Appendix 2 Mill summary sheets

HELLESDON MILL

Table Ba1 Hellesdon Mill Location

Mill name:	Hellesdon Mill
National grid reference:	619800, 310500
Upstream catchment area:	650km2
Length of channel to next mill upstream:	5km
Geomorphological Appraisal (2006) reaches:	W50
River Wensum Restoration Strategy reach code:	RWRS 01
Mill owner:	Environment Agency (site only, mill buildings demolished)
Sluice owner:	Environment Agency
Owner of water rights:	Environment Agency
Listed status:	None

Plate Ba1 Left: View of one of the fixed weirs at Hellesdon Mill: Right: Hellesdon Mill viewed from downstream

Table Ba2 Hellesdon Mill Weir & channel details

Water control level:	3.85m AOD
Drop:	1.21m (to 2.64m AOD)
Length of backwater upstream:	5km (100% reach)
Main structure:	Block A: 1 flume with a steel control sluice and a horizontal steel penstock plus 3 fixed weirs with stop-log facilities and weed screens; Block B: An automated, bottom hinged overshot tilting gate. Invert 2.52m AOD
Operation of main structure:	Block A: Permits majority of flow to enter the section below the mill. Sluice only used during high flows in conjunction with Tud sluices; Block B: Controls mean water level upstream in the River Wensum.
By-pass structure:	Tud sluice acts as bypass channel - see below
By-pass structure operation:	Automated
Gauging station:	None

Table Ba3 Hellesdon Mill Previous works or recommendations

Previous measures:	Sluice connecting the River Wensum to the River Tud (about 100m upstream of the main sluices) was automated in 1999. This allows the Environment Agency to accurately maintain water levels upstream of the mill.
Geomorphological Appraisal (2006) suggestions:	De-silt reach. Remove Hellesdon weir to drop water levels and narrow channel using embankment and dredged spoil. Re-establish riparian wooded margin.

Table Ba4 Hellesdon Mill Restoration strategy recommendations

Main recommendations:	The control water level should be lowered in stages so that the upstream channel stabilises and vegetates rather than exposing extensive silt when flows decline. *Stage 1* The operating level can be reduced at very low cost initially by reducing the operating level of the Tud sluice, by removing wooden boards and opening the sluice in the mill. *Stage 2* There are four bays in the main structure all of which differ. There is also a drop at the outlet of the mill structure at normal flows that would not be changed by the restoration as this is the downstream limit of proposed work. To remove the obstruction of the mill down to the sill level it is necessary to break out the concrete in two of the bays. To maximise connectivity with the downstream reach a fish pass is also desirable.

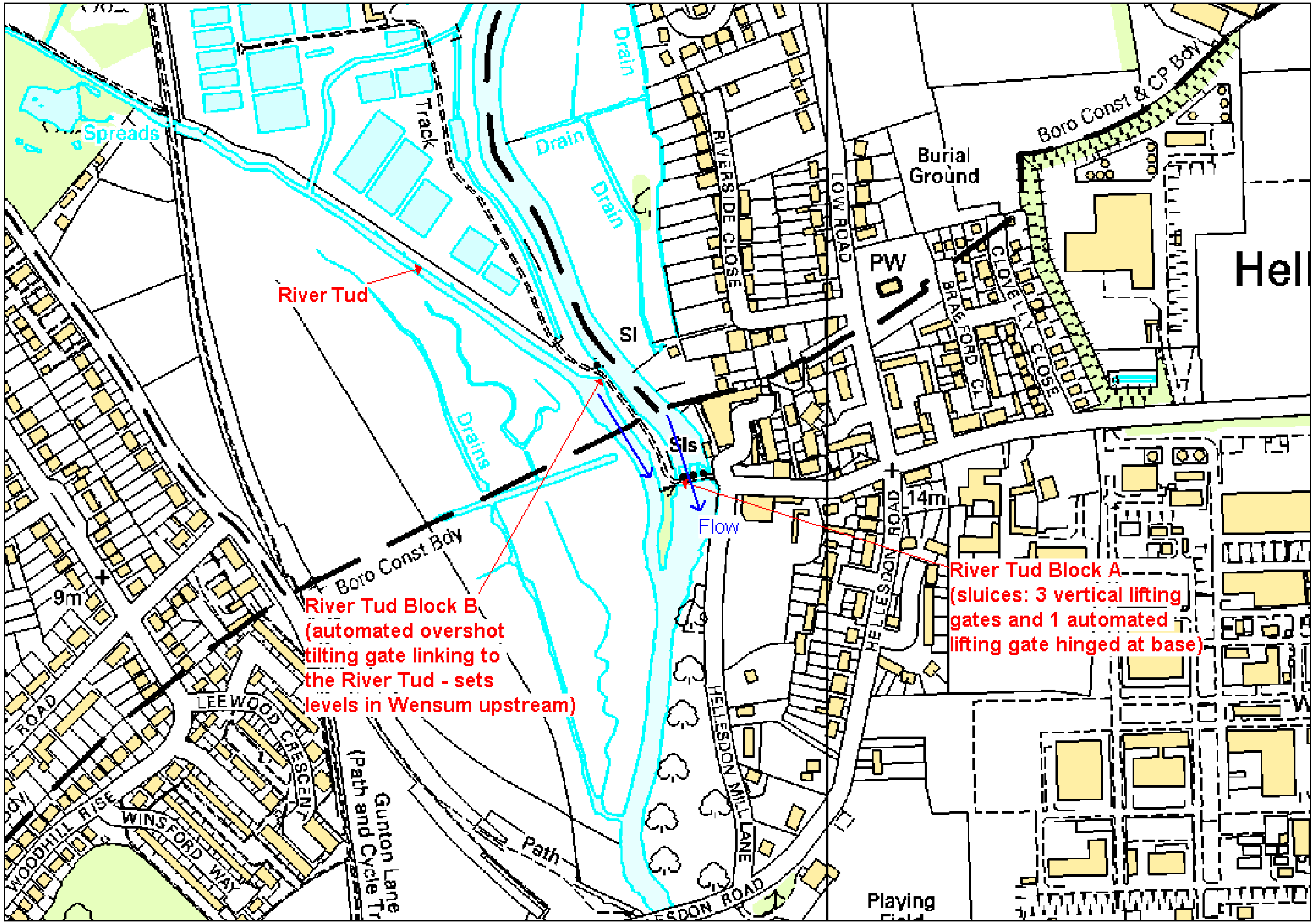

Figure Ba Hellesdon Mill Location Plan

COSTESSEY MILL

Table Bb1 Costessey Mill Location

Mill name:	Costessey Mill
National grid reference:	617700, 312700
Upstream catchment area:	560km^2
Length of channel to next mill upstream:	4km
Geomorphological Appraisal (2006) reaches:	W58 and W57
River Wensum Restoration Strategy reach code:	RWRS 03
Mill owner:	Environment Agency (site only, mill buildings demolished)
Sluice owner:	Environment Agency
Owner of water rights:	Environment Agency
Listed status:	None

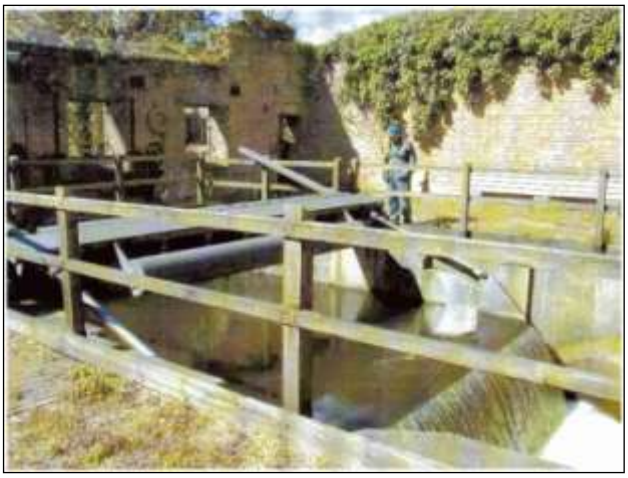

Plate Bb1 Left: Automatic tilting gate within Costessey Mill: Right: Costessey horseshoe weir under construction

Table Bb2 Costessey Mill Weir & channel details

Water control level:	5.38m AOD
Drop:	1.1m
Length of backwater upstream:	2.25km (56% reach)
Main structure:	An automatic tilting gate, and a fixed weir (5.32m AOD) and a slide sluice fish pass (5.1mAOD).
Operation of main structure:	Used to control water levels. Old vertical lifting gates not in operation.
By-pass structure:	The bypass is controlled by a horseshoe weir used for flow measurement
By-pass structure operation:	
Gauging station:	Yes, HiFlows No. 34004. Telemetry outstation and gauging station.
Additional notes:	None

Table Bb3 Costessey Mill Previous works or recommendations

Previous measures:	None
Geomorphological Appraisal (2006) report suggestions:	Reduce level of weirs; Upstream - monitor changes; Downstream - fix sediment ingress points and narrow channel.

Table Bb4 Costessey Mill Restoration strategy recommendations

Main recommendations:	Lower water levels upstream of mill: *Stage 1* The control level could initially be reduced by lowering the automated control gate and allowing the horseshoe weir flow to decline. *Stage 2* The horseshoe weir could be modified to allow flow through at a lower level by removing a number of weir blocks (see construction photo) .and thus achieving desired balance in flow between downstream channels.

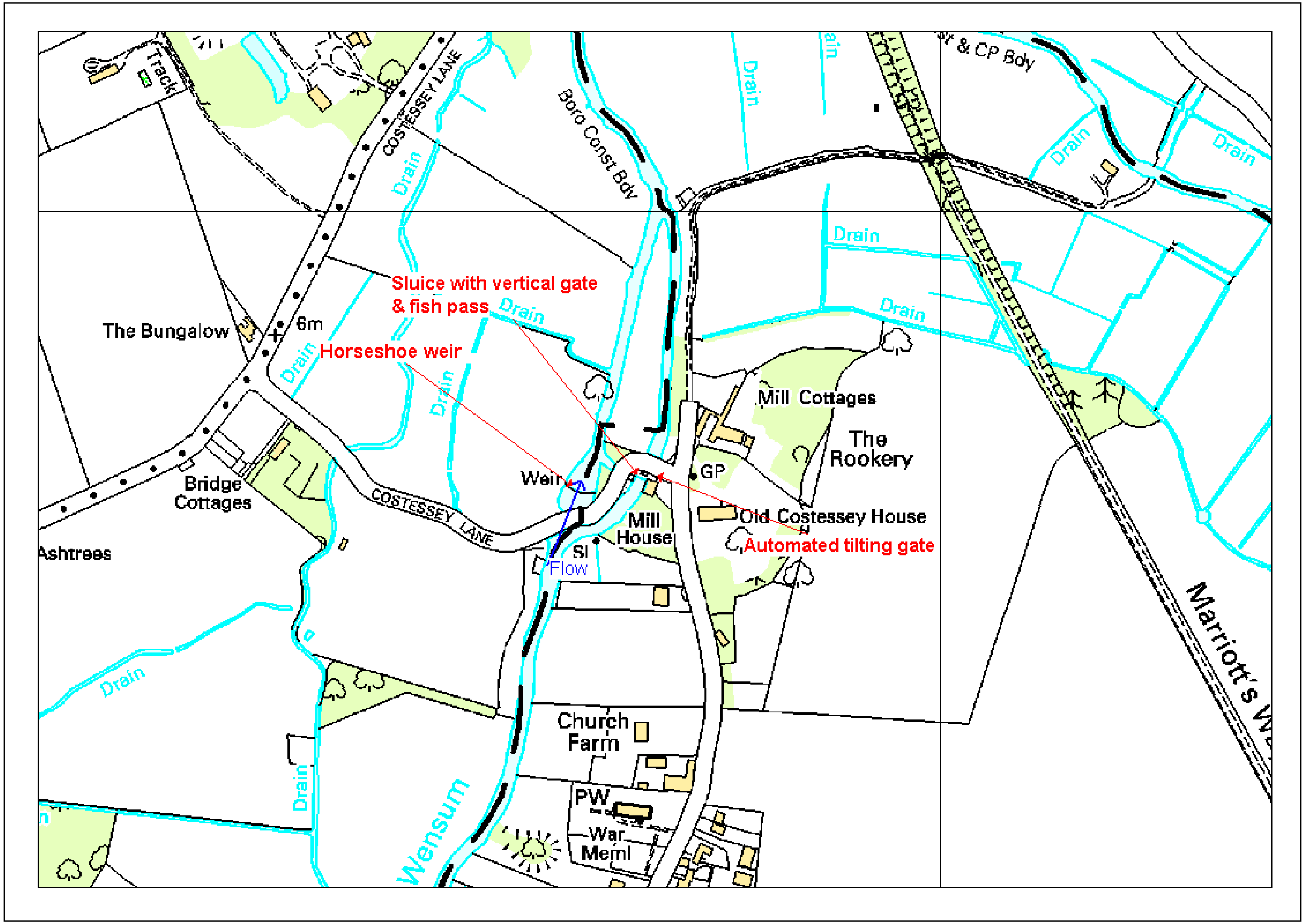

Figure Bb Costessey Mill Location Plan

TAVERHAM MILL

Table Bc1 Taverham Mill Location

Mill name:	Taverham Mill
National grid reference:	615900, 313700
Upstream catchment area:	550km^2
Length of channel to next mill upstream:	13.2km
Geomorphological Appraisal (2006) reaches:	W201 and W200
River Wensum Restoration Strategy reach code:	RWRS 05/04
Mill owner:	Anglian Water Services Ltd. (site only, mill buildings demolished)
Sluice owner:	Anglian Water Services Ltd.
Owner of water rights:	Anglian Water Services Ltd.
Listed status:	None

Plate Bc1 Left: View of weir (Structure #8) at site of Taverham Mill from downstream: Right: Sluice on right bank of Wensum upstream of Taverham Mill site (Structure #2)

Table Bc2 Taverham Mill Weir & channel details

Water control level:	7.6m AOD (estimated)
Drop:	1.41m
Length of backwater upstream:	4.3km (33% reach)
Main structure:	Two vertical lifting gates and two wheel rail timber boards sluice inverts around 6.6mAOD.
Operation of main structure:	Boards removed during flood.
By-pass structure:	Complex system of streams and structures upstream of main road bridge.
By-pass structure operation:	Side stream has brick culvert control. Second side channel has piped overflow.
Gauging station:	None
Additional notes:	Three sluices feed into the main pool. Pools and riffle glide with good variety of habitat downstream known as spawning area.

Table Bc3 Taverham Mill Previous works or recommendations

Previous measures:	None but refer to ECON report priority scheme (by-pass, sluice decommissioning and floodplain wetland creation).
Geomorphological Appraisal (2006) report suggestions:	Fix sediment ingress points. Remove mill sluice and augment gravel bed.

Table Bc4 Taverham Mill Restoration strategy recommendations

Main recommendations:	In co-operation with Anglian Water, remove sluices and install a series of riffles upstream of the current sluices to control water levels. Divert part of flow through the meandering channel on the right bank but ensure a secondary flow path is maintained through the current straightened main channel.

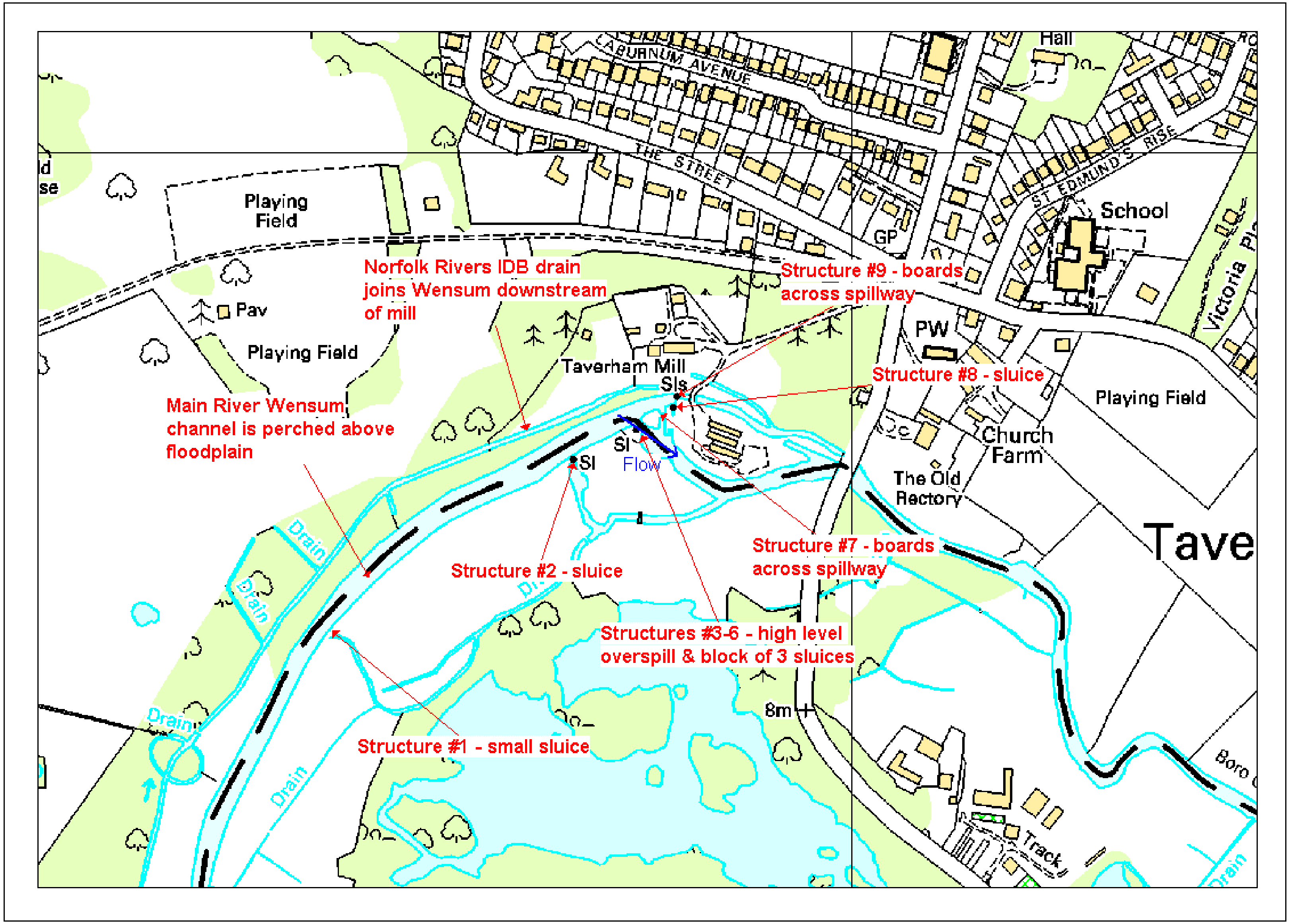

Figure Bc Taverham Mill Location Plan

LENWADE MILL

Table Bd1 Lenwade Mill Location

Mill name:	Lenwade Mill
National grid reference:	610200, 318200
Upstream catchment area:	430km^2
Length of channel to next mill upstream:	5km
Geomorphological Appraisal (2006) reaches:	W303 to w301
River Wensum Restoration Strategy reach code:	RWRS 11/12
Mill owner:	Private (converted to residential use)
Sluice owner:	Environment Agency
Owner of water rights:	Environment Agency
Listed status:	Lenwade Mills, Lenwade Street listed July 1983 (Grade II).

Plate Bd1 View of Lenwade Mill from main road (downstream)

Table Bd2 Lenwade Mill Weir & channel details

Water control Level:	13.6m AOD (estimated)
Drop:	1.5m
Length of backwater upstream:	3.2km (63% reach)
Main structure:	Two automated, bottom hinged overshot gates.
Operation of main structure:	Gates operate automatically to maintain the set water level (12.3m AOD invert). Additional internal mill flume (privately owned) has a regulation gate for use by mill owner (11.7m AOD).
By-pass structure:	Main flow (over automated gates) now bypasses the mill
By-pass structure operation:	Automated gates operated by EA
Gauging station:	None
Additional notes:	Flow is mainly over 2 weirs on the right of the mill. There is a large pool that is ideal for fish. Gabions have been placed on the banks so the riparian habitat is poor. The grass is mowed short (the channel is open) although some alders were planted downstream that influence flow diversity.

Table Bd3 Lenwade Mill Previous works or recommendations

Previous measures:	Flood defence appraisal report at Lenwade Mill in September 2002 (undertaken by Nigel Holmes for the Environment Agency). Sluices automated in 2004.
Geomorphological Appraisal (2006) report suggestions:	Fix sediment ingress points. Reduce level of sluice. Reduce maintenance. Downstream - initiate monitoring.

Table Bd4 Lenwade Mill Restoration strategy recommendations

Main recommendations:	*Stage 1* Lower operating levels of automated sluice progressively - could reduce upstream level by a maximum of approximately 1m. *Stage 2* Create fish pass to lowered gate.

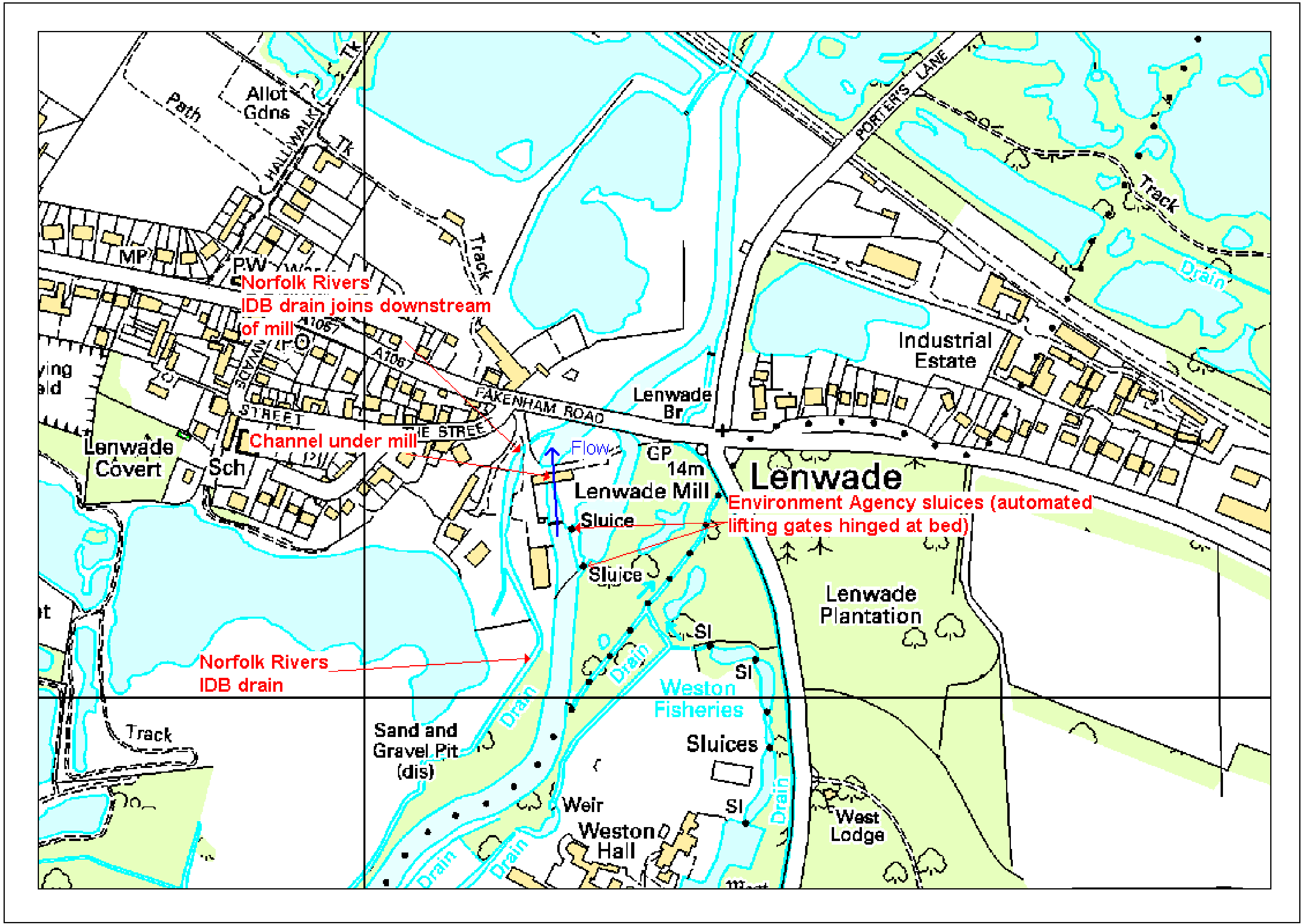

Figure Bd Lenwade Mill Location Plan

LYNG MILL

Table Be1 Lyng Mill Location

Mill name:	Lyng Mill
National grid reference:	607200, 317800
Upstream catchment area:	415km^2
Length of channel to next mill upstream:	3.25km
Geomorphological Appraisal (2006) reaches:	W309, W310 and W352
River Wensum Restoration Strategy reach code:	RWRS 13/14
Mill owner:	Private (site only, mill buildings demolished)
Sluice owner:	Private
Owner of water rights:	Private
Listed status:	Weir bridge, Lyng Road listed November 1984 (Grade II)

Plate Be1 Left: View of Lyng Mill bridge from downstream: Right: View upstream of River Wensum from upstream of Lyng Mill

Table Be2 Lyng Mill Weir & channel details

Water control level:	15.85m AOD (estimated)
Drop:	1.5m
Length of backwater upstream:	3.25km (100% reach)
Main structure:	One vertical lifting gate at the weir.
Operation of main structure:	Gate raised in winter and lowered in summer.
By-pass structure:	Two vertical lifting gates 200 metres upstream of weir.
By-pass structure operation:	Maintained in fixed position
Gauging station:	None
Additional notes:	Summer water levels maintained to prevent stock entering mill pool. Top pool fed by dyke forming a natural by-pass channel that supports fish. Structures associated with pools are impassable to fish.

Table Be3 Lyng Mill Previous works or recommendations

Previous measures:	None
Geomorphological Appraisal (2006) report suggestions:	Remove sluice structures at mill. Monitor changes. Fix sediment ingress points.

Table Be4 Lyng Mill Restoration strategy recommendations

Main recommendations:	Lower operating level by connecting to former course (IDB drain) at a number of locations including derelict sluice. Maintain some flow through existing course by lowering level of part of fixed weir to create low flow channel and maintain amenity. Co-ordinate with potential flood risk management capital scheme.

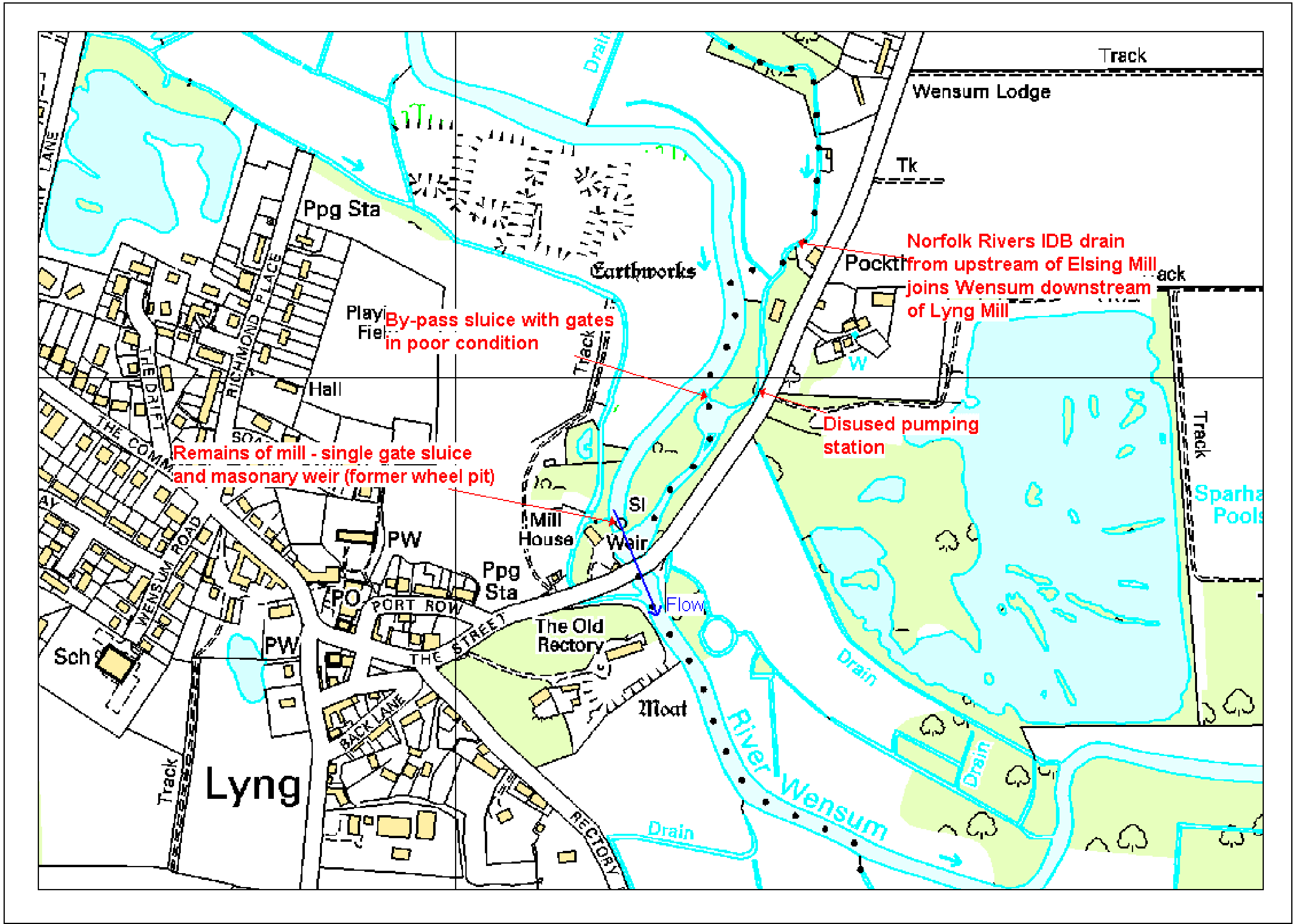

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Figure Be Lyng Mill Location Plan

ELSING MILL

Table Bf1 Elsing Mill Location

Mill name:	Elsing Mill
National grid reference:	605000, 317700
Upstream catchment area:	390km^2
Length of channel to next mill upstream:	5km
Geomorphological Appraisal (2006) reaches:	W351 to W357
River Wensum Restoration Strategy reach code:	RWRS 14/15
Mill owner:	Private
Sluice owner:	Private
Owner of water rights:	Private
Listed status:	Elsing Mill including wheel house and wheel adjoining east mill street listed August 1991 (Grade II).

Plate Bf1 View of by-pass sluices at Elsing Mill from downstream (photo from GeoData, 2006)

Table Bf2 Elsing Mill Weir & channel details

Water control level:	17.5m AOD (estimated)
Drop:	1.85m
Length of backwater upstream:	4.7km (94% reach)
Main structure:	Two vertical lifting gates at mill, plus fixed with wooden board weir in wheel-race.
Operation of main structure:	Constantly observed and adjusted as necessary when wet as there is limited freeboard.
By-pass structure:	One vertical lifting gate (100m upstream).
By-pass structure operation:	Vertical lifting gates opened in flood on by-pass channel.
Gauging station:	None
Additional notes:	Main channel and by-pass impassable to fish although pools have good habitat potential.

Table Bf3 Elsing Mill Previous works or recommendations

Previous measures:	None
Geomorphological Appraisal (2006) report suggestions:	Remove sluice and associated structures. Allow by-pass to silt up as a backwater channel. Permit by-pass to silt up. Monitor changes.

Table Bf4 Elsing Mill Restoration strategy recommendations

Main recommendations:	Lower operating levels progressively using existing sluice control. The invert of the sluices should be adequate to allow a significant decrease in drop without major modifications, although this will need to be negotiated with owners.

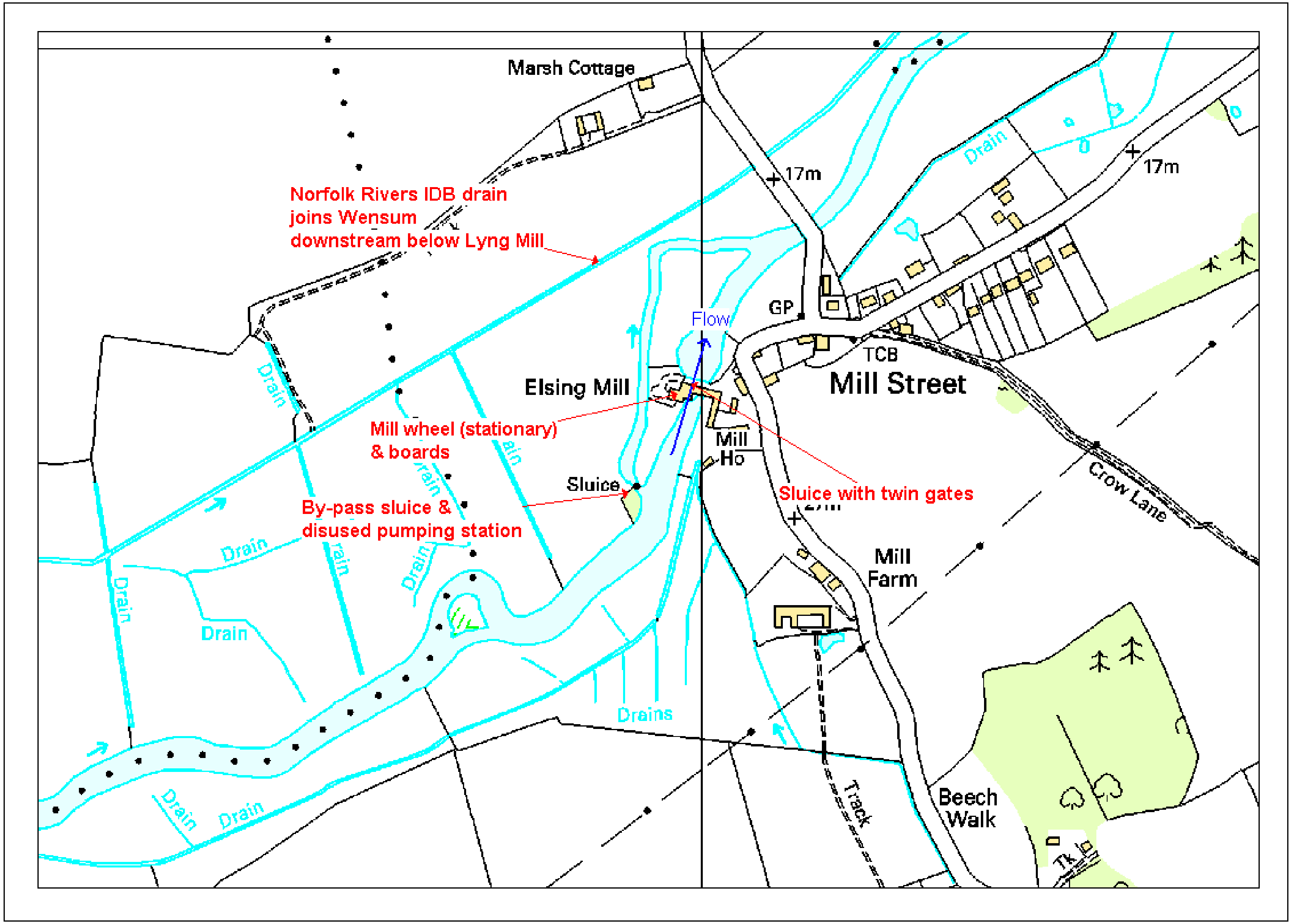

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Figure Bf Elsing Mill Location Plan

SWANTON MORLEY MILL

Table Bg1 Swanton Morley Mill Location

Mill name:	Swanton Morley Mill
National grid reference:	602100, 318600
Upstream catchment area:	390km^2
Length of channel to next mill upstream:	3.7km
Geomorphological Appraisal (2006) reaches:	W405 to W402
River Wensum Restoration Strategy reach code:	RWRS 15/16
Mill owner:	Environment Agency (site only, mill buildings demolished)
Sluice owner:	Environment Agency
Owner of water rights:	Environment Agency
Listed status:	Bridge, Mill Street, Swanton Morley listed May 1985 (Grade II).

Plate Bg1 View of side channel weir at Swanton Morley

Table Bg2 Swanton Morley Mill Weir & channel details

Water control level:	Upstream of original mill weir approx 19.0m AOD Downstream of old mill weir 18.37m AOD Lowest crest height of Swanton Morley 2 arch : 17.83m AOD Lowest crest height of Swanton Morley 3 arch: 18.22m AOD Downstream level approx 17.88m AOD
Drop:	0.73m and 0.64m
Length of backwater upstream:	3.2km (87% reach)
Main structure:	Staggered weirs.
Operation of main structure:	Weirs are fixed.
By-pass structure:	Side weir approx. 200m upstream of mill site
By-pass structure operation:	(Note: EA no longer do this)
Gauging station:	Yes: HiFlows No. 34114 (2 arch) and HiFlows No. 34214 (3 arch).
Additional notes:	Canoe club puts boards at the bridge in order to channel water over the flume. Weirs are passable by trout. Channel divides, is joined by dyke and crosses under road.

Table Bg3 Swanton Morley Mill Previous works or recommendations

Previous measures:	Installation of fixed gauging weirs and associated level monitoring.
Geomorphological Appraisal (2006) report suggestions:	Reduce level of weir. Establish monitoring programme.

Table Bg4 Swanton Morley Mill Restoration strategy recommendations

Main recommendations:	The weirs at Swanton Morley are complex as the main channel has a modern crump profile compound weir beneath three arches of the road bridge and the remnants of the original weir upstream which has a further drop of 0.6-1.0m. If the original weir (which is already damaged) is lowered then there is a danger that the side channel could dry at low flows. It is thus proposed that initially the original mill weir is notched such that upstream levels are reduced by approx 0.5m. The side channel weir should also be lowered by a similar amount which would mean breaking out and recasting the profile of the weir.

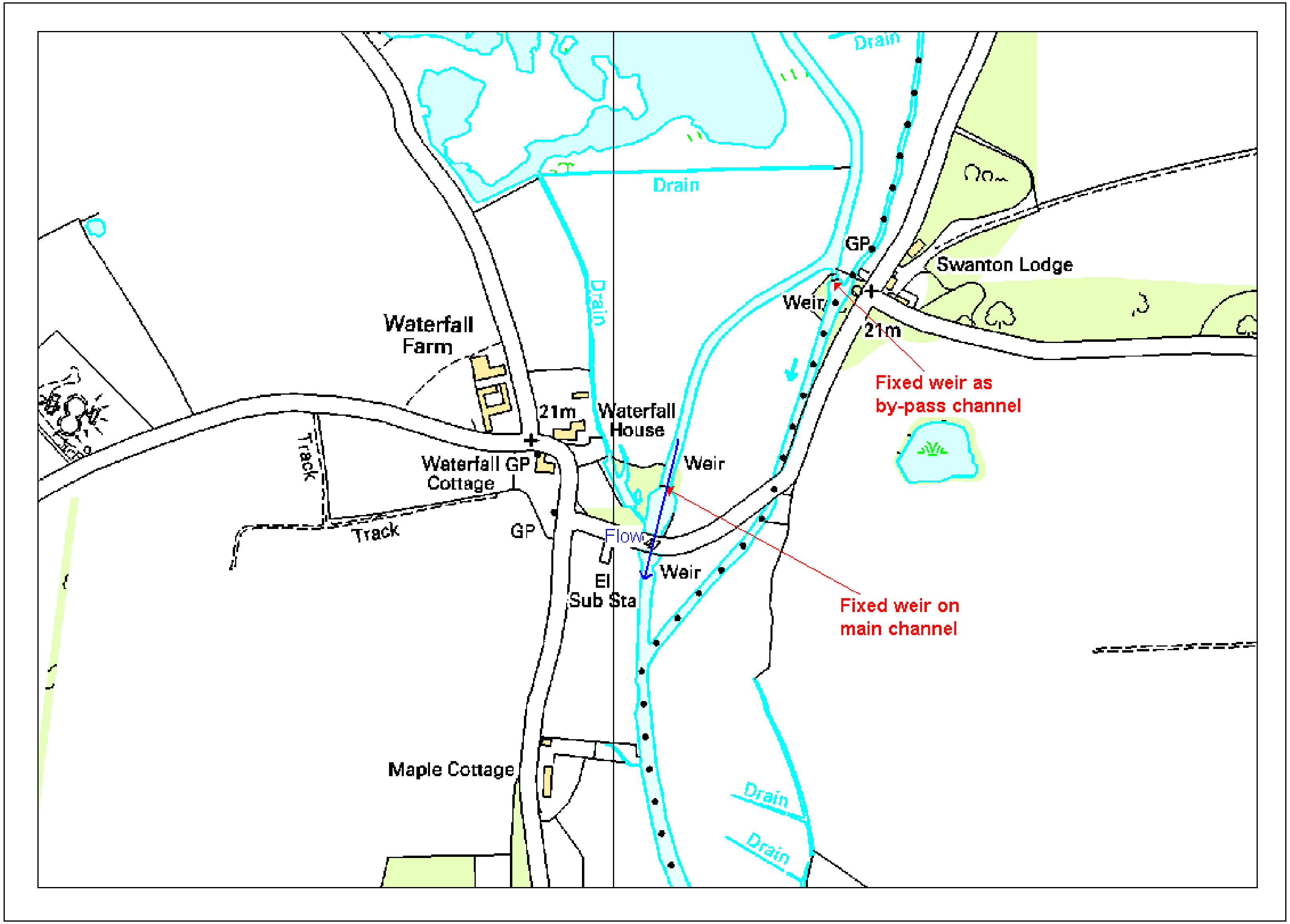

Figure Bg Swanton Morley Mill Location Plan

ELMHAM MILL

Table Bh1 Elmham Mill Location

Mill name:	Elmham Mill
National grid reference:	600300, 320400
Upstream catchment area:	270km^2
Length of channel to next mill upstream:	6.3km
Geomorphological Appraisal (2006) reaches:	W501 and W515
River Wensum Restoration Strategy reach code:	RWRS 17/18
Mill owner:	Private (converted to residential use)
Sluice owner:	Private
Owner of water rights:	Private
Listed status:	None

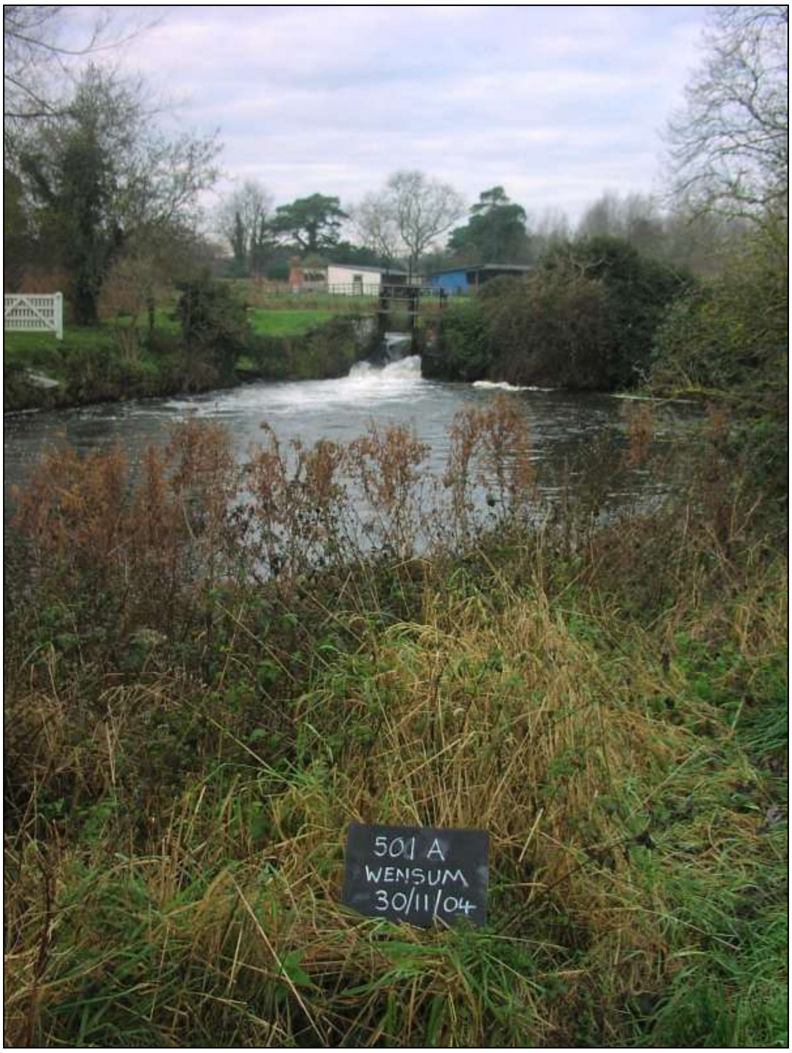

Plate Bh1 View of by-pass sluice at Elmham Mill site from downstream (photo from GeoData, 2006)

Table Bh2 Elmham Mill Weir & channel details

Water control level:	21.8m AOD (estimated)
Drop:	1.2m
Length of backwater upstream:	5.25km (83% reach)
Main structure:	Two vertical lifting gates. Also 2 channels with no control structure.
Operation of main structure:	Mill gates used to balance the flow through the main and by-pass channels.
By-pass structure:	Two vertical lifting gates and a high level overspill.
By-pass structure operation:	Overflow channel opened in flood.
Gauging station:	None
Additional notes:	River and side stream fast flowing - good habitat of high conservation value.

Table Bh3 Elmham Mill Previous works or recommendations

Previous measures:	Structures repaired to enable a turbine to be run.
Geomorphological Appraisal (2006) report suggestions:	Remove mill weir. Fix sediment ingress points.

Table Bh4 Elmham Mill Restoration strategy recommendations

Main recommendations:	Existing gates have invert 20.92 and thus suitable for significant reduction in operating level without major modifications. Negotiate lower operating levels progressively using existing sluice control.

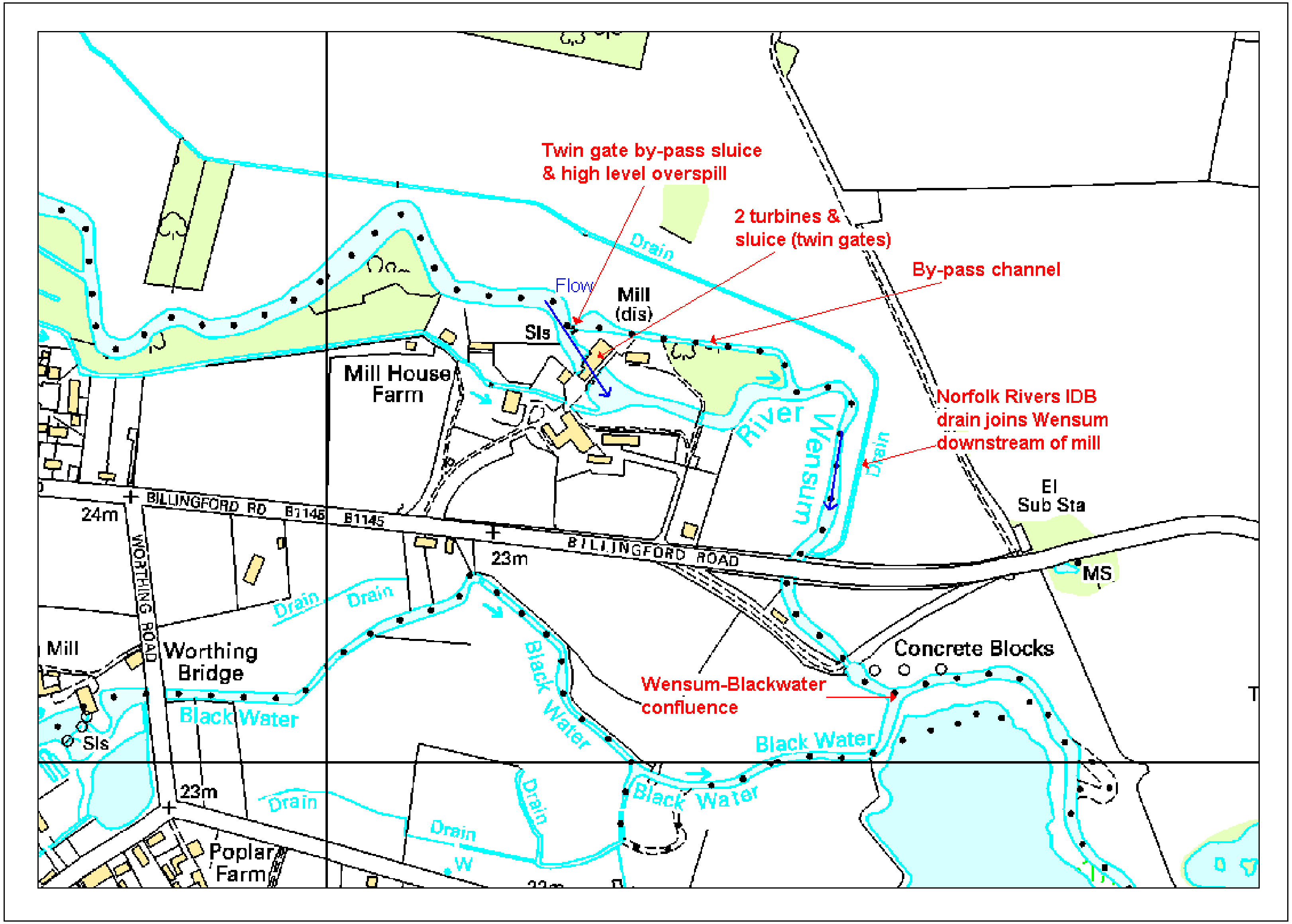

Figure Bh Elmham Mill Location Plan

BINTRY MILL

Table Bi1 Bintry Mill Location

Mill name:	Bintry Mill
National grid reference:	599800, 324300
Upstream Catchment Area:	260km^2
Length of channel to next mill upstream:	5.5km
Geomorphological Appraisal (2006) reaches:	W510 to W512
River Wensum Restoration Strategy reach code:	RWRS 20/21
Mill owner:	Private
Sluice owner:	Environment Agency
Owner of water rights:	Environment Agency
Listed status:	Bintry Mill including bridge and millers house, Mill Road, Bintree listed August 1984 (Grade II).

Plate Bi1 View of by-pass channel at Bintry Mill

Table Bi2 Bintry Mill Weir & channel details

Water control level:	25.95m AOD
Drop:	1.88m
Length of backwater upstream:	4.1km (75% reach)
Main structure:	Vertical drop board sluice gate on the mill. On by-pass channel.
Operation of main structure:	Adjusted for flood control purposes only.
By-pass structure:	Vertical sluice gate (24.51m AOD).
By-pass structure operation:	Was adjusted manually to maintain steady retention levels upstream. Automated in 1999.
Gauging station:	None
Additional notes:	Structure at Guist mill is drowned out by backwater upstream of Bintry mill. If Bintry mill structure is lowered, the structure at Guist may hold an impoundment.

Table Bi3 Bintry Mill Previous works or recommendations

Previous measures:	Bintry Mill refurbished in 1998. By-pass sluice automated in 1999.
Geomorphological Appraisal (2006) report suggestions:	Pump out/dredge silts from channel. Remove/reduce levels at mill and use dredgings to restore channel dimensions. Augment with gravels to restore bed elevation to match downstream and upstream floodplain gravel-levels. Maintain side stream as wet backwater. Downstream - implement a monitoring programme.

Table Bi4 Bintry Mill Restoration strategy recommendations

Main recommendations:	Ultimately as Geomorphological Appraisal (2006), but achieve this progressively to allow upstream channel to stabilise.

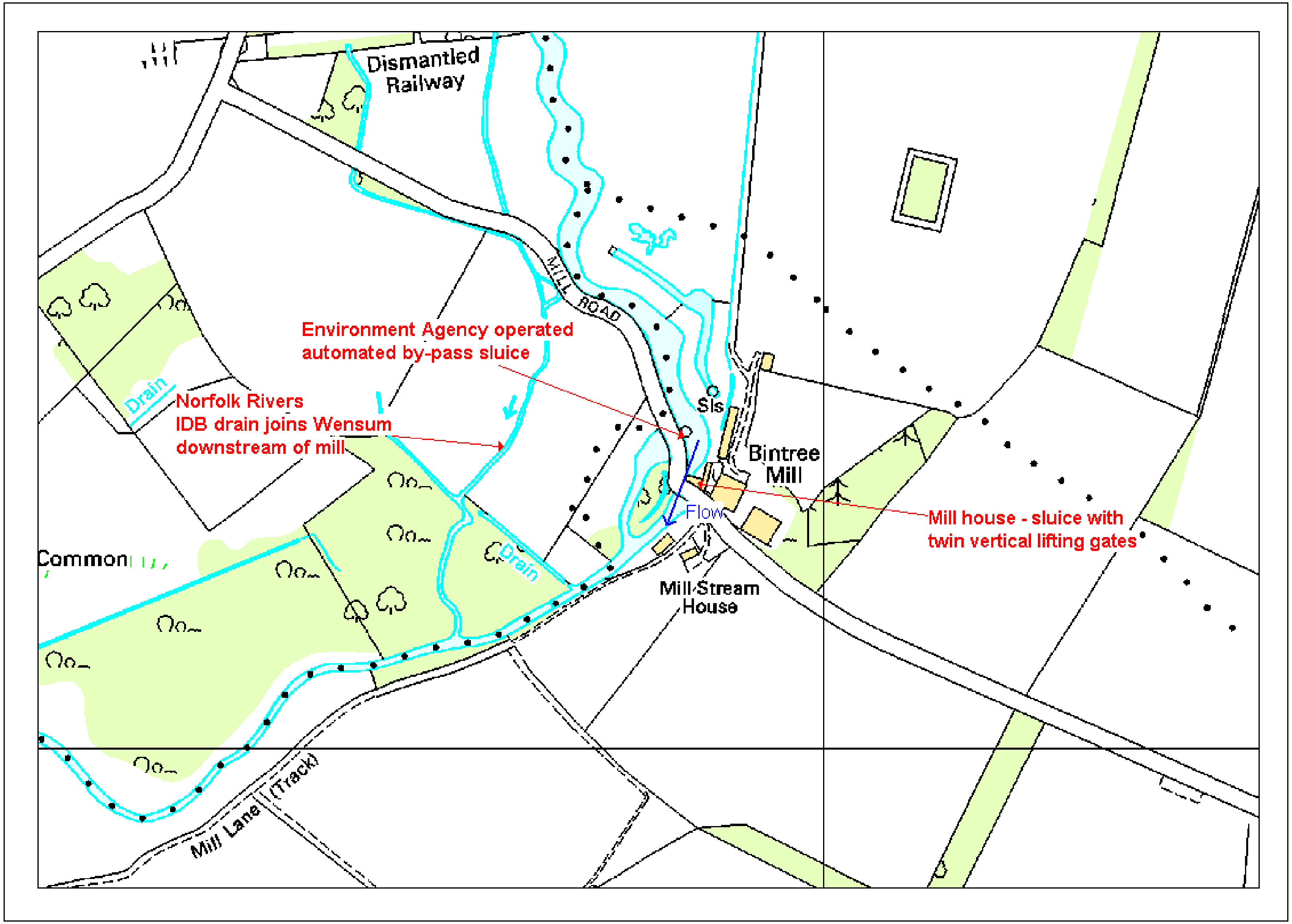

Figure Bi Bintry Mill Location Plan

GREAT RYBURGH MILL

Table Bj1 Great Ryburgh Mill Location

Mill name:	Great Ryburgh Mill
National grid reference:	596400, 326900
Upstream Catchment Area:	200km^2
Length of channel to next mill upstream:	6.6km
Geomorphological Appraisal (2006) reaches:	W554
River Wensum Restoration Strategy reach code:	RWRS 22/23
Mill owner:	Prime Life plc (site only - mill buildings demolished)
Sluice owner:	Prime Life plc
Owner of water rights:	Prime Life plc
Listed status:	None

Plate Bj1 Left: View of old channel on left bank of current River Wensum, downstream of Great Ryburgh Mill: Right: View upstream towards Great Ryburgh Mill

Table Bj2 Great Ryburgh Mill Weir & channel details

Water control level:	30.2m AOD (estimated)
Drop:	2.91m
Length of backwater upstream:	3km (46% reach)
Main structure:	Two vertical lifting gates (29.06m AOD). Gates repaired in 2001.
Operation of main structure:	Gates generally kept open.
By-pass structure:	Fixed weir on left bank adjacent to mill
By-pass structure operation:	None (fixed weir)
Gauging station:	None
Additional notes:	None

Table Bj3 Great Ryburgh Mill Previous works or recommendations

Previous measures:	None
Geomorphological Appraisal (2006) report suggestions:	Re-cut channel to follow old course marked as a boundary on the OS map. Opportunity for substantial channel restoration around mill. Aim to recreate bed levels, channel dimensions and gravel bed throughout reaches upstream and downstream of mill, based on by-passing present mill and using levels in the old channel. Use dredged gravels to re-establish gravel bed and reduce width. Some flood risk management constraints may need to be considered.

Table Bj4 Great Ryburgh Mill Restoration strategy recommendations

Main recommendations:	The side weir is derelict and the main gates are in poor condition. To reconnect the meandering course it will be necessary to modify the operation of the mill such that flow can be diverted into the former channel. To achieve this, modifications will be needed to the by-pass weir as well as to the mill by-pass channel. There is the potential to retain a “sweetening” flow through the artificial, straightened channel downstream of the mill.

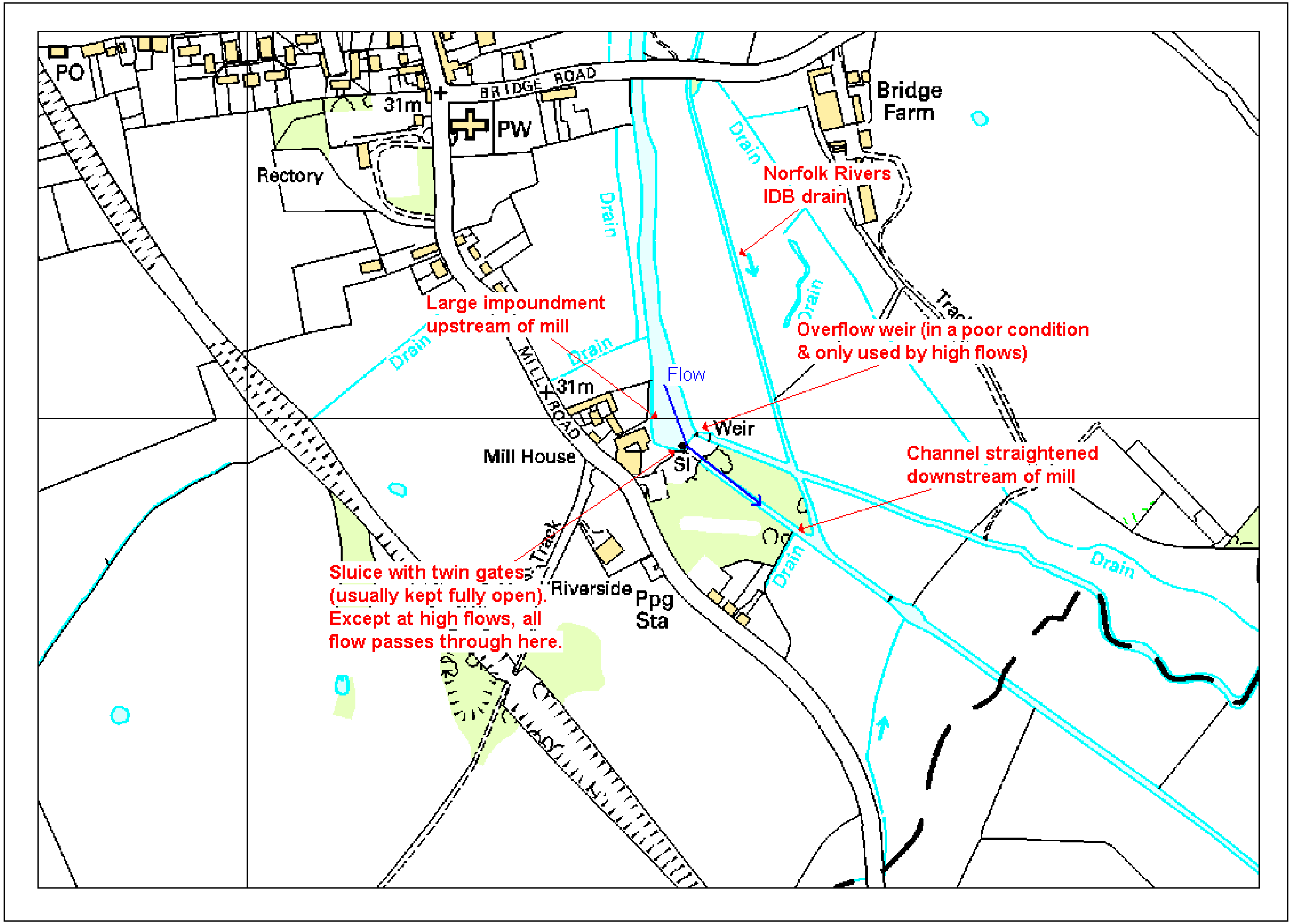

Figure Bj Great Ryburgh Mill Location Plan

FAKENHAM MILL

Table Bk1 Fakenham Mill Location

Mill name:	Fakenham Mill
National grid reference:	591900, 329300
Upstream catchment area:	160km^2
Length of channel to next mill upstream:	3.5km
Geomorphological Appraisal (2006) reaches:	W563
River Wensum Restoration Strategy reach code:	RWRS 26/27
Mill owner:	Private (converted to residential use)
Sluice owner:	Environment Agency
Owner of water rights:	Environment Agency
Listed status:	None

Plate Bk1 View upstream of weir at Fakenham Mill

Table Bk2 Fakenham Mill Weir & channel details

Water control level:	34.1m AOD
Drop:	1.22m
Length of backwater upstream:	2.2km (62% reach)
Main structure:	Variable weir (single steel gate, either open (33.58m AOD) or closed (34.10m AOD) , with enclosed penstock) and adjacent fixed weir (33.97m AOD)
Operation of main structure:	Gate down May to October. Raised in high summer flows and throughout winter.
By-pass structure:	None
By-pass structure operation:	
Gauging station:	Yes, HiFlows No. 34011
Additional notes:	None

Table Bk3 Fakenham Mill Previous works or recommendations

Previous measures:	Sluices automated in 2005.
Geomorphological Appraisal (2006) report Suggestions:	Reduce water levels at mill structure/flume. Remove fine sediments. Use dredged material to create low-flow channel within existing flood protection channel. Use fixed low level log structures to increase physical habitat diversity.

Table Bk4 Fakenham Mill Restoration strategy recommendations

Main recommendations:	The operating level in summer could be reduced initially by 0.4m by leaving the gate open. Further lowering could be achieved through breaking out the crump profile weir and control gate but this would then be limited by the fixed concrete beneath the mill. The bed level immediately upstream of the mill is close to weir level whereas further upstream according to survey sections (1980s) it is over 1m deeper. Silt control in this reach is thus likely to be important.

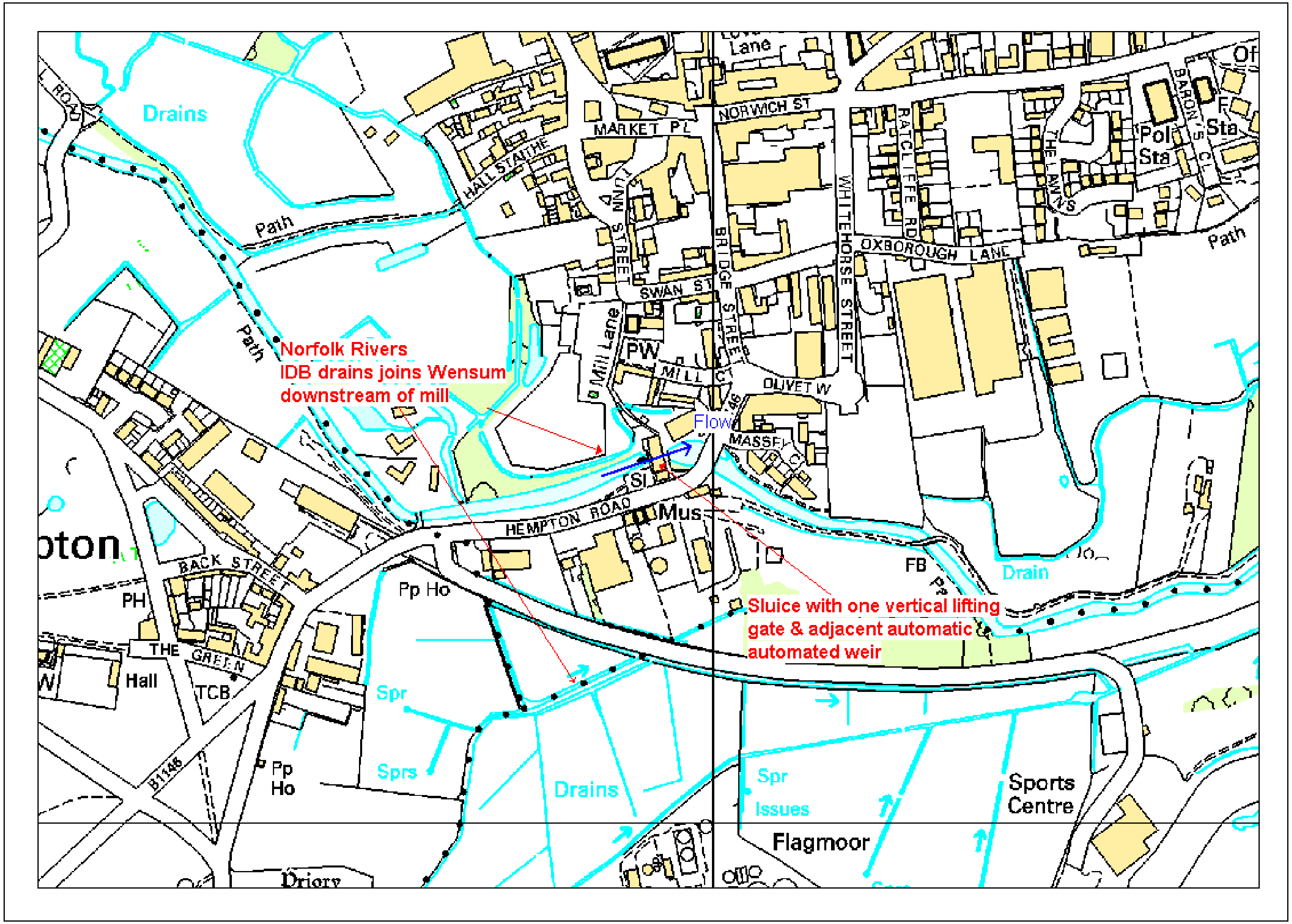

Figure Bk Fakenham Mill Location Plan

SCULTHORPE MILL

Table BI1 Sculthorpe Mill Location

Mill name:	Sculthorpe Mill
National grid reference:	589300, 330300
Upstream catchment area:	145km^2
Length of channel to next mill upstream:	2.7km
Geomorphological Appraisal (2006) reaches:	W570 and W571
River Wensum Restoration Strategy reach code:	RWRS 29/30
Mill owner:	Private (converted to pub/hotel)
Sluice owner:	Environment Agency
Owner of water rights:	Environment Agency
Listed status:	Mill House, Sculthorpe listed January 1984 (Grade II).

Plate BI1 Left: View upstream of Sculthorpe Mill: Right: View downstream of Sculthorpe Mill

Table BI2 Sculthorpe Mill Weir & channel details

Water control level:	36.8m AOD (estimated)
Drop:	1.16m
Length of backwater upstream:	1.4km (53% reach)
Main structure:	Fixed weir.
Operation of main structure:	Not in operation.
By-pass structure:	None
By-pass structure operation:	
Gauging station:	Yes, see WLMP - spot gauging.
Additional notes:	At mill, emergent vegetation narrows the channel.

Table BI3 Sculthorpe Mill Previous works or recommendations

Previous measures:	None although installing a bypass and control gate was considered as part of 1970s drainage scheme.
Geomorphological Appraisal (2006) report suggestions:	Look at options for reducing the level of the mill weir. Provides benefits for upstream channel gradients and dimensions. Dredge silts from channel prior to removal.

Table BI4 Sculthorpe Mill Restoration strategy recommendations

Main recommendations:	Structural change to fixed weir is required to lower weir level. The change in level occurs beneath the mill building and cannot be inspected from banks.

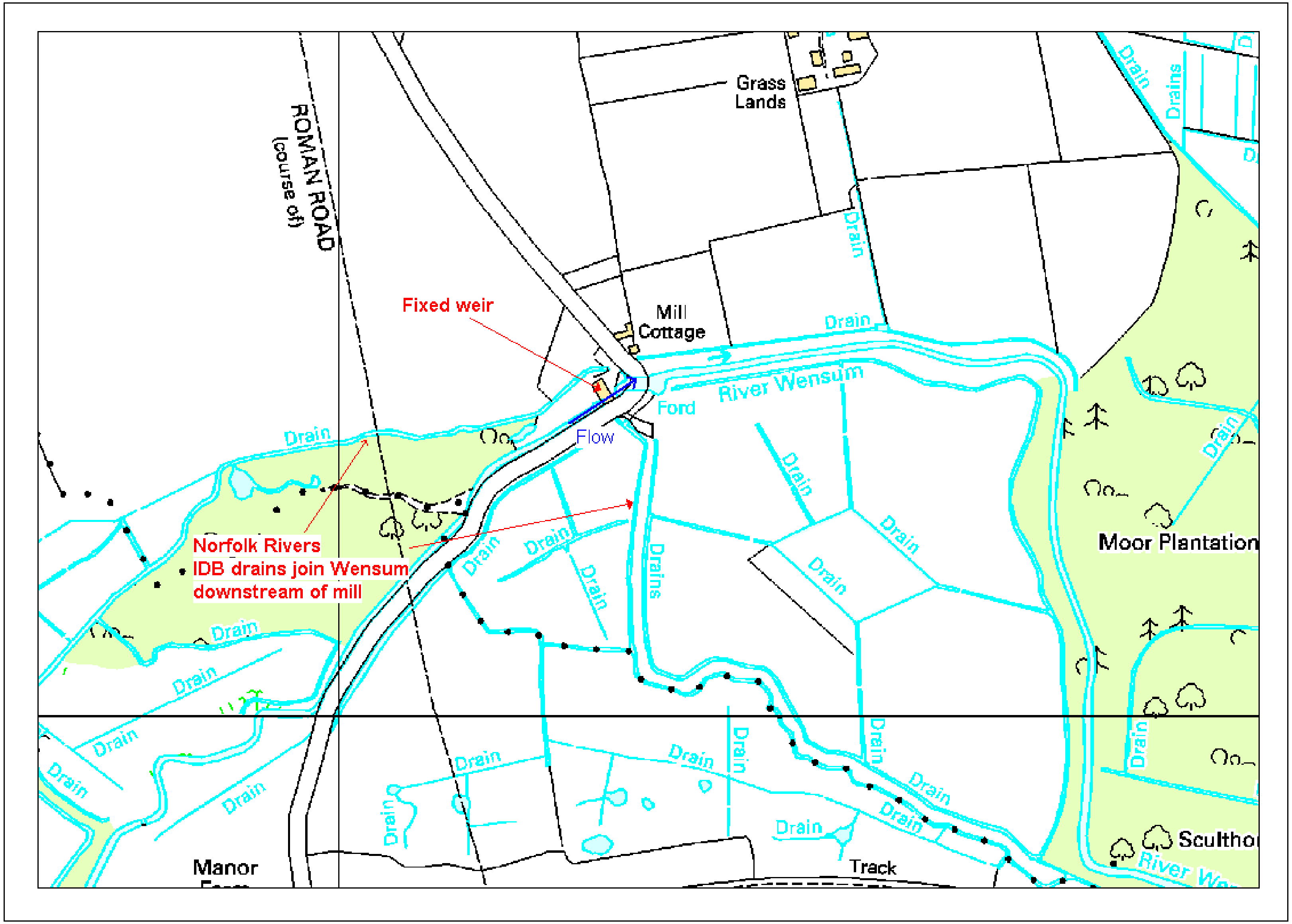

Figure BI Sculthorpe Mill Location Plan

SOUTH MILL

Table Bm1 South Mill Location

Mill name:	South Mill
National grid reference:	588100, 328200
Upstream catchment area:	135km^2
Length of channel to next mill upstream:	No structure upstream of this point
Geomorphological Appraisal (2006) reaches:	W1050
River Wensum Restoration Strategy reach code:	RWRS 30/31
OWNERSHIP DETAILS	
Mill owner:	Environment Agency (site only - no evidence of mill)
Sluice owner:	Environment Agency (no structure present other than small sill under road bridge)
Owner of water rights:	Private
Listed status:	None

Plate Bm1 View of sill on bed at site of South Mill

Table Bm2 South Mill Weir & channel details

Water control level:	No information
Drop:	Small drop at sill under road bridge.
Length of backwater upstream:	Negligible.
Main structure:	Fixed weir (sill under road bridge).
Operation of main structure:	Not in operation and no sign of original features except for bank downstream.
By-pass structure:	None
By-pass structure operation:	
Gauging station:	No but previously used for spot gauging (see WLMP).
Additional notes:	None

Table Bm3 South Mill Previous works or recommendations

Previous measures:	None
Geomorphological Appraisal (2006) report suggestions:	Fix sediment ingress points. See ECON 1999 report for restoration options - which promote reconnection to the old channel line.

Table Bm4 South Mill Restoration strategy recommendations

Main recommendations:	The hard sill beneath the road bridge does not impact significantly on upstream water levels so no action is proposed.

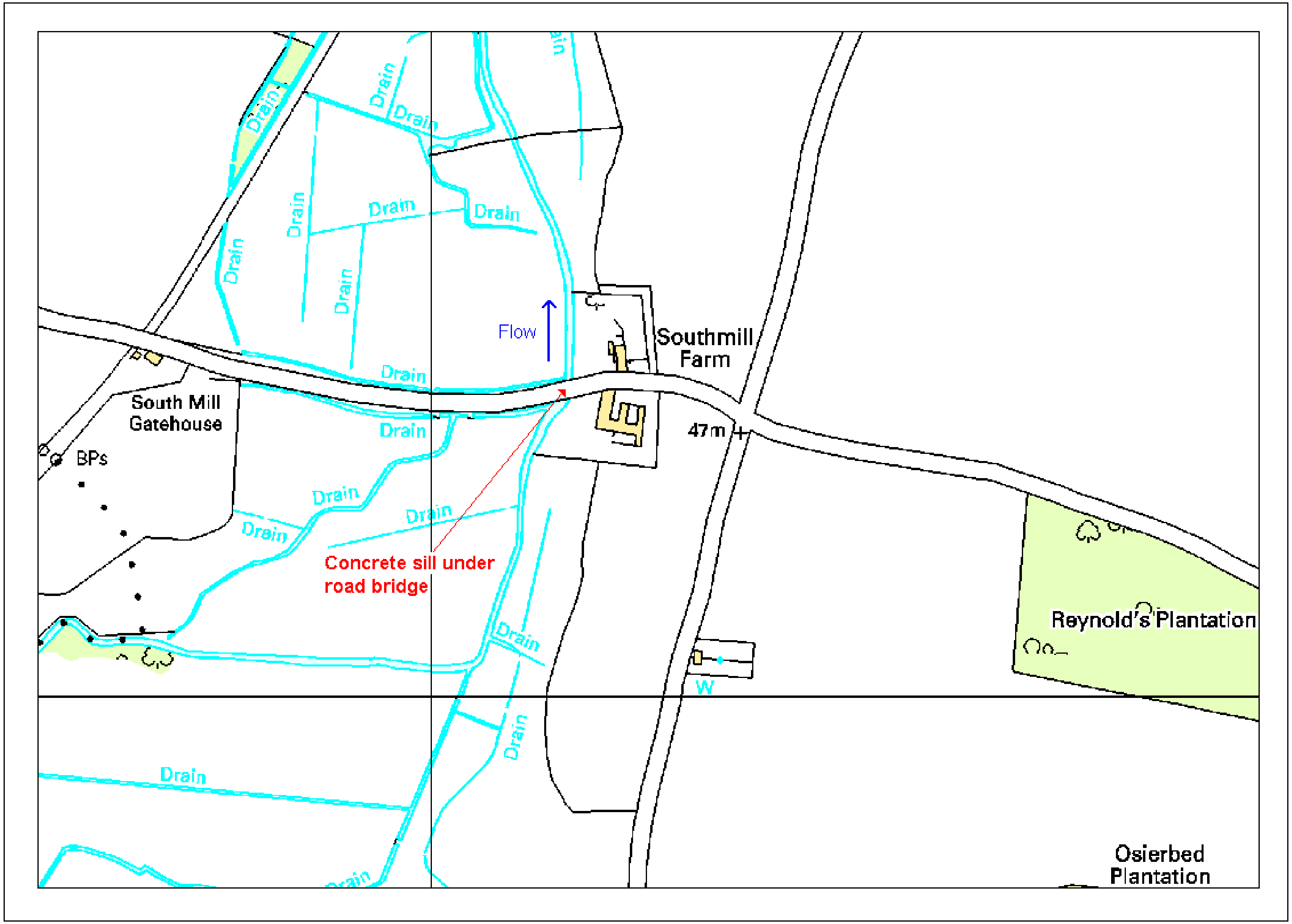

Figure Bm South Mill Location Plan

Appendix 3 Geomorphological Appraisal (GeoData, 2006)

Introduction

The River Wensum Special Area of Conservation (SAC) Geomorphological Appraisal was completed by GeoData in 2005 and it was published in 2006 as an English Nature Research Report (ENRR 685 - A Geomorphological Appraisal of the River Wensum Special Area of Conservation). This document is referred to as the 'Geomorphological Appraisal' in the Technical Report for the River Wensum Restoration Strategy and data collected for the appraisal is referenced to GeoData (2006).

Aim, method and approach

The River Wensum SAC Geomorphological Audit (GeoData, 2005) was commissioned in 2004 by English Nature and was jointly funded with the Environment Agency and the King's Lynn Consortium of Internal Drainage Boards. It was published in 2006 as English Nature Research Report 685 - A Geomorphological Appraisal of the River Wensum Special Area of Conservation. This document is referred to as the 'Geomorphological Appraisal' in the remainder of this report and data collected during the appraisal is referenced to GeoData (2006).

The aim of the Geomorphological Appraisal was, 'to develop, through an understanding of the physical processes of sediment transport, a vision for river restoration for the River Wensum, whilst balancing these against the constraints imposed by flood risk management'[8]. The method set out in the report included:

1) Developing an understanding of chalk stream geomorphological processes.
2) Quantifying the extent of modification of the river, floodplain and catchment.
3) Quantifying the existing characteristics of the physical habitat and channel morphology.
4) Differentiating reaches on the basis of naturalness and the quality of their physical habitat (as relevant to the SSSI/SAC).
5) Considering sediment transport issues that are linked to channel degradation and suggesting options for mitigation.

Three approaches were used to meet the project aim:

- Fluvial Audit - to assess the broad sediment system and channel processes (results were saved in an MS Access database and as GIS layers).
- Geomorphological Dynamics Assessment - to assess sediment transport processes in greater detail.
- Multi-criteria Analysis (MCA) - to classify the river network into river modification, management and sediment system categories.

A summary of these approaches is provided in Section 2.1, 2.2 and 2.3, respectively, of the Geomorphological Appraisal.

[8] GeoData (2006) P.14, Para.6

Catchment characteristics

Details of the Wensum catchment and river network are summarised in Table C1[9]. Further details regarding the catchment's geology, topography, soils and hydrology are given in the Geomorphological Appraisal. In summary, the subdued relief and groundwater dominated hydrology result in a low energy system. Whilst the Wensum catchment is prone to the production of sands and fine silts, gravels in the system are relics of its glacial and peri-glacial processes. Similarly, the current river channel network and processes are the result of historic process and forms. Contemporary channel management and land use have modified the hydrology, sediment production and channel morphology.

The River Wensum has been divided into broad semi-natural hydrogeomorphological zones (Table C2), each of which would support different physical habitats and biotic communities. Channel management will have resulted in modification of reaches within these zones away from the semi-natural.

Table C1 River Wensum catchment characteristics

Attribute	Value			
Principal tributaries	River Tat	Langor Drain	Guist Drain	Wendling Beck or Dereham Stream
	Penny Spot Beck	Blackwater	Swannington Beck	River Tud (Does not feed into the SAC)
Relief	Maximum elevation 95m OD at Bradebham Hill. Generally low relief. Bed falls 60m over 73km drainage path (s = 0.00082). Main features of the valley are the river channels that dissect the eastward dipping chalk hills.			
Geology	Solid geology of the whole catchment is Senonian (Upper Cretaceous) chalk (fine grained fissured limestone). It is overlain with drift (<10m thickness), such as boulder clay on the higher plateaus and glacial sands and gravels on the valley flanks. Chalk outcrops intermittently on the surface (upper Wensum/River Tat; between Bintree and Billingford Bridge; and also between Guist and Costessey).			
Hydrogeology	The well fissure chalk is a major aquifer. Storage also occurs in the permeable sands/gravels/boulder clays overlying the chalk.			
Catchment geomorphology	The current sinuous course of the River Wensum follows a large valley meander that was created by glacial meltwaters. It is likely that the channel metamorphosed over the Holocene period from a high energy (high sediment and runoff) braided channel, to an anastomosed channel, and finally to a single threaded meandering channel due to siltation and infilling of secondary channels following woodland clearance.			

Table continued...

[9] GeoData (2006) p. 8, Table 3.1

Attribute	Value
Hydraulic controls *mill has a long term gauging station	South Mill, Sculthorpe Mill, Fakenham Mill*, Great Ryburgh Mill Guist Mill, Bintry Mill, Elmham Mill, Swanton Morley Mill* Elsing Mill, Lyng Mill, Lenwade Mill, Taverham Mill Costessey Mill*, Hellesdon Mill The headwaters upstream of the confluence between the Wensum and Tat are characterised by steeper bed gradients and an absence of mill structures. Downstream, the mill sluices and their millponds generate a stepped bed and water surface profile. The bed tends to be steeper downstream of the mills and less steep in the ponded stretch upstream of the mills. Backwaters are more extensive at low flows (typically 1-2km).
Hydrology and the flow regime	Groundwater baseflow, direct surface runoff, direct recharge and drainage network. At Fakenham, the Wensum has a high baseflow index (0.82) and a low index of flashiness. The flow regime is similar to that of a typical chalk stream, although the influence of overlying drift deposits is increasingly obvious downstream. The flow regime is typified by a progressive seasonal rise in water levels, peaking in March/April. Flooding tends to develop during high spring discharges. Water level management (abstraction and effluent discharge), the presence of 14 water mills and an extensive drainage network significantly affect levels and flows. The flow regime is modified and not natural.
Soils	Newport series (sandy) occurs in patches in the upper catchment (south of Fakenham, Doughton and upper Tat) and is more extensive downstream of Lenwade and along the downstream tributaries. These light sandy/sandy loam soils are sensitive to water and wind erosion, especially when located on steep valley sides.
Current land use[1] in the floodplain	Typically, the well drained loamy-sandy soils of the upper catchment and valley sides have been intensively farmed for arable crops and, more recently, pig units. In the wet valley bottoms with their clayey soils (low permeability), low intensity grazing has dominated due to poor agricultural quality. The floodplains are generally a mosaic of pasture, scrub, gravel pits/reservoirs, wetlands and scattered woodlands.
Conservation status	The River Wensum was designated a SAC (European features of interest include *Ranunculus* vegetation, Bullhead, Brook lamprey, White-clawed crayfish and Desmoulin's whole snail). Also designated a Whole River SSSI in 1993 in recognition of it being one of the best examples of a naturally enriched calcareous lowland river. The Wensum Valley is also included in the Broads Environmentally Sensitive Area.

[1] Bore et al. (1994) The effects of water resource management on the rivers Bure, Wensum and Nar in north Norfolk, School of Environmental Sciences, University of East Anglia.

Table C2 Semi-natural hydrogeomorphological zones and characteristic habitats[1]

Zone	Extent	Reference condition
0	Throughout main catchment	Dry valley network with spring fed sapped headwalls. No historically recorded flow. Overland flow and natural pathways for runoff. Underlying sediment a mix of colluvial slope wash and re-worked channel lag deposits.
1	Headwaters to Lenwade	Sinuous single-thread channel system with a mixture of surface and groundwater dominated hydrology. Strong coupling of channel and floodplain leading to wet marsh, woodland, fen communities. Some peat development.
2	Lenwade to Hellesdon	Sinuous meandering channel (formerly multi-threaded with woody debris and limited riffle-pool sequence development until deforestation increased siltation). Groundwater dominated hydrology in these lower lying sections of the catchment. Extensive wet fen and carr floodplain communities underlain by peat. Upwelling of groundwater creates a mosaic of wetland habitats, including pools on the floodplain surface.

[1] GeoData (2006) p. 33, Table 3.2.

Modification and management

Land-use

Documented land-use changes since the early 1900's include:

- Loss of floodplain meadows in the river corridor.
- 40% increase in surface water drainage network since 1904 (often at weirs to take advantage of the head change).
- Intensive programme of land drainage in the 1940's to enable the expansion and intensification of cultivation.
- Decrease in permanent grassland and heath.
- Increase in sand and gravel extraction in the Wensum valley - disused workings tend to be used as fishing lakes.
- Increase in free range pig units on sandy soils.
- Expansion of urban areas (locally around Norwich, Dereham, Fakenham) and infrastructure.

These land-use changes will have a direct impact on the quantity, type and quality of surface water drainage and sediment entering the River Wensum catchment. Indirectly, they are partially responsible for the large quantity of fine sediments that have been deposited in the river system, particularly upstream of mill structures.

River channel

The low gradient of the River Wensum and its long history of flow impoundment have resulted in the channel being relatively inactive in a geomorphic sense, with the exception of transport of the finest sediments. Most of the planform changes will have resulted from engineering works on the channel (Table C3). The main types of channel modification include:

- Mill weirs and sluices[10].
  - Relocation of river to floodplain boundary or straightening (to increase hydraulic head).
  - Channel deepening and widening (mill pond for water storage).
  - Modification of low flow hydraulics and water levels (weir creating ponding that backs water upstream 1 to 2km).
  - Barrier to downstream sediment movement.
  - Creation of scour pools and steep gradients downstream of weirs.
  - Floodplain water tables modified (where there are perched/elevated water levels).
  - Long term accumulation of nutrients and organic matter.
  - Floodplain drainage channels (take advantage of head loss at mills).
- Channel straightening (for example, abandoning meander loops), relocation and widening.
- Embankments and reduction in connectivity to floodplain and floodplain meadows.
- Removal of bed substrate (gravel mining, dredging, desilting).
- Control of aquatic and riparian vegetation (for example, weed cutting).
- Altered hydrology (network of floodplain drainage channels takes advantage of head loss at mill structures).
- Regular programmes of channel maintenance (completed by the NRCIDB and the Environment Agency)[11]. The Environment Agency is currently mostly involved in managingflood risk to people and property, in part by ensuring an effective drainage scheme via (partial) weed cutting and desilting.

The Geomorphological Appraisal identified the mills along the River Wensum as being the most significant factor directly affecting the morphology of the channel. The mill structures have been in place along the channel for over 900 years. Some milling regime has altered in the twentieth century. Whilst structures were opened and closed on a daily basis when water was used to power the mills, often today they remain closed during normal flow conditions. The millponds are full, upstream water levels are maintained and accumulated sediments are not flushed downstream.

The Geomorphological Appraisal classed each reach along the Wensum channel according to the extent of modification. Only 21% of the surveyed channel did not show any sign of modification or showed only minor modification. The least modified reaches were identified on the lower course of the Langor Drain, and on the Wensum downstream of Lenwade Mill to Attlebridge Hall and downstream of Taverham Mill. It was concluded that the channel is mostly in less than favourable condition with regards to morphology and physical processes. As a result of the mills, it is a fragmented channel system with a higher than natural capacity for accumulation of fine sediment.

[10] Specific details of the influence of mills are given in GeoData (2006, p.40)

[11] Specific details of the maintenance regime are given in GeoData (2006, p. 44)

Table C3 Timeline of historic channel modifications

	1200 - 1797	1797-1898	1900-1960	1960-1970	1970-1980	1980-1990
Mills	Meanders abandoned to shorten channel at Sculthorpe, G. Ryburgh, Elsing, Lyng, Lenwade.	Major diversions at South Mill (+ straightening down to Sculthorpe) & for 3 mills upstream of Fakenham.		Decline of milling: Removal or modification of mill structure - millpond infills with silt (width tends towards a more natural size); Maintenance of mill structure (fixed water level) - extensive upstream ponded reach and slight readjustment of channel dimensions.		
Flood alleviation		Straightening at L. Ryburgh, G. Ryburgh, Sennowe Hall, N. Elmham, Billingford Common.				Maintenance concentrated on flood risk management (ecological constraints).
Land drainage			Minor planform changes & dredging at Sculthorpe Fen, G. Ryburgh Common & Carr, downstream Bintry Mill, upstream of N. Elmham, near Attlebridge, Ringland & Drayton, at Hempton, at Fakenham, Costessey & Ryburgh mills. 5 mile stretch drag line dredged between Shereford & Sennowe Park (1953-57).	Some evidence of channel narrowing.		70km+ dredged/ year in Wensum and its drains.
Dredging					30km dredged/ year	
Weed cutting			Extensive			Reduced
River maintenance grants						Reduced (75%-35%). Increased in 1988 to 45% for flood alleviation schemes.

Sediment transport

The Geomorphological Appraisal used the tractive force method to determine the stability of the coarse fraction of the bed material in the River Wensum at bankfull flows. It was concluded that at the majority of sites surveyed the gravel bed would be stable under flood conditions by virtue of the low gradient and discharges. An exception to this conclusion includes areas just downstream of the mills, where bed gradients tend to be locally steep, at constrictions in the channel (for example, fallen debris or debris structures, bridges etc.) and at discrete zones of scour (for example, outer banks). Coarse gravels in the River Wensum may well be inherited from previous glacial/peri-glacial periods when coarse sediment transport would have been supported by overland flow over frozen impermeable ground, and higher rainfall.

The stability of sand sized sediment was calculated using the Ackers and White (1973) bedload transport equation for bankfull flows at chosen locations along the River Wensum. The capacity of the River Wensum to transport sand increases with catchment area and, therefore, bankfull discharge.

Using sediment probe data, the Geomorphological Appraisal concluded that the total suspended loads for the River Wensum at Costessey ranged from approximately 2000 to over 3000 tonnes per annum, with the greatest loads being transported during the high flows (October to March). Reportedly, these values are within the lower limits published for yields in chalk streams.

Sediment sources and sinks

Using a system of scores and weights (MCA), the Geomorphological Appraisal provides maps of sediment sources and sinks in the River Wensum catchment[12]. They assessed the channel banks, the catchment and the bed surface as being potential sources of sediment to the River Wensum system. The bed surface and fine sediment berms were criteria used to define sediment sinks.

Bank face

Weathering of the bank face is a relatively unimportant source of fine sediments and an insignificant source of gravels.

Catchment

Due to the subdued catchment topography, there is limited erosion and transport of coarse sediments from the floodplain into the channel. Clay to coarse sand sized sediments are the main source of materials from the catchment and the Geomorphological Appraisal found this source to be substantial[13]. Catchment sediment sources were observed to include runoff from the erosion of:

- Bare or arable fields and pasture (especially where fields exist up to the margin of the channel with no buffer zone).
- Roadside verges by traffic, tracks and footpaths.
- Trampling of the floodplain or banks by livestock.
- Pig farm units.
- Recently cleared drains.

[12] GeoData (2006, p. 69, Section 5.3 and Appendices 2 and 3)
[13] GeoData (2006, P. 54; Section 5.5.5). Note - sediment types and quantities will vary, as will location, depending on antecedent and prevailing conditions at the time of survey

Points of ingress occur where runoff from the catchment surface intersects with the main channel, possibly via a drainage network. Sediment ingress points were listed as:

- Tributary confluences.
- IDB or road drains that discharge into the main channel.
- Footpath/tracks that cross the main channel.
- Runoff from hillslopes.
- Springs that connect to the main channel.

Joint management of the source and routeway of sediment into the channel would provide an effective control on fine sediment ingress. The Geomorphological Appraisal identified 3 main locations of sediment ingress (headwaters to Great Ryburgh, around Lenwade and around Taverham).

River bed and spawning gravel habitat

A visual assessment of bed sediments showed that the bed of the River Wensum is dominated by fine silts and sand throughout its length, with pockets of gravel exposed often downstream of mills. As the gravel bed is not mobile, it is not a major source of gravel to downstream reaches. Fine sediments become trapped upstream of mills, and so fine sediment sources are disconnected by the presence of mill structures. In the headwater reaches, the large proportion of sand present appears to be associated with the high frequency of sediment ingress points and vulnerability of sandy soils to erosion.

Whilst a key element of chalk rivers is the relatively large quantity of fine sediments stored in their gravels, excessive fine sedimentation can obscure the gravel bed and create an impoverished invertebrate fauna. The Geomorphological Appraisal field studies revealed that surface storage of fines were not a predominant feature of the upper Wensum. The highest levels of surficial fines were reported at Bintree, Billingford and Lenwade Bridge. Subsurface fines were found at Bintree, Lenwade Bridge and Lyng. Where semi-natural, the gravel bed and morphology are amongst the highest value conservation features on the River Wensum.

Sediment trapping and storage

Emergent and submerged macrophytes are a ubiquitous feature of chalk streams and lowland channels. Their presence, in association with low flow discharges, degraded morphology and a high fine sediment load, can result in the channel being choked and gravel substrate being infilled with fines. High organic matter loads can also be detrimental to the health of downstream reaches.

The mill structures and associated ponds are the main traps of fine sediment on the River Wensum. These features have had the largest and longest lasting impact on the system. Their management will be an essential part of restoring the natural physical processes and related biota in the catchment.

Channel morphology

A comparison of bankfull widths and depths measured along the Wensum with regime equations for semi-natural chalk streams showed that upstream of the River Tat confluence the channel depth is overlarge but the width is semi-natural. Downstream of the Tat confluence the bankfull widths tended to be larger than predicted (4 to 7m in the middle and lower reaches). Bankfull depths varied.

Natural recovery

The accumulation of silts, sands and the growth of vegetation provide the main method of self-recovery of modified channel dimensions. Lateral sediment accumulation and berm building is extensive along stretches of the River Wensum, particulary those that are not maintained. Boar et al. (1994) report the recovery of the River Wensum at Goggs Mill (Fakenham) following removal of the mill structure in 1957. The bankfull width is reported to have reduced from 20m to about 5m.

Whilst fine sediment ingress into the channel is higher than natural, this may actually provide a cost efficient resource for natural channel recovery, particularly in stretches that are over wide but are not over deepened. In overdeepened stretches, bankfull depth is unlikely to recover naturally due to the absence of a gravel supply. Wherever possible, channel restoration should seek to redress the over deepened channel through the reintroduction of gravels.

Reference condition

In some respects, the River Wensum catchment is not typical of a chalk river catchment as many of its tributary headwaters are not winterbournes but flow from clay and little chalk is exposed in the mid to lower reaches of the River Wensum itself. However, the upper reaches of the River Wensum were classified as JNCC River Community Type III (lowland chalk and oolite rivers with generally stable flow regimes) during the SSSI notification. It is, therefore, important that this river type is maintained or restored if it is not in a favourable condition. Restoration requires an understanding of the reference condition of the channel. Generic reference conditions[14] include:

- Reflecting totally, or nearly totally, undisturbed conditions.
- Lacking artificial instream and bank structures.
- Natural bed and bank materials.
- Unmodified planform and cross sectional profile.
- Lateral connectivity and freedom of lateral movement.
- Lacking instream structures that would limit the movement of sediment, water and biota.
- Having adjacent natural vegetation appropriate to the type and geographical location.

Table C4 provides a summary of the geomorphological features of chalk aquifers in the UK. Physical characteristics of natural chalk streams are given in the Geomorphological Appraisal.

Table C4 Geomorphological features of chalk aquifers in the UK[15]

Aquifer	Power (W/km2)	Bankfull width (m)	Width: depth ratio	Riffle Spacing/ bankfull width	Mean number VSSF/ 500m	Mean number DSSF/ 500m	Sinuosity	n
Chalk	6.1 (17.8)	8.7 (4.4)	18.4(14.0)	51.0	0.1	0.1	1.29 (0.47)	21

Figures in brackets are standard deviations of the sample population.

VSSF = Vegetated sediment storage features (point bars, mid channel bars and side bars).

DSSF = Dynamic sediment storage features (point bars, mid channel bars and side bars).

[14] European Committee for Standardisation (CEN, 2003, Water quality - guidance standard for assessing the hydromorphological features of rivers. EN-14614)
[15] River Habitat Survey Semi-Natural sites (Sear, D., Armitage, P. and Dawson, F., 1999, Groundwater dominated rivers, Hydrological Processes, 11, 14, 255-276)

Further, reference conditions for a semi-natural groundwater dominated river include:

- Low drainage density (limited tributary network).
- Higher duration of flows at bankfull or overbank discharge compared to runoff-dominated streams[16].
- Low stream power per unit catchment area.
- Supply limited and transport limited coarse sediment loads results in a relatively impoverished (but natural) geomorphology, with few riffles or bars forms.
- Stable, armoured bed sediments often with concretion that further limit the transport of bed material and result in a shallow, open-work gravel framework for salmonid spawning that is sensitive to siltation.
- High density of aquatic macrophytes that facilitate flushing of fines.
- Limited accumulation of fine sediments on the bed surface in undisturbed catchments[17].
- Relatively large width to depth ratios (that is, shallow and wide channel with little cross-sectional variability)[18].
- Low rates of lateral channel adjustment[19].
- Irregular to straight channel planforms with variable sinuosity accordingly.
- High residence time of woody debris. Presence of woody debris islands but few debris dams.
- High floodplain water tables leading to organic rich floodplain soils.
- Marsh habitat with open groundwater pools in the floodplain where strong coupling with groundwater is evident.
- Relatively open woodland development with dominance of herbaceous plants due to high floodplain watertables.

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[16] Shallow flow duration curves arise from the relatively small range of discharge. Chalk streams have a high baseflow index (>0.8 where 1.0 is a theoretical 100% baseflow contribution) and a low flashiness index. Bankfull discharge can occur for up to 20% of the time and overbank flows in spring dominated rivers occur up to 13% of the time. The effect of these high stages and prolonged periods of stable high discharges, is the observed saturation of floodplain soils and river banks and the development of organic rich floodplain soils and bank material

[17] There is an intuitive discrepancy between the presence of high width depth ratios, and a lack of sediment storage, since this creates conditions for sediment accumulation. This may be due to:

- an absence of sediment available for transport (limited headwater catchments where streams rise from discrete springs) and a lack of active bank erosion.
- lack of available energy for bedload transport (low bankfull discharge capacity and shallow valley gradients results in low bankfull stream power).
- armouring of the gravel bed and concretion of the substrate by calcareous deposition (Tufa) may further constrain bedload transport.
- fine silts and sands that are stored in zones of relatively low stream power (the long reaches of glide/pool that characterise existing chalk river geomorphology, or in marginal deadwater areas).
- relatively high flow resistance associated with the presence of in-channel vegetation and woody debris.

[18] The relatively long duration of near bankfull flows has sufficient capacity to progressively erode the organic rich and moist bank sediments, while lacking the ability to erode the bed substrate. Channel widening, in such conditions, is progressive over time, not episodic such as one observes in runoff dominated rivers. The model for channel morphology is clearly dependant on the nature of the confining bank materials - with peaty sandy banks being associated with higher width:depth ratios and clay/silt cohesive banks being associated with lower width depth ratios

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

The river management implications of these characteristics include:

- Chalk rivers will be highly sensitive to relatively small increases in sediment loads. Routes from the land into the river network are prime targets for reducing sediment delivery.
- Fine sediments are conveyed readily throughout the system by the relatively long duration of high in-bank flows. This results in strong coupling between the upper catchment and the rest of the river system. Local catchment sources will therefore have widespread impact and should be managed at the catchment scale. Flow reduction (for example, abstraction) will increase the residence time of fine sediments within the river network.
- The geomorphology and physical habitat diversity of chalk streams will be highly localised and sensitive to local controls (that is, weirs, debris fall, planform variation etc.). This creates a system that is best managed for physical habitat at the local scale.
- Fine sediments will be a feature of 'contemporary' chalk streams because of increased catchment sources and will occupy areas of relatively low velocity - bank margins (berms), weed beds etc. Removing these stores will encourage flushing of fines through the system. Manipulation of channel structure is a sustainable way of manipulating the location of fine sediment in the system.
- Aquatic macrophytes increase flow resistance and decrease sediment transport. They trap and temporarily store fine sediments and associated nutrients. Manipulation of macrophtyes is one method of managing the physical habitat of chalk rivers.
- Bank side trees and associated in-channel woody debris is an important element of chalk stream geomorphology. It is a major driver of physical habitat and substrate diversity. Woody debris has a high residence time in groundwater-dominated rivers and it can control flow and geomorphological processes over long timescales.
- An increase in shade results in less macrophyte growth and a reduction in the trapping of fine sediments/better transportation of fines.

River restoration - vision and strategy

The Geomorphological Appraisal laid the foundations for the creation of an unconstrained vision for the River Wensum SSSI catchment using MCA. The subjective criteria, scores and weightings used in the MCA are given in the Geomorphological Appraisal (Appendix 1). Criteria were scored and weighted at each reach surveyed in the Geomorphological Appraisal to identify the naturalness and modification indices at each location. An example of the attributes of the most natural and least modified reaches are shown in Table C5.

Table C5 Example MCA attributes, weights and values

	Weight	Values of most natural reaches	Values of least modified reaches
Percentage fine sediment	4.5	0-4.9%	-
Width depth ratio	4	5-15.9	-
Modification level	4	-	1
Plan modification*	3.75	unmodified	-
Minimum bank height	3	0-1m	-
Percent ponded*	3	-	0-24.9%
Type of flow	2	Run or riffle (maybe glide)	-

Table continued...

	Weight	Values of most natural reaches	Values of least modified reaches
Proportion of reach covered by berms	2	0-24.9%	-
Percentage bed cover by macrophytes*	2	-	0-79.9%
Barriers to sediment movement upstream	1	None	-

Based on the MCA indices (Figures C1 and C2), each reach was then assigned to a channel type (Table C6) and was associated with a management action (Table C7). Definitions are provided in Table C8. Management action classes were mapped at each reach and provide a basis for developing a more detailed strategy throughout the catchment. Rehabilitation and assisted natural recovery were the most frequently assigned actions (36% and 31% of the surveyed channel length), followed by restoration of form and process (18%). Indicative restoration measures were also provided, ranging from fix sediment ingress points and re-meander to recruit woody debris etc (refer to the Geomorphological Appraisal).

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

Figure C1 Classifying reach type

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

Figure C2 Assigning management options

Table C6 Length of River Wensum channel in each channel type

Channel type	Total length along surveyed channel (km)	Percentage of total surveyed channel length
Natural	0	0%
Recovered	1	1%
Semi-natural	4	5%
Recovering	6	7%
Damaged	38	50%
Degraded	23	30%
Severely degraded	5	7%
Artificial	0	0%

Table C7 Length of River Wensum channel in each management action class

Management action class	Total length along surveyed channel (km)	Percentage of total surveyed channel length
Do nothing	0	0%
Restoration	13.1	18%
Rehabilitation	26.0	36%
Enhancement	5.2	7%
Assist natural recovery	22.6	31%
Conserve and monitor	1.3	
Protect and monitor	3.9	7%
Monitor	0.2	

Suggestions for prioritising works included:

- Assess local constraints, landscape/cultural aspects, stakeholder expectations, existing biota etc.
- Set in place a condition monitoring plan for semi-natural and natural or recovering reaches.
- Work from upstream to downstream.
- Link natural and semi-natural reaches first and improve reaches close to these conditions (build out from the best sites). Policy based justification for only tackling restoration on unfavourable reaches under the PSA driver may need to be re-examined to ensure sustainability.
- Treat sediment ingress problems prior to physical habitat restoration, rehabilitation or enhancement (unless these works form part of the sediment control). Short term measures, such as the use of buffer zones, fencing and silt traps may be required while longer term measures (for example, land use zoning and sustainable land management practices) are implemented.
- Weir removal or modification will require restoration of up and downstream channel morphology to ensure the functionality of the floodplain is retained (prevent development of a two-stage channel). Flow modelling may be useful in planning restoration works and assessing flood risk.

Table C8 Definitions of classification systems using in Fluvial Audit

Reference conditions for hydromorphological quality in rivers (from the European Committee for Standardisation, 2004).	Reflecting totally or nearly totally, undisturbed conditions: • Lacking any artificial instream and bank structures that disrupt natural hydromorphological processes, and/or unaffected by any such structures outside the site. • Bed and bank composed of natural materials. • Planform and river profile: not modified by human activities. • Lateral connectivity and freedom of lateral movement: lacking any structural modification that hinders the flow of water between the channel and the floodplain, or prevent the migration of a channel across the floodplain. • Lacking any instream structural works that affect the natural movement of sediment, water and biota. • Having adjacent natural vegetation appropriate to the type and geographical location of the channel.
Restoration	Restoration of channel processes and forms to pre-disturbance conditions.
Rehabilitation	Physical modification to the river form to re-create physical habitats (for example, re-meandering, riffle installation, bed level raising).
Enhancement	Addition of structural features to improve physical habitat diversity (for example, narrowing, woody debris).
Protect & monitor	Afford legal protection to the site and monitor for change in status.
Assisted natural recovery	Amplification of existing processes to encourage recreation of physical habitats (for example, encouraging berm formation to narrow channel, removal of bank revetment to create sediment supply).
Conserve	Protect site against further degradation not necessarily with legal statute.

Appendix 4 Local recollections of changes in the River Wensum

The River Wensum at Fakenham

V.S. Rose - Notes on the decline of the river and adjoining water meadows during and since the care of the rivers came under the East Suffolk and Norfolk River Board in 1948.

V.S. Rose Hempton former bailiff to the board 1953-1970.

The River Wensum upstream from Dening and Kersley's Mill as far as Sculthorpe Mill, having been drained from its original bed for the purpose of storing and feeding water into the three water mills that existing ove a length of approx 2 miles; namely Mrs Grays Mill at Sculthorpe, the Goggs Mill at Hempton and Dening and Kersley's Mill at Fakenham.

Of the three Mills only two now remain, no longer used for grinding corn Mrs Grays Mill at Sculthorpe is now a restaurant and Dening and Kersley's has been converted into flats and the Gogg's Mill was finally destroyed by the Old E. Suffolk and Norfolk River Board in 1957, quote ' in the ineterst of drainage and agriculture'.

The exact date of the diversion is not known no records have come to light and the deeds of Gogg's Mill were never found. However a certain amount of evidence would suggest that it took place during the first 10-20 years of the 18th century. Faden's Map of Norfolk 1797 shows the existence of 3 mills over the length of the water course and although it is obvious that Dening and kersley's mill has been rebuilt,(the original having been destroyed by fire) both Sculthorpe and Gogg's Mills were much older (constructed of red brick and chalk).

The river was apparently moved some 50-70yds south from its natural bed, into an artificial bed, the new course was much wider and deeper than the original and a bed of shingle was laid over the 2 mile stream to assist the river to clean itself. The importance of this will be seen later). Used in conjuction with the operation of the Mill's sluices, constantly flushed the river 24 hours as the mills worked on a rota basis of 5' head of water was stored and released on alternate days.

Old photocopies show the river to be in some places 25'-30' wide and the depth in the pools 12' deep. Obviously no river, only 7 miles from its source would ever naturally have been of such proportions. In places on Ox-Bows and bends wooden hoardings were constructed on the N bank to prevent erosion. As the new river was continuously cutting that bank, in an effort to reach its old bed, traces of these hoardings can still be seen on the north bank of the Sulthorpe Fen.

Having diverted the river into a new course, the Landowners were faced with the major problem of drainage, (the river now in places higher than the surrounding land. To achieve this a complex system of land drains were constructed, the water from these drains emptied into the river in front of the mills. The old river bed was incorporated in the system and emptied its contents into the front of Goggs Mill.

So it can be seen that irrespective of the Mill's holding of water the drainage system was always working (a similar system existed at Ryburgh and Costessey Mills). Assisted by a network of smaller drains the land adjacent to the river was kept in perfect condition in respect of drainage. It has been stated that the River Wensum between Sculthorpe Mill and Denning and Kersleys never directly took a drop of water off the land. Such was the effectiveness of the system the land on both the Hempton side and the Sculthorpe Fen, while it was lower than the water course was kept in a good state enabling grazing and hay making to take place at all times.

The water mills gradually ceased to function, although the sluices at Dening and Kersley were operated on occasion, the river was in excellent condition in respect of the quality of its water , good fishing especially for trout, dace and roach was enjoyed by local anglers and holiday makers. The Wensum

Roach were renowned for their size and colour. The weed growth on the chalk and gravel bed was prolific and varied, producing in the spring and early summer hatches of Mayfly, pale olive duns and many other species. Fresh water shrimp, crayfish and minnows all pointed to the purity of the water, Kingfishers and Otters were common on the Sculthorpe Fen.

Under the new River Board Act of 1948 the care and maintenance of the Wensum came under the control of the E Suffolk and Norfolk River Board. In the early 1950s a scheme was introduced the effect of which was to be disastrous for the Wensum.

Very soon after the E Suffolk and Norfolk River Board took control a statement appeared in the the local press announcing that they intended to carry out a major drainage programme.

For almost 3 years the dredger carried out the programme as staged, the river above Goggs Mill suffered the worst as the laid gravel was easily removed and as the dragline required an operational width of 15' all shrubs and vegetation was destroyed on the south bank.

After the work was completed in 1967, the character of the river completely changed, it became a deep muddy canal. The attractive bends were mostly gone and the fast gravel and chalk runs were replaced by mud and silt. Every spring the river is to this day covered with a layer of filth. As the sun increases the water temperature, the decaying weed rises from the bed and floats in great rafts downstream.

The otters and the Kingfishers have gone and so have the roach and wild brown trout. In June there is no Mayfly hatch from the muddy bottom and with the coming of the nitrate problem the river has been taken over by the worst types of weed and algae.

The worst irony of the whole sorry mess is that the year after the work was completed, the Sculthorpe Fen was flooded, something that before was almost unheard of…. Unless some change in attitude is forthcoming the river will remain almost lifeless.

It is true that stop boards have been introduced at Denning Kersleys Mill during the winter months these boards are lifted to allow surplus water to run off surrounding land lowering the water level some 18". In the spring the boards are lowered and the river again becomes still and dirty.

Admittedly in the river in the winter months returns to some degree of normality. I believe it would be better if the stop boards were removed altogether allowing the river to naturally find its own level, failing that they could be operated on a more regular basis thereby partly simulate the previous action of the mills.

Admittedly the river started to deteriorate the day the last mill stopped working. The attitude of the water authority does nothing to help the situation now.

It is too much to hope for the return of the situation that existed before the war, because the water no longer has any commercial value, and as today everything is reckoned in terms of financial gain, not a great deal of effort can be expected. Certainly it is too much to expect that the river be returned to its natural bed. However if the shingle gravel bottom could be relaid, the banks stabilized, the stop boards used properly and the river be allowed to return to its natural size. Some good may come of the existing mess.

I am afraid however that these things will not be done, The authority will, as foretold by Mr Cotton, continue the programme of dredging every 20-30 years, if only to satisfy public opinion in respect of seeing an open stretch of water.

Tragically after all the effort and cost the surrounding land is worse off in appearance and drainage than it ever was.

Correspondence to EA from Norfolk Wildlife Trust in July 2006 on River Wensum at Fakenham illustrating local complexities that must be considered to implement the Restoration Strategy

The notes indicate that in the past the Sculthorpe Fen/Moor area has or had a significant hydrological relationship with the river and that this influenced river levels. It is worth noting (although I'm sure you're already aware of this) that the future for the Sculthorpe Fen and Moor area looks good, as the Hawk & Owl Trust is taking on the management of another part of the landowners estate so that they will be managing over 200 acres in this area, for conservation. There will be water control and many hybrid poplars will be removed as part of the efforts to restore and re-wet the wider site.

However, the site still remains isolated from the river due to the lowered bed and high banks of dredged material in places. There may be scope to remove or lower some of the high banks with a view to re-connecting the river with the surrounding river valley and perhaps this possibility could be discussed with the RRP contractors. Having said this of course, there are water quality issues in relation to the potential ingress of eutrophied river water into the SSSI fen area.

Secondly there may be scope to assess the feasibility of restoring the old river course downstream of Sculthorpe Mill which runs adjacent to part of the Wensum SSSI and an adjacent County Wildlife Site. Barry also mentions the reinstatement of a meander loop which is now part of the H&O Trust reserve - a dyke follows this old course and is an important part of the water control regime on the site. Such restoration would conflict with current function but I guess would not be insurmountable and again, perhaps this is something that could be raised with the RRP contractors.

Thirdly, the H&O Trust are hoping to take on the management of the southern side of the river opposite Sculthorpe Fen and to help facilitate the movement of cattle there is the potential to create a combined cattle crossing/riffle-glide at a narrow point in the river (mentioned/discussed with you on previous occasions). I'm hoping that this can be achieved largely as a special project within a new HLS agreement. In addition, this stretch has a very high right-hand bank, probably comprised of dredging arisings containing gravels and flints with the potential for recycling these materials back into the channel as done at Costessey Point - thus also helping to reconnect river to valley. I have not seen the initial RRP proposals so have not seen what may be proposed for this stretch but perhaps this proposal could be incorporated.

In relation to re-piling some of the riverbank adjacent to Sculthorpe, water voles occur in places and as such we wouldn't want to see piling restored.

Appendix 5 Restoration Techniques

Introduction

Detailed information regarding restoration techniques is provided in this appendix. It must be noted that the number and type of techniques described here are limited. There is a vast array of restoration techniques described in published guidance and there are often many variations on a technique available to suit different situations. The choice of technique needs to be assessed on a site-by-site basis by experienced geomorphologists/engineers and the impacts of any works must be determined not only for the specific section of channel where works are proposed, but also for the upstream and downstream reaches of river.

Land drainage consent application

Land Drainage Consent must be obtained from the Environment Agency for any works in, under, over or within 9m of Main Rivers (under the Water Resources Act, 1991), or for any works which are anticipated to obstruct or affect the flow in ordinary watercourses (under the Land Drainage Act, 1991). In the case of the Norfolk Rivers IDB Main Drains consent for restoration would need to be obtained from the IDB. When considering Land Drainage Consent applications, the Environment Agency has to consider the likely impacts of the proposal on flood risk and the ecology of the river environment. As a result, an application to the Environment Agency to undertake restoration works will require quite detailed information, such as:

- Scheme location, previous schemes and baseline conditions.
- Proposed works - technical specifications (for example, dimensions, materials, plans, cross sections etc) and method statement (including details of access routes and potential impacts of construction processes etc.).
- Flood risk assessment.
- Environmental impact assessment - the impacts of the proposal on the SSSI, SAC, protected species, breeding birds, fish, channel habitat, ecology and riparian communities, archaeological interest etc.
- Geomorphological impact assessment - sustainability of the scheme.
- Other - for example, issues related to water quality, waste, and recreation.

The Environment Agency has published an "Information Guide to River Enhancement Projects", which gives further advice on the level of flood risk assessment and environmental information which is needed to accompany a Land Drainage Consent application. As part of the application process, the Environment Agency will consult with Natural England regarding the likely impacts on the SSSI and SAC features of the River Wensum. There is no need for the applicant to apply for a separate consent from Natural England.

Published guidance

Numerous publications are available that provide details of specific designs or restoration techniques. The most useful guides include:

- River Rehabilitation Guidance for Eastern England Rivers (2005).
- River Restoration Centre Manual of River Restoration Techniques (2002).
- New Rivers and Wildlife Handbook (1995).
- Australian Rehabilitation Manual.
- USA Stream Corridor Restoration.

In addition, the River Restoration Centre (RRC) provides an advisory service to Natural England and the Environment Agency on river enhancement and restoration. They recently produced a scoping report in conjunction with HR Wallingford for an environmental river engineering design manual (Janes et al., 2004). They state that the purpose of such a manual would be to feature techniques appropriate to UK rivers and to provide an easily accessible inventory of techniques that would suit different environmental engineering objectives. The scoping report is useful to the River Wensum Restoration Strategy as it also lists and references different types of restoration techniques.

The Chalk Rivers Handbook (Mainstone, 1999) also provides useful insight into restoration appropriate to chalk rivers. Techniques used in other chalk rivers, such as the River Kennet and the chalk streams of Lincolnshire, as well as previous projects along the River Wensum, provide reasonably up-to-date case studies that can be consulted for techniques and, in many cases, a post-project appraisal.

Designing rivers with a form characteristic of a chalk river in Norfolk

Mainstone (1999, p.136) provides generic guidance on designing characteristic chalk river channels and floodplains. In general, the aim of channel restructuring should be to reduce cross sectional area of the channel to allow saturation or inundation of riparian land over the winter period. Bank height should be relatively low and the channel relatively wide (although not overly wide as at present on many reaches). Gravel glides and some riffle/pool sequences should be present on the bed, and gravel bars should be located to deflect flows and generate a range of current velocities. In some river sections, it may be necessary to use imported gravels to raise the bed in order to regain hydrological contact with riparian habitats. In many reaches, this is likely to occur naturally through channel narrowing and bank re-profiling.

In areas of low flood acceptability, channel restoration will have to be undertaken mainly within the existing channel. In such situations, marginal habitat can be created on alternate berms set at the appropriate level of typical summer flows (around the level of 95% exceedence flow) creating variations in depth, current velocity and substrate type.

In many instances, it may be possible to allow the river to form a smaller functional channel within the over-sized channel by focusing dredging and weed-cutting works on the central part of the channel. The stocking levels of livestock should be sufficiently low to avoid poaching and destabilisation of the banks, and where grazing intensity is currently too high, this should be addressed through Higher Level Environmental Stewardship Schemes. Fencing of river banks is not ideal as it results in a loss of diversity along the banks as vegetation becomes rank and dominated by ruderal species. If clean gravels are to be achieved along significant lengths of river, silt ingress from arable land also needs to be controlled.

Land-lowering (removal of subsoil to create grassland that is in better hydrological contact with the river) may be attempted in areas of low flood acceptability. This ensures that there is no increase in flood risk, and can often prove beneficial in terms of an increase in flood storage capacity.

Modification of structures (including mill controls and side channels)

Benefits

Weir replacements are discussed in the River Rehabilitation Guidance for Eastern England Rivers (2005). If a water control structure has no apparent use, the guidance suggests removal should be considered in order to:

- Improve aesthetics (if the structure is concrete with unsightly mechanisms).
- Allow free passage for fish and invertebrates.
- Return to a more natural bed and water gradient and bed topography.
- Reconnect the sediment transport system. This will allow fine silts to travel through the reach and deposit in natural eddies, and gravel to be scoured by high velocities. Cleansed gravel will provide loose riffles of value for spawning fish and invertebrate populations.
- Increase velocities and reduce silt deposition.
- Limit in-channel nuisance plant growth.
- Reduce erosive pressure downstream of the weir.

Methods

The impact of sediment build up and regular desilting and weed maintenance upstream of the River Wensum water level control structures has altered the long profile of the river over time. Simple removal of entire structures may lead to instability within the reach and associated impacts up and downstream. This could be alleviated if the channel bed is regraded over the affected length of channel at some or all of the water level control structures in the catchment. Regrading on a large scale will prove expensive and will inevitably disturb existing habitat, some of which may be of high conservation value. Alternatives include the lowering of the structure and creation of a fish pass or the replacement of the structure with a lower, longer crest, such as a fixed riffle. Riffles will gradually raise the water level locally without having an impounding effect upstream. Gravels should ideally be of the same size distribution that occurs locally and may be sourced, at least in part, from spoil heaps present along the banks.

Prior to works at water level control structures, the silt that has accumulated upstream will need to be removed and care must be taken during this process so as not to remobilise excessive amounts of fine sediment. This could destroy gravel glide habitat or riffles in the relatively natural and healthy sections of river downstream of many of the River Wensum mills. The method of silt removal and its disposal will need to be assessed on a site-by-site basis. Removal of dredged sediment from the channel must be undertaken in line with new Agricultural Waste Regulations. Under these regulations, an exemption certificate will be required when slubbings are removed from drains or the channel and spread on the land. It is possible that a certificate will not be required if slubbings are moved from one part of the channel to another, such as during the creation of channel narrowing berms. Since many reaches upstream of mills require narrowing, it is recommended that dredged sediments be tested for their suitability for this purpose.

It is important that engineering works at water level control structures are integrated with rehabilitation of upstream, and if necessary the downstream, reaches along the River Wensum. Often ponds upstream of mills are wide and deep. Rehabilitation will require channel narrowing in addition to bed raising to re-create a regime sized channel that will function naturally. The River Wensum Restoration Strategy recommends adoption or continuance of an appropriate maintenance regime and riparian management to allow the channel to narrow naturally in the first instance. However, in reaches that are very over-wide, physical narrowing may have to be considered in the longer term if full functioning of the channel is not restored naturally over 10 to 15 years.

Examples

In the River Kennet at Ramsbury, retained water levels were lowered by 30cm by changing the management of a downstream sluice to provide a small gradient and restore flow. The water level was determined by experimentation. By changing the sluice settings during low flow periods it was possible to select the level whereby two riffle-like features occurred naturally and gravel ledges were exposed along the bankside.

Consequences

According to the River Rehabilitation Guidance for Eastern England Rivers (2005), the impact of weir replacement is expected to be low in most cases for low energy, lowland rivers (Table E1). It is possible to estimate the impact on flood risk of replacing a weir with a riffle using equations to compare upstream water levels due to changing weir type (the riffle is assumed to be a crump weir), roughness (discharge coefficients) and crest levels. The change in backwater length can also be estimated using hand calculations.

Table E1 Impacts and risks - weir removal

Types of techniques	Risk of increased flood levels			Impacts
	High	Medium	Low	
Replacing weirs			✓	Unlikely to have an adverse impact on capacity. Risk usually low if riffles lower than existing weir (often the underlying rationale for the works).

At some mill sites along the Wensum there are numerous by-pass channels and structures. Simple calculations to assess the impacts of water level control structures removal or lowering may not be sufficient to provide the confidence in a restoration design. More complex hydraulic modelling may be necessary to ensure that restoration measures do not result in the drying up of side channel habitats, channel erosion or increased flood risk. In locations such as Lyng, the water level control structures structure itself may provide a focal point that is worthy of conserving. In these cases, alternative solutions such as mill by-pass may be required to improve fish passage and restore gradients and bed topography.

Channel narrowing

Benefits

The benefits of river narrowing in an over-wide channel are summarised in the River Rehabilitation Guidance for Eastern England Rivers (2005):

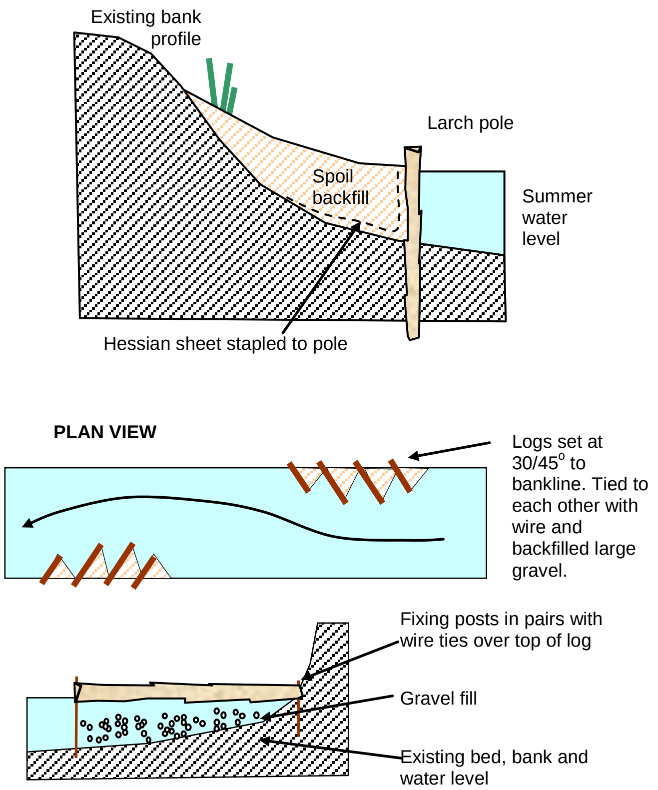
- Increased flow velocities and a reduction in sedimentation and excessive in-channel ‘weed’ growth. (In some cases this can scour the silt and sustain a natural/imported gravel bed that is suitable for trout spawning).
- Reduced low-flow width of the channel to provide more appropriate channel dimensions and velocity in low/normal flow periods but maintenance of flood defence standards.
- Provision of damp/wet marginal habitats.
- Reduction of costly annual maintenance works.

Methods

Narrowing can be achieved by two principal methods:

- Physical narrowing using structures and infill (for example, aquatic ledges and coir fibre matting held in place by larch poles etc.). This is the easiest method to design and implement. The channel is narrowed by the end of the works period.
- Altering the flow and sedimentation patterns to achieve deposition of silt and plant growth at desired locations. By correctly locating structures in a sediment laden reach, siltation can occur within days and marginal colonisation begins to formalise the feature within the growing season. The narrowing may take a year or more to occur and will be sensitive to flow conditons (a flood could scour the feature away completely in the short term).

Figure E1 shows an example of each of these methods. However, there are many variations on these methods related to the materials that can be used, the extent and type of narrowing required, the existing habitats present and the placement of the revetments, deflectors and planted vegetation.



Narrowing through the creation of a low flow level berm. A revetment is created along the agreed line of the new channel and backfill material is placed behind. Materials used for revetment may include faggot bundles, hazel hurdles, coir fibre rolls, natural block stone etc. Stabilisation of the fill is crucial and faggots may be used to aid stability and re-vegetation as well as improving habitat diversity.

Deflectors impede river flow, causing scour at their tips, and eddy currents within which silt is deposited closer to the banks. The most effective type of deflector seems to be those orientated upstream and protruding at the normal low flow level. Deflectors are preferably constructed using natural materials such as tree trunks staked with fence posts and wire, or other materials such as hazel hurdles secured into the lower bank.

Figure E1 Example techniques for channel narrowing

Examples

Both types of narrowing technique were employed on the River Kennet, such as at Ramsbury. Permanent narrowing of the low flow channel was achieved at this site over about 400m by installing vegetated coir rolls onto ledges along the bankside. A number of different types of ledge were constructed using existing material, gravel or rock (depending on river depth). The coir rolls were 3m long and 30cm in diameter and were laid so that they would be two-thirds submerged under low-medium flow conditions. The rolls were pre-planted with vegetation typical of the river, and secured by pairs of stakes driven into the bed at 30cm intervals.

Over thirty deflectors were also installed at Ramsbury (up to 10m long and extending 6m into the channel) to narrow the river. Deflectors were made of posts (10cm diameter) and wire, angled at 30 degrees upstream, and designed to deflect water towards the channel centre and to be submerged at all but the lowest flows. These deflectors snag vegetation and reduce bankside velocities, encouraging silt deposition and sedge/reed growth that will gradually narrow the channel and promote self-cleaning gravels in the centre of the river.

Along the River Wensum, readjustment of the channel width has occurred naturally in some reaches. Silt deposition, in the form of berms along the sides of the channel, can be beneficial if these berms vegetate. Further sediment trapping and vegetation growth encourages width reduction. There are a number of poplar plantations on the river. These no longer have an economic value and have not been harvested. It might be possible to agree the felling of these and use of the timber for narrowing. Macrophyte growth is most likely in open areas that are not maintained, or in wooded areas where gaps in the canopy occur following tree fall (refer to ECON, 1999, upper River Tat). As a result, near natural channel widths still exist at a number of locations in the catchment. These include, downstream of Fakenham Mill (4-5m width), the old river course at Gateley (4m), upstream of the bailey bridge between Lenwade and Lyng (8m) and upstream of Morton Bridge, Attlebridge (8m). Example locations where natural recovery is already underway in the River Wensum SSSI include upstream of Sculthorpe Mill and downstream of Lenwade Mill (ECON, 1999).

Consequences

According to the River Rehabilitation Guidance for Eastern England Rivers (2005), the impact of narrowing is expected to be directly related to the extent of the works (Table E2). Channel narrowing may reduce the capacity of the channel (storage volume), and its conveyance (the ability of the channel to convey water), and hence cause a rise in flood risk. Modelling can be used to assess the impact of channel narrowing on flood risk. If a reduction in channel capacity does increase flood risk, it may be necessary to consider combined measures, including bank re-profiling or 2-stage channels, or provision of alternative flood storage.

Table E2 Impacts and risks - narrowing of channel width

Types of techniques	Risk of increased flood levels			Impacts
	High	Medium	Low	
Narrow <10% channel			✓	Potential to affect conveyance. Risk directly related to extent of works.
Narrow about 20% channel		✓		
Narrow >50% channel	✓			

Gravel bed augmentation

Benefits

Gravel glides, shoals, bars and riffle/pool sequences are natural formations on gravel bed rivers. In chalk rivers, there should be a high occurrence of gravel substrate and glide habitat (reaches where flow is slow and laminar). Gravel shoals and riffles (shallow and rapid flow with a disturbed surface over gravels or cobbles) have limited occurrence, not least due to a lack of channel gradient in chalk rivers. In the River Wensum, the flow is no longer capable of naturally eroding and transporting the gravel materials required for diverse bed topography. The gravel forms that are present in the Wensum are almost exclusively relic features of the post-glacial period and, as a result, are of high conservation value as they cannot reform through natural processes under the current climatic regime. The covering of gravel features by silt deposits, or their removal by in-channel works such as dredging, means that this important habitat feature has been degraded in many reaches of the river.

Specific benefits of a gravel bed include:

- Increased flow speeds over gravel shoals and riffles helps to ensure that gravels are kept free of silt, and improves aeration, enabling invertebrate species with higher water quality preferences to colonise.
- Spawning and/or foraging habitat for dace, bullhead, chub, brown trout, brook lamprey and barbell.

- Diverse channel morphology, promoting varied flow velocities (fast flows over shallower sections, slack or sluggish flow regions in pools and back eddies). In turn, this creates more diverse river habitats, providing opportunities for a wider range of invertebrates and aquatic plants.

Methods

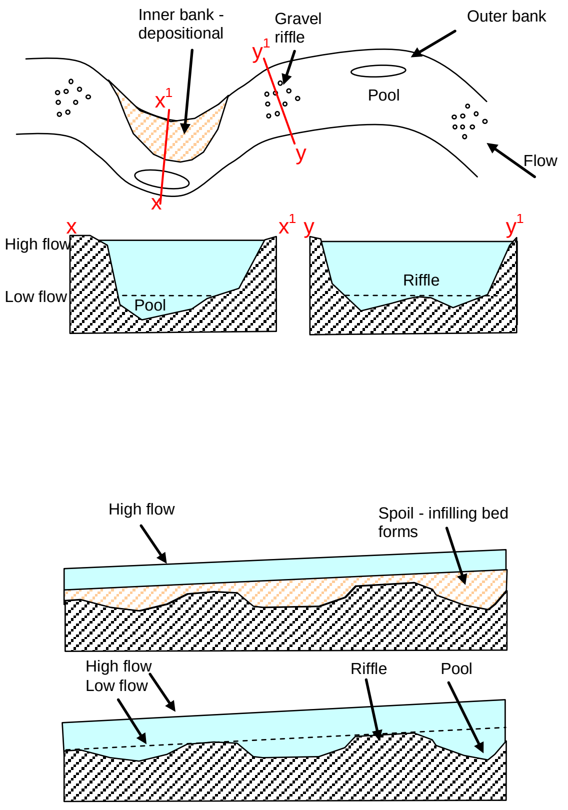
The practice of gravel bed augmentation is explained in the River Rehabilitation Guidance for Eastern England Rivers (2005). It is generally undertaken for two linked, but essentially separate, objectives:

- Reducing the depth of the river bed (for instance, in dredged and over-deepened channels). The prime aim is to achieve a shallower river over a length of channel. 'Bed raising' can be a costly exercise as it tends to involve importing clean material in large volumes.
- Restoring/recreating riffle and pool sequences in a shallow, good gradient river (Figure E2). Riffle creation involves restoring or recreating shallow fast-flowing, habitat. However, the installation of riffles in a reach where the gradient is insufficient could result in the 'drowning out' of upstream riffles. The gravel may be washed away downstream if it is not appropriately located.

In the River Wensum, the aim of gravel bed augmentation is a mix of both of these objectives. General bed raising is needed along much of the channel where it is overdeep due to previous dredging. In some locations, it will be appropriate to restore variations in bed depth and glides or riffle-pool sequences. As the bed gradient of the Wensum is relatively low in the study area (approximately 1 in 1850), riffle features will only be appropriate at sites where the gradient is sufficient to accommodate them without causing an excessive backwater or drowning out of upstream channel features.

In reality, glide habitat (long stretches of gravel bed with a relatively even bed gradient) is likely to be more appropriate in many reaches of the Wensum. Unfortunately, there is no available guidance on creating glides. The difference between riffles and glides relates to the length and height of the gravel bed feature. Riffles are characteristically topographic high points along the bed and occur between pools (topographic low points). As flow passes from the pool towards the crest of the riffle, its flow paths converge and velocity increases. As flow passes over the crest of the riffle and towards the downstream pool, its flow paths diverge and velocity slows. At glides, as variations in bed topography are less marked downstream, there are less marked changes in flow properties.

Given that the River Wensum is a low energy stream, it will be important that the shape and extent of any placed gravels are suitable to generate appropriate flow paths and local velocity distribution profiles. The stream energy will not generally be capable of redistributing existing gravel bed materials and such materials are relic features that cannot be reproduced by the catchment. The River Restoration Centre have stated that, in the Wensum, the location and type of gravel bed augmentation must be assessed on a case-by-case basis by experienced geomorphologists following a site visit. It is also likely that adaptive management of these features will be required to ensure that they function as required and a cautionary approach needs to be taken in relation to the importation of restoration designs from elesewhere.



Recreating riffle/pool bed forms (Brookes, 1990):
1.Determine if riffles are appropriate for channel (for example. is there sufficient slope to prevent the drowning out of upstream riffles, is a gravel bed appropriate to the river etc.).
2.Observe size of gravel and the gravel mix in existing riffles.
3.Typical riffle spacing is 6 times channel width.
4.Riffles and pools should be 1 to 3 widths long.
5.Riffles should be created at the exit of meander bends/in cross-over areas and pools on the inside of meander bendways.
6.Riffles should be 300-500mm above the natural gradient and pools a minimum of 300mm deep.
7. At lower flow levels, flow over riffles tends to be faster and shallower than pools.
8. At higher flows, flow velocity and depths become more equal in riffles and pools.

An even bed profile of fine sediments can be engineered to create topographic high points using imported gravel if they are not still in existence under the spoil. If riffles are created, pool and slack areas should then naturally develop, producing a riffle/pool type sequence and valuable flow and habitat diversity.

Figure E2 Creating riffle/pool sequences (adapted from Knighton, 1998)

The source of gravels for gravel bed augmentation can be local or imported. However, it is critical that the gravel is unwashed river gravel of an appropriate size for the river. On reaches where the gravel bed has been covered by fine silt deposits, de-silting (either naturally using coarse woody debris deflectors or by mechanical excavation) may uncover valuable gravel resources. Where dredged materials have been placed as spoil on the bank sides, gravels may be recycled and used in bed augmentation. Further, given the low energy of the River Wensum, and the low likelihood of movement of the bed material, there is an opportunity to lower the costs of gravel bed augmentation by using a core of low cost fill material topped by a layer of suitably sized gravel at the surface of the glide or riffle.

Examples

Bed raising has been used at a number of locations on the River Kennet, including Mill Lane Ford where a more natural width to depth ratio was needed (Figure E3). The bed was raised asymmetrically (different depths across the channel) to ensure a narrow low-flow meandering course and shallow edges that encourage marginal vegetation encroachment. Bed levels were increased so that at low flow the depth was 0.5 to 1.0m (based on the Q90 discharge levels - the level at which flows are exceeded 90% of the time). Gravel flints obtained from the floodplain adjacent to the river were used to raise the bed as such material was assumed to be representative of natural bed sediments. After 2 years, the reconfigured channel had typical chalk stream habitat, with a self-cleansing gravel bed that is used by trout for spawning.

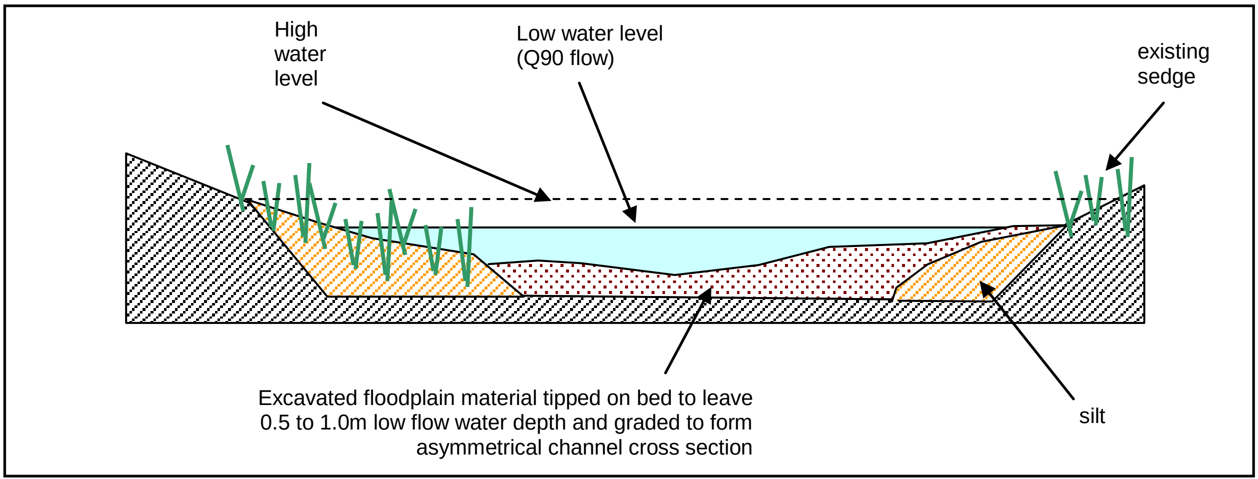


Figure E3 Bed raising on the River Kennet

Examples of gravel bed augmentation in the River Wensum include restoration projects at Costessey Point, Sayers Meadow (Lyng), Bintry Mill and Swanton Morley. Method statements for previous Wensum schemes are available in some detail and have been useful in identifying many of the issues that may arise during the planning and implementation of works (for example, sourcing and storing materials, calculating flood risk, sequence of works etc). However, it would appear that the main method used to locate, size and shape riffles has been best-judgement and not standard geomorphological guidance. Further, Wensum riffle designs have previously been required to include a weed-cutting boat channel. The main post-project issues associated with previous designs include the drowning out of upstream riffles (such as at Costessey Point) and the preferential flow at low discharges through the boat channel, which has instigated bank erosion and channel widening. In addition, these schemes have not always been accompanied by suitable bank planting programmes, or work on meander bend apices. Channel morphology has been improved, but has not been fully restored. An audit of river restororation reaches is recommended in order to inform future design.

Consequences

According to the River Rehabilitation Guidance for Eastern England Rivers (2005), the impact of gravel bed augmentation varies (Table E3).

The impacts of riffles are:

- Increased water levels at low flows due to raised crest level and increased bed roughness locally.
- Very small impact at higher flows if riffle heights are small in comparison with the bank height, and drown out at moderate to high flows.

Thus, to minimise impacts on flood risk, riffles need to be designed as low level features which provide flow diversity at low flows and drown out at higher flows.

The impacts of bed raising are:

- Very small increase in roughness through introduction of gravel into deep sluggish reaches, which are below the original bed profile.
- Increased roughness and water levels if gravel is placed into deep sluggish reaches which are raised above the original bed profile.

As with weir replacement, the impact of gravel bed augmentation can be modelled, or basic details (such as backwater lengths) can be calculated by hand.

Table E3 Impacts and risks - gravel bed augmentation

Types of techniques	Risk of increased flood levels			Impacts
	High	Medium	Low	
Riffles			✓	Potential to affect conveyance and roughness. Riffles should only raise low flow levels by <10cm, or crest height less than 20% relative to bank height. Should be drowned out by moderate to high flows.
Cobble riffles/rock weirs	✓	✓		Greater potential to affect conveyance and roughness. Structures that raise low flow levels by >20cm, or crest height greater than 20% relative to bank height. This would not result in a channel form characteristic of a chalk river in Norfolk.
Infilling to original bed level			✓	Applies where channel is over-deep relative to downstream depths and infilling seeks to increase velocity/reduce deep silty pools. Where gravel is not currently the dominant bed type.
Raise bed above original level and raise water level		✓		Bed level raised above the original bed level therefore increasing water levels. Where gravel is not currently the dominant bed type.

Riparian management

Benefits

Riparian management includes management of the floodplain, bankside areas and the margins of the channel (for example, emergent or submergent vegetation). Potential benefits of riparian management include the following:

- Marginal berms can produce in-stream channel meandering and improve flow and habitat diversity. They can also assist recovery of natural channel width without the need for physical narrowing techniques.
- Riparian vegetation helps create in-stream cover and increases the number of refuge areas for fish (adult, juveniles and fry) and invertebrates.
- Introduction of *Ranunculus* may restore a characteristic feature of the chalk river and provide additional cover for fish/invertebrates, as well as promoting flow diversity.
- Control of invasive non-native plant species (for example, Himalayan balsam, Japanese knotweed) can prevent loss of native species through competitive pressure.
- Buffer strips adjacent to the river channel help reduce the effects of soil erosion, nutrient enrichment and other pollutants.
- Bankside trees and shrubs create areas of shade and provide a contrasting temperature environment to more open areas, so benefiting habitat diversity.
- Opening up wooded sections encourages the growth of aquatic and marginal vegetation and increases the diversity of associated fauna.

Methods

Marginal wetlands and bank re-profiling

On many reaches, the River Wensum channel is wide, uniform and open, with a lack of floodplain, bank and waterside vegetation. However, in places where marginal vegetation colonises the river margin, silt becomes trapped around its root systems and the channel is gradually narrowed until a balance between summer flows and channel width is achieved. As with artificially narrowed channels, parts of the river that have narrowed through natural processes tend to have more diverse flow patterns, an exposed gravel substrate, a capacity for self-cleansing (that is, they can flush silt through the system) and provide a wide array of habitats.

Therefore, one solution to deal with uniform, open channels is to imitate/encourage observed processes of natural recovery. In reaches that are not substantially over-wide, this may be achieved by enhancement of littoral margin vegetation or by assisted recovery (reduction in maintenance or the continuance of a relatively low level of riparian management by the Environment Agency or Norfolk Rivers IDB).

In natural chalk rivers, marginal vegetation includes watercress (*Rorippa nasturtium-aquaticum*), brooklime (*Veronica beccabunga*) and water forget-me-nots (*Myosotis* spp.). Marginal vegetation characteristically encroaches into the channel as flow recedes (spring/summer), reducing the effective width and maintaining current velocities in the main channel. Natural in-channel vegetation includes water crowfoots (*Ranunculus* spp.) and starworts (*Callitriche* spp.).

Construction of a low wet shelf or berm, at one or both sides of the channel, will encourage the growth of a wide strip of wetland vegetation. Where banks are high and steep, bank re-profiling will be required to form a range of submerged and wet shelves. A proportion of the re-profiled bank can be left to colonise naturally and the remainder can be planted using transplanted vegetation from elsewhere on the site or by importing pre-planted coir rolls and mattresses. This will help improve the appearance of the finished scheme and will stabilise the banks and provide instant marginal habitat.

Newly formed margins will need to be protected by stock fencing to keep out livestock, so allowing natural riparian vegetation to establish. Fences are ideally placed 3-5m from the bank to create a buffer of vegetation that will also reduce silt ingress and pollutants. However, some plant species prefer trampled/eroded areas, which can also be of value for invertebrates. It is, therefore, recommended that fencing should be a temporary measure and should be removed once marginal vegetation is established. Continued light grazing of marginal areas should then be encouraged through the implementation of Higher Level Environmental Stewardship Schemes.

Emergent vegetation

Water crowfoot (*Ranunculus*) can be collected from elsewhere in the channel and secured to the stream bed using snowshoe shaped woven hazel frames.

Riparian trees

Overhanging trees provide valuable habitat for fish. Cover for fry can be enhanced by trailing branches and submerged roots along the edges of a stream. Tree cover, and the associated build up and retention of logs and woody debris, is an important part of a natural stream. However, it is important that trees do not shade out the river completely otherwise macrophytes will fail to grow. If necessary, coppicing or pollarding can be used to manage riverside trees. As a guideline:

1) In very open areas, occasional trees (willow/alder) should be planted to provide some shade as well as structural diversity to the channel. Trees should be planted as close as possible to the edge of the bank.
2) In wooded areas, trees can be felled to create permanent open areas or managed on short rotation by coppicing (cutting back the tree at the base and allowing it to re-grow) or pollarding (cutting back to head-height and allowing subsequent re-growth).

Floodplain

Mainstone (1999, p.146) outlines measures to enhance riparian areas for nature conservation, including:

- Reduction in high livestock densities in riparian meadows or erection of fences along banksides.
- Discouraging arable cropping and promote the extent of lightly grazed permanent grassland.

- Where arable cropping exists, widen strip of permanent vegetation (buffer strip) between the river and field.
- Restore hydrological continuity between the river channel and riparian areas.
- Where there is an issue, restrict angler path widths and limit number of access points to the river.
- Restrict general tree planting and growth but introduce targeted tree planting and scrub development (to encourage both shade intolerant and shade tolerant species).

Ideally, the majority of riparian land in the floodplain would be managed as lightly grazed pasture with minimal poaching of the margins. This should create areas with both short/medium length grasses and bare soil that supports flora and fauna characteristic of chalk rivers.

Examples

At Swanton Morley (Phase 2), a section of the left bank was re-profiled to create a wet margin (1m wide by 40m long). At Swanton Morley (Phase 3) extensive stretches of the right bank were re-profiled to form a range of submerged and wet shelves. Portions of the bank were planted with vegetation from elsewhere on site and some were covered with pre-planted coir rolls (Figure E4).

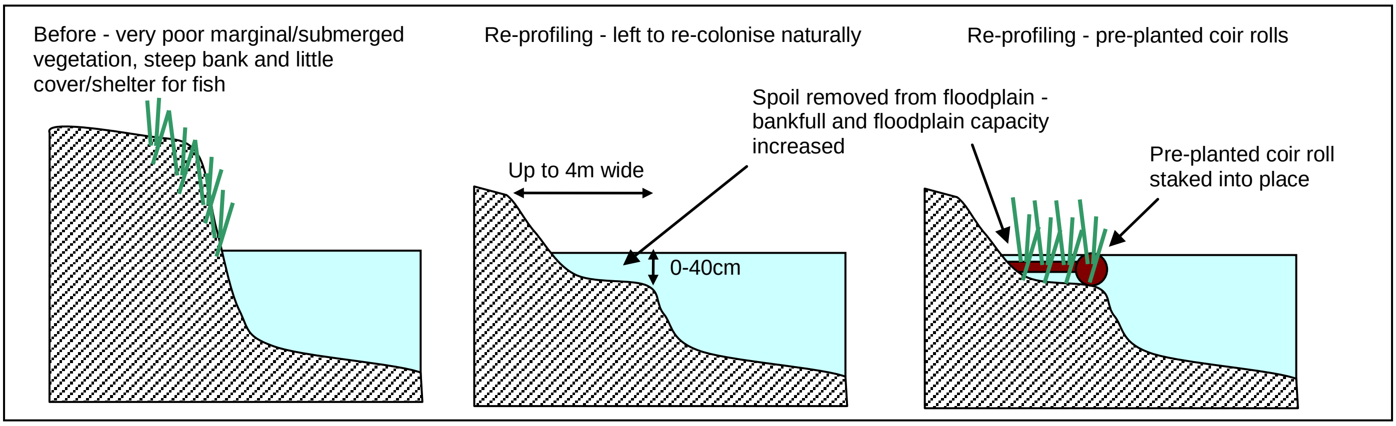


Figure E4 Bank re-profiling at Swanton Morley (Phase 3)

Consequences

Bank re-profiling should be avoided on banks of high wildlife interest. Similarly, it should be avoided where interesting features exist (for example, shallow berms and shelves in the bank side) or where vegetation is providing bank support or promoting habitat and flow diversity.

As the River Wensum channel is often overwide, it is important that enhancing margins by cutting wetland shelves does not increase channel width still further. A period of monitoring will be required, especially in areas that are not enhanced by planting, to ensure the establishment of vegetation and natural channel recovery.

Backwaters

Benefits

In heavily managed river systems, areas of slow or still water connected to the main channel are rare. Backwaters tend to silt up and colonise with vegetation, eventually succeeding to fen. They are important as refuge areas for fish and invertebrates in times of flood/high flow velocities and they provide shallow warm water for fry. As they are a transition between the running waters of the main river and the still water of a pond, they also add to the diversity of habitat available in a reach. Backwaters are very limited in extent along the Wensum valley.

Methods

The creation of backwaters or Off-River Support/Supplementary Units (ORSU) may occur as a useful by-product of re-routing or re-meandering of an old river course. Grazing marsh drains, cattle drinks and abandoned side channels also form important backwaters.

Backwaters should be designed with a variety of animal and plant species in mind. A mosaic of water depths, bank slopes, margin substrates etc. should be incorporated into the design.

Examples

At Swanton Morley and at Costessey Point along the River Wensum, ORSUs were created primarily as fish fry refuges. The Swanton Morley (Phase I) report by the Environment Agency stated that one of the major factors limiting the River Wensum fishery is poor recruitment success, linked to changes in river form and the number and quality of nursery areas for larvae and fry. The Environment Agency identified the channel habitat in the Worthing stretch as particularly limiting for fry, with long stretches subjected to relatively high flows and with little natural cover.

During the implementation of Swanton Morley (Phase 1), two fry refuges were created on the left hand bank. Each refuge consisted of a small bay (varying between 8 and 12m by 5 and 8m) with a narrow opening to the river channel. The depth of the bay was excavated such that it would contain both deep and shallow sections during the summer.

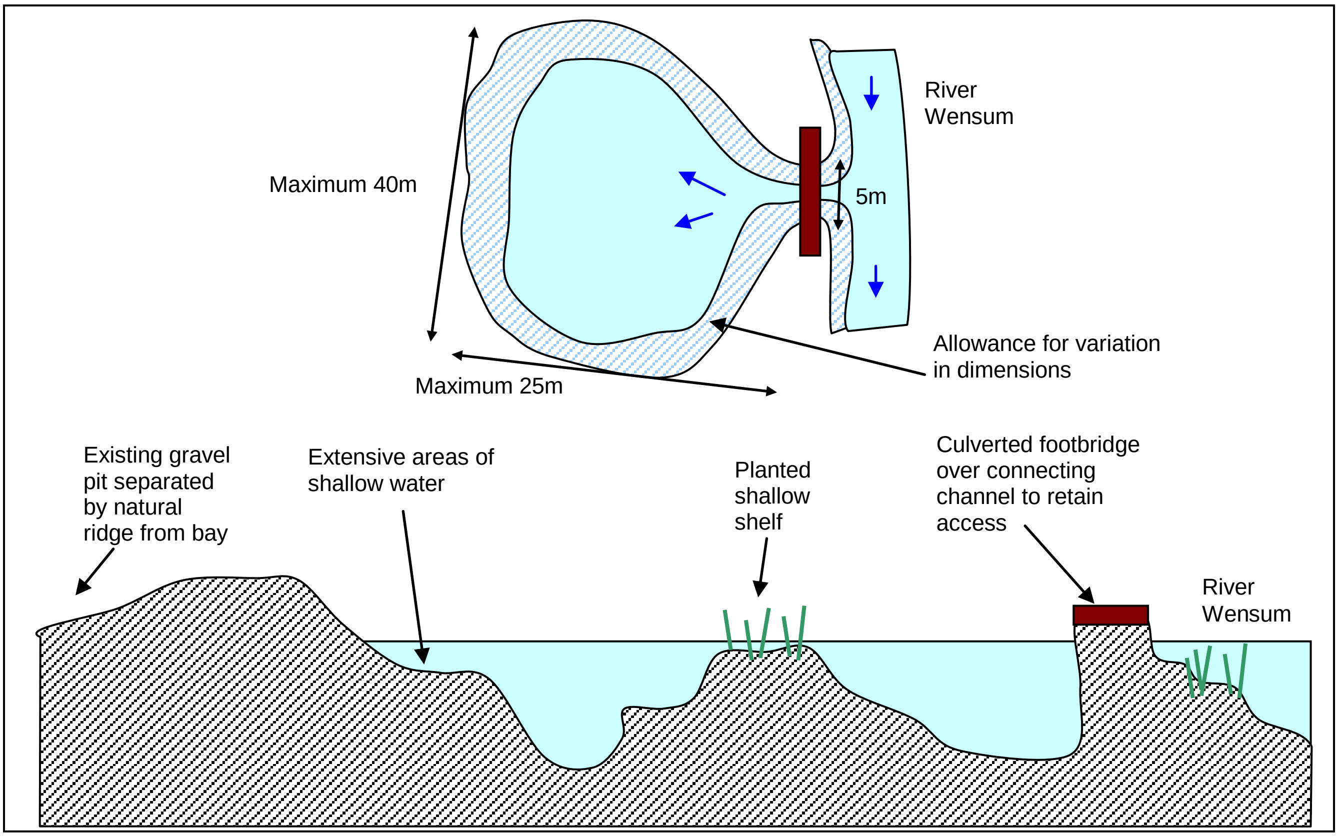


Figure E5 Fry Refuge at Swanton Morley (Phase 3)

Swanton Morley (Phase 3) involved the creation of 4 fry nursery and refuge bays similar, but on a larger scale, to those of Phase I (Figure E5). Each bay had a varied shape and a variety of bank profiles to maximise habitat diversity. Extensive areas of gently sloping bank were created to provide the shallow water conditions favoured by fry. Excavation depths were mainly between 0 and 0.5m below the mean summer water level, although depths up to 1.5m were created. Within each bay, areas of submerged and emergent vegetation were established to provide cover, using imported pre-planted coir rolls containing native wetland species (*Carex* spp., *Phalaris* spp. and *Juncus* spp.). In the case of the largest bay, a culverted footpath was created over the connecting channel to allow access by anglers and walkers.

Consequences

Table E4 Impacts and risks - backwaters

Types of techniques	Risk of increased flood levels			Impacts
	High	Medium	Low	
Backwaters			✓	No impact, minimal risk.

According to the River Rehabilitation Guidance for Eastern England Rivers (2005), the impact of ORSUs on flood risk is minimal (Table E4).

Backwaters are often low lying areas that flood frequently. However, as they are off-river ponded areas, they provide, in effect, (often small) additional storage capacity for the main channel.

River restoration

Benefits

The benefits of reconnecting remnant meanders where the old channel remains (partially) intact are summarised in the River Rehabilitation Guidance for Eastern England Rivers (2005):

- More features such as pool and riffle bedforms with varying flow depths and velocities, inner bendway point bars and outer cut-banks are established in the meandering channel, producing highly varied habitat features and ecological niches for fauna and flora.
- The channel and water surface are restored to a more natural, lower gradient, with benefits for downstream flood risk management due to flood water attenuation.
- Remnant meanders tend to be at a higher level than the canalised channel. Restoration results in better connection with the floodplain, which is inundated more frequently as a result.
- Restoration of river-floodplain connectivity is beneficial for characteristic chalk river floodplain habitats, such as marginal wetlands.
- The canalised section sometimes remains with a sweetening flow or can become a backwater/off-river refuge.

Methods

River rehabilitation aims to restore the form and function of the river as far as possible within the constraints that exist. In a location where the past course and dimensions of the river have been lost or blurred by centuries of management, it may be necessary to undertake historical research and to make complex design decisions in order to re-create a meandering course. Where the old channel remains intact and is apparent in the floodplain, there is greater potential to restore the channel with significantly less design cost. The principle is to excavate the old course to the original dimensions and use this as the 'natural' cross section and channel capacity. Original dimensions may be estimated using a reference site in a semi-natural channel of similar catchment area, or by using regime equations suitable for that river type. Asymmetry and longitudinal variation in depth and width are incorporated into the design at appropriate locations using principles of fluvial geomorphology.

Restoration will also require that any downstream controls on water levels are removed, that the bed is augmented with gravel, and that the littoral margins of the channel are restored appropriately. It is usual to incorporate protection measures, such as tree planting or insertion of woody debris, especially on areas vulnerable to instability (for example, steep outer banks) and to key-in the upstream extent of the restored channel to avoid bed incision. A period of post project monitoring is also recommended to ensure that riparian vegetation is establishing and to check levels of downstream sediment transport.

Examples

A previous restoration scheme was undertaken on the River Wensum at Hempton (upstream from Fakenham Mill). The restoration reconnected an old meander course and involved vegetation clearance, recreation of original channel dimensions and the installation of riffles.

ECON (1999) suggests further meander loop re-connections at Hellhoughton, Billingford, Castle Farm (Swanton Morley) and Attlebridge based on evidence of previous meander planforms on OS maps. The Billingford meander loop was restored in 2000 by the Environment Agency. This section of channel had been used as an ORSU since the 1970s but had silted up and ceased to function effectively as a refuge for fish. Sheet piling was removed from both ends of the meander loop and material was dredged and deposited thinly on the floodplain. A deflector was placed at the upstream end of the old meander loop to divert flow into the restored section. Water now circulates freely around the meander, which acts as a backwater but is fully connected to the main river.

Whilst many sections of the River Wensum have been straightened, there are few places where the original channel is still present on the floodplain. Other than a few short meander loops at East Raynham and upstream of Pensthorpe, the only significant length of a previously meandering channel that is still obvious on the floodplain is just downstream of Great Ryburgh Mill. This section of channel was partially restored by the National Rivers Authority, but the restored channel is now infilled with silt and vegetation and there is no longer a through-flow of water. Although the meandering channel was reconnected, there was no attempt to divert the full flow of the river into the original channel. A more holistic restoration is possible here and would require the main flow to be channelled down the restored section using upstream flow deflectors, combined with full or partial closure of the existing straight channel.

Consequences

If the artificially cut channel (that is, the more recent, ‘improved’ channel) was constructed to be larger and shorter (steeper) than the original channel meander morphology, it would have increased flood capacity and conveyance. Reversing this process, by restoring the old (that is, smaller and longer) course may reduce the capacity of the channel and increase roughness, with a potential increase in flood risk. According to the River Rehabilitation Guidance for Eastern England Rivers (2005), the impact of reconnecting remnant meanders on flood risk can be high (Table E5). Where there is not a significant risk to people and property, the improved connection of the river to the floodplain and increased storage of water on the floodplain may reduce the risk of flooding downstream.

Table E5 Impacts and risks - meander reconnection

Types of techniques	Risk of increased flood levels			Impacts
	High	Medium	Low	
Reconnecting remnant meanders	✓			Re-routing the flow will have consequences for water levels and flood inundation. Modelling should be an integral element of this type of work unless sound justification is provided.

Channel maintenance

Weed cutting

Mainstone (1999, p.142) provides guidance on weed management in chalk rivers. He states that:

“Best practice for nature conservation purposes is to allow plant succession to progress as naturally as possible, starting with a mosaic of submerged plants (*Ranunculus* and other species) and bare gravel in spring and early summer, leading into progressive dominance by encroaching marginal vegetation with a central, strongly scoured channel and consequent decline in submerged growth in later summer. Good submerged plant cover in spring allows water levels to remain high, with the necessary hydrological contact between the river, its banks and riparian meadows at this critical time of year. Retention of considerable amounts of marginal growth in the late summer and autumn allows focused scouring in the main channel and protects banks against water erosion over the winter period.

In practical terms, the desired effect can be achieved by limiting the frequency and spatial intensity of management to the minimum necessary, and using cutting patterns that mimic the characteristic habitat mosaic and encourages a central low-flow channel. In most cases, land drainage and flood defence requirements can be satisfied by cutting no more than 30% of the channel width at any one time. Where increased water table levels and inundation of riparian meadows are acceptable, lighter weed cuts can be undertaken.

In terms of fishery requirements, adoption of the desired changes by fishery owners and angling clubs may rely on the challenge that such a new regime would present to angler skill. There will also be benefits in terms of improved mid-channel gravel scouring and consequently enhanced natural recruitment of salmonids". Cutting a central channel will also lead to a faster rate of berm development and will therefore assist in narrowing the channel to more natural dimensions. Access to the river can be improved by clearing bays and providing firm substrate.

Mainstone (1999, p.144) provides a 'best weed-cutting practice' check list for land drainage/flood risk management and for fisheries.

Silt removal

Mainstone (1999, p.146) provides guidance on silt removal in chalk rivers. He states that:

"Best practice for nature conservation is to retain silt beds where they form part of the natural mosaic of substrate types, typically associated with marginal vegetation in slack water. The occurrence of submerged plants that thrive in silty conditions, such as *Callitriche* spp., should not be taken as a signal that large-scale silt removal is required. Such species may be an important component of the diverse plant community characteristic of chalk rivers, and silt removal works should seek to maintain this diversity. Limited removal of plant roots and silt (across no more than half the channel width) to help define a low-flow self-scouring channel with wet margins," is suggested.

"If silt accumulation is a major problem across the whole channel, it is important to identify and control the sources … If the source is not dealt with, narrowed channel may not have the capacity to scour eventual loads. Where silt removal has been undertaken, some marginal siltbeds and emergent plants should always be retained, with works focusing on the middle part of the channel. Information on the location of priority species reliant on silty/sandy substrates should be gathered … so that particularly important areas are left untouched. Side channels and backwaters are important habitats at various stages of in-filling and should not be desilted without clear objectives and consideration of ecological impact".

Woody debris

Woody debris is described by Mainstone (1999) as a characteristic of natural chalk rivers. According to the Staffordshire Wildlife Trust (Managing Woody Debris in Rivers and Streams[20]), woody debris is a vital component of watercourses and its removal can severely degrade their health. The positive ecological contribution of large/coarse woody debris has often been overlooked or downplayed, while impacts on water flow and erosion have been misunderstood or exaggerated. Benefits of woody debris/coarse woody debris include:

- Additional stability of river banks and beds.
- Increased floodwater storage (regulates flow velocity).
- Habitat for fish (shelter, shade, food, spawning grounds and nursery areas).

[20] URL: **www.staffordshirewildlife.org.uk/reports.asp?ses=&pl=false**

- Creates niche habitats (adds complexity - pools, bars etc).
- Provides space and food for colonisation.
- Supports a diverse assemblage of invertebrates, including many scare or rare species.

However, large and coarse woody debris has often been removed from river channels, due to concerns that it will cause blockage or snag other debris and increase flood risk. Best practice is for woody debris be left in watercourses unless there is a strong case for removal or repositioning.

'Engineered log jams' have been successfully applied to numerous small river systems in America to restore damaged in-channel habitats and reconnect floodplains. According to the Scottish Environmental Protection Agency (SEPA), this indicates that similar approaches may offer viable solutions to river management issues in the UK (Richardson, 2005, RRC Newsletter). SEPA recently commissioned a review of engineered log jams technology in North America with a view to developing pilot projects in Scotland (Herrera Environmental Consultants, 2006). Obviously, this review is being carried out in the context of Scottish environments. However, some of its conclusions may be helpful in relation to the quite different conditions associated with lowland rivers. The findings of this review may prove useful to rehabilitation using woody debris in the River Wensum catchment.

As the underlying principle of the technology is stated as being 'biomimicry', or imitation of natural conditions, it relies strongly on an understanding of fluvial processes, disturbance regimes, historical change, riparian vegetation and site constraints. In their report, Herrera Environmental Consultants explain that there are many types of log dam structure and the selection of materials and architecture depends on the particular site, project goals, acceptable levels of risk, costs etc. Whilst their experience to date suggests that in certain circumstances engineered log dams can provide an economical method of managing woody debris and re-establishing important habitat elements, there are also situations where it would be inappropriate. Given that this engineered log dam technology is in its infancy in the UK, its use in the Wensum should be considered on a site-by-site basis, using adaptive management at a pilot site.

Monitoring

As discussed elsewhere in this report, monitoring should be seen as an essential element of the River Wensum Restoration Strategy for a number of reasons. These are summarised below. The River Restoration Centre recently held a workshop to discuss guidelines for project monitoring (December, 2006). They are keen that monitoring is seen as an integral part of restoration projects.

Developing new techniques

In the first instance, removal or lowering of water level control structures in the Wensum will be a complex process and will require innovative techniques. This is on account of the complex arrangement of channels and structures at mill sites, the extent of lowering required at the structures and the issue of dealing with silt that is currently accumulated upstream of the mills. The baseline conditions must be assessed prior to works commencing, and monitoring will be necessary during the works to check that there are no detrimental impacts up or downstream. It will highlight if there is a need for remedial action to be taken in affected areas.

Adaptive management

Before works commence, it is likely that a feasibility study will take place, followed by a detailed design. This process should identify many of the issues or problems that will be faced during the works. However, there will inevitably be additional issues that become apparent during the works, or due to changing circumstances. For this reason, monitoring is essential to advise when adaptive management is required. Lessons learnt can be taken into account when planning subsequent phases of river restoration.

Post project appraisal

Following restoration, monitoring should continue and should be used to check that the objectives of the project have been reached, as well as to continue to inform about impacts of the works elsewhere in the catchment and about the requirement for adaptive management.

Hankinson Duckett Associates produced a monitoring report for the Upper Kennet Rehabilitation Project (2004). Methods of monitoring included:

- Topographic surveys (assessing cross sectional change).
- Flow monitoring (especially of flow velocity).
- Macrophyte surveys (Joint Nature Conservation Committee method and Modified Mean Trophic Rank method).
- Macro-invertebrate surveys.
- Electro-fishing.
- Freeze core sampling (to examine the composition of the bed substrate).
- Redd (brown trout spawning sites) surveys.
- Water vole surveys.

One objective of the Kennet project was to report the success of different techniques, materials and monitoring programmes to further best practice. Hence, the lessons learnt during the Kennet study should be adopted during the restoration of the Wensum. Similarly, many published manuals of restoration techniques, including the River Restoration Centre Manual, provide useful case studies and a summary of subsequent site performance.

RRC audit

An audit of all restoration designs that have been carried out to date on the River Wensum is currently taking place by the RRC. The aim of the audit is to assess what has and has not worked and whether the objectives of the previous restoration attempts have been met.

Appendix 6 Extract from conservation objectives

Table F1 Site-specific definitions of favourable condition

Conservation Objective for this habitat type	To maintain the **freshwater habitats and species on the River Wensum SSSI** in favourable condition, with particular reference to relevant specific designated interest features. Favourable condition is defined at this site in terms of the following site-specific standards:
Site-specific details of any geographical variation or limitations (where the favourable condition standards apply).	
With regard to the Type III chalk river, it should also be noted that Norfolk has been overlain by deposits of boulder clays, sands and gravels, and as a consequence, the upper river is not a 'classic' chalk river. River restoration on these reaches should therefore aim to restore the river to a form characteristic of a chalk river in Norfolk.	
The headwater reaches tend to be fed by surface runoff rather than through springs directly from the chalk. As a consequence there are no winterbournes on the River Wensum. (N.B: Some of the tributaries arise on sands and gravels and therefore there is a baseflow component to flow - that is, not all the flow is direct run-off. Springs from the chalk tend to rise at the junction of the floodplain and valley sides. These are intercepted by drainage ditches, but can contribute significantly to flows in the river).	

Table F2 Site-specific standards defining favourable condition

Criteria feature	Attribute	Measure	Site-specific Targets	Comments	Use for CA?
Rivers	Habitat functioning: water quality	EA monitoring	**Suspended solids** No unnaturally high loads	Many characteristic species of different river types are susceptible to elevated solids levels, through reduced light availability (for photosynthesis), the clogging of respiratory structures, impaired visibility or siltation of coarse substrates. Lowland clay and alluvial river sections are more depositional in character and resident biota are generally more tolerant. Suspended solids measurements are also essential to the estimation of particulate loads within the river network (in combination with gauged flow data), to provide an indication of the risk of siltation. Targets should be set locally according to river type, catchment characteristics and an analysis of available data. The highest value that may be appropriate is 25 mg L-1 (annual mean), based on the EC Freshwater Fish Directive. Considering prevailing concentrations in most SSSI rivers, a more precautionary target of no more than 10mg L-1 is likely to be suitable for most river reaches. Targets of considerably less than 10 mg L-1 may be appropriate for some river sections where solids levels are currently very low (such as chalk streams through the growing season) - an analysis of available data is suggested to verify target selection. Through the targeting of agri-environment schemes, the Catchment Sensitive Farming Delivery Initiative for the Wensum catchment will address silt ingress resulting from arable farming practices and poaching by livestock. In addition to addressing soil erosion at source, action will be required to address the mechanisms by which silt laden runoff actually reaches the river, and the cooperation of Norfolk County Council in relation to the management of runoff will be an important element of the overall strategy to reduce the impacts of diffuse pollution.	Yes

Table Continued...

Criteria feature	Attribute	Measure	Site-specific Targets	Comments	Use for CA?
				The achievement of targets can only be truly assessed through continuous monitoring of turbidity on the main river. Monthly sampling is appropriate with regard to the evaluation of the impacts of turbidity in the water column, as the concern in this instance is chronic exposure, rather than the impact of transient events. However, exposure of substrates to impacts of turbidity is strongly related to deposition events linked to run-off events. This can be looked at via the condition of the substrate itself, or via water column suspended sediment concentrations, or both. For data on suspended sediment concentrations to allow an evaluation of impacts in relation to substrate condition, it is necessary to ensure that data is collected in relation to sediment concentrations during high flow events, and for this the most appropriate monitoring regime is the use of continuous turbidity monitoring or event-triggered auto-sampling. In the case of classic chalk streams, continuous monitoring is not deemed necessary. However, the River Wensum SAC is not a classic chalk stream, as the chalk is overlain by varying depths of gravels, sands, silts, crag and boulder clay and a monthly sampling regime would not be sufficient to assess the impacts on substrates. The Wensum Catchment Sensitive Farming Project will carry out continuous turbidity monitoring in the catchment, but this will be focussed on the tributaries that feed the main river from the target catchments and will not be carried out on the main river itself. The monitoring of sediment yields is desirable, as a means of characterising sediment delivery problems within the catchment. However, this would require a good understanding of the concentrations of solids during high flows, and continuous turbidity monitoring would be required.	

Table continued…

Criteria feature	Attribute	Measure	Site-specific Targets	Comments	Use for CA?
Rivers	Habitat structure: substrate	Field observations	**Siltation** No excessive siltation. Channels should contain characteristic levels of fine sediment for the river type.	Siltation levels vary naturally, depending upon the reach type and hydrodynamic regime. Most sites should have a variety of channel substrates. Localised accumulations of silt on the inside of bends or in back channels do not necessarily indicate a problem. However, widespread siltation of riverine sediments, caused by high particulate loads and / or reduced scour within the channel (due to artificial channel modifications such as weirs), is a major threat to the characteristic river habitat and associated flora and fauna. Many characteristic species of fish, invertebrates and even plants are susceptible to siltation at some stage in their life-cycle. Mechanisms of impact can relate to reduced interstitial spaces in coarse substrates, reduce water flow-through the substrate leading to poor quality of interstitial waters, and reduced sediment surface 'roughness' that eliminates refugia for animals with epibenthic habitats and prevents plant seeds and fragments from lodging in the substrate and taking root. For river types characterised by extensive *Ranunculus* beds, there should be a predominance of 'clean' gravels, pebbles and cobbles, with relatively low cover by silt-dominated substrates. Maximum fines content should not be too great to prevent establishment of new plants. Fines are defined as particles< 0.83 mm. Sources of silt include run-off from agricultural land, sewage and industrial discharges. A fluvial audit is recommended where specific problems have been identified, for example, where there is a perceived risk of damage occurring or where species characteristic of the habitat are already believed to be in decline. Fluvial audit is not a monitoring tool but can deliver an understanding of geomorphological problems unattainable by any other method, and help to discriminate between problems of sediment delivery and problems of channel structure.	Yes

Table continued...

Criteria feature	Attribute	Measure	Site-specific Targets	Comments	Use for CA?
				A Geomorphological Appraisal of the River Wensum SAC has been carried out, consisting of a detailed fluvial audit, geodynamic assessments and multi-criteria analysis. This has concluded that the high levels of silt in the river are derived from run-off from agricultural land, particularly in the headwater reaches, rather than erosion from the river banks or river bed	
Rivers	Habitat structure: channel and banks	Assess river morphology using RHS (**see text and Appendices 4 and 5 of the monitoring protocol for details**). In addition, for planform: map data, aerial survey data, historical records and local knowledge.	**Channel form** Channel form should be generally characteristic of river type, with predominantly unmodified planform and profile. For planform the target is a score for the assessment unit of at least 3 (**see Appendix 4 of the monitoring protocol**). For naturalness of the profile using transect data the target is a score for the assessment unit of 4 or 5 (**see Appendix 5 of the monitoring protocol**). No RHS site to have any of the eight categories of bank profile modification (Section I in RHS 2003 form) recorded as 'extensive'.	The river should support all of the habitat features necessary for characteristic flora and fauna to thrive, in characteristic proportions. Widening or deepening of channels, and extensive artificial reinforcement of banks, are indicators of unfavourable condition. Headwater sections are particularly vulnerable to reprofiling. Watercourses with a high degree of naturalness will be governed by dynamic processes which result in a variety of physical habitat features, including a range of substrate types, variations in flow, channel width and depth, in-channel and side-channel sedimentation features, erosion features and both in-channel and bankside vegetation cover. The new version of Habitat Modification Score (HMS) enables a more sophisticated assessment to be made, based on the nature of modifications to a river and their estimated persistence. Details are being finalised by the Environment Agency, but a guideline target might be 90% or more of condition monitoring sites should fall within the semi-natural HMS class 1, with the remainder predominantly unmodified (class 2).	Yes

Table continued...

Criteria feature	Attribute	Measure	Site-specific Targets	Comments	Use for CA?
				Physical targets will need to be adjusted to be compatible with the Wensum River Restoration Strategy which is being developed according to the draft Proposed Guidelines for the restoration of physical and geomorphological favourable condition on river SSSIs in England. In relation to channel form, the Geomorphological Appraisal of the River Wensum SAC has concluded that: • The gravel bed is a relic from higher energy flows during periglacial climatic conditions and once removed can not be reformed under current climatic conditions. • Over-deepening, over-widening and the impoundments upstream of mills have had a profound impact on geomorphological process. The Geomorphological Appraisal presents restoration options on a reach by reach basis. However, this needs to be developed into a River Restoration Plan for individual restoration schemes to be developed and taken forward. River Restoration Techniques appropriate for Type I and Type III rivers are presented in the notes section below. Water levels are inextricably linked with channel form. The Geomorphological Appraisal of the River Wensum SAC, and development of the River Wensum Restoration Strategy will be of assistance in reviewing and updating the WLMP for the River Wensum.	

Other notes

River Restoration Techniques appropriate for Type I - Lowland, low gradient rivers:

- **Reduced/modified channel maintenance operations**, to promote natural recovery of form and function.
- **Bank reprofiling** to improve the hydrological transition zone, for the benefit of characteristic riparian plants such as brooklime, water speedwells, water-cresses water-mint and marsh woundwort.
- **Removal/lowering of in-channel control structures**, to re-establish riffle habitat, restore characteristic water depths and allow free movement of fauna.
- **Remeandering or meander reconnection** to restore habitat length/area and improve flow, substrate and depth diversity, thereby provide improved habitat conditions to a wider range of fauna and flora.
- **Reinstatement of coarse bed material** for the benefit of riffle-dwelling fish and invertebrates, preferably using material reclaimed from the flood banks using grading machinery.
- **Introduction of large woody debris**, as part of bank re-profiling or as partial logjams, to restore diversity of substrate and water depth/velocity.
- **Removal/set-back of embankments** to restore hydrological continuity with the floodplain, allowing the recreation of wet grassland communities including breeding waders. (Note: There are few if any true flood banks on the Wensum, though deposited dredgings often effectively sever the connectivity between river and floodplain).
- **Riparian tree-planting** along stretches with no trees, to provide a beneficial mosaic of channel and riparian conditions and enhance the introduction of woody debris into the channel.

River Restoration Techniques appropriate for Type III - Chalk rivers and other base-rich rivers with stable flows:

- **Reduced/modified channel maintenance operations**, to promote natural recovery of form and function, particularly in respect of the seasonal encroachment of marginal vegetation and the establishment of woody debris in the channel.
- **Bank reprofiling** to improve the hydrological transition zone, for the benefit of characteristic riparian plants such as brooklime, water speedwells, water-cresses water-mint and marsh woundwort.
- **Removal/lowering of in-channel control structures**, to re-establish riffle habitat, restore characteristic water depths and current velocities, reduce siltation of gravel substrates and allow free movement of fauna.
- **Reinstatement of coarse bed material** for the benefit of riffle-dwelling fish and invertebrates, preferably using material reclaimed from historical spoil using grading machinery.
- **Introduction of large woody debris**, as part of bank re-profiling or as partial logjams, to restore diversity of substrate and water depth/velocity.
- **Remeandering or meander reconnection** to restore habitat length/area and improve flow, substrate and depth diversity, thereby providing improved habitat conditions to a wider range of fauna and flora.
- **Reconnecting the floodplain**, allowing the recreation of fen, carr and wet grassland communities.
- **Riparian tree-planting** along stretches with no trees, to provide a beneficial mosaic of channel and riparian conditions and enhance the introduction of woody debris into the channel.

Table F3 Site-specific definitions of favourable condition

Conservation Objective for this habitat type	To maintain the terrestrial compartments and adjacent bankside habitats of the SSSI so as not to negatively affect the functionality of the **freshwater habitats and species of the River Wensum SSSI** so as to ensure that they remain in favourable condition. Favourable condition is defined at this site in terms of the following site-specific standards:
Site-specific details of any geographical variation or limitations (where the favourable condition standards apply)	
These targets will be of assistance in drawing up the objectives for agri-environment schemes and for evaluating the management on areas covered by existing schemes, both on terrestrial units of the River Wensum SSSI, but also with regard to land on the floodplain.	

Table F4 Site-specific standards defining favourable condition

Criteria feature	Attribute	Measure	Site-specific Targets	Comments	Use for CA?
Rivers	Functionality of Terrestrial compartments.	Field observation.	The terrestrial unit is in hydrological continuity with the river.	Terrestrial compartments of the SSSI should be maintained in accordance with the 89 Guidelines.	Yes
			The terrestrial unit supports semi-natural vegetation.		Yes
			Management of the terrestrial units does not contribute to the unfavourable condition of the river units.	The management of the terrestrial components of the SSSI should not result in detrimental impacts with regard to the riverine interests of the River Wensum SSSI.	Yes
Rivers	Functionality of Terrestrial compartments and adjacent bankside habitats.	Field observation.	Management of the adjacent bankside and floodplain habitat, where not included within a terrestrial unit of the SSSI does not contribute to the unfavourable condition of the river units.	The management of floodplain habitats immediately adjacent to the SSSI boundary should not result in detrimental impacts with regard to the riverine interests of the River Wensum SSSI.	No

Audit trail

Rationale for limiting standards to specified parts of the site

None

Rationale for site-specific targets (including any variations from generic guidance)

- **Terrestrial Compartments of the River Wensum SSSI** - Although not part of the riverine interest of the site, the management of the terrestrial compartments of the SSSI and adjacent floodplain habitats should not negatively impact the riverine interest of the SSSI. Objectives for the terrestrial compartments of the SSSI should ensure that these areas continue to support semi-natural communities and remain hydrologically linked to the river as per the '89 Guidelines.
- **Bankside Habitats immediately adjacent to the River Wensum SSSI** - It should be noted that the management of all floodplain habitat immediately adjacent to the channel of the Type III river reaches of the River Wensum SSSI has potential impacts on the aquatic and emergent communities on the river. This has implications with regard to the targeting of future HLS schemes on the floodplain as whole, and also on the evaluation of management associated with existing agri-environment schemes. The Wensum Valley should be regarded as a key wildlife corridor in the Norfolk Ecological Network which is being developed by the Norfolk Biodiversity Partnership.

Rationale for selection of measures of condition (features and attributes for use in condition assessment)

- (The selected vegetation attributes are those considered to most economically define favourable condition at this site for the broad habitat type and any dependent designated species).

Other notes

N.B Where road run-off has been diverted off the road, through a terrestrial compartment, and straight into the river, the terrestrial unit should be regarded as being in unfavourable condition.

Appendix 7 SSSI citation (from Natural England web-site)

Date of Notification: 4 February 1993

COUNTY: **Norfolk**

SITE NAME: **RIVER WENSUM**

Status: Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act 1981, section 17 of the Water Resources Act 1991, Section 4 of the Water Industry Act 1991 and Section 13 of the Land Drainage Act 1991.

National Rivers Authority Region: Anglian

International Drainage Board: Norfolk Rivers

Water Company: Anglian Water Plc

Local Planning Authorities: North Norfolk District Council, Norfolk County Council, King's Lynn & West Norfolk District Council, South Norfolk District Council, Breckland District Council, Broadland District Council

National Grid Reference: TF 942246 to TG 250078

Length of River SSSI: Approx 71km **Area**: 393.31 (ha) 971.9 (ac)

Ordnance Survey Sheet 1:50,000: 132 133 134 1:10,000: TF 82 SE NE NW, TF 93

SE, TF 92 SE NE NW, TF 83 SE, TG 01 NE NW, TG 02 SW, TG 11 SE SW NW

Date of Notification (under 1981 Act): 1993

Other Information: New site

Description and Reasons for Notification:

Key features

The Wensum has been selected as one of a national series of rivers of special interest as an example of an enriched, calcareous lowland river. With a total of over 100 species of plants, a rich invertebrate fauna and a relatively natural corridor, it is probably the best whole river of its type in nature conservation terms, although short stretches of other similar rivers may show a slightly greater diversity of species.

The upper reaches are fed by springs that rise from the chalk and by run-off from calcareous soils rich in plant nutrients. This gives rise to dense beds of submerged and emergent vegetation characteristic of a chalk stream. Lower down, the chalk is overlain with boulder clay and river gravels, resulting in aquatic plant communities more typical of a slow-flowing river on mixed substrate. Diversity of plant species is further enhanced by mills and weirs; upstream the river slows to produce characteristic deep water plant communities, whilst below the barriers they are replaced by species tolerant of swirling and turbulent water.

Unusually for a lowland river in England, much of the adjacent land is still traditionally managed for hay crops and by grazing, giving a wide spectrum of grassland habitats some of which are seasonally inundated. The mosaic of meadow and marsh habitats, including one of the most extensive reedbeds in the country outside the Broads, provide niches for a wide variety of specialised plants and animals.

The river itself supports an abundant and diverse invertebrate fauna including the native freshwater crayfish *Austropotamobius pallipes* as well as a good mixed fishery. Brown trout *Salmo trutta fario* form the major component of the fish community of the upper Wensum, whilst the middle and lower reaches are dominated by chub *Leuciscus cephalus*, pike *Esox lucius*, eel *Anguilla anguilla* and barbel *Barbus barbus*. Kingfisher *Alcedo attthis* and little grebe *Tachybaptus ruficollis* breed along the river, whilst the adjacent wetlands have good populations of reed warblers *Acrocephalus scirpaceus*, sedge warblers *Acrocephalus schoenobaenus* and barn owls *Tyto alba*.

Flora

In the upper reaches on gravel substrates lesser water-parsnip *Berula erecta* and the brook water-crowfoot *Ranunculus penicillatus* form a large component of the flora. Where silt has been deposited, spiked water milfoil *Myriophyllum spicatum*, blue water-speedwell *Veronica anagalis-aquatica*, opposite leaved pondweed *Groenlandia densa*, willow moss *Fontinalis antipyretica* and the nationally rare short-leaved starwort *Callitriche truncate* occur.

The middle and lower stretches of the river are characterised by rich lowland plant communities. The dominants are yellow water-lily *Nuphar lutea*, flowering rush *Butomus umbellatus*, fennel pondweed *Potamogeton pectinatus*, perfoliate pondweed *Potamogeton perfoliatus*, arrowhead *Sagittaria sagittifolia* and unbranched bur-reed *Sparganium erectum*.

Variations in the aquatic plant community reflect the alternation of fast-flowing shallows with deep slow-moving water. Other species with widespread distribution along the Wensum include rigid hornwort *Ceratophyllum demersum*, spiked water-milfoil *Myriophyllum spicatum*, fan-leaved water-crowfoot *Ranunculus circinatus*, branched bur-reed *Sparganium erectum*, common club-rush *Scirpus lacustris*, horned pondweed *Zannichellia palustris* and the nationally scarce river water-dropwort *Oenanthe fluviatilis*. The marginal and bankside communities are typical of lowland rivers. Often there are dense and continuous stands of reeds or sedges. Reed sweet-grass *Glyceria maxima* is dominant in the lower reaches. Elsewhere stands of reed canary-grass *Phalaris arundinacea*, greater pond-sedge *Carex riparia*, reedmace *Typha latifolia* and common reed *Phragmites australis* are widespread. Where edges are not dominated by tall emergents, straggling or low growing herbs such as fool’s water-cress *Apium nodiflorum*, water-mint *Mentha aquatica*, water forget-me-not *Myosotis scorpioides* and brooklime *Veronica beccabunga* occur.

Of the semi-natural habitats associated with the river, the most frequently occurring are acidic or neutral unimproved wet grasslands. The flora of these grasslands is typified at Helhoughton and Turf Common by bogbean *Menyanthes trifoliata*, marsh marigold *Caltha palustris*, yellow rattle *Rhinanthus minor*, ragged robin *Lychnis flos-cuculi*, southern marsh orchid *Dactylorhiza praetermissa*, common spotted orchid *Dactylorhiza fuchsii*, water mint *Mentha aquatica* and yellow iris *Iris pseudacorus*.

Elsewhere the land is seasonally inundated so that grazing is restricted; extensive areas of reedbed and tall mixed fen communities have developed which provide valuable breeding and hunting grounds for birds such as the barn owl *Tyto alba* and hen harrier *Circus cyaneus*. Examples include Guist Common which is reed dominated; Goggs Mill Reserve near Fakenham which has a mixed fen community with species such as meadowsweet *Filipendula ulmaria*, angelica *Angelica sylvestris* and meadow rue *Thalictrum flavum*, and Sculthorpe Moor, which although gradually being invaded by willow *Salix* spp. scrub has a fen community of saw sedge *Cladium mariscus* and black bog-rush *Schoenus nigricans*.

Although there are several areas of alder swamp interspersed with the above communities, Guist Carr forms the main example of wet woodland within the SSSI. All of the habitats within the SSSI are intrinsically linked to and dependent on the river for their continued existence. Appropriately, in times of drought, these adjacent wetlands have a vital role in buffering the river against low flows; in wetter periods they absorb river flood waters and become swamp-like in nature.

Two tributaries have been included in the SSSI, the Tat and the Langor Drain. They are both major flow contributors to the main river; historically, the Tat may have been the original Wensum. The Langor valley comprises an extensive area of semi-natural habitat which is dominated by fen vegetation. The specific composition ranges from almost exclusively reed to a mixture of meadowsweet and sedge species. Parts of Little Ryburgh Common are grazed, having bittersweet *Solanum dulcamara*, branched bur-reed *Sparganium erectum*, water cress *Rorippa nasturtium-aquaticum*, greater tussock sedge *Carex paniculata*, lesser water parsnip *Berula erecta*, water mint *Mentha aquatica*, and marsh marigold *Caltha palustris* as elements in their flora. The vegetation of the drier areas of Little Ryburgh Common includes bracken *Pteridium aquilinum*, honeysuckle *Lonicera periclymenum*, field scabious *Knautia arvensis*, harebell *Campanula rotundifolia* and soft rush *Juncus effusus*.

Invertebrates

The Wensum has an abundant and diverse mollusc fauna which includes the nationally rare, small snail *Vertigo moulinsiana*, which is associated with aquatic vegetation at the river edge. Two other aquatic molluscs which occur, *Valvata piscinalis* and *Gyraulus albus*, have a localised distribution in England. Water beetles are well represented; *Brychnus elevatus*, of localised distribution in England, is found in deep slow-flowing sections of the river. The mayflies *Ephemerella ignita*, *Caenis luctuosa*, *Centroptilium luteolum* and *Centroptilium pennulatum* are also of local distribution. There is a species of stonefly, *Amphinemura standfussi*, more usually associated with upland rivers. The flatworm *Crenobia alpina* is of note, being a relict in southern England where it is confined to cold-water springs.

Appendix 8 SAC designation

UK SAC data form

NATURA 2000

STANDARD DATA FORM

FOR SPECIAL PROTECTION AREAS (SPA)
FOR SITES ELIGIBLE FOR IDENTIFICATION AS SITES OF COMMUNITY IMPORTANCE (SCI)
AND
FOR SPECIAL AREAS OF CONSERVATION (SAC)

1. Site identification:

1.1 Type B

1.2 Site code UK0012647

1.3 Compilation date 200103

1.4 Update

1.5 Relationship with other Natura 2000 sites

1.6 Respondent(s) International Designations, JNCC, Peterborough

1.7 Site name River Wensum

1.8 Site indication and designation classification dates

date site proposed as eligible as SCI	200103
date confirmed as SCI	
date site classified as SPA	
date site designated as SAC	

2. Site location:

2.1 Site centre location

longitude	latitude
00 59 38 E	52 43 04 N

2.2 Site area (ha) 381.74

2.3 Site length (km)

2.5 Administrative region

NUTS code	Region name	% cover
UK402	Norfolk	100.0%

2.6 Biogeographic region

Alpine	Atlantic	Boreal	Continental	Macaronesia	Mediterranean
	√				

3. Ecological information:

3.1 Annex I habitats

Habitat types present on the site and the site assessment for them:

Annex I habitat	% cover	Representativity	Relative surface	Conservation status	Global assessment
Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation	20	B	C	B	**B**
Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*	0.5	D			
Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion alvae*)	0.5	D			

3.2 Annex II species

	Population				Site assessment			
	Resident	Migratory						
Species name		Breed	Winter	Stage	Population	Conservation	Isolation	Global
Vertigo moulinsiana	Common	-	-	-	C	B	C	**C**
Austropotamobius pallipes	Common	-	-	-	C	B	B	**B**
Lampetra planeri	Common	-	-	-	C	B	C	**C**
Cottus gobio	Common	-	-	-	C	B	C	**C**

4. Site description

4.1 General site character

Habitat classes	% cover
Marine areas. Sea inlets	
Tidal rivers. Estuaries. Mud flats. Sand flats. Lagoons (including saltwork basins)	
Salt marshes. Salt pastures. Salt steppes	
Coastal sand dunes. Sand beaches. Machair	
Shingle. Sea cliffs. Islets	
Inland water bodies (standing water, running water)	42.0
Bogs. Marshes. Water fringed vegetation. Fens	12.0
Heath. Scrub. Maquis and garrigue. Phygrana	
Dry grassland. Steppes	
Humid grassland. Mesophile grassland	40.0
Alpine and sub-alpine grassland	
Improved grassland	
Other arable land	
Broad-leaved deciduous woodland	6.0
Coniferous woodland	
Mixed woodland	
Non-forest areas cultivated with woody plants (including orchards, groves, vineyards, dehesas)	
Inland rocks. Screes. Sands. Permanent snow and ice	
Other land (including towns, villages, roads, waste places, mines, industrial sites)	
Total habitat cover	**100%**

UK SAC data form

4.1 Other site characteristics

Soil & geology:

Alluvium, Basic, Clay, Neutral, Nutrient-rich, Peat, Sand, Sedimentary

Geomorphology & landscape:

Floodplain, Lowland, Valley

4.2 Quality and importance

Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation

- for which this is considered to be one of the best areas in the United Kingdom.

Vertigo moulinsiana

- for which the area is considered to support a significant presence.

Austropotamobius pallipes

- for which this is considered to be one of the best areas in the United Kingdom.

Lampetra planeri

- for which the area is considered to support a significant presence.

Cottus gobio

- for which the area is considered to support a significant presence.

4.3 Vulnerability

A stepped profile, with alternating fast- and slow-moving reaches, was imposed on the river with the construction of water-mills. Habitat diversity has been reduced by the modification of the channel form.

The input of silt and agricultural chemicals as a result of arable farming practices are a concern and the reversion of arable fields to low-input grassland should be encouraged. A strategy should be devised for silt management in the river and catchment to minimise disturbance to the channel and bankside. Further development on the flood plain might alter the flow regime of the river.

More detailed studies on groundwater resources should be carried out so as to determine suitable flow objectives to ensure that the river's ecology is not threatened by water abstraction. At adjacent sewage treatment works, phosphorous removal will be a statutory requirement by 2004. However, a holistic strategy is needed to identify further mechanisms for the control of eutrophication.

Any increase in the distribution of *Pacifastacus leniusculus* within the catchment would threaten the long-term viability of *Austropotamobius pallipes*. Populations of *Lampetra planeri* and *Cottus gobio* are dependent on the maintenance of riffle habitats and might also be vulnerable to the introduction of non-native fish species. Populations of *Vertigo moulinsiana* are susceptible to interference with the emergent bank-side vegetation in which they occur.

5. Site protection status and relation with CORINE biotopes:

5.1 Designation types at national and regional level

Code	% cover
UK04 (SSSI/ASSI)	100.0

Figure H1 NATURA 2000 Standard Data Form

Appendix 9 European features - preferences

Annex I habitats that are a PRIMARY reason for SAC designation

3260 "Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation (CB)"

Watercourses characterised by this habitat form a priority habitat of international importance. Concern has been increasing about recent declines in macrophyte diversity in European rivers and plant species associated with this habitat.

This habitat is characterised by the abundance of water-crowfoots *Ranunculus* spp., subgenus *Batrachium (Ranculus fluitans, R. penicillatus* ssp. *penicillatus, R. penicillatus* ssp. *pseudofluitans* and *R. peltatus* and its hybrid). Floating mats of these white-flowered species are characteristic of channel in early to mid-summer. They may modify water flow, promote fine sediment deposition and provide shelter and food for fish and invertebrate animals.

The definition of watercourses characterised by this habitat is very wide. In practice, it covers the majority of rivers and streams with aquatic plant communities of note. There are several variants of this habitat in the UK, depending on geology and river type. In each, *Ranunculus* species are associated with a different assemblage of other aquatic plants. Three main sub-types are defined by the dominant species in the *Ranunculus* community and substrate.

The **River Wensum** is sub-type 1 (CB1), which is found on rivers on chalk substrate and is characterised by water-crowfoot species (*Ranunculus* spp.):

- Pond water crowfoot (*R. peltatus*) in spring-fed headwater streams (winterbournes).
- Stream water crowfoot (*R. penicillatus*) in middle reaches (dominant species in the Wensum).
- River water crowfoot (*R. fluitans*) in downstream sections.

It is also typically associated in the upper and middle reaches with starwort species (*Callitriche obtusangula* and *C. platycarpa*). This sub-type has a limited distribution in the UK and, therefore, they receive particular attention during SAC site selection.

Preferences[21]

"The occurrence of the Ranunculus suite of species is dependent on the geomorphology of the river (flow, substrate and channel morphology), and is influenced by factors such as water quality and climatic cycles."

- It is adversely affected by nutrient enrichment (sewage input and agricultural), siltation, reduced flows and unsympathetic engineering works.
- Unnaturally low flows and low velocities can have adverse effects on *Ranunculus* communities.
- Water-crowfoot is adversely affected by nutrient enrichment (sewage inputs/agriculture), siltation and is vulnerable to artificial reductions in flows.
- Its occurrence with associated species (for example, water starworts) is regarded as important in terms of conserving characteristic plant communities.

[21] Natural England. IN114, *Monitoring Ranunculion fluitantis and Callitricho-Batrachion Vegetation Communities*. 2003.

Annex II species that are a PRIMARY reason for SAC designation

White-clawed crayfish (*Austropotamobius pallipes*)

The white clawed crayfish lives in a diverse variety of clean aquatic habitats but especially favours hard water streams and rivers. It is widespread in most parts of England. A significant part of the EU resource is found in the UK but the species is now seriously threatened over most of its UK range.

Habitat preferences[22]

- The most severe threat to this species (including in the Wensum channels) is the non-native American signal crayfish, which are larger, more aggressive and the carrier of the 'crayfish plague'.
- White-clawed crayfish are often associated with overhanging bank sections (which exhibit heterogeneous flow patterns and provide ideal nesting/nursery sites), gravel/boulder beds and watercourses with depth ranging between 0.75-1.25m.
- Populations may also occur in very shallow streams (0.05m depth, although low water levels increase vulnerability to predation) and in deeper, slow-flowing rivers (2.5 m depth).
- Although populations occur both in still and running water, standing waters are becoming more important habitats as alien crayfish expand in running waters. Where flow is strong, these crayfish require suitable refuges such as weirs and boulders.
- In-stream rocks, riffles, organic debris (for example, large-woody debris (LWD) and leaf litter) and macrophytes are required for refuge and for food. Tufa deposits associated with organic material in calcareous catchments are important food sources during moulting.
- Flow conditions which affect bankside vegetation and submerged plant communities may have indirect consequences to white-clawed crayfish.
- Increased silt loads (and turbidity) caused by land practices or flow changes (natural and induced) can clog the gills of crayfish.

Annex II species that are a QUALIFYING feature but not a primary reason for SAC designation

Desmoulin's Whorl Snail[23] (*Vertigo moulinsiana*)

Physical Habitat Preferences

- Groundwater levels need to remain close to the surface to ensure moist conditions, at least during summer periods. However, aquatic plants (for example, watercress) may take over if conditions become too wet which is undesirable for the snails.
- In periods of high flow, the snail may be able to colonise new areas by floating downstream.
- Heavy cattle trampling is undesirable (this is most likely a particular problem where cattle have easy access to the channel).
- Desmoulin's whorl snail requires unbroken stands of tall grasses, sedges and reeds that usually stand in shallow water (for example reed sweetgrass *Glyceria maxima* and/or greater pond sedge *Carex riparia*, and/or lesser pond sedge *C. acutiformis*). Regular mowing/cutting/grazing is detrimental.
- Shading vegetation (that is, trees and scrub) should not become dominant or dry out the ground. English Nature recommends that less than 10% of a habitat suitable for the snail should remain in deep shade, and less than 30% in dappled shade. Light, patchy cattle grazing may be acceptable as a way of limiting scrub encroachment.

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[22] URL: **www.ukbap.org.uk/UKPlans.aspx?ID=124** and Natural England. IN101, *Ecology of the White-Clawed Crayfish*. 2003.
[23] URL: **www.ukbap.org.uk/UKPlans.aspx?ID=629** and Natural England. IN105, *Ecology of Desmoulin's Whorl Snail*. 2003.

Brook Lamprey[24] (*Lampetra planeri*)

(Freshwater, Non-migratory, primitive jawless fish.)

Physical habitat preferences

- Eggs are laid on clean gravel substrates (in shallow depressions formed by the adult lamprey), and the ammocoetes (larval stage) drift/swim downstream to silt deposits in still waters into which they burrow and lay dormant for a number of years. Emergent adults swim back upstream to spawning ground, although they do not migrate far from their natal site, and so having spawning and nursery habitats in close proximity to each other is important for their success.
- Weirs and impassable structures may act as barriers for ammocoetes drifting downstream and adults migrating upstream, as well as re-colonisation.
- Studies on the River Avon suggest that macrophyte encroachment and the reduction of flow velocities may be detrimental to the lampreys. De-silting and vegetation removal may improve re-colonisation potential.
- Low velocities are required in localised areas for the deposition of nursery habitat. However, where low flows result in reduced mid-channel velocities, spawning beds may become clogged with silt.
- Channel re-sectioning, re-profiling, dredging, and narrowing, that reduce variations in microhabitat, should be avoided.
- Submerged, floating and emergent vegetation helps create and maintain nursery habitat by trapping silt, acts as a source of organic matter (ammocoete food), and can locally increase current velocities in spawning gravels. Cutting/removal of aquatic vegetation (including communities of *Ranunculus* species, see above) should be minimised.
- Ammocoetes show an aversion to high levels of light (photophobia). Shade from bankside trees and riparian vegetation is therefore important.

Bullhead[25] (*Cottus gobio*)

- Siltation over coarse substrates due to changes in flow regime or sediment supply and transport rates reduces viability of spawning nests (by reducing aeration) and may affect the type and abundance of invertebrate food sources.
- Bullhead prefer moderate velocities, and can become displaced from their home territory by high flow events without adequate refuge (for example, cobbles, side channels, slack water, pools, woody debris, submerged tree root systems and marginal vegetation).
- A diversity of flow characteristics should be maintained to provide suitable habitat for all life stages of bullhead. In particular, moderate flowing riffles and slack water refuges are thought to be important.
- A natural sinuous channel form with associated pools and riffles provides the necessary substrate and flow for bullhead, and will support greater densities of bullhead than in modified rivers (widened, deepened and/or straightened channels have reduced habitat heterogeneity).
- Submerged plants, including *Ranunculus* species characteristic of the Wensum habitat sub-type, are likely to be of value for refuge and cover against predators. ‘Cutting operations or other perturbing activities should leave a significant proportion of vegetation in a mosaic pattern with clean gravel in-between’.
- Structures over 20 cm high, where no bypass route exists, are potential barriers to migration. This may be a significant problem on the Wensum considering its high degree of regulation.

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[24] Natural England. IN104, *Ecology of the River Brook and Sea Lamprey*. 2003.
[25] Natural England. IN103, *Ecology of the Bullhead*. 2003.

Appendix 10 Impact of restoration works on IDB drainage and flooding in rural settlements

The engineering works of dredging and widening carried out in the post war period were designed to lower river levels and improve drainage. Concern was expressed by the IDB that higher water levels in the main river due to the restoration could seriously affect the drainage network and might increase flood risk at villages served by the IDB.

To give an indication of potential changes, the drainage from Reepham and Foulsham were considered and the potential backwater effects in drains in the Lyng area were modelled as illustrative examples.

There was not any detailed information or survey of drains but drain sizes can be estimated and the long section generated by consideration of the land levels along the route of the drain.

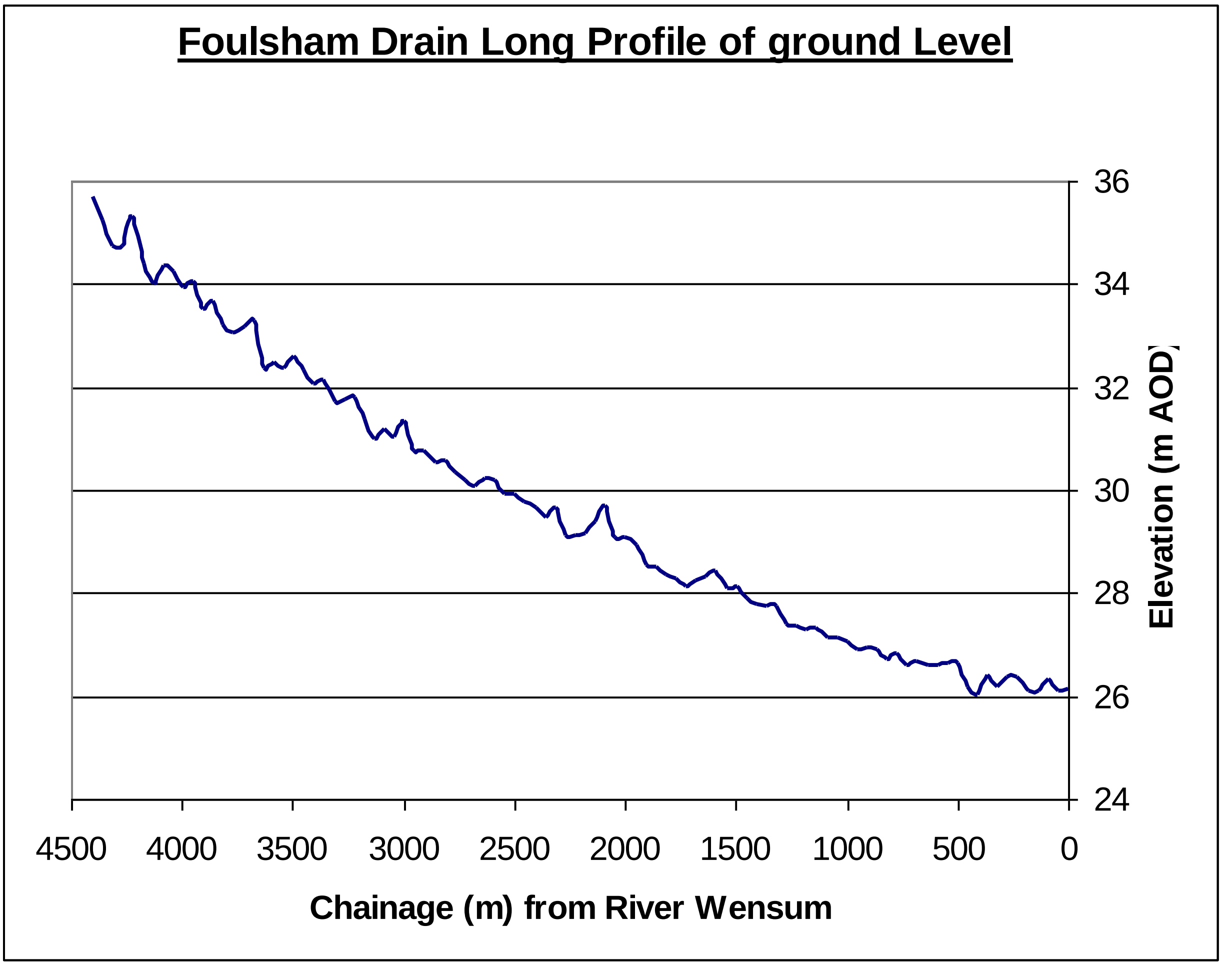


Figure I1 Long profile of ground along route of IDB drain to Foulsham

Although the topography of the area is of a flat valley bottom, most settlements served by the IDB drainage system away from the river are at slightly higher elevations as shown by the example of Foulsham and Reepham.

The influence of a potential change in River Wensum flood levels of at most the order of 0.5m (due to bed raising and narrowing) at the discharge point of the drain on the settlements can thus be illustrated by backwater analysis.

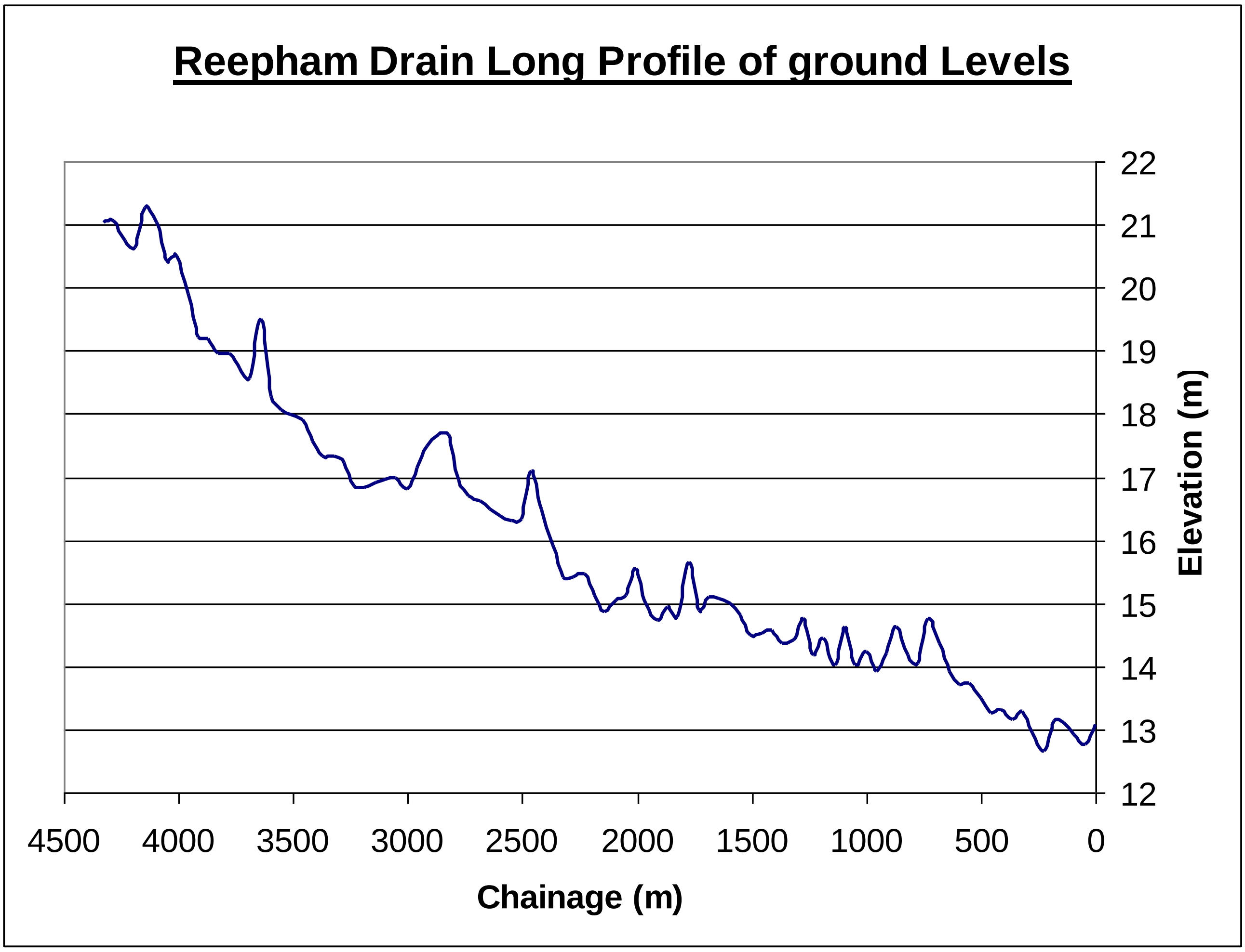


Figure I2 Long profile of ground along route of IDB drain to Reepham

The drain bed levels and top widths were available from an EA survey near to Lyng. From this information a small hydraulic model was built and the effect of changing water levels in the River Wensum simulated for a high ‘in bank’ flow in the drain. The location of these drains is indicated Figure I3. It can be seen that the drain to the south of the main channel drains the urban part of Lyng whereas to the north, drain of agricultural land predominates and the drain continues parallel to the main river (but with lower water levels). The drainage network is dendritic and many smaller drains connect with the larger collectors that discharge into the Wensum downstream of Lyng mill. Scour pools are seen downstream of sluices and the drain to the north of the main river increases significantly in size after the first sluice connection from the River Wensum.

The effect of the restoration will be to increase water levels where shallowing dominates and in more limited lengths to lower levels where ponding has been decreased close to mills. The drains generally discharge downstream of mills and thus in lengths where increased water levels would be expected. During high floods changes in water level may not be large but during normal conditions water levels could be increased by a similar amount to the bed raising. Thus the effect of raising the main river water levels was tested to demonstrate typical effects using a hydraulic model based on the IDB channel data presented in Figure I3. For typical high in bank drain flows the discharge level was estimated for current conditions in the River Wensum and for the future conditions with restoration. Applying this to the drain the results are shown in Figures I4 and I5. Both of the drains have high water level gradients as they approach the Wensum and thus the backwater effect is limited in both cases.

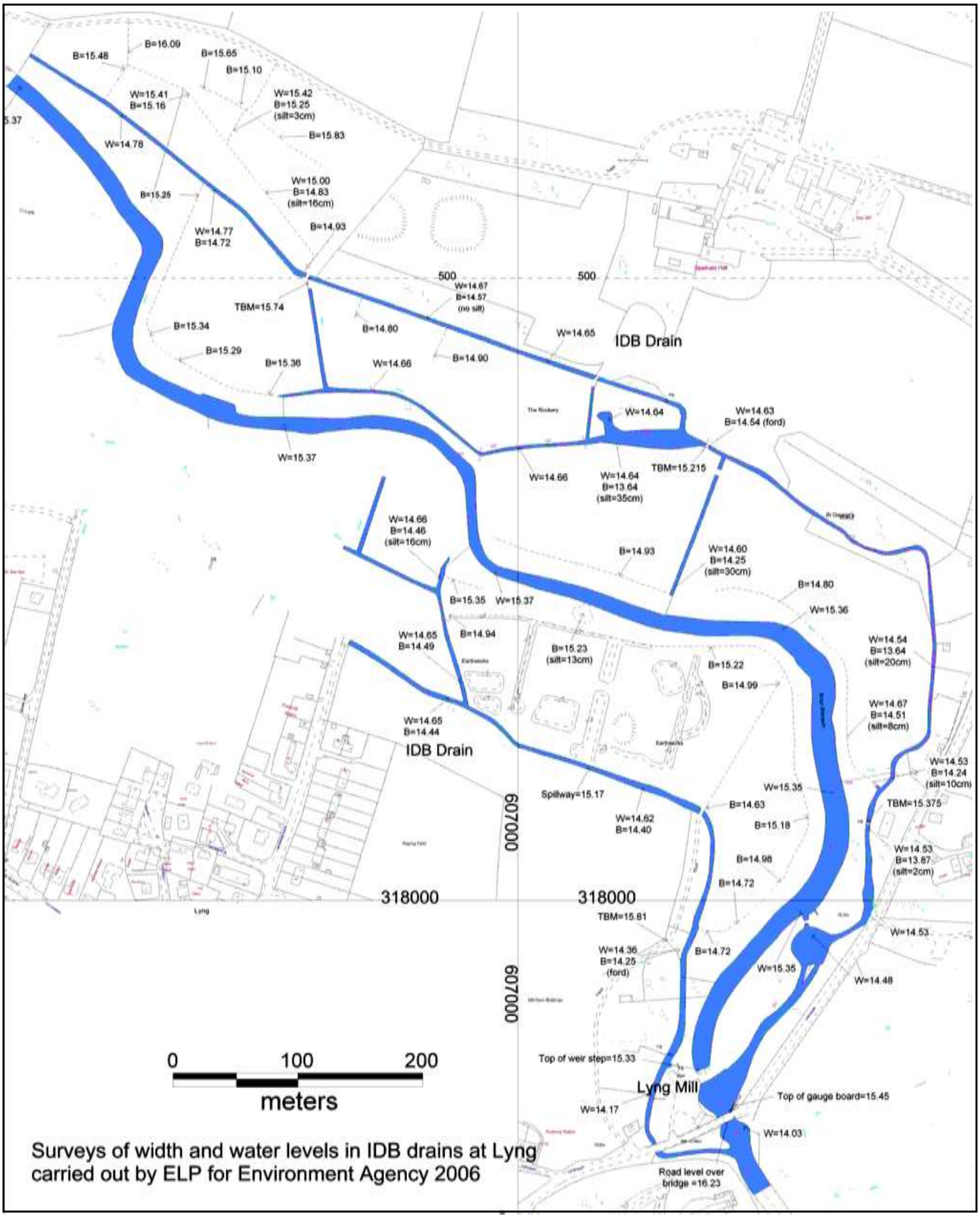
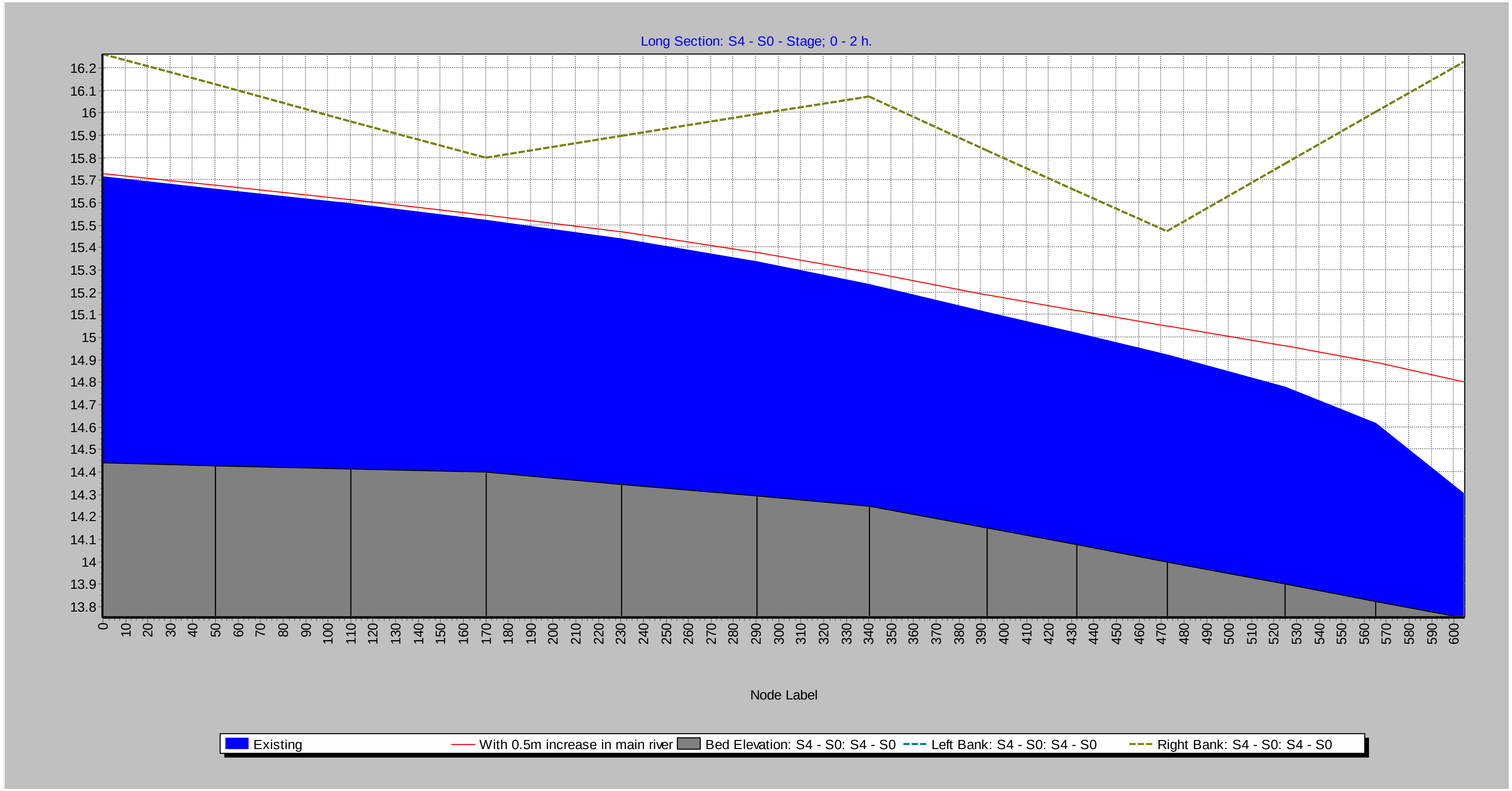


Figure I3 IDB Drains survey at Lyng by ELP in 2006 showing drain widths and water levels



Solid colouring indicates current condition and the red line the water level with the restoration of the river in place.

Figure I4 Sensitivity of IDB drain water level (South channel at Lyng) to an increase in water level at the discharge point to the River Wensum

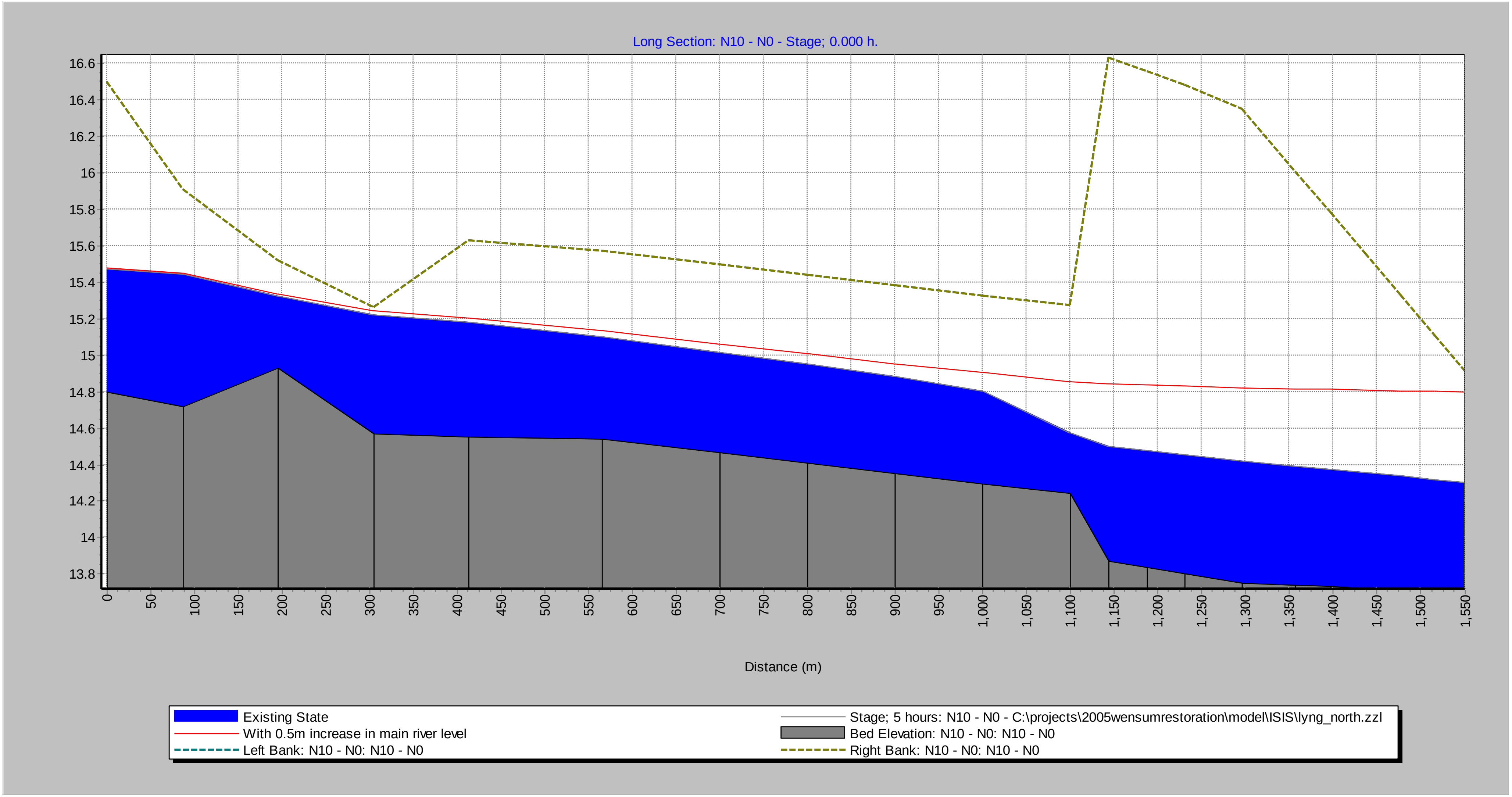


Figure I5 Sensitivity of IDB drain water level (North channel at Lyng)

Appendix 11 A4 maps of river sections

North

[Scale 1:220,000 at A4]

LEGEND

River Wensum catchment

River Wensum channel

Reach dividers and code — No.

Backwater upstream of mill

Mill — ★ Name

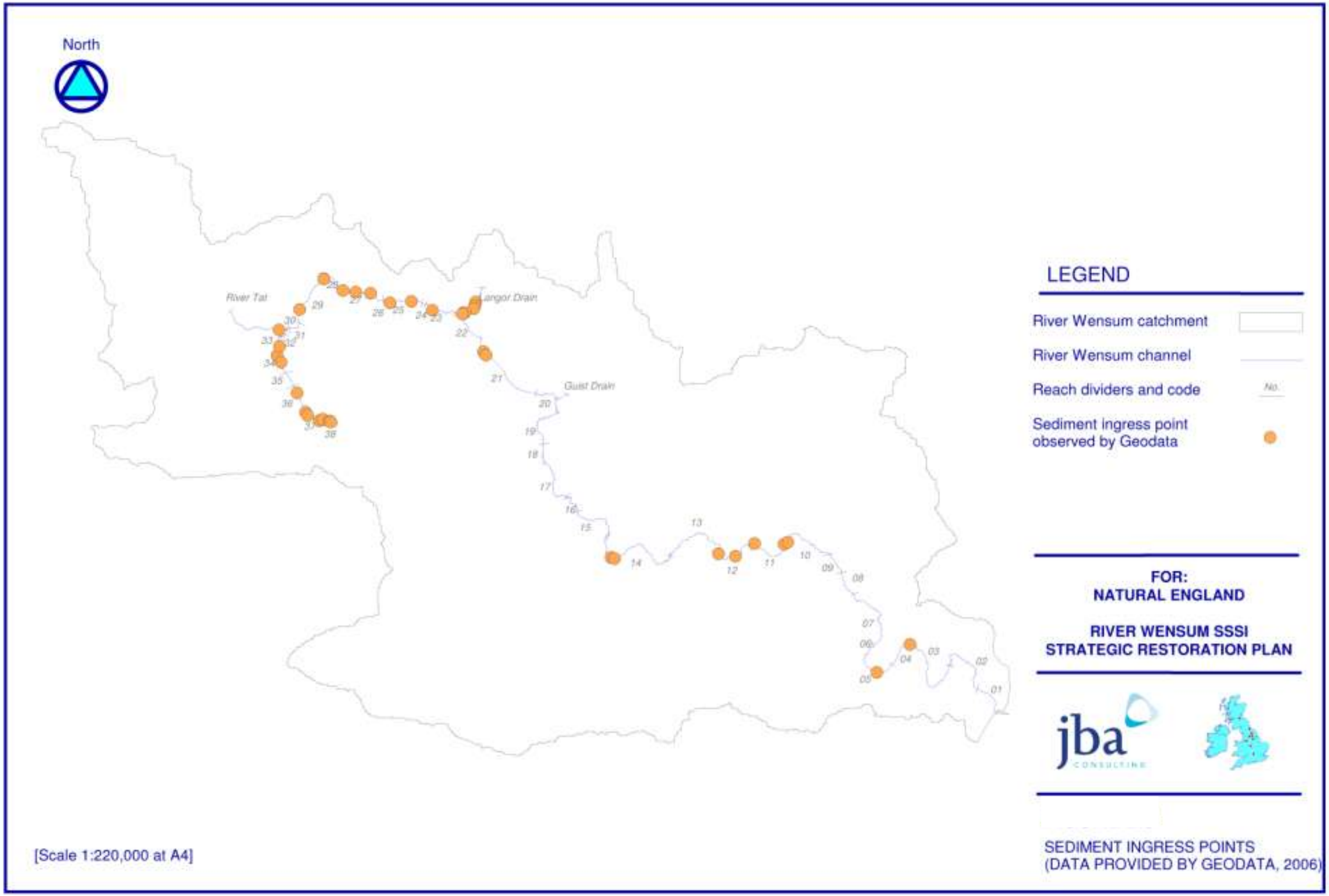
FOR:
NATURAL ENGLAND

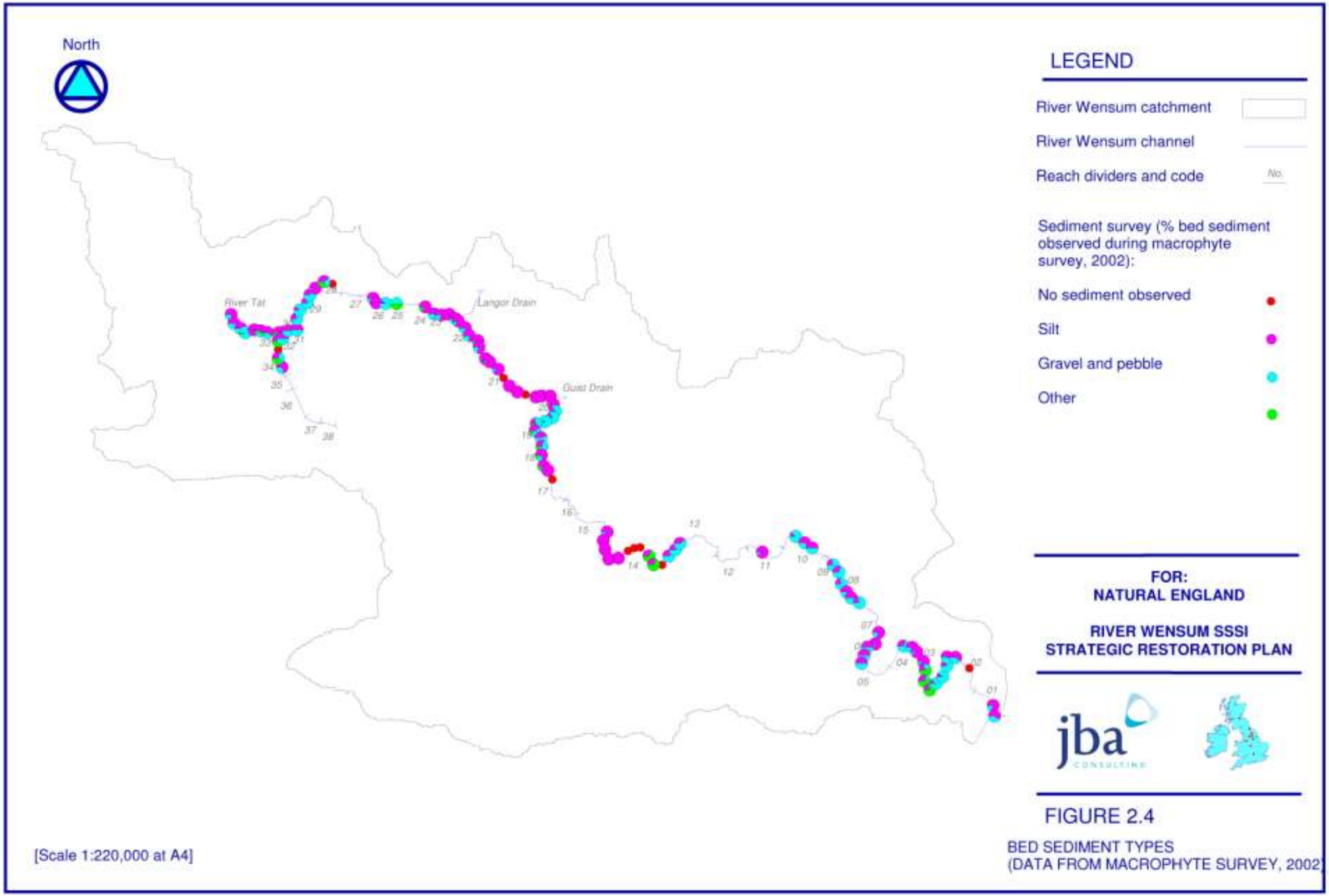
RIVER WENSUM SSSI
STRATEGIC RESTORATION PLAN

jba consulting

FIGURE 2.2

EXTENT OF BACKWATER EFFECT AT MILLS


North
River Tat
angor Drain
Guist Drain
LEGEND
River Wensum catchment
River Wensum channel
Reach dividers and code
No.
Sediment ingress point observed by Geodata
FOR:
NATURAL ENGLAND
RIVER WENSUM SSSI
STRATEGIC RESTORATION PLAN
jba
SEDIMENT INGRESS POINTS
(DATA PROVIDED BY GEODATA, 2006)
[Scale 1:220,000 at A4]

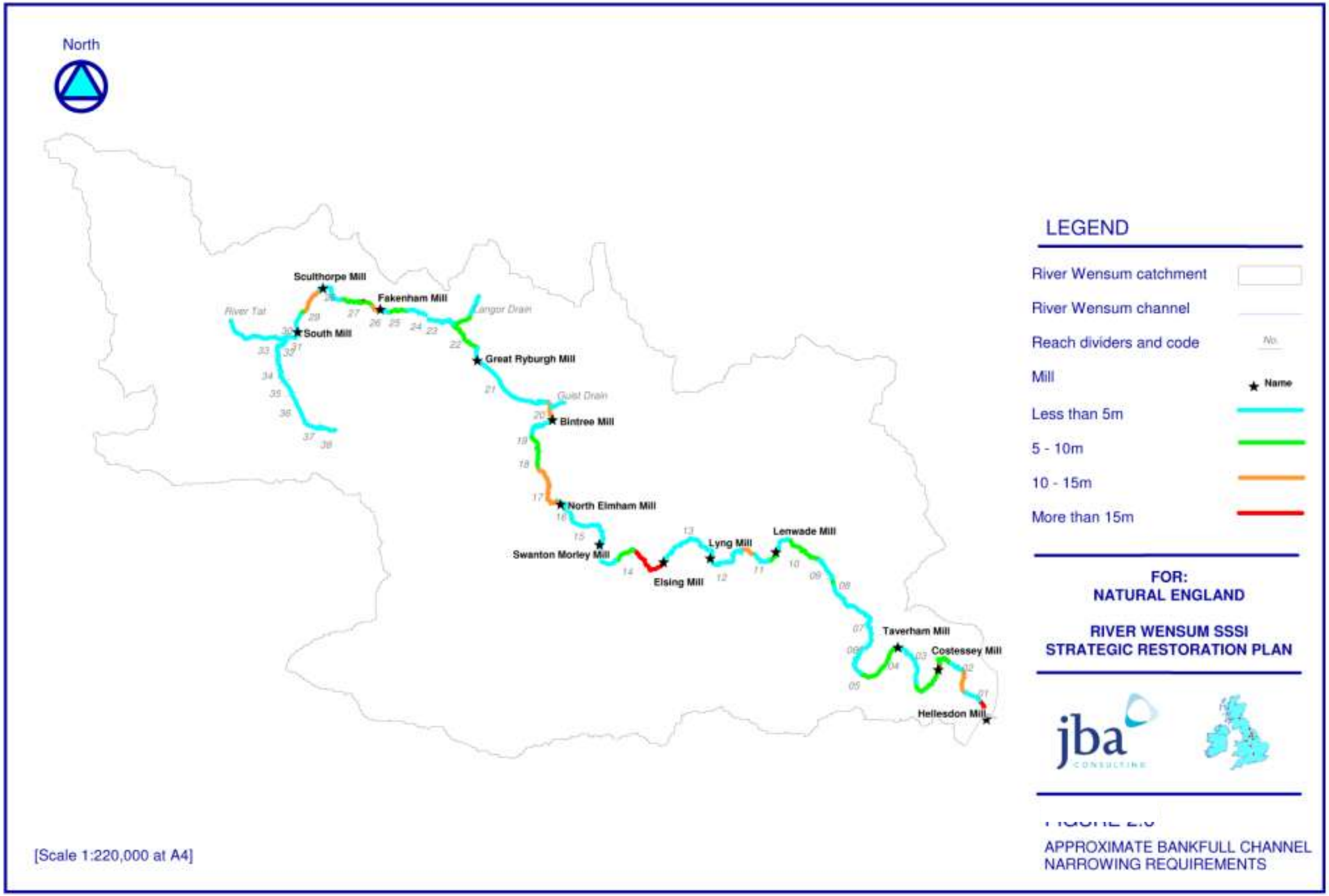


FOR:
NATURAL ENGLAND

RIVER WENSUM SSSI
STRATEGIC RESTORATION PLAN

FIGURE 2.4

BED SEDIMENT TYPES
(DATA FROM MACROPHYTE SURVEY, 2002)



APPROXIMATE BANKFULL CHANNEL NARROWING REQUIREMENTS

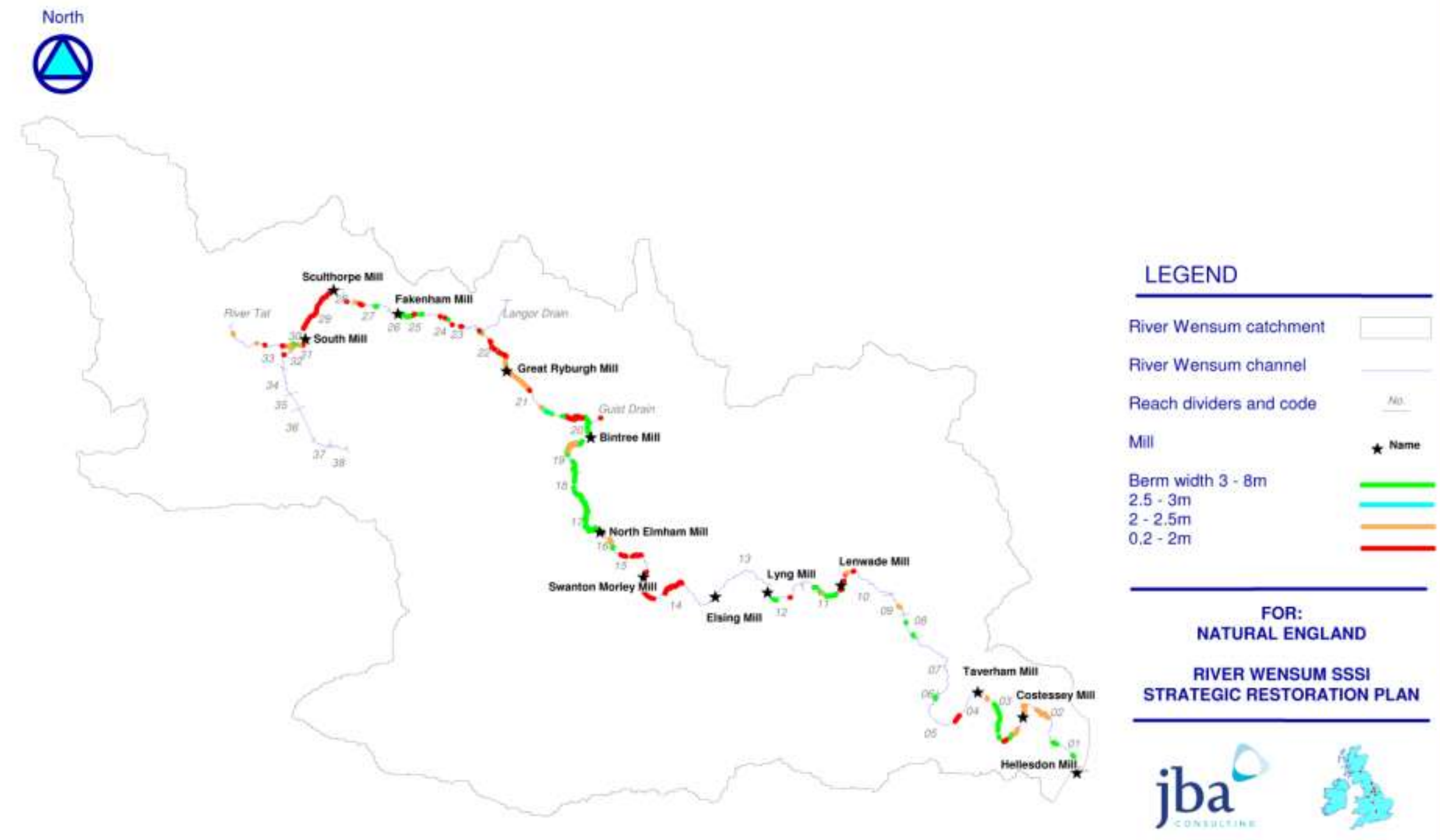
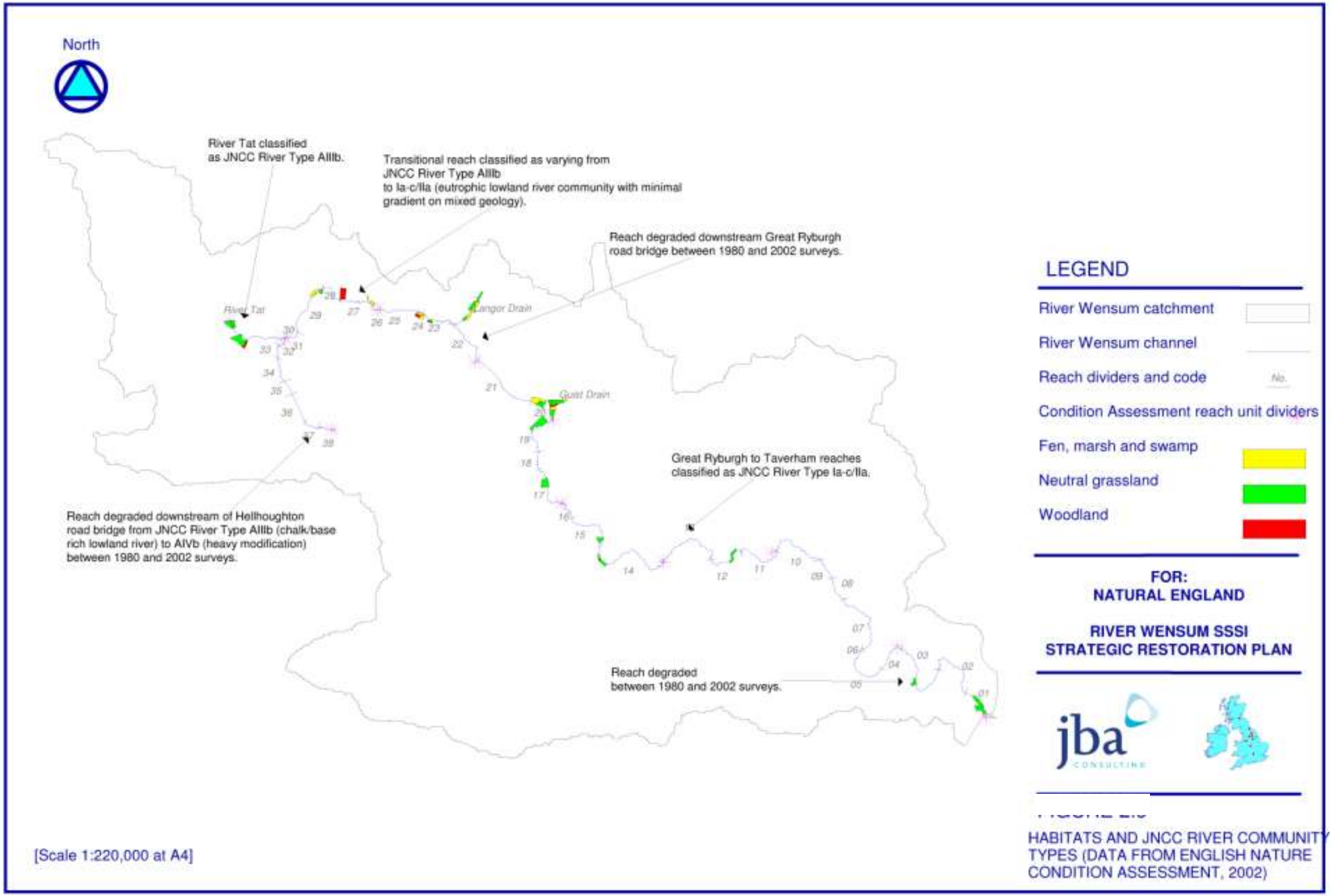
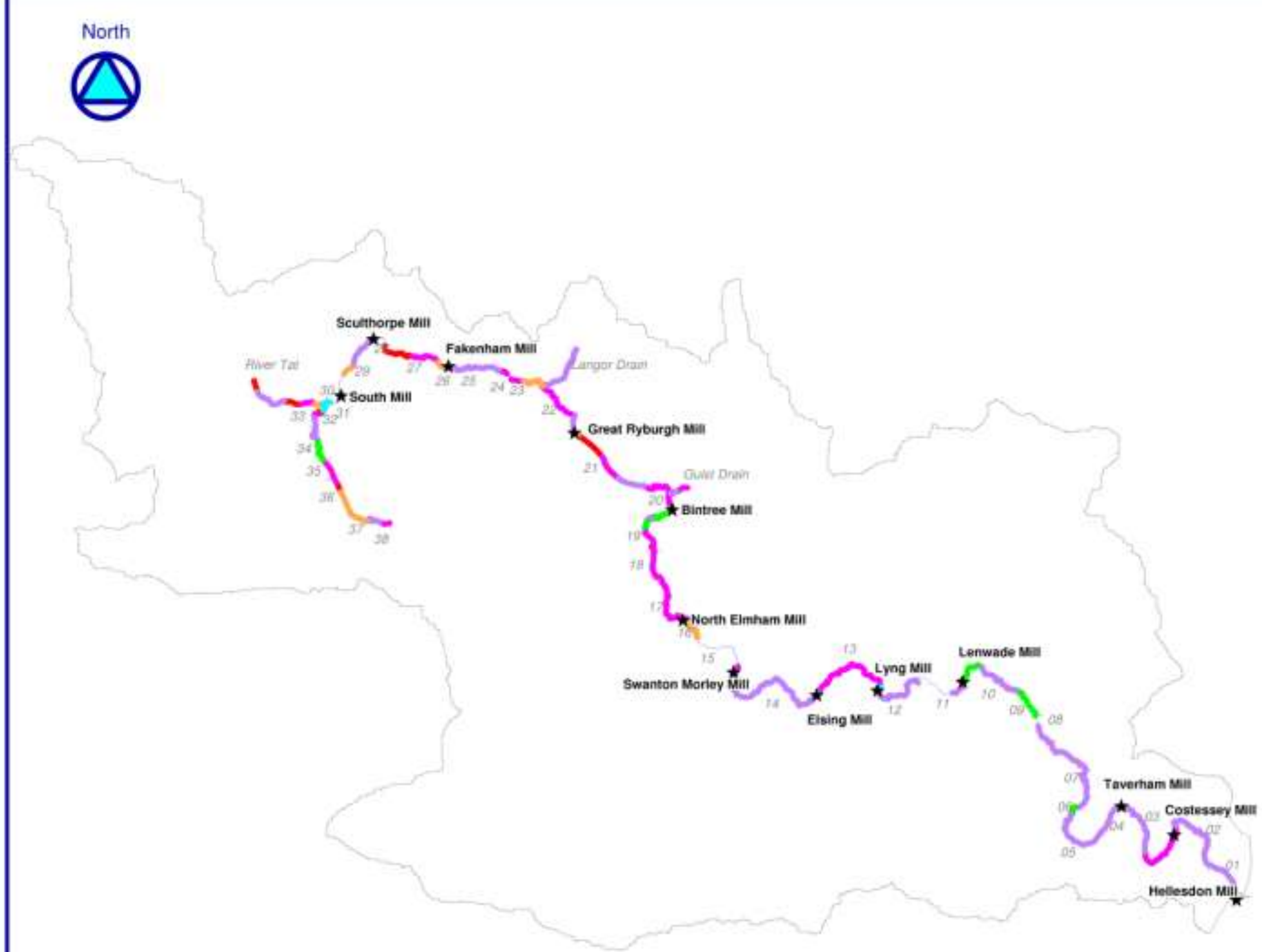


FIGURE 2.7

WIDTH OF VEGETATED SEDIMENT BERMS (DATA FROM GEODATA, 2006)

[Scale 1:220,000 at A4]


North
River Tat classified as JNCC River Type AIIIb.
Transitional reach classified as varying from JNCC River Type AIIIb to Ia-c/IIa (eutrophic lowland river community with minimal gradient on mixed geology).
Reach degraded downstream Great Ryburgh road bridge between 1980 and 2002 surveys.
River Tat
Langor Drain
Guist Drain
Great Ryburgh to Taverham reaches classified as JNCC River Type Ia-c/IIa.
Reach degraded downstream of Hellhoughton road bridge from JNCC River Type AIIIb (chalk/base rich lowland river) to AIVb (heavy modification) between 1980 and 2002 surveys.
Reach degraded between 1980 and 2002 surveys.
LEGEND
River Wensum catchment
River Wensum channel
Reach dividers and code
Condition Assessment reach unit dividers
Fen, marsh and swamp
Neutral grassland
Woodland
FOR:
NATURAL ENGLAND
RIVER WENSUM SSSI
STRATEGIC RESTORATION PLAN
HABITATS AND JNCC RIVER COMMUNITY TYPES (DATA FROM ENGLISH NATURE CONDITION ASSESSMENT, 2002)
[Scale 1:220,000 at A4]



[Scale 1:220,000 at A4]

LEGEND

- River Wensum catchment
- River Wensum channel
- Reach dividers and code
- Mill
- Semi-natural
- Recovered
- Recovering
- Damaged
- Degraded
- Severely degraded

FOR:
NATURAL ENGLAND

RIVER WENSUM SSSI
STRATEGIC RESTORATION PLAN

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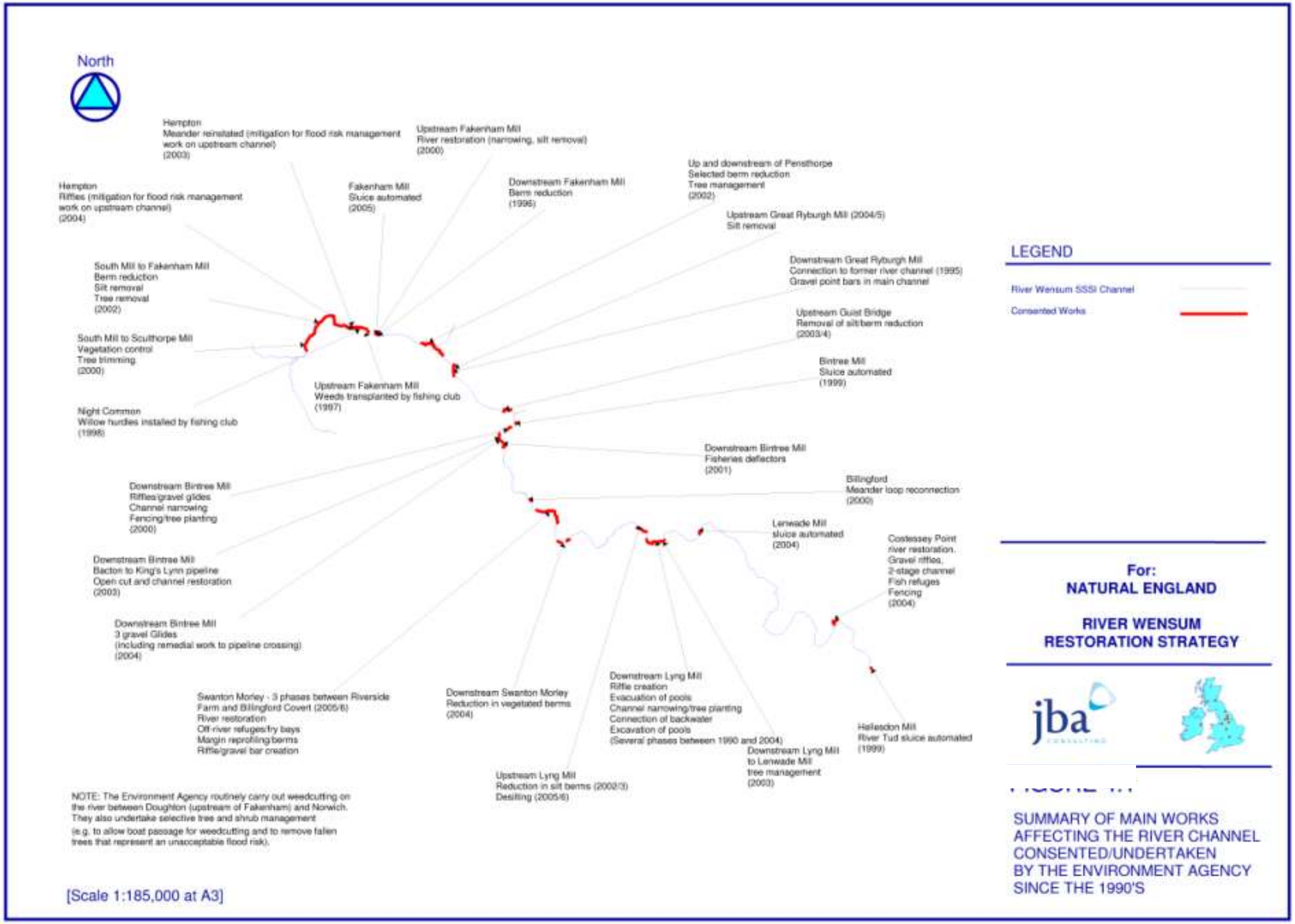
FIGURE 3.1

REACH STATUS (AS CLASSIFIED IN THE GEOMORPHOLOGICAL APPRAISAL, 2006)


North
Hempton
Meander reinstated (mitigation for flood risk management work on upstream channel)
(2003)
Upstream Fakenham Mill
River restoration (narrowing, silt removal)
(2000)
Up and downstream of Pensthorpe
Selected berm reduction
Tree management
(2002)
Hempton
Riffles (mitigation for flood risk management work on upstream channel)
(2004)
Fakenham Mill
Sluice automated
(2005)
Downstream Fakenham Mill
Berm reduction
(1996)
Upstream Great Ryburgh Mill (2004/5)
Silt removal
South Mill to Fakenham Mill
Berm reduction
Silt removal
Tree removal
(2002)
Downstream Great Ryburgh Mill
Connection to former river channel (1995)
Gravel point bars in main channel
South Mill to Sculthorpe Mill
Vegetation control
Tree trimming
(2000)
Upstream Guist Bridge
Removal of silt/berm reduction
(2003/4)
Bintree Mill
Sluice automated
(1999)
Upstream Fakenham Mill
Weeds transplanted by fishing club
(1997)
Night Common
Willow hurdles installed by fishing club
(1998)
Downstream Bintree Mill
Fisheries deflectors
(2001)
Downstream Bintree Mill
Riffles/gravel glides
Channel narrowing
Fencing/tree planting
(2000)
Billingford
Meander loop reconnection
(2000)
Lenwade Mill
sluice automated
(2004)
Costessey Point
river restoration.
Gravel riffles,
2-stage channel
Fish refuges
Fencing
(2004)
Downstream Bintree Mill
Bacton to King's Lynn pipeline
Open cut and channel restoration
(2003)
Downstream Bintree Mill
3 gravel Glides
(including remedial work to pipeline crossing)
(2004)
Downstream Lyng Mill
Riffle creation
Excavation of pools
Channel narrowing/tree planting
Connection of backwater
Excavation of pools
(Several phases between 1990 and 2004)
Swanton Morley - 3 phases between Riverside Farm and Billingford Covert (2005/6)
River restoration
Off-river refuges/fry bays
Margin reprofiling/berms
Riffle/gravel bar creation
Downstream Swanton Morley
Reduction in vegetated berms
(2004)
Hellesdon Mill
River Tud sluice automated
(1999)
Downstream Lyng Mill to Lenwade Mill
tree management
(2003)
Upstream Lyng Mill
Reduction in silt berms (2002/3)
Desilting (2005/6)
NOTE: The Environment Agency routinely carry out weedcutting on the river between Doughton (upstream of Fakenham) and Norwich. They also undertake selective tree and shrub management (e.g. to allow boat passage for weedcutting and to remove fallen trees that represent an unacceptable flood risk).
[Scale 1:185,000 at A3]
LEGEND
River Wensum SSSI Channel
Consented Works
For:
NATURAL ENGLAND
RIVER WENSUM
RESTORATION STRATEGY
jba
SUMMARY OF MAIN WORKS
AFFECTING THE RIVER CHANNEL
CONSENTED/UNDERTAKEN
BY THE ENVIRONMENT AGENCY
SINCE THE 1990'S

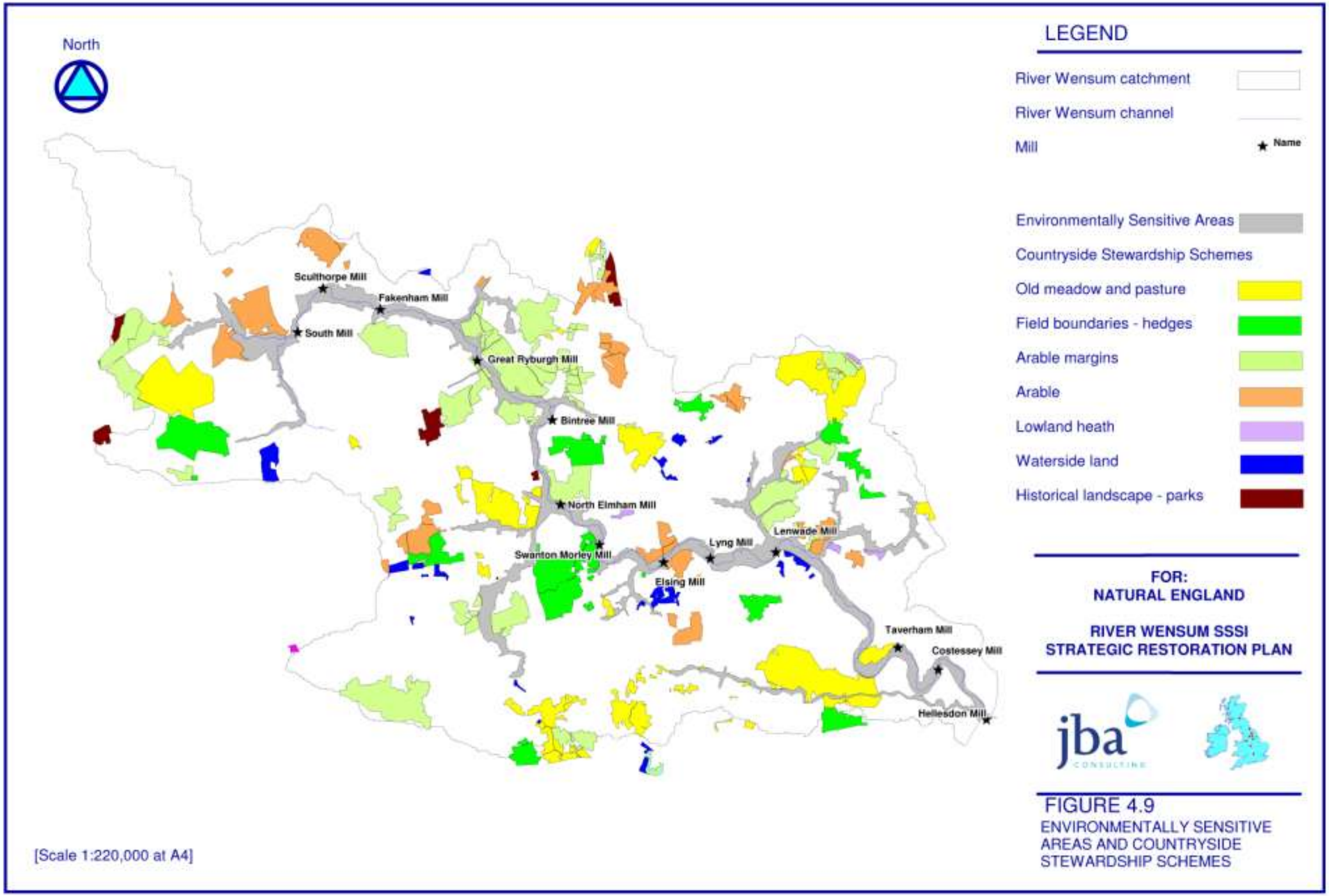


FIGURE 4.9
ENVIRONMENTALLY SENSITIVE AREAS AND COUNTRYSIDE STEWARDSHIP SCHEMES

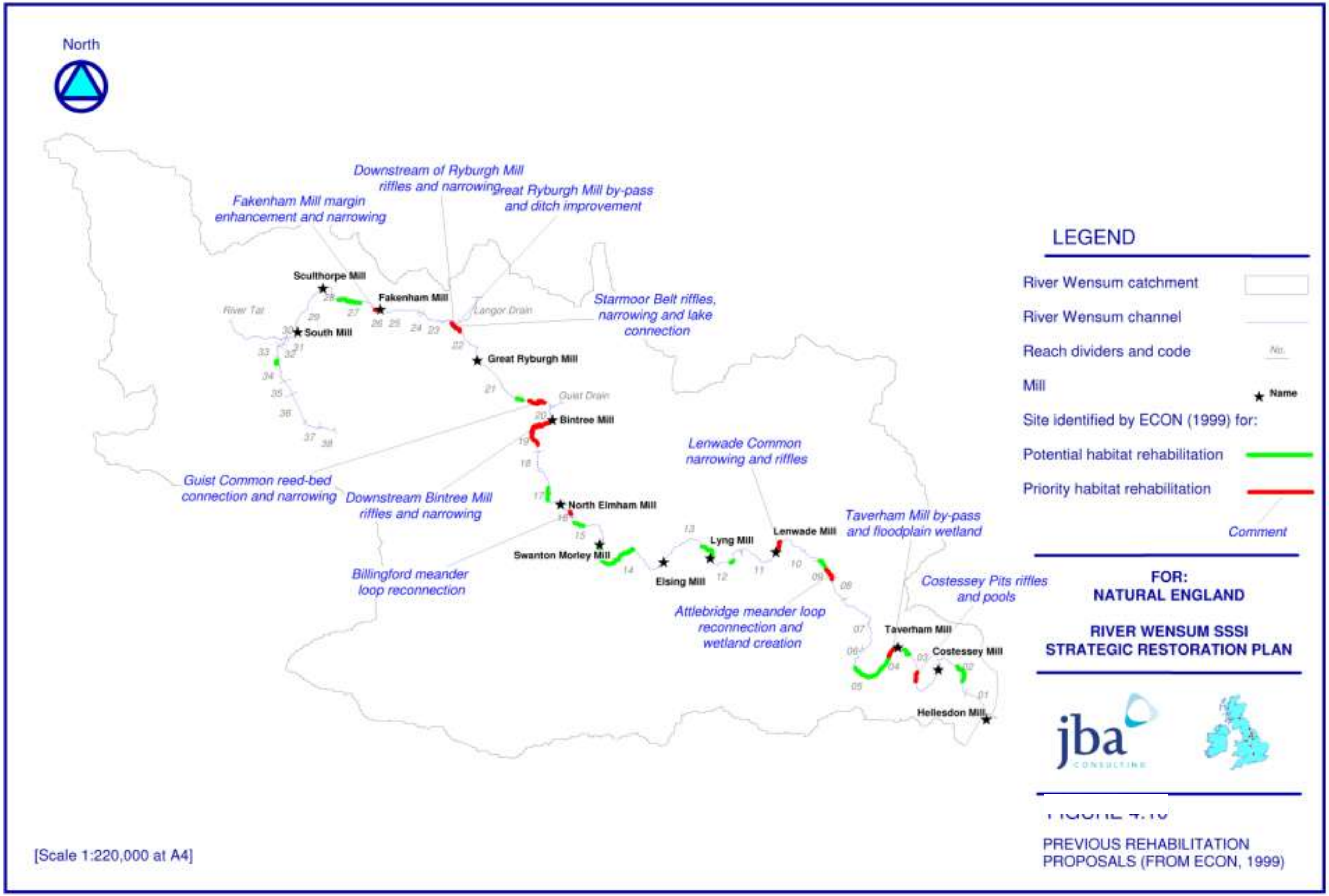


FIGURE 4.10

PREVIOUS REHABILITATION PROPOSALS (FROM ECON, 1999)

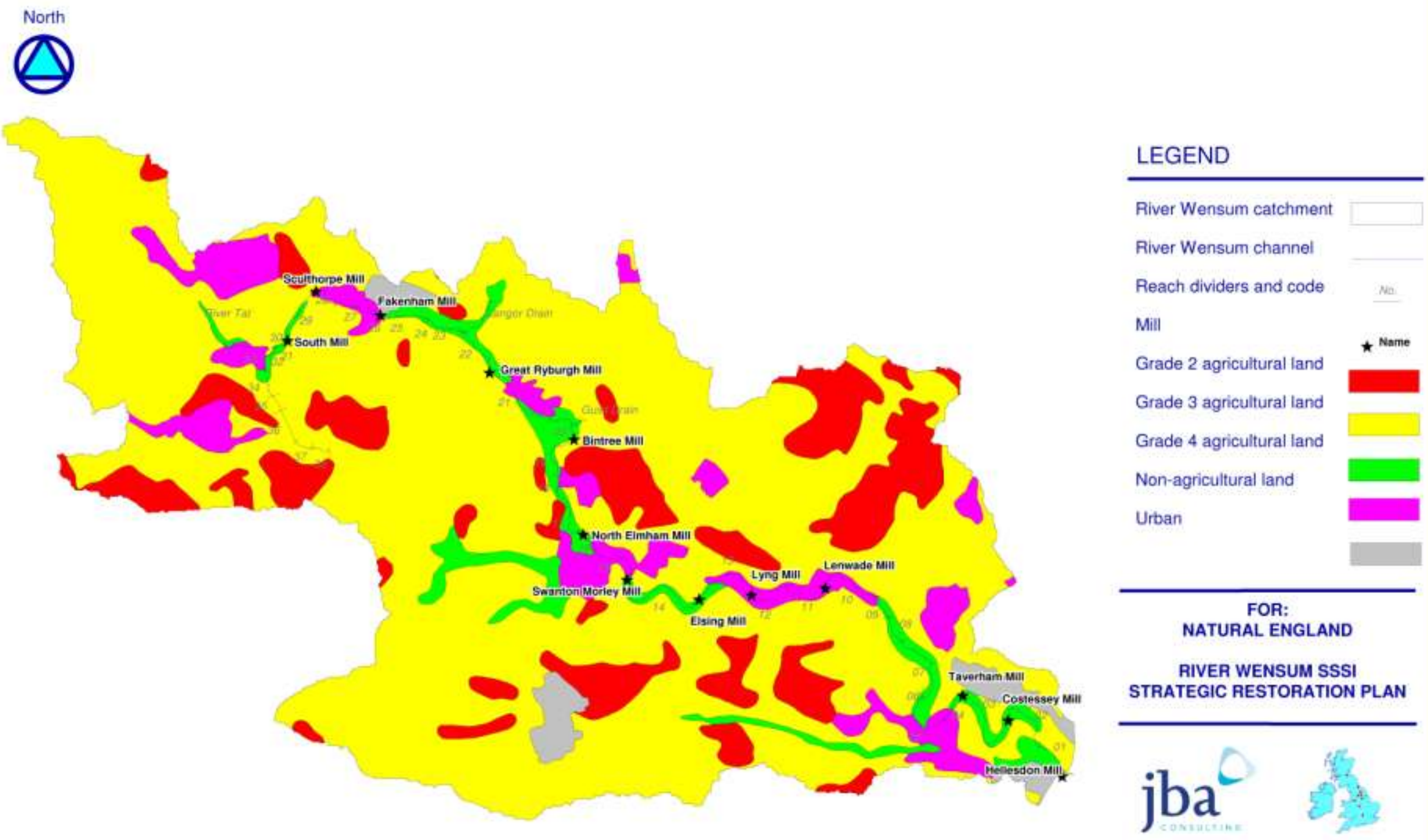
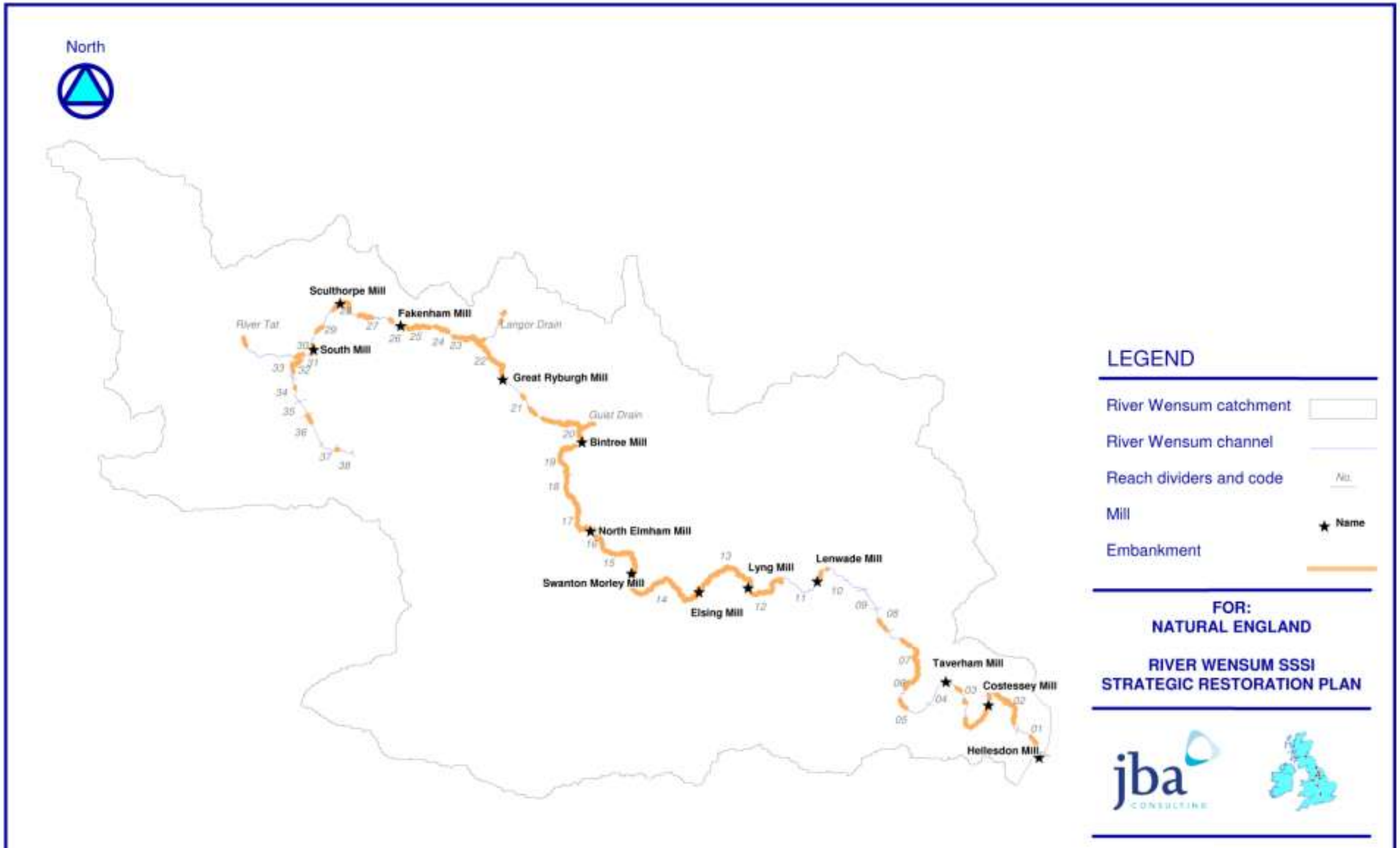


FIGURE 5.1

AGRICULTURAL LAND CLASSIFICATION

[Scale 1:220,000 at A4]



[Scale 1:220,000 at A4]

FIGURE 5.2

LENGTH OF EMBANKMENTS
(DATA FROM GEODATA, 2006)

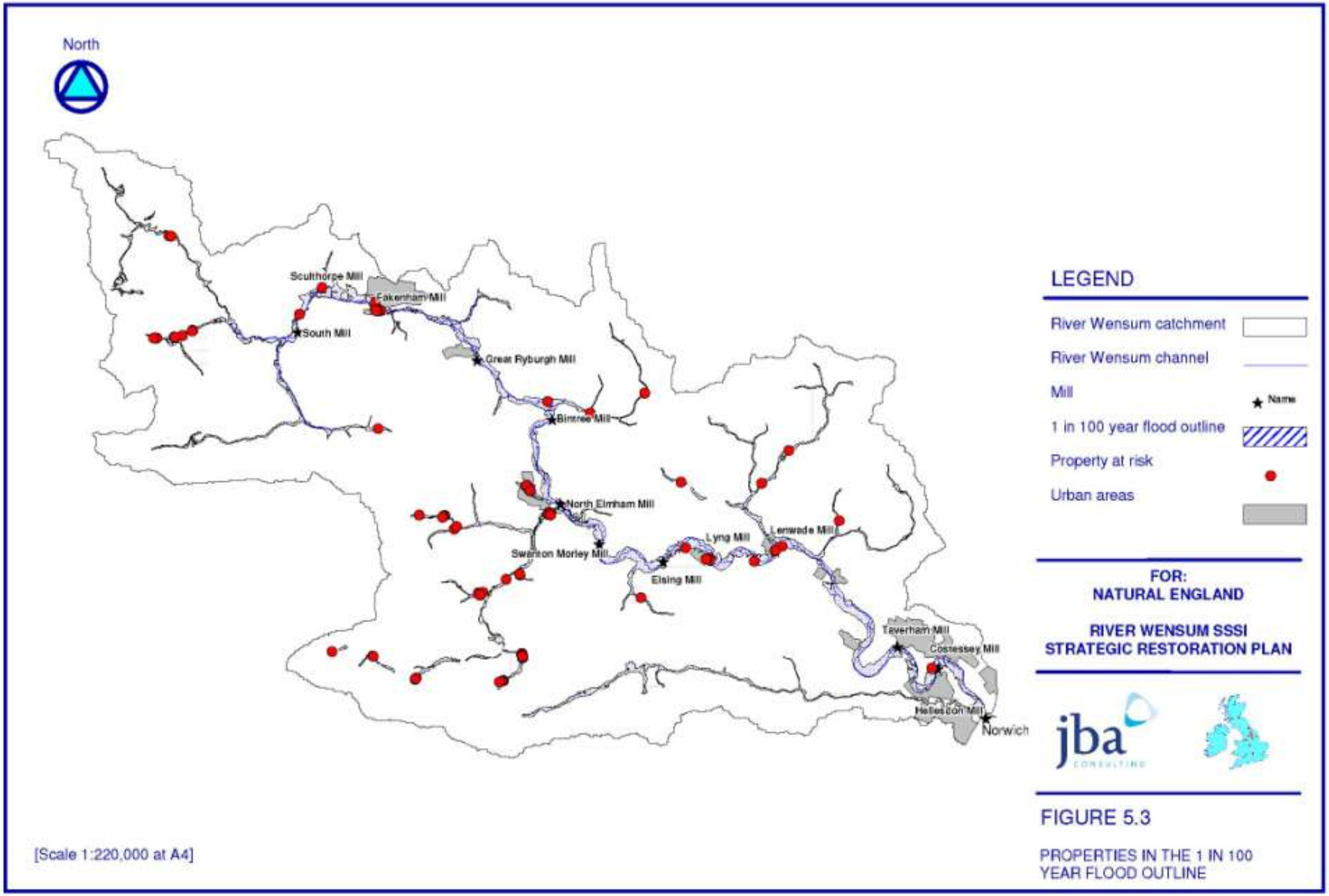
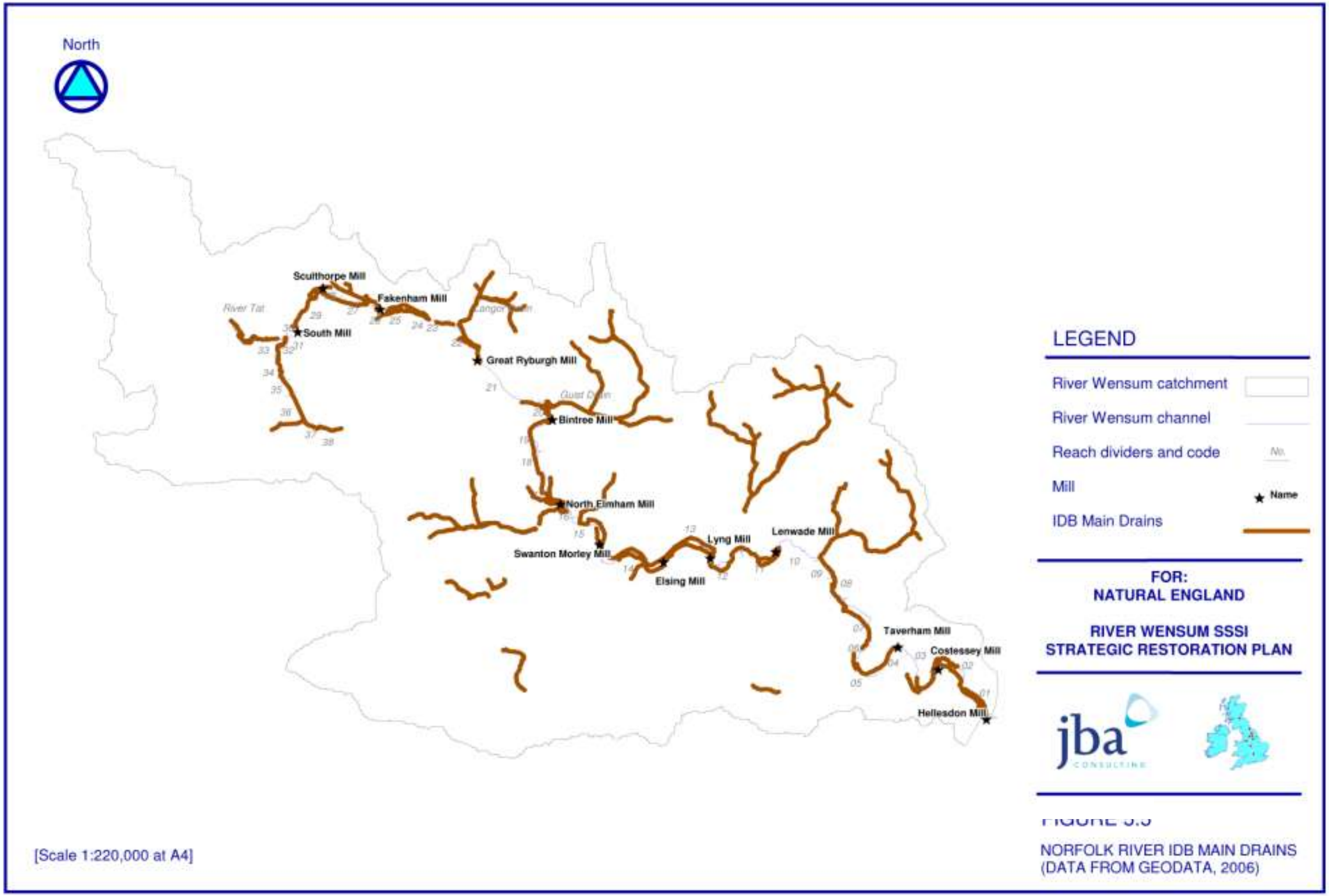
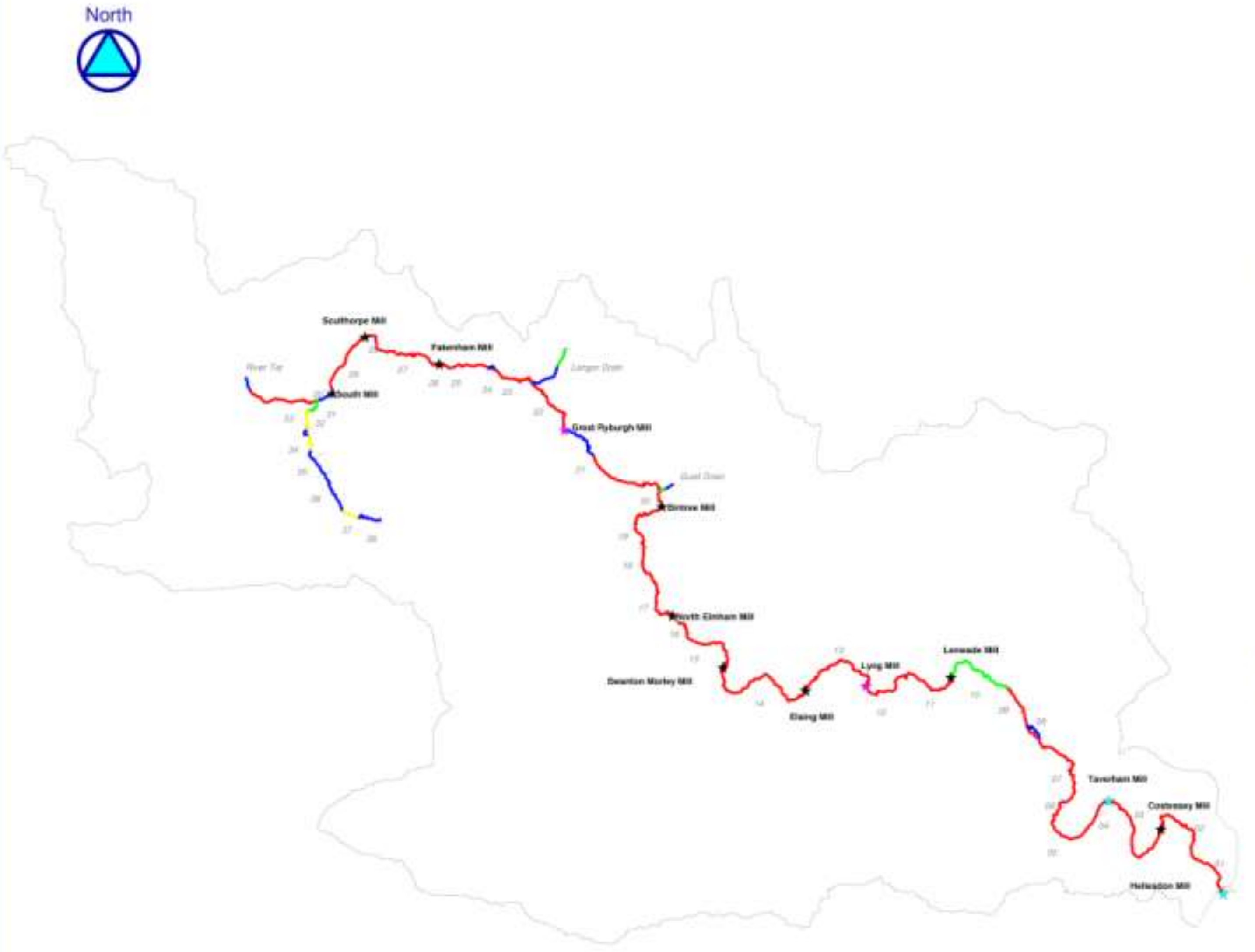


FIGURE 5.3

PROPERTIES IN THE 1 IN 100 YEAR FLOOD OUTLINE


North
River Tat
Sculthorpe Mill
Fakenham Mill
South Mill
Great Ryburgh Mill
Bintree Mill
North Elmham Mill
Swanton Morley Mill
Elsing Mill
Lyng Mill
Lenwade Mill
Taverham Mill
Costessey Mill
Hellesdon Mill
LEGEND
River Wensum catchment
River Wensum channel
Reach dividers and code
Mill
Name
IDB Main Drains
FOR:
NATURAL ENGLAND
RIVER WENSUM SSSI
STRATEGIC RESTORATION PLAN
NORFOLK RIVER IDB MAIN DRAINS
(DATA FROM GEODATA, 2006)
[Scale 1:220,000 at A4]



LEGEND

River Wensum Catchment
Mills - lower
Mills - remove
Mills - bypass
Restoration
Rehabilitation
Enhancement
Assist Natural Recovery

For:
NATURAL ENGLAND

RIVER WENSUM SSSI
STRATEGIC RESTORATION PLAN

FIGURE 6.3
WENSUM RESTORATION PLAN

[Scale 1:150,000 at A3]

Natural England works for people, places and nature to conserve and enhance biodiversity, landscapes and wildlife in rural, urban, coastal and marine areas.

www.naturalengland.org.uk