ENVIRONMENT AGENCY

River Ure:
Geomorphological Audit

Report N°: UC446/1

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River Ure: Geomorphological Audit

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Geomorphological Audit
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1.0 River Ure Geomorphological Audit

The Geomorphological Audit of the River Ure from Worton to Ripon has been undertaken as a response to a number of perceived issues for the sustainable management of the channel and catchment. The geomorphological controls and implications on these multidisciplinary issues required further examination.

This Geomorphological Audit will identify the sediment supply, storage and transport within channel reaches and to identify how these relate to past and present management processes at a catchment and river channel scale. The technique is used to investigate perceived management problems prior to remedial actions or capital works and when planning rehabilitation or restoration.

The Geomorphological Audit forms a component of fluvial geomorphological assessment techniques developed for the Environment Agency. This sequence consists of Detailed Catchment Baseline (DCBS), Fluvial Audit (FA), Dynamic Assessment (DA) and Environmental Channel Design (ECD) assessment. The sequence, application and outcomes of these methods are described in more detail within (Downs, *et al*, R+D 661).

The full sequence of geomorphological surveys may not be appropriate at all sites and depend on the circumstances, the perceived problems and the use to which the survey and assessment will be put. A single approach may be modified from the idealised sequence to address specific issues. A modified Geomorphological Audit approach has been employed along the River Ure which emphasises assessment of the controls on and extent of erosion and sediment deposition along the channel. It incorporates some of the elements of the bank stability assessment methodology. Further details of the assessment methodology are described in section 2.

Two volumes have been produced, the report (this volume) and the portfolio of maps.

1.1 Rationale for the study

The initiation of a partnership between the Environment Agency, Yorkshire Water Services, English Nature and others, in order to develop 'The Sustainable Management of the River Ure' has prompted the commission of an investigation into the geomorphology of the River Ure.

By defining the geomorphological processes that occur within the River Ure and understanding the drivers and controls, it is possible to provide a management strategy for future problems and issues that may occur relating to geomorphology. Specific issues such as locations of historical activity and inactivity, present areas of erosion and deposition, presence of bank protection and the main controls on channel change will be tackled within this report.

Ultimately these data will inform the Environment Agency and provide the foundation to future proposals for sustainable river bank management.

The issues of concern include:

- the environmental implications of abstraction
- river bank erosion (in particular stock poaching between Middleham and Jervaulx)
- foundation for sustainable river bank management

1.2 Objectives

The objectives of this project are focused on developing an understanding of the geomorphology of the river Ure. The two main objectives are:

1. To develop and carry out a geomorphological assessment of the River Ure from Worton to Ripon

This will be achieved by:

- Investigating historical channel movement, showing the locations of past river channels and old river courses, using historical maps and aerial photographs
- Undertaking a field survey of present erosion, deposition, bank protection, flow types, sediment sources and controls on channel stability

2. defining major zones of geomorphic control on channel stability

1.3 Strategy and development

In order to achieve the objectives the investigations of the geomorphology of the River Ure are two fold; historic and contemporary field survey.

Firstly an investigation into the recent historical record regarding catchment and channel planform change has been undertaken. By digitally capturing and comparing the planform shape of the River Ure, from historical maps from different periods, areas of activity can be identified and zones of channel change defined. In addition, by understanding the influences from the changing catchment a holistic interpretation of geomorphological control can be defined.

Although the historical information can identify areas that may have a greater propensity to change, it is the contemporary data on the river channel that provides the reasons/understanding of why and identifies the controls on the system. The field methodology was developed using a number of previous investigation formats. A hybrid methodology was used akin to the Detailed Catchment Baseline Survey, but with additional reconnaissance survey of the bank structures and materials, channel deposits, and the hydraulic habitat types. Much of the data has been combined within a GIS and the field survey data recorded against channel reaches. These reaches have been defined on the consistent definition of channel form or process within a reach with reaches changing as these factors change significantly. This information has been used to produce a series of thematic maps (see map portfolio). This approach extends beyond that of the DCBS where the output map is based on a single summarising index of channel sensitivity. The approach adopted here displays analysed datasets. Further information is available within the GIS data tables.

2.0 Catchment description

2.1 Study Area

The River Ure to Ripon drains an area of 634.4 km^2.

Within this area four contiguous reaches have been identified for study:
- Worton to Wensley (c 18km)
- Wensley Bridge to Kilgram Bridge (c 12 km)
- Kilgram Bridge to West Tanfield (c 20 km)
- West Tanfield to Ripon (c 12 km)

These reaches are illustrated in Map 1.

Whilst these reaches are all Main River the geomorphological audit methodology looks more widely to catchment scale controls that may affect the issues identified within the study reaches.

The catchment of the Ure is categorised (Catchment Management Plan NRA 1996) as upper, middle and lower catchment areas, based primarily on geomorphological form, geological divisions and topographical divisions. The areas of the respective units are given below.

Upper catchment	506.6 km^2
Middle catchment	336.1 km^2 , although 208.3 km^2 is within the catchment to the junction of the River Laver with the River Ure, below Ripon.
Lower catchment	117.6 km^2 below Ripon

The lower catchment area (below Ripon to the junction with the Swale) is outside the present study zone and represents the lowland wider floodplain environment.

2.2 Catchment Characteristic Summary

In order to provide an overall picture of the landscape within which the River Ure flows, the catchment can be considered as consisting of a number of broad zones. These zones are based on the character areas identified within the Countryside Character Initiative and provide an insight into the changing dominant physical features that exist within the River Ure catchment and along with valuable information regarding the geomorphology of the area.

These zones will be discussed in further detail, with specific reference to the physical characteristics and land management, in the following sections and are:

- The Upland Dales - This area is composed of high exposed moorland dissected by the River Ure (forming Wensleydale). Topography and geology are the most dominant geomorphic controls.
- The Fringe Dales - This area is similar to that of the upland dales, with some variations in geology and a wider valley floor. Topography and glacial deposits are the most dominant geomorphic controls.
- The Magnesium Limestone Ridge - This area is low-lying with completely different geology to its adjacent areas and as such geology is the dominant geomorphic control.

- The Vale of York - This area has a wide floodplain which the River Ure meanders through, cutting through glacial and alluvial deposits which overlay a softer geology??. The dominant geomorphological control here is glacial deposits of boulder clays.

Table 2.1 Summary of catchment characteristics

Characteristic	Description
Catchment area	842.7 km^2
Study reach length	62 km
Relief/slope	716 to 50 metres AOD (mean slope 0.0107m/m)
Solid geology	Millstone Grit, Carboniferous Limestone and Magnesium Limestone
Drift geology	Glacial drift dominant in the Fringe Dales area. Holocene terraces and alluvium deposits
Hydrology	-
Hydrogeology	Directly influenced by the underlying geology. Magnesium Limestone considered as a major aquifer in the area, with the Carboniferous Limestone, Millstone Grit and the glacial drift as minor aquifers. The mudstones, marls and shales are considered to be impermeable and non-aquifers
Soils	The upper reaches of the River Ure are dominated by peats, which are non-alluvial and seasonally waterlogged. In the river valleys the soil is dominantly 'Brown' and suitable for agriculture
Landuse	Dominantly rough pasture on the valley sides and pasture with some arable on the floodplains. Moorland occupies the upper slopes.
Principle tributaries	River Bain, River Cover, River Burn, River Skell, River Tutt and River Swale
Conservation areas	Part of the Ure Valley is found within the Yorkshire Dales National Park. Smaller areas are designated as SSSI's and ESA's

2.2 Topography and drainage network

The River Ure catchment rises to 716 m within the National Park moorland of Great Shunner Fell. The downstream location at Ripon lies at c 50m AOD.

The drainage network within the upper part of the River Ure catchment is dense and the catchment is strongly right bank dominated. In the lower parts of the catchment the preference for right bank tributaries continues but with a sparser drainage network.

2.3 Geology

The geology within the Ure catchment is a dominant control on morphology of both the catchment and particularly within the upper channel network.

There are three main solid geological groups that outcrop within the channel of the River Ure. These are Carboniferous Limestone, Millstone Grits and Magnesium Limestone. The Carboniferous Limestones are found at Aysgarth Falls and the outcropping rock here forms the Lower, Middle and Upper Forces that the area is so well known for. The channel planform becomes confined here and the underlying bedrock provides no sources of sediment. The Millstone Grits outcrop to form a gorge like feature upstream of Mickley. This area is mainly wooded with a few scars visible further away from the river. This geology creates obvious constrictions on the channel planform and the bed. The Magnesium Limestone outcrops downstream of West Tanfield and forms the step features within the channel found at the Mill. The constrictions on the planform are limited here and only a few cliffs prevent lateral movement of the left bank. There is an outcrop of Middle Marl (Permian) which is a softer material and forms a cliff on the outside of a meander bend opposite Plasterpitts Farm providing an input of finer materials with some gypsum when eroded.

The drift geology is quite complex and can be considered as a number of reaches. Above Aysgarth Falls the drift deposits are dominantly alluvium with some Boulder Clay with more limited drift away from the channel. Below Aysgarth to West Witton the deposits are still dominantly alluvium with glacial sands and gravels. From West Witton to Mickley alluvium is still dominant but the presence of fluvial terraces increases further downstream. Downstream of Mickley the outcrops of Magnesium Limestone are interspersed with alluvium, fluvial terraces and fluvio-glacial terraces. Below North Parks Farm the dominant deposits are alluvium and a few river terraces, with one outcrop of Middle Marl (Permian) on the right bank opposite Plasterpitts Farm.

Erosion of the river banks within any of the drift deposits would produce a certain amount of sediment. Depending on the type of drift deposit the sediment could be a number of sizes and cohesion and therefore, it is important to distinguish between them to a certain degree. The fluvial deposits are all relatively recent (post-glaciation) and the alluvium deposits are composed predominantly of sand and fine gravels, the fluvial terraces are of mixed sand, fine and coarse gravels. The glacial deposits are generally older than the fluvial and tend to be more consolidated and less susceptible to erosion. In addition these glacial deposits will have larger clasts and a more mixed range of sediment sizes. The fluvio-glacial terraces are overall coarser and less rounded material with sands and fines, the glacial sands and gravels have a wide range of sand and gravel sizes and the Boulder Clay ranges from boulders and gravels to sands, silts and clays.

2.4 Landuse

The headwaters and right bank tributaries of the upper catchment drain upland grass moor, blanket bogs and dwarf shrub moorland of the rounded hilltops. The slopes above the valley floor are allotments (land which is semi-improved below the moorland wall) which is a mixture grading from improved or semi-improved grasslands towards the bottom of the slope to a rougher grazing at the top of the slope. This allotment land is largely put to sheep extensive grazing.

The uplands also have a proportion of bare rock and scree and in the former mining areas, particularly on the hills of Bolton Moors the surface spoil areas are generally poorly vegetated due to the toxicity of the scree, silts and gravels. The lower dales valley floors are predominantly improved pastures with cattle and sheep grazing. Within the middle of the Ure catchment there is a greater proportion of improved pasture and arable land.

The upper Pennine Dales have been identified as being Environmentally Sensitive Areas for land management purposes. This designation covers just the lower levels of the hillslopes and valley floor of the right bank tributary dales.

2.5 Conservation

The majority of the upland area of the Ure is within the Yorkshire Dales National Park (see Map 2).

The right bank tributaries within the middle catchment are designated as the Nidderdale Area of Outstanding Natural Beauty. A number of smaller Sites of Special Scientific Interest occur within the upper reaches of the Ure basin.

Two large Sites of Special Scientific Interest occur within the moorland sections of the catchment, East Nidderdale Moors and Low Seat-Stainton Moors. A number of smaller wet grassland sites occur along the floodplain including Ripon Park, Mar Field Fen, River Ure Grasslands and Wanlass Grasslands. Other wetlands sites adjacent to the river occur upstream of the study area. The conservation interest of these grasslands relates closely to their proximity to the river and the presence of former river courses which tend to be the wetter areas within the floodplain. The meanders in the lower section of Ripon Park are themselves of geomorphological scientific significance, although they are not currently identified as SSSIs.

There are a number of designated Environmental Sensitive Areas (ESA's) within the River Ure catchment mainly found on the upper right bank tributaries and within the National Park.

3.0 Methodology and data capture

In order to identify areas of geomorphological significance within the River Ure river channel the following methodology has been developed. This methodology consists of both historical and contemporary data collection and attempts to provide an overall understanding of the River Ure, where the zones of instability/stability are and what are the dominant controls of that instability/stability.

3.1 Historical approach

3.1.1 Catchment-scale

The factors within the catchment that have a direct influence on the sediment and water regime are assessed by examining both current and historic maps and through a review of the literature. This has included materials from contract reports, academic literature and the reports of the Yorkshire Dales National Park (Drewitt 1991, Countryside Commission 1991).

In addition, land cover mapping and vegetation surveys have been used to identify land cover changes. Catchment scale controls are mapped at 1:100,000 in Map 2.

3.1.2 Channel scale

Historic change in the channel has been charted by the use of the historic Ordnance Survey maps plotted against the modern 1:10000 scale maps. The following sheets of the First Edition were used to indicate the changes over the last 130 years. These maps are of an early date, with a date range of 1873-1875. Summary of the data sources used is given in table 3.1. The British Library and the University of Leeds Geographic Resources Unit supplied historic maps.

Table 3.1 Summary of source data

Map	Scale	Date
First Edition OS	1:10,560	1873-1875
Country Series	1:10,560	1920
B+W raster	1:10,000	1979–1980
LandLine data	1:2,500 and 1:10,000 vector	1999

The line of the channel and the in-channel features have been digitised from the First edition to the 1980 raster maps in order to allow effective comparison of the extent of change between the different periods and with the most recent mapping based on the LandLine data. The channel line and the position of bars and former channel lines has been digitised from these historic maps, although there may be other relevant contextual data available on the mapping which is of relevance to understanding the historic development of the channel. Where this occurs it has been used in the interpretation of patterns of change.

Map 1-illustrates the overall changes that have occurred within the study area and the Maps 4.1 to 4.5 illustrate the locations where (on the basis of the historic sources) there is evidence of particular marked change.

Evidence also remains within the floodplain. This evidence comprises:

- Historic embankment lines now divorced from the main channel line
- Lakes and ponds within the floodplain, representing cut-off channels.
- Historic lineaments of jurisdictional boundaries indicative of former channel centrelines
- Landform features (e.g. steep banks which may have been bluffs, linear wetlands)
- Occasionally the maps record "old course of river" or "Old Ure" indicating the former course alignment.

These floodplain features have been separately mapped within the GIS. Many of these features are well preserved in the floodplain whilst others may be more conjectural such as those based on the locations of landform features and boundaries which are often indicative of former channel lines. First edition OS data also generally records these features better (in more detail) than do subsequent versions of the OS mapping.

3.2 Contemporary geomorphological assessment

In order to define the present day geomorphological controls on the stability of the River Ure, a field survey was undertaken late Feb 2000. The following protocol was adopted.

3.2.1 Bank survey

Eroding and non-eroding banks were identified in the field using the form shown in Appendix 1. The form provides a standardised method of data collection from which and an overall view of the present lateral instability within the system can be formed. The form specifically details information that can be used to interpret the dominant controls on bank erosion, based on the wealth of published literature available. The data are collected continuously along the channel and a new reach is defined if there is a change in the dominant control on geomorphology and subsequent erosion. The form is divided into four main sections (the fourth is for eroding banks only):

- **General information** - This section provides information on the date, surveyor, and reference to the location of photographs taken and their orientation and the river the work is being undertaken on. All these factors ensure continuity and provide information for repetition and reference. In addition, flow conditions are noted to explain problems that may result from the 'drowning-out' of geomorphological features. The reach code links the form to the map and the request for identification of left or right bank ensures that no mistakes are made in identifying the correct reach. The eroding y/n box indicates the type of bank being observed. An eroding bank will be studied in detail and all sections completed, the total length of the reach will be identified on the base map with lower and upper extents marked. A non-eroding bank still requires the form to be filled in (although the last section is ignored) but a new reach is only identified if there is a dominant change in the controls on stability, (for example, a change from bedrock to bank protection.

- **Bank features** - This section explores the range of parameters that determine stability/instability within an individual river bank. Firstly the bank dimensions, the profile of the bank face and the average bank height across the designated reach. Bank type is another important factor and there is a choice between; cohesive, non-cohesive, bedrock and bank protection. However, if the bank is composite then the percentage of gravel within the bank is estimated and recorded and the remaining part of the bank is assumed to be cohesive. In addition to this the dominant material in the bank is noted as a bank can be cohesive and have a dominant bank material of sand or clay which may have a very different failure mechanism and hydrology. Finally, the dominant bed material is noted, the material type ranges from fines to boulders and also includes bedrock and artificial materials.

- **Bank vegetation** - The bank vegetation is a key factor in instability and bank vegetation cover requires an estimate of the total percentage of vegetation cover from the toe to the top of the bank. The percentage of woody vegetation (out of the total percentage of vegetation previously noted) is recorded for three separate locations; the top, middle and bottom of the bank. Additional information required for describing woody vegetation is its density within the reach and its approximate age (maturity).

- **Erosion** - This section is only filled in if the bank is considered to be eroding or there is evidence of recent erosion. Information gained from this section allows the process of erosion to be identified. Fluvial entrainment removes grains directly from the bank and transports them downstream. Geotechnical failure occurs due to the failure of the internal structure of the bank and its material. Subaerial weakening and weathering involves a number of processes acting on the surface of the bank, including freeze/thaw action, rain drop impact and saturation. Poaching due to cattle and other animals usually has little impact when viewed at the scale of the total length of river, however, in concentrated areas it can be detrimental to the bank stability. The severity of the erosion is also noted and is described in three categories of low, medium and high severity. The state of the eroding toe is described based on the presence or absence of accumulating material, either fallen vegetated blocks or bare material as this is indicative of the potential for self-stabilisation. In addition, whether undercutting has occurred is noted along with any evidence of self-healing (the deposition of sediment on a recently failed bank) or whether there is vegetation colonisation at the toe.

3.2.2 Locations and dimensions of channel bars

In order to determine the potential sediment sources within the river system it is necessary to measure the amount of sediment stored in bars within the river channel. This section details the field methodology for establishing bar dimensions.

Each bar within the river is allocated a number that is marked on the base map and the survey form. The dimensions of the bar are estimated by pacing. The x dimension is measured from the upstream end of the bar to the downstream end of the bar (parallel to the flow). The y dimension is measured at a right angle to the x line at the widest point. Finally the z dimension is the depth of the bar from the bed of the river to the highest point on the bar. The volumetric values for stored sediment are therefore maxima, and in practice may be smaller. The importance is in the relative volumes and the geography of the storage in relation to other aspects of the channel morphology and grainsize. The form for this data collected is shown in Appendix 1.

Table 3.2 Bar material

Bar Material	Code	Description
Fines	F	Includes silts and clays, very fine material <0.06 mm
Sand	S	< 2 mm but < 0.06 mm
Fine Gravel	FG	2-16 mm in diameter
Coarse Gravel	CG	16-64 mm in diameter
Cobble	C	Loose material 64-256 mm in diameter
Boulder	B	Loose rocks >256 mm in diameter

The dominant bar material and its size needs to be noted since the volume of storage of different material within the system is likely to change according to particle size. The key to be used in the table is shown below. (Source : Environment Agency, 1997, River Habitat Survey, 1997 Field Survey Guidance Manual)

Information on the bar type is also required; the table below gives information on the types of bars, the codes to be used in the table and the descriptions for each type.

Table 3.3 Bar types

Bar Type	Code	Description
Bedrock/Boulders	B	Exposed bedrock or boulders outcropping or protruding above the water level. Often covered with mosses in upland streams
Unvegetated mid-channel bar	MB	A distinctive depositional feature composed of unconsolidated material (usually coarse gravels or sands) derived from the channel, exposed at low flow, with a shallow slope into the water. Unvegetated is defined as <50% perennial plant cover. Will be covered during periods of high flow.
Vegetated mid-channel bar	VMB	A distinctive depositional feature composed of bed material from the channel, exposed at low flow with a shallow slope into the water. Perennial vegetation occupying >50% of area. Include moss-covered substrate, as this is an indicator of stability. Will be covered during periods of high flow.
Mature Island	MI	Permanent mid-channel feature with surface at or above bankfull height. Invariably vegetated, often with established scrub and trees. If significant deposits of fresh material surround a mature island, then both mature island and unvegetated mid-channel bar should be recorded. This indicates the presence of a mature feature and unstable, active deposition.
Point bars	PB	A distinctive depositional feature composed of bed material from the channel, found on the inside of meander bends with a shallow slope from the bank into the water.
Side bars	SB	A distinctive depositional feature composed of bed material from the channel found alternating on either side of a straight channel.
Braided bars	BB	A collection of bars, usually mid channel, dissected by a number of small channels.

Environment Agency, 1997, River Habitat Survey, 1997 Field Survey Guidance Manual

3.2.3 Sediment from tributaries

The Brief specified the reaches to be surveyed and excluded the tributary streams. Nevertheless tributaries can be a large source of sediment and this potential source needs to be roughly estimated. The first column of the form (shown in Appendix 1) capturing this information requires a code that should also be annotated on the base map. In addition to this code the name of the tributary in question should be noted.

In order to determine the potential of the tributary, with regard to sediment supply, a visual estimate of the number of bars, both downstream of the confluence in the main river and upstream of the confluence within the tributary is required. The categories are relatively self-explanatory, however; none = 0, few = 1-3, many = more than 3, as far as can be seen.

3.2.4 Flow types and biotopes

The flow types within a river system indicate the diversity of physical habitat and the influence of weirs, bridges and geomorphological structures. Increasingly, physical habitats (sometimes called mesohabitats or biotopes) are recognised as useful indicators of biodiversity representing a surrogate measure of the combination of depth and velocity as a major determinant of habitat diversity and hence biological colonisation. Biotopes have also been related to particular assemblages of invertebrate communities. In this report they are used to define the hydro-geomorphology of the system, and may be used to identify areas of relatively steep fast flows, as well as those associated with relatively gentle gradients and slower flows. The dominant physical habitat was defined for each reach, and changed as a new dominant flow type was encountered. A line on the map crossing the channel at that point distinguishes a change in flow type. The table below shows the descriptions of the different flow types and the codes allocated to each type which were used to build the maps of flow types. However, it may be noted that the flow types may vary across the channel, for example with slackwater or marginal deadwater adjacent to an area of rapids. In the case of such multiple channel flow types occurring the dominant type has been ascribed to the reach. This may result in an underestimate of the diversity of flow types if considered at a higher resolution but is considered appropriate at the more strategic level of this survey.

Table 3.4 Flow types

Flow Type	Code	Description
Waterfall	W	A feature of bedrock channels. Free fall flow which separates from rock
Cascade	C	Chute flow occurring over boulder substrates or bedrock outcrops. Often associated with broken standing waves
Rapid	Ra	Best identified from the white water broken standing waves, normally over a cobble, boulder or bedrock substrate, with a steep gradient
Riffle	Ri	Shallow, fast-flowing water with a distinctly disturbed surface. Unbroken standing waves dominant
Run	Ru	Generally fast-moving water with rippled surface but no other major features of turbulence. Often associated with a high-velocity feature (eg rapid or riffle) just upstream or where the channel narrows and therefore speeds up the flow. Also, where relatively narrow channel has moderate, even gradient
Boil	B	An upwelling flow feature found below falls, some chutes, in meander bends (in the scour pool) and around fallen debris (trees)
Glide	G	Water can move quite fast in glides but 'effortlessly' as smooth flow; only careful inspection reveals the turbulence. Also common on smooth bedrock surfaces but may be quite a short feature in those cases. In gently sloping clay rivers, a glide can extend to hundreds on metres in length
Pool	P	A distinct natural feature of deeper water. In dry weather conditions, there is no perceptible downstream flow. Back currents may be present. Pools should occupy most of the wetted channel width
Ponded Reach	PR	No perceptible flow created by natural bedrock control or artificial obstructions (such as weirs) downstream
Marginal Deadwater	MD	Marginal areas with no perceptible flow – perhaps where the bank has eroded into an embayment. Also in remnants of old abandoned channels

Environment Agency, 1997, River Habitat Survey, 1997 Field Survey Guidance Manual

4.0 Historical geomorphology

4.1 Historical catchment geomorphology

4.1.1 Introduction

Changes within the catchment may have profound affect on the channel through influences over the runoff and the sediment yield and delivery. Natural causes and human influences may both be influential in promoting active erosion and sediment delivery to the main channel, although these influences can rarely be isolated. A summary of the catchment scale controls and influences on the channel is illustrated in Map 2. The primary factors considered within the River Ure catchment are:

Natural catchment scale controls which include:

- Relief and topography
- Geology
- Hillslope form
- Drainage network
- Land cover

The main human influences on the sediment and water regime include:

- Mining (lead)
- Aggregate extraction (sand and gravel)
- Quarrying (limestone)
- Railway construction dating from 1846
- Milling (water and woollen)
- Abstraction (esp. at Kilgram Bridge)
- Afforestation
- Moorland drainage (gripping)
- Land management

4.1.2 Results

The channel within the upper catchment is typical of many moorland situations with extensive gills and a dense network of smaller, sub-parallel channels, Figure 1. The land use within the National Park is predominantly unimproved, with grass moorland and dwarf shrub heath. The channel network shown is dominant on the right bank of the Ure with little channel development on the left bank predominiantly determined by geological divisions. The dense network of radiating channels is typical of the steep and deeply dissected hillslopes. These gullies drain the higher peat and grass moorland areas and incised into the glacial drift materials, principally boulder clays.

The upper channels draining these steep hillslopes are distinct from the channels within the study reaches both by virtue of the slope and the planform. The headwater channels are frequent and sub-parallel. Within the middle catchment the network density declines and the planform changes to a more meandering form. These gills and gullies are important sediment supply zones, often with bare soils and active failures with contribution from the steep eroding slopes. Both high suspended sediment loads and high bedloads are produced with coarse debris cones at the downstream end of the gills. Suspended sediment loads may be high, but the coarser materials may be mobilised only during extreme flood events.

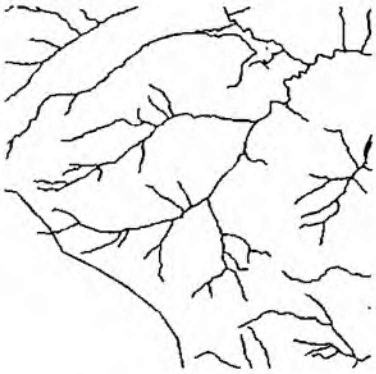

Figure 4.1. Contrast between the drainage pattern of the steep upper catchment tributaries and the mid-catchment drainage planform.

Removal of collected coarse material may increase erosion rates within the gulleys following the event. These may reinitiate slope instability within these hillslopes locations where material collected at the toe may have protected the slope from further collapse, but flood removal may reinitiate slope failures (Harvey, 1991). Harvey et al (1979) have estimated rates of erosion from such gills on the River Lune in Cumbria using repeat photographic evidence. These gill and gulleys areas generally have a high percentage of bare ground or with only partial vegetation cover on the steep slopes, increasing the potential for sediment supply. The river channel itself is confined to bedrock dominated areas or to alluvial gravels and sands, although within the middle Ure catchment the channel abuts terrace deposits.

Mining activity, and in particular lead mining was a specialisation within Wensleydale. The spread of disused mines within East and West Bolton Moors illustrates the primary locations for this industry. Mineral extraction was undertaken by shaft and adit, and surface levels worked where veins were exposed.

The mining has left spoil in a number of areas particularly on Boulton Moors where there has been little vegetation colonisation, making these areas more susceptible to erosion. These spoil areas also occur around water courses and former "hushes" that were artificial channels developed to flush ore material down the hillside. The result was the evacuation of large quantities of silts and gravels that have collected in the lower channels and developed spreads of more contaminated soils.

Quarrying for limestone still occurs within the catchment area. Its influence on the channel is of lower significance.

Moorland gripping is the process of digging drainage ditches. This activity extends the drainage network into an area of sub-parallel channels within waterlogged areas and generates a significant increase in the drainage network length. Thus grips may have a significant impact on the nature of the flow regime, although this may depend on soil type and season (Robinson 1990). The generalised result of gripping is the drainage of waterlogged catchment water stores and the more rapid runoff of surface flows into the channels, altering the time to peak and base flow.

Land use change statistics are not available for the whole catchment, although the changes noted within the moorland sections largely within the National Park may be more significant in terms of sediment supply. The figures analysed for the Countryside Commission (CC1991) indicate land use changes between 1970-1980. This includes increases in the extent of coniferous forest and improved pasture. There was a corresponding decrease in un-improved pasture. Whilst these figures are for the whole of the NP it appears likely that the relative increases within Wensleydale are less marked given the small representation of coniferous plantation within the catchment.

4.2 Historical channel change

4.2.1 Introduction

River channel change is a natural adjustment to variations in the external boundary conditions (primarily sediment load and discharge) and in response to human interventions. Natural rates of change may vary greatly due to extreme events (droughts or floods), local composition of materials and during recovery from disturbance. Human influences may be both direct within the channel and indirect, affecting catchment scale processes of sediment and water supply. Recovery of channel planform from destabilising events is dependent on the ability of the channel to rework the sediment either through erosion and deposition.

Assessing the channel historical map sequence (section 3.1.2) five sites show marked channel change and are summarised within Table 4.1. The three sections towards the downstream end of the reach may be considered as a single reach although for descriptive purposes they have been treated separately as they are separated by short reaches which have remained stable over the last 130 years. The five locations where significant change has occurred are illustrated in Maps 3.1 to 3.5.

Table 4.1 Characteristics of the channel change reaches.

Site of channel change	Distance (km)	Upstream grid ref	Downstream grid ref	Comments
d/s of Wensley	0.8	410800 489000	411200 489200	Short section of channel change associated with a meander bend. The channel change comprises accumulation of a gravel shoal and widening of the channel with subsequent modification of the channel boundary
The Wising	1.17	412600 488700	412870 488540	Former channel line predating the First edition of the OS mapping (i.e. pre 1870) with landscape features reminiscent of the channel line.
Thornton Steward at Jervaulx Abbey	1.5	416000 486360	417130 486040	Short sequence of change developed over c 1.5 km and three meander bends.
d/s of West Tanfield to Maple Hill	3.78	428750 477700	431000 476320	Sequence of meanders which show continuous change over a length of 5 km from the First Edition to the present day. The area includes cut-offs predating the First Edition maps and spreads of gravels as mid-channel bars and attached vegetated bars.
u/s of Ripon at Nunwick	3.57	431450 474560	431360 472560	The most significant changes are adjacent to North Stainley. The sequence of change tends to suggest a channel more active at the time of the First Edition than now. Modern mapping indicates fewer mid-channel bars and a more regular channel line. Short section of marked channel change developed over c 2.45 km and two meander bends with development of mid channel bars. Historically the channel appeared to contain more gravel bars than currently suggesting greater activity within this reach in the past. Changes are ongoing with the maps showing extensive more recent change (1980 – present).

Comparing the nature of the changes to the channels apparent within the historic mapping the most obvious feature of the channel is one of stability over the period of historic mapping (130 years). Of the 62km of channel studied only 10.8 km (17.5%) shows marked changes to the planform. However, there is more widespread small-scale adjustment of the channel, but the validity of the changes is less certain given the ability to discern such changes from digitisation of historic maps (Downward 1995). Such small-scale changes may reflect the difficulty in determining the position of the channel margin from historic data. However the pattern may reflect the nature of the bank failure mechanisms to the extent that small oscillatory changes may occur where bank failure results in localised stabilisation of the bank toe with subsequent bank repair by deposition. This results in only small net changes of bank line between profile surveys, which may mask a more continuous process of erosion along the channel. Similar situations are recorded in the River Dee between Holt and Worthenbury where historic mapping and field evidence indicates geotechnical failures "repairing" through bankside deposition over quite short timescales (Gurnell & Petts 1996).

The more major channel changes appear to be associated with the presence of gravel bars and shoals. However, the historic mapping may be misleading to an extent, as the representation of bar features is generally better in the earlier editions of the Ordnance Survey mapping. Confirmation from the field reconnaissance shows there to be, in general, less active gravel storage than at the time of the 1st Edition maps. This parallels similar evidence recorded for the River Tyne and Severn (Passmore 1994), and which has been attributed to a wetter and more flood prone climatic phase at the end of the 19th Century (Macklin & Rumsby, 1994).

The floodplain features are also largely associated with sites of most marked historic channel change and particularly within the downstream sections from West Tanfield to Ripon (shown in Maps 4.1 to 4.7). Previous studies on the Ure downstream of Ripon show further evidence of the extensive meander evolution within a wide floodplain (Howard *et. al.,* 2000). The presence of a more complicated channel planform in the past is a feature reported from other UK rivers (Sear, 1992; Passmore *et. al.*, 1993) and has been related to the relatively high flood frequency documented during the Little Ice Age (17th – late 19th centuries). Merret & Macklin (1999) document an increase in recorded flood deposits in tributary channels of the Dales Rivers between 1750 and 1900 that they ascribe to climate change. A decrease in gradient, and a change in drift geology, to fluvio-glacial outwash sands and gravels mark this latter section downstream of Bellflask Wood. Incision into this material, coupled with a reduction in energy, leads to deposition and lateral channel activity, making the reach more susceptible to climate driven channel change.

4.2.2 Human-induced change

In channel structures and activities have influenced the channel along much of the River Ure and many of these features are of considerable age. These are evident from the field visit and the analysis of historic and current maps. These influences on channel change are displayed in Maps 4.1 to 4.7.

Engineered features

- Weirs
- Mills and associated structures
- Bypass channels
- Channelisation
- Bridges
- Breakwaters
- Embankments
- Bank protection works (e.g. rip-rap, blockstone, willows planting etc)

A series of mills and control structures are present along the River Ure. Most of these have had a direct effect on the channel planform. Most of the villages along the channel had a mill and although these may no longer operate the infrastructure remains, including side channels, upstream weirs and mill races. These features are seen at:

- Sleningford Water Mill
- Tanfield Mill
- Mickley
- Masham
- Former Abbey Mill (Jervaulx)
- Danby Low Mill
- Asygarth

Records from the Environment Agency also suggest that stabilisation and channel improvement schemes affected much of the Ure over the period 1951-1955 (Table 4.2), principally associated with the repair and improvement of flood embankments. Most likely in response to flood events proceeding that period. There are no records of major channel modifications, bed and bank erosion control or desilting, the management term for sediment removal. It is possible that local removal of gravel shoals for aggregate by farmers has occurred, but no large-scale protection works have been documented. That being said, it is clear that the Jervaulx Abbey reach has had substantial bank protection works applied at some point in the recent past. A further bank protection work was undertaken here in 1991 (Sear, 1991), but the reaches affected are all relatively discrete. Sear, 1991 noted evidence for much earlier bank protection works along the same Jervaulx reach. During this survey, there was no confirmation that other lengths of the river were similarly protected.

Table 4.2 Location of records of channel capital works on River Ure (data derived from EA database).

Location	Date	Works	Primary	Secondary
Thornton Steward 400 yards	1951	STS	BS	-
Norton Conyers 300 yards	1951	STS	BS	-
LB Newby with Mulwith 700 yards	1952	STS	BS	-
LB Danby Hall 800 yards	1952	STS	BS	-
Myton 2400 yards	1953	CIS	EM	EI
Thornton Steward 1200 yards	1953	CIS	EM	EI
Mulwith 700 yards	1953	CIS	EM	EI
Thornton Steward	1954	CIS	EI	EM
Myton	1954	CIS	EI	EM
Mulwith	1954	CIS	EI	EM
Longthorpe	1954	CIS	EI	EM
Clifton Castle	1954	CIS	EI	EM
Clifton Castle and Longthorpe	1955	CIS	EI	EI
Lower Dunsforth RB	1962	CIS	EM	EM ST

STS=(stabilisation scheme), CIS=(channel improvement scheme), BS=(bank raised and straightened), EM=(embanked), EI= (embankment improvement), ST=(stoned).

The extent of channel change at Nunwick shows the most extensive and rapid changes in the channel planform. The sequence of historic maps runs from the 1880, 1920, 1980 and the recent LandLine data for 1998. The channel has been laterally active for much longer than the map evidence alone reveals, but it is relatively discrete, and affects two large channel bends.

The sinuosity of this reach has increased over the period from the 1880s when the channel was first accurately surveyed. Furthermore, spreads of gravel and in-channel bars and vegetated bars have declined and the channel planform appears to have narrowed within this period.

Table 4.3 *Changing sinuosity in the Parks, Nunwick sub-reach*

Date	Channel length	Sinuosity
1880	2.8	1.14
1920	3.15	1.28
1980	3.5	1.43
1999	3.57	1.45

The rates of change indicated in this section suggest that the stream powers are high, well above the threshold for erosion and sediment transport. The reach has been characterised by sediment storage, such as is typical of so-called wandering gravel-bed rivers. Discrete braiding of the channel is typically a response to locally increased sediment supply and storage. A reduction in braiding and an increase in sinuosity, such as recorded for this reach, is typical of a reduction in sediment supply followed by incision. It is known, that significant commercial gravel extraction occurred from the bed of the Ure in the 1960's, upstream of this reach (Morland pers comm.2000). The effect of which would be to reduce sediment loads downstream and initiate the type of response observed (Sear & Archer, 1999).

The older evidence such as the boundary lines is less certain and the evidence may be difficult to assign to a single period of floodplain occupation. However it is clear that, in contrast to most of the floodplain of the study reach, the Parks at Nunwick floodplain has been considerably reworked over the period of historic maps.

5.0 Contemporary geomorphology

5.1 Data capture and manipulation

In order to interpret the data and define zones of stability and instability by determining the role of geomorphology and its influence on bank erosion, it is necessary to represent the controlling variables spatially.

Map 1 shows the River Ure eleven sectional map. These are used to display the thematic information on individual maps, for the main variables collected during field survey at a scale of 1: 15 000. Additional data have been analysed within the GIS and are not mapped here.

The following sections identify the main variables that are required to determine the stability of the River Ure planform from both historical and contemporary data. There are a few areas of the River Ure that were inaccessible due to topography and geography, a thin grey line, on the maps indicates these sections of the river. The sequence of maps illustrates the bank erosion, bank material and flow types. The data from the field surveys is attributed to the channel bank line within the GIS and the flow types to the channel area.

Bank erosion

The bank erosion data was collected during the walk-through survey using the form in Appendix 1. The information collected was held within the GIS, which was linked to a location on the river. This location is a line that has been on-screen digitised from the field maps as line data.

Two maps at different scales have been used to identify the main areas of contemporary bank erosion. The first map (Map 5) shows the presence or absence of bank erosion at a catchment scale in order to identify the basic areas of instability. This uses the 'eroding - Y/N'

However, there is additional information that is required in order to identify the processes and severity of this erosion and maps 5.1 to 5.7, provide this information. Reaches are attributed with the information, the first is the process of erosion, indicated by the colour of the line. The main processes of erosion are through fluvial action, geotechnical failure and subaerial erosion (Thorne 1982). Although these processes may work together to form a particular type of failure. For example, cantilever failure is initiated by fluvial action, which removes the toe of the bank, the failure is completed through geotechnical failure when the block of overhanging sediment becomes saturated and too heavy; a tension crack forms and the block falls to the toe of the bank.

The severity of erosion is depicted by the black dashed lines. The smaller the gap between the dashes the more severe the erosion. The severity of the erosion is an important factor to determine, as erosion can exist but be of no real problem to the overall planform of the river. However, more severe erosion can lead to instability of the morphology of the channel and therefore, an awareness of their locations is imperative if an effective management system is to be introduced and maintained.

The status of the toe, whether eroded or protected can provide information regarding the availability of sediment within the reach and the efficiency of the flow (Lawler et al 1997). Three different symbols are used to display information regarding the toe of the bank. Each symbol signifies a status of toe stability. The triangle indicates a bank that is undercutting, the circle a bank with no accumulation and the diamond is a bank with an accumulating toe. The green diamonds depict toes that show evidence of self-healing by revegetation of the blocks that have fallen at the toe.

Material

As with the bank erosion data the information regarding the material within the River Ure was collected during the walk through survey. The bed and bank material was identified using the bank survey form in Appendix 1, the bar material type and volume using form in Appendix 1 and the information regarding tributary supply was collected using the form in Appendix 1. Maps 6.1 to 6.7, show this information on material within the River Ure.

The bank material data is also attributed to the bank line within the GIS. The bank material type helps to determine the nature of the failure or potential failure that the bank is undergoing. Different colours on the maps represent these bank material types. As mentioned in the methodology there are a number of materials that can be depicted as cohesive materials. In order to distinguish between these, a dashed line of different spacing represents the dominant material type with the cohesive bank materials. A dotted line represents sandy bank material and a more closely spaced dotted line glacial material.

The bed material data was recorded as area datasets, showing the zones of bed material size. The bed material was generalised across the channel using the dominant cover class, ignoring the finer scale variations, in a similar manner to the flow types. Bed materials are depicted by a range of colours, grey being an artificial substrate. The colour scheme used matches that used for bank materials.

Information on channel bars is recorded as attributes of point locations. The material size and volume is displayed using size (volume) of the point and colour (size of material) of the point. The larger the point the larger the volume of material and the darker the colour the larger the bar material size.

Flow types

Flow types were collected during the walk-through survey and provide information on the potential transport rates of the river and its gradient and stream power as well as indicating the channel biotopes. This information is shown in maps 7.1 to 7.7. The data were included as attribute to areas within the GIS. Specific colours were allocated to the different flow types. Hatched colour rather than solid depicts flows where the water was broken.

5.2 Erosion & bank stability

Bank erosion along the study reach is shown in simplified form in Map 5. Bank erosion of some form and severity is present throughout the study reach, although bedrock exposures produce two reaches of relative stability. These are associated with the Aysgarth Falls reach, and a section lower down the study reach, around West Tanfield. What is of interest, is the difference between the historical areas of instability described above, and the extent of contemporary bank erosion. The latter is more extensive than the former, although the historically unstable zones are also areas of contemporary bank erosion. The details of the bank erosion are presented in Maps 5.1 – 5.7.

In total 57.9% of the riverbanks exhibit some form of erosion, amounting to 55.2 km length (includes left and right banks). Figure 5.1 details the proportions of bank erosion type along the study reach.

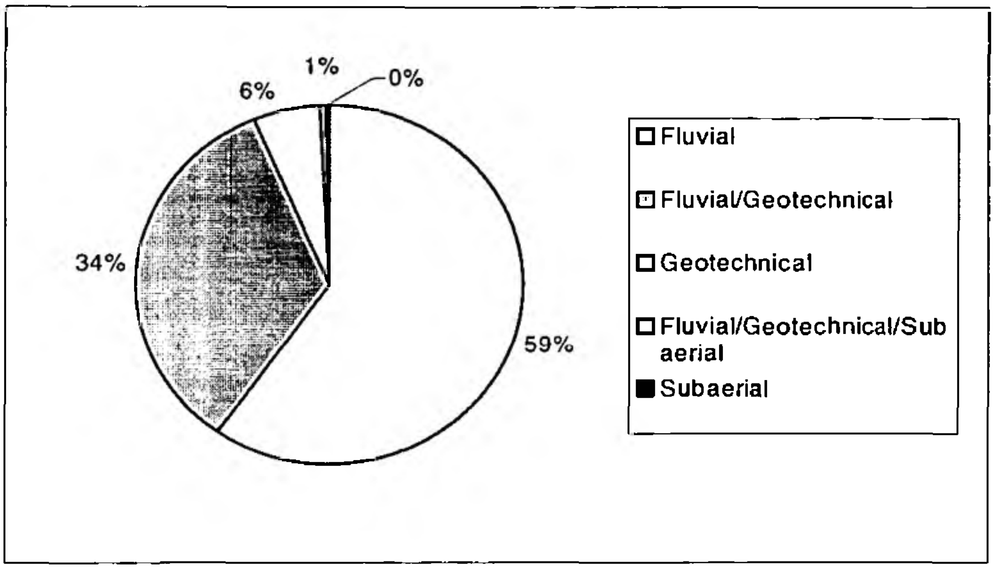

Figure 5.1 Percentage of bank Erosion types

The dominant forms of erosion in the Ure study reach are fluvial and combined fluvial and geotechnical. Both arise from the presence of composite bank material with a weaker gravel layer at the toe, a weaker cohesive material within the bank structure due to the presence of sand or purely as a result of scour of the bank at the outside of meander bends. Of interest is the frequent presence of erosion on both outside and inside of meander bends and along relatively straight reaches. This is often evidence for channel incision (and bank collapse) or more likely in the Ure, as evidence of channel widening. This latter scenario may reflect recovery of the Ure following recent large flood events, particularly those in 1995. Whatever the cause, the pattern of contemporary erosion contrasts with the historical picture of lateral stability along much of the watercourse. Closer examination of the historical maps indicates some evidence of minor adjustment in the bankline, which at least indicates that more of the bankline might have been active, but never resulted in major adjustment of planform or migration of the channel. The limits of accuracy in both surveyed and digitised data make this interpretation speculative. However, analysis of the toe status information recorded on Maps 5.1 to 5.7 lends some credence to this argument; in most cases, the bank toe is accumulating, and in many cases the toe material shows signs of vegetating, both of which are good indicators of a capacity for self-healing of the erosion. Indeed, many of the bare faces, interpreted in the field as eroding, may in fact be maintained simply because of weathering processes at the bank face. Rates of bank retreat in most of these cases are very slight. This contrasts with locations of relatively mobile banks associated with the meander bends. Particular examples are those immediately upstream of Middleham, although historically these again have shown relatively limited migration despite high planform sinuosity. Interestingly, the presence of strong turbulence at the outside of one of these bends, has resulted in no net accumulation of sediment at the bank toe, and may indicate an area of migration, rather than stability.

Figure 5.2, shows that of those banks that are eroding, only 6% (7.6km) can be classified as severe, the majority are in the moderate and low erosion severity rating. Most of the severe categories occur on the outside of tightly meandering bends, or where extensive erosion occurs at the "Terrace" river cliff downstream of West Tanfield. Overall, the majority of banks do not show any significant bank erosion.

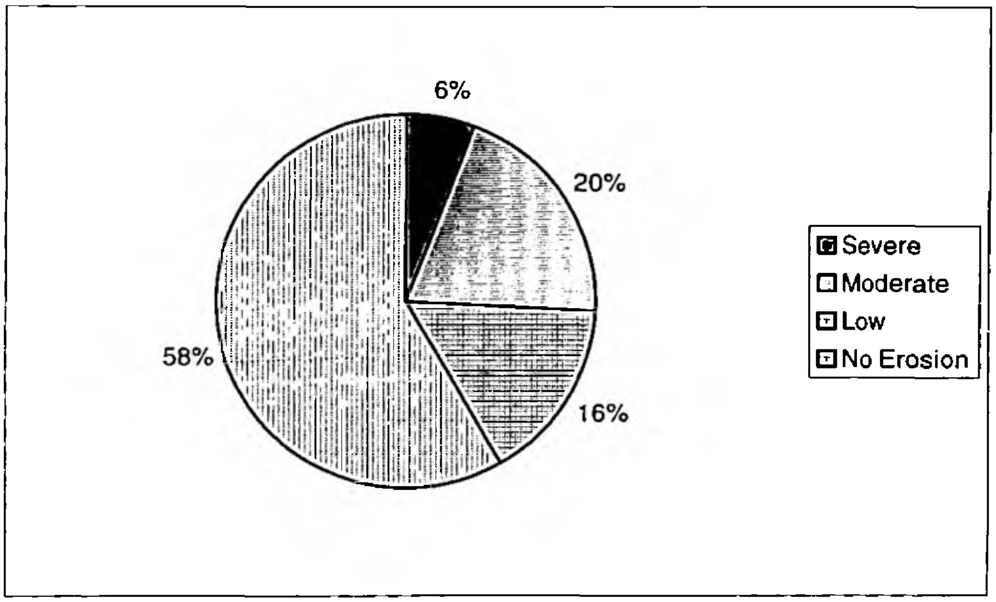

Figure 5.2 Erosion severity rating along study reach

Seven erosion-defined reaches can be identified within the study reach. These are detailed in Table 5.1 and identified spatially in Map 8.

Reach E1 is a sequence of eroding banks associated with the alluvial basin upstream of Aysgarth, where the Ure cuts into fluvial sediments. Erosion is associated with the meanders downstream of Worton Bridge, but also along the less sinuous reach downstream. Reach E2, is a laterally stable section associated with the bedrock exposures and valley confinement. Reach E3 includes erosion associated with the meandering sections upstream of Middleham and at Jervaulx Park. This is a similar reach to E1, in that it is associated with an alluvial valley floor within which the Ure intermittently meanders. At this these points, flow structure, composite bank materials and sediment storage, generate local erosion zones. At Jervaulx Park, Sear (1991) attributed erosion to a combination of factors, not least the confinement of flood flows between embankments, the presence of composite gravel-toed banks, and a relatively sinuous planform. The contribution of sediment from Harker Beck may also be a factor. The banks through this reach are largely accumulating material at the toe, and have, along much of the southern bank, had the weaker gravel toe protected by concrete revetment. This is a reach of known historical activity, although over the past 147 years this has been relatively minor. The two lower bends through the Jervaulx Park Estate, show no accumulation at the toe and are therefore currently more susceptible to erosion.

Downstream of Kilgram Bridge (Reach E4) the valley becomes confined by high terraces of fluvial deposits, and the Ure cuts into the valley side drift of glacial boulder clay. A potentially significant source of sediment occurs at Squirrel bank, downstream of Kilgram Bridge. Clear evidence of geotechnical instability at this site and a pattern of slumps, followed by stabilisation suggest long term instability of the cliff face, though with relatively little lateral migration over time. The face itself shows relatively little evidence of deep seated slips, rather the surface is periodically affected by shallow slides associated with scour at the toe. The rate of supply of sediment from the slips to the toe is greater than the capacity of the Ure to remove it, hence the bankline is stabilised and maintained. In addition the material is cohesive glacial till which can withstand relatively steep, and high banklines.

Table 5.1 Erosion defined reaches

Reach	Erosion Defined Reaches	Description
E1	Worton Bridge – Aysgarth (Eroding Reach)	Erosion along most of this reach, affecting both banks. Banks are vegetated, and between 0.5 – 2.5m high. Alluvial reach in confined valley. Severity of erosion is related to sinuosity:- high severity in meanders. Historical stability associated with much of this reach, suggests recent erosion is post-flood adjustment. Toe status dominantly accumulating.
E2	Asygarth – Wanless Park (Non-eroding Reach)	Bank erosion is limited to discrete reaches of bank, generally low-moderate severity. Bank heights highly variable and influenced by bedrock and glacial drift (0.5 - +40m). Stability is controlled by cohesive or solid bank and bed material.
E3	Wanless Park – Kilgram Bridge (Intermittent eroding reach)	Bank heights typically 0.5 – 2.5m, material is sands and composite banks with gravel toe. Erosion severity typically low-moderate though with some discrete banks exhibiting more severe erosion. Erosion process dominated by fluvial with slumping of undercut banks. Overall toe status is accumulation, with variable bank vegetation. Alluvial reach, often with embankments close to channel.
E4	Kilgram Bridge – Squirrel Bank (Intermittent eroding reach)	Major change in bank height and materials. Glacial drift confines the valley leading to a series of much higher banks (5 – 40m), some affected by geotechnical failure. Overall, erosion severity is moderate – low. Vegetation of banks and toe accumulation suggests that banks self-stabilise.
E5	Squirrel Bank – Masham (Intermittent eroding reach)	Erosion severity low-moderate, dominated by fluvial processes. Bank heights are variable, with some river cliffs where the Ure abuts glacial drift. Most bank heights are 2.5m. Bank materials cohesive with sands.
E6	Masham – d/s West Tanfield (Park (Non-eroding Reach)	Erosion is confined to discrete sections of bank often with low severity rating. Vegetation and bedrock help control the bank erosion in this reach. Materials are generally cohesive where not bedrock. Sand is present throughout the bank material.
E7	West Tanfield – Ripon (Intermittently eroding reach)	Sections of quite severe erosion locally occur along this reach, which flows through glacial and fluvial outwash terraces. Fine gravels and composite banks, provide for more unstable banklines, although again erosion tends to be intermittent. Bank heights are variable (0.5 – 40m). A significant sediment source is a river cliff at "The Terrace"

A long reach of intermittent erosion (E5) occurs between Squirrel Bank and Masham, with decreasing erosion occurring from Masham – West Tanfield (E6). In reach E5, the Ure, again flows through an alluvial basin, with bank heights up to 2.5m, but often with limited fluvial erosion. Downstream of Masham, the Ure again cuts through bedrock, and the valley floor becomes confined. Reach E6 down stream to West Tanfield, is characterised by relatively steep, high banks, often wooded, and, around West Tanfield particularly, underlain by bedrock. The result is a relatively stable bank line, with little significant erosion, although it should be noted that visibility of the bank line was difficult in many places.

Reach E7 downstream of West Tanfield, is the laterally most active reach on the whole 63km. The channel banks become more active, and there is a concomitant change in bed material grainsize from coarse gravel and bedrock, to fine gravel and sands. The river cuts into fluvial gravels and sands associated with former river terraces and glacio-fluvial outwash gravels. A combination of a decrease in dominant grainsize and a reduction in channel (and valley floor gradient around Bellflask Wood) account for the relative instability of this section of river channel, that culminates in the major instability zone at The Parks, Nunwick. The area is known to have been subject to commercial gravel extraction, and it is possible that incision of the river has occurred in response to removal of gravel from the bed. This would exacerbate bank instability through geotechnical failure if the value for critical bank height were exceeded. There are proportionally higher frequencies of undercutting and no accumulation recorded for the bank toe status supporting the observation that this is one of the most laterally active reaches on the Ure. Interestingly, the Parks meanders mostly show accumulating and vegetating bank toe material suggesting that erosion is currently slowing, although an exception is at the first concave bend at the head of this reach, where severe erosion is occurring (Newson 1996). Further analysis of this site is presented in Section 6.0.

Throughout the River Ure study reach, riverbanks were generally vegetated with completely bare faces comparatively rare. However, much of the vegetation was grazed grass that offers little structural strength to the bank line, and little cover for the in-stream ecology. Not unsurprisingly, the areas of active erosion were associated with bare unvegetated bank faces. This is not considered to be a case of cause and effect, rather the fact that active erosion will remove bank face erosion. Overall, the evidence for major livestock poaching was limited. The characteristic bank form seemed to be a steep bare face with a vegetated toe, arising from cantilever failure and slumping of sections of bank that have now stabilised fluvial toe scour. Whilst it might be true that livestock may wear the vertical bank face, and graze the bank vegetation, there was no significant evidence for the breaking up of banks and bank toes by livestock. Clearly, livestock fencing would encourage denser and more woody vegetation colonisation of the riparian bankline, but overall, the bank line is not significantly unstable. Those areas of significant erosion can be explained by contingent factors, including areas of complex planform morphology, locally weak bank material (presence of a significant gravel toe), and where sediment size valley gradient decrease, resulting in much more mobility and storage of sediments.

5.3 Sediment storage and bed and bank materials

Sediment storage is overestimated by the approach adopted, but it is the location and relative scales of storage that are important for analysis. Maps 6.1 to 6.7, detail the location of sediment storage in the study reach, together with information on the bed and bank materials and the contribution of sediment from tributary streams. The map series crudely depicts the natural sequence of downstream fining of bed material dominant grainsize, from cobbles, boulder and bedrock upstream of Wensley, through coarse gravels with patches of cobbles and bedrock outcrops upstream of West Tanfield, to fine gravels downstream of West Tanfield into Ripon. It is notable, that this latter section is associated with the highest rates of historical lateral instability, and braiding. Sandy silts dominate bank materials with a relatively cohesive nature for most of the length of the reach. Overall, the evidence for bank protection was minor, affecting relatively discrete reaches on the outside of bends near to the fringe of settlements. At Bellflask House, coarse cobbles, left from the gravel extraction processing, have been pushed to the side of the channel presumably to protect the riverbank and embankments. Sear (1991) mentions the presence of old wooden bank protection along the Jervaulx park reach, and hypothesised that this may reflect a more widespread form of protection on the Ure. No evidence was found by this survey to confirm this. The stability of the bank line over much of the River Ure, must therefore result from the strength of the bank materials, the presence of vegetation on the banks and bank face, and as advanced above, the accumulation of fines at the toe of the bank that appears to protect the bank from further fluvial scour.

The patterns of sediment storage in the river Ure are of interest since there is a clear link between areas of former lateral channel activity, meandering planform and the presence of bars. A broad view of the river suggests that most of the sediment storage is associated with reaches of high sinuosity where meanders reduce sediment transport capacity and their associated flow structures can deform the bed creating locations for sediment accumulation. Good examples are in the reaches downstream of Worton Bridge, through the bends upstream of Middleham, The Jervaulx park reach, Clifton-on-Yore and in the reach downstream of Norton Conyers. In the majority of cases, these reaches are also associated with sections of bank erosion, often with composite banks, suggesting that most of the material is derived from local bank erosion. However, there is a known feedback between sediment accumulation, the resulting flow complexity and the presence of erosion, thus it is impossible to say at this stage how much of the current sediment load results from bank erosion and what results from bedload transport from upstream reaches and tributary injections. Five sediment storage reaches are identified, although isolated bars occur throughout the river Ure. Table 5.2 details these reaches and they are shown spatially within Map 8. All but one, the Deep Nick Dub-Miller Wood reach, are associated with a meandering planform. The Deep Nick Dub reach is explained by its location at a break in gradient downstream of a higher energy bedrock and waterfall section upstream.

Table 5.2 Sediment Storage defined reaches

Reach No.	Sediment Storage Defined Reaches	Description	Dominant sediment stored
S1	Worton Bottoms – Thornton Rust	A sediment storage zone comprising a series of small bars (<400m^3) associated with higher sinuosity meandering planform	Cobble & coarse gravel
S2	Deep Nick Dub – Miller Wood (u/s Wensley)	A sediment storage zone located at gradient change downstream of high-energy bedrock section. Comprises a series of small bars in relatively low sinuosity reach	Cobbles & boulders
S3	The Wisings – Beggars Mouth (Middleham)	A sediment storage zone comprising a series of small – medium bars (<4,500m^3) of relatively fine sediments associated with high sinuosity meanders	Coarse gravel & sand
S4	Harker Beck Mouth – End of Jervaulx Park Meanders	Sediment storage zone comprising a series of small bars of cobbles, associated with meandering planform and input from Harker Beck.	Cobbles
S5	Bell Flask Wood & Nunwick Reach	Sediment storage zone comprising medium – large (<42,000 m^3) bars of fine and coarse gravels, associated with meandering planform and wider reaches of channel (possibly influenced by gravel extraction).	Fine gravel & coarse gravel

In general the calibre of the material stored in bars, matches that of the local bed, with boulder and cobble bars dominating the upper reaches, progressively fining to store coarse and fine gravels downstream. Despite the dominance of sand in the banks of the River Ure, there are relatively few bar forms that are dominated by sand. Two reasons for this are firstly, that the sand load is washed through the system quite rapidly, and forms benches along the margins of the channel. This may account for the presence of toe accumulations of sand along much of the river. The second reason is that much of the sand is stored beneath an armour layer of coarser particles, the fines having been removed from the surface layers, leaving behind a coarse lag of gravels, cobbles or boulders. It is the surface of the bed and bars that are used in this classification, thus under-representing the quantity of sand in the system. A third reason that would account for the relative absence of finer sands, silts and clays is the transmission of fines into storage on the floodplain during overbank flows. This may account for up to 50% of the total suspended load of rivers like the Ure.

Throughout the study reach there is evidence of the stabilisation of former sediment storage features by vegetation, although overall the river is dominated by unvegetated bars. These vegetated features relate to periods of past channel activity associated with flood events, and which have subsequently been colonised during periods when inundation has not occurred sufficiently frequently to remove developing vegetation. It is interesting to note the presence of vegetated bars in the relatively active reach around and downstream of Norton Conyers, that suggest that for the present the degree of channel activity is less than in previous years. The record of historic floods developed by Merrett & Macklin (1999) remind us that this is only temporary, and in fact phases of activity and relative stability, driven by climate, characterise upland Dales rivers.

The field survey indicates that the input of coarse sediment from tributary streams is small compared to other sources, based on the absence of sediment storage features in the channels. However, this may only reflect recent flow and sediment transport regimes, and over time this situation may reverse. It is notable that sediment storage occurs in the Jervaulx Park reach immediately downstream of the Harker Beck confluence, and similarly, that limited sediment accumulation occurs downstream of Masham where the River Burn enters the Ure. Tributary confluences are important sites to monitor for evidence of sediment transfer into the main river as they provide the most efficient route for sediment derived from the wider catchment.

5.4 Flow Types and channel bedforms

Flow Types, or Physical Biotopes, represent the hydraulic expression of substrate and gradient within a river, and have been linked explicitly to instream ecology (Maddock, 1999). The presence or absence of particular flow types may be directly linked to the presence or absence of certain species of fish, invertebrates or plants. Thus in the study reach of the Ure higher energy flow types, consistent with steeper gradients and larger substrates dominate over low energy flow types, associated with deeper flows, shallow gradients and finer substrates. The flow types also reflect the geomorphology of a reach, in particular the complexity of the long-profile.

Maps 7.1 – 7.7 detail the distribution of dominant flow types or Physical Biotopes, observed for the study reach during the time of survey. The flow at the time was at low winter levels, following a period of at least bankfull flooding.

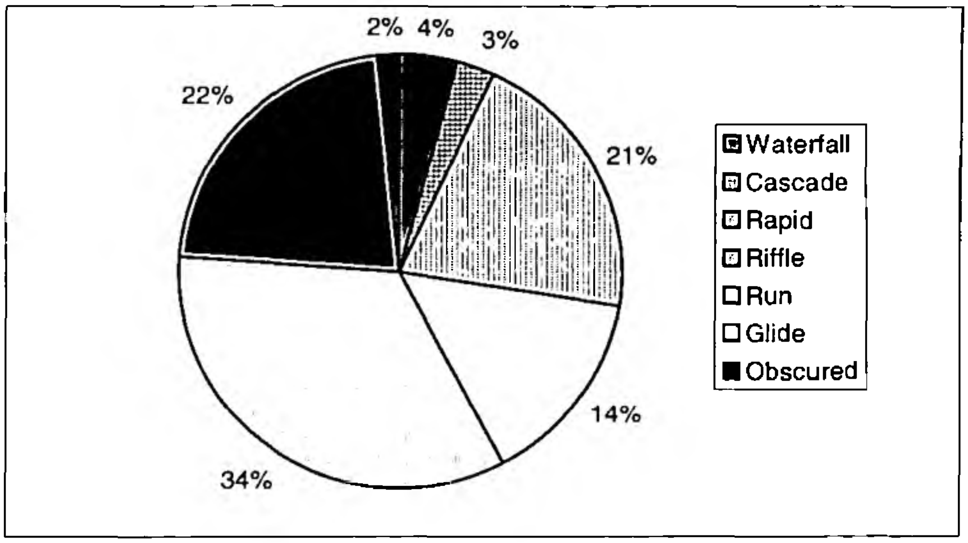

Figure 5.3 River Ure Flow type (Physical Biotope) inventory: Low Winter Flows

Figure 5.3 summarises the proportions of the different flow types for the whole study reach. The categories reflect the flow conditions and gradient within the Ure, and thus do not contain any slower flow type categories (pools or marginal deadwaters). The presence of bedrock exposures plays a significant role in developing reaches with diverse flow type categories including higher energy types such as waterfalls and cascades. This contrasts with other reaches (e.g. Jervaulx-Clifton-on-Yore) where at the time of survey the dominant flow types remained relatively uniform for several kilometres. The lack of riffles recorded at the Jervaulx reach represents an error in the field surveying since Sear (1991) details several riffles in this reach. The dominant flow types are Glides and Runs, with relatively few riffles and more rapids. In terms of the overall area, however, there is more riffle habitat than rapid, as these latter features are generally more discrete. Overall, the Ure has a moderate – high flow type diversity. Seven reaches may be identified in terms of flow types present and extent of flow types (Table 5.3) and displayed spatially in Map 8.

The Flow Type diversity of a given reach is often complex but should not be taken to infer a need for restoration if diversity is low. For example, the low Diversity reach between Worton Bridge and Aysgarth, is not in need of rehabilitation to increase flow type diversity, rather it has an alternating sequence of runs and glides, that is consistent with the stream substrate and gradient. The Ulshaw Bridge – Clifton-on-Yore reach is lacking in flow type diversity which is inconsistent with the geomorphological diversity and evidence for limited channel management. This reach should be re-surveyed to confirm or reject the current findings. Overall, the study reach is diverse, and reflects the flow types expected for a steeper coarse substrate river. There was no evidence of a need to introduce new flow types through rehabilitation in the study reach.

Table 5.3 Flow Type Defined Reaches

Reach	Flow Type Defined Reaches	Description
F1	Worton Bridge – Aysgarth	Low diversity: Alternating sequence of 9 Runs and 7Glides
F2	Aysgarth – Wanless Park	High diversity: Complex sequences of all higher velocity flow types. 12 waterfalls, 8 Cascades, 11 riffles, 27 rapids, 19 Runs, 9 Glides
F3	Wanless Park – Ulshaw Bridge	Moderate – High Diversity: Complex sequence of 22 Runs, 18 Glides, 5 Rapids, 11 Riffles. Complexity highest around Wensley – Middleham Bridge.
F4	Ulshaw Bridge – Clifton-on-Yore	Low Diversity Reach: 5 Rapids, 6 Runs, 1 Cascade. Note, Cascade associated with Kilgram bridge. Flow conditions obscuring riffles.
F5	Clifton-on-Yore - Masham	Low-Moderate Diversity Reach: 9 Rapids, 4 Glides, 9 Runs.
F6	Masham – Bell Flask Wood	Moderate Diversity Reach: 18 Glides, 13 Rapids, 15 Riffles, 26 Runs, 5 Obscured.
F7	Bell-Flask Wood – North bridge(Ripon)	Moderate Diversity Reach: 10 Glides, 10 Runs, 2 Rapids, 6 Riffles.

5.5 Geomorphological Interpretation

The River Ure, in the study reach, has a diverse and interesting geomorphology and physical habitat. There are seven geomorphologically defined reaches along the 63km study reach detailed in Table 5.4. and shown spatially in Map 8. These reaches represent a study reach classification based on erosion, sedimentation, flow types, materials and valley floor geomorphology. These reaches might be viewed as "natural" linear units, with specific assemblages of materials, geomorphology and associated channel dynamics. These form the basis for sustainable management, and could be used to interpret subsequent changes in channel behaviour and to monitor the impacts/effectiveness of channel management, for example bank line habitat improvements through fencing. The table is considered to be self-explanatory, and thus detailed interpretation is not undertaken except for the most laterally active reach downstream of West Tanfield.

Table 5.4 Geomorphologically defined reaches of the River Ure: Worton Bridge – North Bridge, Ripon.

Reach No.	Location	Description
G1	Worton Bridge – Aysgarth	Alluvial Basin with floodplain. Low diversity alternating flow types (F1 sub-reach). (E1 sub-reach) Sediment Storage sub-reach associated with meandering planform (S1 sub-reach)
G2	Aysgarth – Wanless Park	Confined bedrock Reach with limited Floodplain. High Diversity, high energy flow types (F2 sub-reach). Non-eroding section (E2 sub-reach). Low volume, coarse sediment storage as isolated sporadic bars (S2 sub-reach).
G3	Wanless Park. – Kilgram Bridge.	Alluvial basin with extensive floodplain and fluvial terraces. Flow-Type sub-reaches F3/F4 (moderate – Low diversity). Erosion E3 subreach – intermittent erosion associated with meanders Sediment Storage sub-reaches S3/S4 associated with meanders
G4	Kilgram Bridge – Mickley	Confined valley with discrete alluvial basins and periodically wider floodplain. Flow Type sub-reach (F4, F5, F6) Erosion Sub-reaches E4, E5, E6. Intermittent eroding and non-eroding reaches. Low sediment storage limited to discrete bars.
G5	Mickley – West Tanfield	Alluvial Basin with locally wide floodplain, confined at either end by bedrock. Flow Type sub-reach F6 Erosion sub-reach E6. Limited erosion. Low sediment storage, discrete bars at meander bend.
G6	West Tanfield – The Parks, Nunwick	Wide Alluvial basin with terraces and floodplain. Flow Type sub-reach F6, F7, moderate diversity. Erosion sub-reach E7. Historically most active zone with instability reaches and large eroding river cliffs in places. Sediment Storage sub-reach S5. High volume sediment storage downstream of Bellflask wood associated with change in gradient and change in substrate dominance to finer gravels and sands. Reach affected by gravel-mining.
G7	The Parks, Nunwick - North Bridge, Ripon	Confined floodplain, bordered by fluvial terraces. Low lateral channel activity over past 147 years. Flow Type sub-reach F7. Limited fluvial erosion (E7) and sedimentation.

West Tanfield – The Parks: Specific study reach

The reach downstream of West Tanfield is; both historically and recently the most active section of the River Ure, and has been the subject of concern regarding erosion of land (Newson, 1996). This survey indicates that this reach is different to all others, in being incised into finer gravels arising in part from glacial outwash sands and gravel drift, but also due to a major decrease in local valley and channel gradient, which promotes deposition. The Parks, meanders, can be seen in Figure 5.4, to lie downstream of a significant series of sediment sources, in particular the river cliff at "The Terrace". Sediment storage in the reach upstream of the Parks is less than the potential annual supply suggesting significant capability for further storage, or perhaps incision of this reach following gravel mining. The values for sediment supply are also over-estimates, since the value if derived from the total length of eroding bank line, multiplied by the average bank height, and multiplied again by an erosion rate determined by dividing the maximum width of floodplain re-worked by the Ure since the OS 1st edition by the 147 years since the date of the first survey.

Material clearly accumulates preferentially at The Parks meanders, and it is this situation that results in high levels of channel activity. The erosion is therefore not a local phenomenon, and as such is not suitable for treatment through normal means of protection. The storage capacity in The Parks reach also provides an important regulatory function for reaches downstream through Ripon. Any activity that reduced this functionality could have serious impacts on the downstream channel capacity and dynamics. In contrast to the Newson (1996) report, and whilst recognising the call in this report for more research on this site, it is not recommended that bank protection is undertaken. Rather, it is suggested that the site is managed in order to preserve its the sediment storage functionality, and that the bank lines are protected only in so far as they are encouraged to re-vegetate through fencing off of livestock.

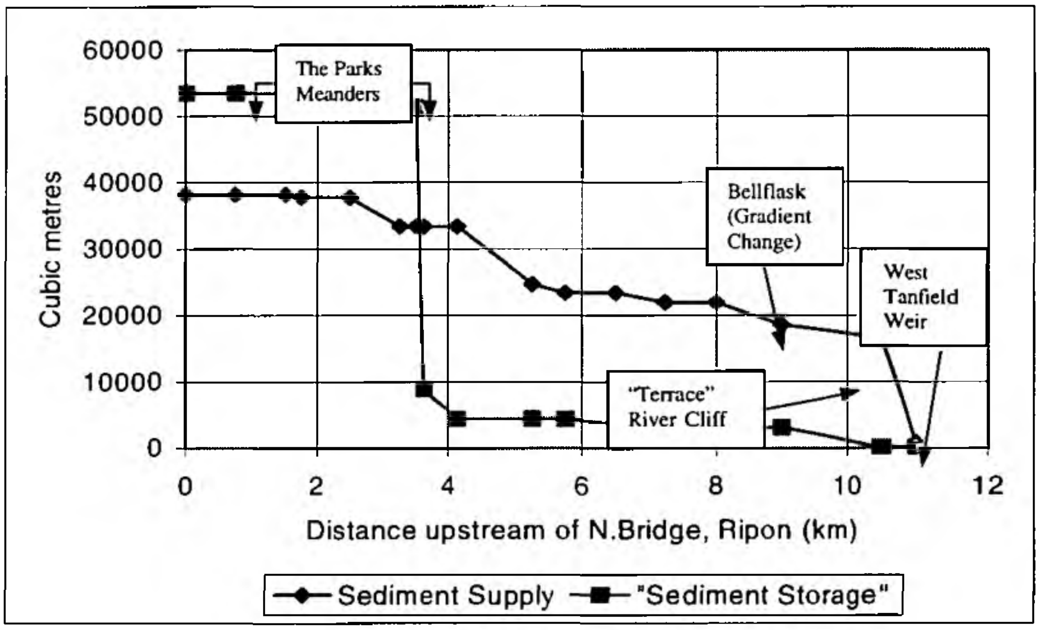

Figure 5.4 Sediment budget for West Tanfield – North Bridge Reach

6.0 Management Implications

The main implications arising from this study refer to the management of the naturally active reaches downstream of West Tanfield (see above), and general comments regarding erosion and deposition in the river.

6.1 Erosion

Most of the of the river has been laterally stable over the past 147 years. Local instability zones exist, and have been documented. The major instability sites are located downstream of West Tanfield, where some spectacular braiding has occurred in the past. Channel management should recognise the functionality of these sites as local zones of sediment storage, that provide important adjustment capability in response to changes in flood and sediment transport regimes. These sites can be expected to re-activate over time. It is recommended that these instability zones are considered in terms of their geomorphological conservation value and that land and channel management reflects their potential activity and sediment storage functionality. Other sites of channel erosion appear to be spatially limited and reflect general bank line adjustment to the sequence of large floods that occurred in the mid-late nineties. In terms of erosion control, it is clear that grazing has a significant effect on the biomass of the riparian zone, and that this in itself makes bank more susceptible to weathering and fluvial scour than would otherwise be the case if a dense riparian vegetation community existed. That being said, livestock damage is minimal, and does not contribute to the erosion to any great degree. The best form of bank management is to fence off a riparian "buffer" and to reduce grazing in that zone. The implications of this action should also be considered, as tree management may be necessary with time. Tree scour, an erosion feature associated with the presence of trees on banks in the absence of woody understorey, should be prevented by removal of grazing.

6.2 Sedimentation

There is ample evidence of sedimentation in the Ure at instability zones, and at other discrete sites. Overall, there appears to be little reason to remove shoals. The floodplain is extensive, and the major land loss confined to certain reaches. Sensitive reaches do exist, notably where major tributaries (e.g. Harker Beck, River Down) join the river, and these should be monitored after major floods, for evidence of sedimentation. However, unless there are good reason to remove shoals (for example, for flood protection where it can be proved that channel capacity has been significantly reduced), then no removal should be considered the default advice. If shoal removal is undertaken then care should be exercised not to remove riffles, but only to scrape off the top of a shoal.

6.3 Physical habitats

The Physical habitat structure of the channel of the Ure does not appear impoverished except in terms of lower energy flow types. However, this is a function of the substrate and gradient of the Ure, rather than a reflection of any "problem". Indeed, if the survey was continued below Ripon, then extensive low-energy flow types could be expected. What is not clear, is the status of the floodplain during over bank flows, but it is likely that extensive low-energy habitat is missing from the floodplain as a result of land management practices that have removed damp riparian woodland, and embanking that has reduced floodplain connectivity with the main river. The Riparian corridor is extensively grazed, and fencing off of the riverbanks would improve the diversity of channel margins.

6.4 Use of this report

The value of this report lies in the future use that is made of the information. The reconnaissance is a rapid, auditable form of data capture that provides excellent base line data against which subsequent channel activity may be compared. Three types of repeat survey are envisaged and encouraged:

- Regular surveys of geomorphological status (every 5 – 10 years) would provide a valuable means of identifying changes in geomorphological activity of the river helping to monitor extension or contraction in sediment storage/erosion. This could be incorporated in summary form in LEAP reviews, and used to assess claims of channel change/erosion problems etc. in a wider context.

- Impact Assessment of specific local channel management may be measured, for example, it would be possible to re-survey local reaches of the channel where bank or river disturbance had occurred and compared to the 2000 survey data.

- Flood Impact assessment, would provide important contextual data on the role of high magnitude, low frequency floods such as Hurricane Charlie (1986), that resulted in extensive geomorphological activity within the Swale.

In addition to the values of repeat surveys, it is recommended that the Maps/Database are updated with information on channel management that affects the extent of erosion (i.e. bank protection, rehabilitation works) or sediment storage (shoal removal, river rehabilitation). A useful appendage would be to obtain and digitise aerial photographic coverage for input into the historic map assessment of channel change and to provide wider geomorphological context including the floodplain.

A specific recommendation is to undertake Physical habitat mapping at a higher flow, close to bank full in order to provide an upper envelope on the available habitat during flood conditions. The role of the floodplain in providing habitat at higher flows should also be considered, and explored with reference to the location of embankments and opportunities for reinstating riparian woodland.

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Appendices

Appendix 1 - Field Survey Forms

Bar dimensions, material and types

Date	
Surveyor	

River	

Bar No.	X – us/ds	Y – x/s	Z - depth	Material	Type

Tributary Sediment Form

Date	
Surveyor	

River	

Tributary		Main channel: bars d/s of confluence			Tributary : bars u/s of confluence		
Code	Name	None	Few	Many	None	Few	Many

Bank survey form

Date		Surveyor		River	
Reach Code		Eroding Y/N		Bank L/R	

Photograph Codes	Orientation (°)

Description:-

Flow conditions Low flow ☐ M. flow ☐ High flow ☐

Bank profile Vertical ☐ Steep ☐ Moderate ☐ Gentle ☐ Flat ☐ **Average bank height** m

Bank type Cohesive ☐ Non cohesive ☐ Composite ☐ Bedrock ☐ Bank Protection ☐

Bank material Fines ☐ Sand ☐ F.Gravel ☐ C.Gravel ☐ Cobble ☐ Boulder ☐ Bedrock ☐ Artificial ☐ Glacial ☐

Percentage of gravel in bank %

Bed material Fines ☐ Sand ☐ F.Gravel ☐ C.Gravel ☐ Cobble ☐ Boulder ☐ Bedrock ☐ Artificial ☐

Bank vegetation cover % Woody cover Top % Middle % Bottom %

Spacing Sparse ☐ Moderate ☐ Dense ☐ Age Young ☐ Mature ☐

Process of erosion Fluvial ☐ Geotechnical ☐ Subaerial ☐ Poaching ☐ Other ☐

Severity of erosion Low ☐ Medium ☐ High ☐

Toe status Accumulation: Vegetated blocks ☐ Bare sediment ☐ Gravel ☐

No accumulation ☐ Undercut ☐ Evidence of vegetation colonisation ☐

Appendix 3 Photos of the River Ure


Plate 1 Glide


Plate 2 Run


Plate 3 Riffle


Plate 4 Rapids


Plate 5 Cascade


Plate 6 Waterfall


Plate 7 Bedrock cliff downstream of West Tanfield


Plate 8 Bedrock outcropping downstream of West Tanfield


Plate 9 Area of channel change


Plate 10 Eroding terrace


Plate 11 Cantilever failure


Plate 12 Evidence of revegetation at the toe


Plate 13 Evidence of self healing


Plate 14 Typical reach with bar


Plate 15 New planform


Plate 16 Erosion on the outside of a meander bend

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