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Geomorphological Appraisal of the River Nar Site of Special Scientific Interest

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D.A. Sear, M. Newson, J.C. Old and C. Hill

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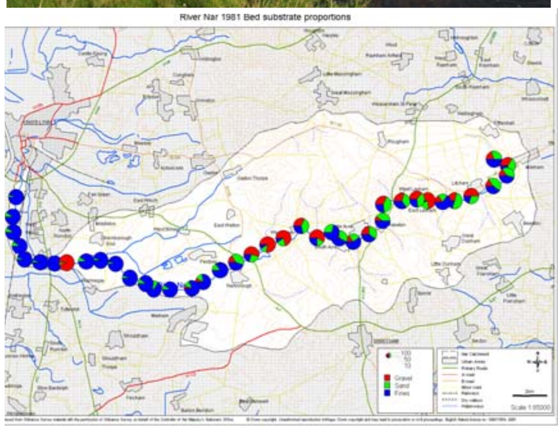

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Cover note

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Foreword by English Nature

The geomorphological appraisal of the River Nar Site of Special Scientific Interest (SSSI) has been jointly funded by English Nature, the Environment Agency, the King's Lynn Consortium of Internal Drainage Boards, and the Borough Council of King's Lynn & West Norfolk (on behalf of EEDA and English Partnerships).

The objective of this work has been to understand the mechanics of the river in order to determine how best the river can be managed. This will be used so as to benefit both the chalk river habitats of the Upper Nar between Mileham and Marham and the fenland river habitats of the Lower Nar between Marham and King's Lynn. However, it will also be used to assist our understanding of the possible impacts and opportunities in relation to future developments on the river.

The appraisal involved a detailed fluvial audit to establish the physical nature of the river channel and geodynamics assessments to understand how the river functions within this channel. The report also details a new methodology designed to integrate scientific evaluation of natural geomorphological conditions with data on channel modifications. This multi-criteria analysis is used to extract a set of indices of geomorphic function and morphological condition relative to natural condition. Using these methodologies, the report sets out a geomorphologically unconstrained vision so as to indicate how the river could be maintained and where appropriate restored.

With regard to the upper River Nar, the principle that underlies the report is that providing the physical processes and environmental parameters characteristic of chalk streams are maintained, then the niches for habitats and species associated with chalk streams will also be maintained. However, the report also provides an understanding of the issues in the wider catchment that impinge on the environmental integrity of chalk rivers and indicates that these should be addressed at the catchment scale.

With regard to much of the lower River Nar, it is recognised that it 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.

The production of the report on the geomorphological appraisal of the River Nar SSSI takes our understanding of the river to a new level and gives us a valuable new tool in order to develop a vision for its future management.

Richard Leishman
Conservation Officer

Executive summary

This report details an extensive assessment of the fluvial geomorphology of the River Nar Site of Special Scientific Interest (SSSI), surveyed during the winter of 2004. It contains guidance on the methods used and the interpretation of the data derived from the standardised methods of fluvial audit and geomorphological dynamics assessment. The report also details a new methodology designed to integrate scientific evaluation of natural geomorphological conditions with data on channel modifications. This Multicriteria Analysis is used to extract a set of indices of geomorphic function and morphological condition relative to natural condition. The result is a reach classification of the River Nar against a geomorphological reference condition. This information is then used to derive a set of management approaches to move each reach back towards favourable geomorphological condition. Reach-based information is summarised in this report and the accompanying maps, and full datasets are provided within the supporting GIS and database.

Specific recommendations are also made on the proposed mitigation in relation to the Nar Ouse Regeneration Area (NORA), and proposals for the reinstatement of navigation between King's Lynn and the Flood Diversion Channel, as well as other existing restoration proposals.

The assessment shows that the River Nar bed substrates are a relic of past geomorphological processes that are no longer operating at the same rate. This makes the River Nar sensitive to changes in morphology and substrate arising from human activity. This means there is little natural sediment supply of coarser grade materials, and consequently little scope for natural readjustment to channel modifications. Where more natural features do occur they are of high conservation value

Fine sediment, derived mostly from catchment sources (from road, field and drainage ditches) accumulates within the gravel bed and may be detrimental to ecological function, due to a lack of natural gravel "flushing". Remediation through gravel jetting will release up to 650kg of fine sediments per riffle into the river reaches downstream.

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 Internal Drainage Board (IDB) main drains connect 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 prolific weed growth which is promoted by high nutrient levels. Long term, management of the lower Nar towards more favourable condition and natural conditions would require set back of the flood embankments and encouragement of shading to suppress dense weed growth. The current perched nature of the channel precludes embankment set back, except in the reach upstream of Marham flume.

Large woody debris is also a missing element of the upper Nar chalk stream geomorphology; with little opportunity to recruit more woody debris due to the managed channel margins. Woody debris creates local scour, habitat diversity and local floodplain connectivity.

The fluvial audit and geomorphological dynamics assessment indicates that nearly 90 % of the total length of the River Nar has been modified to some degree, although even where the

channel is semi-natural it is still affected by modified catchment processes. 48% of the channel is severely degraded and 25% is degraded relative to characteristics of natural conditions. 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.

The analysis identifies the approaches that may be used to help restore the river to natural conditions; 14% of reaches can be improved by assisted natural recovery through removal of excessive fine sediment deposits and shading out of weed growth. 42% of reaches can only recover through enhancement of existing form, with little prospect of significant improvement in condition.

Multi-Criteria Analysis techniques have been developed to generate indices of geomorphological function (sediment source, sediment sink), naturalness, and modification that help to identify appropriate management and restoration approaches. The report provides reach-based guidance (in tabular and mapped format) on the form of management required to improve the condition of the River Nar towards a more naturally functioning river in terms of geomorphological processes. These objectives are guided by the evaluation of the morphological processes and features that characterise natural channel types for chalk and fenland river systems. These management and restoration options should be guided by catchment-scale requirements. These include:

- Establishing a programme for addressing 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.
- Setting in place a condition monitoring plan for all semi-natural/natural and recovering reaches.
- Prioritizing the restoration/rehabilitation/enhancement on the basis of linking existing natural/semi-natural reaches first.
- Seeking to improve those reaches closest to semi-natural conditions.

Acknowledgements

We would like to acknowledge the help and assistance of a number of agencies and individuals in the provision of data, those participants at the workshop and those who commented on a draft of this report.

We are also especially grateful to the riparian landowners along the River Nar who permitted access to their property for the surveys.

Richard Leishman and Keith McNaught managed the programme from English Nature and Chris Mainstone and David Withrington contributed at the workshop.

We are grateful to many within the Environment Agency for data and comments including John Adams, Pippa Caswell, Andy Sadler, Karen Partridge, Jonathan Lampar and Ros Stockley.

Comments were also received from Lou Mayer (Conservation Officer) and Tony Godwin (Engineer) of the King's Lynn Consortium of Internal Drainage Boards, and also from Jean Marriott of the East of Ouse Internal Drainage Board.

Thanks are also due to Roy Matthews and Brian Lawrence of MACE, Andy Brown and Chris Graby (Anglian Water Services Ltd) for access to detailed sediment records, and Lou Mayer and Pippa Caswell for taking water samples to calibrate turbidity records.

We are grateful to those commenting on the successive drafts of this report including Lou Mayer, David Fraser, Richard Leishman, and John Adams.

Contents

1 Introduction

In its upper reaches, the River Nar is a low gradient groundwater dominated river (*sensu* Sear and others 1999) with a transition to Fenland river with tidal influence in the lower reaches. The river has a long history of management for water use and navigation. The river channel has been notified as Site of Special Scientific Interest (SSSI), and according to the Joint Nature Conservancy Council (JNCC) River Type Classification, supports good examples of JNCC Type III Chalk stream habitat in the River Nar upstream of Narborough, and JNCC Type I Fenland River habitat downstream of Narborough. English Nature commissioned the River Nar Fluvial Geomorphological Audit in collaboration with the Environment Agency, the King's Lynn Consortium of Internal Drainage Boards, and the Borough Council of King's Lynn & West Norfolk (on behalf of EEDA and English Partnerships) to develop an inventory of morphological features and to identify and understand the geomorphological processes which influence and control the channel activity, morphological quality and favourable condition status of the river system.

A 42 km length of the River Nar, between King's Lynn tidal sluice (TG617194) and the principal source at Mileham (TG896194), has been investigated in detail through field survey. This approach has used a standard field methodology, fluvial audit, which consists of:

i) a desk study to collate historical data sources which record natural and anthropogenic changes in the catchment, which may have disturbed the fluvial system (discharge or sediment supply), and thereby are likely to have had direct implications on the channel morphology (change in channel planform, long profile and cross sectional geometry).

ii) a contemporary field survey which integrated the key components of both a Detailed Catchment Baseline Survey (DCBS) and Fluvial Audit and emphasised assessment of the controls and extent of erosion and deposition along the channel.

The fluvial audit field survey has investigated the channel morphology, and in particular the presence of sediment accumulation and erosion within the river network. This, together with historic analysis enables an assessment of the stability or dynamics of the river system over time and how this has adjusted to the prevailing flow processes and sediment dynamics. The survey has also related the presence or absence of morphological features to the condition parameters that are identified as habitat preferences for SSSI interests.

In addition, a more detailed Geomorphological Dynamics Assessment has been undertaken to establish the extent of fine sediment input to the main river network, the grainsize characteristics of the fines stored within the river, the magnitude of fine sediment storage on the river bed and an estimate of the ability of the river to mobilise the bed sediments.

1.1 Aims and objectives

The aim of this project is:

To develop, through an understanding of the physical processes of sediment transport, a tool than can be used to develop a vision for river restoration for the River Nar, whilst balancing these against the constraints imposed by flood risk management.
The specific objectives are:

- To develop an understanding of the geomorphology of the River Nar in terms of sediment transport processes and resulting geomorphology.
- To evaluate the impact of past and present channel management and modification on natural geomorphological processes.
- To determine a methodology for classifying river reaches in terms of their divergence from natural condition
- To develop a management plan for the river that aims to enhance the favourable habitat condition for the SSSI river Type whilst recognising the constraints of flood risk management.
- To consider the impacts of proposals associated with the Nar Ouse Regeneration (NORA) Project and the proposed reinstatement of navigation (between King's Lynn and the Flood Diversion Channel) on channel processes and morphology and to suggest opportunities for enhancement.

1.2 River geomorphology

Thorne (1997) describes the fluvial system in terms of three sets of variables: (1) driving variables, (2) boundary conditions, and (3) adjusting variables or channel form (Figure 1.1). The driving variables of the fluvial system are the inputs of water and sediment, represented in Figure 1.1 as water and sediment hydrographs. Although these variables are often considered to be independent of channel form at timescales greater than a year, this is not necessarily the case. Reach-scale adjustment of channel form may control water and sediment flux downstream through changes in available storage, thereby controlling the form of the downstream channel, independent of catchment scale processes.

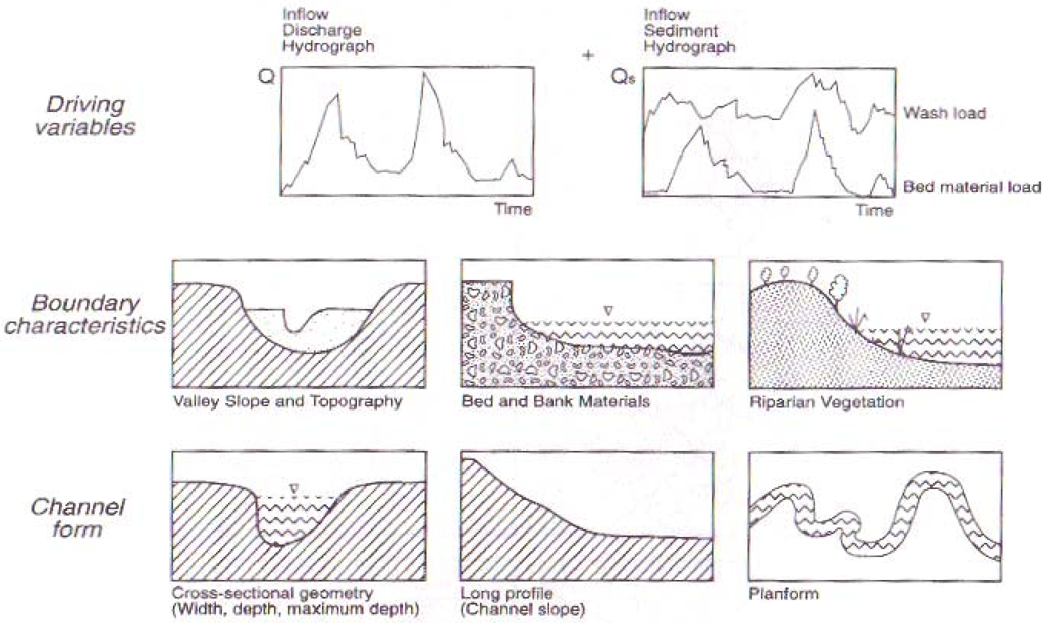

Figure 1.1: Independent and dependent controls on channel form (after Thorne 1997).

According to this conceptual model of driving variables, inputs, of water and sediment generated from upstream within the catchment and through channel processes, interact with the boundary characteristics to form the channel. These characteristics may be considered as independent variables, inherited by past geomorphological processes for example, the valley slope and bank materials. The nature of the valley form is significant in that it determines the degree of coupling that exists between the channel system and the valley slopes. In incised, confined valleys the channel may be frequently coupled with the slopes. Channel form will then be influenced as much by slope processes as by channel processes. Harvey (1986) documents the dynamic nature of river channels occupying this type of valley setting in the uplands, and describes switches in channel morphology from braided to meandering and back, largely driven by high magnitude flood events.

As a floodplain evolves, alluvial sediments increasingly form the dominant boundary material, and the river channel becomes increasingly "self-formed". Self-formed alluvial channels have a morphology that results from erosion/deposition processes generated by stream flow. This is complicated however by the presence of vegetation communities that may significantly influence channel form, and the rates and location of erosion/deposition along an alluvial reach. The interaction between the driving variables and boundary characteristics creates channel and floodplain morphology. These are defined in three dimensions as the channel planform, long profile and cross-section. Alterations in any of these three morphological descriptors, together with sediment size may be defined as adjustment.

2 Methodology

This methodological approach is based on:

1) Developing an understanding of chalk stream geomorphological processes as is possible based on a review of existing literature coupled with specific analysis of the River Nar.

2) Quantifying, through field reconnaissance survey and existing information on the River Nar, the extent of modification to the river, floodplain and surrounding catchment.

3) Quantifying, through field survey and existing information, the existing characteristics of the physical habitat and channel morphology of the River Nar.

4) Investigating the sediment transport capacity of the River Nar and quantifying the sediments available for transport.

5) Utilising Geographical Information Systems (GIS) modelling to differentiate reaches of varying states of naturalness and physical habitat quality in so far as they support features relevant to the SSSI status and to identify those reaches that are degraded in this respect.

6) Using a reference condition approach based on the processes and features of natural and good physical habitat quality to specify a design template for those degraded reaches along the River Nar and to provide guidance on the options for restoration.

7) Considering the sediment transport issues associated with the degradation of the river SSSI and to suggest options for mitigation.

The River Nar Geomorphological Audit methodology has applied three approaches to the collection and analysis of geomorphological and ecological data:

1) Fluvial Audit methodology to understand broad sediment system and channel processes.
2) Geomorphological Dynamics Assessment to understand sediment transport processes in more detail.
3) Multi-Criteria Analysis for the classification of the river network into river modification, management and sediment system (supply and sink) categories.

2.1 Fluvial Audit

The Fluvial Audit was conducted following the Research and Development 661 approach (Universities of Nottingham, Newcastle and Southampton 1998), which uses contemporary (field survey) and historic (archive desk study) data collection methods to gain a comprehensive understanding of the river system. The data requirements for this methodology are diagrammatically shown in Figure 2.1, and are documented within the reference, thus are not repeated here. The method is extended by the use of GIS and databases to record the field survey and secondary spatial data information and this forms a key deliverable from this programme.

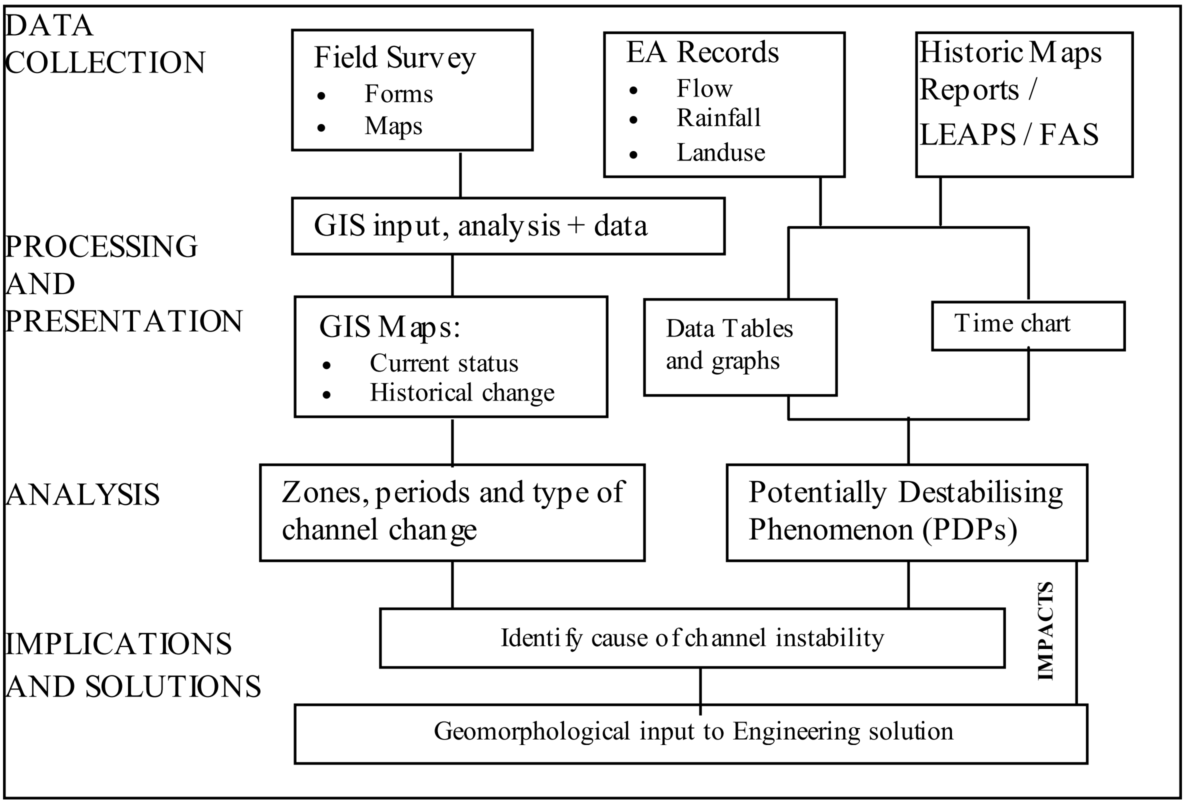

Figure 2.1 Primary inputs and outputs of the fluvial auditing process.

Extensive documentation existed for the River Nar, in excess of that for most other river systems, reflecting the level of interests and activity on the system. This information was reviewed and sifted for relevance to the project aims. A full description of the documentation is given in Appendix 1.

In the field, the methodology included:

1) Field mapping at c 1:2,500 (on an enlargement of the 1:10,000 scale maps), which divided the 45 km study reach into a series of smaller homogeneous geomorphological reaches and indicated the specific location of the following attributes:

   a. geomorphological reach breaks
   b. bank erosion type and severity
   c. bank protection type
   d. poaching
   e. in-channel modifications (ie weirs, fords)

2) Field forms, which collated reach-aggregated information on the following:

   a. bank properties (bank height, material type, structure, vegetation cover, erosion process, and toe condition)
   b. channel properties (wetted width, in-channel sediment storage (bar deposition), flow types, anthropogenic controls on hydraulics and bank erosion, and evidence of reach instability (incision or aggradation))
   c. catchment influences (landuse and sediment sources)

3) Photographic record which summarise the overall geomorphological character of each reach, and provide detailed visual information on specific attributes or feature of the river or modifications to it where these are considered to be of importance in interpreting the controls on processes operating on the River Nar.

The standard fluvial audit methodology has been augmented for the River Nar by the addition of field data parameters specific to SSSI river systems relevant to the River Nar.

A further modification to the standard Fluvial Audit is the data handling through GIS and databases. Map output has been generated from the digital formats and much of the data for further use is held within the GIS. It is anticipated that this report will be used in conjunction with the spatial data sources and photographic archive. Field form data is entered into a Microsoft Access database and the data linked to the GIS based on the reach polygons defined during the field survey and subsequently mapped in the GIS. Additionally, the field based map data (extent and severity of erosion and the locations of bank protection and modifications and sediment inputs / sources are also created as GIS layers. A number of other data layers are either acquired from secondary sources or created (eg indicative floodplain, conservation designations, historic river channel locations etc).

The full GIS / database implementation of the Fluvial Audit has been supplied to English Nature, the Environment Agency, the King's Lynn Consortium of Internal Drainage Boards, in addition to the full documentation of the data layers generated.

The approach adopted is evidence-based and uses a range of data sources. It is constrained by available information and that which can be reasonably collected during the timescale and resourcing of the project.

The GIS and database records of the Fluvial Audit field survey (map based and database field form) and the desk study form the bulk of the data within this report and are provided as digital data files. See Appendix 6 for a copy of the field form. A separate report is held by English Nature on the GIS and database data layers.

Field survey was conducted during the period from November 2004 – February 2005; the extended period was due to the added sediment sampling which was not within the original programme of works.

2.2 Geomorphological Dynamics Assessment

The Geomorphological Dynamics Assessment (GDA) took the form of four separate more detailed assessments of sediment transport characteristics of the River Nar based on an initial review of the existing documentation, discussion with EN Local staff, and an initial walk-through survey. These were:

1) Installation of a continuous turbidity probe at Marham Flume and collection of bottle samples for calibration from turbidity units (collected in 15 min intervals by Anglian Water) into suspended solids loads with the purpose of quantifying the flux of suspended loads over the study period (Autumn/Winter 2004/5) and reconstruction of longer term records using local turbidity data where this was available.
2) Initiation of a storm event monitoring survey undertaken by staff of the Environment Agency/King's Lynn Consortium of Internal Drainage Boards following a specific protocol (See Appendix 2) with the aim of identifying and quantifying fine sediment ingress points and sources of fine sediment from the catchment surface over the period of study.
3) Determination of the extent of fine sediment storage within potential spawning gravels.
4) Modelling the mobility of the river bed gravels to determine the ability of the channel to recover from modification and to flush fines from within the river bed.

The results of the GDA are detailed in Section 5.0.

2.3 Multi-Criteria Assessment

A new approach was developed for this project which permitted analysis, classification and visualisation of multiple data sets based on an index value system. Multi Criteria Assessment (MCA) is an approach that is amenable to GIS modelling and enables combinations of spatial data to be undertaken within a framework of scoring and weighting to represent the relative importance of each variable or variable combination. The choice of variables, combinations of variables and the weighting and scoring of variables/combinations is undertaken using 'expert' input. This framework has the potential to include different stakeholder/expert inputs within the system, although the initial stages have used 'expert' assessment within the context of Favourable Condition criteria for the SSSIs. The method is flexible enough to be used to communicate the implications of other options and provides a relatively simple method of supporting adaptive management. It should also be seen as dynamic – ie new understanding of the River Nar may change the underlying conceptual model and lead to a different definition of Favourable Condition. This needs to be recognised and can be incorporated via the MCA.

The MCA process is outlined in Figure 2.2, and the steps below:

1) Identification of the specific analysis **objectives** or problem (is a site more or less suitable for habitat restoration?)
2) **Selection of criteria** and measures appropriate to the objective derived from field and secondary data (which features are important? – use scientific and or expert opinion)
3) **Scorings** of these criteria (internal assignment of score for each attribute – expert opinion).
4) Allocation of **weighting** (relative importance of the individual factors – between attributes)
5) **Interpretation** of the results (relative to uncertainties and sensitivities).

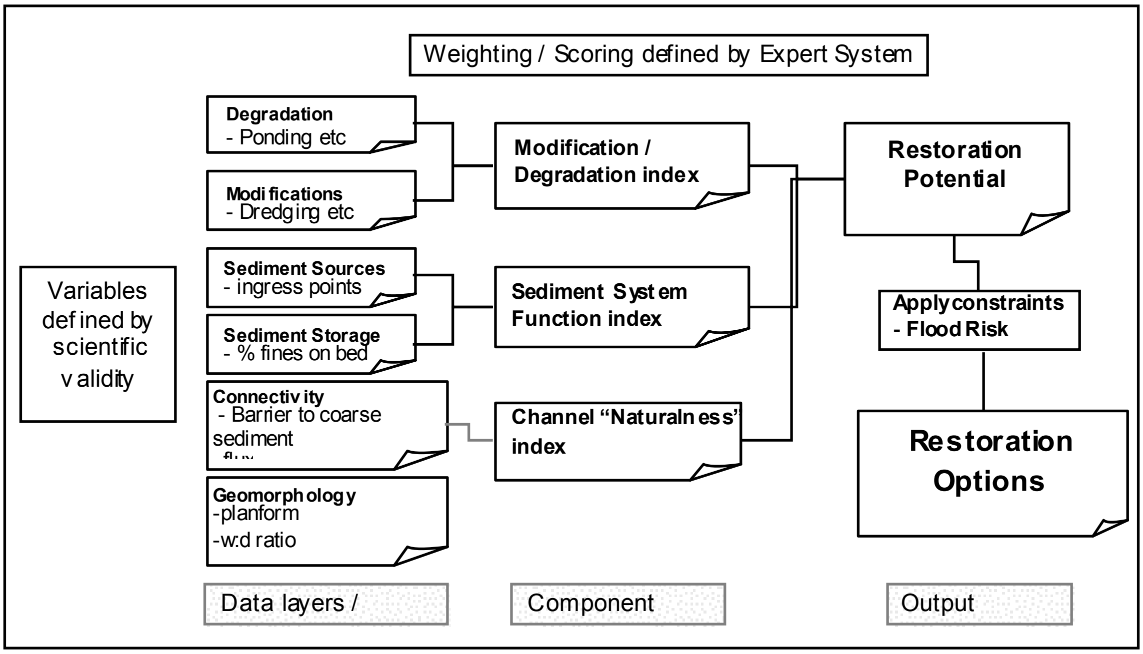

Figure 2.2: Multi-Criteria Assessment applied to River Nar SSSI using datasets derived from the Fluvial Audit.

The outputs from the MCA are detailed in section 4.0 and form the basis for the identification of reaches requiring different forms of habitat management.

3 Catchment characteristics

3.1 Introduction

The River Nar has two major channel units; the upland freshwater fluvial catchment draining the plateau and chalk scarp to Narborough, and the lower gradient alluvial and formerly tidal river section on the eastern margin of the Fen basin at King's Lynn. The two units are marked not only by physical differences but also by the history and type of channel modification. However, the principle controlling differences are channel gradient and continuity/discontinuity of the river with its floodplain. The average gradient upstream of Narborough is 0.0020 whilst downstream it is 0.00003. This has a huge impact on sediment transport and channel hydraulics which would, in the absence of human modifications, result in very different physical habitats and biotic communities. The details of the River Nar catchment and river network are summarised in Table 3.1.

Table 3.1 Summary of River Nar catchment characteristics

Attribute	**Value**
Catchment Area	260 km2 (153 km2 upstream of Narborough; 208 km2 drained by gravity downstream of Narborough in the Fen margin (Ecoscope 2000)
Stream Length	42 km
JNCC River Type Classification	IIIb Chalk Stream Ia Fenland Channel
River gradient (m/m)	0.003-0.002 (upper Nar) 0.001-0.0005 (lower Nar)
SSSI	1992 designation from headwaters to tidal sluice, just downstream of the A47 road bridge
Hydraulic controls	Tidal Flap (1988), Bridges, Mill weirs, High Level carrier from Narborough to A47, Flood Diversion Channel to the Great Ouse, Flood Storage Reservoir by High Bridge.
Hydrology	Base Flow Index 0.90 Mean Flow 1.16 m3s-1 Tidal Range 3.0m (neap) 5.5m (spring).
Geology	Cretaceous Chalk, Upper Greensand & Gault, Lower Greensand and Speeton Clay, Kimmeridge Clay. Sequence progressing towards west. Drift geology is a spatially heterogeneous mix of glacial boulder clay, outwash sands and gravels. Nar Valley clay provides a significant aquiclude in middle reaches downstream of Narborough.
Soils	Vary spatially between the catchment upstream of Narborough, and downstream to King's Lynn with increasing organic (peat) and clay rich solids downstream of Narborough and Sandy soils upstream.
Land Use	**Upstream of Narborough** valley floor is a mix of low intensity grazing marsh, arable farming, wetland habitats and woodland. Gravel working in the past has created a series of floodplain lakes. Farming and forestry dominate the catchment and valley sides. Pig farming, maize and arable cropping dominate the wider catchment. **Downstream of Narborough**, land use is a mix of urban (King's Lynn), grazing and intensive arable farming on peat and skirtland. Sand and gravel working still operational on valley sides at Blackborough.

3.2 Geology, topography & soils

The River Nar has a westerly draining catchment, and flows over a mixed geology overlain by quaternary sediments of mixed origin. Solid geology is best described as a cretaceous chalk cuesta forming a west-facing scarp. The chalk dips gently to the east, with the result that the underlying sequence of Lower Greensand, Speeton Clay, and Kimmeridge Clay are exposed to the west (Figure 3.1). Drainage was formerly easterly and associated with the large Pleistocene river network prior to the Anglian glaciation (Rose and others 2001) (Figure 3.2).

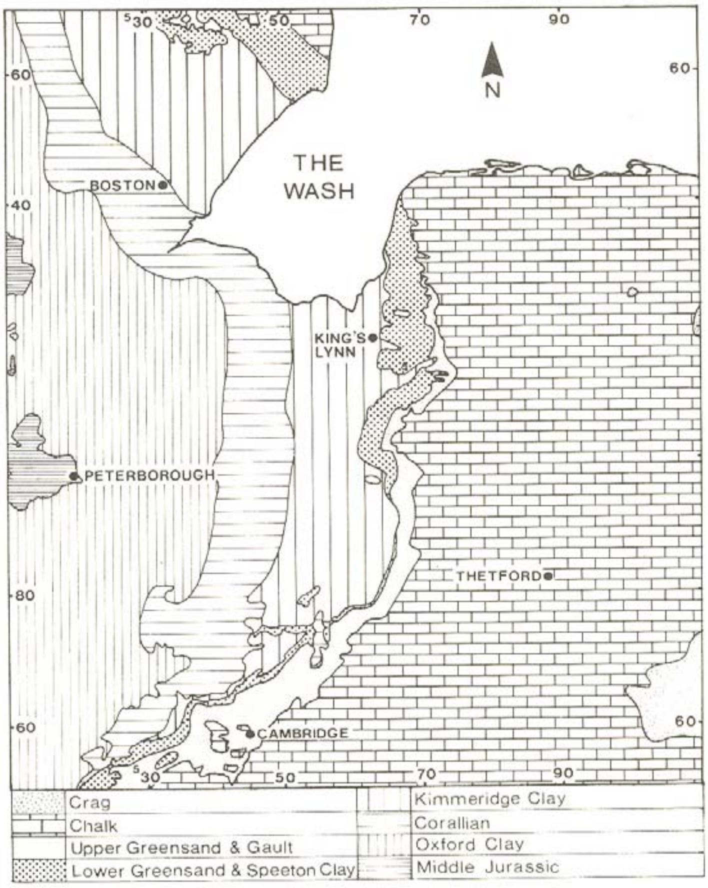

Figure 3.1: Solid geology of the Fen basin and west Norfolk, after Whiteman (1991).

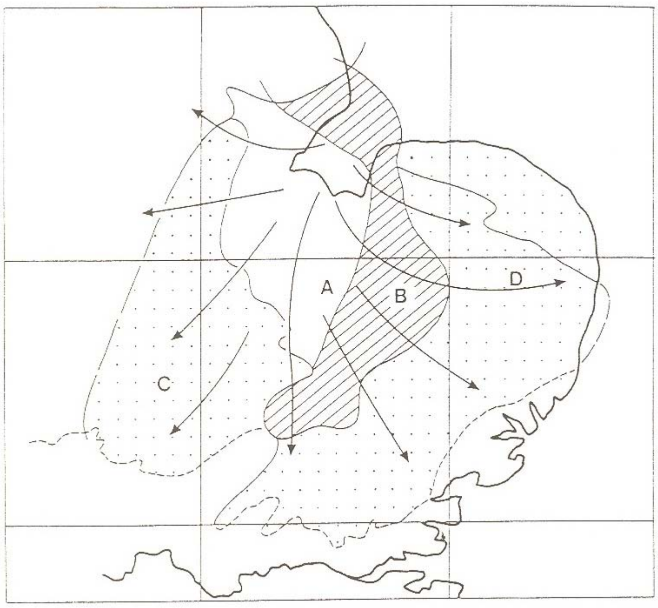

Figure 3.2: Glaciation of the Fen/Wash basin and the emplacement of chalky boulder clay during Anglian glacial (after Clayton 2000).

The evolution of the major landscape units in the Nar valley relate primarily to two main periods of geomorphological activity; the Anglian glaciation (480-430k BP), that created the Fen Basin, and the subsequent re-modelling of the Anglian glacial landscape by periglacial slope and fluvial processes during the Wolstonian glacial (300 – 130k BP) (Gibbard 1991).

The Anglian glaciation (Isotope stage 12) resulted in erosion of mudrock and chalk of the Fen Basin, and the deposition of chalky boulder clay over the area covering the upper Nar and Wensum catchments (Clayton 2000). The lower Nar (downstream of Narborough) is thought to have only come into existence following regression of the sea that occupied the lower valley during the Hoxnian interstadial around 350k BP.

The lower Nar valley was blocked by ice during the early Wolstonian and the formation of an ice-dammed lake led to the development of deltaic and glacial-lacustrine deposits derived from upstream valley incision under periglacial conditions (Gibbard 1991). It is likely that much of the dry valley forms of the upper Nar and Wensum were formed under periglacial conditions during the Anglian and Wolstonian glacials. Slope processes and runoff characteristics of frozen ground are very different to the temperate conditions associated with the current climatic regime. Furthermore valley gradients at that time were generally steeper, since base-levels were lower (Gibbard & Lewin 2003). Sediment evacuated from the valley slopes would have been transported and reworked under these conditions. Thus as climatic conditions ameliorated towards 130k BP, a phase of aggradation and incision, driven by climatic fluctuations, created a suite of river terraces within the Nar valley(only fragments of which remain), utilising the available sediments derived from earlier slope activity.

The soil series within the Nar catchment is strongly influenced by the complex geological history described above. It is also essential to understand this geological history in order to interpret the large scale controls on sediment supply from erosion of the land surface. Figure 3.3 depicts the association of soils and topography at the margin of the Fen Basin around King’s Lynn, which clearly shows the relationship between the geology, topography and soil formation.

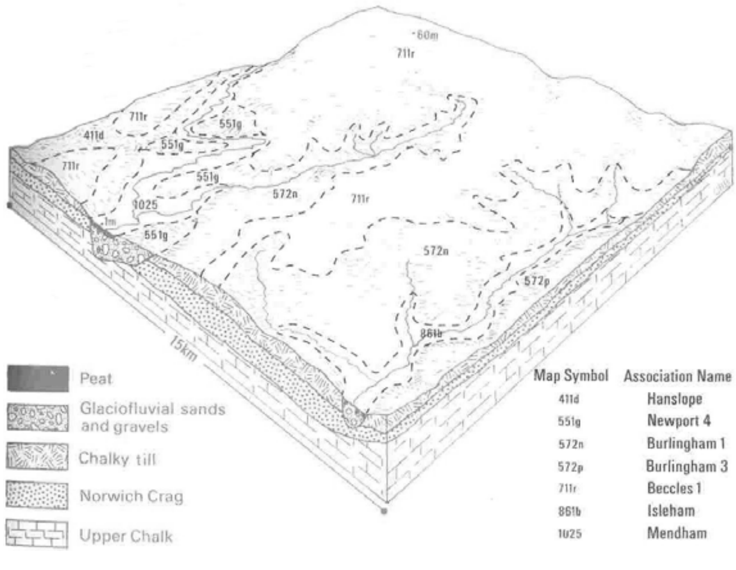

Figure 3.3: Relationship between soil associations, geology and topography in the Nar catchment after Hodge and others (1984).

There is a clear correlation between topography, geology and soil erodibility that highlights the steeper valley sides and lighter sandy/sandy loam soils as sensitive to both water and wind erosion (Hodge and others 1984). Hodge and others (1984) highlight the need for careful management of the erodible soils of the area. The distribution of soils across the Nar catchment is shown in Figure 3.4 based on the Soil Survey.

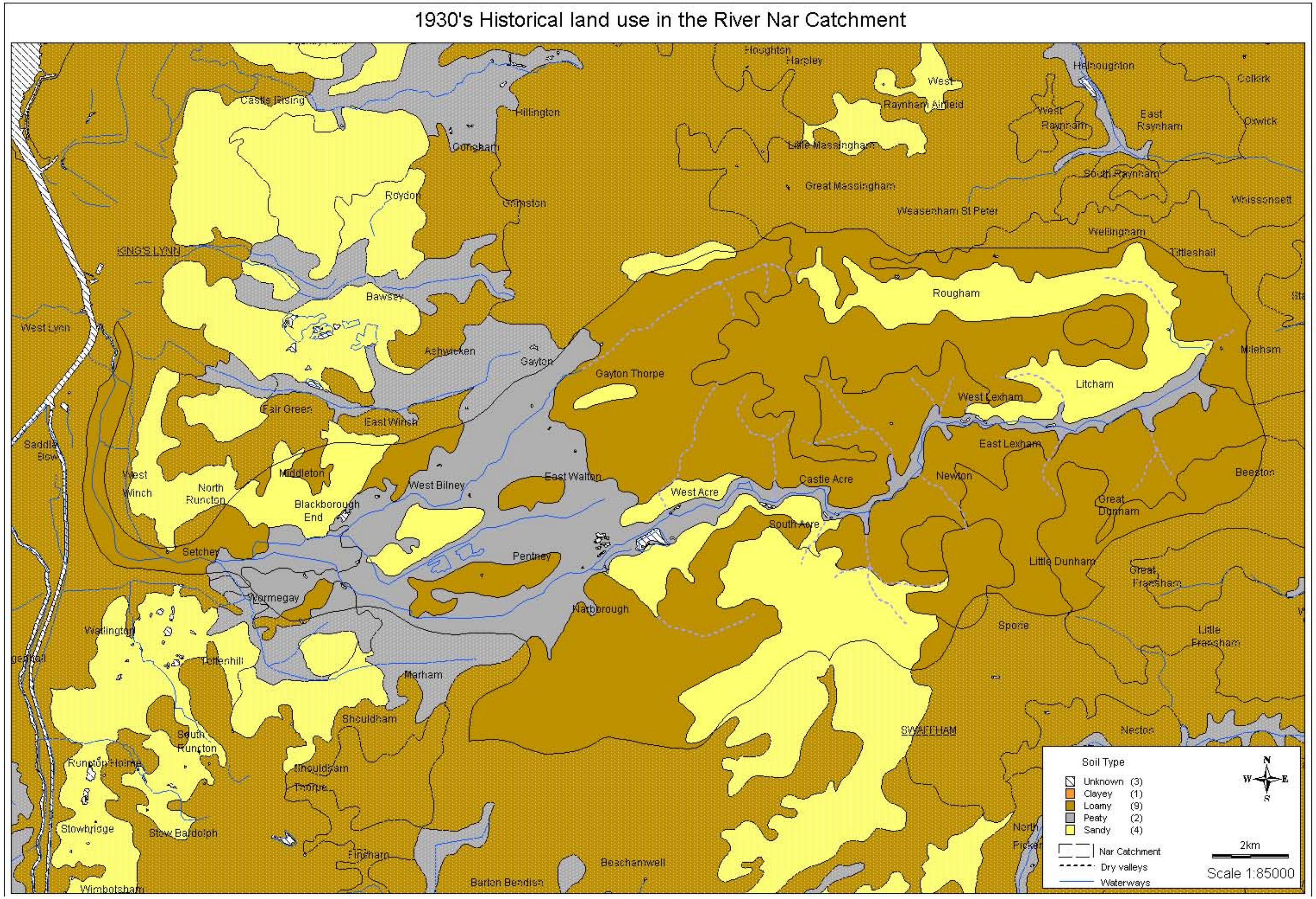

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Figure 3.4: Distribution of broad soil types within the Nar catchment. Note the location of water erodible sandy soils around the headwaters, middle reaches (Castle Acre – Narborough) and around Blackborough. Peat forms an extensive soil mantle covering the sands and loams of the alluvial basin of the lower Nar.

The resulting pattern of deposits through which the River Nar flows, are given by Silvester (1988) in Figure 3.5. These differentiate between marine silts in the lower reaches, and peat deposits in the upper catchment. Alluvial sands and gravels underlie the freshwater silts and sands throughout the upper Nar valley. The influence of soil types strongly affects the hydrological properties of the soils and river network. In the analogous environment of the Broads rivers, clay soils are associated with better drainage and less seepage from the main rivers, whereas peat soils tend to waste with drainage and to be susceptible to seepage from the main river (Lambert 1965). Furthermore, peat wastage promotes lowering of the land surface relative to the river level, reinforcing seepage from the main channel. Seepage in the River Nar corresponds to the silt skirtland downstream of Setchy Bridge.

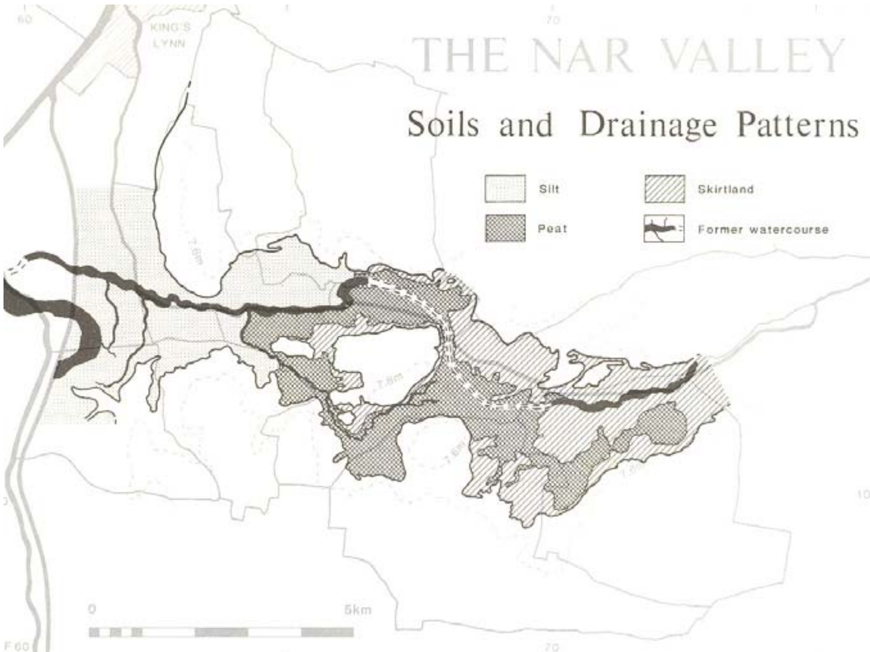

Figure 3.5: Soils and general drainage of the lower Nar resulting from the sequences of Flandrian marine transgression and peat formation after Silvester (1988).

The topography of the Nar catchment is relatively subdued with a maximum elevation above OD of 91m at a point north of Home Farm (NGR: TF790192), giving a total topographic range of 81m. The primary topographic features are the east-west orientated valley of the River Nar and the north-south scarp of the Chalk/Greensand outcrop that forms the eastern margin of the Fen Basin (Figure 3.6). The escarpment and Nar valley are dissected by a network of dry valleys which extend several kilometres into the catchment above the perennial stream head (Figure 3.6). There is no evidence that these are ephemeral channels but they are relics of the extended river network associated with spring sapping and runoff under periglacial process regimes. Four perennial tributaries join the River Nar; downstream of Mileham (TF903182), West Lexham (TF837170), via IDB pumping stations at (TF650134) and via gravity drainage at High Bridge (TF670135).

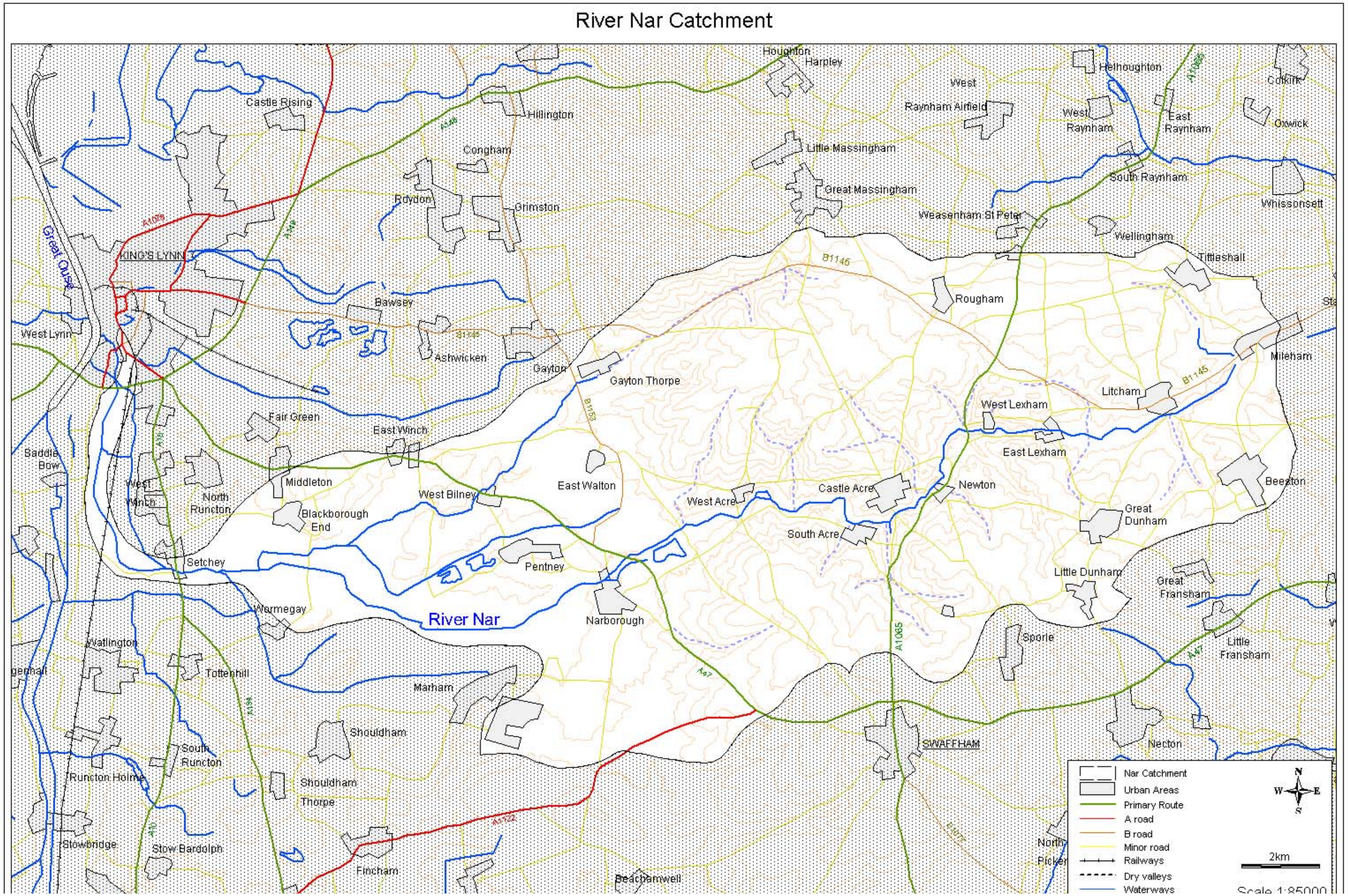

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Figure 3.6: Catchment of the River Nar illustrating the perennial river and dry valley network.

The formation of the Fen basin and the dissection of the chalk have resulted in a complex long profile from the headwaters to the point of discharge into the tidal Great Ouse, marked by an abrupt gradient transition (Figure 3.7) at Narborough. This transition is natural and strongly controls the geomorphological processes within the river. The detail of the low gradient reach reveals a more gradual transition with a steeper reach from Narborough to just downstream of Marham flume, a reduction in gradient to High Bridge, and an ultra-low gradient reach from High Bridge to the Tidal Flap in King's Lynn.

Upstream of Narborough the long profile steepens upstream in a series of low gradient steps, possibly the result of long term decreases in base level or isostatic adjustments following glaciation but since the details of the long profile are based on Ordnance Survey 1:25,000 contours and channel length between points at which the contours cross the river, this must remain a matter of conjecture. The steeper reaches on the profile correspond with the headwaters upstream of Litcham, and the reach between East Lexham and Newton (Figure 3.7).

3.3 Hydrological characteristics

The River Nar has two strong natural hydrological controls on flow processes:

- A ground water dominated flow regime arising from the chalk/greensand aquifer
- A tidal control at the point of discharge into the Great Ouse.

These are further modified by a series of hydrological controls including abstractions and discharges from the aquifer and perennial channel network (Ecoscope 1998), a tidal flap at the outfall into the Great Ouse, a Flood Diversion Channel between the Nar and Great Ouse upstream of King's Lynn, a flood storage reservoir at High Bridge, extension of the natural drainage network by field drainage systems, and modifications through gravity drainage and pumped drainage schemes in the Fen Basin/embayment. **The flow regime is therefore modified and not natural**.

The River Nar has a groundwater dominated flow regime characterised by a high Base Flow Index (BFI) (an index of the groundwater contribution to the surface water flow) and a low index of flashiness (ratio of mean annual flood to mean flow) (Figure 3.8). The flow regime is similar to other "classic" chalk streams but does show some moderating influence as a result of the overlying glacial deposits.

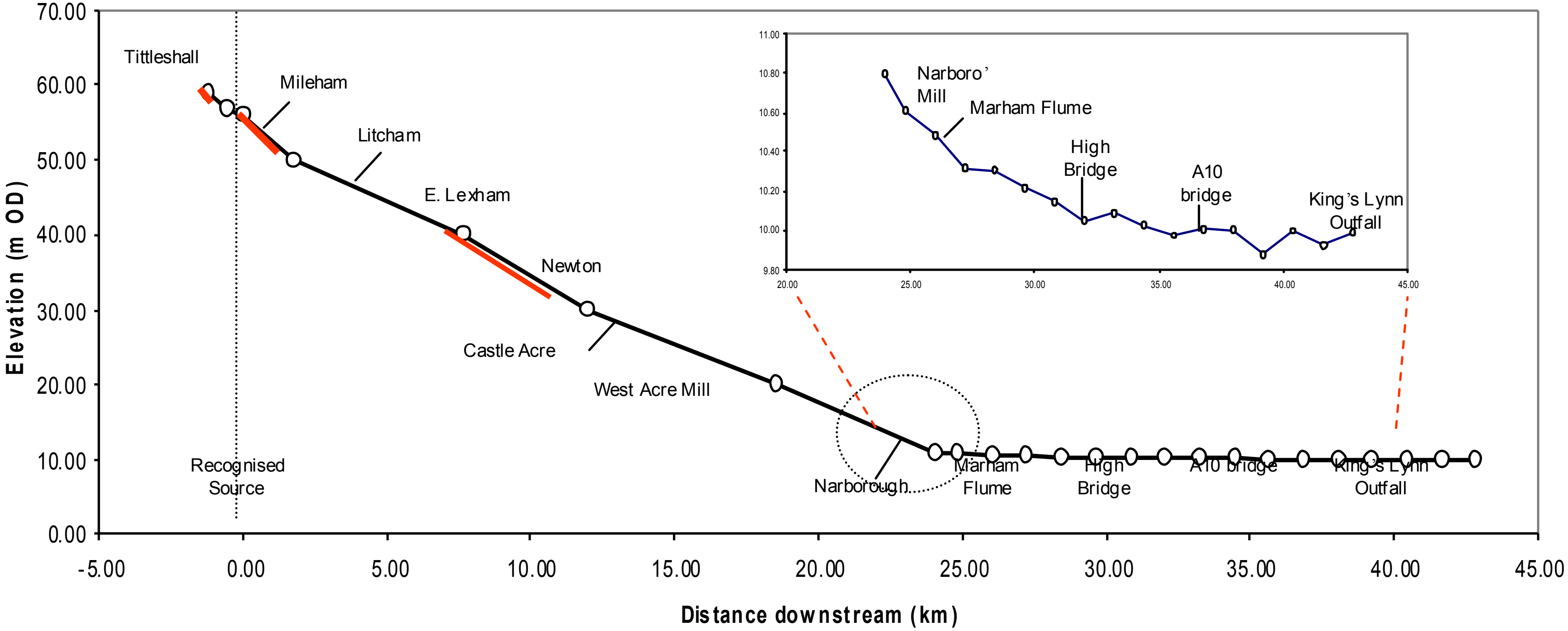

Figure 3.7: Long profile of the River Nar from source upstream of Mileham to the tidal flap at King's Lynn. Red lines denote the reaches with the steepest gradient (>0.0025). Extension to the drainage network upstream of Mileham follows a ditch along the bottom of a dry valley. Natural abrupt gradient transition at the Fen margin provides a strong control on river processes. The inset illustrates in greater detail the long profile from Narborough to the King's Lynn outfall (m OD) against km downstream.

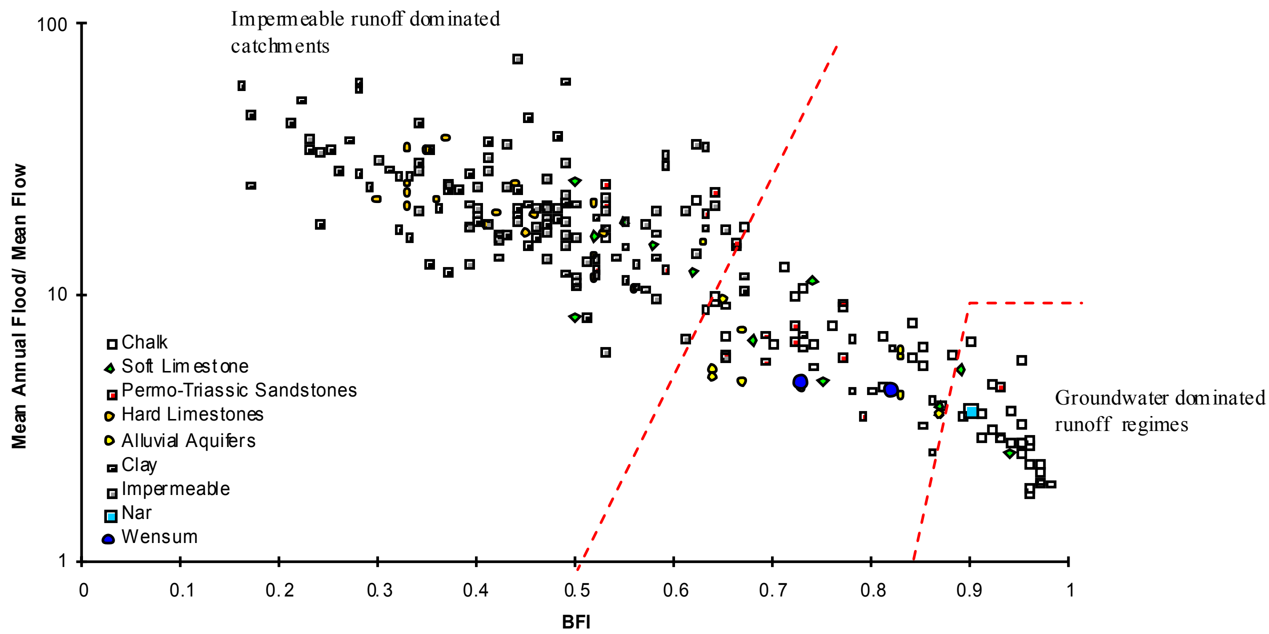

Figure 3.8: Groundwater dominated flow regime of the River Nar is slightly moderated by overlying glacial deposits. "Pure" chalk stream hydrology is characterised by a Base Flow Index (BFI) > 0.9. Lack of flashy hydrological response of the River Nar is evident from the low ratio of MAF/Mean Flow (after Sear and others 1999).

The influence of groundwater leads to a flow regime typified by a progressive seasonal rise in water levels within the channel, peaking in March and April (Figure 3.9). Aquifer recharge occurs in the previous autumn; hence low flows are a function of low autumn rainfall in the preceding year. Naturally, flooding of adjacent floodplain occurs during the high spring discharges. In the past this was managed at Castle Acre through a system of water meadows after *c.*1600.

Flows in the River Nar are sustained by a series of springs, with major springs occurring at West Lexham, and Castle Acre. Upstream of Lexham flows are sustained by groundwater seepage and surface water runoff. The Ecoscope (1998) report highlights the potential sensitivity of the reaches upstream of Lexham to low-flows, particularly under climate change scenarios or where abstraction has reduced the levels of local groundwater tables.

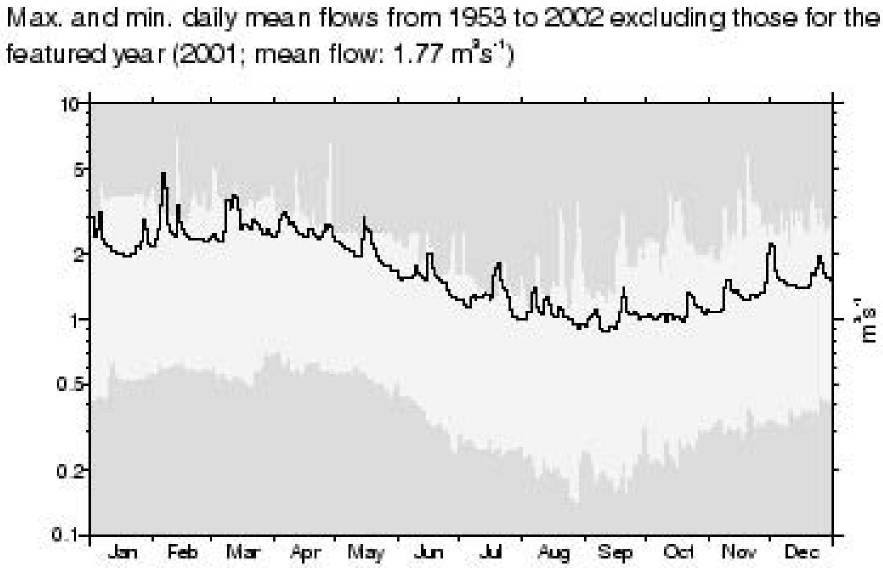

Figure 3.9: Average annual flow regime for the River Nar at Marham flume. Source: CEH National Water Archive.

The creation of a series of ornamental and gravel-pit lakes increases the surface area of water and the extent of evaporation losses to the system.

Downstream of Narborough, the River Nar is joined by the County Drain, a tributary which drains a 57km^2 catchment around East Winch and Blackborough. Natural drainage patterns are influenced by the network of gravity drains maintained by the East of Ouse IDB, with discharge points limited to High Bridge and the pumping stations upstream of Setchey. On downstream reaches where the River Nar is a high level carrier, the remaining surface drainage from the Greensand is captured in the north, by the Puny Drain, and to the south by way of a drain that takes flows from Wormegay directly to the Great Ouse (Figure 3.10).

Tidal ponding extends 13.6km upstream of the confluence with the Ouse at high spring tides. Tidal scour affects the reach between the “old sluice” and the tidal flap. During flood flows, peak water levels are now discharged into the Great Ouse via a diversion channel located some 3.5km south of King’s Lynn at TF616154. This prevents overtopping of the embankments downstream on the reaches that flow through King’s Lynn. A small Flood Storage Reservoir also operates in flood flows upstream of High Bridge and discharges into the IDB system of Main Drains. Within the lower Nar, the level of the land falls away until around 1 km downstream of Marham flume the low flow water levels are above ground levels. This continues until a point 1.8km south of the tidal outfall. Throughout this length of channel the river is effectively disconnected from the groundwater and is perched above the land level between artificial embankments. Water loss via seepage through these embankments is considered an issue, particularly between Setchey and the relief channel and formerly around the old gravel workings (TF680-TF690) and in a reach 0.5-1km upstream of Setchey (Figure 3.10).

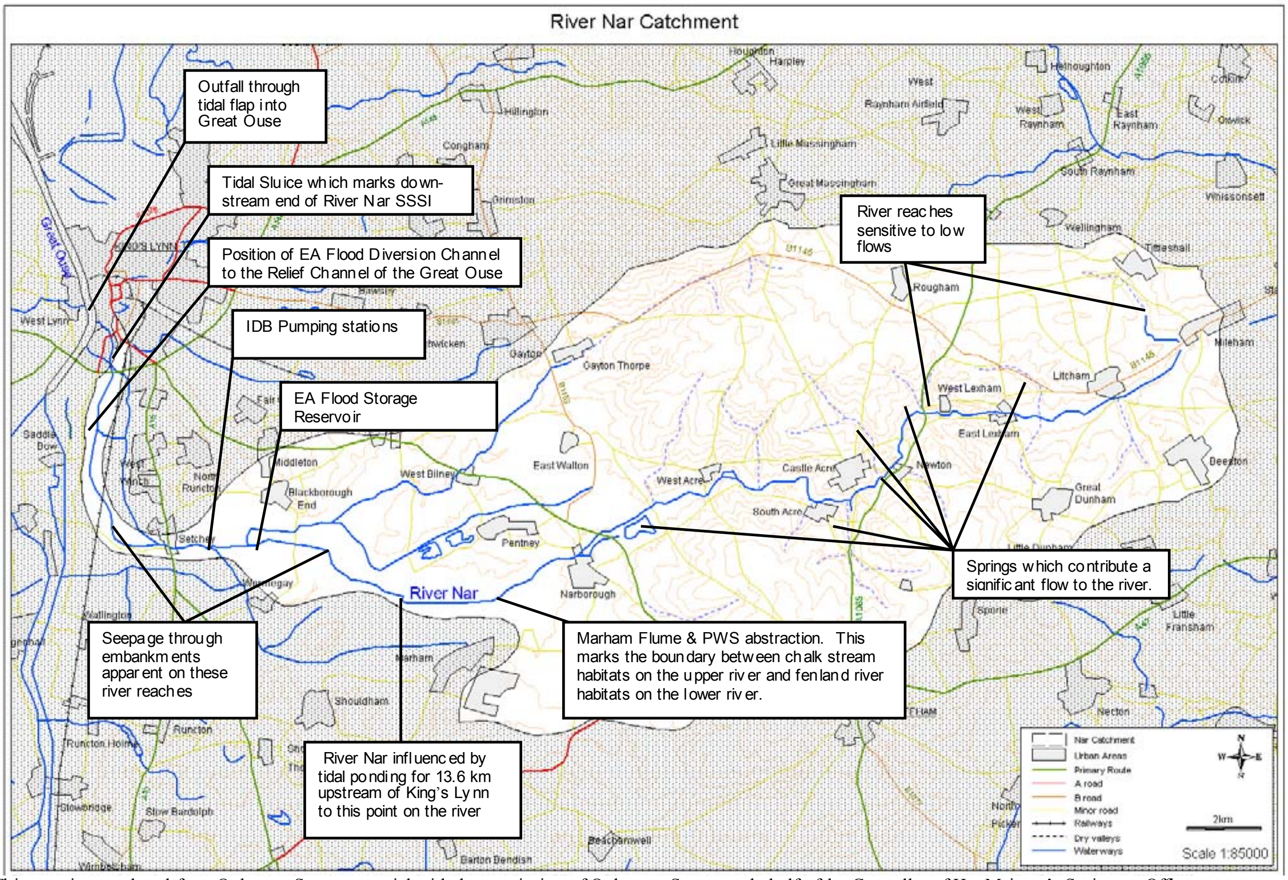

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Figure 3.10: Hydrological features of the River Nar catchment.

Water quality issues are detailed in the Ecoscope (1998) report. However, of particular relevance to this geomorphological study is the evidence of runoff from the catchment surface associated with agricultural activity. This runoff is considered to be responsible for the elevated phosphorous levels in the river, but particularly in the reaches upstream of West Lexham.

3.4 Geomorphological processes & catchment evolution

Section 3.1 detailed the development of the main geological and topographic features of the Nar catchment. In this section we focus on the more recent processes that have been active in the catchment and specifically the evolution of the valley floor and river channel.

The next main phase of landscape evolution has occurred during the past 10,000 years of the Flandrian. This period was characterised by a succession of marine incursions and regressions leading to a sequence of marine and freshwater deposits over the Fen Basin and lower Nar valley. It was also characterised by a sequence of valley floor alluviation and incision creating the most recent fluvial terraces in the Nar valley. In the lower Nar valley, the former River Nar flowed west, apparently joining the Great Marshland River (former Great Ouse) in the Parish of Wigenhall St Germans (Silvester 1988) Figure 3.11.

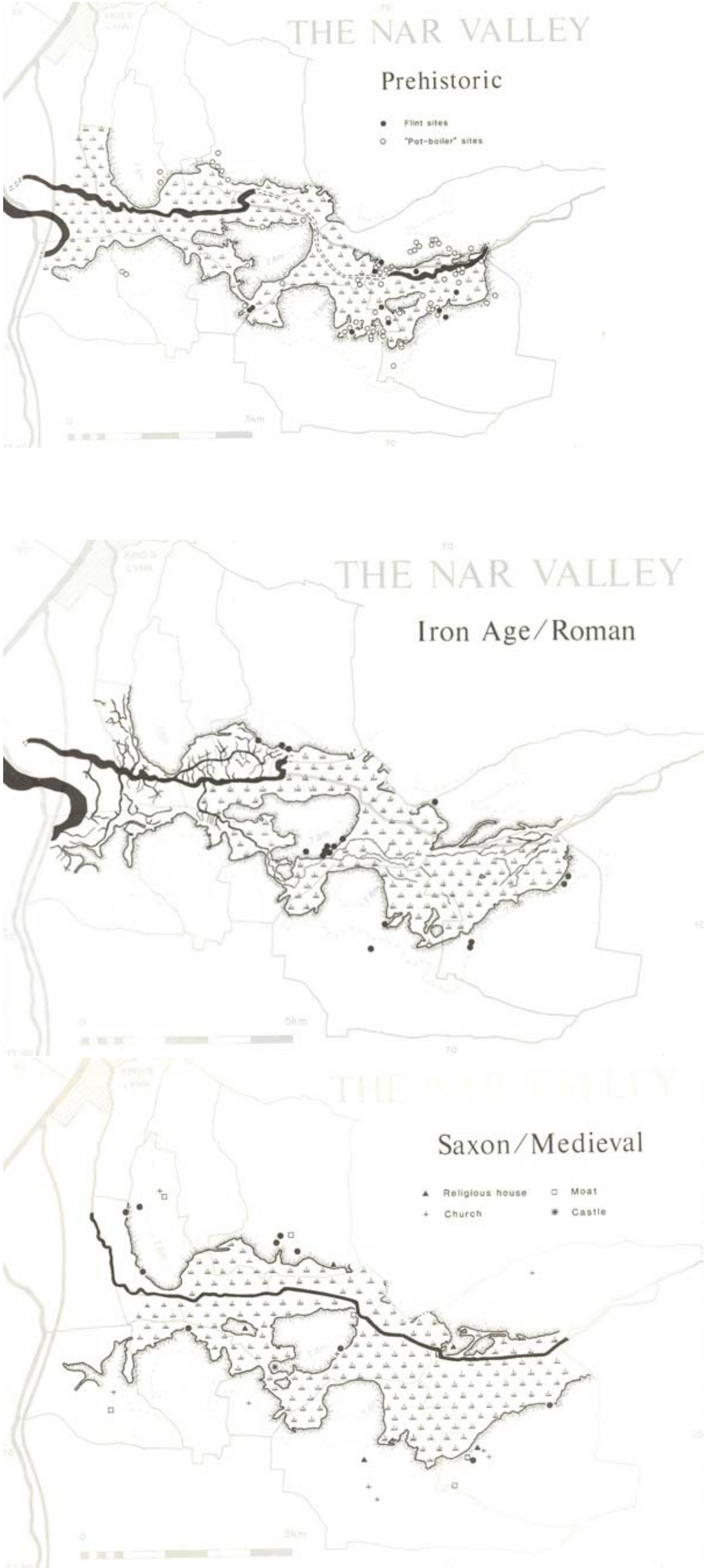


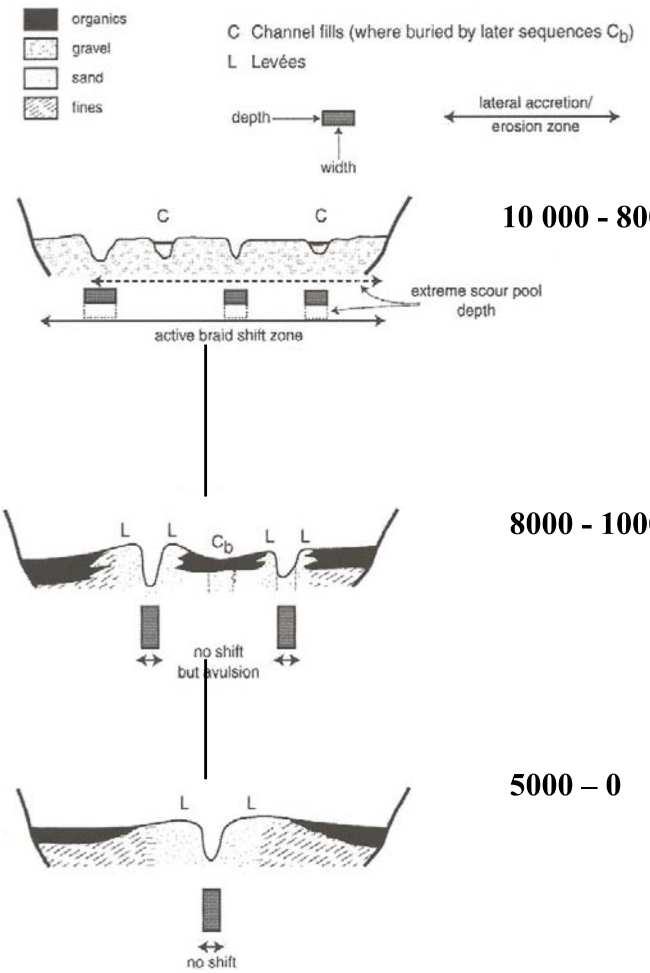
Figure 3.11: Evolution of the Lower Nar over the past 5000 years (After Silvester 1988)

With a steadily rising sea level around 7500 BP., peat developed under waterlogged conditions. Ultimately, at around 5000 BP, this resulted in a marine incursion, which deposited fen clays over the underlying peat. These deposits of fen clays are found at least as far upstream as Wormegay (Sivester 1988). With the succeeding marine regression, peat formed over these clays, with a further marine incursion resulting in a successive deposit of silt at around 4000 -3000 BP. (Figure 3.11). The deposition of silt at this time did not penetrate as far upstream but impaired drainage in the Nar valley upstream of Tottenhill (Silvester 1988). During the Iron Age and Roman period the lower course of the River Nar was tidal, with a network of tidal creeks and associated salt marshes and fen. In the valley upstream of Shouldham, peat growth blocked the channel resulting in waterlogged peat with a complex network of channels. The present course of the River Nar was largely adopted during the medieval period and has been associated with the drainage activity undertaken during the development of religious houses in the valley (Figure 3.11).

The specific conditions in the upper valley floor are unknown and require investigation, however the sequence of valley floor alluviation that developed on other lowland river systems suggests that climatic deterioration and amelioration resulted in phases of valley alluviation and incision. During the early Holocene, the river channel metamorphoses from an inherited braided river system dominated by higher energy gravel/sand associated with periglacial conditions with higher runoff, to multiple channel anastomosed rivers confined by cohesive floodplain fills and woodland. Subsequent mobilisation of fine sediments by forest clearance (typically from c.5000 BP) of the catchment and valley sides results in blocking of these multiple channels with fine sediment and the creation of the stable, single-threaded meandering channels occupying the present river course (Brown 2002). This sequence is considered to be analogous to those of the interglacial, hence the sequence of valley fills within lowland river valleys tends to be complex (Gibbard & Lewin 2003). The channel sequence most likely to have occurred within the upper Nar valley is shown in Figure 3.12.

At Castle Acre, there is evidence of channel diversions and the creation of flash locks to enable boat traffic on the River Nar (Albone 2000). At some point in this period, the course of the River Nar was directed north along its present course to King's Lynn. The meandering channel followed the present course and Silvester (1988) has associated the drainage of the marshes and initial canalisation of the lower Nar with this period. The lower Nar was tidal south of King's Lynn into the medieval period, and the land use was predominantly grazing marsh with salterns in the lower reaches around and to the south of King's Lynn. The floodplain of the River Nar downstream of Narborough was maintained as grazing marsh until the Second World War (Silvester 1988).

The abrupt gradient change downstream of Narborough creates conditions in which sediment transport progressively reduces according to grainsize. In these conditions unless discharge and flow depth are maintained, shear stress is rapidly reduced (Ferguson 2003). Shear stress is a measure of the force of water available to transport sediment, therefore in situations where it rapidly declines, transport of coarser sediment is reduced relative to the finer size fractions. Abrupt transitions in grainsize occur over short distances marking the effective limit of transport (Ferguson 2003; Sambrook-Smith & Ferguson 1995). It can be expected that the River Nar would naturally exhibit a gravel to sand transition in the reaches downstream of Narborough, marking a change in substrate, associated channel geomorphology and biotic communities.



Braided River
Dynamic gravel-sand bars and channels migrating over valley floor.

10 000 - 8000 BP

Anastomosed River
Stable multiple channels confined by cohesive fine sediments and floodplain forest. Peat development

8000 - 1000 BP

Meandering River
Stable single channel confined by cohesive fine sediments and floodplain forest. Peat development.

5000 – 0

Figure 3.12: Holocene floodplain and channel evolution of the upper Nar. A conceptual model based on Gibbard & Lewin (2003).

The River Nar can therefore be seen in a natural condition to be divided up into distinct hydro-geomorphological Types, each of which would support different physical habitats and associated biotic communities. Table 3.2 details the broad semi-natural geomorphological reach types existing within the Nar catchment and Figure 3.13 illustrates types from the photo archive collected within the field survey. These are visualised in Figure 3.14. It is important to note that the boundaries between reach Types in the lower Nar are speculative, but broadly consistent with reported limits of the tidal channel in the Middle Ages, and current location of gravel-sand transition. Channel management within these types has created a suite of reaches with more or less modification from the semi-natural conditions. The "Types" and reference conditions do not necessarily follow similar classifications systems being developed under the Water Framework Directive.

Table 3.2: Geological/hydrological/topographically determined zones along the River Nar. These zones can be visualised through reference to the GIS and hot-linked photos for each reach.

Types	Extent	Ref. Condition geomorphology & habitat
0	Throughout the main catchment	Dry valley network with spring sapped headwalls. No historically recorded flow but overland flow and natural pathways for runoff possible. Underlying sediment a mixture of colluvial slope wash and re-worked channel lag deposits.
1	Mileham –East Lexham plus Perennial tributary streams in headwaters.	Sinuous single-thread channel system with mixed surface and groundwater dominated hydrology. Strong coupling of channel and floodplain leading to wet marsh/woodland/fen community with peat development.
2	East.Lexham – Narborough	Sinuous meandering channel formerly multi-threaded with woody debris and limited development of pool-riffle sequence. Ground water dominated hydrology with extensive wet fen/Carr floodplain communities underlain by peat. Upwelling groundwater creates mosaic of wetland habitats including pools on floodplain surface.
3	Narborough – Tidal influence (Abbey Mill Farm)	Low gradient alluvial channel within broader floodplain with gravel-sand transition in upper reach resulting from marked change in gradient.
4	Abbey Mill Farm - Saline Limit	Tidally influenced low gradient mobile sand bedded channel with adjacent peat floored marsh and Carr communities on wide floodplain.
5	Saline Limit – Tidal outfall	Tidal river with saline intrusion supporting increasingly brackish water habitats downstream and adjacent marsh communities.

Type 0 Dry valley network (field drainage ditch) *N307*

Type 1 Sinuous single thread (N301)

Type 2 Sinuous meandering channel (N1009)

Type 3 Low gradient alluvial channel (N006)

Type 4 Tidally-influenced low gradient (N002)

Type 5 Tidal river with saline intrusion (N001)

Figure 3.13: Photographs of ‘typical’ river channel geomorphology typology for the River Nar and tributaries. Reaches are labelled and refer to the overview map of reaches.

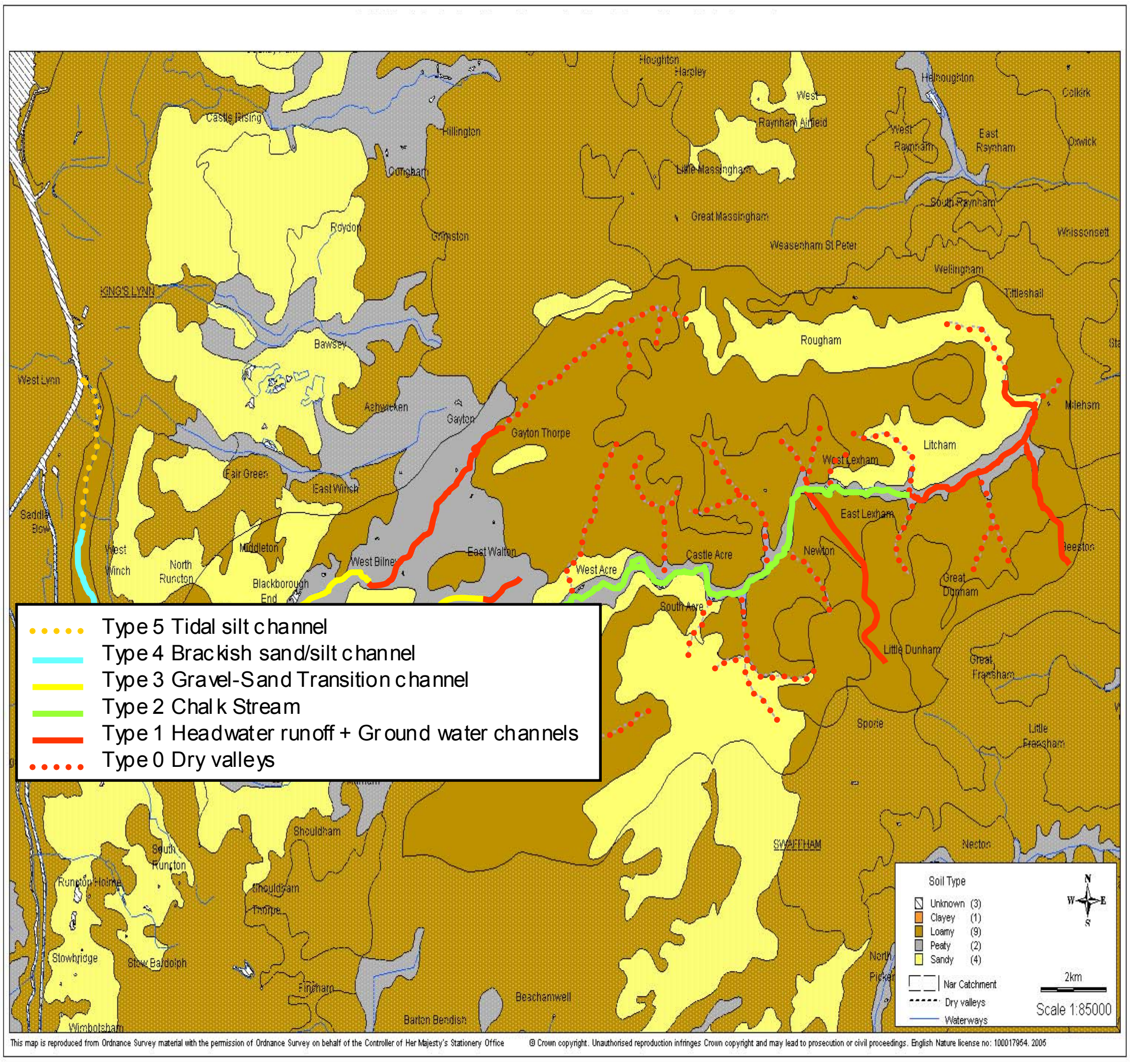


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Figure 3.14: Typology of river channel geomorphology for the River Nar and tributaries. Boundaries are speculative in Types 5-3.

3.5 Catchment summary

The Nar is a catchment prone to production of sands and fine silts as a result of its glacial and periglacial history. It is a groundwater dominated hydrology with a relative absence of high energy floods. A relatively subdued relief creates low gradients throughout the river that, coupled with the low discharges associated with the groundwater hydrology, result in a low energy river sediment system. The existence of a Fen basin and embayment created by glacial processes introduces an abrupt transition from gravel-bedded chalk stream to sand and silt dominated tidally influenced river. Thus the current river channel network and major controls on processes are seen to be the result of past processes. Contemporary channel management and land use management have subsequently modified the hydrology, sediment production and channel morphology.