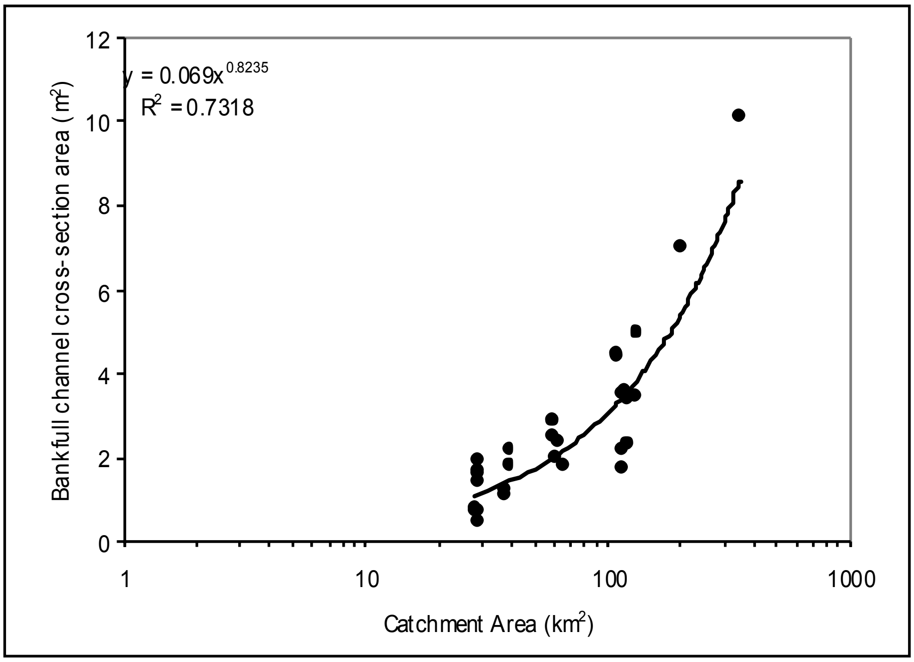


Figure 6.4: Regime equations for semi-natural Norfolk chalk streams.

Table 6.2: Classification of river reaches on the River Nar. Restoration options are given along with the sediment source and sediment sink scores. Data is visualised in Maps 6.1-6.6 and as a layer in the GIS. Coloured reaches are those with high sediment source and high sediment sink values. Coarse Woody Debris (CWD) Heavily Modified Water Body (HMWB). The table does not attempt to give the individual, site specific design of restoration options at a reach; which would need to be the subject of separate design specification and local evaluation.

Reach code	Reach length (m)	Distance d/s (km)	Reach status	Reach management class	Indicative restoration options	Naturalness	Modification	Sediment sink score	Sediment source score
N307	471	0.471	Degraded	Rehabilitation	Fix sediment ingress / recut new river channel / establish riparian woodland.	45.75	16	22.5	32.5
N306	219	0.69	Severely Degraded	Rehabilitation	Recut new river channel / establish riparian woodland.	61.75	27	4.5	4.5
N305	784	1.474	Severely Degraded	Rehabilitation	Recut new river channel / establish riparian woodland.	52.75	37	4.5	13.5
N304	659	2.133	Severely Degraded	Rehabilitation	Recut new river channel / establish riparian woodland.	51.75	16	22.5	22.5
N303	190	2.323	Artificial	HMWB	Fix sediment ingress / recut new river channel/establish riparian woodland.	74.25	22	45	45
N302	638	2.961	Severely Degraded	Rehabilitation	Fix sediment ingress / recut new river channel / establish riparian woodland.	60.75	16	22.5	36.5
N301	839	3.8	Severely Degraded	Rehabilitation	Fix sediment ingress/raise bed elevation using gravel / recut new river channel/ establish open riparian woodland / introduce CWD to channel.	39.75	6	22.5	41.5
N300	279	4.079	Damaged	Restoration	Bed level raising/manage open riparian woodland / reconnect with floodplain / introduce CWD to channel.	49.75	0	22.5	27.5
N231	415	4.494	Damaged	Assist natural recovery	Fix sediment ingress to reach/ re-establish old channel course/introduce woody debris and mixed riparian margin (woodland + gaps).	46.75	0	9	14
N230	129	4.623	Degraded	Rehabilitation	Fix sediment ingress to reach / re-establish old channel course/introduce woody debris and mixed riparian margin (woodland + gaps)	36.25	16	22.5	36.5

Reach code	Reach length (m)	Distance d/s (km)	Reach status	Reach management class	Indicative restoration options	Naturalness	Modification	Sediment sink score	Sediment source score
N229	638	5.261	Degraded	Rehabilitation	Fix sediment ingress to reach / re-establish old channel course/introduce woody debris to channel and mixed riparian margin (woodland + gaps).	42.75	16	4.5	13.5
N228	344	5.605	Severely Degraded	Enhancement	Fix sediment ingress to reach / re-establish old channel course/introduce woody debris to channel and mixed riparian margin (woodland + gaps).	76.25	16	45	54
N227	352	5.957	Degraded	Rehabilitation	Establish new river course to south of lakes / channel to connect reach 300 (Litcham) and 2220 (East Lexham) / By-pass and cut off lakes / Establish riparian margins and introduce woody debris to channel.	38.75	16	4.5	9.5
N225	237	6.194	Severely Degraded	Rehabilitation	Establish new course to south of lakes / channel to connect reach 300 and 2220 / By-pass and cut off lakes / establish riparian margins and introduce woody debris to channel.	53.75	16	22.5	22.5
N226	203	6.397	Severely Degraded	Rehabilitation	Establish new course to south of lakes / channel to connect reach 300 and 2220 / By-pass and cut off lakes / establish riparian margins and introduce woody debris to channel.	62.75	16	22.5	22.5
N223	160	6.557	Artificial	HMWB	Establish new course to south of lakes / channel to connect reach 300 and 2220 / By-pass and cut off lakes / establish riparian margins and introduce woody debris.	94	35	45	45

Reach code	Reach length (m)	Distance d/s (km)	Reach status	Reach management class	Indicative restoration options	Naturalness	Modification	Sediment sink score	Sediment source score
N222	166	6.723	Artificial	HMWB	Establish new course to south of lakes / channel to connect reach 300 and 2220 / By-pass and cut off lakes / establish riparian margins and introduce woody debris.	84.25	27	45	45
N221	279	7.002	Degraded	Rehabilitation	Establish new course to south of lakes / channel to connect reach 300 and 2220 / By-pass and cut off lakes / establish riparian margins and introduce woody debris to channel.	44.25	16	22.5	22.5
N2220	371	7.373	Severely Degraded	Rehabilitation	Establish new course to south of lakes / channel to connect reach 300 and 2220 / By-pass and cut off lakes / establish riparian margins and introduce woody debris to channel.	53.75	16	9	18
N511	395	7.768	Degraded	Rehabilitation	Raise bed levels using gravels from dredgings / introduce bed morphology / manage riparian margins to provide woody debris and open gaps in woodland.	49.25	12	22.5	22.5
N510	516	8.284	Degraded	Rehabilitation	Raise bed levels using gravels from dredgings / introduce bed morphology / manage riparian margins to provide woody debris and open gaps in woodland.	36.75	22	9	19
N509	475	8.759	Recovering/Semi -Natural	Enhancement	Enhance downstream reach / allow woody debris to remain in channel / monitor silt accumulation in channel.	30.5	0	22.5	22.5
N508	382	9.141	Recovering	Assist natural recovery	Fix sediment ingress & establish morphology and woody debris / wooded riparian margins.	28.25	16	22.5	32.5
N507	348	9.489	Degraded	Rehabilitation	Consider options for re-cutting new natural channel form through parkland, by-passing sluice & lakes.	53.75	12	22.5	22.5

Reach code	Reach length (m)	Distance d/s (km)	Reach status	Reach management class	Indicative restoration options	Naturalness	Modification	Sediment sink score	Sediment source score
N506	537	10.026	Recovered	Enhancement	Remove structures / establish wooded riparian margins with shade & open patches / introduce large woody debris.	21.5	12	9	24
N505	201	10.227	Semi-Natural	Protect & Monitor	Remove structures / do not remove large woody debris.	16.5	8	9	9
N504	1113	11.34	Damaged	Assist natural recovery	Lower reach manage wooded riparian margins to create shade. Upper straightened reach consider restoring former course to south along old drain.	37.5	8	22.5	22.5
N503	81	11.421	Damaged	Assist natural recovery	Remove any barriers creating ponding.	37.5	0	22.5	22.5
N502	653	12.074	Semi-Natural	Protect & Monitor	Maintain existing management regime.	20.5	8	9	9
N501	345	12.419	Recovering	Assist natural recovery	High - Fix sediment ingress / establish wooded riparian corridor with open gaps / introduce woody debris.	25.5	12	22.5	32.5
N500	306	12.725	Semi-Natural	Protect & Monitor	Monitor condition.	16.5	8	9	9
N220	239	12.964	Natural	Protect & Monitor	Monitor condition.	12	0	22.5	22.5
N219	161	13.125	Semi-Natural	Enhancement	Remove groynes / establish wooded riparian corridor & introduce woody debris.	12	0	22.5	27.5
N218	118	13.243	Damaged	Assist natural recovery	Re-establish bed levels / establish wooded riparian corridor/allow some woody debris.	42.5	8	22.5	22.5
N217	103	13.346	Damaged	Restoration	Fix sediment ingress from drain. Establish appropriate morphology by raising bed elevation using gravel from dredgings / establish wooded riparian corridor.	76.25	0	45	64

Reach code	Reach length (m)	Distance d/s (km)	Reach status	Reach management class	Indicative restoration options	Naturalness	Modification	Sediment sink score	Sediment source score
N216	128	13.474	Damaged	Restoration	Fix sediment ingress from drain. Establish appropriate morphology by raising bed elevation using gravel from dredgings / establish wooded riparian corridor.	52.5	8	28.5	31.5
N215	217	13.691	Semi-Natural	Protect & Monitor	Fix sediment ingress from drain. Narrow channel by 30%. Establish open wooded riparian corridor to provide shade / reduce grazing pressure on banks.	25.5	8	22.5	32.5
N214	231	13.922	Semi-Natural	Protect & Monitor	Improve north bank riparian margins.	12	0	22.5	22.5
N213	594	14.516	Semi-Natural	Protect & Monitor	Fix sediment ingress from drain and road / Remove excess fine sediment/ Remove embankment to reconnect floodplain.	23	8	28.5	36.5
N212	178	14.694	Recovering	Assist natural recovery	Fix sediment ingress points from road / ford.	32.75	16	9	18
N211	246	14.94	Recovered	Conserve & Monitor	Monitor condition.	23.25	16	22.5	22.5
N210	495	15.435	Recovering	Assist natural recovery	Reduce width by using large woody debris in over-widened reaches - encourage mixture of shade / light.	30.5	16	22.5	22.5
N209	832	16.267	Degraded	Rehabilitation	Fix sediment ingress point in downstream end or reach. Reduce width by using large woody debris in over-widened reaches - encourage mixture of shade / light.	36.5	16	28.5	31.5
N208	868	17.135	Degraded	Rehabilitation	Remove embankment. Establish wooded riparian corridor with open patches.	50.75	16	15	9
N207	296	17.431	Degraded	Rehabilitation	Remove accumulation of sand. Narrow channel by 30% using gravel from dredgings, introduce woody debris to channel.	41.75	16	22.5	22.5

Reach code	Reach length (m)	Distance d/s (km)	Reach status	Reach management class	Indicative restoration options	Naturalness	Modification	Sediment sink score	Sediment source score
N206	304	17.735	Recovered	Conserve & Monitor	Selected tree management to provide light patches. Allow woody debris to remain in channel.	23.25	16	22.5	22.5
N205	114	17.849	Recovered	Conserve & Monitor	Selected tree management to provide light patches. Allow woody debris to remain in channel.	12	16	22.5	22.5
N204	313	18.162	Recovered	Conserve & Monitor	Selected tree management to provide light patches. Allow woody debris to remain in channel.	23.75	16	4.5	4.5
N203	164	18.326	Recovering	Assist natural recovery	Look to reduce ponding from mill. Selected tree management to provide light penetration / suction-dredge silt beds from mill pool.	28.25	31	22.5	22.5
N202	72	18.398	Degraded	Rehabilitation	Monitor condition	36.75	16	9	9
N201	1035	19.433	Degraded	Rehabilitation	Fix sediment ingress from road runoff. Establish woody riparian corridor with gaps.	42.5	14	22.5	36.5
N200	86	19.519	Recovering	Assist natural recovery	Suction dredge sand deposits.	30.5	16	22.5	22.5
N100	616	20.135	Recovered	Conserve & Monitor	Monitor condition.	20.5	16	9	9
N1014	1104	21.239	Recovering	Assist natural recovery	Fix sediment ingress from pig unit / field runoff down road. Increase penetration of light by selected tree management / establish woody debris in channel.	29.25	16	28.5	31.5
N1013	260	21.499	Recovered	Conserve & Monitor	Monitor condition.	23.25	16	22.5	22.5
N1012	455	21.954	Recovering	Assist natural recovery	Monitor fine sediment accumulation on bed. Check fish farm for sediment input.	27.75	16	9	9

Reach code	Reach length (m)	Distance d/s (km)	Reach status	Reach management class	Indicative restoration options	Naturalness	Modification	Sediment sink score	Sediment source score
N1011	182	22.136	Severely Degraded	Rehabilitation	Suction-dredge fine sediment.	65.25	16	51	45
N1010	451	22.587	Recovering	Assist natural recovery	Selective woodland management to create light patches / introduce woody debris into channel to create diversity of habitat.	27.75	16	9	9
N1009	350	22.937	Recovering	Assist natural recovery	Selective woodland management to create light patches/ introduce woody debris into channel to create diversity of habitat.	27.25	16	22.5	22.5
N1008	473	23.41	Recovered	Conserve & Monitor	Monitor condition	23.25	16	22.5	22.5
N1007	163	23.573	Severely Degraded	Rehabilitation	Remove silts and treat ingress of sand (road drainage) / establish habitat enhancements.	64.25	16	45	45
N1006	479	24.052	Severely Degraded	Rehabilitation	Remove silts and treat ingress of sand (road drainage) / establish habitat enhancements.	64.25	16	45	45
N1005	222	24.274	Degraded	Rehabilitation	Urban flood risk, enhancement opportunities.	39.75	16	4.5	4.5
N1004	383	Branch	Degraded	Rehabilitation	Remove silts / establish habitat enhancements (formalise narrowing).	36.75	16	22.5	22.5
N1003	198	Branch	Severely Degraded	Rehabilitation	Desilt, remove mill weir or modify management of mill structure.	64.25	16	45	45
N1002	103	Branch	Recovering	Assist natural recovery	Monitor fine sediment accumulation on bed.	9	9	33.25	16
N1001	274	Branch	Recovered	Enhancement	Enhancement structures in channel Urban flood risk.	23.25	16	22.5	37.5
N8	131	24.491	Recovered	Enhancement	Improve bank morphology / create in-channel habitat diversity using wood structures.	15	22	22.5	22.5

Reach code	Reach length (m)	Distance d/s (km)	Reach status	Reach management class	Indicative restoration options	Naturalness	Modification	Sediment sink score	Sediment source score
N7	2381	26.872	Degraded	Rehabilitation	Continue existing rehabilitation. Set-back embankments & re-profile margins / establish wooded riparian margins / fix woody debris structures in channel.	45.75	22	22.5	22.5
N6	29548	29.548	Severely Degraded	Enhancement	Reduce bank angles and look to pull back embankments. Manage weed growth to create sinuous channel within flood channel.	80	16	45	64
N5	32990	32.99	Severely Degraded	Enhancement	Reduce bank angles and look to pull back embankments. Manage weed growth to create sinuous channel within flood channel.	67	16	22.5	31.5
N4	39208	39.208	Severely Degraded	Enhancement	Fix sediment ingress from County Drain and pumping station under jurisdiction of East of Ouse IDB. Reduce bank angles and look to pull back embankments. Manage weed growth to create sinuous channel within flood channel.	89	16	45	54
N3	39778	39.778	Severely Degraded	Enhancement	Reduce bank angles and look to pull back embankments. Manage weed growth to create sinuous channel within flood channel.	51	16	45	45
N2	41090	41.09	Severely Degraded	Enhancement	Reduce bank angles and look to pull back embankments. Manage weed growth to create sinuous channel within flood channel.	81	16	45	45
N1	43067	43.067	Severely Degraded	Enhancement	NORA Scheme - Enhancement of riparian margins.	81	16	45	45

6.4 Existing rehabilitation proposals

Specific options for enhancement exist on the River Nar, through existing programmes, plans and projects. These include:

- The Nar Ouse Regeneration Area (NORA) landscape enhancement works.
- Lower Nar Navigation.
- Cinderella Chalk Streams Project.
- Nar Rehabilitation plan
- Conservation Strategy for the River Nar SSSI.
- Castle Acre Fishing club rehabilitation proposals.

These can be assessed against the recommendations made in Table 6.2 of this report. The Cinderella Chalk Streams Project and the lower Nar rehabilitation work are both broadly consistent with the findings of this report. The Castle Acre Fishing Club recommendations are again broadly consistent in principle, but differ in technical implementation.

6.4.1 Implications for the Nar Ouse Regeneration Area (NORA)

The NORA proposals lie immediately downstream of the SSSI boundary. Notwithstanding, the implications of these findings, this report provides some context for the proposed modifications to the channel in this reach. It should be noted that this reach is influenced by tidal processes, with ponding at high tides and scouring flows through the tidal outfall. Analysis of sediment samples taken from this reach confirm that the fine sediment in this reach is largely composed of fine silts with sand. This is commensurate with the ponded nature of flows, possible introduction of suspended sediments from the tidal Great Ouse, and its position at the end of a long, low gradient fenland drainage channel. The proposals outlined in the Shiels Flynn strategic landscape report (2003), (Table 6.3) suggest modifications to the River Nar bank profiles, although there is suggestion that these proposals are already out of date and that the current proposals are much reduced and centre on enhancing river margins.

Table 6.3 provides a comparative assessment of the advice provided by the NORA restoration objectives and the advice derived from the Fluvial Audit assessments.

Table 6.3 Comparative objectives and advice from the NORA projects and those from the Fluvial Audit.

Area	Design objectives & proposed character/habitat	Fluvial audit guidance
River Nar corridor to south of Central park	Widened river corridor designed to create more extensive and ecologically varied wetland areas bordered by native meadow. The river will be allowed to colonise the wetlands within the wider corridor, generating a natural habitat.	Expect siltation by suspended sediments on lower areas during ponding by high tides and times of fluvial flooding. Rates of accumulation uncertain due to lack of information on sediment transport rates. Opportunity to create marginal reed beds and carr woodland in keeping with natural tidal river habitat.

Area	Design objectives & proposed character/habitat	Fluvial audit guidance
Central Park	Contemporary park – opportunity to experience wetlands at close quarters. East bank wetlands designed to receive water from River Nar on a seasonal basis. Floodplain lowered and sculpted to create sinuous depression. West bank, a backwater channel created.	Expect siltation by suspended sediments on lower areas during ponding by high tides and times of fluvial flooding. Likely rapid infilling of backwater channel and conversion to wetland. Rates of accumulation uncertain due to lack of information on sediment transport rates. Opportunity to create marginal reed beds and carr woodland in keeping with natural tidal river habitat.
River Nar corridor to north of Central Park.	River corridor widened and excavated to lower level. Partially river braided channel. Island mound planted with native trees. To north river confined within existing step banks.	Expect siltation by suspended sediments on lower areas during ponding by high tides and times of fluvial flooding. Rates of accumulation uncertain due to lack of information on sediment transport rates. Opportunity to create marginal reed beds and carr woodland in keeping with natural tidal river habitat. **Note:** 'braiding' is not the appropriate term since this describes an active sand or gravel channel with mobile sediment bars.

These river reaches accumulate fine silts and sand. These sediments are scoured at low tides from the central channel leaving deposits on the banks. The proposals are unlikely to affect the sedimentation processes in the main channel, but will encourage deposition on the lower (rougher) margins and low lying areas. It is not possible to estimate rates of fine sedimentation, but experience from upstream de-silting regimes suggests 0.3m accumulation over a typical 5-10 year period in the upper channel. The documentation available to this study does not currently make mention of the projected impacts of relative sea level rise. Sea level rise over the next 50-100 years will impact on tidal levels and standards of flood risk management. The impacts of these on sedimentation processes in this reach are unknown. The proposed designs should plan to accommodate progressive fine sediment accumulation. At present there are no opportunities for maintenance of the river channel by de-silting. Given the depositional nature of this river reach, access for de-silting should be considered. Monitoring of sediment accumulation rates in this reach and in particular the role of tidal vs. fluvial sediment sources is recommended as an aid to planning the management of the NORA Nar corridor proposals.

Off-site channel enhancement opportunities for the lower Nar are likely to be most effective in two areas:

1) Management through land use planning and runoff control in the Country and Blackborough drains. This might have positive benefits for the sedimentation of the downstream reaches.

2) Habitat enhancements in reach N7 upstream of Marham flume with a view to set back of flood embankments and reconnection of the channel and floodplain together with in-channel habitat enhancement.

6.4.2 Implications for the navigation proposals

Navigation of the lower Nar is once again under consideration. The proposal currently involves:

1) Creating a new access channel along the course of the present flood relief channel direct into the Eau Brink Cut on the Great Ouse.
2) Dredging, widening and straightening the existing River Nar from the flood relief channel to the tidal sluice.
3) Raising water levels within the lower Nar to accommodate boat access into Boals Quay marina.
4) Developing a marina at Boals Quay.

The geomorphology of the proposed reach is currently dominated by fine silt and sand accumulation within a heavily modified watercourse. Morphologically the reach is not in favourable condition and is classified as severely degraded compared to natural conditions. The gradients through this reach are low, and in high tide flows become ponded.

The main implications of the navigation (apart from the obvious impacts on the NORA enhancement proposals discussed above) would be the creation of a wider, deeper more ponded channel. Given the depositional character of this reach, these conditions in association with increased bed and/or bank erosion arising from boat wash/propeller activity, will most likely result in an increase in the rate of deposition in this reach. Morphologically, the navigation will provide no net improvement in the natural processes or form of this reach. Opportunities for bank side enhancements to bank morphology will be offset by increases in flow depth. Maintenance of the navigable channel will be required in the form of de-silting, further disturbing the channel morphology and substrate.

The Stage 1 report on the navigation outlines potential enhancement opportunities outside the proposed navigation in recognition of the detrimental impacts on the SSSI condition. Off-site channel enhancement opportunities for the lower Nar are likely to be most effective in two areas:

1) Management through land use planning and runoff control in the Country and Blackborough drains. This might have positive benefits for the sedimentation of the downstream reaches.
2) Habitat enhancements in reach N7, upstream of Marham flume, with a view to set back of flood embankments and reconnection of the channel and floodplain together with in-channel habitat enhancement.
3) Funding of elements of the restoration vision outlined in this report.

6.4.3 Further management implications

A number of other management options proposed for the River Nar should be informed by the fluvial audit report, whilst being outside the remit of the report itself. In particular, the management objectives of the fisheries (poaching control, management of *Sparganium*) should be informed by the report and GIS datasets (in terms of the location and severity). *Sparganium* has not been mapped as part of this project and may therefore limit the information that can be gained from the fluvial audit, although the role of aquatic macrophytes in the geomorphology of the channels is discussed.

The management of the groundwater resources in the upper catchment will be informed by the Environment Agency's Restoring Sustainable Abstraction Program. In taking this forward, water resources should be considered as a key driver that affects the transport of fine sediment, and nutrients. The restoration of sustainable abstraction is therefore an important mechanism for river restoration so as to ensure sufficient flows to sustain natural flow regimes.

The King's Lynn Consortium of Internal Drainage Boards should consider the implications of this report when reviewing or revising its Standard Maintenance Operations. In addition to the control of sediment ingress to the river, further sustainable management options, related to fine sediment and macrophytes, include the use of woody debris and trees to management shading.

7 Conclusions

- The River Nar geomorphology and bed substrate are a relic of past geomorphological processes that are no longer operating at the same rate. The River Nar is therefore highly sensitive to changes in morphology and substrate arising from human activity. The gravel bed is stable across all flows in most reaches except those that are artificially deepened (eg around Litcham). Natural development of pool-riffle sequences and meandering planforms with gravel point bars are highly unlikely. Where gravel beds occur in a semi-natural or natural condition, these are of high conservation status.
- The River Nar no longer receives a significant supply of gravel. Removal of gravel from the river will not be replenished and is lost to the river. Fine sediment is mostly derived from catchment sources, with limited contribution from bank erosion. The sand load is mobile throughout the river under flood conditions. As a result, input points of fine sediment can have long distance impact in the upper reaches.
- The gravel bed stores high levels of fine sediment which may be detrimental to ecological function. This results from a lack of natural gravel "flushing". Remediation through gravel jetting will release up to 650kg of fine sediments per riffle into the downstream river.
- Fine sediment sources are largely produced from road, field runoff and disturbance of drainage ditches by maintenance. 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 transition from a gravel-sand dominated river to a low gradient sandy-silt dominated river downstream of Narborough is a natural transition and should be recognised as a valuable ecological gradient.
- The lower Nar sediment transport system is dominated by fine sands and silts derived from the upstream catchment and two main ingress points where the East of Ouse IDB drainage system connects with the main river. Sedimentation is significantly influenced by the naturally low gradient and ponding due to tidal backwatering. In the short term (<10years) fine sediment accumulation has less impact on water levels than weed growth.

- Management of weed growth in the lower Nar is not a geomorphological issue other than it represents a process whereby fine sediment can be trapped and over time develop into low level berms and in time create a 'floodplain' within the over-widened channel. It is therefore a process of natural channel width adjustment. However, the quantity of weed growth is a product of high nutrient and unnaturally high light levels resulting from the managed channel margins. Long term, management of the lower Nar towards more favourable condition would require set back of the flood embankments and encouragement of shading to suppress weed growth. The current perched nature of the channel precludes the setting back of the embankment except in the reach upstream of Marham flume.
- Suppression of light by shading represents a method of controlling prolific weed growth in narrow channels such as the upper Nar and is characteristic of the natural chalk stream riparian corridor.
- Large woody debris is an important missing element of the upper Nar chalk stream geomorphology. Woody debris creates local scour and habitat diversity. Local accumulations also increase channel-floodplain connectivity. At present woody debris is removed from the river and there is an absence of wooded riparian margins from which to recruit debris.
- A methodology for classifying the whole River Nar in terms of condition relative to natural has been developed based on data provided by the scientific literature and River Habitat Survey. A new Multi-Criteria Analysis approach has been developed to create indices of geomorphological function (sediment source, sediment sink) naturalness, and modification.
- The MCA analysis has demonstrated that only 11.2% of the total length of the River Nar had no documented modification.
- Over 48% of the length of the River Nar is severely degraded relative to the natural geomorphological condition (Figure 7.1).
- 25.1% of the total river length is in a damaged or degraded state relative to natural geomorphological condition.
- Some 23% of the total river is natural/semi natural/recovered or recovering towards a more natural geomorphological condition. This is all located upstream of Narborough.
- 11.2% of the River Nar is in a semi-natural or natural geomorphological condition (though these reaches are affected by modified catchment processes).
- 14% of reaches can be improved by assisted natural recovery through removal of excessive fine sediment deposits and shading to reduce the growth of emergent and aquatic macrophytes.
- 42% of reaches can only recover through enhancement of existing form, with little prospect of significant improvement in condition.
- 33% of the total river length of 43.067 km would benefit from rehabilitation or restoration to improve channel condition.
- Table 6.2 and the accompanying Maps and GIS provide reach-based guidance on the form of management required to improve the condition of the River Nar towards a more naturally functioning river.

The prioritisation of the restoration options should be guided by catchment scale requirements. These include:

- The establishment of a programme for treating the sediment ingress problems identified by this report prior to any physical habitat restoration/rehabilitation or enhancements except where these form part of the sediment source control.
- The introduction of a condition monitoring plan for all semi-natural/natural and recovering reaches.
- Prioritisation of the restoration/rehabilitation/enhancement on the basis of linking existing natural/semi-natural reaches first.
- The objective of seeking to improve those reaches closest to semi-natural conditions.

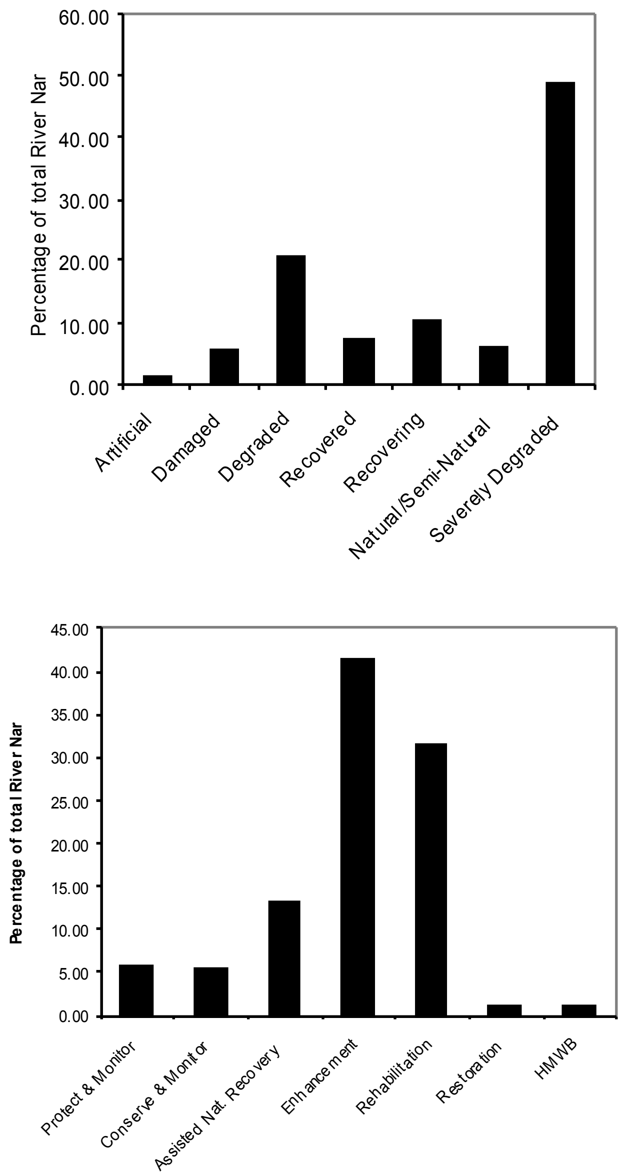


Figure 7.1: Summary output data for geomorphological condition relative to natural and management actions required to improve condition. Proportions relate to the total SSSI length.

8 Further research

Two main areas of further research have been identified that would improve the quality of the decision making on the River Nar:

1) The output from this report has been hampered by a lack of data on sediment transport rates. Calibration of the turbidity records collected by Anglian Water Services at Marham public water supply abstraction point would make possible an estimation of sediment load from the upper catchment. This would enable more evidence-based estimates of fine sediment accumulation within the lower Nar to be made.

2) The very high levels of fine sediment stored within potential spawning gravels throughout the River Nar raise questions about the quality of these habitats. A study to determine the oxygen supply potential within the gravels should be undertaken together with measurements of sedimentation rates. This would provide guidance on the habitat quality for spawning salmonids (sea trout and brown trout) as well as the efficacy of potential remediation works.

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