APPENDIX 1: SITE SURVEY

1 METHODOLOGY

1.1 Introduction

For the purpose of conducting topographic cross section surveys and velocity readings for the five trial sites, Royal Haskoning commissioned Longdin and Browning Surveyors Ltd to undertake the surveys during the three-year trial study. For this purpose, a Topographic Survey Specification Report was produced and provided to Longdin and Browning detailing the aims of the study, areas to be surveyed and number of cross-sections to be conducted within each reach (Royal Haskoning, 2005). The Topographic Survey Specification Report can be found in Appendix D, however the rest of this report summarises the main methods and techniques employed during the project.

1.2 Cross-sectional surveys

General

In order to obtain a baseline condition for all five trial sites throughout the UK, cross section surveys were carried out in 2005 (Year 1 of the R&D project), between 26th July and 9th September in the following order:

- River Kent July/August 2005
- Long Eau River August 2005
- River Dearne August 2005
- River Eden August/September 2005
- River Harbourne September 2005

In July 2007 and September 2007 (Year 3 of the R&D project), repeat surveys were carried out for the River Eden, River Dearne and River Long Eau. Further details on the areas surveyed can be found in Section 3.2.2.

Appropriate quality assurance procedures were used. Levels were related to at least two listed Ordnance Survey bench marks and the miss-closure between benchmarks was no greater than 20mm.

1.2.1 Baseline Cross Section Surveys carried out in 2005 (Year 1)

The location and quantity of the cross-sections was based on a consideration of the following factors:

- Extent of changes in alignment
- How regular the sediment formation was along/across the channel
- To coincide as much as practicable with the River Habitat Surveys.

Table 1.1 below shows the number of cross sections taken at each site. Location maps showing the location of each cross-section as well as RHS points have been produced. Details of each cross-section are provided within the Survey Drawings.

Table 1.1 Quantity of Cross Section per location in 2005

Location	Main Study Reach	Control Reach	Total
River Kent	10 (Stromengate Bridge to Romney Bridge)	3 (downstream of Kendal)	13
Long Eau River	9 (4 – within 1990's wetland scheme, 5- within 2005 wetland scheme)	3 (downstream of wetland schemes)	12
River Dearne	9 (3 - d/s end of the 1996/7 re-meandering scheme , 6 – u/s end of the 1995 re-meandering scheme)	3 (length between the two 1990s schemes)	12
River Eden	8 (4 – Weir to Mill Channel, 4 - (Foot bridge to Vexour Bridge)	3 – Old river channel to Foot Bridge)	12
River Harbourne	7 (d/s of Habertonford Town Bridge)	4 (u/s of Habertonford Town Bridge)	11

The cross-sections were numbered in an upstream direction, with the last cross-section being located at the upstream end of the reaches. The spacing of the cross-sections was dependent on the level of risk to any adjacent properties and the location of any in-channel structures.

Cross-sections of the channel, both up and downstream of the key hydraulic structures, as well as cross-sections of the face of the inlet and outlet of the structure were taken. Less significant structures were surveyed with just one cross-section. In addition to the cross-sections, a longitudinal profile was taken of each study reach and control reach, and was also accompanied with River Cross-sectional photographs and Differential GPS readings to enable locations to be easily found for repeat surveying over the three-year period.

Bank surveys were also undertaken with bank levels recorded at 50m intervals. Where there were significant changes in the topography of the banks these were recorded at 20m intervals.

1.2.2 Repeat Surveys carried out in 2007 (Year 3)

In July 2007 and September 2007 (Year 3 of the R&D project), repeat surveys were carried out for the River Eden *(all cross sections resurveyed)*, River Dearne (*six cross* *sections resurveyed)* and River Long Eau (*five cross sections resurveyed)* only. Reasons for this are associated with the increased scope from 3 cross sections to 12 per site in 2005 (Year 1), and therefore this limited the available budget to carry out resurveys. Therefore the project team, based on analysis and observations in Year 1 and 2), decided to focus the repeat surveys on the River Eden, Dearne and Long Eau, as these sites showed the greatest change in response to differing flows and maintenance regimes, and would assist more in achieving the initial aims and objectives set-out at the beginning of the project. It must be noted that no in-channel structures were surveyed during the repeat 2007 surveys. Table 1.2 below shows the number of cross sections taken in July 2007.

Location maps showing the location of the cross sections repeated in July 2007 for the three sites can be found in Appendix C.

Table 1.2 Quantity of Cross Sections per Location in July 2007

Location	Main Study Reach	Control Reach	Total
Long Eau River	4 4 – within 1990's wetland scheme		4
River Dearne	5 (4 - d/s end of the 1996/7 re-meandering scheme , 1 – u/s end of the 1995 re-meandering scheme)		5
River Eden	8 (4 – Weir to Mill Channel, 4 (Foot Bridge to Vexour Bridge)	4 – Old river channel to Foot Bridge)	12

Analysis of cross sections carried out in July 2007, identified that some cross sections had not been resurveyed in the correct position. It appeared that the surveyor had failed to measure the cross section at 90 degrees to the watercourse and in some cases actually surveying totally in the incorrect position. This highlights the need for continuity in surveyors from year to year when repeat surveys are required, thereby reducing potential errors which may prevail when personnel change.

In light of this the survey contractor agreed to resurvey the three sites again, which were done in the September 2007 in the following order:

- River Eden
- River Long Eau
- River Dearne.

Despite these errors, this also presented an ideal opportunity for the project team to look at the direct impact of floods on channel change. The July 2007 surveys were actually taken before the 'Summer 2007 floods' and provided the project team with snap shots of new sections along each watercourse prior to the high flows experienced. It was agreed that the cross sections carried out in the incorrect positions would also be resurveyed to capture the impact of the summer floods. Table 1.3 below shows the quantity of cross sections carried out per site in September 2007.

Table 1.3 Quantity of Cross Sections per Location in September 2007

Location	Main Study Reach	Control Reach	Total
Long Eau River	5 5 – (within 1990's wetland scheme)		5
River Dearne	5 (4 - d/s end of the 1996/7 re-meandering scheme) 1 – u/s end of the 1995 re-meandering scheme)		5
River Eden	8 4 – (Weir to Mill Channel) 4 - (Foot bridge to Vexour Bridge)	3 – Old river channel to foot bridge)	16

1.3 Velocity Readings

In 2005 the surveyor team were also instructed to obtain velocity measurements at each of the five trial sites. This was done at four locations at each cross section and taken at 20% and 80% of the present water depth for all five sites. For the River Kent only, they were taken at eight locations along each cross section again at depths of 20% and 80% of the present water depth. Water levels were also observed with time and dates recorded.

Table 1.4 and 1.5 below shows the example velocity measurements obtained in 2005 for the River Eden and River Kent respectively.

RIVER VELOCITY READINGS - RIVER EDEN-TONBRIDGE						
SAMPLE READINGS ON SECTION 10 (ALL FIGURES IN ms^{-1})						
	LEFT BANK					RIGHT BANK
Chainage		3.23	4.5	5.77	7.12	
20% depth		0.301	0.29	0	0	
80% depth		0.29	0.229	0	0	
looking downstream						

Table 1.4 Example of velocity data collected from the River Eden, cross-section 10

RIVER VELOCITY READINGS - RIVER KENT-KENDAL										
SAMPLE READINGS ON SECTION 1 (ALL FIGURES IN ms^{-1})										
	LEFT BANK									RIGHT BANK
Chainage		13.42	15.41	17.28	19.04	21.06	22.82	24.69	26.55	
20% depth		0.91	0.189	0.178	0.277	0.343	0.246	0.099	0.088	
80% depth		0.16	0.18	0.111	0.127	0.184	0.206	0.167	0.088	
looking downstream										

Table 1.5 Example of velocity data collected form the River Kent, cross-section 1

Appendix 2 River Habitat Surveys and Habitats

1. Introduction

1.1 BACKGROUND TO RIVER HABITAT SURVEY (RHS)

The River Habitat Survey (RHS) is a method developed in the UK to characterise and assess, in broad terms, the physical character of freshwater streams and rivers. Field survey follows the strict protocols given in the 2003 RHS Manual (EA 2003).

Data are entered onto the RHS database. This now contains field observations, map-derived information and photographs from more than 19,000 surveys undertaken since 1994. During 1994-96 a stratified random network of sites established a geographically representative baseline cross-section of streams and rivers across the UK. It is this set of data that is used to set the national context of habitat quality and degree of modification, see below.

The RHS database allows sites of a similar nature to be grouped together for comparative purposes. Slope, distance from source, height of source and site altitude are used to cluster RHS sample sites for so-called “context analysis” based on principal component analysis (PCA) plots. This enables any site in the UK to be compared with other sites of a broadly similar nature, either nationally, regionally or locally.

Indices of habitat quality and channel modification can be derived from RHS data, and these can be used for a variety of purposes; for this study, they were used to assess the relative degree of modification, and extent of habitat variety, of our reaches compared with sites of a similar character nationally.

Habitat Quality Assessment (HQA) is a broad indication of overall habitat diversity provided by natural features in the channel and river corridor. Points are awarded for the presence of scoring features such as point, side and mid-channel bars and cliffs (all fluvial habitat features) as well as marginal tree roots, woody debris, waterfalls, marginal reeds and floodplain wetlands. Additional points reflect the variety of substrate, flow-types, in-channel vegetation (affected by the presence of fluvial features), and also the extent of trees and semi-natural land-use adjacent to the river.

Points are added together to provide the HQA. In contrast to the Habitat Modification Score (HMS), the higher the score, the more highly rated the site. The diversity and character of river habitat features at any site is influenced by natural variation and the extent of human intervention, both in the channel and adjacent land. The RHS database allows HQA scores to be compared using sites with similar physical characteristics (e.g. slope, distance from source) and geology.

Habitat Modification Score (HMS) is an indication of modification to the river channel morphology. To calculate HMS for sites, points are awarded for the presence of artificial features such as culverts, weirs, current deflectors, and bank revetments. Points are also awarded for modifications to the channel such as re-sectioned banks or heavily trampled margins. The more severe the modification then the higher is the score. The cumulative points total provides the Habitat Modification Score (HMS). A Habitat Modification Class

(HMC) has been developed which allocates a site into one of five modification classes, based on the total score. In contrast to HQA, higher scores reflect more intervention and modification of the river channel. HMS and HQA scores for the sites are given in Section 2.

1.2 FIELD DATA COLLECTION OF RHS FOR THE STUDY

In the first year of this study pre-survey site visits were carried out with other members of the team. Site assessments were made to establish the optimum location for each 500m sub-reach, taking into account the requirements of other surveys as well as the RHS.

The location of the sub-reaches and their co-ordinates are given in Table 1.1 below.

Table 1.1 Location of RHS Reaches

River	Reach[1]	GPS Upstream End	GPS Downstream End
Long Eau	Upstream	TF 41034 86605	TF 41258 86905
	Middle	TF 40599 86033	TF 40847 86330
	Downstream	TF 40105 85553	TF 40280 85887
Dearne	Upstream	SE 47751 01992	SE 48172 01799
	Middle	SE 48479 01843	SE 48897 01603
	Downstream	SE 49230 01245	SE 49612 00980
Eden	Upstream	TQ 49801 46400	TQ 50019 46106
	Middle	TQ 49988 46019	TQ 50212 45653
	Downstream	TQ 50491 45662	TQ 50771 45530
Harbourne	Upstream	SX 77736 55970	SX 77999 56126
	Downstream	SX 78456 56174	SX 78936 56244
Kent	Downstream[2]	SD 51383 90106 SD 51313 90171 in 07	SD 51262 89943
	Upstream	SD 51918 92957	SD 51631 92556
	Middle	SD 51662 91935	SD 51806 91516

Notes: [1] Reaches are not necessarily in upstream to downstream order.
[2] Extended 50m upstream in 2007 for comparison with national database.

From Table 1.1 it can be seen that for the Long Eau, Dearne, Eden and Kent two 'managed' sites were surveyed alongside a control, but for the Harbourne a single managed site and a control site were surveyed. Field data were submitted to the RHS team at Warrington, and having been subject to Quality Control, were entered on to the EA's RHS database. Once data were entered, the RHS team were able to provide summary data for the sites, calculate quality/impact scores, and undertake context analysis.

The locations of each spot-check was recorded using GPS and are shown on maps in Appendix 9.

1.3 ADDITIONAL FIELD OBSERVATIONS ON FLUVIAL FEATURES

RHS is a formal method of rigorously recording river features and characteristics at spot locations, as well as summarizing other attributes of a river that occur in at least 1% of the 500m site. As the research sites had a limited extent of fluvial features present, and when they were present they were often too small to be recorded by the RHS protocol, field observations of erosion or deposition features were made by three members of the research team when they visited the sites. Whilst undertaking the RHS surveys, the surveyor also noted the location of fluvial features on the sites that may, or may not, have been recorded during the formal RHS survey procedure. This information was summarized on annotated maps and passed to geomorphological team members who incorporated this information with data that was gathered during the field work. All the data was input into a Geographical Information System (GIS) to enable the data from the surveys of the different disciplines to be super-imposed and compared. This enabled all the available data to be superimposed and viewed together.

In addition to these, when the macrophyte surveys were being taken a note was taken of the location and character of any erosion or deposition features present in the sites; this information was also passed to geomorphological team members on annotated maps for incorporation into the habitat feature maps that are given in Appendix 9.

1.4 PRESENTATION OF COLLECTED RHS AND FIELD OBSERVATION DATA FOR THE FIVE RIVERS

RHS data from the surveys carried out have been summarized in Section 2. The features observed during the RHS surveys were entered onto the GIS so that they could be superimposed on the data obtained from the other surveys.

1.5 CONTEXT ANALYSIS AND DETERMINATION OF HQA AND HMS/I

Once the EA's RHS team at Warrington had successfully imported the quality-assured site data on to the database, team members could abstract summary information from the raw data to establish site HQA and HMS/C. The team could also provide summary tables to indicate the recorded components from which the scores were derived. The resultant scores are independent of PCA and river typology, and have been tabulated in summary form in Section 2.1.

To enable the habitat quality, and degree of modification, of the research reaches to be assessed against the variation in quality of such rivers across the UK, it was necessary to determine the 'position of the sites' on the RHS PCA map of UK rivers. The analysis for this was undertaken by the EA's dedicated RHS support team in Warrington. Since all the sites within each of the five reaches were close together, the position of the individual sites on the PCA were virtually identical. The middle site of the three (or heavily modified site in the case of the Harbourne where there were only two RHS sites) was used for this purpose. The site information used (EA database references for future applications) are detailed below. Figure 1.2 is the output plot from the analyses.

River	Site ID	Survey ID	NGR	Year of Survey
Dearne	18705	32125	SE4871201783	2005
Long Eau	18314	32150	TF4077086170	2005
Eden	18709	32129	TQ5006645822	2005
Kent	18717	32147	SD5176791736	2005
Harbourne	18713	32132	SX7870456251	2005

PCA plot of Habitats and Sediments Sites compared to Baseline sites

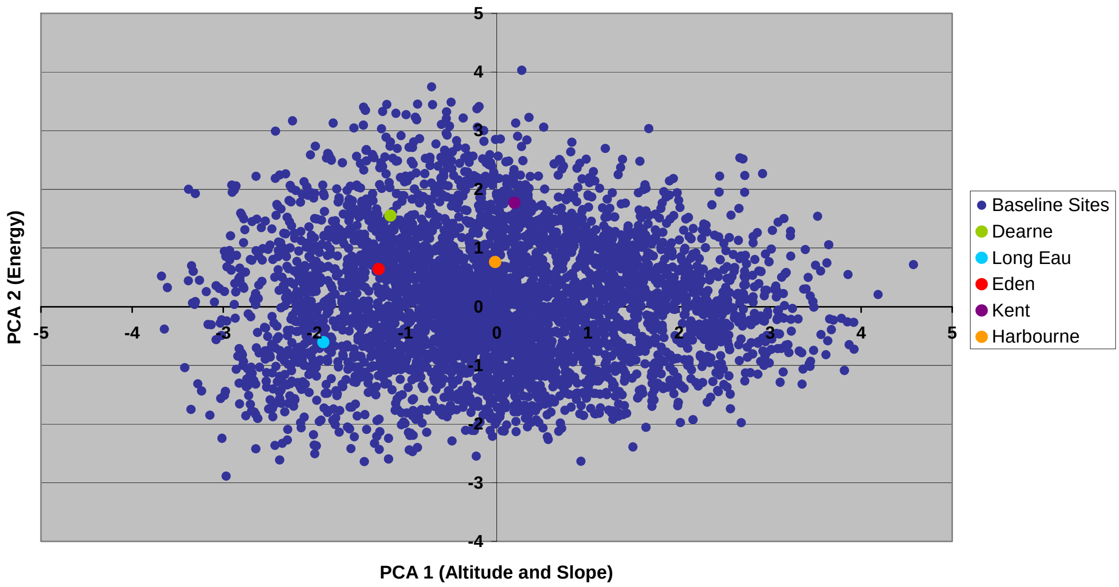


Figure 1.2 Position of the Five Research Reaches on the EA RHS Database PCA Map

Figure 1.2 shows that The Long Eau is in the middle of the sector of sites that are low energy, low gradient and low altitude. The Kent is markedly different, being in the high energy, high gradient and higher altitude sector. The Harbourne is closest to the Kent in terms of energy and character, with the Dearne and Eden being intermediate in energy between the Harbourne and the Long Eau.

Once the location on the PCA map had been determined, it was then possible for the RHS team to calculate HQA and HMI for the sites and compare them with rivers of a similar type (i.e. only comparing with sites on the PCA map that lie adjacent to the five locations shown in Figure 1.2). In the case of the HQA, it is possible to calculate the 'HQA-adjusted' scores that take account of the expected habitat variability for rivers in each sector of the PCA if in near-natural condition. This information is given in Section 3.

One exercise carried out in the latter part of the project was to experimentally look at RHS data for clay bed rivers, of a similar width, in south-east England to ascertain if any long reaches of such rivers had consistently better HMI and HQA scores than the Eden. Using the database, the Warrington team compared small clay rivers sites with each other, and found that parts of the Arun, in West Sussex, consistently scored higher quality, and with less modification, than the Eden. This information is given and Section 3, alongside an assessment of the comparative maintenance regimes on the two rivers.

2. RHS data for the five rivers

2.1 INTRODUCTION

The following sections provide a summary of the RHS data collected for each river. This is only a summary, and detailed information is available by interrogation of the RHS database. Each subsequent sub-section of this part of the Appendix first summarizes RHS data in tabular and map form before adding additional information on fluvial features gathered by other means.

For simple comparative purposes, HQA and HMS scores for all rivers and sites are given below in Table 21 (HQA) and 2.2 (HMS/C). To gain easily a picture of the comparative HQA scores for each river site, the data in Table 2.1 have been plotted in Figure 2.1. As all survey sites, apart from the control site on the Harbourne, were found to have an HMC of 5, these classes have not been plotted.

Table 2.1 HQA scores for the Sites Surveyed

RIVER	Year of Survey	NGR Site	HQA score	HQA Bank Veg sub score	HQA Channel Features sub score	HQA Channel Substrates sub score	HQA Flow Types sub score	HQA In-stream Channel Veg sub score	HQA Land Use sub score	HQA Special Features sub score	HQA Trees & Associated Features sub score	HQA Bank Features sub score
LONG EAU												
32134 (us 2)	2005	TF4014885760	24	5	1	6	5	4	1	0	2	0
32143 (us 2)	2006	TF4014885760	24	6	0	6	5	4	1	0	2	0
32460 (us 2)	2007	TF4014885760	28	7	1	6	6	4	1	0	3	0
32150 (MID 1)	2005	TF4077086170	34	8	3	8	8	4	1	0	2	0
32149 (MID 1)	2006	TF4077086170	36	9	4	8	8	4	1	0	2	0
32459 (MID 1)	2007	TF4077086170	33	8	2	7	7	6	1	0	2	0
32135 (ds c)	2005	TF4121586691	29	5	4	6	8	4	1	0	1	0
32139 (ds c)	2006	TF4121586691	30	5	4	6	7	6	1	0	1	0
32458 (ds c)	2007	TF4121586691	28	5	5	6	5	5	1	0	1	0
DEARNE												
32127 u/s	2005	SE4794001842	39	10	1	4	9	10	0	1	4	2
32144 u/s	2006	SE4794001842	41	11	3	5	8	6	0	0	5	3
32462 u/s	2007	SE4794001842	39	10	2	4	8	6	0	0	5	3
32125 mid	2005	SE4871201783	32	11	0	2	4	7	1	0	7	0
32145 mid	2006	SE4871201783	30	10	0	3	4	4	1	0	8	0
32463 mid	2007	SE4871201783	31	11	0	5	4	3	1	0	7	0

RIVER	Year of Survey	NGR Site	HQA score	HQA Bank Veg sub score	HQA Channel Features sub score	HQA Channel Substrates sub score	HQA Flow Types sub score	HQA In-stream Channel Veg sub score	HQA Land Use sub score	HQA Special Features sub score	HQA Trees & Associated Features sub score	HQA Bank Features sub score
32126 d/s	2005	SE4941401096	35	11	2	4	6	7	0	0	5	0
32148 d/s	2006	SE4941401096	37	11	2	4	8	6	0	0	5	1
32464 d/s	2007	SE4941401096	42	11	2	6	9	5	1	0	6	2
EDEN												
32130 (u/s)	2005	TQ4996046299	43	11	4	4	9	7	0	0	7	1
32137 (u/s)	2006	TQ4996046299	44	12	3	5	7	9	0	0	6	2
32455 (u/s)	2007	TQ4996046299	43	12	3	5	7	6	0	0	6	4
32129 (MID)	2005	TQ5006645822	36	12	1	3	6	9	0	0	4	1
32136 (MID)	2006	TQ5006645822	38	12	2	3	8	7	0	0	4	2
32456 (MID)	2007	TQ5006645822	39	12	2	5	7	6	0	0	4	3
32128 (d/s)	2005	TQ5058845579	46	12	3	5	7	9	2	0	6	2
32138 (d/s)	2006	TQ5058845579	45	11	3	5	6	9	2	0	7	2
32457 (d/s)	2007	TQ5058845579	47	11	3	7	7	5	2	0	7	5
HARBOURNE												
32131 u/s	2005	SX7788056017	46	10	5	5	9	7	0	0	8	2
32141 u/s	2006	SX7788056017	50	10	6	3	9	7	0	0	10	5
32132 d/s	2005	SX7870456251	52	10	4	5	12	7	1	0	8	5
32140 d/s	2006	SX7870456251	55	12	4	5	12	6	1	0	7	8
KENT												
32133 u/s	2005	SD5180092726	42	7	6	7	11	4	0	1	4	2
32142 u/s	2006	SD5180092726	43	9	5	6	11	5	0	1	4	2
32454 u/s	2007	SD5191892957	43	10	5	7	10	5	0	1	3	2
32147 mid	2005	SD5176791736	45	7	6	7	10	3	0	1	3	8
32146 mid	2006	SD5176791736	46	9	5	7	10	4	0	1	3	7
32466 mid	2007	SD5176791736	47	10	4	8	10	5	0	1	3	6
32465 d/s	2007	SD5135290074	39	5	3	6	10	2	1	0	4	8

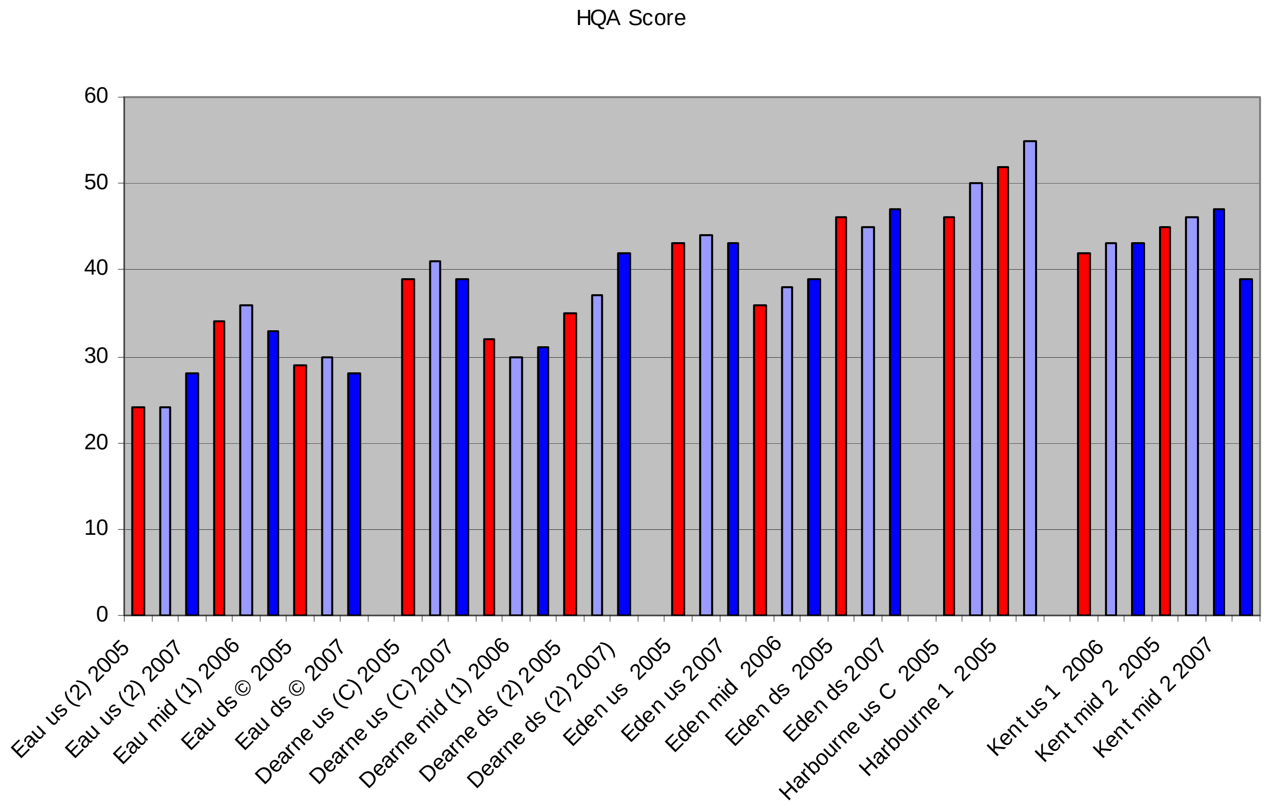


Figure 2.1 **HQA Scores for the RHS survey sites. Scores for 2005 are shown in RED, 2006 in PURPLE and 2007 in BLUE**

Table 2.2 HMS and Classes for the Sites Surveyed

Survey ID	**Year of Survey Date**	**NGR Site**	**HMS Class**	**HMS Score**	**HMS Outfall, Deflector Sub Score**	**HMS Berms Embankments Sub Score**	**HMS Bridges Sub Score**	**HMS Culverts Sub Score**	**HMS Fords Sub Score**	**HMS Poaching Sub Score**	**HMS Re-inforced Bank & Bed Sub Score**	**HMS Resectioned Bank & Bed Sub Score**	**HMS Weirs Sub Score**
LONG EAU													
32134 (us 2)	2005	TF4014885760	5	3224	0	224	200	0	0	0	0	2800	0
32143 (us 2)	2006	TF4014885760	5	3224	0	224	200	0	0	0	0	2800	0
32460 (us 2)	2007	TF4014885760	5	3224	0	224	200	0	0	0	0	2800	0
32150 (mid 1)	2005	TF4077086170	5	3525	25	600	100	0	0	0	0	2800	0
32149 (mid 1)	2006	TF4077086170	5	3545	25	620	100	0	0	0	0	2800	0
32459 (mid 1)	2007	TF4077086170	5	3505	25	580	100	0	0	0	0	2800	0
32135 (ds C)	2005	TF4121586691	5	3220	0	420	0	0	0	0	0	2800	0
32139 (ds C)	2006	TF4121586691	5	3220	0	420	0	0	0	0	0	2800	0
32458 (ds C)	2007	TF4121586691	5	3220	0	420	0	0	0	0	0	2800	0
DEARNE													
32127 u/s	2005	SE4794001842	5	2867	25	32	0	0	0	10	0	2800	0
32144 u/s	2006	SE4794001842	5	2867	25	32	0	0	0	10	0	2800	0
32462 u/s	2007	SE4794001842	5	2877	25	32	0	0	0	20	0	2800	0

Survey ID	Year of Survey Date	NGR Site	HMS Class	HMS Score	HMS Outfall, Deflector Sub Score	HMS Berms Embankments Sub Score	HMS Bridges Sub Score	HMS Culverts Sub Score	HMS Fords Sub Score	HMS Poaching Sub Score	HMS Re-inforced Bank & Bed Sub Score	HMS Resectioned Bank & Bed Sub Score	HMS Weirs Sub Score
32125 mid	2005	SE4871201783	5	2832	0	32	0	0	0	0	0	2800	0
32145 mid	2006	SE4871201783	5	2832	0	32	0	0	0	0	0	2800	0
32463 mid	2007	SE4871201783	5	2832	0	32	0	0	0	0	0	2800	0
32126 d/s	2005	SE4941401096	5	3336	0	296	0	0	0	0	240	2800	0
32148 d/s	2006	SE4941401096	5	3336	0	296	0	0	0	0	280	2800	0
32464 d/s	2007	SE4941401096	5	3376	0	296	0	0	0	0	240	2800	0
EDEN													
32130 (us)	2005	TQ4996046299	5	2770	0	0	250	0	0	0	80	2440	0
32137 (us)	2006	TQ4996046299	5	2660	0	0	100	0	0	0	80	2480	0
32455 (us)	2007	TQ4996046299	5	2550	50	0	100	0	0	0	80	2320	0
32129 (MID)	2005	TQ5006645822	5	2610	0	0	0	0	0	10	0	2600	0
32136 (MID)	2006	TQ5006645822	5	2570	0	0	0	0	0	10	0	2560	0
32456 (MID)	2007	TQ5006645822	5	2570	0	0	0	0	0	10	0	2560	0
32128 (ds)	2005	TQ5058845579	5	2200	0	0	0	0	0	0	0	2200	0
32138 (ds)	2006	TQ5058845579	5	2520	0	0	0	0	0	0	200	2320	0
32457 (ds)	2007	TQ5058845579	5	2195	75	0	0	0	0	0		2120	0
HARBOURNE													
32131 u/s	2005	SX7788056017	3	460	200	0	0	0	120	80	60	0	0
32141 u/s	2006	SX7788056017	3	425	125	0	0	0	120	100	80	0	0
32132 d/s	2005	SX7870456251	5	3765	350	20	200	0	0	0	680	1680	835
32140 d/s	2006	SX7870456251	5	4135	300	20	200	0	0	0	700	2080	835
KENT													
32133 (u/s)	2005	SD5180092726	5	4225	100	0	500	0	0	0	1370	1400	855
32142 (u/s)	2006	SD5180092726	5	4235	100	0	500	0	0	0	1380	1400	855
32454 (u/s)	2007	SD5180092726	5	4480	100	0	500	0	0	0	1380	1720	780
32147 (mid)	2005	SD5176791736	5	5905	75	20	450	0	0	0	1170	1800	2390
32146 (mid)	2006	SD5176791736	5	5785	75	20	450	0	0	0	1170	1800	2270
32466 (mid)	2007	SD5176791736	5	6015	75	20	450	0	0	0	1160	2040	2270
32465 (d/s)	2007	SD5135290074	3	430	125	0	0	0	0	30	100	0	175

2.2 LONG EAU RHS

The HMS and HQA scores for the three sites surveyed on the river in 2005 to 2007 are tabulated below.

Site Name	HQA Score	HMS	HMC
Eau us (2) 2005	24	3224	5
Eau us (2) 2006	24	3224	5
Eau us (2) 2007	28	3224	5
Eau mid (1) 2005	34	3525	5
Eau mid (1) 2006	36	3545	5
Eau mid (1) 2007	33	3505	5
Eau ds © 2005	29	3220	5
Eau ds © 2006	30	3220	5
Eau ds © 2007	28	3220	5

Maps showing the nature and location of features observed in the RHS survey are in Appendix 9.

The most upstream site starts at a footbridge and the bed-width is narrower than the two sites downstream. There has been a more recent enhancement scheme involving lowering of the right embankment to allow (what must be very infrequent) fluvial flooding of an adjacent wetland. The banks are still very high and steep, with very limited channel diversity and little riparian vegetation. Vegetation management is now planned only to cut around half of the channel width but evidence of change is limited. Surveys carried out in summer indicate luxuriant reed growth and no evidence of any discrete deposition habitat features; surveys carried out in April reveals many small silt shoals at the margin that would not be considered discrete enough to form clear-cut RHS habitats, but are never-the-less contrasting habitats that could develop further if encouraged to do through vegetation management. HQA scores were consistently the lowest, primarily because of the virtual total lack of in-channel habitats and poor diversity of flow types.

The middle site is a length of high level carrier where the embankment on the left has been lowered considerably allowing flooding of the adjacent wetland. Berms and 'riffles' have also been created; in this gravel/clay/silt bed river where some small silt accumulations occur due to past over-widening. The lowering of the embankment has had a major visual impact, as well as re-established connectivity of the floodplain with the river. However, a lesson learnt from the introduction of gravel and pebbles to form artificial 'riffle habitats' is that this is fraught with difficulty, and likely not achieve objectives, where channel gradient is very slack. In this case the gradient is virtually non-existent, and so the 'riffles' simply pond water between each other, and the intervening areas become silted. HQA was consistently the highest as the capital works had created improved environments for bankside vegetation diversity; due to the construction of the 'riffle' features flow types and channel feature diversity was greater than upstream.

The downstream site is a continuance downstream of the high level carrier, but with unmodified embankments and unchanged vegetation management (channel cut full width with minimum 10% left) once per annum in contrast to 50% cut on reaches 1 and 2. The reach becomes choked with vegetation in late summer. Vegetated silt deposits, resembling bars, could be seen in spring, and a natural berm is present at the downstream end. The section has a more varied plan-form than the other two and appears to have a slightly steeper gradient. A result of this is that numerous constructed riffles do form contrasting habitat without too much upstream ponding, and a semblance of riffle/pool sequences in evidence. HQA scores were intermediate between the other two, with similarly poor bankside vegetation scores at site 2, but with better flow-type and channel features diversity because of the greater gradient, and the installation of gravel 'riffles'.

2.3 DEARNE RHS

The HMS and HQA scores for the three sites surveyed on the river in 2005-2007 are tabulated below.

Site Name	HQA Score	HMS	HMC
Dearne us (u/s) 2005	39	2867	5
Dearne us (u/s) 2006	41	2867	5
Dearne us (u/s) 2007	39	2877	5
Dearne mid (mid) 2005	32	2832	5
Dearne mid (mid) 2006	30	2832	5
Dearne mid (mid) 2007	31	2832	5
Dearne ds (d/s) 2005	35	3336	5
Dearne ds (d/s) 2006	37	3336	5
Dearne ds (d/s) 2007	42	3376	5

Maps showing the nature and location of features observed in the RHS survey are in Appendix 9.

The upstream site is located downstream, and outside the influence of, a large flow gauging weir. The site is noted for varied substrate & flow conditions created by low scrub & silt/reed on the margins that act as flow deflectors, mainly in the upstream half but also beginning to develop in the downstream half. In the lee of the marginal shrub 'deflectors', as a geomorphic response to past over-widening, silt has accumulated along the margin, and this has been colonized by reeds. It is understood that regular maintenance has now ceased and the development of the marginal features, resulting in narrowing of the low-flow channel, would not be occurring under the previous vegetation control measures of the 1980s. Alternating deep glides & shallower gravel runs with good lengths of clean gravel substrate are present. It is noteworthy that the control site had consistently higher HQA scores than the two downstream sites that were modified to improve fisheries.

The middle reach is a meandering, artificial stretch of river with flood embankment, as in all three sites. The site starts 50m downstream of a large outfall on the left bank. It is the upstream limit of a capital improvement scheme carried out about 10 years ago to improve the fishery and reduce the need for maintenance. Within a wide, relatively straight channel, the river was narrowed and made slightly sinuous. The site is located within the modified section that is deep and with minimal gradient. Despite the scheme, the site is still extremely over-wide, deep and silty with slow to slack flow. Open reaches of bank with tall reeds and herbs alternate with clumps of sallow and willows; silt is accumulating around the overhanging branches & wide stands of bur-reed growing in the gaps. There are no discrete habitats present at all, and even minor features are absent. HQA scores were consistently the lowest due to minimal variations in substrate and flow types, and total absence of any channel features.

The downstream site starts downstream of a loose stone weir, possibly constructed by children. The site includes the section of river most obviously narrowed & re-meandered by constructed berms on alternate banks during the capital habitat improvement scheme. This work has created a self-cleansing flow with shallow gravel/pebble runs & pools in the upstream half. Scouring of the underlying clay bed in the downstream half has created a shelf underwater. Constructed berms are dry and the backwaters overgrown. The scheme most certainly created self-cleansing conditions in a narrower low-flow channel, but because the edges of the narrowed channel were armoured with stone, there is no potential for habitat features to develop. The survey extended slightly beyond the scheme where bank erosion & marginal siltation was evident; being the only location of any erosion or sediment-related habitats in the two downstream reaches confirmed the scheme had resulted in a negative impact of natural process forming habitats. HQA scores were intermediate between the other two, with reasonable scores for channel substrates due to the effects of the narrowing. The HMS was highest due to the extent of marginal armouring.

2.4 EDEN RHS

The HMS and HQA scores for the three sites surveyed on the river in 2005 to 2007 are tabulated below.

Site Name	HQA Score	HMS	HMC
Eden us 2005	43	2770	5
Eden us 2006	44	2660	5
Eden us 2007	43	2550	5
Eden mid 2005	36	2610	5
Eden mid 2006	38	2570	5
Eden mid 2007	39	2570	5
Eden ds 2005	46	2200	5
Eden ds 2006	45	2520	5
Eden ds 2007	47	2195	5

Maps showing the nature and location of features observed in the RHS survey are in Appendix 9.

	Page 1				Page 2				Page 3						
	Rif	Pool	UPB	VPB		SC	VP	NB		EC	SC	VPB	UPB	silt D	VS B
Eden us 2005	1	8	0	0							1				
Eden us 2006	1	4									1				
Eden us 2007	1	4		1		1(1)				1	1				1
Eden m 2005	0	2					1(1)			1					
Eden m 2006	1	1								1	1				
Eden m 2007	1	2		2						1	1	1			
Eden ds 2005	1	5	1										1		
Eden ds 2006	1	5	1							1			1		
Eden ds 2007	1	6	1	1				1(1)		1	1	1	1	1	1

The upstream site starts at a field boundary on the left bank and ends upstream of the confluence with the old mill stream. It was chosen as ‘the control’ as it had been subject to maintenance dredging several years before the project started (2002/3). There are several pools and one gravel riffle but a mostly smooth flow characterised the site. Small marginal features of silt, gravel and mussel shells were noted to be developing. The site had been visited immediately after the dredging, and it was noted that the implementation had been exemplary in that low berms and shelves had been left and full-width dredging had not taken place. HQA scores were greater than in the middle section, and similar to the downstream section; higher scores were mainly due to the higher diversity of flow types.

The middle site is meandering and over-deepened with steep, high banks. The whole reach has a ‘flashy’ flow regime, but evidence of this was greatest within this site. Site 1 begins where the channel narrows downstream of the confluence with the old mill stream. Bank slumping and past dredging has created dry berms. Gravel/pebble/clay forms the bed with some siltation on the margins, and some small marginal features (too small to record as features in RHS) are beginning to develop. The reduced extent of trees on the banks, and paucity of channel features and channel diversity, results in poor HQA scores.

The downstream site starts at a gravel riffle alongside a dip/field boundary. Generally there is limited flow diversity but there is variable flow depth, with several deep meander pools. Numerous old ash and oak trees are present on the banks side, some with very impressive and extensive exposed root systems. These features, combined with points for a small patch of non-intensively farmed riparian habitat, gives rise to consistent HQA scores for this site.

2.5 HARBOURNE RHS

The HMS and HQA scores for the three sites surveyed on the river in 2005 and 2006 are tabulated below.

Site Name	HQA Score	HMS	HMC
Harbourne us 2005	46	460	3
Harbourne us 2006	50	425	3
Harbourne ds 2005	52	3765	5
Harbourne ds 2005	55	4135	5

Maps showing the nature and location of features observed in the RHS survey are in Appendix 9.

The upstream site starts at the river flow level marker downstream of the flood retention scheme dam. The channel is extensively meandering with, at first glance, a very natural character. It has a good gravel bed, extensive riffles and several pools. Small point bars are developing and there are extensive areas with bankside trees on one, or both banks. There is some siltation on the margins where the channel is over-wide. The meandering plan-form is ‘natural’, but large blockstone reinforcement on the toe of the banks in places means that it cannot meander freely; otherwise it is relatively ‘natural’. The HMS for this site is lower than for any of the other sites surveyed because the banks have not been re-sectioned, being the only one not to have an index of ‘5’. The site’s score of 3 reflects the impact of the local blockstone armouring on meanders, some poaching by cattle, and fords. Despite the relative naturalness of the site, the HQA is not as good as for the impacted downstream site.

The downstream site covers the capital flood alleviation scheme area. The river is constrained by walls for much of its length on both banks, and the bed has been re-graded. There is a disused mill leat present, and a short length of channel at the downstream end was deliberately over-widened to enable flood water to be evacuated from the village as well as allow sediment-related habitats to develop. The reach starts at a large weir of cemented cobbles and includes several constructed riffles, some of which have been engineered to create bed scour habitats. There is very limited evidence of natural deposition in the constrained reach but gravel bars are forming at the downstream end, where intended. HQA scores are higher than expected (i.e. slightly higher than in the more natural section upstream); this is primarily due to the **artificial** increase in flow diversity resulting from the construction of weirs.

2.6 KENT MAP RHS

The HMS and HQA scores for the three sites surveyed on the river in 2005 to 2007 are tabulated below.

Site Name	HQA Score	HMS	HMC
Kent us 2005	42	4225	5
Kent us 2006	43	4235	5
Kent us 2007	43	4480	5
Kent mid 2005	45	5905	5
Kent mid 2006	46	5785	5
Kent mid 2007	47	6015	5
Kent ds 2007	39	430	3

Maps showing the nature and location of features observed in the RHS survey are in Appendix 9.

The most upstream site is heavily modified; including weirs, bridges, and a gravel trap. The site starts at the large weir downstream of Stramongate Bridge. Like site 2, it is set within a totally urban environment (Kendal - much of it parkland) with walled banks. The bed, however, shows signs of being very dynamic with cobble/pebble/bedrock substrates and riffles, bars and one pool. Downstream of Miller Bridge there are ‘introduced’ mid-channel boulders. HMS were extremely high (i.e. greatly modified) due to the complete armouring of the channel, but HQA scores were reasonable due to the diversity of substrates and flows types.

The middle site runs from Nether Bridge to Romney Road Bridge. This site is similar to the upstream site with more numerous low, boulder weirs, most of which are totally underwater even under moderately low flows. Some bedrock has been removed in the past, and very narrow pebble/gravel bars occur at the base of the walled banks in several places, and a natural berm is present at the downstream end. The HMS indicates even greater extent of engineering than upstream, but the HQA scores were slightly higher due to the presence of marginal shoals at the base of the walled banks.

The downstream site is downstream of the town of Kendal in a rural setting. Two low weirs and small rock groynes are present, but otherwise it is largely untouched (i.e. the planform and banks are natural, with no armouring etc.). The site runs from a meander to a field boundary on the right bank but extended 50m upstream in 2007. Cobble/bedrock is the substrate with riffles and large boulder/cobble/pebble bars. There is evidence of very mobile sediments & bars, with poached and eroding banks. This is in total contrast to the totally constrained channel in the two upstream sub-reaches through Kendal.

2.7 FIELD OBSERVATIONS AND MAPPED MINOR FEATURES FOR THE FIVE REACHES

As described above, the field observations noted during the RHS, macrophyte and geomorphological surveys were consolidated into a GIS. The data was contained in different layers. This meant that all the data could be viewed either separately or together. A hard copy version of the maps that were produced is presented in Appendix 9. These maps show the different data types as different sheets. The original intention had been to provide hard copy maps showing all the data superimposed. It was found in practice that data from the different surveys overlay each other to such an extent that the hard copy maps became unusable. This is why the data is presented separately in the Appendix. The data can be overlain within the original GIS which forms part of the project record.

3. River Habitat Quality; Context Assessment

3.1 INTRODUCTION

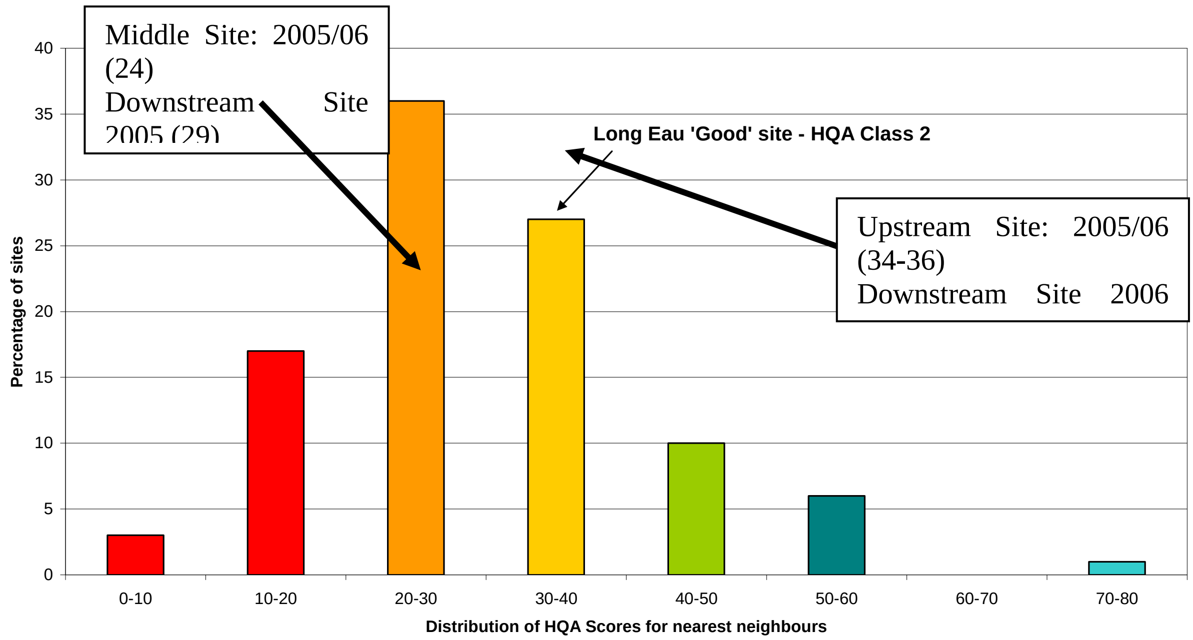
Using the RHS database it was possible to generate the HMS and HQA scores for the sites surveyed during the project in 2005-7. These data are presented in this section. Taken in isolation, the scores tell us little about how the sites compare with rivers of a similar type across the UK. To determine this, the RHS team generated HMS and HQA scores for the 150 nearest sites on the PCA map; for this purpose the 1994-1996 baseline survey data set was used so that the comparisons were made against randomly selected site locations, unbiased by surveying more in one area than another.

The nearest 150 baseline sites were selected in terms of site altitude, slope, distance to source and height of source. The same procedure was followed to calculate the range of HMS scores for the project sites, and the 150 nearest neighbour river types for the five rivers. These data are presented in the proceeding sections

3.2 LONG EAU

From the illustrated data in Figure 3.1 it can be seen that rivers similar to the Long Eau have a tendency to have very low HQA scores (<30), and scores greater than 40 are rare, and greater than 50 exceptionally so. The low HQA scores recorded for the Long Eau are, therefore, typical of the river type. HMS, in contrast, are variable, but the Long Eau is in the worst quintile of scores for such a river, indicating severe modifications based on RHS rules.

Habitat Quality Assessment of the Long Eau (HQA 34) in relation to nearest neighbour sites



Habitat Modification Score for the Long Eau (HMS 3525) in relation to nearest neighbour sites

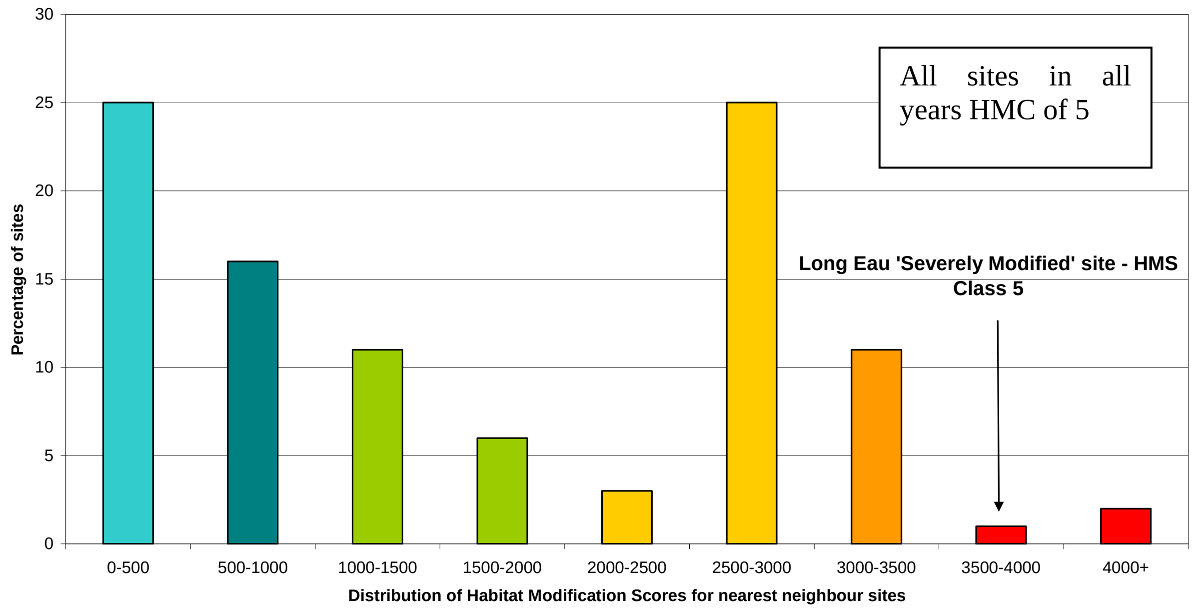
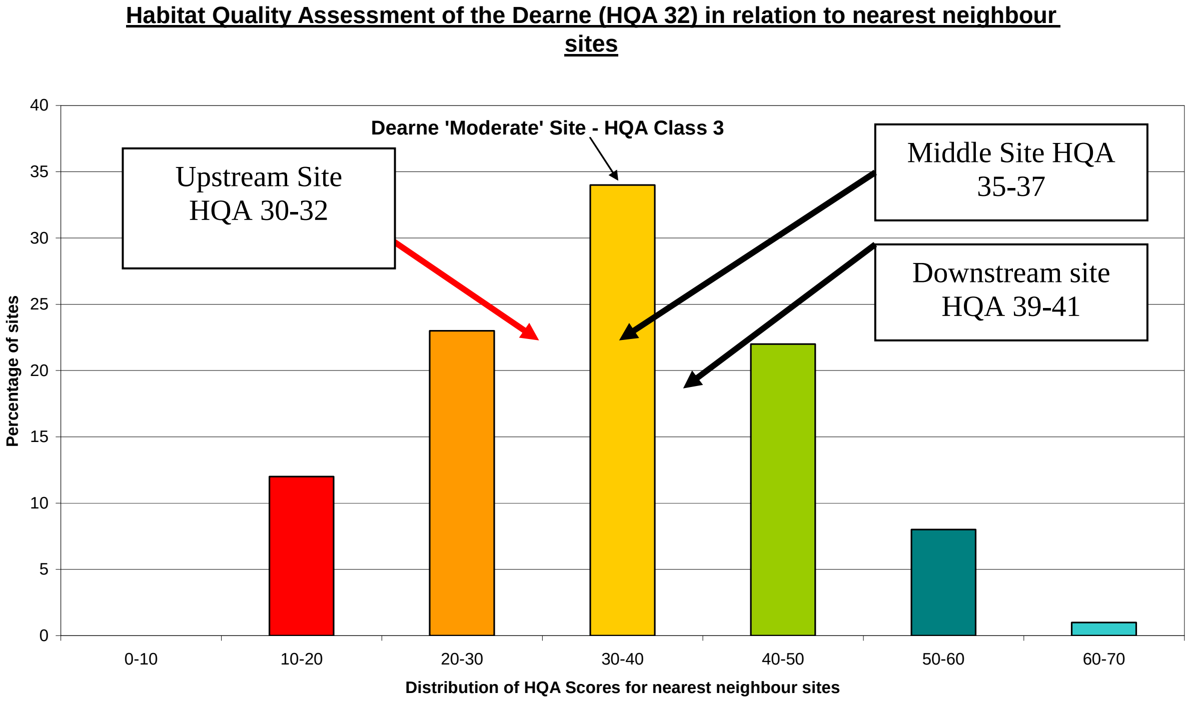


Figure 3.1 **Range of HMS and HQA scores for the 150 nearest neighbour sites on the RHS database for the baseline data-set; the scores for the middle Long Eau site in 2005 are shown for comparison**

3.3 DEARNE

From the illustrated data in Figure 3.2 it can be seen that rivers similar to the Dearne have a tendency to rarely have exceptionally low HQA scores less than 10, or have high scores greater than 50. The middle site surveyed had a moderate HQA score typical of the type. HMS, in contrast, most typically, are low (best), but the Dearne is in the worst quintile of scores for such a river, indicating severe modifications based on RHS rules.



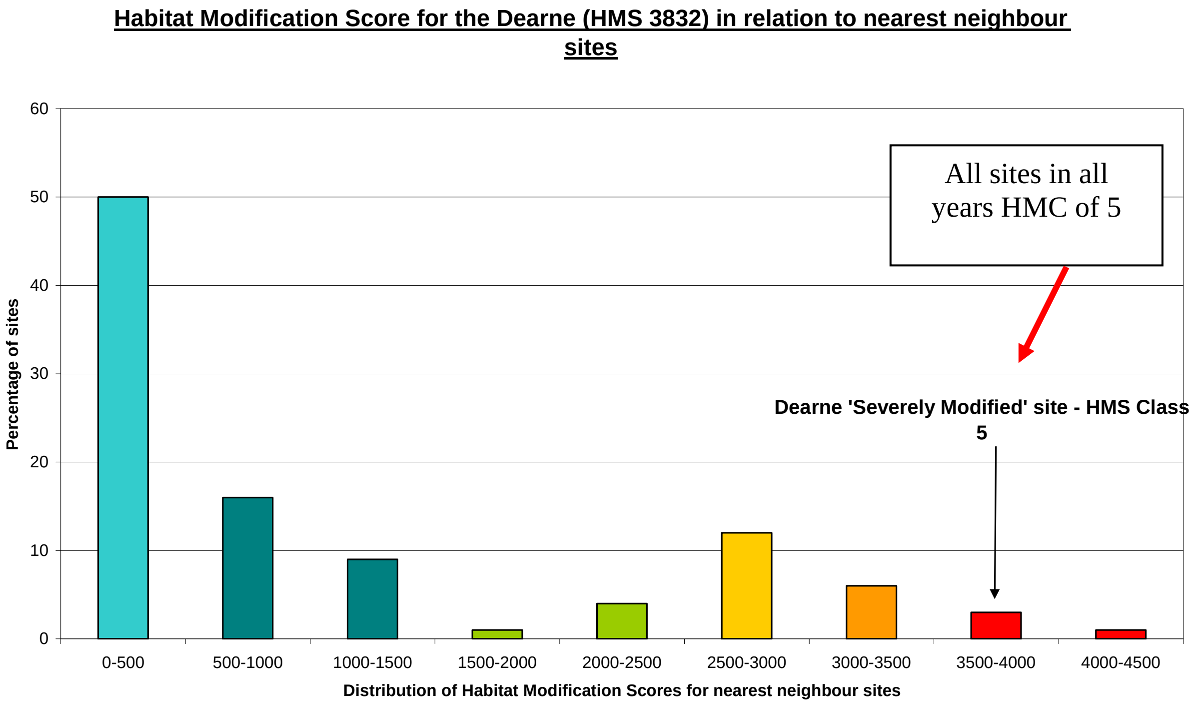
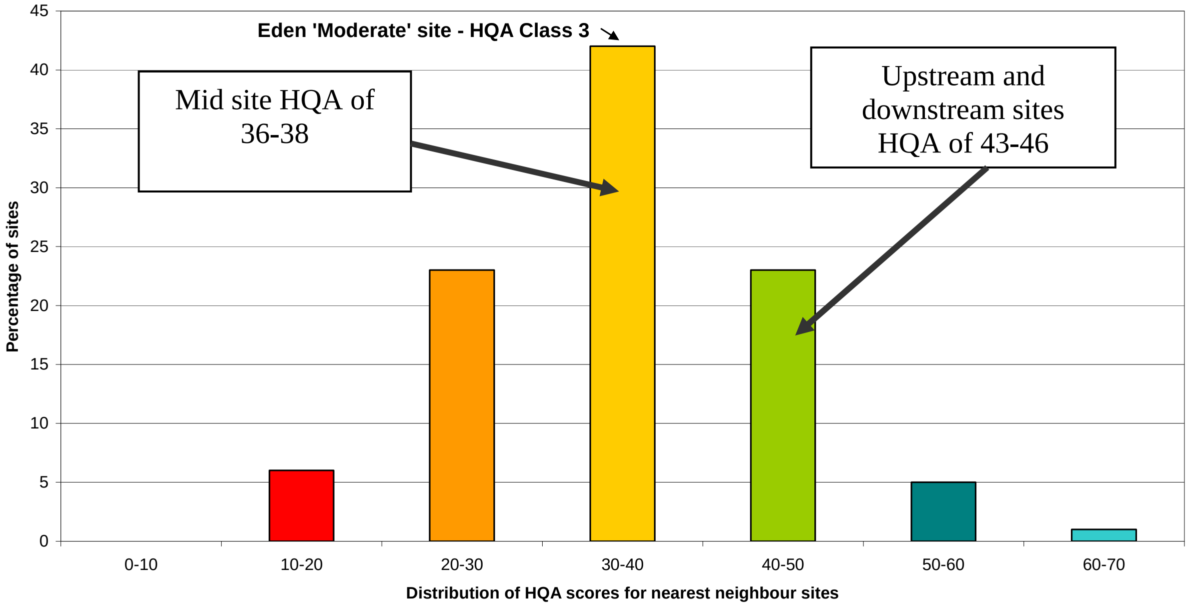


Figure 3.2 Range of HMS and HQA scores for the 150 nearest neighbour sites on the RHS database for the baseline data-set; the scores for the middle DEARNE site in 2005 are shown for comparison

3.4 EDEN

From the illustrated data in Figure 3.3 it can be seen that rivers similar to the Eden have a classic tendency to have moderate HQA classes, with scores rarely less than 20, or greater than 50. The middle site surveyed had a moderate HQA score typical of the type. HMS, in contrast, most typically, are low (best), but the Eden is in the worst quintile of scores for such a river, indicating severe modifications based on RHS rules.

Habitat Quality Assessment of the Eden (HQA 36) in relation to nearest neighbour sites



Habitat Modification Score for the Eden (HMS 2610) in relation to nearest neighbour site

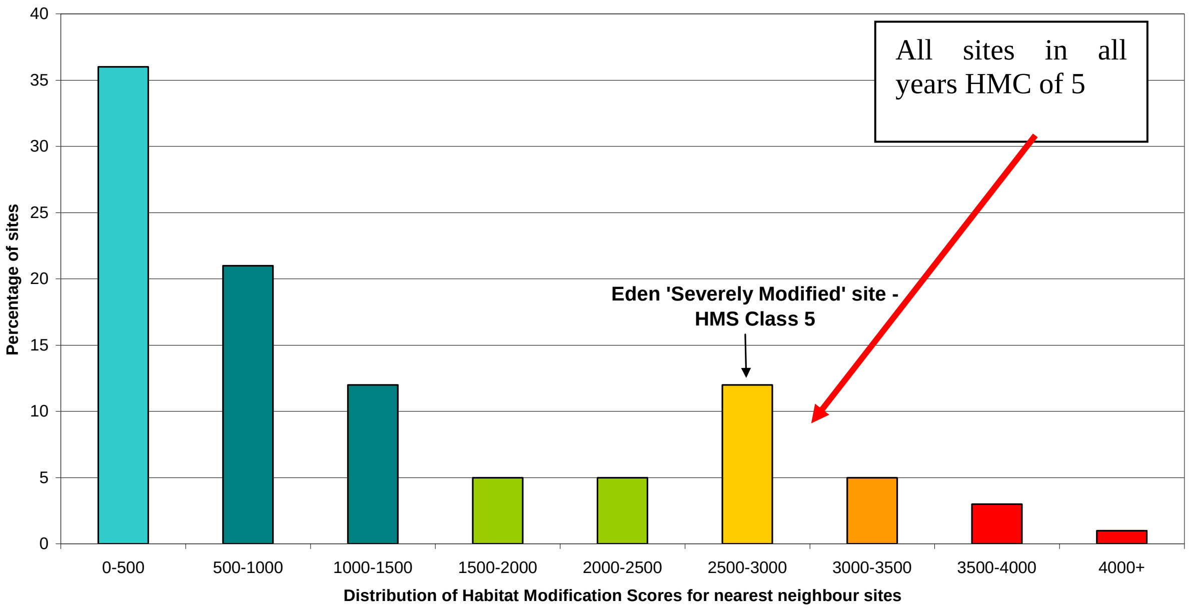
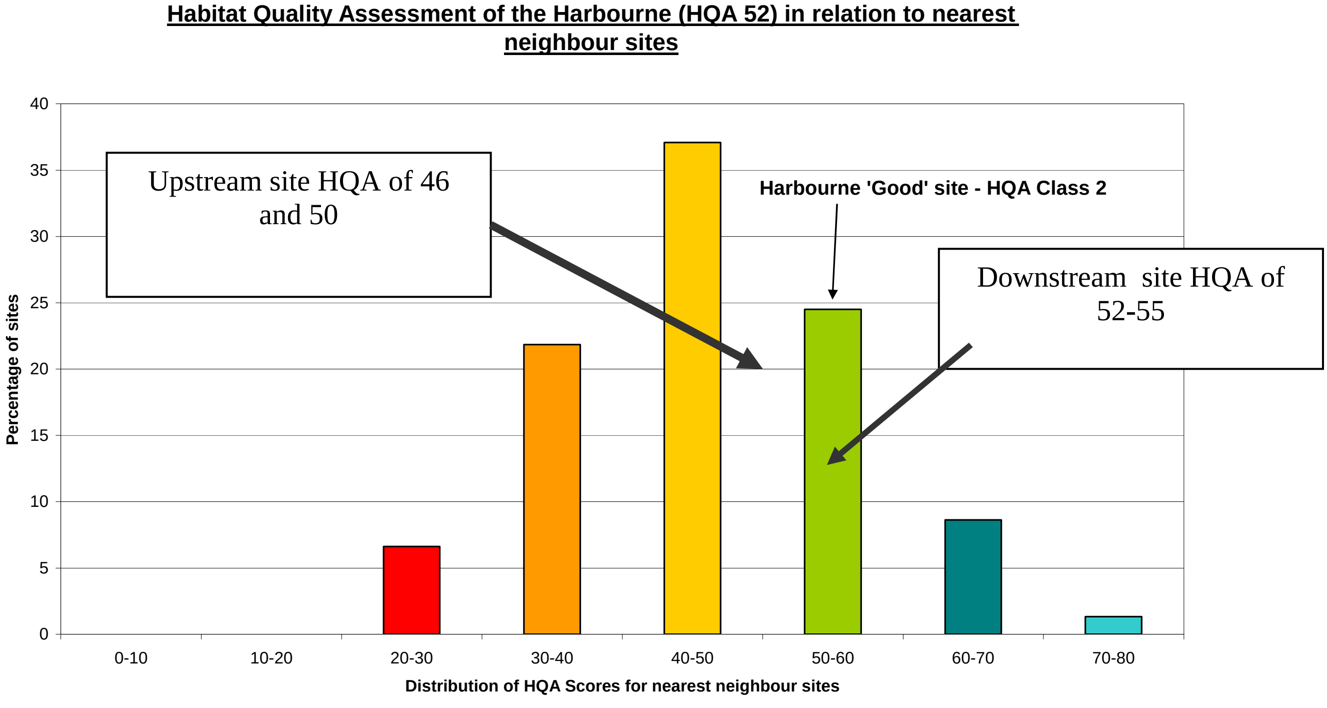


Figure 3.3 Range of HMS and HQA scores for the 150 nearest neighbour sites on the RHS database for the baseline data-set; the scores for the middle EDEN site in 2005 are shown for comparison

3.5 HARBOURNE

From the illustrated data in Figure 3.4 it can be seen that rivers similar to the Harbourne have a tendency to have higher HQA scores and an even greater preponderance of sites with no (or minimal) modifications. The lower site surveyed had a good HQA score for its type, reflecting a high degree of habitat diversity (engineered through introduction of weirs). HMS, in contrast, most typically, are very low, but the Harbourne site, not surprisingly considering the capital scheme carried out, was classed in the worst quintile of scores for such rivers.



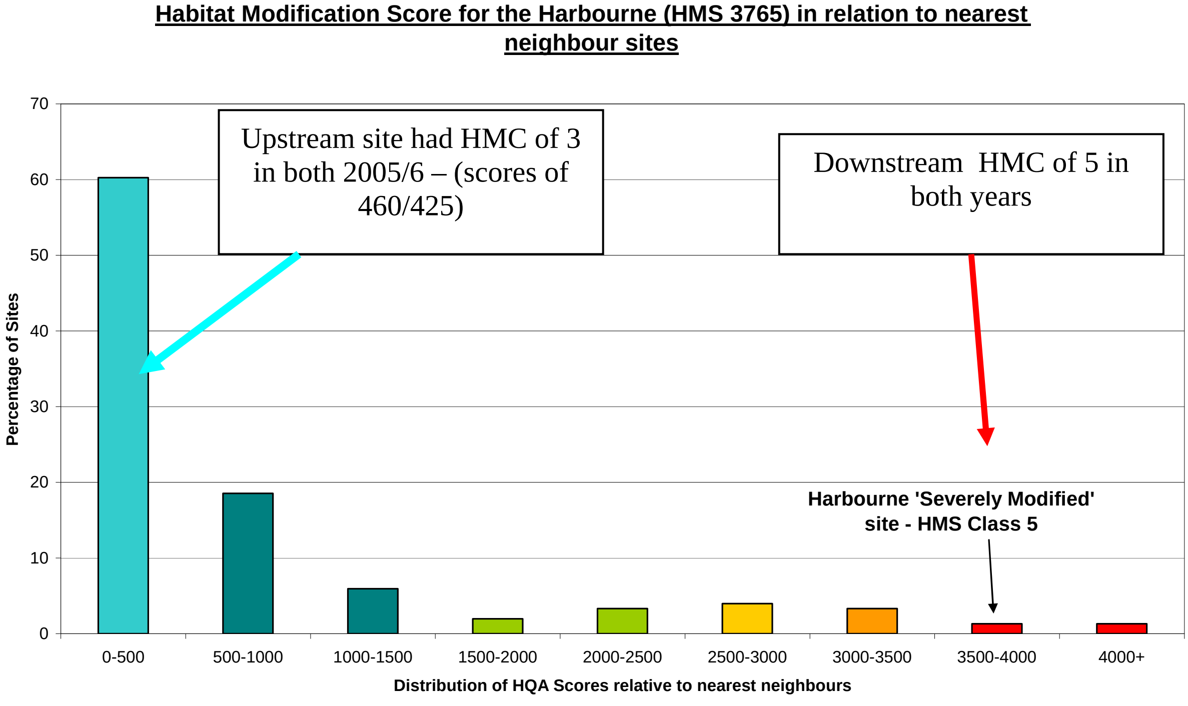
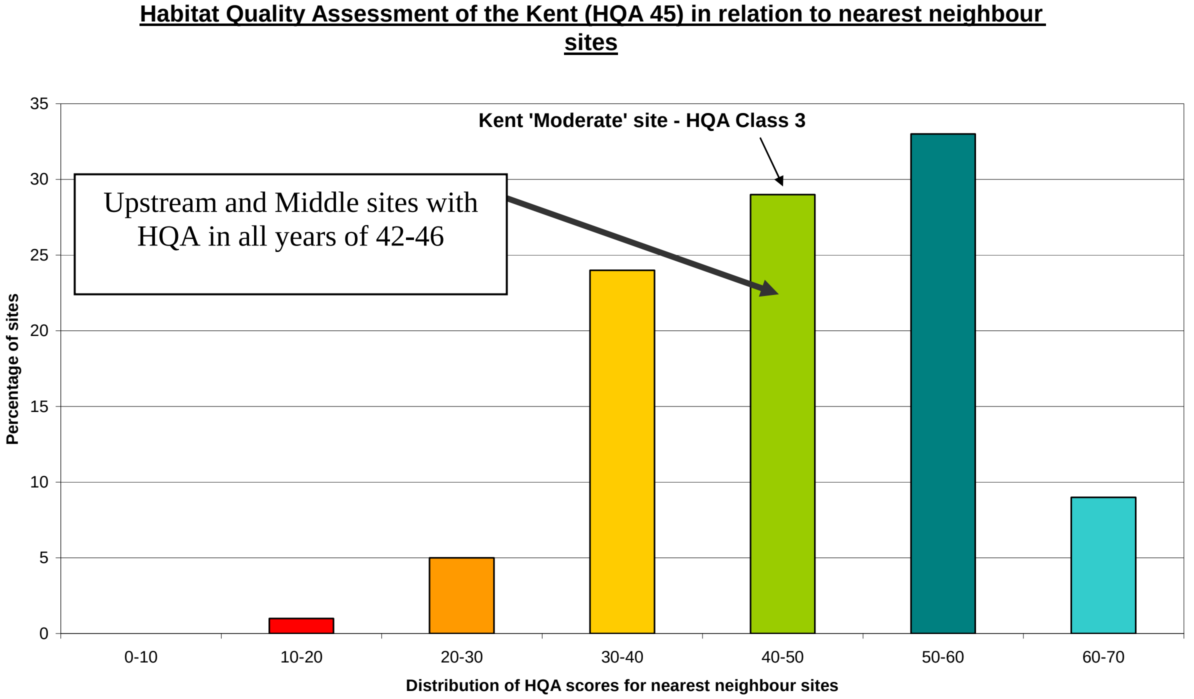
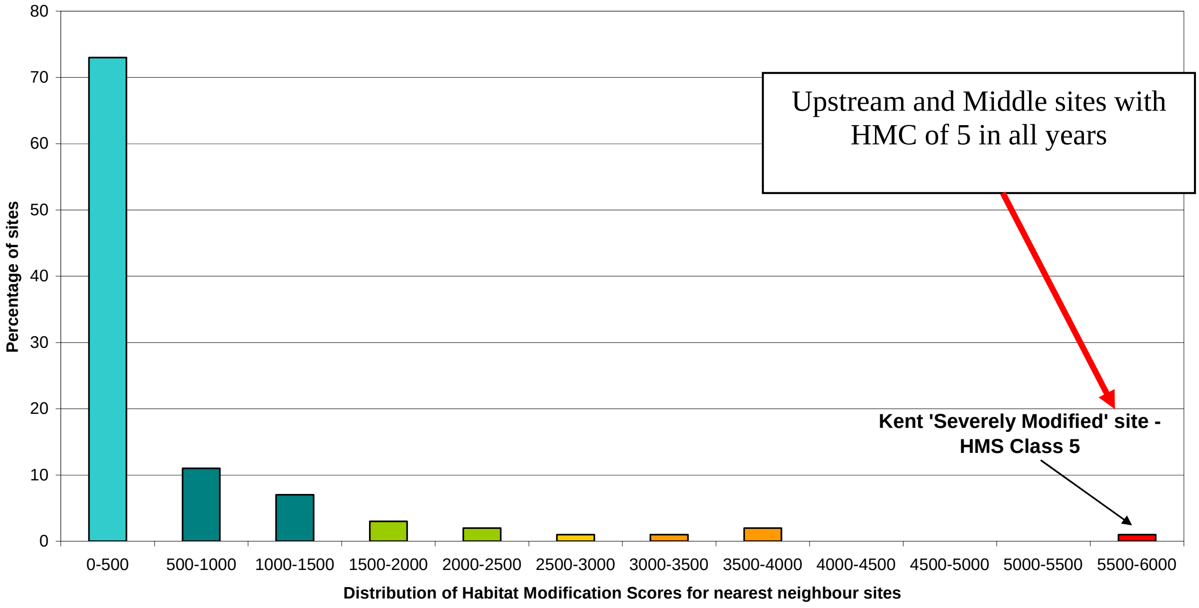


Figure 3.4 Range of HMS and HQA scores for the 150 nearest neighbour sites on the RHS database for the baseline data-set; the scores for the d/s HARBOURNE site in 2005 are shown for comparison

3.6 KENT

From the illustrated data in Figure 3.5 it can be seen that rivers similar to the Kent have a tendency to virtually never have even moderately low HQA scores less than 20, and commonly have sites scoring greater than 50. The middle site surveyed had a moderate HQA score typical of the type. The classification into the middle quintile is the same as for the Dearne, but the score is much higher. Both exhibit, therefore, moderate habitat diversity for their type, but the Kent has greater diversity than the Dearne. HMS, in contrast, most typically, are predominantly in the very lowest (best) category, but the Kent is in the worst quintile of scores for such a river, indicating severe modifications based on RHS rules (severe bed and bank armouring).





Habitat Modification Score for the Kent (HMS 5905) in relation to nearest neighbour sites

Figure 3.5 Range of HMS and HQA scores for the 150 nearest neighbour sites on the RHS database for the baseline data-set; the scores for the middle KENT site in 2005 are shown for comparison

4. A comparison of sites on the River Arun and Eden: based on RHS data

4.1 RATIONALE FOR WORK

Although the 5 key sites that make up the main focus of this research were carefully chosen to help demonstrate the key project objectives and highlight the main maintenance practices currently undertaken in England, nonetheless it was recognised that it would be beneficial to broaden the investigation and demonstrate how different maintenance approaches or no maintenance regime may affect habitat quality. It was decided that using the RHS database would be the most appropriate tool to use to identify appropriate reaches with similar characteristics. A decision was made to use a pilot site to evaluate if the RHS tool was sensitive enough to find sites with similar characteristics for comparison. Reaches that were similar in characteristics to those on the Eden were made the focus of investigation. The main reasons for choosing one site was because the project team were aware that collating the data from the RHS database in an appropriate format for this project's requirements and then visit the individual sites to collect repeat photographic evidence would take a significant amount of time to coordinate. This was especially so given that the RHS interrogation needs to completed by an Environment Agency employee who was unlikely to have prior knowledge or understanding of the aspirations of this project. The Eden was opted for because sufficient data needed to have been collected and analysed for the core site. At the point of RHS database interrogation significant amounts of data relating to the Eden catchment had been captured and this, together with the detailed knowledge from the Environment Agency about the sensitive management regime that was outlined for the Eden, made it the most appropriate candidate to focus on for the pilot study and to compare outcomes to sites that were noted as natural or semi-natural as opposed to obviously modified within the RHS database.

4.2 CHOICE OF SITES

A search of the RHS database was completed with the help of Alison Ingleby (Environment Agency). Initially the aim was to look for sites along the Eden in Kent that, not only had similar characteristics to the project reaches, but also had a good Habitat Modification Index (HMI) that indicated that they appeared to be either semi-natural (1) or pre-dominantly unmodified (2). It was recognised, however, that the number of sites that would have similar characteristics to those reaches associated with the key research sites and not fall into the HMI of 3 (obviously modified) would be limited. Thus the search was widened to encompass clay dominated catchments, with a bankfull width of between 5-15m in the Sussex, Kent or Surrey areas. Total Habitat Quality Assessment (HQA) scores and those that contributed to both in-channel and riparian characteristics were also provided. The full data was displayed on a colour-coded map showing the distribution of sites that had consistently good or bad scores in terms of the modification index: those with a score of 3 (obviously modified) were not included. Figure 4.1 shows the distribution of small clay river sites in S-E England with high and low Habitat Modification Classes (the location of the Eden is shown in RED, and the Arun, in BLUE). From the map it can be seen that only the Arun has consistently less modification than any other clay river in the Region.

From this information, a subset of the data was derived based on the fact that there were a series of sites relatively close together in geographical proximity that scored either a 1 or 2 for under the HMI. A further subset was derived from the fact that those in the lower part of the river are all tidally influenced and therefore would not provide an appropriate comparison to those on the Eden whilst some had no associated photos for comparison purposes. The final subset is shown in Table 4.1 with RHS data completed in 1996.

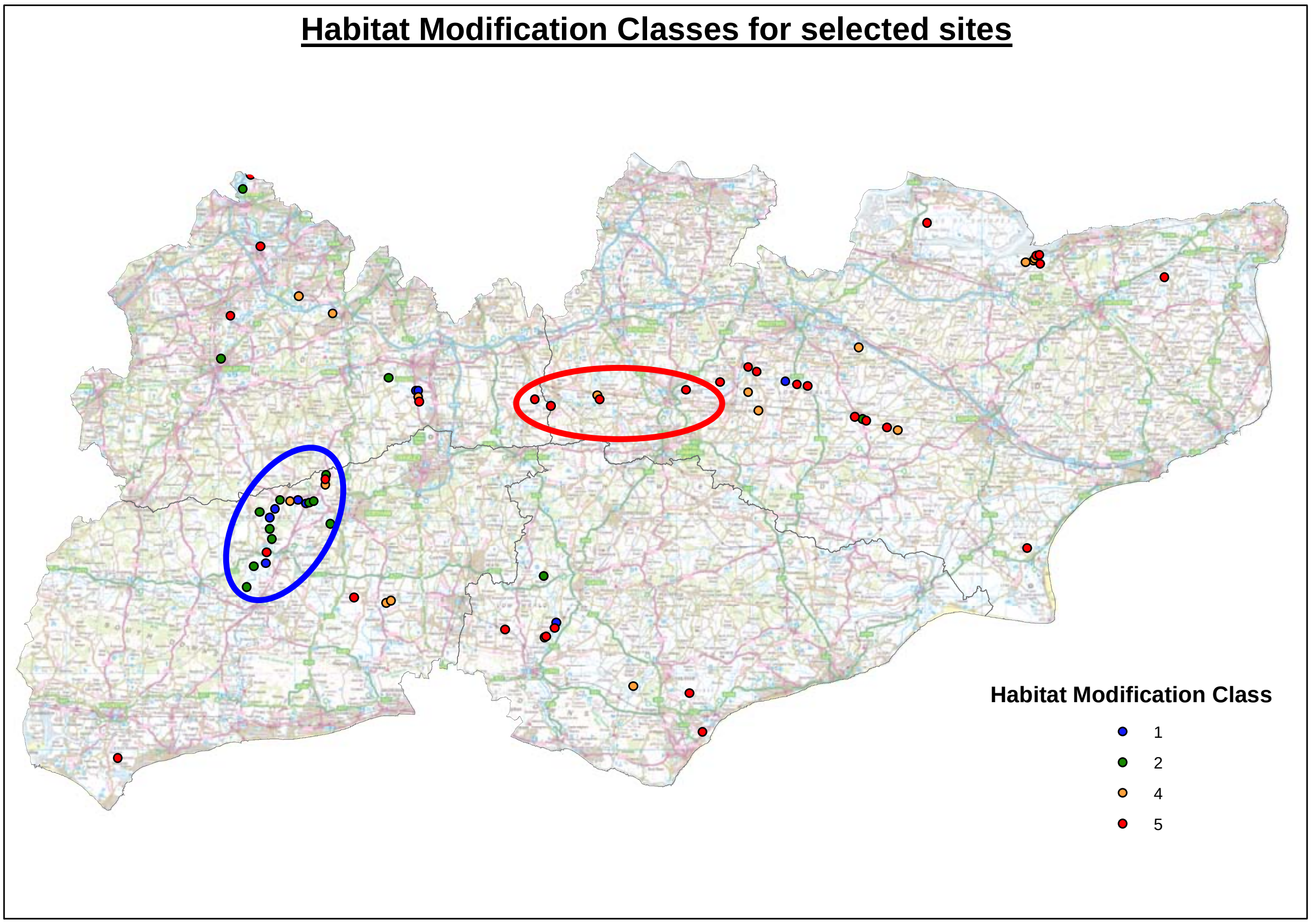


Figure 4.1 Distribution of small clay river sites in S-E England with high and low Habitat Modification Classes

Figure 4.2 shows the distribution of small clay river sites in S-E England with high and low Habitat Quality Assessment classes (again the location of the Eden is shown in RED, and the Arun, in BLUE). From the map it can be seen that only the Arun has consistently higher HQA scores than other clay rivers in the Region.

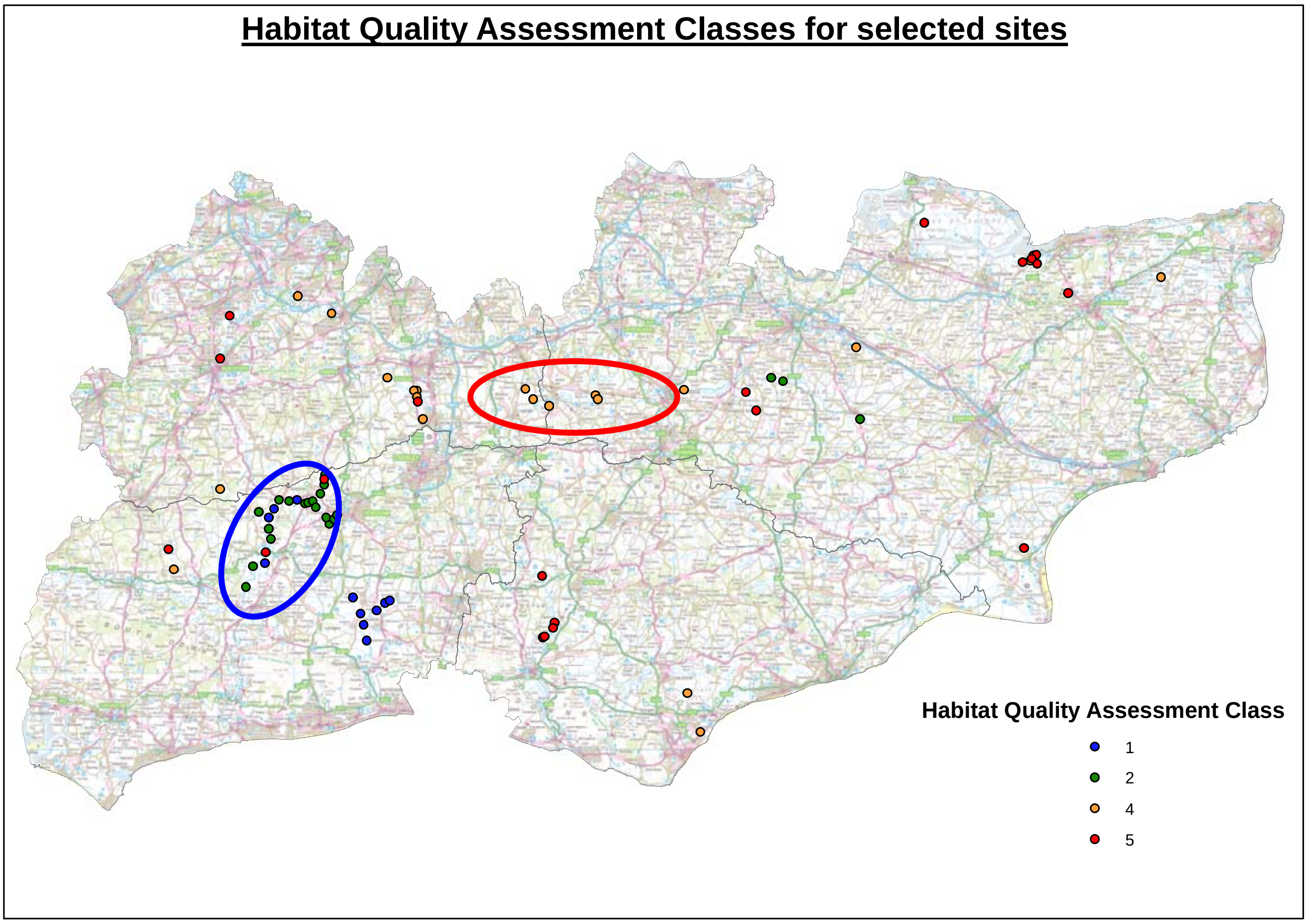


Figure 4.2 Distribution of small clay river sites in S-E England with high and low Habitat Modification Classes

Based on the fact that the Arun consistently had lower HMC and higher HQA than any other clay rivers in the region, this river was chosen for comparison with the Eden to determine if there were any consistent differences in management of the two rivers.

Before completing any site visits the Environment Agency were contacted to see if there was any historical maintenance schedule for the sites. In all cases it was revealed that no major maintenance had been completed at any of these sites during the last 10 years in terms of weed cuts. However, there has been some 'pioneering of trees and vegetation when required' which means the removal of woody debris under bridges and small amounts of vegetation removal on a very localised basis where it might be perceived to present a risk to property if water were to back up as a result of either the woody debris of vegetation encroachment.

Table 4.1 Location and habitat scores (1996) for the site visits along the River Arun

Coordinates	RHS data code	HQA Score	Bank Features	Bank Vegetation	Channel Features	Channel Substrates	Flow Type	Channel Veg	Trees
TQ1470029600	7352	42	1	11	2	6	5	10	4
TQ0370021300	13152	21	0	5	1	3	4	5	3
TQ0460024000	13154	31	1	9	4	4	5	6	2
TQ0620024400	13155	34	0	9	1	3	6	6	7
TQ0700027600	13157	38	0	10	3	3	7	6	6
TQ0670028900	13158	35	2	10	2	4	5	6	6
TQ0670030400	13159	31	0	9	2	4	5	6	4
TQ0540031100	13161	39	1	12	1	3	5	4	10
TQ0740031500	13162	33	0	11	0	3	3	4	11
TQ1040032700	13165	51	4	11	3	5	7	6	12
TQ1150032200	13166	46	0	12	3	6	7	9	7
TQ1190032300	13167	35	0	8	4	4	7	0	9
TQ1250032500	13168	43	1	11	2	5	8	5	9

4.3 COMPARISON OF RHS SCORES FOR THE RIVER ARUN DATA SET WITH THE EDEN

One of the key differences between the River Eden and the River Arun RHS data is the HMI code. In the case of the Eden all sites have been coded as 3 (obviously modified) whereas those for the Arun have either been coded as natural/semi-natural or pre-dominantly unmodified. The RHS manual acknowledges that even the most experienced surveyors can still overlook modifications and given the past now known history of maintenance along the Arun it would appear that this is the case here. On visiting the reaches (see also photographic evidence discussion below) there are clearly raised banks in places that are remnants of spoil heaps but it is recognised that without a lot of past experience of spotting these features they could easily be missed.

When a comparison is made between the total HQA scores between the 2 sites, interesting there is very little significant difference between the 2 sets of data with the exception of a few of the sites (compare Tables 4.1 and 4.2). Where over all scores do stand out there may be a range of explanations for this which can be inferred from the map locations. Key points are as follows:

Site 7352 is not located on the main Arun, but instead a small tributary. This section is clearly shown on the map as a section of watercourse that is highly sinuous in nature. In addition it is close to a wooded area, which when revisiting the site also turned out to be a local nature reserve. It is however, also shown as close to sewage works. When looking at the individual HQA scores the 2 components that are most instrumental in increasing the overall score are the bank vegetation and in-channel vegetation which could conceivable be a direct result of nutrients from the sewage works or because it is a more natural section. In the case of section 13165 (the reach achieving the highest overall score it is a combination of the bankside vegetation and tree cover that is significantly increasing the score whilst the map location shows this section as flowing though a wooded area. The other two reaches with scores over 40 are 13166 and 1368. Neither of these is on located on the main Arun and in the case of 13166 is clearly a drainage ditch with a score that is increased by in-channel vegetation maybe as a result of the associated low flow regime compared to the channel size predicted in this type of environment. Reach 1368 is located on the North River with the highest score for in-channel features which could be a reflection in this case of less past maintenance but this is not known.

Irrespective of site though, it appears that bank vegetation is a key component of all the HQA scores with more trees along the river Arun in most cases being instrumental in increasing the HQA scores slightly. Conversely bank features score low for both river systems. In most cases the Arun scores slightly higher then the Eden in terms of channel features which according to the RHS data scored zero for all reaches.

One of the key objectives of this section of the research was to establish what was influencing the scores between the two sets of data. Initial it was hoped that there would be a direct comparison between the known maintenance regime completed along the Eden and more natural sites along the Arun. However, since it was subsequently found out that maintenance had stopped just prior to the RHS data collection in 1996 it is interesting to note that overall the scores are not dissimilar and it would appear that for the most part, it is local influences such as tree cover that are affecting the scores. One clear difference is that in the case of the Arun data there are indications of some in-channel channel features as opposed to none. This justified the need to re-visit the site and try to re-examine the photographic evidence and to see if these features had significantly changed as a result of the minimalist maintenance regime now adopted at this sites.

Table 4.2 Summary of RHS data for the River Eden (2006) for the 3 reaches

Site	**Grid reference**	HQA Score	Bank Features	Bank Vegetation	Channel Features	Channel Substrate	Flow Type	Channel Veg	Trees
Upstream	4998846019	33	2	12	0	5	5	7	4
Middle	4981346400	27	0	12	0	8	8	6	0
Downstream	5049145662	34	2	11	0	5	5	4	5

4.4 COMPARISON OF ON SITE DATA (REPEAT PHOTOGRAPHY)

Repeat photography of the sites on the River Arun proved to be a difficult task. The main reasons for this were 6 fold:

1. Relocating the precise coordinates of the RHS reaches was difficult not least because the RHS data sets were collected pre GPS and therefore the references are only within 100m. It also appeared that some minor errors may have been introduced in the data handling which resulted in some of the coordinates being some distance from the watercourse. Whilst this has little impact on the information recorded for the reaches it made precise repeat photography extremely difficult.
2. The use of a different and digital camera has meant that the focal length is different and hence providing perfect repeats is almost impossible.
3. It is not known precisely what time of the year the RHS data was collect but it is assumed it was earlier in the year than the repeat photos (August 2007) were taken and this will have an impact on vegetation abundance recorded and the photographic repeats.
4. The site visits were delayed because of extremely high water levels in the weeks following. In some reaches it appeared that some of the vegetation had either been flattened or destroyed thus given perhaps, a false impression of the in-channel vegetation cover.
5. During the site visit period there was an outbreak of foot and mouth near Guildford and the exclusion zone extended to this area. The remaining repeat photographs were taken in March 2008.

6. No details were given of which side of the bank the photos were taken from so this sometimes made repeat photography difficult.

Despite these limitations it was still possible to complete some of the repeat photography and it was valuable to revisit the sites to compare and contrast changes that have occurred as a result of the changes in maintenance. The dates when repeat photography was completed are shown in the Table 3 and this must be taken into account when comparing the photographs. The information recorded below is also based on an overall brief assessment of the reaches as part of a rapid walk over survey.

Plates 4.1 to 4.17 are of sites on the Arun. In addition three photographs of the River Eden have been included as Plates 4.18 to 4.20 to aid the reader to make comparisons between the two rivers.

Table 4.3 Showing when repeat photographs were taken and key access etc issues

RHS data code	Repeat photo date	Comment
7352	August 2007	Access to precise site impossible – changes in landuse locally.
13152	August 2007	Virtually no change – reasonable likeness to Eden
13154	August 2007	Series of low sinuous meanders – difficult to identify precise bend but repeat photo reflects the overall reach characteristics
13155	August 2007	Range of macrophytes indicative of slow flow silty conditions
13157	August 2007	Very wide and pond like – acting as a silt trap
13158	August 2007	Very difficult to access due to significant sections of fencing. Large amounts of invasive species and access made a direct repeat very difficult but good example photo of reach features.
13159	March 2008	Photo taken in March 2008 due to foot and mouth access prevention in 2007. Difficult to find exact location but good example of reach characteristics.
13161	March 2008	Photo taken in March 2008 due to foot and mouth access prevention in 2007.
13162	March 2008	Wide and silty? Probably not best options
13165	March 2008	Foot and mouth prevented access!
13166	March 2007	This is not part of the main river – a drain? Into it
13167	March 2008	Foot and mouth prevented access!
13168	March 2008	Foot and mouth prevented access!

Note: All photos taken in March show high silt loading because of storm a few day prior to the visit.

Reference: 7532 (see Plate 4.1)

7352 – 1996	7352 – 2007
	

Plate 4.1 Tributary of River Arun: Photographs of section 7352

Key observations:

It was impossible to find precisely the same site. This may be because of the significant changes in surrounding land use including the development of an industrial estate which prevented access to most of the section. A photograph of a section upstream was taken but the level of confidence that it is a direct comparison to that shown in 2006 is very low.

The section close to the nature reserve however, did have a range of channel substrates and gravel areas with some small pool- riffle sequences along the channel (see Plate 4.2). In-channel vegetation was limited in this section though conversely tree cover was high. Trying to determine any changes in habitat quality or sediment as a result of maintenance changes was impossible to achieve given the on-site limitations.

Plate 4.2 River Arun: Gravel substrate in small tributary through wooded section at site 7352

Reference reach 13153 (see Plate 4.3)

13152 – 1996	13152 – 2007
	

Plate 4.3 River Arun: Repeat photographs of reach 13153

Key observations:

This section had hardly changed within 10 years. The photo is a good example of the characteristics of the whole reach. It appeared that the in-channel vegetation may have died back a little when comparing the sites but this hardly surprising since the Arun had been subjected to some high summer flows a few weeks previously (which had prevented the field work). A few additional trees had grown, but surprising few, which might mean that the local farmers may still be maintaining this reach on an ad hoc basis. On the photographic evidence and walkover survey this reach could be classified as very stable with the change of maintenance having very little impact.

Reference reach 13154 (see Plate 4.4)

13154 – 1996	13154 - 2007
	

Plate 4.4 River Arun: repeat photographs of section 13154

Key observations:

This whole reach showed little change in characteristics since 1996. Overall bank vegetation was similar and flow characteristics were generally sluggish. The 1996 RHS data indicates some in-channel vegetation some of which was still present but very patchy along the reach. There is still a significant amount of silt in this section and limited indication of gravel substrate. The channel may be narrowing in places but this seems to be mostly related to local bank failure. Some small trees are beginning to grow but these are not in any sufficient numbers to increase the original tree habitat score.

Reach 13155 (see Plate 4.5)

13155 – 1996	13155 - 2007
	

Plate 4.5 River Arun: Repeat photography of reach 13155

Key observations:

Little overall change was observed in terms of overall dimensions or bank characteristics. However, there did appear to be a large amount of silt in this reach. Despite being August and, given the floods earlier in the year, there was still a significant amount of in-channel vegetation indicative of silty, slow flowing conditions. Apart from this little changed could be observed as a result of the cessation of maintenance.

Reference reach 13157 (see Plate 4.6)

13157 – 1996	13157 - 2007
	

Figure Plate 4.6 River Arun: Repeat photography of reach 13157

Key observations:

In 1996 this was a wide pond-like section with a considerable amount of lilies and pondweed within the watercourse. This section does not appear to have changed.

Reach 13158 (see Plate 4.7)

13158	RHS 2007
	

Plate 4.7 River Arun: Repeat photography of reach 13158

Key observation:

This whole section has been fenced sometime since 1996 and, given its relatively un-weathered state, this is more likely to have been within the last few years. This has resulted in a change of bank vegetation with a significant amount of invasive species noted (especially Himalayan balsam and Giant hogweed). In terms of in-channel morphological changes there appear to have been very little change but habitat features may have declined as a result of the change in bankside vegetation cover.

Reach 13158 (see Plate 4.8)

13159 -1996	13159 – 2008
	

Plate 4.8 River Arun: Photographs of reach 13159

Key observations:

The repeat photographs at this site had to be taken in March 2008 because of the foot and mouth restrictions last summer. An exact replica was impossible to achieve but nonetheless, the photograph is a good example of the whole reach. There is a marked change in the amount of live bankside vegetation, which gives a false impression of the width of channel. The vegetation (which had recently been battered by a large flow event) was still clearly visible and lilies were still present within the watercourse. Overall there appeared to be little change in this section as a result of the change in weed cutting regime.

Reach 13161 (see Plate 4.9)

13161- 1996	13161 - 2007
	

Plate 4.9 River Arun: Photographs of reach 13161

Key observations:

Most notable here has been the change in the amount of tree cover in this whole reach. Hawthorn in particular has become more prevalent along the banks. This in turn is now beginning to fall into the river with no obvious signs of management to remove it. It is in the locations where the wood has remained that the major changes in flow dynamics and bed variation has occurred (see Plate 4.10).

Plate 4.10 River Arun: An example of large wood within the channel supporting natural river hydromorphological processes

Reach 13162 (see Plate 4.11)

13162 - 1996	13162 - 2007
	

Plate 4.11 River Arun: Photographs of reach 13162

Key observations:

Although finding the exact spot to compare photographs was not possible, nonetheless this section is similar to much of the River Arun in terms of its wide, silt bed. It was, however, highlighted in having significant tree cover in this section within the RHS data collected in 1996. The amount appears to have remained fairly static.

Reach 13165 (see Plate 4.12)

13165 - 1996	13165- 2007
	

Plate 4.12 River Arun: Repeat photographs section 13165

Key features:

Unlike other sections the repeat photograph was easy to find here. It shows the outside of a bend with a deep pool and over-wide section consistent with natural processes. Although the bankside vegetation was limited because of the time of the year compared to the 1996 photograph, it was easy to see that the overall morphology of this section at the pool had not significantly changed. Just upstream, however, there was some evidence of channel narrowing (possibly through local bank slumping) and this has resulted in locally improved flows and the beginning of the formation of a run (Plate 4.13). It will be interesting to see if this change in flow dynamics, which is now clearly pushing the thalweg over to the pool, will cause any morphological changes in the future. In the 1996 RHS, the key features of this reach were bank vegetation and tree cover, although flow type and channel substrate scored relatively well compared to other locations (7 and 6 respectively). Overall it was this reach that scored most highly. Upstream there is a small tributary which is highly sinuous with gravels in the bed that will be feeding this reach where gravels are present in places.

Plate 4.13 River Arun showing local narrowing and the beginning of the formation of a small run.

Reach 13166 (see Plate 4.14)

13166-1998	13166- 2007
	

Figure Plate 4.14 Tributary of River Arun: repeat photos of reach 13166

Key features:

This section is not on the main river but is a drain. There has been significant changes in land management along side the watercourse and a track has resulted in clearance of vegetation on one bank. The channel was coded as having reasonable amounts of in-channel vegetation (9) in the 1996 RHS. It is assumed (given the amount of Apium Nodiflorum) present in March that this encroaches across the drainage ditch in summer but becomes more free flowing in winter. The overall morphology does not appear to have changed.

Reach 13167 (see Plate 4.15)

13167 - 1996	13167 -2008
	

Plate 4.15 River Arun: repeat photographs of reach 13167

Key observations:

The bank vegetation in this section had clearly been recently affected by the local high flows. In addition the trees had been cleared on the left hand bank, probably related to the new track that has been made associated with a house on that bank. As with most of the other sections visited along the Arun, the channel features are limited. There are some in-channel features and these are being enhanced though local bank failure (see Plate 4.16) which should over time help to narrow over-wide sections.

Plate 4.16 River Arun showing local bank failure which may help to narrow overwide reaches over time.

Reach 1368 (see Plate 4.17)

13168- 1996	13168 - 2008
	

Plate 4.17 Tributary of River Arun: repeat photographs of Reach 1368

Key observations:

This reach is not on the main River Arun but instead located on the North River. The RHS highlighted the highest score for flow type probably because of the slightly higher gradient of this channel. On the day of the site visit in March it was difficult to see the bed of the river, as was the case with all sites visited in March, due to the heavily silt laden flow following the storm the week before. However, probing the bottom of the bed with a ranging pole did confirm sections of hard bed. As with some of the other reaches, one of the main opportunities for variations in flow patterns was directly related to the deposition of large wood.

4.5 SUMMARY OF REACHES

The comparison of the data for the Arun has highlighted some key issues for each reach as summarised in Table 4.4.

In addition it has shown that:

- Identifying heavily modified sections is a difficult task and can have a major impact on RHS analysis in terms of defining comparison sites when trying to understand the effects of river maintenance
- There is a high silt load in the Arun catchment and the Arun, even 10 years after cessation of weed cutting, remains very silty, overwide and sluggish in nature for the most part with bank vegetation and trees still providing the highest contribution to habitat features.
- In tree lined areas, where they have been allowed to fall into the river, it is these sections that demonstrate the majority of flow variation characteristics.
- Banks are slumping in a few places and this has resulted in the beginning of improved hydraulic conditions.
- Some reaches remain devoid of tree cover despite the cessation of maintenance; are local farmers still taking on ad hoc maintenance?

Table 4.4 Observed impact due to cessation of maintenance

Site reference	Observed impact due to cessation of maintenance
7352	None derived – impossible to make assumption since no easy access to site and changes in surrounding land use.
13153	Very stable – limited change – a few more trees – as these being removed by local farmer?

13154	Limited change – no increase in tree cover (as above) possible localised narrow due to some small amounts of bank failure
13155	Possible increase in silt and encroachment of juncus etc into the watercourse
13157	No obvious changes – remains a wide ponded reach with significant amounts of in-channel vegetation
13158	Fencing along this section has resulted in notable levels of invasive species which is likely to have affect bankside vegetation feature scores. In channel is very similar to 1996
13159	Little obvious change – still a silty section with ponded reach type of in-channel vegetation
13161	Significant increase in bankside tree cover. Little change in channel morphology except where trees had fallen into section. At these localised points there was clear increases in channel form and processes
13162	Little change – tree cover relatively high in 1996 but appears to have remained static.
13165	Key noticeable change is the increase in size of an side channel bar, with resultant narrowing and improved hydrological properties. With this affect the downstream pool area over time?
13166	Little change associated with in-channel weed cutting.
13167	Some slumping of banks
13168	This is the North River. There is a high level of tree cover and where trees have fallen into the watercourse this has resulted in improved hydromorphological conditions locally.

It has been 10 years since any annual maintenance programme has been carried out on these reaches. However, in most cases the change in morphological features appears (based on a very rapid site visits) to be changing very slowly with the more rapid habitat and hydromorphological feature changes being related to bankside trees. Initially this was encouraging but the repeat visits to the sites seemed to suggest a lack of visible evidence for the impact of reduced maintenance

Plate 4.18 River Eden 2007 upstream reach

Plate 4.19 River Eden: Middle reach

Plate 4.20 River Eden: Downstream reach, 2007

5. Conclusions

For all the sites the HQA and HMS scores were determined for the study sites. These scores were then compared with scores from other, similar rivers. This comparison showed that, in general, the selected sites were representative of that river type. The HQA scores were, in general, well within the range expected for those river types. One surprising but local anomaly was that the sub-reach of the Harbourne through Harbertonford which had been subject to a flood alleviation scheme had a higher HQA score than the less disturbed sub-reach upstream.

The HMS scores indicate the amount of modification that has taken place to the river channel morphology. All the sites had been selected as they have been subject to either maintenance or capital works and so it is not surprising that all of the sites have HMS that are in the worst quintile. Considering variations between the sub-reaches studied at the sites it is noticeable that for the Kent the HMS for the lowest sub-reach is substantially smaller than for the upstream two sub-reaches, which one would expect as the upstream sub-reaches have been subject to major alterations through the centre of Kendal. It is perhaps more surprising that at the other sites there is not greater diversity in the HMS scores between the different sub-reaches reflecting the differences in management techniques between the sub-reaches.

It has to be appreciated, however, that the RHS scores include many factors which are unaffected by in channel maintenance and, therefore, high or low overall scores or differences in scores may arise from factors unrelated to in-channel maintenance.

Comparison of the RHS Flow Type sub-scores with detailed analysis of the channel hydraulics, see Appendix 5, suggests that the values of the sub-scores correlate with the flow diversity in terms of velocity and depth. The analysis also shows that these sub-scores are impacted by in-channel maintenance. This shows that in-channel maintenance does impact on flow diversity and that this is reflected in RHS scores. It further shows that this impact can be predicted with the use of modelling.

Comparison of the geomorphological observations (Appendix 6) with those of the RHS shows that there is an issue with the scale of the features that are recorded within RHS. Experience has shown that RHS provides an excellent approach to assessing the overall habitat quality of rivers. The scale of in-channel sediment related features may however be on a spatial scale which is smaller than the spacing of the RHS survey sections so they may not always be fully recorded within a standard RHS survey. Due to the nature of this study, such small scale features were recorded within this study but this is not standard practice. The presence or absence of sediment related features may be reflected, however, in some of the sub-scores such as:

Channel features and
Flow type.

The comparison of the Eden with the Arun was undertaken on the basis of an analysis of the RHS database to identify similar rivers in the geographical area. The Arun was distinctive in being a similar river in the same area but with significantly less evidence of modifications. The HMI code for all the sub-reaches on the Eden was ‘obviously modified’ while for the Arun the sites were coded as ‘natural/ semi-natural’ or ‘predominantly unmodified’. Comparison of the HQA scores for the two rivers showed little significant difference except for a few sites where the difference could be explained by local conditions. In contrast to the Eden, the Arun had not been subject to in-channel maintenance for ten years. This suggested that the differences in the values of the HMI reflected this difference in maintenance in the recent past. Visits to sites on the Arun, however, showed that there had been little or no development of in-channel sediment related features in the last ten years. It would appear that the differences in HMI code between the Eden and Arun arise from factors unrelated to in-channel maintenance.

The RHS studies that have been carried out suggest that RHS data and associated metrics can be used to provide information about the impact of in-channel maintenance. Values of HQA are likely to be too broadly based to provide information in sufficient detail and it is likely that individual sub-scores would have to be used. Of these the most useful would probably be the Channel Features and Flow Type sub-scores.

6. References

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Raven, P J, Holmes, N T H, Dawson, F H, Fox, P J A, Everard, M, Fozzard, I and Rouen, K J (1998). *River Habitat Survey Quality: the Physical Character of Rivers and Streams in the UK and the Isle of Man*. Environment Agency, Bristol.

Appendix 3 Macrophytes

1 Introduction and methods

Macrophytes (plants visible to the naked eye and identifiable in the field) were surveyed on all five river reaches. Surveys on the Long Eau, Dearne, Eden and Harbourne were carried out in 2005 and 2006; on the Kent surveys were carried out in the three years 2005-2007.

The main survey method employed was the Mean Trophic Rank (MTR) system (Holmes *et al.* 1999a). Using the MTR system, an indication of the trophic (nutrient) status of the water and sediment can be gained from the results of the survey. Details of what the cover value scores mean in terms of cover, and how they are used for calculating trophic scores, are given in Annex 1. Two MTR sites were surveyed in each of the 500m RHS sites except for the downstream site on the River Kent. In total, therefore, 27 MTR sites were surveyed. The locations of the survey sites are shown on the maps in Appendix 9.

In addition to the MTR surveys carried out, a one-off 500m site was surveyed on the Long Eau, Dearne, Eden and Kent using another standard method that can be used to characterize the watercourses in a national classification. The Joint Nature Conservation Committee (JNCC) method (Holmes *et al.* 1999b) is the standard approach taken by conservation agencies (in England - Natural England) to survey streams for macrophytes and to assess their conservation value. The method involves recording species occurring in 500m lengths, coding the occurrences on a three-point scale of abundance, and making separate records for species within the bed of the channel, and those at the base of the bank. Data from these surveys have been entered on to the national database. A site on the Harbourne was not surveyed since the control and managed sites were so different.

The Mean Trophic Rank (MTR) method (Holmes *et al* 1999a) involves recording species occurring in 100m lengths: being smaller units, accuracy of coding abundance can be done more accurately and occurrences are recorded on a nine point scale of abundance, with records made for species on a defined check-list. Originally the method was developed to enable plants to be used for water quality assessment, but recently (Environment Agency 2007) the check-list has been extended to enable use for water resources Catchment Abstraction Management Strategies (CAMS) and Water Framework Directive characterization. The survey at the sites included searching for, and recording if present, all the additional taxa on the check-list. The taxa on the new EA check-list have been identified on the survey result sheets so these data can be added to the EA's BIOS database (as it is consistent with the 2007 methodology). Data have been provided to Area biologists for this purpose should they wish to do so.

The 500m JNCC sites were identical to one of the RHS survey sites in each of the four rivers Long Eau, Dearne, Eden and Kent; for locations of which one was selected, see Appendix 9. The smaller 100 MTR sites were selected within all the 500m RHS sites in the five river reaches so that two representative samples were taken. These sites were also chosen in locations where the exact upstream and downstream limits could be clearly defined and determined in the field (thus allowing repeat surveys at anytime in the future by new personnel). GPS references for the upstream and downstream limits of the sites were recorded. Maps were drawn to help define the sites, and these have been sent to EA Area biologists for future reference, together with the recording sheets on to which summary information on physical attributes of the sites is recorded. The macrophyte surveys at each site were carried out by walking the banks of the sites first, noting all taxa present (as well as rough proportions of each taxon) before wading within the rivers for closer inspection. More intensive searches were made within the 100m sites until one complete traverse of the site failed to find any additional taxa, and no re-adjustments to cover value scores were made.

Data for MTR surveys for each river were entered on to excel spreadsheets, with separate spreadsheets for each river. Data for JNCC surveys were entered alongside each other for the four rivers on one spreadsheet prior to the data being entered on to the dedicated JNCC templates before submission to the JNCC lead freshwater coordinating officer (Alison Lee) in Edinburgh.

Using the JNCC classification (Holmes *et al*. 1999b) sites can be classified into one of ten river River Community Types (RCTs). For more information, and interpretation of the data within Table 1.2, see Annex 1.

The following sections present the details of the macrophyte data furnished from the surveys carried out for the project, as well as making note of any data furnished for coincident, or adjacent, sites collected by the EA. In this introduction a summary of the MTR scores derived for each site is given in Table 1.1 and illustrated graphically in Figure 1.1. The data for the JNCC sites is given in Table 1.2.

From the derived MTR scores shown in Figure 1.1 it can be easily seen that the scores are lowest for the Long Eau and Dearne, intermediate for the Eden, and highest for the Harbourne and Kent. The data clearly confirm the eutrophication from which the Long Eau and Dearne suffer, and the more pristine waters of the Harbourne, and more particularly the Kent.

Long Eau						
	Upstream Sub-reach A	Upstream Sub-reach B	Middle Sub-reach A	Middle Sub-reach B	Downstream Sub-reach 1	Downstream Sub-reach 2
2005	26	23	21	23	25	24
2006	31	34	30	26	28	24
Dearne						
	Upstream Sub-reach 1	Upstream Sub-reach 2	Middle sub-reach A	Middle Sub-reach B	Downstream sub-reach A	Downstream sub-reach B
2005	20	22	22	19	25	23
2006	21	22	24	23	25	23
EDEN						
	Upstream Sub-reach 1	Upstream Sub-reach 2	Middle Sub-reach 1	Middle Sub-reach 2	Downstream Sub-reach A	Downstream Sub-reach B
2005	33	32	33	32	35	35
2006	33	30	33	30	34	33
HARBOURNE						
	Upstream Sub-reach 1	Upstream Sub-reach 2	Downstream Sub-reach A	Downstream sub-reach B		
2005	47	47	43	48		
2006	51	53	46	48		
Kent						
	Upstream Sub-reach 1	Upstream Sub-reach 2	Middle Sub-reach 1	Middle Sub-reach 2	Downstream Sub-reach 1	
2005	53	56	54	56	51	
2006	53	53	57	54	53	
2007	51	52	50	54	50	

Table 1.1 Summary MTR Scores for all Surveys

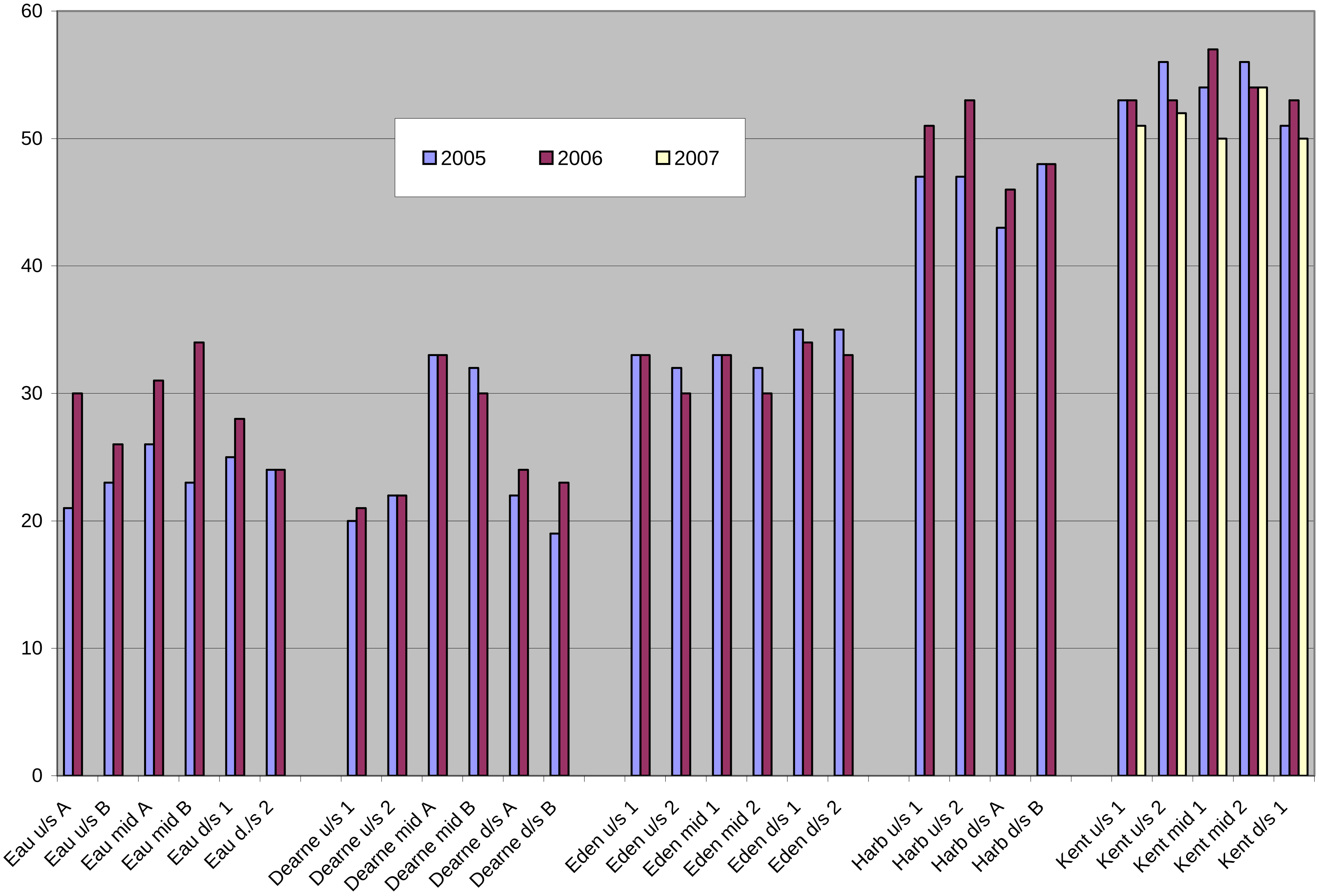

Figure 1.1 Summary MTR Scores for all Surveys

Species/sites		KENT	DEARNE	EAU	EDEN
Phormidium	Blue-green-alga felt	1100		1100	
Hildenbrandia rivularis	Red encrusting alga	1100			2200
Batrachospermum sp.	Toad-spawn alga				
Cladophora agg.	Blanketweed	1100	3300	1100	2200
Cladophora aegagropila	Axeminster alga	1100			
Vaucheria agg	Mole-pelt alga	1100	2300	2200	
Enteromorpha/Ulva	Tube-weed		1100	2200	1100
	Diatom film			2200	
	Other filamentous algae	1100			
Encrusting lichen	Encrusting lichen	1111			1100
Conocephalum conicum	Liverwort	0011			
Lunularia cruciata	Liverwort	0011			
Pellia endiviifolia	Liverwort	1111			1111
Amblystegium fluviatile	Moss	1122			1111
Brachythecium rivulare	Moss	0022			
Calliergon cuspidatum	Moss	0011			
Cinclidotus fontinaloides	Moss	1122			1111
Cratoneuron filicinum	Moss	0011			
Dichodontium spp.	Moss	0011			
Dicranella palustris	Moss	0011			
Fissidens sp(p.)	Moss				1100
Fontinalis antipyretica	Willow Moss	1100	1100		
Fontinalis squamosa	Moss	1100			1111
Leptodictyum riparium	Moss	1100	1111		1111
Rhynchostegium riparioides	Moss	2200	1100		1111
Schistidium rivulare	Moss	0011			
Thamnobryum alopecurum	Moss	1111			
	Ferns	0011			
Angelica sylvestris	Angelica				0011
Apium nodiflorum	Fool's Water-cress			1111	1111
Callitriche obtusangula	Blunt-fruited Starwort				1100
Callitriche platycarpa	Various-leaved Starwort				1100
Callitriche hamulata	Starwort	1100			
Callitriche stagnalis	Common Starwort	1100	1111		1100
Epilobium hirsutum	Great Willow-herb	1122	1122	1122	1133
Eupatorium cannibinum	Hemp Agrimony		0011	1122	1122
Filipendula ulmaria	Meadowsweet	0011	1111		1122
Heracleum mantagazzianum			0011		
Impatiens glandulifera	Indian Balsam	1122	0011		0011
Lycopus europaeus	Gypsywort		1111	0011	1111
Lythrum salicaria	Purple Loosestrife		0011	0011	1111
Mentha aquatica	Water-mint	0011	1111	0011	1122
Mimulus guttatus agg.	Monkey-flower	1111		0011	
Myosotis scorpioides	Water For-get-me-not	1111	1111		1111
Myriophyllum alterniflorum	Alternate W-milfoil	1100			
Nuphar lutea	Yellow Water-lily				3300
Oenanthe crocata	Hemlock Water-dropwort	1111	1111		1111
Persicaria amphibia	Amphibious Bistort				1111

Persicaria hydropiper	Water-pepper	0022	1122		1111
Petasites hybridus	Butterbur	0011			
Ranunculus fluitans	River Water-crowfoot	2200			
Ranunculus sceleratus	Celery-leaved crowfoot				0011
Ranunculus pen. vertumnus	Brook Water-crowfoot	3300			
Rorippa nasturtium-aquaticum	Water-cress	1111	1111	1111	1111
Rorippa sylvestris	Creeping Yellow-cress	1122			
Sagina procumbens	Pearl-wort	0011			
Scrophularia auriculata	Water Figwort	0011	0011	0011	0011
Senecio aquaticus	Marsh Ragwort	0011			
Solanum dulcamara	Bittersweet		1111	2222	1111
Stachys palustris	Marsh Woundwort		1111		1111
Tussilago farfara	Coltsfoot	0011	0011		
Veronica beccabunga	Brooklime		1111		1111
other dicots	not aquatic flowering plants	1122	1122	1133	1122
Alnus glutinosa	Alder	0011			1111
Salix spp.	Willow/Sallow	0011	1133	0011	1122
other trees/shrubs	Other trees	0011	1111	0011	0022
Alisma plantago-aquatica	Common Water-plantain		1111		1100
Butomus umbellatus	Flowering Rush				1111
Carex riparia	Greater Pond-sedge				0011
Elodea canadensis	Canadian Pondweed	1100			1100
Elodea nuttallii	Nuttall's Waterweed		1100		1100
Glyceria maxima	Reed Sweet-grass		1122	3333	2233
Glyceria sp(p.) other taxa	sweet-grass sp(p.) indet.	1111	1111	1111	1111
Iris pseudacorus	Yellow Flag		0011		1111
Juncus acutiflorus	Acute-flowered Rush	1111	1111		1111
Juncus effusus	Soft Rush	0011	0011		0011
Juncus inflexus	Hard Rush		0011	0011	0011
Lemna minor	Common Duckweed		1100	2200	2200
Lemna minuta	Minute Duckweed		1100	1100	2200
Phalaris arundinacea	Reed Canary-grass	1133	1133		
Phragmites australis	Common Reed		1111		
Potamogeton crispus	Curly Pondweed	1100	1100		
Potamogeton pectinatus	Fennel Pondweed		3300	1100	
Schoenoplectus lacustris	Bulrush		1100		1100
Scirpus sylvaticus	Wood Club-rush				1111
Sparganium erectum	Branched Bur-reed	1100	2200	2211	3322
Spirodella polyrhiza	Greater Duckweed				2200
Typha latifolia	Common Reedmace		2222	2200	
Zannichellia palustris	Horned Pondweed			1100	
other (non-aquatic) monocots	monocots not aquatic	1133	1133	1133	1122
River Community Type		VI	II	II	I
Number of Scoring Taxa		53	43	25	54

Table 1.2 Tabulated JNCC data for: Kent @ Kendal – Reach 1 at top (2007); Dearne – site 2 in the most engineered section (2006); Eau – Mid-site 1 (2006); Eden – Mid-site (2006). For interpretation of data see Annex 1.

2 LONG EAU

Appendix 9: Maps 1 to 3 show the project reach, incorporating three 500m reaches surveyed using RHS. The most upstream sub-reach (Appendix 9: Maps 1 and 7) has been subject to having a partial width of the vegetation cut annually, the middle sub-reach (Appendix 9: Maps 2 and 8) has been subject to 'habitat enhancement' and the downstream 500m, where vegetation is cut from bank toe to bank toe, is the downstream sub-reach, Appendix 9: Maps 3 and 9). Appendix 9: Map 6 also shows the location of the EA site where recent MTR data have been collected.

Two surveys, one in 2005 (29th July) and the other in 2006 (April 29th), were carried out. In 2006 the survey was carried out in spring so that habitat characteristics of the site could be recorded. In summer the extent of vegetation obscures all evidence of small habitat variations.

Upstream Site - Long Eau (TF40105 85553 to 40280 85887). This is the upstream of the two 'modified management' stretches. 2 MTR sites.

The flora throughout this sub-reach and within the MTR units was very impoverished, as in the other modified management reach. Over time, if flow diversity and edge habitat variety increases, the flora should respond positively; however, the diversity within the catchment may limit this.

Middle reach - Long Eau –- TF 40599 86033 to 40847 86330. This is the sub-reach where the left bank embankment has been removed, some habitat rehabilitation carried out (installation of gravel to form 'riffles'), and sympathetic weed management (partial width removal) implemented. Two MTR sites were surveyed. The sub-reach is noteworthy for having four artificial 'riffles' installed, the effect of which is minimal in summer low flows (except to pond water upstream), and only with minor influence in higher flows. Discrete silt deposit features were less evident than in the upstream sub-reach, perhaps due to the older nature of these works here, and the presence of the artificial riffles creating smooth flow evenly upstream and impacting the natural tendencies for such deposits to develop on the lee of obstructions, or on the inside of meanders. Reed Sweet-grass fringes were common in the lower part of the sub-reach.

The annual vegetation management has been modified from removing all the vegetation from bank toe to bank toe, to leaving fringes on either side of the river. Both surveys suggest this is having no major benefit on diversifying flow character as the over-riding influence is from the artificial riffles, and the ponding effects they have.

The flora throughout the site, and within the MTR units, was very impoverished.

Long Eau Downstream TF41034 86605 to 41258 86905 This is a high level carrier with unmodified embankments; the vegetation in the channel is cut full width (min 10% left) once per annum in contrast to the approximately 50% cut on the upstream sub-reaches. Two MTR sites were surveyed.

None of the vegetated silt deposits present resembled discrete bars at the time of the macrophyte survey. Then, the vegetation choked the channel, raising water levels, drowning the RHS observed features, and producing negligible flow velocities.

In the spring 2006 survey there was clear evidence of depth, velocity and other diversity within the reach, but mainly due to the presence of seven artificial riffles. In many ways the upper ones have the potential to perform more naturally as they could narrow flows and in addition there is common reed encroaching from the margins. The flora was slightly more diverse than in the modified management sub-reaches, perhaps because the removal of the encroaching reeds provides open habitat for more competition-sensitive species to colonize.

All the sub-reaches had poor floras and very low MTR scores indicating poor water quality (as poor as the Dearne). In July 2005 vegetation growth was so great it raised water levels and occluded all features. The survey in 2006 was carried out in the spring so that features could be noted.

MTR survey data are given in Tables 2.1 and 2.2, the first listing all MTR taxa and their cover values, and the latter listing the non-MTR taxa also recorded. Figure 2.1 illustrates graphically the MTR scores for the sites surveyed. This shows that all were low (indicating enrichment), and the scores for 2005 were consistently lower than in 2006. Surveying in spring in 2006, rather than summer 2005, meant that there was much less algal cover at the time of the survey, as well as an absence or rarity of low-scoring higher plant macrophytes such as *Potamogeton pectinatus & Zannichellia*.

The macrophyte surveys show, therefore, that the flora of the whole reach is extremely limited, and reflects high levels of eutrophication. The management measures that have been implemented have either not been operating long enough, or are insufficiently different, to have made a difference to the flora. A prime reason that no difference has been observed is that during summer low flows the discharge is so small that the proportion of channel vegetation removed needs to be much less than even 50% of the channel width to help create a self-cleansing low-flow channel. It also would require the same area to be cleared each year, allowing the remainder of the width of the channel to accrete sediment.

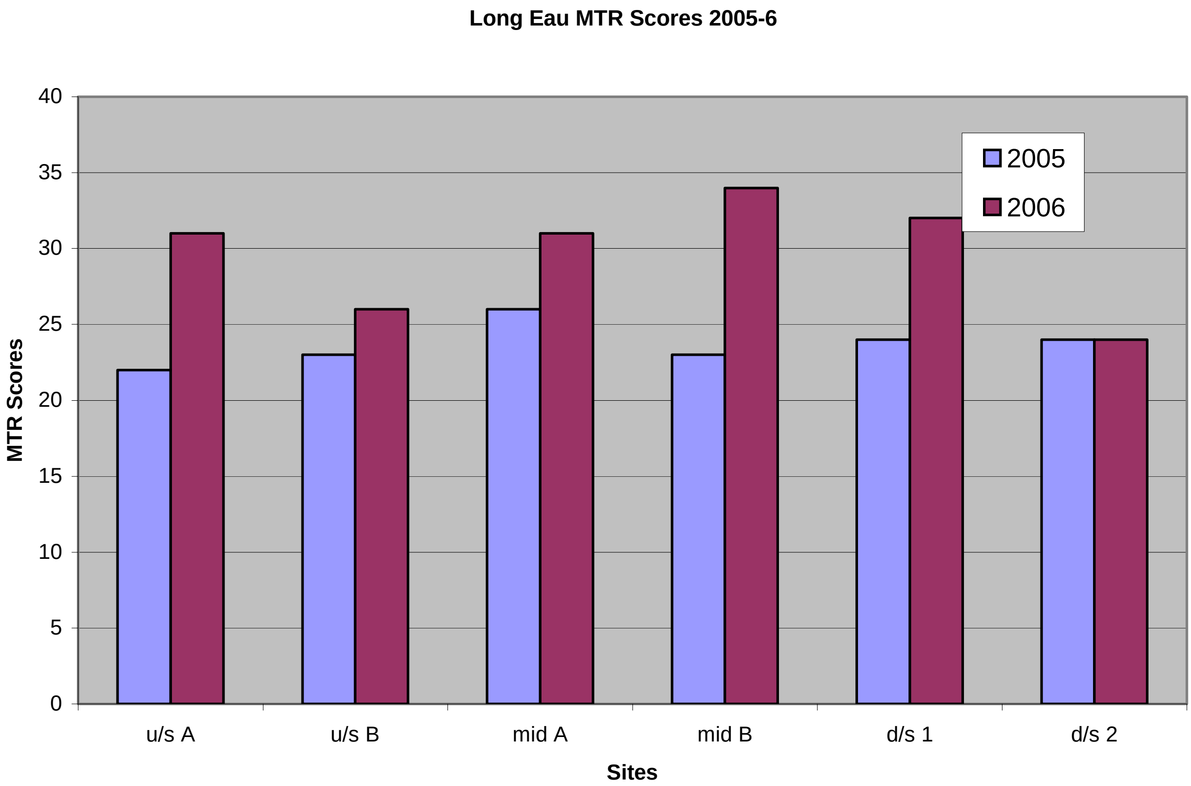

Figure 2.1 MTR scores for Long Eau sites.

EA macrophyte data

Only a single MTR site has been surveyed close to this reach by the EA (see Box 2.1 below). This site was immediately upstream of the upstream sub-reach (Little Carlton - TF-40123-85384). It was surveyed just once, in September 2007. Only three taxa were recorded – *Rorippa nasturtium-aquaticum, Alisma plantago-aquatica & Zannichellia palustris*. The MTR score was 28.8. *Alisma* was not recorded by the project surveys but the other two taxa were; also *Zannichellia* was the dominant species in 2005 when the river was surveyed in summer, but not when surveyed in April. The MTR score was intermediate, and consistent with, the range of scores derived from the project surveys in upstream reach of was between 23 and 34.

Water Body	LONG EAU	LONG EAU
Site/Station Name	THREE BRIDGES M	LITTLE CARLTON MTR SITE
Site/Station ID	97621	144222
Site/Station Location	TF-43900-88200	TF-40123-85384
Sample Date	21-Jul-04	03-Sep-07
Sample Type	MACROPHYTE	All macrophyte samples (including WFD)
Analysis Type	FIELD ANALYSIS	FIELD ANALYSIS
TAXA	PCT COVER BAND	PCT COVER BAND
Cladophora	2	-
Enteromorpha	1	-
Ceratophyllum demersum	8	-
Epilobium hirsutum	1	-
Myosotis	3	-
Rorippa nasturtium-aquatic	2	2
Alisma plantago-aquatica	-	1
Glyceria maxima	3	-
Lemna minor	3	-
Phalaris arundinacea	6	-
Potamogeton pectinatus	6	-
Zannichellia palustris	-	5
MTR Score	22.4	28.8
MFR Score	1.29	1.67

Box 2.1 EA MTR data for the Long Eau adjacent to the research reach

River Eau - July 29th 2005 & 29th April 2006			2005		2006		2005		2006		2005		2006		2005		2006		2005		2006		2005		2006	
		STR	u/s A		u/s A		u/s B		u/s B		Mid A		Mid A		Mid B		Mid B		d/s 1		d/s 1		d/s 2		d/s 2	
			SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS
***Vaucheria* agg.**	Mole-pelt alga	1	4	4	2	2	4	4	2	2	2	2	1	1	5	5	1	1	2	2	3	3	2	2	2	2
Cladophora agg.	Blanketweed	1	4	4		0	1	1	1	1	1	1		0	1	1		0	8	8	2	2	8	8	2	2
***Enteromorpha* sp(p)**	Tube weed	1	4	4	1	1	4	4	2	2		0		0		0		0	3	3	2	2	4	4	3	3
Hydrodictyon reticulatum	Net alga	3		0		0		0		0		0		0		0		0	2	6		0	2	6		0
Pellia endiviifolia	Liverwort	6	1	6	1	6		0		0		0		0		0		0		0		0		0		0
Apium nodiflorum	Fool's Water-cress	4		0		0	1	4	1	4	1	4		0		0	1	4		0		0		0		0
Persicaria amphibian	Amphibious bistort	4	2	8	1	4		0		0		0		0		0		0	3	12	1	4	3	12	1	4
Rorippa nasturtium-aquat	Water-cress	5	1	5	1	5	1	5	1	5	2	10	1	5	1	5	2	10		0	1	5	2	10	1	5
Elodea Canadensis	Canadian waterweed	5	1	5	1	5		0		0		0		0		0		0	1	5	1	5	1	5	1	5
Glyceria maxima	Reed Sweet-grass	3		0		0	7	21	6	18		0		0		0		0		0		0	3	9	2	6
Iris psuedacorus	Yellow-flag	5		0		0		0		0		0		0		0		0		0		0		0		0
Lemna minor	Common Duckweed	4	2	8	1	4	2	8	1	4	1	4	1	4	1	4	1	4	3	12	1	4	2	8	1	4
Lemna minuta	Minute Duckweed	3	1	3		0	1	3		0	1	3		0	1	3		0	1	3		0	1	3		0
Phragmites australis	Common Reed	4		0		0		0		0		0		0		0		0	5	20	5	20		0		0
Potamogeton crispus	Curled Pondweed	3		0		0		0		0	1	3		0		0		0	1	3		0	1	3		0
Potamogeton pectinatus	Fennel Pondweed	1	7	7		0	4	4		0	1	1		0	1	1		0	3	3	1	1	3	3	1	1
Sparganium erectum	Branched Bur-reed	3	7	21	5	15	7	21	3	9	6	18	5	15	7	21	5	15	5	15	4	12	6	18	4	12
Typha latifolia	Common Reedmace	2	2	4	2	4	2	4	3	6		0		0		0		0		0		0		0		0
Zannichellia palustris	Horned Pondweed	2	1	2		0	1	2		0	7	14		0	7	14		0	1	2		0	2	4		0
			37	81	15	46	35	81	20	51	23	60	8	25	24	54	10	34	38	94	21	58	40	95	18	44
MTR scores			**22**		**31**		**23**		**26**		**26**		**31**		**23**		**34**		**24**		**32**		**24**		**24**	

Table 2.1 MTR survey data for the Long Eau (MTR taxa only).

Site		u/s A		u/s B		Mid A		Mid B		d/s 1		d/s 2	
Year of Survey		2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Phormidium	Blue-green algal scum		2		2		6		3		2		4
	Diatom film	4	2	4	2	5	3	6	2	2	3	2	4
Epilobium hirsutum	Great Willow-herb	4	2	4	3	5	2	4	2	3	2	3	2
Eupatorium cannibinum	Hemp Agrimony	1		1	1	2	1	3	1	1	1		
Filipendula ulmaria	Meadowsweet	1	1	1				1	1	1	1	1	1
Mentha aquatica	Water-mint					2	1	2	1	1	1	1	1
Myosotis scorpioides	Water For-get-me-not					3	1	3	2	3	2	3	2
***Mimulus* sp.**	Monkey-flower				1	1	1						
Scrophularia auriculata	Figwort	1	1	1	1	1	1	1	1	1	1	1	1
Solanum dulcamara	Bittersweet	4	3	4	3	4	2	3	3	3	3	3	3
Veronica beccabunga	Brooklime	1		1		1	1						
***Glyceria fluitans* agg.**	Sweet-grass					3	2	1	1	1	1	2	1
Juncus articulatus	Jointed rush									1	1	1	1
Juncus inflexus	Hard Rush	1	1	1	1					2	2	2	1
Phalaris arundinacea	Reed Canary-grass	2	1	3	2	2	1	2	1	2	1	2	1

Table 2.2 MTR survey data for the Long Eau (Non-MTR taxa only); taxa shaded in green are additional taxa on the new EA survey check-list.

JNCC Surveys

Information from the JNCC survey is presented in Table 1.2 alongside data from the other JNCC surveys carried out on the Dearne, Eden and Kent. Using the JNCC classification tool (Holmes *et al.* 1999b) the site was classified as a Type II river. Based on sites on the JNCC database in 1999, such river community types are most typically found on non-calcareous and calcareous clay. The mean number of taxa found at such sites is 38, with a minimum number recorded as just 10, and a maximum of 61. Table 1.2 shows that only 25 taxa were recorded from the middle sub-reach of this research reach; this shows that the reach is impoverished compared with its type overall in Great Britain. The very low diversity of plants, including the number of marginal taxa, suggests the pulling back of the banks did not result in increased river plant diversity, but a more luxuriant growth of robust plants.

3 DEARNE

Appendix 9: Maps 10 to 12 show the project reach, incorporating three 500m sections surveyed using RHS. The most upstream site was not subject to re-meandering and narrowing and has subsequently had maintenance discontinued. The middle and downstream sub-reaches were narrowed and re-meandered about 10 years ago, partly as a fisheries enhancement project and partially to create a more self-cleansing channel to reduce the amount of vegetation control (previously occluded with bur-reed every summer).

Two surveys, one in August 2005 and the other in July 2006, were carried out. Two MTR sites were surveyed in each 500m sub-reach, making a total of six sites surveyed. The locations of the MTR sites are shown in Appendix 9: Maps 16 to 18.

Dearne Upstream Sub-reach SE47751 01992 to 48172 01799. This is the upstream sub-reach where no narrowing and re-meandering was carried out. It is understood to have minimal or no management now.

The upstream sub-reach is shallower flowing, with firmer sediments, than the downstream sub-reaches. It is very interesting as the substrate varies due to marginal obstructions to flow causing deposition of fines in the lee of marginal trees, reducing flow velocity, and often extensive reed beds are developing to create distinct habitats. All are reed ‘shelves’ accreting sandy fines (self low-flow narrowing occurring and development of almost discrete fluvial features) and will be expected to form ‘berms’ (RHS features) if left with no management in the reach. The narrowing from these reedy habitats is already resulting in firmer and coarser bed materials, and faster velocities, and this is reflected in the reported improvements in fish species such as barbel, chub, roach and dace.

Dearne Middle Sub-reach 1 SE 48479 01843 to 48897 01603. This is the middle sub-reach of the river that was slightly re-meandered. There are no fluvial features present. It was supposed to have been modified by narrowing and re-meandering, but there is very little evidence of this on the ground as it is still very deep and sluggish, but the Google Earth images show some meandering, but to a less extent than in the downstream sub-reach.

It was impossible to survey this site accurately for macrophytes without a boat; in 2005 it was also hampered by poor water clarity following a large spate in the previous few days. However, as a grapnel (plant grab) was used throughout the 100m, and no new taxa were dragged out by this method, it is probably that the surveys did give a good reflection of the impoverished flora of the site.

The MTR sites in this section, as for all the sites on the Dearne, had relatively poor flora, and very low MTR scores indicating poor water quality (similar to the Long Eau).

Dearne Downstream Sub-reach SE49230 01245 to 49612 00980. This is the downstream sub-reach of river that was more obviously re-meandered. This site shows very obvious signs of being narrowed by constructed berms alternating along the banks. This work has created reaches of self-cleansing flow, with shallow gravel/pebble substrate dominant. The whole section was shallow enough to be able to do accurate survey by wading, which was impossible in the middle sub-reach. Despite the narrowing, and creation of a self-cleaning channel, no fluvial features were recorded – this is because the potential to do so has been ‘engineered out’ by rock constraining margins (not rehabilitation measures that induce formation, or creation, of features). The reduced bed width reduces/eliminates, as intended, silt deposition, but this is carried downstream, and not deposited anywhere in the channel as habitat. The gradient of the site is also much steeper than site 1. At the end there are some discrete reedbed margins forming, but these are not developing into fluvial features, and not expected to do so as the bed is too narrow to allow anything other than the thinnest margin.

MTR Results for Dearne Surveys

The results of the surveys of 2005/6 are shown in Table 3.1 and illustrated in Figure 3.1. They show that the flora was extremely impoverished, indicative of gross enrichment, and showing no significant differences within the six units surveyed. The results for each individual MTR site, in both 2005 and 2006, varied little within the three 500m RHS sites. The scores were all very low, being between just 20 and 25.

The upstream sub-reach was the most impoverished in terms of species recorded; just 13 scoring taxa for the combined surveys compared with 16 in the middle sub-reach, and 19 in the most obviously modified downstream sub-reach. This suggests that the habitat enhancement may have improved macrophyte diversity, even though it did not result in creating conditions for habitats to develop over time. Alternatively it could be that the greater gradient within this section results in a greater diversity of macrophytes.

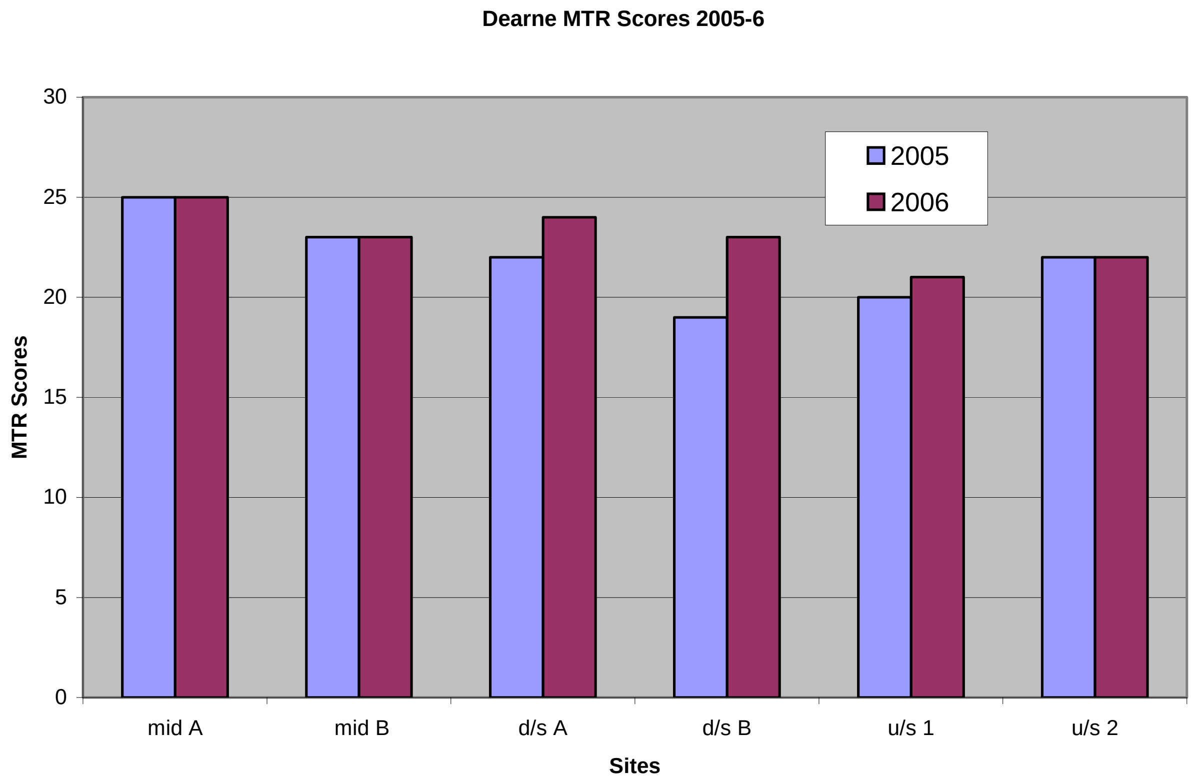

Figure 3.1 MTR scores for Dearne sites.

Julie Winterbottom, the EA Environmental Appraisal Team leader, reports there are no macrophyte data collected by the EA for the research reach of the Dearne, or anywhere adjacent to it.

River Dearne Macrophyte MTR Results		Yr	2005		2006		2005		2006		2005		2006		2005		2006		2005		2006		2005		2006	
		STR	Mid A		Mid A		Mid B		Mid B		d/s A		d/s A		d/s B		d/s B		u/s 1		u/s 1		u/s 2		u/s 2	
Vaucheria agg.	Mole-pelt alga	1	4	4	1	1	3	3	2	2	2	2	3	3	3	3	3	3	1	1	1	1	1	1	1	1
Cladophora agg.	Blanketweed	1	2	2	4	4	3	3	3	3	7	7	7	7	5	5	6	6	4	4	4	4	4	4	4	4
Enteromorpha sp.	Tube alga	1			2	2			2	2			1	1			1	1			2	2		0	2	2
Amblystegium fluviatile	moss	5				0				0				0			1	5				0		0		
Amblystegium riparium	moss	1		0		0	1	1		0	1	1	1	1	1	1	1	1		0		0		0		0
Fontinalis antipyretica	moss	5		0		0		0		0		0	1	5		0		0		0		0		0		0
Rhynchostegium riparioides	moss	5		0		0		0		0	1	5	1	5	1	5	1	5		0		0		0		0
Apium nodiflorum	Fool's Water-cress	4	1	4	1	4		0		0		0		0		0		0	1	4	1	4	1	4		0
Myriophyllum spicatum	Spiked Water-milfoil	3			1	3		0		0		0		0		0		0	1	3	1	3	2	6	2	6
Oenanthe crocata	Hemlock Water-dropwort	7				0		0		0		0	1	7		0	1	7								
Persicaria amphibia	Amphibious bistort	4	1	4	2	8	2	8	2	8		0		0		0		0		0		0		0		0
Rorippa nasturtium-aquaticum	Water-cress	5		0		0		0		0		0		0		0		0		0		0	1	5	1	5
Alisma plantago-aquatica	Common Water-plantain	3	1	3	1	3		0		0		0	1	3		0		0		0		0		0		0
Elodea nuttallii	Nuttall's Waterweed	3	3	9	3	9	4	12	3	9	3	9	3	9	2	6	2	6	2	6	2	6	3	9	3	9
Eleocharis palustris	Common Spike-rush	6				0		0		0	1	6	1	6		0		0		0		0		0		0
Glyceria maxima	Reed Sweet-grass	3	3	9	3	9	3	9	3	9		0		0		0		0		0		0		0		0
Lemna minor	Common Duckweed	4	1	4	1	4	1	4	1	4	1	4	2	8	1	4	2	8	1	4	2	8	1	4	2	8
Lemna minuta	Least Duckweed	3			2	6			1	3			1	3			2	6			2	6		0	2	6
Phragmites australis	Common Reed	4	3	12	3	12		0	1	4	1	4	1	4		0		0		0		0		0		0
Potamogeton crispus	Curled Pondweed	3	1	3	1	3	1	3	1	3	2	6	1	3	1	3	1	3	1	3	1	3	2	6	1	3
Potamogeton pectinatus	Fennel Pondweed	1	4	4	5	5	4	4	5	5	7	7	6	6	5	5	5	5	8	8	8	8	8	8	8	8
Schoenoplectus lacustris	Common Bulrush	3				0				0	2	6	2	6		0		0		0		0		0		0
Sparganium erectum	Branched Bur-reed	3	6	18	6	18	6	18	6	18	5	15	5	15	3	9	3	9	6	18	6	18	6	18	7	21
Typha latifolia	Common Reedmace	2				0			1	2		0		0	2	4	2	4		0		0		0		0
NON-MTR Taxa	MTR Score			25		25		23		23		22		24		19		22		20		21		22		22
Callitriche platycarpa	Starwort																				1					
Callitriche stagnalis	Common Water-starwort		1		1		1				2		2		1		1		1		1		1			
Epilobium hirsutum	Great Willow-herb		r		r		o		r		r		o		r		r		f		f		f		f	
Filipendula ulmaria	Meadowsweet				r						r		r						r		r		r		r	
Heracleum mantegazzianum	Giant Hogweed				r								r													
Impatiens glandulifera	Indian Balsam		r		r		r		r				r		r		r		r		r		r		r	
Persicaria hydropiper	Water-pepper				r		r		r				r		r		r		r		o		r		o	
Phalaris arundinacea	Reed Canary-grass		a		a		a		a		d		d		a		a		a		a		a		a	

Table 3.1 MTR survey data for the Dearne; taxa shaded in green are additional taxa on the new EA survey check-list

JNCC Surveys

Information from the JNCC survey is presented in Table 1.2 alongside data from the other JNCC surveys carried out on the Long Eau, Eden and Kent. Using the JNCC classification tool (Holmes *et al.* 1999b) the site was classified as a Type II river. Based on sites on the JNCC database in 1999, such river community types are most typically found on non-calcareous and calcareous clay. The mean number of taxa found at such sites is 38, with a minimum number recorded as just 10, and a maximum of 61. Table 1.2 shows that 43 taxa were recorded from the mid-section of this research reach, slightly above average species-richness for such sites of its type on the database. The above-average number of taxa was not expected, but the large number of bankside taxa was responsible for the relatively high diversity; it may be concluded, therefore, that the modification of the banks by the capital scheme may have increased river bankside plant diversity.

4 EDEN (KENT)

The river was surveyed on the 16th August 2005 and July 17th 2006. The date of the Survey was later than intended in 2005 as the attempted survey in July had to be aborted due to high flows. The reach location, and the survey units, is shown in Appendix 9: Maps 25 to 27.

Eden Upstream Sub-reach TQ49813 46400 to 50046 46115 Two MTR sites were surveyed.

It should be noted that this site was dredged in November 2003. It is not, therefore, a control of 'do nothing' but one of observations after works had been carried out. The site had steep clay banks and a number of high berms that had arisen from previous bank slippage, or long term accretion of sediments by bankside reeds, in particular *Phalaris*.

Eden Middle Sub-reach TQ49988 46019 to 50212 45653 Two MTR sites were surveyed in 2005 and 2006 and a JNCC site surveyed in 2006 (mid-site). The middle and downstream sub-reaches have had similar treatments of very light spot silt dredging and limited vegetation removal. The sub-reach is more open than the one downstream, with high clay banks covered in tall herbs and some scrub.

In 2005 the whole 500m sub-reach showed evidence of maintenance dredging, with several high berms retained, and the rest of the bed cleaned; this meant they are now high, dry and of no ecological value as they cannot sustain wetland edge macrophytes as they are too dry. In most parts emergent reeds form distinct stands, and will/are gradually accrete(ing) sediment. The presence of *Conium maculatum* on the riparian zone was a clear sign of dredgings have been recently deposited on the bank.

Eden Downstream Sub-reach - U/s of Vexour Bridge

The sub-reach is generally deep with many vertical clay banks, some with mature oaks and ash trees casting significant shade in some places. Although the water velocity through much of the site was predominantly slack, there were some deep pools present, but no genuine shallow riffles. At the downstream end there are dense margins of reeds, as there is throughout much of the lower half of the site, but there is a lack a discrete fluvial features. Only during extreme low flows, and when vegetation has died back, can variations in depth through the site be observed.

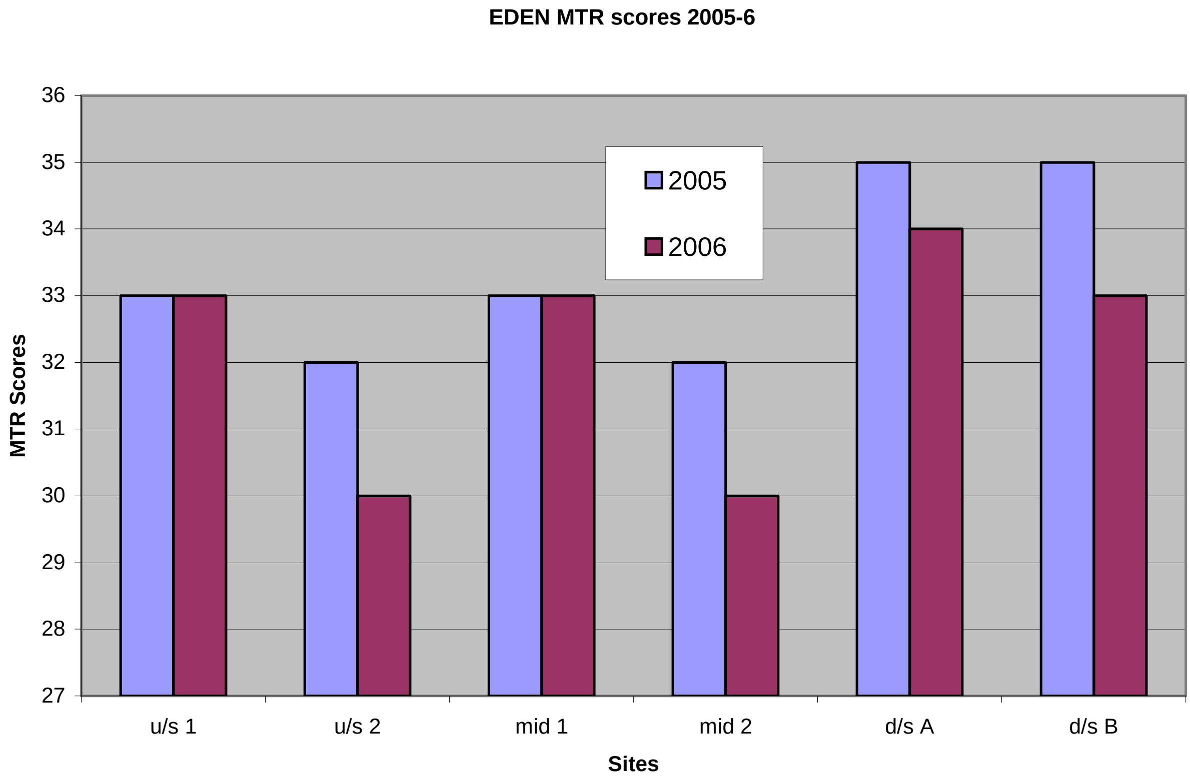

Figure 4.1 MTR scores for site surveyed on the Eden

Reference to Figure 1.1 shows that the MTR scores for the Eden were intermediate between the Dearne and Long Eau (most eutrophic) and the Harbourne and Kent (the most oligotrophic). Scores for all 12 surveys varied only from 30 to 35; all such scores indicate enriched sites, either due to nutrient inputs to the water, or from the sediment. Scores in 2006 were lower in four of the six sub-reaches surveyed, primarily because there was more duckweed present due to prolonged low-flow periods in that year compared to the previous survey period.

In total 19 MTR scoring taxa were recorded, with 11 being recorded from the upstream sub-reach; the same number of taxa were recorded from the middle sub-reach sites too. In contrast, the downstream sub-reach, upstream of Vexour Bridge had 18 of the 19 taxa recorded. The reasons are possibly two fold: i) the river within this sub-reach shows progression to greater natural maturity (large pools, large mature bankside trees [that provide habitat for two of the taxa – *Fontinalis & Amblystegium riparium*]), and as such increases in taxa would be expected; ii) there is less evidence of regular and invasive maintenance, or the effects of past capital schemes. In terms of habitats recorded in RHS it is less clear than from visual observations, but the improved macrophyte taxa assemblage is related to the reduced evidence of creating channel habitat uniformity through regular de-silting and periodic re-sectioning.

The results show no significant differences between the upstream sub-reaches within the reach, but a potentially significant difference in the downstream sub-reach. The flora generally indicates typical enrichment due to agricultural runoff and impoverishment due to physical habitat degradation. It could be improved through some adjustment to management practices, but this might be slow, and the impacts of past works may not be undone naturally. The proposed abandonment of management should help macrophyte recovery, but the extent to which this will occur is not known.

EA data

EA have MTR data from Penshurst Clappers Sluice for 2000-2007, but this site is many kilometres downstream of the research reach, close to the Medway confluence. It is an Environmental Change Network (ECN) site surveyed every year. A broadly similar community to that recorded in the project site was recorded on all occasions, but the site was slightly more species-rich. MTR taxa recorded over the eight years of survey (i.e. four times more than the research reach) resulted in the following MTR taxa being recorded that were not recorded at the project site: *Callitriche obtusangula, Elodea canadensis, Myriophyllum spicatum, Nymphoides peltata, Potamogeton crispus, Ranunculus sceleratus, Sparganium emersum & Typha latifolia*. At the project site the three bryophytes listed in Table 4.1 were not recorded at the EA site (but 'moss' was), nor were *Apium nodiflorum, Rorippa nasturtium-aquaticum & Iris pseudacorus*.

At the routine invertebrate site at Bough Beech just upstream of the Research reach, the EA has made *ad hoc* records when invertebrate sampling (1995-2003). The species recorded add little to the data collected by the project, but listed below for completeness. The record for *Oenanthe fluviatilis* is unlikely to be correct. The data for the Penshurst Clappers Sluice site are note annexed to this report as they have been collected too far away from the research site to be of sufficient relevance.

Dicotyledon	Monocotyledon
Apium nodiflorum	*Carex*
Nymphaea alba	*Glyceria maxima*
Oenanthe	*Juncus*
Oenanthe fistulosa	*Juncus inflexus*
Oenanthe fluviatilis	*Lemna*
Stachys palustris	*Phalaris arundinacea*

Macrophytes recorded at Bough Beech u/s of Eden Reach by EA as *ad hoc* records when sampling invertebrates (1995-2003)

JNCC Surveys

Information from the JNCC survey is presented in Table 1.2 alongside data from the other JNCC surveys carried out on the Long Eau, Dearne and Kent. Using the JNCC classification tool (Holmes *et al.* 1999b) the site was classified as a Type I river. Based on sites on the JNCC database in 1999, such river community types are most typically found on non-calcareous and calcareous clay. The mean number of taxa found at such sites is 46, with a minimum number recorded as 29, and a maximum of 67. Table 1.2 shows that 54 taxa were recorded from the mid-section of this research reach, well above average species-richness for such sites of its type on the database. The above-average number of taxa was not expected, given the highly managed nature of the river, but reflects that the Eden is a relatively species-rich lowland clay river.

Eden Non-MTR Wetland/Bank spp.		U/s1		U/s2		MidA		MidB		D/sA		D/sB	
		05	06	05	06	05	06	05	06	05	06	05	06
Verrucaria	Encrusting lichen	3	4					2	3	2	3	1	1
Ephydatia	River sponge	2	1					1	1	2	1		
Angelica sylvestris	Wild Angelica								r				
Bidens tripartitus	Tripartite Bur-marigold		r										
Dipsacus fullonum	Teasel	r	r	r	r					r	r		
Epilobium hirsutum	Great willow-herb	o	r	o	r	o	r	o	r	o	r	r	r
Filipendula ulmaria	Meadowsweet		r	o	o	o	o	o	o	o	o	o	o
Lycopus europaeus	Gypsywort					r	r	r	r	r	r	r	r
Lythrum salicaria	Purple loosestrife	f	f	f	f	r	o	f	A	f	f	o	o
Lysimachia vulgaris	Yellow loosestrife					r	r						
Mentha aquatica	Water-mint	f	o	f	o	r	r	r	r	r	r	r	r
Myosotis scorpioides	Water-for-get-me-not	r	r			r	r						
Myosoton aquaticum	Water chickweed	f	r	f	r	f		A	r	o			
Persicaria hydropiper	Water-pepper	o	o	o	f	o	f	r	f	o	f	o	o
Solanum dulcamara	Bittersweet	r	r	r	r	r	r	r	r			r	r
Stachys palustris	Marsh Woundwort	o	f	o	o	o	f	o	o	o	o	r	o
Juncus acutiflorus	Sharp-flowered rush									r	r	r	r
Juncus effusus	Soft rush	r	r							r	f		r
Phalaris arundinacea	Canary-grass	A	A	A	A	A	A	f	f	f	f	o	o
Scirpus sylvaticus	Rush	r	r			r	r	r	r	o	o	r	r

Table 4.2 MTR data for the Eden (non check-list taxa only) 2005-2006 Taxa highlighted in green now added to the extended EA check-list

River Eden - 16.08.05 & 17.07.06		STR	u/s 1 2005		u/s 1 2006		u/s 2 2005		u/s 2 2006		Mid A 2005		Mid A 2006		Mid B 2005		Mid B 2006		d/s A 2005		d/s A 2006		d/s B 2005		d/s B 2006	
Hildenbrandia	Red alga	6	3	18	3	18		0		0		0		0	1	6	1	6	2	12	2	12	1	6	1	6
Cladophora agg.	Blanketweed	1	2	2	4	4	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	2	2	2	2
Enteromorpha	Tubeweed	1				0				0											2	2			1	1
Amblystegium riparium	Moss	1		0		0		0		0		0		0		0		0		0	1	1		0		0
Fontinalis antipyretica	Moss	5		0		0		0		0		0		0		0		0		0	1	5		0		0
Apium nodiflorum	Fool's Water-cress	4	3	12	2	8	2	8	1	4	1	4	1	4		0		0	2	8	1	4	2	8	1	4
Nuphar lutea	Yellow Water-lily	3	5	15	4	12	4	12	4	12	5	15	5	15	6	18	6	18	5	15	5	15	5	15	6	18
Oenanthe crocata	Hemlock Water-dropwort	7	1	7	2	14	2	14	2	14	2	14	2	14	1	7	1	7	1	7	2	14	2	14	2	14
Persicaria amphibia	Amphibious bistort	4		0		0		0		0	2	8	1	4	1	4	1	4		0		0		0		0
Rorippa nasturtium-aquat	Water-cress	5	1	5	1	5		0	1	5		0		0		0		0		0	1	5		0		0
Alisma plantago-aquatica	Common Water-plantain	3		0		0		0		0		0		0		0		0	1	3	1	3		0		0
Alisma lanceolatum	Narrow-leaved Water-p	3		0		0		0		0		0		0		0		0			1	3		0		0
Butomus umbellatus	Flowering Rush	5		0		0		0		0		0		0		0		0	4	20	4	20	2	10	1	5
Glyceria maxima	Reed Sweet-grass	3	1	3	1	3	3	9	4	12	3	9	3	9	3	9	4	12	2	6	2	6	3	9	4	12
Iris psuedacorus	Yellow-flag	5		0		0		0		0		0		0		0		0	1	5	1	5		0		0
Lemna minor	Common Duckweed	4	2	8	4	16	2	8	3	12	2	8	2	8	2	8	2	8	1	4	2	8	2	8	2	8
Lemna minuta	Minute Duckweed	3	1	3	1	3	2	6	2	6	2	6	1	3	2	6	3	9	1	3	2	6	2	6	3	9
Sparganium erectum	Branched Bur-reed	3	5	15	4	12	6	18	6	18	5	15	6	18	6	18	7	21	6	18	6	18	6	18	6	18
Spirodela polyrhiza	Great Duckweed	2	1	2	4	8	2	4	4	8	1	2	2	4	2	4	2	4	1	2	2	4	1	2	2	4
			21	70	23	77	24	76	28	84	24	80	24	80	22	71	27	82	30	106	39	134	28	98	31	101
	MTR Scores		33		33		32		30		33		33		32		30		35		35		3.5		33	

Table 4.1 MTR data for the Eden (check-list taxa only) 2005-2006

5 HARBOURNE

Two 500m sites were assessed in the upstream and downstream sub-reaches, see Appendix 9 Maps 30 and 31. The sites were surveyed on 5th June 2005 & August 4th 2006.

Harbourne Downstream Sub-reach SX78456 56174 to 78936 56244. This is the flood defence reach through the village immediately downstream of the bridge. Map 31 shows the location of the 500m site, and where the two MTR surveys were carried out. The grid refs for the MTR sites were: SX78543 56228 to SX78619 56202 and SX78781 56282 to SX78863 56275.

The upstream part of the site is heavily constrained, with weirs, armoured banks and a narrow channel in which the formation of fluvial habitat features is unlikely in the long term. The flora is still struggling to get going again after the FAS works, and is very sparse. The downstream part of the FAS within this site was made deliberately over-wide with the express aim of enabling fluvial habitats to develop. Sediment related habitat is now developing and changed through the 14 month period June 2005 to August 2006. The bars have become both more vegetated and enlarged. A new, small, mid-channel bar may be developing downstream of the MTR site and this has been planted with some exotic wetland plants to go with the ones planted originally on the upstream shoal.

Harbourne Upstream Sub-reach SX77736 55970 to 77999 56126. This is the 'natural' river upstream of the village, but downstream of the flood retention area. The whole 500m is totally different from the 'managed sub-reach' downstream. The grid refs for the MTR sites were: 1: SX77880 55980 to SX77919 56046; 2: SX77919 56046 to SX77914 56132. In contrast to the managed downstream sub-reach, the two MTR sites were, therefore, reasonably natural, despite a significant amount of bank revetment, and had limited development of sediment-related habitats.

MTR Results for surveys

Data from the surveys carried out are given in Tables 5.1 (MTR taxa) and 5.2 (non-MTR taxa) and the derived MTR scores are plotted in Figure 5.1. The MTR scores were not significantly different in the upstream control section and the impacted section. Scores were marginally higher in 2006 compared with 2005, and scores for the upstream sub-reach were marginally higher than in the downstream impacted sub-reach; as the differences were similar to the inter-year differences, the FAS could not be considered to have had an impact on MTR scores.

The MTR scores, being predominantly in the high 40s, reflected mesotrophic water chemistry, with nutrients levels neither high nor low.

Reference to Table 5.1, and comparing it with Tables 2.1, 3.1 and 4.1 reveals that the dominant MTR scoring taxa are bryophytes; this is even starker than the list for the Kent (Table 6.1). Two mosses were present in the control that were not found in the impacted sites, but the impacted site was noteworthy for the greater number of higher plants, with *Bolboschoenus, Iris & Sparganium* associated with the wide section where the shoal was developing. Twenty three taxa in all were recorded from the reach (not significantly more than in the three previous rivers), with 20 in the control section and 21 in the impacted section. The scores for the individual sections were higher than the norm.

In conclusion no impact on macrophytes from the FAS could be determined by the surveys, but since the physical character was so different before the scheme was carried out, the only conclusion can be that it did not have a significant negative impact. It is probable that the engineering to allow a shoal to develop will at least maintain the status quo for macrophytes, or enhance the presence of marginal taxa. It has been subjected, however, to inappropriate planting.

EA data

Andy Haigh from the EA Exeter office has confirmed they hold no macrophyte (MTR) data for the site.

JNCC Survey

A survey was not carried out as the control and impact sites were so different.

Harbourne River - June 5th 2005 & August 4th 2006		STR	u/s 1				u/s 2				d/s 1				d/s 2			
			2005		2006		2005		2006		2005		2006		2005		2006	
Hildenbrandia rivularis	Red alga	6	6	36	6	36	6	36	6	36	1	6	2	12	2	12	2	12
Lemanea fluviatilis	Wiry alga	7	2	14	1	7	2	14	1	7	2	14	1	7	3	21	1	7
Cladophora agg.	Blanketweed	1	3	3	3	3	5	5	3	3	2	2	2	2	2	2	2	2
Vaucheria agg.	Mole-pelt alga	1	6	6	1	1	4	4		0	3	3	2	2	2	2	1	1
Chiloscyphus polyanthus	liverwort	6	2	12	3	18	2	12	3	18	1	6	1	6	1	6	1	6
Pellia endiviifolia	liverwort	6	1	6	1	6	1	6	3	18	1	6	1	6	1	6	1	6
Amblystegium fluviatile	moss	5	1	5	2	10	2	10	2	10	1	5	2	10	2	10	3	15
Amblystegium riparium	moss	1	3	3	2	2	2	2	1	1	1	1	1	1	2	2	2	2
Brachythecium rivulare	moss	8	1	8	1	8	0	0		0	1	8	1	8	1	8	1	8
Calliergon cuspidatum	moss	8	1	8		0	0	0		0		0	1	8	1	8	1	8
Cinclidotus fontinaloides	moss	5	2	10	2	10	1	5	2	10	1	5	1	5	1	5	1	5
Dichodontium pellucidum	moss	9	1	9	1	9	0	0		0		0		0		0		0
Fontinalis antipyretica	moss	5	3	15	4	20	2	10	3	15	1	5	1	5	1	5	1	5
Fontinalis squamosa	moss	8	2	16	1	8	1	8		0		0		0		0		0
Rhynchostegium riparioides	moss	5	1	5	1	5	1	5	1	5	1	5	1	5	2	10	2	10
Thamnobryum alopecurum	moss	7	0	0	1	7	1	7	2	14		0		0	2	14	2	14
Apium nodiflorum	Fool's Water-cress	4	2	8	2	8	2	8	1	4	1	4	2	8	2	8	2	8
Oenanthe crocata	Hemlock Water-dropwort	7	2	14	2	14	2	14	2	14	1	7	1	7	2	14	3	21
Ranunculus pen v en	Brook Water-crowfoot	6	3	18	3	18	6	36	4	24	0	0		0	1	6	1	6
Rorippa nasturtium-aquaticum	Water-cress	5	1	5	1	5	1	5		0	1	5	2	10	2	10	2	10
Bolboschoenus maritimus	Club-rush (cultivar)	3		0		0		0		0		0		0	2	6	3	9
Iris pseudacorus	Yellow-flag	5		0		0		0		0		0		0	2	10	2	10
Sparganium erectum	Branched Bur-reed	3		0		0		0		0		0		0	1	3	1	3
	Sub-scores		43	201	38	195	41	187	34	179	19	82	22	102	35	168	35	168
	MTR scores		47		52		47		53		43		46		48		48	

Table 5.1 MTR Survey Results for the Harbourne (MTR taxa only)

Harbourne River - June 5th 2005 & August 4th 2006		u/s 1		u/s 2		d/s 1		d/s 2	
		05	06	05	06	05	06	05	06
Non-MTR wetland/riverbank species									
	Diatom film		R		O		O		O
Dermatocarpon	Foliose lichen	R	R						
Verrucaria	Encrusting lichen	F	F	F	F	R	O	O	F
Conocephalum conicum	Liverwort	R	R	F	F	R	R	R	R
Lunularia cruciata	Liverwort								
Fissidens	Moss	O	O	F	F			R	O
***Orthotrichum* sp.**	Moss	R	R	R	R				
Angelica sylvestris	Wild Angelica	R	R			R	R	R	R
Bidens tripartitus	Tripartite Bur-marigold				R				
Caltha palustris	Marsh marigold							R	R
Epilobium hirsutum	Great willow-herb	R	R	R	R	O	O	O	O
Filipendula ulmaria	Meadowsweet	R	R	O	O	R	R	R	
Gnaphalium	Marsh Cudwheat		R						
Impatiens glandulifera	Indian Balsam				R				
Mentha aquatica	Water-mint	R	R	R	R	R	R	O	F
Myosotis scorpioides	Water-for-get-me-not	O	O	R	R	R	O	R	O
Persicaria hydropiper	Water-pepper	R	O	R	R	R	O	R	O
Pulicaria dysenterica	Common fleabane	R	R	O	O				
Scrophularia auriculata	Figwort							R	R
Solanum dulcamara	Bittersweet	R	R	O	O				
Stachys palustris	Marsh Woundwort	R	R	R	R		R	R	O
Veronica beccabunga	Brooklime	R	R		R	O	O	O	O
Carex pendula	Pendulous sedge						R		
Carex remota	Remote sedge							R	R
***Glyceria* sp.**	Sweet-grass	O	O			O	O	R	R
Juncus acutiflorus	Sharp-flowered rush			R	R		R		R
Juncus effusus	Soft rush	R	R	R	R	R	R	R	R
Phalaris arundinacea	Canary-grass	O	O	O	O	R	R	R	R

Table 5.2 Non-MTR taxa recorded from the Harbourne. Taxa highlighted in green are additional taxa now on the extended EA check-list.

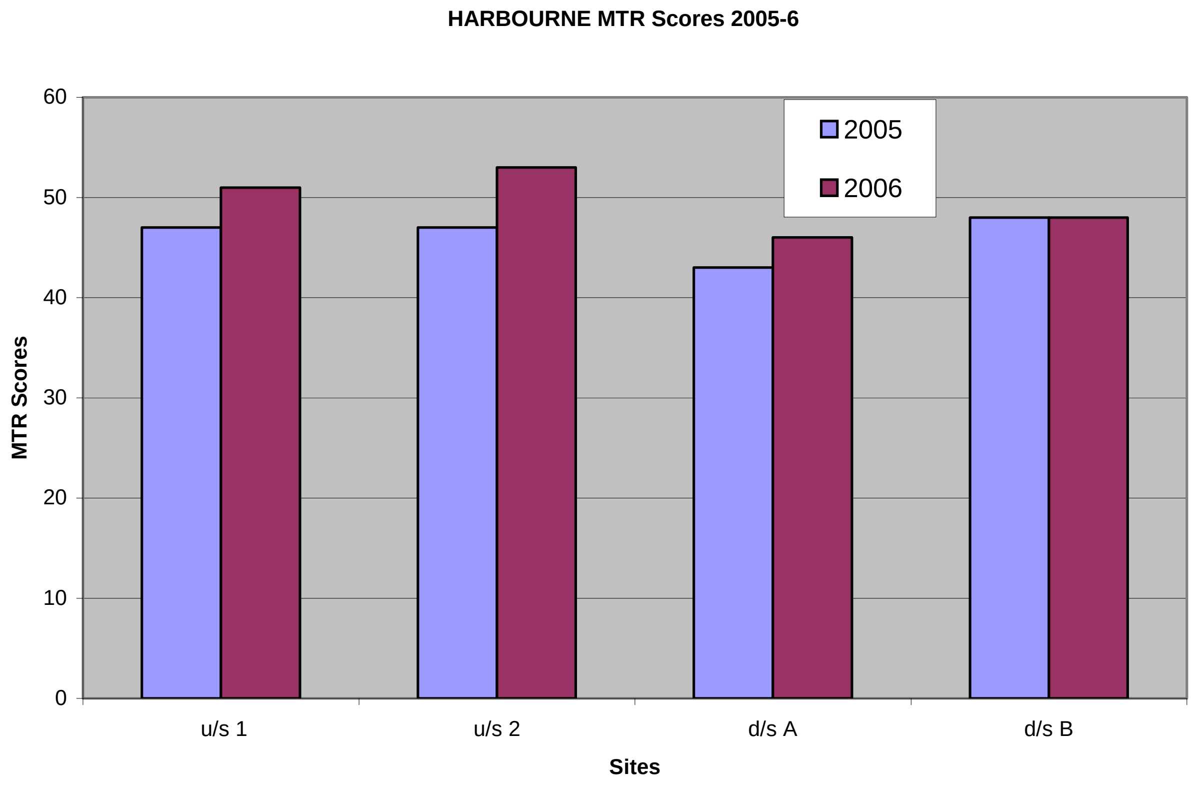

Figure 5.1 MTR scores for the Harbourne

6 RIVER KENT

Three 500m sites were surveyed in 2005, 2006 and 2007. A third survey was carried out in 2007 because in 2006 flows were high and there were concerns that the survey may not have been accurate enough. The 2007 survey provided similar results and, therefore, confirmed the 2006 data as reliable. The location of sites surveyed is shown in Appendix 9: Maps 32 to 34.

Kent Upstream sub-reach SD51918 92957 to 51631 92556. Two MTR sites were surveyed. One MTR site was located exactly downstream of the weir that has gravel removed on a regular basis (d/s Stramongate Bridge – U1). The second MTR site was in an area that is more stable and not subject to regular management (u/s Bridge street – U2). Locally a large fluvial (gravel bar) feature had developed. A JNCC survey was carried out in this section in 2007.

Kent 2 Middle sub-reach SD51662 91935 to 51806 91586. The two MTR sites that were surveyed were of very different character. The whole stretch is characterised by a series of low weirs, which means there is limited sediment habitat feature development in the majority of the site, except on meanders, where high point bars develop inside walled banks. The upstream MTR site was upstream of the A66 bridge (M1) in a very shallow and stable location; the second was also upstream of a bridge (Romney Bridge; M2) but the site was more unstable and deeper.

Kent Downstream sub-reach SD51383 90106 to 51262 89943. One MTR site was surveyed in this sub-reach. The downstream sub-reach contrasts markedly with the upstream sub-reaches. The two upstream sub-reaches are within the town of Kendal, whereas the downstream one is downstream of the town. Here the river flows in its natural plan-form and does not have walled banks to constrain it. The in-channel substrate is a combination of bedrock and cobble/pebbles, as upstream.

Data from the MTR surveys are depicted in Tables 6.1 and 6.2 and the MTR scores are illustrated in Figure 6.1. From the figure it can be seen that MTR scores ranged from 50 to 57; with reference to

Figure 1.1 it can be seen that these scores are the highest for any of the rivers surveyed, indicating the Kent is less nutrient rich than the other rivers. Figure 6.1 shows that the downstream sub-reach has slightly lower scores than the ones upstream; the reason is probably due to the influence of the sewage discharge that enters the Kent between the upstream engineered sites and the downstream sub-reach. As the downstream sub-reach is so different physically from the upstream sites and also receives the towns effluent, it is, therefore, not a good control site for determining the impact of shoal management on macrophytes. The data can thus be only used for characterising the flora of the river rather than for management impact assessment.

Twenty-six MTR scoring macrophytes were recorded from the sites, more than in the other rivers. There was a good mix of algae, bryophytes and higher plants, including abundant growth of two species of *Ranunculus*. Following a period of reasonably low flow in 2007, and lack of major winter scour, the *Ranunculus* cover in 2007 was consistently greater than previously recorded. It was the greater cover of some algae in the same year that primarily gave rise to the slightly lower scores at some sites in 2007 compared with previous years.

The number of MTR taxa recorded from each site varied from 15, in the two sites in the middle sub-reach, to 22 in the downstream sub-reach. Reference to Table 3.6a shows that more taxa were recorded in 2007; this was a result of several taxa being present just as small fragments which may have been over-looked in previous surveys when flow levels were higher. However this does not apply to the upstream sub-reach where four higher plants (*Callitriche hamulata, Rorippa nasturtium-aquaticum, Elodea canadensis, Potamogeton crispus*) were recorded; the latter two were in a new tiny backwater habitat close to the gravel shoal that was not present in the previous two surveys.

River Kent MTR Score 2005-7

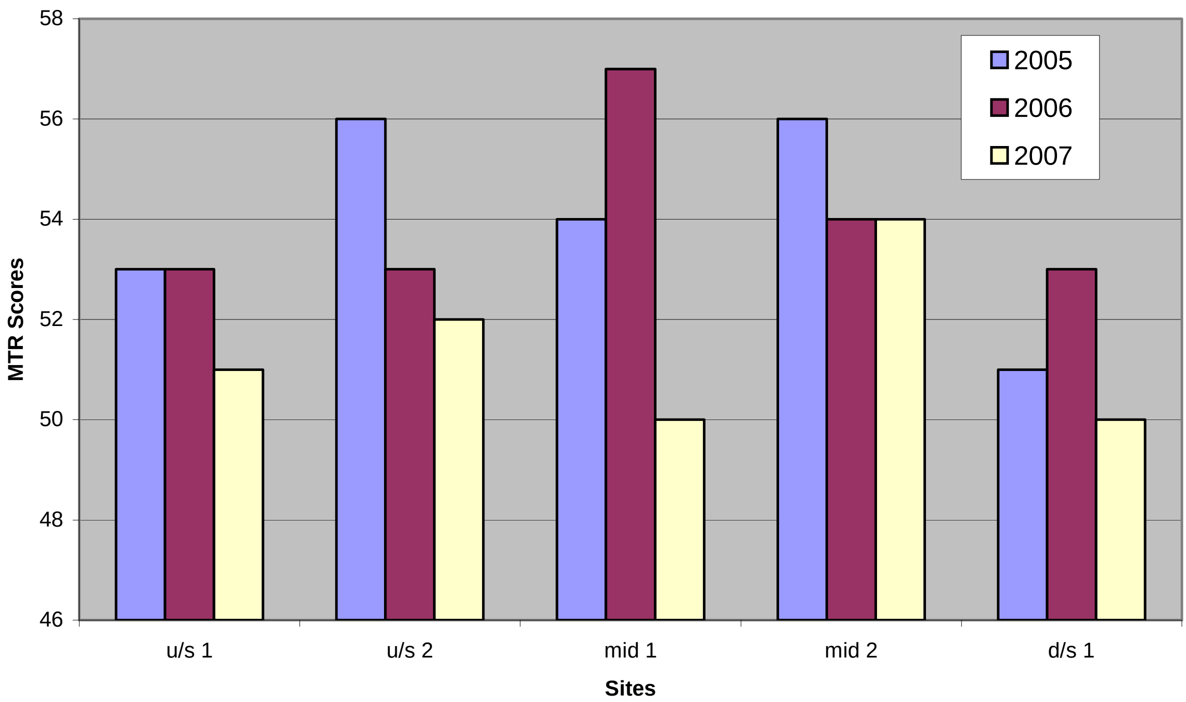

Figure 6.1 MTR scores for the River Kent sites

River Kent Macrophytes		STR	2005 u/s 1		2006 u/s 1		2007 u/s 1		2005 u/s 2		2006 u/s 2		2007 u/s 2		2005 Mid 1		2006 Mid 1		2007 Mid 1		2005 Mid 2		2006 Mid 2		2007 Mid 2		2005 d/s 1		2006 d/s 1		2007 d/s 1	
Overall Total Cover			1%		<1%		<45%		4%		4%		25%		40%		10%		50%		3%		3%		10%		12%		15%		20%	
			SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS
Lemanea fluviatilis	Wire alga	7	1	7		0		0	1	7		0		0		0		0		0	2	14		0		0	3	21		0		0
Hildenbrandia rivularis	Red encrusting alga	6		0		0		0	1	6	2	12	1	6		0	1	6	1	6	2	12	2	12	1	6	4	24	3	18	3	18
***Vaucheria* agg.**	Mole-pelt alga	1		0		0	1	1		0		0	1	1	1	1	1	1	1	1		0		0	1	1	2	2	1	1	3	3
Cladophora agg.	Blanketweed	1	1	1	1	1	1	1		0		0	1	1	1	1		0	1	1		0		0		0	3	3	1	1	2	2
Pellia endiviifolia	Liverwort	6		0		0		0		0		0		0	1	6	1	6	1	6		0		0		0	1	6	1	6	1	6
Amblystegium fluviatile	moss	5	2	10	1	5	2	10	2	10	2	10	2	10	2	10	2	10	1	5	2	10	2	10	2	10	3	15	3	15	3	15
Amblystegium riparium	moss	1		0		0	1	1	1	1	1	1		0		0		0	2	2		0		0		0	2	2	2	2	2	2
Brachythecium rivulare	moss	8	1	8	1	8	1	8	1	8	1	8	1	8	1	8	1	8	1	8	1	8	1	8	1	8	1	8	1	8	1	8
Cinclidotus fontinaloides	moss	5	1	5	1	5	1	5	1	5	1	5	1	5	1	5	1	5	1	5	1	5	2	10	2	10	1	5	2	10	2	10
Dichodontium pellucidum	moss	9					1	9						0					1	9						0	1	9	1	9	1	9
Fontinalis antipyretica	moss	5	1	5	1	5	1	5	1	5	1	5	1	5		0		0		0	1	5	2	10	3	15	3	15	3	15	2	10
Hygrohypnum ochraceum	moss	9		0		0		0		0		0		0		0		0		0		0		0		0	2	18	1	9	2	18
Rhynchostegium riparioides	moss	5	2	10	2	10	3	15	1	5	1	5	3	15	1	5	1	5	2	10	2	10	2	10	2	10	5	25	5	25	5	25
Thamnobryum alopecurum	moss	7		0		0		0	1	7	1	7	1	7		0		0	1	7		0		0		0	1	7	1	7	1	7
Callitriche hamulata	Hammer-leaved Starwort	9		0		0	1	9						0		0		0		0		0		0		0		0		0		0
Myriophyllum alterniflorum	Alternate-fl. Milfoil	8		0		0		0	1	8	1	8	2	16	1	8	1	8		0		0		0	2	16	1	8	1	8	1	8
Oenanthe crocata	Hemlock water-dropwort	7	1	7	1	7	1	7	1	7	1	7	1	7	2	14	1	7	1	7	1	7	1	7	1	7	1	7	1	7	1	7
Persicaria amphibia	Amphibious bistort	4		0		0		0		0		0		0		0		0		0	1	4	1	4		0		0		0		0
Ranunculus fluitans	River Water-crowfoot	7	2	14	1	7	3	21	2	14	2	14	3	21	2	14	3	21	1	7	1	7	1	7	2	14	2	14	4	28	4	28
R. pen. subsp. vertumnus	Brook Water-crowfoot	5	2	10	1	5	7	35	4	20	3	15	6	30	7	35	5	25	7	35		0	1	5	5	25	3	15	4	20	5	25
Rorippa nasturtium-aquaticum	Water-cress	5					1	5						0						0		0				0						0
Alisma plantago-aquatica	Water-plantain	4		0		0		0		0		0		0		0		0		0		0		0		0	1	4	1	4		0
Elodea canadensis	Canadian waterweed	5		0		0	1	5		0		0	1	5		0		0		0		0		0		0	1	5		0		0
Iris pseudacorus	Yellow-flag	5		0		0		0		0		0		0		0		0		0	1	5	1	5	1	5	1	5		0		0
Potamogeton crispus	Curly Pondweed	3		0		0	1	3		0		0		0		0		0		0						0				0		0
Sparganium erectum	Branched Bur-reed	3	1	3		0	1	3	1	3	3	9	3	9		0		0		0	1	3	1	3	1	3	2	6	2	6	2	6
(RED = on edge but included)			15	80	10	53	28	143	19	106	20	106	28	146	20	107	18	102	22	109	16	90	17	91	24	130	44	224	38	199	41	207
MTR Scores			53		53		51		56		53		52		54		57		50		56		55		54		51		52		50	

Table 6.1 MTR survey results (MTR check-list taxa only) for the River Kent

MTR			U/s 1			U/s 2			Mid 1			Mid 2			D/s 1		
Non-MTR aquatic/wetland bank spp.			2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Lyngbya vandenBerghenii	Boring Blue-green alga		3	1		2	2		2	2		2	2		2	2	2
Cladophora aegagropila	carpet alga											2	2		2	1	1
	Filamentous algae				2									1			2
Verrucaria	Encrusting lichen		1	1		2	2		3	4		2	3		5	5	4
Lunularia cruciata	Liverwort											p	P	p			
Porella pinnata	Liverwort														p	p	p
Rhizomnium longirostrum	Moss														p	p	p
Schistidium rivulare	Moss				1										p	p	p
Callitriche stagnalis	Common Starwort				1												
***Callitriche* indeterminate**	Starwort				1												
Epilobium hirsutum	Great Willow-herb		p	p	p				p	p	p	p	P	p	p	p	p
Filipendula ulmaria	Meadowsweet		p	p		p	p		p	p		p	P		p	p	p
Impatiens glandulifera	Indian Balsam		p	p								p	P		p	p	p
***Mimulus* sp(p.)**	Monkey-flower		1	1	1	p	p		p	p							
Persicaria hydropiper	Water-pepper		p		p	p	p	p		p	p	p	P	p	p	p	p
Petasites hybridus	Butterbur														p	p	p
Rorippa sylvestris	Creeping Yellow-cress				p		p	p	p	p	p	p		p	p	p	p
Sagina procumbens	Pearlwort					p	p	p				p	P	p			
Senecio aquatica	Marsh Ragwort				p												
Tussilago farfara	Coltsfoot														p	p	p
Veronica beccabunga	Brooklime		1	1													
***Salix* sp.**	Sallow				1			1									
Deschampsia cespitosa	Tufted Hair-grass					1	1	1									
Glyceria fluitans	Floating Sweet-grass				1												
Juncus acutiflorus	Sharp-flowered Rush		1	1	1	1	1	1									
Phalaris arundinacea	Reed Canary-grass		1	1	2	1	1	3	1	1	1	1	1	1	1	2	2
Scirpus sylvaticus	Wood Club-rush														1	1	1

Table 6.2 MTR survey results (MTR non-check-list taxa only) for the River Kent; species highlighted in green are additions to the EA new check-list (p = present; numbers are the same cover values as used for standard MTR taxa).

EA MTR data

The EA provided data for just two surveys, with references N526/527 (see Table 6.3 for locations). The surveys were carried out in 1995 and 1999, one upstream, and one downstream, of the sewage discharge. The downstream site is almost identical to the Control site. Data from the EA spreadsheet are reproduced below as Table 6.3. From the Table it can be seen that MTR scores were 45 and 54 in the two surveys, with the score of 54 for the upstream site consistent with the data collected in 2005-7, but the score for the downstream site was much lower than the recent surveys. The reason was a bloom of the alga *Hydrodictyon* in 1995 that was not recorded in 1999 by the EA in the upstream site, nor in the recent survey.

Broadly the EA data conform to the data collected in the recent surveys, with the more recent surveys recording a more diverse community.

Taxa	Cover u/s STW 19/07/99 (N256)	Cover d/s STW 15/08/95 (N257)

Hildenbrandia		2
Cladophora	2	1
Hydrodictyon		9
Chiloscyphus	1	
Cinclidotus fontinaloides	1	1
Fontinalis antipyretica	1	1
Fontinalis squamosa	1	1
Rhynchostegium riparioides	2	
Myriophyllum alterniflorum	1	
Oenanthe crocata	1	1
Persicaria amphibia	1	
Ranunculus indet a	2	4
Ranunculus indet b	2	3
MTR SCORE	54	45

Table 6.3 Date from EA MTR surveys on the Kent downstream of Kendal

JNCC Surveys

Information from the JNCC survey is presented in Table 1.1 alongside data from the other JNCC surveys carried out on the Long Eau, Dearne and Eden. Using the JNCC classification tool (Holmes *et al.* 1999b) the site was classified as a Type VI river. Based on sites on the JNCC database in 1999, such river community types are most typically found in sandstone and limestone catchments. The mean number of taxa found at such sites is 40, with a minimum number recorded as 6, and a maximum of 60. Table 1.2 shows that 53 taxa were recorded from the upstream section of this research reach, well above average species-richness for such sites of its type on the database. The above-average number of taxa might not have been expected, given the highly engineered banks, but the in-channel habitats of shoals and backwaters provided contrasting habitats for macrophytes to the main free-flowing open water areas of the section.

7 REFERENCES

Holmes N T H, Newman JR, Chadd S, Rouen KJ, Saint L & Dawson FH (1999a) *Mean Trophic Rank: A Users Manual.* R&D Technical Report E38, Environment Agency, Bristol.

Holmes N, Boon P & Rowell T (1999b) Vegetation of British Rivers: a Revised Classification. JNCC, Peterborough.

EA (2007) *Surveying Freshwater Macrophytes in Rivers: Operational Instruction.* Environment Agency, Bristol.

Annex 1 Interpretation of Macrophyte Data

Two types of survey were undertaken, which essentially were carried out in a similar manner. The MTR method requires more intensive searching for plants that are submerged, or are emergent, within the channel. The survey unit is just 100m long. To ensure repeat surveys can be made, simple sketches are made of the site boundaries and access features so that re-location is easy in the future. Recording of taxa makes use of a check-list (Holmes *et al.* 1999a), so that the absence of a species is as noteworthy as its presence.

MTR Survey Interpretation

Each species on the MTR check-list has been assigned a 'Species Trophic Rank' (STR) of 1-10, depending on how tolerant of eutrophication they are – 1 being the most tolerant, 10 being the least. The rank assigned to each species found during the surveys is given in the third column in the Tables presented in Sections 3.2-3.6.

At each site, species are recorded on a 9 point scale of abundance thus: 1 = <0.1%; 2 = 0.1-1%; 3 = 1-2.5%; 4 = 2.5-5%; 5 = 5-10%; 6 = 10-25%; 7 = 25-50%; 8 = 50-75%; 9 = >75% cover. These data for each 100m site are given in the columns marked 'SCV' – Species Cover Value.

To work out a Mean Trophic Rank score (MTR):
the cover value (SCV) of the taxon is multiplied by the trophic rank of the species (STR) – such data for each species is given in the columns marked CVS (Cover Value Score);
the numbers in the SCV and the CVS columns are added;
then the total CVS score is divided by the total SCV score to obtain a MTR score (multiplied by 10 to give a range from 10-100).

At most sites there are wetland taxa that may encroach into the water that are not on the MTR check-list, and, therefore, are not used in the calculation of the scores. In 2007 the Environment Agency (EA; 2007) produced a draft list of additional taxa that should be recorded to enable an assessment of the morphological degradation under the Water Framework Directive (WFD). The lists of recorded taxa for each site included such taxa that were present at the sites surveyed during this project.

JNCC Survey Interpretation

The JNCC method (Holmes *et al.* 1999b) covers 500m, and records plants from both within the wetted area of the channel (called river records), and those found at the margin of the river at the base of the bank that is intermittently wetted and dried through the year (known as bank records). Data are held by the JNCC so that the records for any site can be classified, and the community put in context in terms of its conservation significance.

Data from four JNCC surveys has been given in Section 3.1. Any species present within a JNCC site is denoted by a double set of numbers, either as 'River' or 'Bank'; note for marginals present both within the channel and at the base of the bank two double sets of figures are given. The two numbers are essentially estimates of abundance. For each species recorded, either two or four figures will appear in the tabulated data.

If only two numbers are given following 00, the taxon was present just on the margin (bank species). If four figures are given, and the last two numbers are 00, the taxon only occurred within the channel. If four figures are given with no 00, then the taxon was found in both the channel and on the bank.

The first number in each of the paired numbers refers to the relative abundance of species judged against other species present at that site. Therefore, at least one taxon has to be recorded as '3' – abundant or dominant (even if there is only a small scrap present) for the channel and bank. 2 = occasional or frequent; 1 = rare. The second figure of each pair refers to the absolute abundance based on percentage cover in the river or at the base of the bank: 1 = <0.1%; 2 = 0.1-5%; 3 = >5% cover.

Site data have been entered on to spreadsheets and submitted to the JNCC freshwater lead team (Alison Lee in Edinburgh) so they can be added to the database. The JNCC method of survey allows classification of sites into River Community Types (RCTs), and reference to the database enables the individual site data to be put into context in terms of species rich-ness, typicality etc.

Appendix 4 Other Biota

1. Introduction

As part of the project no new fishery data were collected by the team. Any data on fish for the sites has been provided by the Environment Agency. In contrast, a one-off survey of invertebrates was carried out at all the sites. The purpose of the latter survey was to collect data that would enable the invertebrate communities at the time of the research project to be related to water quality and any more long-term invertebrate data, and also undertake some surveys to determine if communities were different where management treatments were different, but water quality was not a confounding factor. Findings are summarised in section 3 of this appendix Macrophyte data were collected from all the research sites, and information from these, and other relevant macrophyte data, have been covered in Appendix 3.

Despite the fact that it was not within the scope of the project to collect substantial biological data, it is essential that interpretation of the links between river management, to reduce flood risk, and sediment-related habitats is also related to the probable links to biota too. This appendix, therefore, has three discrete sections. The first two briefly review available data for fish and invertebrates from the five research reaches themselves (and adjoining sites if useful data are available) to put the systems in context. The third section reviews some of the recent literature that provides ample evidence of the importance of sediment-related habitats to diversity of invertebrates, some of which are very specialist and rare. The first two sections, by necessity, rely for the most part on data provided by the Environment Agency (EA); their routine invertebrate sampling concentrates almost entirely on aquatic taxa, and, therefore, does not cover species, genera or even families of invertebrates at the margins that are associated with semi-terrestrial, sediment-related habitats. The brief review of sediment-related habitats and invertebrates, therefore, draws information from a wide range of sources that relate primarily to species associated with the margins that are only periodically inundated.

2. Review of Fish Data

2.1 INTRODUCTION

No fish surveys were carried out as part of the project, and for the most part data on fish for the five research reaches was limited. The EA alone has been able to provide data to report on here, and, in general, it is so sparse that it is difficult to draw any substantive conclusions from it. As with invertebrates and macrophytes, showing recovery from maintenance, cessation of it, or any changes in practices, can only be proved by comparison of samples collected by proper pre- & post-implementation surveys that also include upstream & downstream sites (i.e. both temporal and spatial controls). The review of data here can, therefore, simply identify what data are available, characterise the communities, and suggest if there are sufficient data to justify more fish surveys in the event of more R & D being carried out in relation to the changes in management.

2.2 LONG EAU

Data were provided by the EA's Spalding Office, through Julie Fielding. Data from three sites were provided, surveyed in 2003 and 2007. The sites were at Castle Carlton (TF395844 – c1km u/s of the research reach); Walk Farm (TF422869 – c2km d/s); and Three Bridges (TF437881 – many km d/s). Therefore no fish data have been collected (or made available to the project) from the managed reach and, therefore, there are no data to help interpret in any effects on the fish have resulted from changing the cutting regime.

The fish community in the Little Eau from all sites from which data were provided included the following taxa, all but one being coarse fish, but including stocked rainbow trout. 3-spined stickleback [*Gasterosteus aculeatus*], Brown / sea trout [*Salmo trutta*], Common [wild] carp [*Cyprinus carpio*], Dace *[Leuciscus leuciscus*], European eel [*Anguilla anguilla*], Perch [*Perca fluviatilis*], Pike [*Esox lucius*], Rainbow trout [*Oncorhynchus mykiss*], Roach [*Rutilus rutilus]*, Rudd [*Scardinius erythrophthalmu*s], Stone loach [*Barbatula barbatula*] and Tench [*Tinca tinca*].

The presence of brown or sea trout at the downstream site is interesting, but could be a result of stocking the former species. As would be expected, the fish community of the river is totally dominated by coarse fish, but there is no information for the stretches where management has been modified, or indeed where habitat enhancement was attempted. No conclusions of the effect of either can be determined.

2.3 DEARNE

The capital works that resulted in the lower part of the reach being meandered and narrowed was carried out to both reduce maintenance and enhance fisheries. Work was carried out between 1995 and 1997. In a publication by the EA (undated; c1999) entitled '*River Rehabilitation; Practical Aspects from 16 Case Studies*', the Dearne scheme is featured as one of the examples. The text reads: *'Ecological and fish surveys were carried out before the rehabilitation works, and monitoring is planned for five years after completion of works. The scheme will be deemed a success if fish populations in the river improve and a greater variety of species occur. Before the rehabilitation the species present were mainly roach (Rutilis rutilis), perch (Perca fluviatilis) and gudgeon (Gobio gobio). Fish population surveys carried out on the first section of the reprofiled channel in 1997 and 1998 have indicated substantial improvements in the populations of chub (Leuciscus cephalus), dace (L. leuciscus) and barbel (Barbus barbus). Many of the fish caught in the surveys were juveniles, indicating clearly that the new habitat is providing improved spawning and nursery conditions for this species.*'

During the course of the project, whilst undertaking field work, many of the anglers were seen on site, and some were asked about their views on the river as a fishery, and the effects of the capital works themselves. Few had knowledge of the changes to the river that had been carried out, but from those that did, the overwhelming conclusion was that 'fishing' had improved since the works had been carried out. Interestingly they were not confident in attributing this to the works themselves, and suggested a general trend in improvement in the river as whole, and in particular, the reduced pollution problems, may be significant. The general trend in improved fishery in the Dearne generally was confirmed in discussions with Dan Smallwood.

The middle sub-reach, being sluggish and deep, anglers reported different species were targeted here compared with the faster downstream sub-reach: mainly carp and bream, with the occasional tench being caught. When the river was flowing faster due to higher discharge, anglers may target chub.

The majority of anglers used the upstream sub-reach reach, not the ‘enhanced’ reaches downstream. Elsewhere in the report it has been noted that lack of management in the upstream sub-reach has enabled habitat to develop that should be beneficial to fish. It may be concluded, therefore, that improvements to angling within this study reach may be attributed to:

- reduced management enabling greater in-channel diversity to develop in the upstream sub-reach;
- spawning and recruitment of fry has improved by the provision of self-cleansing substrates in the ‘enhanced reaches’ that then move out from here to the rest of the river, including the control reach.

As sub-reaches are contiguous, increased discharge or water quality cannot be responsible for the improvements in the control reach compared with the managed two reaches.

2.4 EDEN

Data for fisheries on the Eden were supplied by Perikles Karageorgopoulos from the Malling office in Kent. He supplied five years worth of data at two locations that have been surveyed immediately adjacent to the research reach. The excel spreadsheet contained the raw data (lengths and calculated weights) and a pdf with length frequency histograms for each species. These data can be obtained from Area fisheries team if required, but have not been annexed here as the sites do not exactly match the location of the research reach. The sites were at Bough Bridge, upstream of the reach (TQ4947746120) and at Vexour Bridge, immediately downstream of the reach (TQ5098645553).

In a note accompanying the data, Perikles stated that the ‘*Eden holds very good fish populations*’. This was evident from the data that showed that the sites had broadly similar communities, both dominated by bleak, gudgeon and roach. In addition, the following were also recorded, some in large numbers: chub, bream, dace, pike, tench, three-spined stickleback, carp (rarely), stone loach (rarely) and minnow (rarely). From this it is clear there is a good variety of taxa present that characterises the community as being a rich coarse fish assemblage. The data set was not collected to assess the potential effects of different management practices, and so to attempt to attribute any direct effect of management would be impossible.

2.5 HARBOURNE

There are very limited data available for this river, with Andrew Haigh providing the limited amount there are. Being a river in South-West England, on the edge of Dartmoor, it is seen from the information available that the river is a salmonid system with just salmon and brown trout recorded.

The three sites surveyed include two within Harbertonford (Football Field & Road Bridge) – the latter is within the flood alleviation modified area. The lack of any data post-2003 makes it impossible to determine if the works had any medium-long-term impacts (either positive or negative).

Harbertonford Investigation Sites

		Density (no./area)			
Year of survey		2002		2003	
Site Name	NGR	Salmon	Brown Trout	Salmon	Brown Trout
Upstream Dam	SX7762556004	0.276	13.251	0.865	14.702
Football Field	SX7830056200	0.414	7.041	Nil	7.613
Downstream Road Bridge	SX7850056100	0.231	11.299	4.643	16.638

2.6 KENT

Limited data on fish in and around Kendal area exist. Some surveys of juvenile fish have been carried out at New Road, New Mills and Kentrigg. What data that are available have been supplied by the EA Penrith office by Ben Bayliss. Very limited data exist for the Kent (provided by Ben Bayliss), comprising a single survey site in 1993, and several in 2004. Only trout and salmon fry and parr were recorded. He also confirmed that the river structures in and around Kendal are not a barrier to fish migration.

2.7 SUMMARY

The amount of fish data available for all rivers, and in particular in the stretches affected by the changes in flood risk management practices, is very limited for all rivers. Not only are data either sparse or totally lacking for the reaches where changed practices are being assessed by the research, there are no data sets with pre- and post-implementation data. No impacts, either positive or negative, can be attributed to the changes in management. In view of the paucity (and again in places total lack) of pre-implementation fish data, fisheries surveys would not be a priority consideration for future monitoring should research be continued at any of the five research reaches in the future.

3. Review of Invertebrate Data

3.1 INTRODUCTION

This section briefly reviews available invertebrate data for the five river reaches. Two sources of information have been used:

i) data collected as a one-off exercise from all rivers in 2005/6 within the reaches subject to the research;
ii) data from the five reaches, or adjacent to them, provided by the EA. These data deal solely with aquatic taxa, and the aim of the section is to inform the reader about the extent of data available, and then to put the communities recorded into context. This context covers a description of the type of communities recorded, and how this can be interpreted in terms of diversity, typicality and departure from 'good status'.

As data have generally been collected by the EA previously with water quality in mind, the assessment of the data allows the impact of poor water quality to be described through tried and tested systems (e.g. BMWP taxa analysis).. Thus far it is difficult to determine the impact of habitat degradation on invertebrate communities, other than through measures of reduced species richness, ASPT, etc. but steps to remedy this are progressing as tools are developed to implement the Water Framework Directive (WFD) – John Murray-Bligh; EA pers. comm. Apart from looking at the species recorded in the one-off survey carried out by HR, many of the tools that are used by the Agency cannot be applied to this dataset as it was not collected using the EA standard survey protocol.

Details of the dedicated surveys carried out for the project are given in Annex 1. As the protocol used differed from that used by the EA, this has to be taken into consideration in any attempt to directly compare data gathered as part of the project with those of the EA.

3.2 LONG EAU

There are no EA data available for the Eau within the reach subject to monitoring through the duration of the project. As for the Eden, there is a site outside the study reach that has been subject to long-term monitoring. The characterization of invertebrates from this area, using EA data provided by Julie Figures, is based on information that spans the period 1990-2005 at this site (Little Carlton). This site is less than 200m upstream of the start of the research stretch.

Since the invertebrate data relate solely to a site out of the research area, the information can be used only to assess water quality of the river, and give a general indication of species-richness. Of the 26 samples, seven (>25%) may be considered to indicate 'Very good' water quality; significantly, five of these were samples in 2002-2005. Fifteen samples, by far the majority, indicate 'Good' quality, three indicate 'Moderate' quality, and only one (summer 1999) indicates 'Poor' quality. The ASPT scores were typically around 4.5 with again higher scores in recent years, and a single poor score in 1999. The number of taxa was generally less than 20, with only five scores as good as this out of 18 up until 2001, but five out of eight being greater then 20 since 2002. BMWP scores rarely reached 100 until 2002, but typically exceed this in recent samples.

All data suggest a very significant trend in improvement in scores over the 15 years of survey. Significantly, in the earlier years, better scores were very much associated with years following good flows (1993-95). Such information on improving water quality suggests that improvements in habitat structure would result in improvements to invertebrate communities because water quality is now much less likely to be a limiting factor here.

The HR surveys were carried out in spring 2006. In this research site three separate habitat types were targeted and compared: clay/silt substrates; one of the ‘artificial riffles’ and marginal vegetation/soft sediment. Relatively few individual animals were captured, with most being found in the riffle habitat. ASPT scores at all sites were below 4, and BMWP scores were all poor (<70), but best in the marginal vegetation. It is noteworthy from a habitat/species relationship viewpoint that the clay substrate supported fewest taxa, and the marginal vegetation supported most.

Something has been gained from the spring 2006 surveys, despite the methodology used not providing data to make even basic water quality comparisons with more long-term EA data of any value. On the positive side the different taxa recorded from contrasting habitats shows the importance of retaining/restoring habitat diversity through flood risk management work, and highlighted the importance of fringing vegetation (which the modified maintenance practises are attempting to retain).

3.3 DEARNE

Julie Winterbottom has confirmed that the EA has not carried out any invertebrate surveys in this reach post 1990. This was surprising since there were plans for surveys of biota to monitor the response to the fisheries enhancement works (see Section 2.3).

Further investigations have shown that there are no EA data available for the Dearne within the reach subject to monitoring through the duration of the project, but Julie Winterbottom also thought a student may have done a survey on the area; she has tried to find out if there is a report held anywhere, but has not located it. Should future work be done to monitor this site, making further efforts to find this might be warranted.

As has been the case for the Long Eau and Eden, whilst data have not been found relating to precisely the same location as the research stretches, information from a site less than 0.5km upstream has been found that has been subject to long-term monitoring.

Since the invertebrate data relate solely to a site out of the research area, the information can be used only to assess water quality of the river, and give a general indication of species-richness. Of the 20 samples, none indicate ‘very good’ water quality, and only three indicated ‘good’ quality. Seven indicated ‘moderate’ quality and 50% (10) indicated ‘poor’ quality. Consistent with anecdotal information from anglers (see Section 2.3), the majority of the ‘poor’ quality samples were prior to 1996, and ‘good’ samples were only made post-1996. Had sampling been carried out pre- and post-scheme implementation an extensive programme would have been needed to show conclusively if improvements occurred, whether they were due to improved habit, improved water quality, or a combination of the two.

The ASPT scores were typically below 4.00, with one score above this before 1999, whereas the average after 1999 was greater than 4.00. The number of taxa was the lowest of all research reach surveys, with only one sample (1996) exceeding 20. BMWP scores were very low too, with more than 50% below 50, and with just three (15%) exceeding 75. All data suggest poor water quality but a definite trend towards intermittent improvement over the last decade. Invertebrate data suggest that improvements in habitat structure would result in only marginal improvements to invertebrate communities because water quality is still likely to be at least a partially limiting factor here.

Since the river has physically changed dramatically from 1996, and water quality has improved slightly, had data been available it would have been difficult to separate responses by biota from improved habitat or water quality improvements.

The HR surveys were carried out in autumn 2005. A single site was chosen for survey in the control reach and the two modified reaches. Despite very large differences in habitat between the three, results were almost identical (No of taxa 14/15; BMWP 52-57; no of animals 165-185). The data indicate ‘moderate’ water quality, consistent with data collected in recent years by the EA.

3.4 EDEN

There are no EA data available for the Eden within the reach subject to monitoring through the duration of the project, but a site less than 0.5km upstream has been subject to long-term monitoring. The characterization of invertebrates from this area, using EA data provided by Emily Whittingham, is based on information that spans the period 1995-2006 at this site (Bough Beech). Data for another site, a few kilometres downstream, were also provided but not assessed.

Since the invertebrate data relate solely to a site out of the research area, the information can be used only to assess water quality of the river, and give a general indication of species-richness. Of the 13 samples, nine may be considered to indicate very good water quality, three good quality, and only one (May 2000) being moderate. The ASPT scores were typically around 5.00, number of taxa >20, and BMWP scores exceeded 100 in nine of the 13 samples. All data suggest good water quality and no trends in deterioration or improvement in scores over the decade of survey. Such information suggests that improvements in habitat structure would result in improvements to invertebrate communities because water quality is unlikely to be a limiting factor here.

The HR surveys were carried out in autumn 2005. Three small sites were selected for survey that were either within (1 SITE – upstream Vexour Bridge) or just outside the site. The choice was made to compare different management regimes:

- Chiddingstone Mill; naturalising after sensitive dredging;
- U/s Vexour Bridge – recent dredging and bare clay bed;
- D/s Vexour Bridge – appeared very natural and with no recent management.

The upstream Vexour Bridge site, with its bare clay bed, had very few animals, poorer ASPT of 4.1.a poor BMWP score of 62 and subsequently categorization into only ‘moderate’ water quality. In contrast the other two sites had higher ASPT scores, BMWP scores were almost doubled, and more than three times more animals were collected using the same sampling effort. The results meant the sites are categorized as ‘very good’; this is consistent with recent EA surveys.

The data provided by the recent surveys confirm that in degraded habitats, it is possible to have a reduced invertebrate community that reduces the ability of the community to reflect the water quality. It also shows that where flood risk management is sensitive, and marginal habitats are retained, invertebrates are either unaffected, or recover quickly.

3.5 HARBOURNE

There are limited data available for this river, with Andrew Haigh providing these. The characterization of invertebrates from this area, using EA data, is based on information from several surveys between 2002-3.

The data from the EA are extremely detailed as recorded to species level. Being a site with very good water quality, the number of species is very high, and so is the number of genera. This is by far the most species-rich site with more than 25 genera the norm, with ASPTs all above 6 and and BMWP scores close to 200.

The data are insufficient to enable determination of any positive or negative impacts from the scheme, but confirm a consistently very high water quality where recovery of invertebrates would not be hindered by water quality issues.

The HR surveys were carried out in autumn 2005. The data match the high scores derived from EA samples of previous years.

3.6 KENT

Data from the EA have been provided by Brian Ingersent. There are no EA data available after 1999, but several locations have been surveyed both within, and close to, the research site (for details, see Annex 4B). The characterization of invertebrates from this area, using EA data, is based on information that spans the period 1991-2006.

Of the more than 50 samples, the majority may be considered to indicate ‘very good’ water quality, with many others indicating ‘good’ quality, and only three (c5%) indicating ‘moderate’ quality. Many of the scores which were not ‘very good’ were associated with a site upstream of Stramongate Bridge between 1990 and 1994. Some of the other samples that did not indicate ‘very good’ conditions were associated with the river downstream of the STW discharge; even here, however, all but one sample was either ‘very good’ or ‘good’.

The ASPT scores were typically high, in the high 5s and sometimes exceeding 6. The numbers of taxa predominantly exceeded 20, but were consistently lower in the Stramongate site and downstream of the STW until recent years. BMWP scores frequently exceeded 130, but were usually less than 100 at the Stramongate site and downstream of the STW until recently. All data suggest water quality is good, with a trend in deterioration downstream of the STW and an improvement in scores at Stramongate.

In terms of the research project, aquatic taxa were possibly not the key interest here. Species of riverine sediments that are semi-terrestrial, and inhabit gravel shoals, are the key interest and these would not occur in the EA’s routine sampling. For more information, see Section 4.4. Suffice to say here that water quality is not likely to impair colonization of suitable habitats by invertebrates.

The HR surveys were carried out in spring 2006. Two sampling sites were investigated; a stable zone and an unstable area where a gravel bar had been removed. Both samples indicated 'good' water quality, but the disturbed area had slightly reduced BMWP and ASPT scores, slightly fewer taxa, but massively less numbers of animals captured. It is not possible to know if the reduced numbers of animals is a reflection of the intrinsic instability of the habitat that has gravel removed from it, or the reduced numbers of animals is a direct result of the disturbance caused by the removal of the gravel or the modifications that have been carried out to the river channel.

3.7 SUMMARY

No EA data have been found to enable the response of invertebrates to be linked to changes in flood risk management practices at the sites selected for the project. All that can be said is that results indicate that water quality varies from site to site, and in order of quality, the sites can be ranked thus:

- Harbourne River – consistently very good all the time.
- River Eden and River Kent – predominantly very good to good, but occasionally moderate.
- Long Eau – improved over past 15 years from moderate/good to very good/good
- River Dearne – improved from poor around 1990 to moderate/good in more recent surveys.

Data provided by the dedicated surveys of the project indicate that water quality is:

- Very good on the Harbourne River.
- Very good / moderate on the River Eden.
- Good on the River Kent.
- Moderate on the River Dearne
- Moderate / poor on the Long Eau.

From the data collected by the project the following conclusions can be tentatively drawn regarding aquatic invertebrates and habitats (but with considerable caution as single samples provide only 'clues', not definitive answers):

- On the Eden, recovery was quick, or no damage occurred, where desilting was light and marginal habitats were retained;
- The Eau and Eden provided good evidence that solid clay substrates are poor habitats for invertebrates, and so management that results in an increase in this habitat will result in impoverishment of the invertebrate community;
- On the Kent, instability of substrate resulted in paucity of animals, and a reduction, albeit slight, of taxa; it is not known if this is a result of natural response to bed instability, or disturbance resulting from gravel removal;
- Sub-samples on the Eau from marginal vegetation where silt was accumulating, were the richest, providing support for retaining marginal fringes wherever possible when undertaking any flood risk management on rivers.
- Uniform habitat (as on the Eden) can result in very poor invertebrate communities, and when the assemblages are used to assess water quality the indication is that the quality is worse than it is in reality.

4. Brief Review of Literature Relating to Invertebrates and Exposed Riverine Sediments

4.1 INTRODUCTION

The purpose of this brief review is to highlight the importance of marginal, sediment-related habitats for many specialist invertebrates. Many of the species associated with marginal river habitats are rare, red data book species, but are not recorded in routine EA invertebrate monitoring because they do not spend the majority of their life cycle underwater. They are, however, very influenced by channel form that is affected by flood risk management works. This section, therefore, aims to ensure that the relevance and wellbeing of this importance assemblage of species is linked to other aspects of the R&D project.

Much attention in the past ten years has been focussed on invertebrates in Exposed riverine sediments (ERS), as these represent important primary habitats within the land-water ecotone of river corridors. ERS habitats have long been associated with rare and nationally scarce invertebrates in the UK. Exposed riverine sediments are defined in EA (2003) as 'the shoals, bars and spits present in river channels'. They represent deposits which are exposed for some time during periods of normal or lower than average flow. The sediments range in size from cobbles and boulders to silt and sand. In general, coarser sediments build up in high-energy river systems and form extensive and variable areas of sediment. In lowland river systems, much smaller marginal deposits of sediment (more commonly of sand and silt) may be found at the toe of riverbanks. The character, shape, size, location and sediment composition varies greatly, making the habitat diversity of ERS very significant.

Prior to this attention to marginal habitats, Harper *et al.* (1998a/b; 1998) developed the concept of 'functional habitat'. They covered marginal features, but also described different in-stream habitat types that provided contrasting niches for animals, and hence supported very different biotic communities (measured through the invertebrate assemblages). Some of the contrasting habitats are not exposed, and therefore not ERS, so have not been subject to the surge in research that that habitat has received. The distribution of macro-invertebrates within the different "functional" habitats is detailed within a National Rivers Authority research project (NRA 1995). England (2006) provides some good insight into invertebrates responses to habitat modifications. RHS provides information on discrete habitats at the 'meso-scale', but in our research sites we found that small habitat variations, resulting from sediment deposition, could be important for invertebrates but were too insignificant in scale to be recorded by RHS.

4.2 RECENT ENVIRONMENT AGENCY R & D ON ERS

Sadler and Bell (2002) reported on the early phase of the EA-funded Invertebrates of ERS research. Eighty one silt, sand and shingle sites across England and Wales were used to establish what factors were important in determining species assemblages on ERS. Two large species databases of Coleoptera (beetles) and Araneae (spiders) were created during the work. An examination of the important environmental variables that define site quality identified type of substrate, habitat heterogeneity, the percentage of shade, the amount of grazing and ERS size as important presciptors of invertebrate 'quality'. A number of management implications could be drawn from the work and they indicated the importance of river regulation, engineering and stocking densities for ERS invertebrates. The best ERS sites were noted to have a markedly western distribution in the UK, found on unregulated rivers, and by definition un- or minimally-managed river systems. Phase 1 noted that threats to ERS habitats are considerable.

EA (2003) provides a simple overview of why ERS habitats are so important for invertebrate diversity, and also point out some of the ways in which they are affected by management. This leaflet also identifies what can be done to conserve and minimise damage to them, and also outlines recent research findings. The EA leaflet points out that ecologists are increasingly turning their attention to the riparian zone (margins, banks and adjacent land next to the bank). Terrestrial invertebrates contribute greatly to the variety of river corridor biodiversity, with many more species living beside rivers and streams than in them, illustrating the great importance of ERS. Several hundred invertebrate species are found in river margins. The link to management is made in the leaflet by stating: '*Many rivers are highly engineered, restrained by flood banks, often straightened, reinforced or re-profiled and impounded by weirs. Many of these highly managed rivers are dredged and, therefore, prevented from creating ERS habitats. As ERS habitats provide contrasting homes to open water or vegetated riparian zones, variety of wildlife is reduced if they are lost'*.

River management practices affecting the number, size and composition of ERS are summarized in EA (2003). It notes that the impact of partial sediment (shoal) removal is difficult to predict, but that complete removal and the creation of steep marginal slopes should be avoided. The document also highlights that management can be beneficial, by scraping lower some marginal bars, if bed lowering leads to them being left too high, or they have accreted too much sediment.

Timing of engineering works on rivers is also an important consideration for invertebrates of ERS. Spring-breeding invertebrates are active on ERS between April and July, but water beetles use ERS habitats for pupation in the summer. Avoiding river engineering operations in spring and summer, as is the norm by the EA, lessens any impact on invertebrates. As it is probably impossible to avoid affecting some interests, the recommendation is that as small an area as practicable is affected at any one time, and leaving some parts of ERS untouched.

An important consideration for this R&D project, where sediment management is deemed still to be required, is that creative engineering can be used to protect, enhance or add to existing conservation features. This applies to rivers that are already heavily degraded, and adoption of sensitive approaches should follow the EA's own operational guidelines to enhance where there is degradation, and protect where there is high quality.

4.3 RECENT OTHER RESEARCH ON ERS

The EA research of ERS concentrated to a large degree on invertebrates associated with coarse sediments, such as gravel, pebbles and boulders. These rivers tend to be more associated with the west and north of Britain and in the uplands than the south and east and lowlands. To some degree, the invertebrates associated with finer silt/sandy ERS had received less attention, but they are the habitats associated with rivers receiving more regular flood risk management. As stated on the 'Buglife' website (see references) *'Sandy rivers are a surprisingly rich but neglected habitat. At first glance the banks and islands of bare stones and sand that skirt river edges appear to be devoid of life, however, closer inspection reveals them to be rich in rare flies and beetles'.*

Buglife secured funding from Natural England, The Environment Agency, SEPA and the John Lewis Spedan Trust Fund, to investigate the fly fauna of this poorly understood habitat. From 2005 to 2006, consultants surveyed 18 rivers all over the UK and the research showed how rich sandy RHS can be for invertebrates, and also support many rare species. They recognise that the surveys were *'just the tip of the iceberg of flies associated with sandy rivers; however this survey has provided a starting point for future research'*. For example, the initial survey has shown ERS to be rich in fly species with 850 species recorded, 87 of which were nationally rare or scarce species, with six species that are new to Britain. Stiletto-flies are one such example that were found several times, with the research greatly expanding the knowledge of where stiletto-flies occur and providing numerous new records. For the Southern silver stiletto-fly, new sites were found on the Wey, Rother and Tay and they were recorded for the first time in Scotland.

As a direct result of Martin Drakes' survey work he published three papers in the 'Dipterist Forum', on three new fly species to Britain: *Rhaphium suave, Hilara tenella and Hilara aartseni* (links to these and the survey report can be found on the Buglife website). The findings of the entire project are given in Drake *et al.* (2007). In terms of factors affecting fly interests, and especial BAP and red data book species, proximity to the water's edge, vegetation cover and shade were the main factors operating on the assemblages. They point out too that dry, often vegetated sediment was relatively poor in ERS specialists but usually as rich in uncommon species – from a river management viewpoint, it is important that we have due regard for these too. The report also suggested that the term Exposed Riverine Sediment should be used more carefully when referring to river margin habitat of most value to flies, since high interest is not confined to 'exposed' sediments, but the interface between submerged and exposed habitats.

As a follow-on, the ERS EA-funded R & D, Countryside Council for Wales (CCW) commissioned more in-depth research on a stretch of river rich in ERS. This work is reported in Sadler *et. al* (2006), working on a 5km length of the Severn. It showed further evidence that rich invertebrate communities, and rare species associated with ERS, are most closely linked to upland, dynamic, gravel-bedded rivers (e.g. most relevant to consideration alongside the Kent cases study). Statistical analyses showed that larger and diverse ERS within the sample reaches were associated with more habitat space and with more specialist (usually rarer) beetles.

Bates *et al*. (2005) also noted how true flies (Diptera), spiders (Araneae), ants (Formicidae), and bugs (Hemiptera) are important components of the invertebrate fauna of ERS in the UK, beetles dominate in terms of numbers of specialist and rare species, and most probably in terms of abundance and biomass. ERS specialist beetles have been the focus of an ever-broadening body of research. They also point out that ERS habitats are subject to a diversity of threats, including river channelization and river management. They also point out that the nature of these threats varies considerably as works include channel enlargement, channel realignment, embanking, dredging and the removal of obstructions. The diversity of threats and the way in which they affect different rivers and ERS communities make generalizations problematic. However, modifications that reduce the availability of suitable resources, connectivity, habitat diversity and temporal heterogeneity within the river system diminish ecological integrity and will typically reduce the species diversity and conservation quality of ERS. In addition they also point out that lack of management and lack of natural process leading to habitat changes may result in increased vegetation growth and stabilization that will lead to reduced invertebrate interest.

The importance of other riparian management and land-use, therefore, cannot be ignored as such factors are important in shaping marginal habitat characteristics, and subsequently invertebrate communities. Bates *et al.* (2007) discuss the complexity of managing river marginal habitats to cater for a diverse range of interests, as some taxa have conflicting requirements. Harrison (2000), following research fellowship work funded by the EA, emphasised the role of marginal vegetation and its significance for stream macro-invertebrate biodiversity and production in comparison with other mid-channel habitats. He found that the community diversity and equitability were greatest in the physically complex margin. Marginal vegetation was utilised by macro-invertebrates for oviposition and as a link between aquatic and terrestrial environments and thus acted as a focus for reproduction and recruitment for chalk streams.

In a study of the Afon Tywi, a river of renowned importance for invertebrates on the river shingles, especially beetles, the research findings highlighted that, whilst trampling of river margins may increase bankside habitat diversity, and even lead to enhance fly and other invertebrate interests, it may lead to degradation of the beetle fauna. Species richness was positively associated with stocking levels, probably because of the addition of species associated with resultant elevated levels of silt and organic matter. The paper refers to an 'ERS quality score', which is a measure of conservation value based on the rarity of specialist ERS beetles, which was negatively associated with measures of trampling damage. It was concluded, therefore, that livestock trampling reduces the conservation value of beetle communities on high quality ERS. A reduction in score resulting from trampling, however, may lead to richer fly communities.

Sadler *et al*. (2004) note that ERS are disturbance-dominated systems and that the '*hydrological regime is the engine that drives diversity of these systems*'. In addition, they stressed that stabilization of ERS resulting from management that leads to vegetation succession and a reduction in the amount of bare and well-sorted substrates, is damaging to invertebrates ERS interest. They concluded that any management for flood engineering on these dynamic habitats needs careful planning.

In a very recent review, Saddler *et al.* (2008) confirm that the diversity of ERS specialist beetles is low in environments with little disturbance (as they require large expanses of bare sediments as habitat), but also state that diversity is also lower in environments with a greater levels of disturbance. In terms of river management this is important, and they also state that the magnitude, frequency and timing of disturbances can have variable effects on different species. Whilst they considered this to be a research area that urgently requires further focus, their R & D review has shown that there is still much to learn regarding the clear and direct linkage to management practices.

Clifford *et al*. (2006) reappraises the fundamental questions of biotope recognition and integrity, and suggests that if these remain uncertain: '*attempts to link biotopes with ecological response appear, at best, premature*'. Their attempts to link biotopes with ecological response did, indeed, suggest that it was premature, and suggested further research might be directed to identifying possible associations between combinations of flow types and bedforms or functional habitats. Harvey *et al.* (2007) have begun to utilize the EA's RHS database to explore if linkages between surface flow conditions (flow biotopes), local channel morphology (physical biotopes) and biologically distinct vegetative and habitat units (functional habitats) exist. They have found that attempts to identify one-to-one connections between surface flow types, units of channel morphology and functional habitats oversimplify a complex and dynamic hydraulic environment. Instead, a nested hierarchy of reach-scale physical and ecological habitat structures exists, characterised by transferable assemblages of habitat units. Five flow biotopes show strong correlations with functional habitats, and differing combinations of three of these account for over 60% of the distribution for all functional habitats. Work is on-going and improvements on our understanding of biotopes and species may help provide better guidance on what are preferable approaches to managing rivers with important sediment-related habitats.

4.4 JUDY ENGLAND THESIS

In the course of her study, England (2006) reviewed macro-invertebrate - habitat relationships, and, in particular, the conclusions of Downing (1984), NRA (1995) and Harper *et al.* (1998) that the richness, diversity, density and taxon composition of an aquatic macro-invertebrate community is directly influenced by this habitat composition. Many studies had concentrated on assessing the difference in the macro-invertebrate assemblages of riffles and pools alone. Other studies had examined the habitat composition at a wider scale (river or reach) or smaller scale (micro or meso-habitat) or a combination of the two. Most studies reached similar conclusions, confirming Armitage *et al*. (1995) earlier findings that distinct meso-habitats support different faunal assemblages.

Many studies have examined the habitat composition of streams around the world and have looked at the factors influencing habitat distribution such as flow velocity, substrate and the presence of wood, detritus and vegetation and how these affect macro-invertebrate assemblages. Her review of literature showed that the main influences upon habitat composition result from the interactions of flow, substrate, vegetation and woody debris. She then described some of the associations of invertebrates with these factors, all of which are affected by how and when flood risk management works are carried out.

Velocity and flow have a direct impact upon the in-stream ecology of a watercourse, but also has an indirect effect via its influence of the substrate composition. Studies have found different faunal assemblages associated with particular substrate types, for example, DeMarch, (1976).The review also concluded how important vegetation has been demonstrated to be by numerous studies, including Kornijow and Kairesalo (1994) and Lillie and Budd (1992). The presence of vegetation can influence the abundance, distribution and composition of macro-invertebrate assemblages. This was demonstrated by Wright *et al.* (1984) who studied sections of the River Lambourne and recorded a higher macro-invertebrate diversity at the sites covered with macrophytes. Alternatively the influence may be as a direct food source.

The importance of structure, rather than the species of macrophyte, was highlighted during a survey of the River Welland by Smith *et al*. (1991) who found that it was habitat structure which was important, not the individual plant species. For example, a particular fauna was associated with emergent narrow leaf vegetation but no difference was detected when comparing the fauna found within each individual macrophyte species. This view was supported by later work by Armitage *et al*. (1995) who applied the theory of functional habitats within riverine systems. This has important implications for river managers as it shows that operatives need to identify habitat structure, not plant species.

Species diversity index gives a measure of the richness and relative abundance of taxa, and is normally reduced in rivers that have been physically degraded. In England's studies (2006), where river rehabilitation works attempted to restore some natural habitats lost by previous river channel works, the recovery of invertebrates was staggering, as shown by Figure 4.1 below taken from her thesis. Each bar represents the average diversity, with the standard error also shown. At the control sites there was no change or a drop in diversity, but where habitats were restored, diversity more than doubled over the same time period.

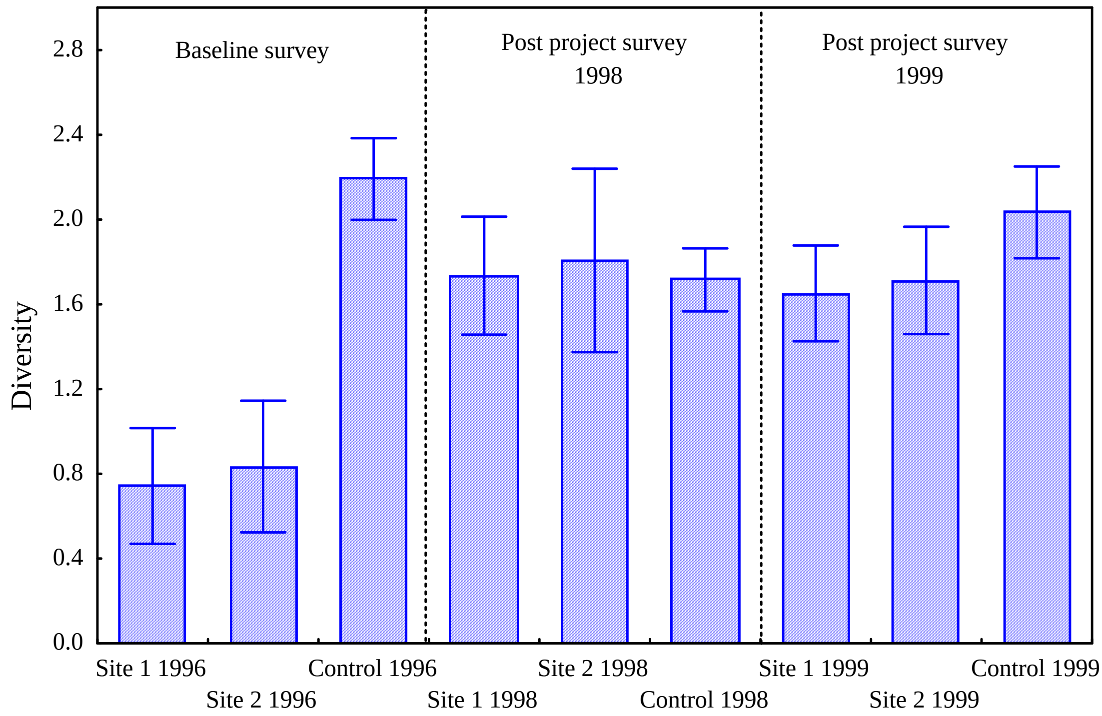

Figure 4.1 Diversity of invertebrates related to rehabilitation works

England's thesis (2006) contains numerous examples confirming the association of different invertebrate species to the habitat types that were restored in her study streams. Some are clearly more sensitive and specific in their requirements than others, but the outputs dramatically demonstrate the importance of different habitat structure in rivers, and in particular those formed by re-worked sediment. This is not the place to do justice to the detail of the research, and those wishing to know more are advised to read the thesis.

4.5 SUMMARY AND KEY POINTS

The huge literature on invertebrates of Exposed Riverine Sediment (ERS) and recent large research effort by EA and others (CCW), has shown that there is not only an important link between rare and specialised invertebrates and marginal habitats, but this relationship is affected by management of sediment during flood risk management operations. Perhaps more importantly, research has shown that there is a great many factors affecting the habitat itself, but a key factor is disturbance.

Therefore, if sediment-related habitats are formed that pose a flood risk, management (as is perceived the need on the Kent downstream of Stramongate Weir) may not be ecologically damaging. If only parts of the bar habitat are disturbed at any one time, this may not only pose minimal threat of long-term damage, but it may be beneficial because it will halt the process towards terrestrialization (shown in research to be a threat to invertebrates of ERS).

Several papers have reported that vegetation structure is very important in enhancing invertebrate community diversity. It appears that for the most part it is not the species that is important, but the growth form. This has important implications for river managers as it shows that operatives need to identify the habitat structure formed by the growth forms of a variety of species, and do not have to be concerned about which species are responsible.

It is not just exposed riverine sediments that form shoals in high energy rivers that are important. Shallow margins composed of silt and sand, where there is extensive interface with the underwater habitats of the channel, have been shown to be exceptionally important too. Such habitats are destroyed by dredging that leaves the habitat ‘high and dry’ with a vertical, truncated, interface with the aquatic river habitat. Management is not alone in destroying such habitats, as lack of trampling and complete colonization by vegetation can lead to their demise too. Small areas at the margins of rivers, left when undertaking de-silting operations or vegetation cutting, can provide ideal habitats for rare marginal species. Some such habitats were developing on the Long Eau following the introduction of limiting the width of ‘weed’ cut – the habitats were probably large enough for colonization by invertebrates, but were too small to be recorded as discrete habitats in RHS.

Where management is being undertaken on rivers that have been severely degraded there is ample evidence that implementing the operations to encourage local deposition, and formation of shallow margins, will result in responses by invertebrates. This applies to rivers that are already very heavily degraded, and adoption of sensitive approaches should follow the EA’s own operational guidelines to maximize recovery potential. Equally, when managing rivers of higher habitat quality, following guidelines to protect the habitats is equally important.

The collection of invertebrate data as part of the project provided only limited information in relation to habitats and biotic responses. The review of the literature has highlighted the extreme importance of sediment-based habitats in river ecosystems, especially for invertebrates. On-going work at Cardiff by Dr. Ian Vaughan, funded by the EA, should provide new insights into species/habitat relationships as he undertakes a thorough review of the RHS, water quality and biological archives of the Agency. Findings should provide more definitive guidance, and clearer justifications, relating to sensitive flood risk management options.

5. References

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Appendix 5 Hydraulics and Hydrology

1. Introduction

A major factor determining the nature of in-channel habitats is the nature of the flow conditions which can be described in terms of flow velocities and depths. To provide data on the range of flow conditions and how these are affected by changes, hydrological and hydraulic modelling was undertaken. One of the factors considered in selecting sites was the availability of flow records. Under the project the available flow data was obtained and analysed to provide information on flows and their variability. This also allowed the modelling of flood events with specified probabilities and also the simulation of long flow sequences.

The hydraulic modelling was carried out using both a one-dimensional flow model and also the Conveyance Estimation System (CES) which provided more detailed information on the lateral variation in flow depths and velocities. The work showed how modelling can be used to assess and evaluate flow diversity. The work also showed the connection between the detailed hydraulics of the system and habitat diversity.

2. Long Eau

2.1 BACKGROUND

The Long Eau is a low energy river system in Lincolnshire. Historically, over-deepening of the channel, coupled with the construction of high flood embankments, has reduced floodplain connectivity. In the upstream sub-reach an enhancement scheme had been carried out that involved lowering the right embankment to allow more frequent fluvial flooding of the adjacent wetland while in the middle sub-reach artificial riffles had been introduced. The study reach represented, therefore, an example of carrying out engineering works to improve a low energy stream. Vegetation cutting is carried out in the reach and so the site provided an opportunity to investigate aspects of vegetation maintenance.

2.2 DATA FOR HYDRAULIC MODELLING

2.2.1 Cross-section survey

A cross-section survey of twelve cross-sections was used to construct the hydraulic model, see Appendix 1. The locations of the cross-sections are shown in Figure 2.1.

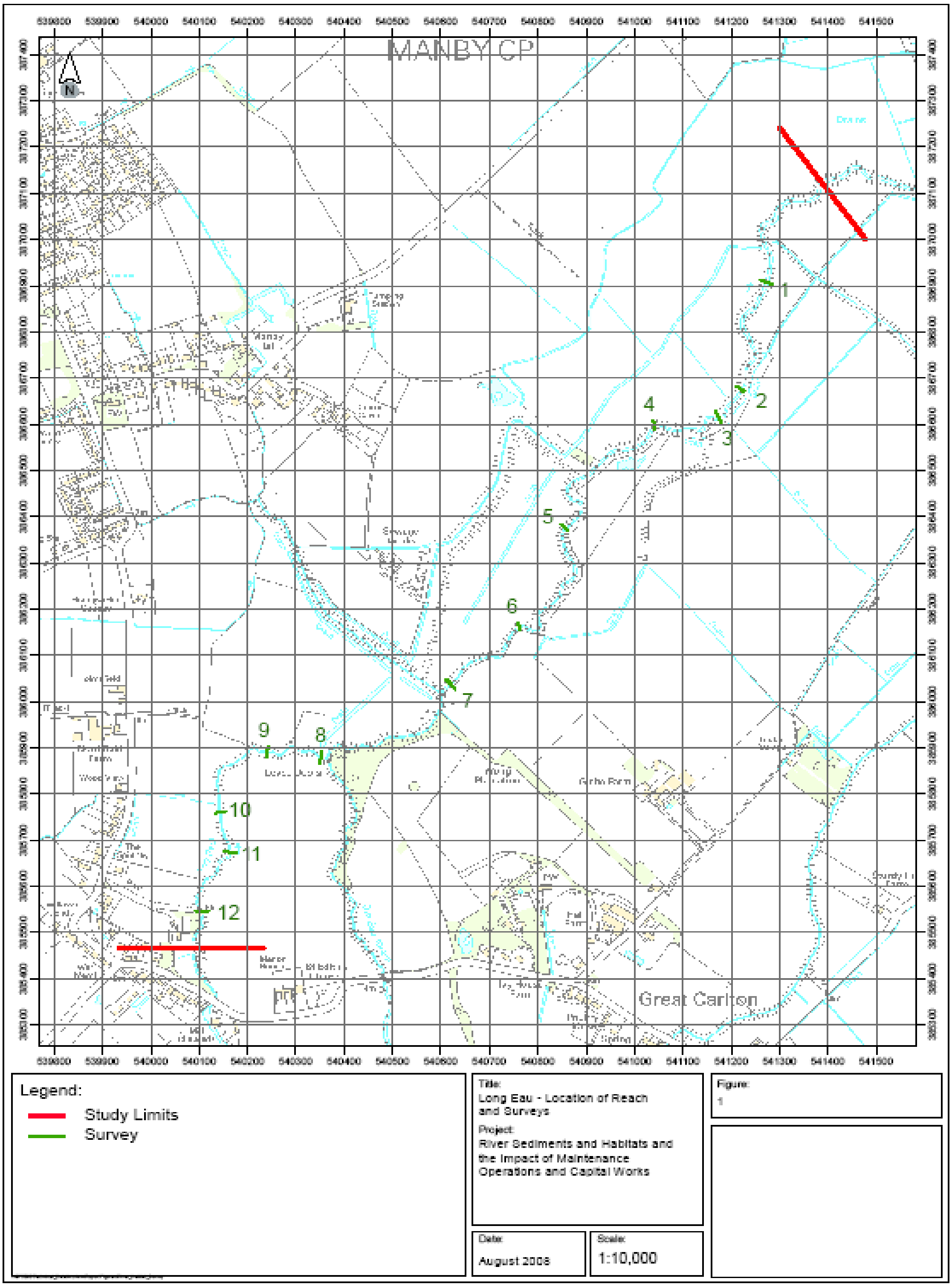

Figure 2.1 Location of cross-sections

2.2.2 Section spacing

The cross section spacing is generally around 200 metres with an average cross-section width of approximately 8 metres.

2.2.3 Longitudinal profile

The reach contains a number of artificial riffles and some of these are visible in the longitudinal bed profile. The average reach slope is 1 metre in 1000 metres.

2.2.4 Hydraulic Roughness

Hydraulic roughness zones were created using the CES roughness advisor. Survey photographs of the Eau have been compared to the standard examples in the roughness advisor and used to estimate the unit roughness at each cross section.

2.2.5 Sinuosity

The sinuosity, calculated as a reach average, is 1.05.

2.2.6 Downstream boundary

The downstream section has been copied and moved downstream so that its bed level is 1 metre lower than that of the true section. The distance moved has been calculated assuming the average reach slope and a 1 metre change in elevation. In this case the cross section is 1000 metres downstream of the last cross-section in the reach. This is to ensure that any errors in the downstream boundary do not affect water levels in the reach. The downstream boundary is a normal depth rating curve generated from the cross section properties.

2.3 HYDRAULIC MODELLING

2.3.1 Variation in depth, velocity and shear stress over an annual cycle

The hydraulic model was run for a typical annual flow period and the temporal variation in depth, velocity and shear stress were determined. For each variable the maximum, 75%ile, mean, 25%ile and minimum values during the period were determined. In addition the standard deviation of the variable was determined over the annual period. The model was run for a range of different hydraulic roughness conditions, including:

a) fixed, low hydraulic roughness, representing no vegetation conditions
b) fixed, high hydraulic roughness, representing channel with vegetation
c) time varying hydraulic roughness, representing the growth and die-back of vegetation
d) time varying hydraulic roughness with an assumed 70% cut in mid July
e) time varying hydraulic roughness with an assumed 70% cut in mid August.

Figure 2.2 shows the temporal variation of water levels through the year with the low and high fixed hydraulic roughness and the time varying hydraulic roughness with vegetation. It shows that when the hydraulic roughness varies due to the vegetation growth and die back, during the winter period the water levels track the water levels corresponding to the low, fixed hydraulic roughness and during the summer the water levels track those corresponding to the high hydraulic roughness value.

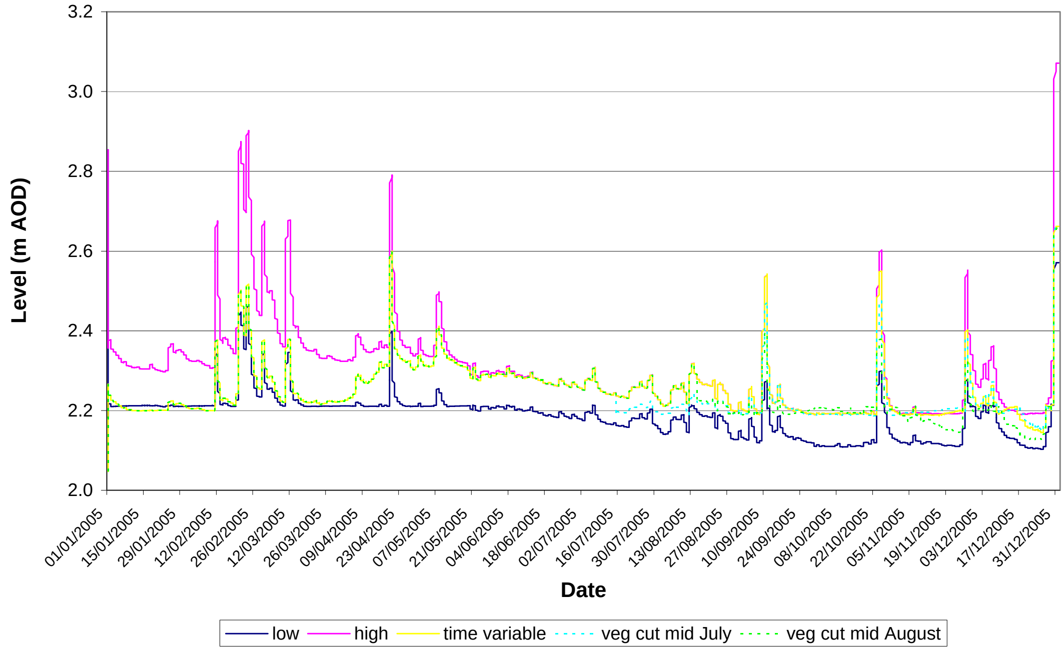

Figure 2.2: Long Eau – temporal variation in stage for low and high fixed hydraulic roughness and for different vegetation management options of no cutting, cutting in mid July and cutting in mid August

The Figure shows the importance of taking into account the temporal variation in hydraulic roughness. It also demonstrates that when considering the water levels associated with different discharges it is important that the time of the year is considered and that the hydraulic roughness selected corresponds to that period.

The temporal variations in flow velocity and shear stress for the case of the time varying hydraulic roughness were investigated.

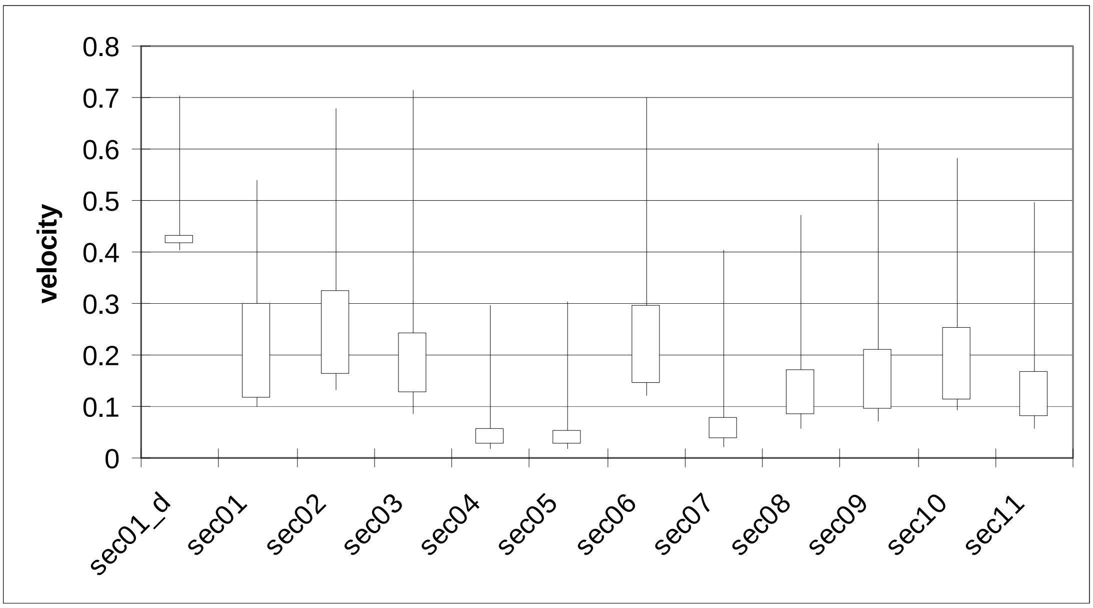

Figure 2.3: Long Eau, longitudinal variation in velocity

Figure 2.3 shows the maximum, 75%ile, 25%ile and minimum values of velocity over the annual cycle. It can be seen that lower velocities occur at some sections (Sections 4, 5 and 7) in the middle of the reach, where the flows are in general deeper than in the reaches upstream and downstream. In general the downstream part of the reach shows greater spatial variation than the upstream part. This may reflect the impact of the works that have been carried out in this reach.. .

Figure 2.4 shows the corresponding variation in shear stress.

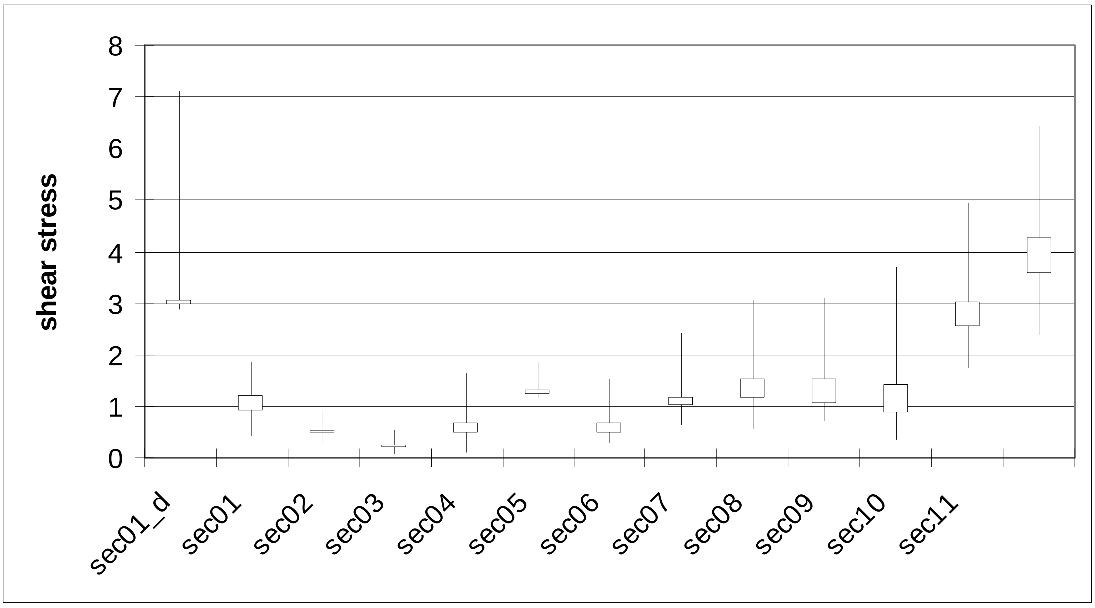

Figure 2.4: Long Eau, longitudinal variation in shear stress

There is a general trend of reducing shear stress and reducing spatial variation in shear stress as one goes in the downstream direction. The shear stresses on the Long Eau are generally lower than in the other rivers modelled though they are comparable with the lowest values determined for the River Dearne. The low shear stresses in the downstream part of the reach are consistent with the ineffectiveness of the constructed riffles. It is interesting to note that the observations of the channel suggest that the riffles in the most downstream part of the reach are more successful than those further upstream. The modelling suggests that in the lower part of the reach the shear stresses are in general lower than further upstream. This may point to the importance of the details in the design and construction of the riffles affecting their performance, particularly in locations where their performance is marginal. The trend of reducing spatial variation in shear stress in the downstream direction is confirmed by Figure 2.5.

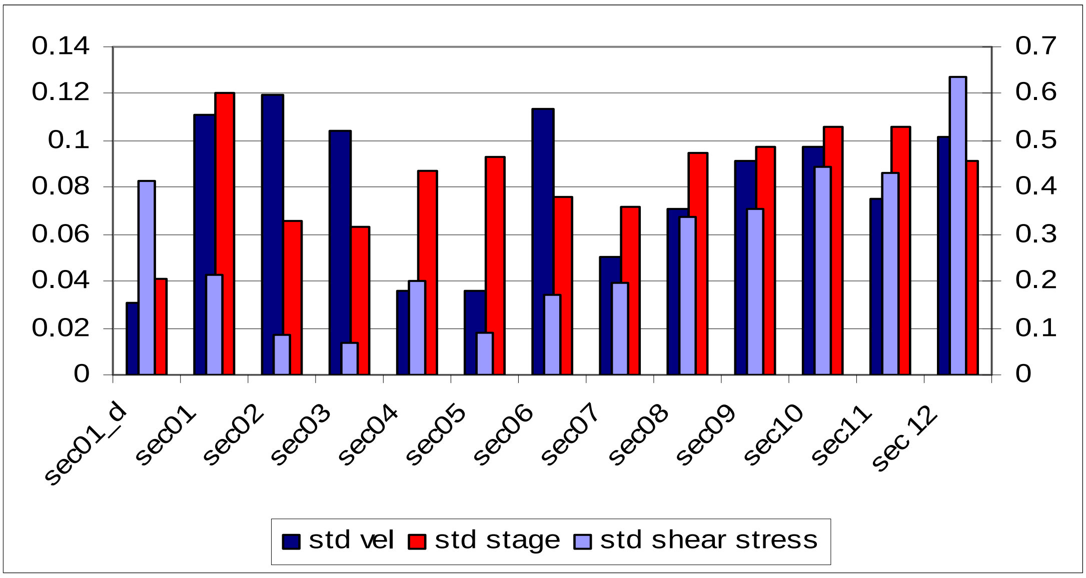

Figure 2.5: Long Eau, longitudinal variation in standard deviations for velocity, stage and shear stress

It is noticeable, however, that the spatial variation of standard deviation for stage and velocity does not show a marked reduction as one progresses downstream. This arises as the water surface slope must be relatively insensitive to the discharge. The reduction in shear stress variation may be associated with the impact of downstream water levels. The very flat slope of the Great Eau, into which the Long Eau discharges, means that water surface slope variation reduces as one progresses down the study reach.
It would appear that setting back the flood banks in the upstream reach has done little to add to flow diversity for non-flood flows. The similarity of the nature of the flow and its variability along the reach is reflected in the results of the macrophyte surveys which showed little variation in MTR scores along the reach (see Appendix 3).

2.3.2 Impact of vegetation management on flow velocities and depths

The impact of vegetation management on velocities and depths was investigated further by applying CES to individual cross-sections and simulating the impact of different vegetation cutting strategies. Three different vegetation cuts were imposed, 30% of width, 60% of width, which corresponds approximately to the Environmental Options W9 cut, and a cut over the full width of the channel, which corresponds to the Environmental Options W1 cut. Calculations were carried out for three discharges corresponding to the Q50 flow, the Q05 flow and the flow with an annual probability of exceedence of 0.5 (T02). Figure 2.6 shows the variation in water levels and flow velocities for Q05 flow. It can be seen that the no vegetation cut gives smallest overall flow velocities. These are relatively uniform across the channel width. Cutting just 30% of the width of the channel significantly increases the flow velocity in the central portion of the channel and leads to a significant reduction in water level. Progressively increasing the width of channel that is cut increases the maximum flow velocity in the channel. As more of the channel width is cut the velocity profile broadens. The difference between a 50% cut and a 70% cut in terms of both flow velocity and depth is small.

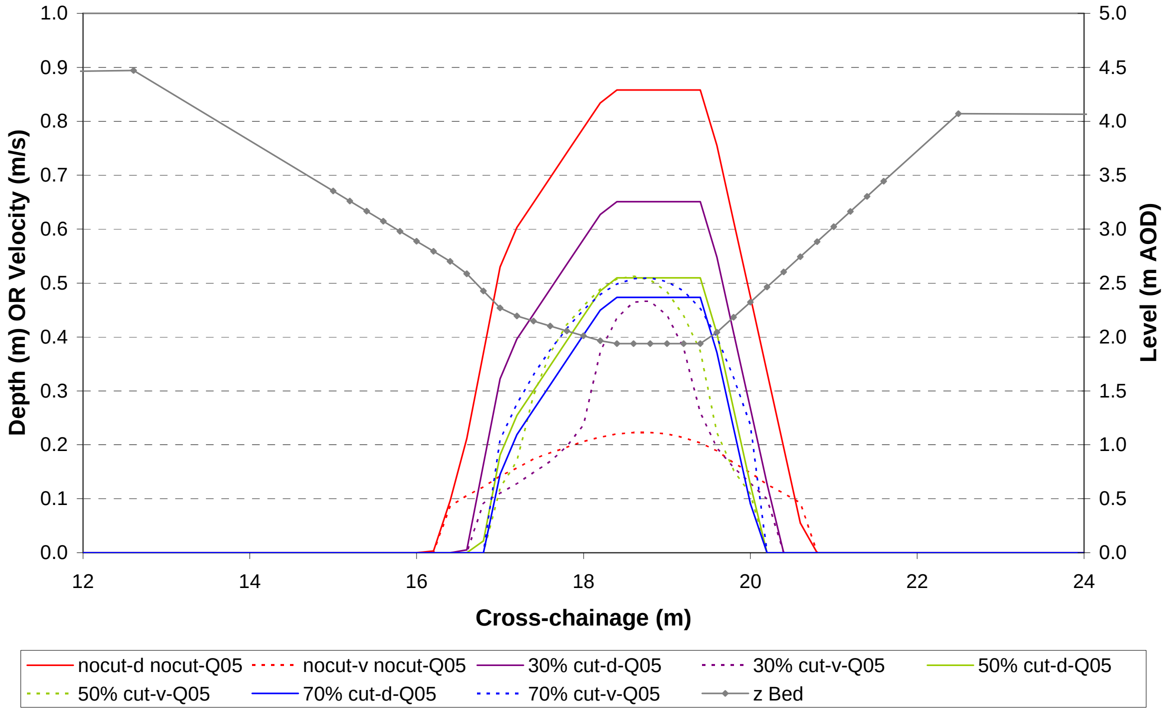

Figure 2.6: Impact of different vegetation cuts on flow velocities and depths for Q05 discharge

It is noticeable that when 30% of the width of the channel is cut the velocities at the margins of the channel are lower than with the 50% width and 70% width cuts. These lower flow velocities are likely to encourage sediment deposition in the channel margins and the formation of sediment related features.

Figures 2.7 and 8 show the % change in flow depth and velocity as a result of different vegetation cuts. These show that the largest percentage change occurs for the lower flows (Q50 and Q05) and that the percentage change is smallest for the largest flow (T02). For the lower flows it can be seen that the difference between a 50% width cut and a 70% width cut is small. This demonstrates that in many circumstances little increase in conveyance is achieved by cutting vegetation on the channel margins. For the largest flow corresponding to a flow with an annual probability of exceedence of 0.5, there is a noticeable difference in water depths for a 50% cut and a 70% width cut. This is related to the shape of the channel and is due to the cross-section being narrow with high banks. For wider channels one would expect little change in water depth between the 50% width and 70% width cut.

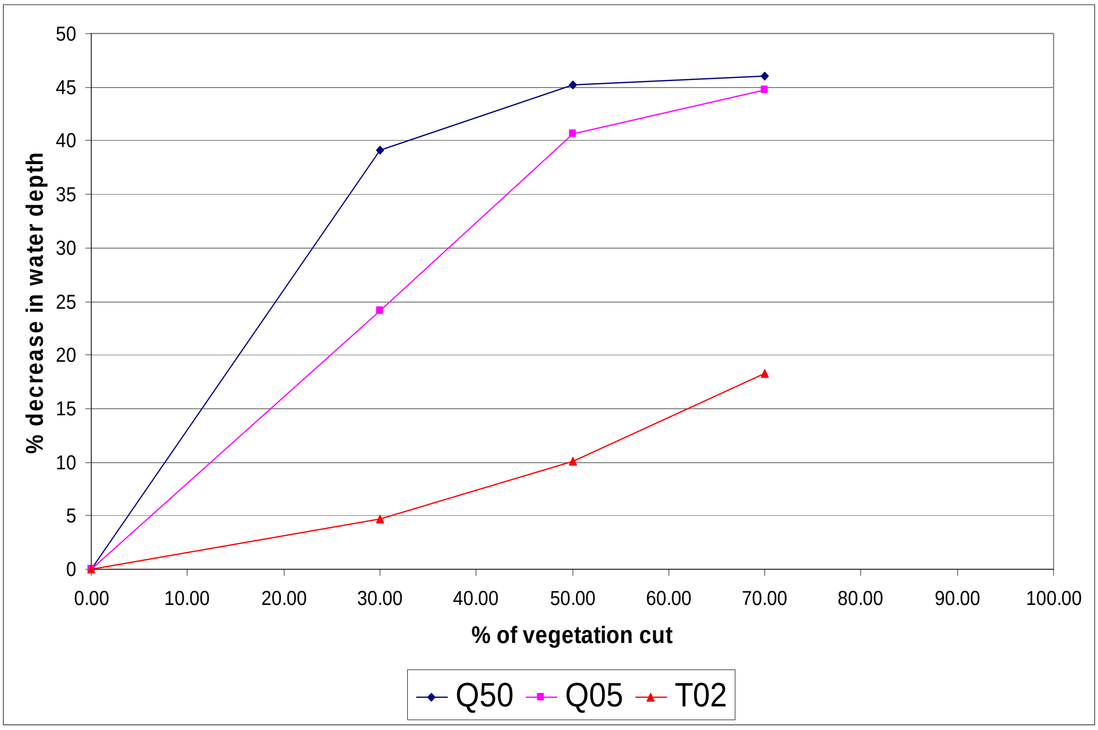

Figure 2.7: Impact on maximum water depth of different vegetation cuts for different discharges

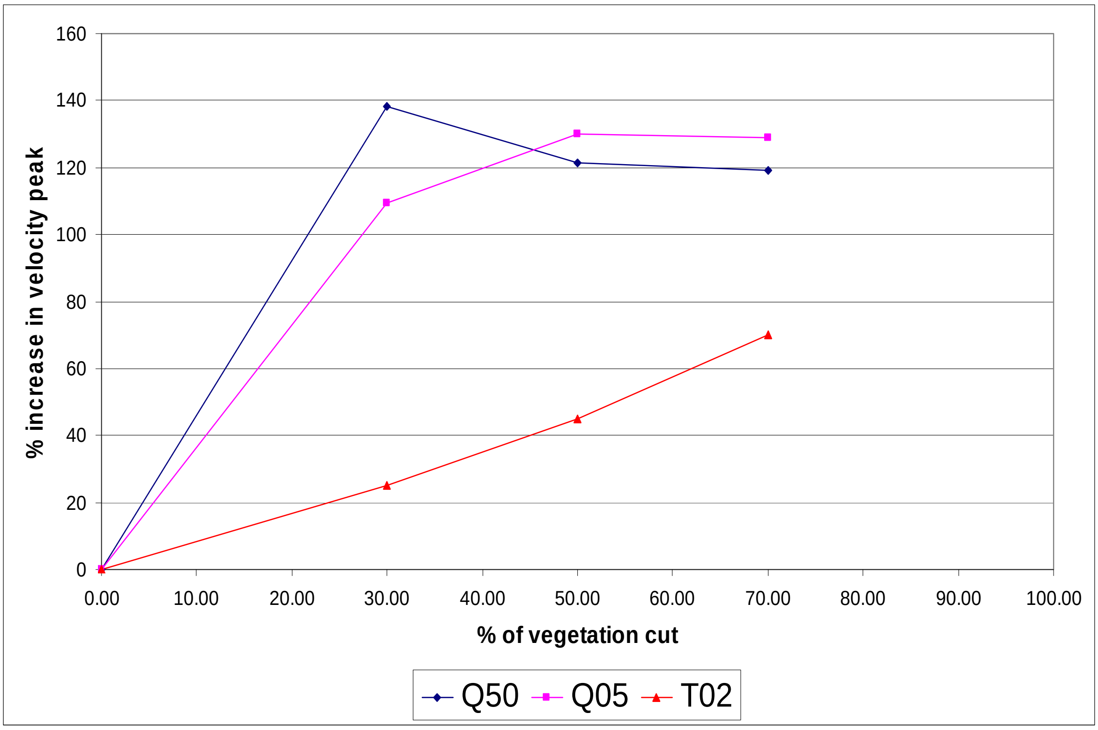

Figure 2.8: Impact on maximum velocity of different vegetation cuts for different discharges

2.3.3 *Impact of timing of vegetation management*

Fisher (1995) demonstrated the impact on flood levels of vegetation cuts at different times through the year. Using the Candover Brook as an example, the work showed that if no vegetation management took place the flood risk was greater during the summer than the winter, as though the expected flows were lower, the increased hydraulic roughness during the summer led to higher water levels. This is illustrated in Figure 2.9. The Figure also shows the impact of cutting the vegetation at different times during the summer period. It is clear from this work that the timing of vegetation cuts has an impact on the flood risk. The impact of cutting the vegetation at different time periods was, therefore, investigated.

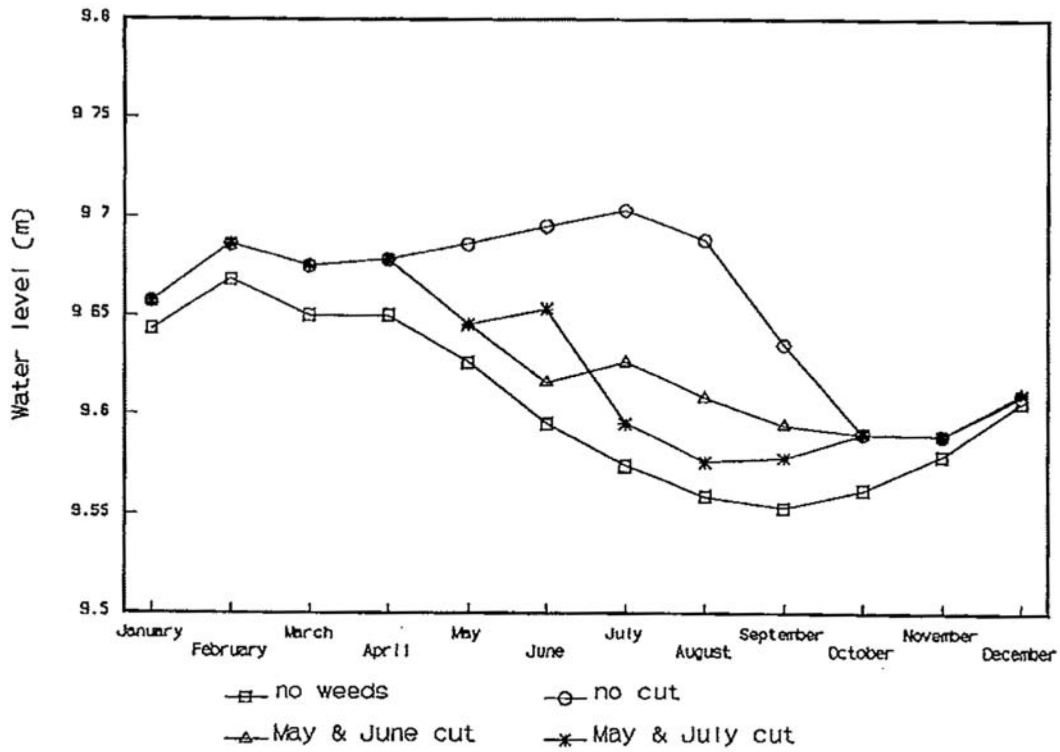

Figure 2.9: Candover Brook, Impact on flood levels of different vegetation cutting times (from Fisher 1995)

For the following analysis Section 7 was selected as representing a typical cross-section in the reach. Figure 2.10 shows the impact on water levels at Section 7 of cutting the vegetation in mid-July and mid August. In the model a uniform 70% cut across the full width of the channel has been assumed. It can be seen that the impact of cutting the vegetation in mid July lowers water levels and that the impact on water levels is sustained until early winter. The lowering of the water level for the same discharge results in a corresponding increase in flow velocity.

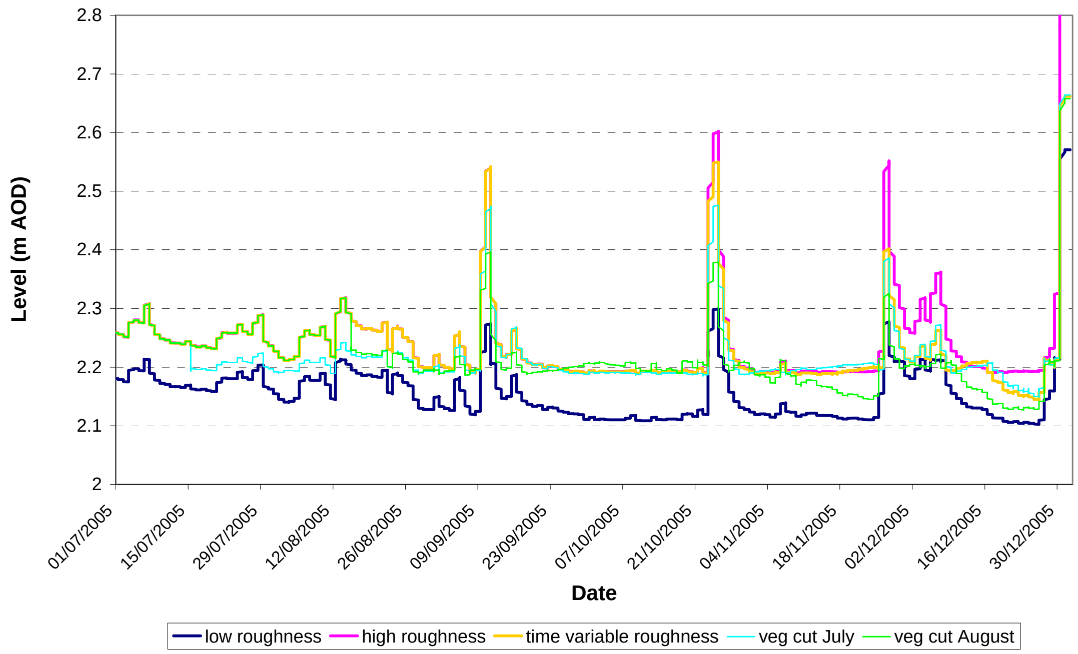

Figure 2.10 Temporal variation in water levels at Section 7 as the result of different vegetation maintenance options

Cutting the vegetation in mid July and mid August was also simulated for an annual flow sequence. It can be seen that for the flood flows during the record, the impact of the vegetation cutting on water levels can be in excess 100 mm. Table 2.1 shows a comparison of summarising statistics for the flow, stage, velocity, depth and shear stress for the three cases of:

a) Vegetation growth and die-back
b) Vegetation with cut in mid July
c) Vegetation with cut in mid August,

for Section 7.

Vegetation - No cut

	Flow	Stage	Velocity	Depth	Shear stress
average	0.131	2.250	0.066	0.656	1.116
STD	0.143	0.071	0.050	0.071	0.196
Max	1.374	2.662	0.404	1.068	2.413
Min	0.033	2.047	0.022	0.453	0.654
25percentile	0.063	2.200	0.036	0.606	0.981
75 percentile	0.143	2.280	0.077	0.686	1.189
Median	0.104	2.231	0.053	0.637	1.072

July cut

	Flow	Stage	Velocity	Depth	Shear stress
average	0.131	2.244	0.066	0.650	1.088
STD	0.144	0.070	0.050	0.070	0.195
Max	1.376	2.664	0.403	1.070	2.420
Min	0.033	2.047	0.022	0.453	0.654
25percentile	0.062	2.200	0.037	0.606	0.964
75 percentile	0.143	2.278	0.077	0.684	1.180
Median	0.104	2.220	0.055	0.626	1.028

August cut

	Flow	Stage	Velocity	Depth	Shear stress
average	0.131	2.243	0.067	0.649	1.093
STD	0.143	0.070	0.050	0.070	0.192
Max	1.371	2.658	0.405	1.064	2.401
Min	0.034	2.047	0.023	0.453	0.654
25percentile	0.062	2.201	0.037	0.607	0.974
75 percentile	0.143	2.279	0.077	0.685	1.185
Median	0.104	2.223	0.054	0.629	1.040

Table 2.1: Summary statistics of flow variables for different vegetation management for Section 7

As the impact of the vegetation management is only effective over part of the year but the statistics are based on a year’s flow record, the changes between the different management options appear small. During the summer period when the vegetation management has its largest impact in terms of hydraulic roughness the flows are low and so the impact on stage and flow velocities is small. One would expect little impact of the higher winter flows and a larger impact for the lower flows, as represented by the 75 percentile flow. Comparing the results for the minimum and 75 percentile flows one can see that the impact of the different vegetation maintenance strategies is small. The statistics show that though the weed cutting affects flow conditions over the summer months the impact on the overall flow regime of the river in terms of velocities and depths is small.

To investigate the differences in more detail, the differences were investigated on a daily basis. Comparing the differences in stage and flow velocity between cutting in mid July and mid August showed the distribution of differences in Table 2.2

Difference in stage (m)	No of days in year a) No vegetation cut and cut in mid-July	b) Cut in mid- July and cur in mid August
>0.05	13	15
0.05>0.04	19	9
0.04>0.03	10	12
0.03>0.02	7	16
0.02>0.01	13	14

Difference in velocity (m/s)	No of days in year a) No vegetation cut and cut in mid-July	b) Cut in mid- July and cur in mid August
>0.015	1	-
0.015>0.01	3	1
0.01>0.005	11	6

Table 2.2: Duration of differences in stage and velocity between No vegetation cut, vegetation cut in mid July and vegetation cut in mid August for Section 7.

The results show that, although cutting vegetation can have a significant impact on hydraulic roughness and flood risk, for the lower flows that typical occur during the summer period the impact on stage and velocity of cutting at different times is modest.

2.3.4 Discussion of results from flow modelling

The key results from the modelling are:

- Temporal variations in the hydraulic roughness of vegetation impacts on flood risk
- In assessing flood risk it is important to use the hydraulic roughness of vegetation that is appropriate to the time of year
- The predicted values of shear stress in the Long Eau are low in comparison with the other rivers modelled which is consistent with the river being a low energy system.
- The calculated low shear stresses are consistent with the problems that have been experienced with the artificial riffles that were constructed in the channel.
- Vegetation cutting has an impact on flow depths and the distribution of velocities across the channel.
- Cutting vegetation over only a proportion of the channel width leaves areas of low flow velocities at the margins which are likely to encourage the development of sediment related features.
- In general, there is little difference in channel conveyance between cutting only 60% of the channel width (Environmental Option W9) and cutting the entire channel width (Environmental Option W1). The only exception may arise for narrow, steep-sided channels.
- Cutting vegetation has little impact on the overall annual flow regime.
- Cutting vegetation at different times may affect the overall flood risk but the timing of vegetation cuts has little impact on the overall annual flow regime.

3. River Dearne

3.1 BACKGROUND

3.1.1 Description of restoration works done

Traditionally dredging and vegetation clearance was routinely carried out on the River Dearne. In 1995, as part of a restoration scheme in the downstream parts of the reach a narrowed low flow channel was created, RRC (2002). The previous 10m wide channel was narrowed by up to 5.5m. The sinuous low flow channel replaced a wide straight channel which was choked with vegetation in the summer. The intention was to increase velocities to 0.5m/s in the upstream bends created. The inside of the bends was defined by placing limestone boulders into the channel and the outside of the bend shaped by excavating material from the opposite steep bank. Backwaters were excavated and created within the low berms. The berms and banks were seeded and the new course and seeded grass and reed berms can be seen in Figure 3.1. The design standard for the channel was calculated to be approximately 1 in 50 years and the maintenance demanded would be reduced.

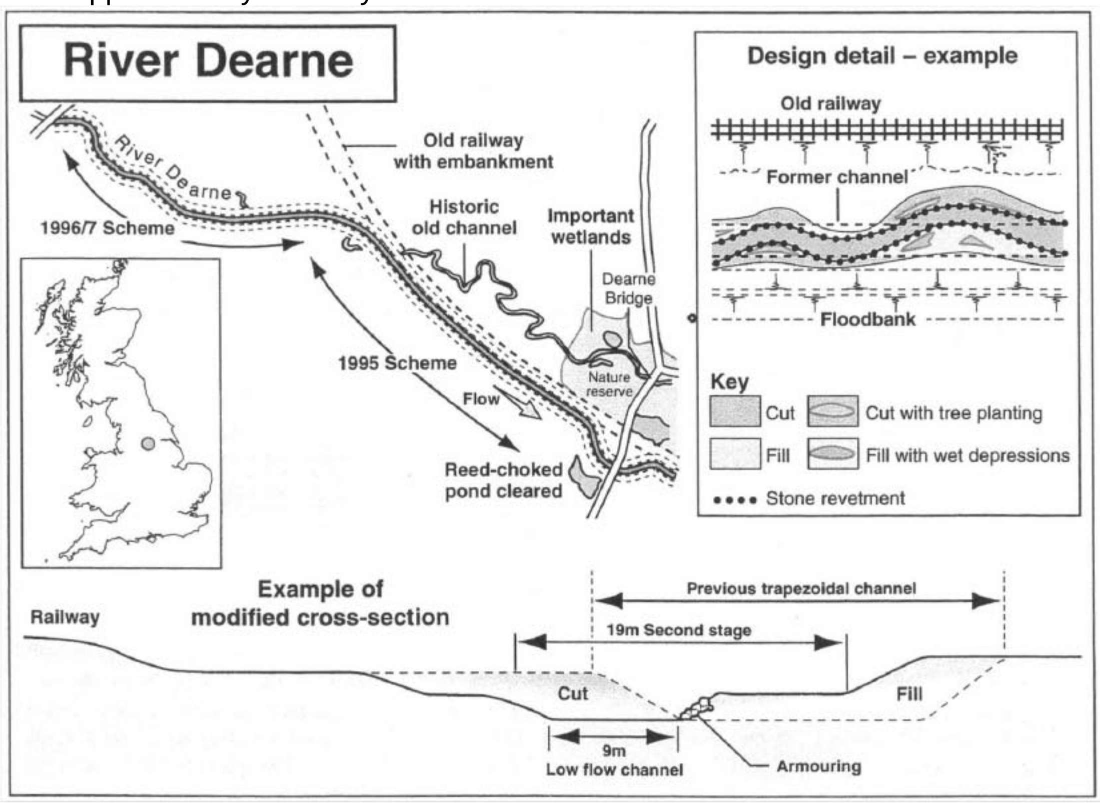

Figure 3.1 Restoration work undertaken in 1995

The plan form of the channel has been set with the limestone blocks and the gradient through this restored part of the reach is much greater than it was previously. Plates 3.1 show the channel pre and post restoration with the new meanders, berms and planted reeds.

River Dearne. Wide and straight, choked in summer

New sinuous reed-fringed course

Plate 3.1 River Dearne, downstream part of reach, pre and post restoration, 1995

Plate 3.2 River Dearne, downstream part of reach, November 2007.

Plate 3.2 shows this part of the river in 2005 and 2007 where it can be seen that the vegetation on the berms has increased significantly and trees and bushes have encroached onto the banks.

3.2 DATA COLLECTION AND COMPARISON

A cross-section survey of eleven cross-sections and one weir crest was taken in 2005 for an understanding of the levels through the reach and to construct the hydraulic model. This extended from Mexborough Road Bridge at the downstream end to the bridge at the upstream and, therefore, covered all the restored reach and upstream weir. The survey was repeated in 2007 for Sections 5 to 11. The locations of the surveyed cross-sections are shown in Figure 3.2

Figure 3.2 Locations of cross-sections

3.3 DISCUSSION OF TOPOGRAPHIC SURVEYS

Figure 3.3 shows the comparison between the minimum bed levels through the reach for 2005 and 2007. Surveys of Sections 1 to 4 were not repeated in 2007 as it was considered that as these were constructed in block stone as described above, it would be very unlikely that there would be any changes to the bed levels. When these sections were compared with the designed sections they have remained very similar. Figure 3.4 shows Section 1 design and 2005/2007 bed profiles showing that the section has changed very little in 10 years.

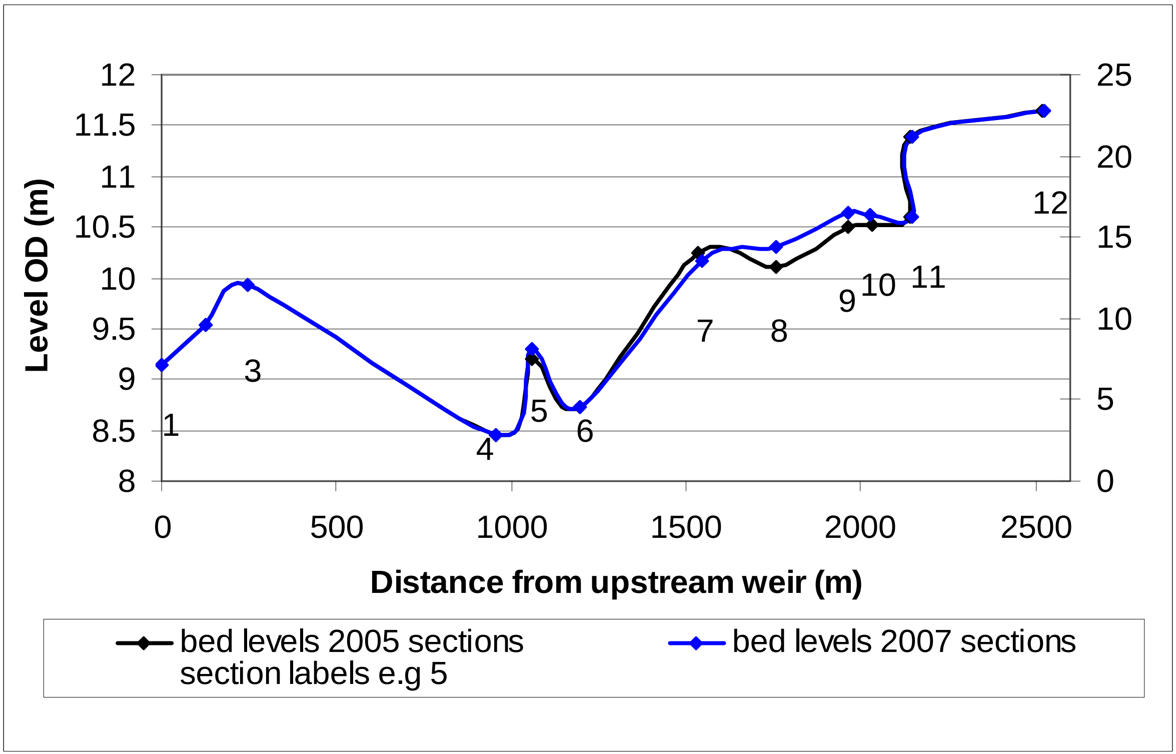

Figure 3.3 Minimum bed level for River Dearne reach in 2005 and 2007

Figure 3.4 Comparison of cross-section profile for Section 1 in 2005, 2007 with designed section

The sections through the restored reach have maintained a similar shape and size to the designed section. A comparison of the section properties with the section properties upstream is made in a later section of the report.

From Figure 3.3, it can be seen that the changes in bed levels between Sections 5 and 11 in the two year period from 2005 to 2007 are small but they show a trend which, when considered with the maintenance regime may become more significant. There has been a small amount of deposition between Sections 8 and the weir upstream raising the bed level by up to 19cm. At Section 7 the bed level has eroded by just over 9cm. The implications and reasons behind these changes are detailed below.

3.4 DIFFERENCES IN SECTION SHAPES AND CAPACITY

From 2005 to 2007 there are some small changes in bed level and shape with berms being created. There are some differences along the reach, however, between the restored reach, Sections 1, 2 and 3 the reach immediately upstream which is straight, Sections 4 and 5 and the reach upstream of the footbridge, Sections 7 to 10.

Sections 1, 2, 4 and 6 have a much smaller capacity, in terms of conveyance, than Sections 7 to 10 upstream. Of these, Section 4 has the smallest capacity, being half of the conveyance capacity of Sections 1, 2 and 6 at bankfull and a third of the capacity of the other sections, see below. Figure 3.5 shows the comparison of the cross-section profile of Section 4, with the sections upstream and downstream. It is deeper and narrower than these sections and causes a constriction from which the water ponds upstream.

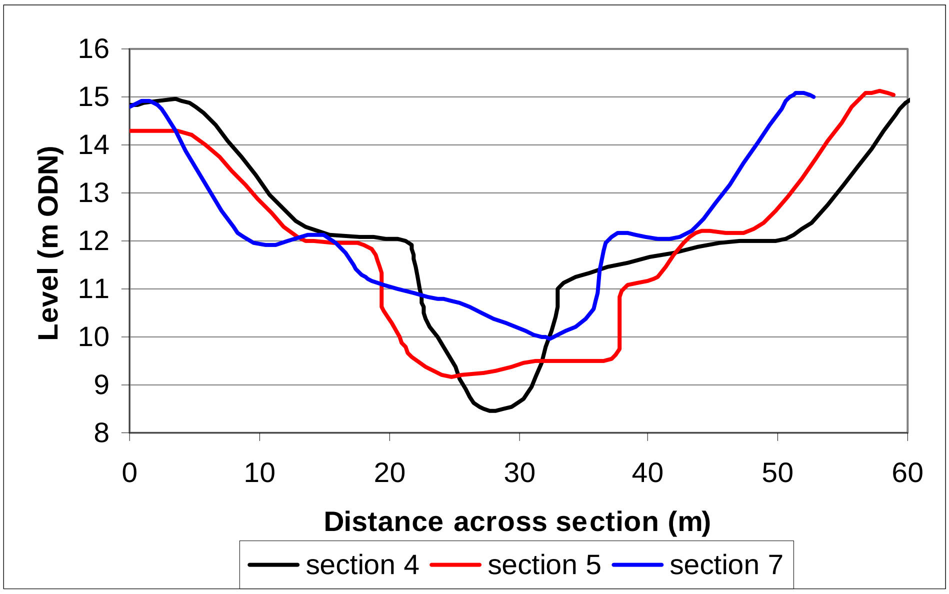

Figure 3.5 Bed profiles for Sections 4, 5 and 7.

Figure 3.6 shows the relationship between conveyance and depth for the upper part of the reach, Sections 7 to 10, the mid parts Sections 4 to 6 and the lower restored reach, Sections 1 to 3 and compares these with the conveyance relationship for the designed section. The bankfull depth is approximately 2.0m.

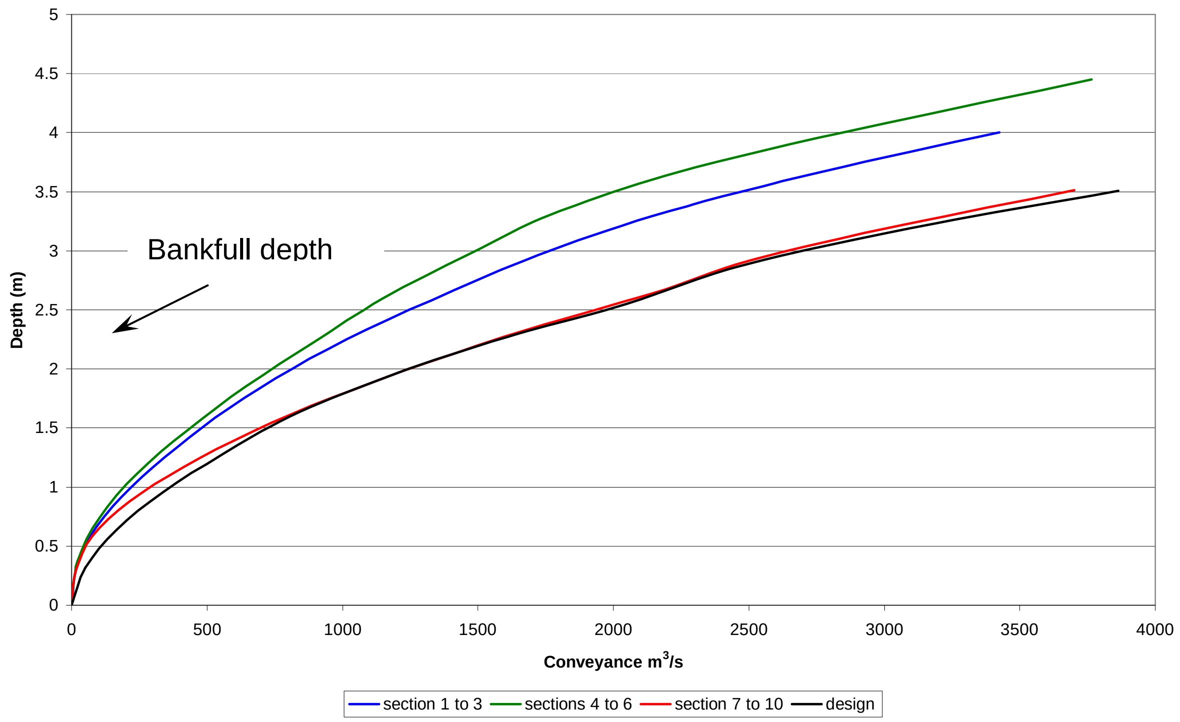

Figure 3.6 Conveyance depth relationships for parts of the River Dearne reach for 2007 sections

The conveyance depth relationship in 2007 for the upper part of the reach is very similar to the designed sections in the lower restored sections. The restored sections themselves have "lost" conveyance due to the roughness increasing on the berms with the growth of vegetation, trees and bushes. The conveyance in these lower sections should be similar to the design conveyance. The conveyance of the Sections 7 to 10 and the design sections are approximately double the conveyance of the sections in the lower and middle parts of the reach. None of the sections have been maintained during the last few years apart from grass cutting on the embankments in the lower sections and grazing of the embankment banks further upstream. There has been no in channel maintenance and berms have been created and the channel narrowed with emergent vegetation in Section 7 to 10. As these sections had a higher conveyance initially, the increase in roughness has reduced the conveyance to the design standard and created a more varied habitat and low flow channel.

The sections in the middle of the reach have not developed berms or low flow channels and the flow is ponded upstream from Section 4 by the change in slope and section shape. The decreased conveyance in these middle sections is influenced by the tree and bush growth on the banks, as shown in Plate 3.3

Plate 3.3 Cross Section 4 of River Dearne showing enchroaching vegetation growth on berms and banks

3.5 HYDRAULIC MODELLING OF RIVER DEARNE REACH

The reach of the River Dearne was modelled using INFOWORKS for the 2005 and 2007 cross-sections. In the 2007 model the roughness was adjusted to reflect the vegetation growth in the channel, on the berms and floodplains. An additional hydraulic model was created using the 2007 cross-sections and increased roughness in the channel, on the berms and floodplains, to simulate projected conditions in 20 years time, assuming no future maintenance took place. The models were run for a 1 in 100 year flood flow and over an annual period. Details of the models and the runs are given below.

Data

The cross-section surveys of eleven cross-sections and one weir crest from 2005 and 2007 were used to construct hydraulic models which were then run with different flow conditions.

Hydraulic Roughness
Hydraulic roughness zones were created using the CES roughness advisor. Survey photographs of the Dearne have been compared to the standard examples in the roughness advisor and used to estimate the unit roughness at each cross section.

Sinuosity
The present river course is engineered with the old course of the River Dearne appearing as a sinuous channel to the north-east of the present channel. This engineered channel was effectively straight and even the attempts to re-meander the lower part of the reach has not significantly increased the overall sinuosity of the channel. The sinuosity for the present channel, as a reach average, is 1.08.

3.6 FLOOD MODELLING

The hydraulic models for 2005, 2007 and projected forward 20 years with the 2007 cross-sections were run with the flood flow with a 1% annual probability of exceedence of 84 m^3/s. The results from these model runs are shown in Figure 3.7. The water levels for the flood flow with a 1% annual probability of exceedence are lower for the 2005 cross-section survey and associated roughness values. The water levels are higher in 2007 all along the reach, other than at the downstream end where the level is fixed by the downstream boundary condition in the model. The rise is up to 0.475m at Section 11, just downstream of the weir. This rise is partly due to the changes in bed level around Section 7 to 10 and the impact on the slopes downstream. The main reason for the rise in water levels is due to increased roughness from the vegetation growth on bed and banks.

If there was a rise in bed levels only, there would be a rise in water levels of 0.175m downstream of the weir, at around Section 10 and 11. The added increase in water levels for a flow with a 1% annual probability of exceedence, of 0.3m is due to the increase in roughness due to vegetation growth, based on expected vegetation growth over a 20 year period. If vegetation was allowed to grow in a similar manner without maintenance, over a 20 years period, the increase could be up to 0.63m, above the 2005 water levels, downstream of the weir. This is an additional 0.15m of water level increase, above the 2007 levels, in flood with an annual probability of exceedence of 1%. This is shown in Figure 3.7 by the projected 20 years on simulation. This increase in flood levels is due to the increase in hydraulic roughness due to the future development of the vegetation in the absence of vegetation and does not take into account any impact due to bed level change.

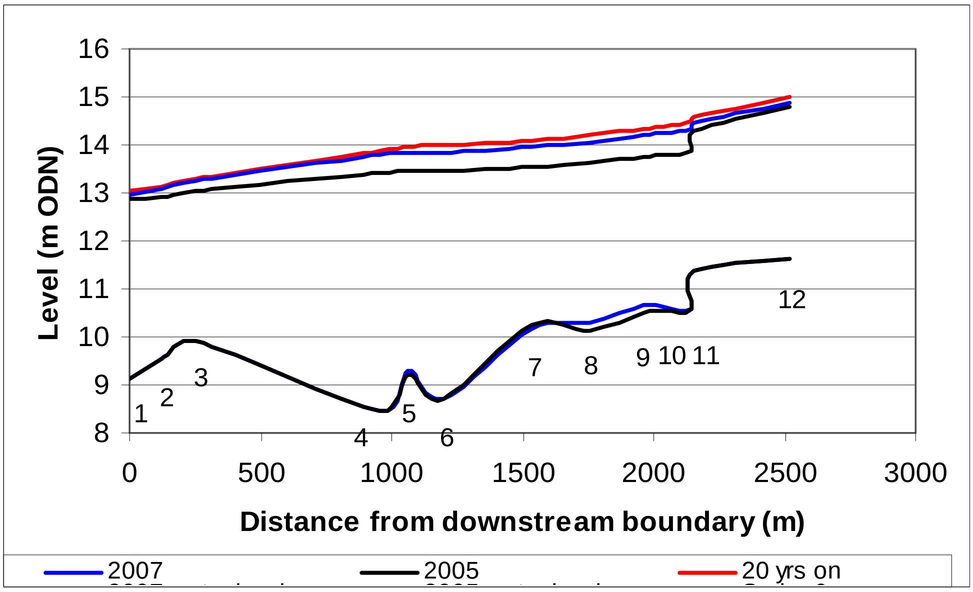

Figure 3.7 Flood levels for a flow with a 1% annual probability of exceedence for 2005, 2007 bed surveys and 20 years on from 2007

3.7 VARIATIONS IN DEPTH, VELOCITY AND SHEAR STRESS OVER AN ANNUAL CYCLE

The three models, for 2005, 2007 and 20 years on using the 2007 cross-section survey, were run for a typical annual flow cycle using the 2005 flow data from a nearby gauging station. The standard deviation in depth and velocity for each of sections and the velocity and shear stress distributions for annual runs are given below in Figures 3.8 and 3.9

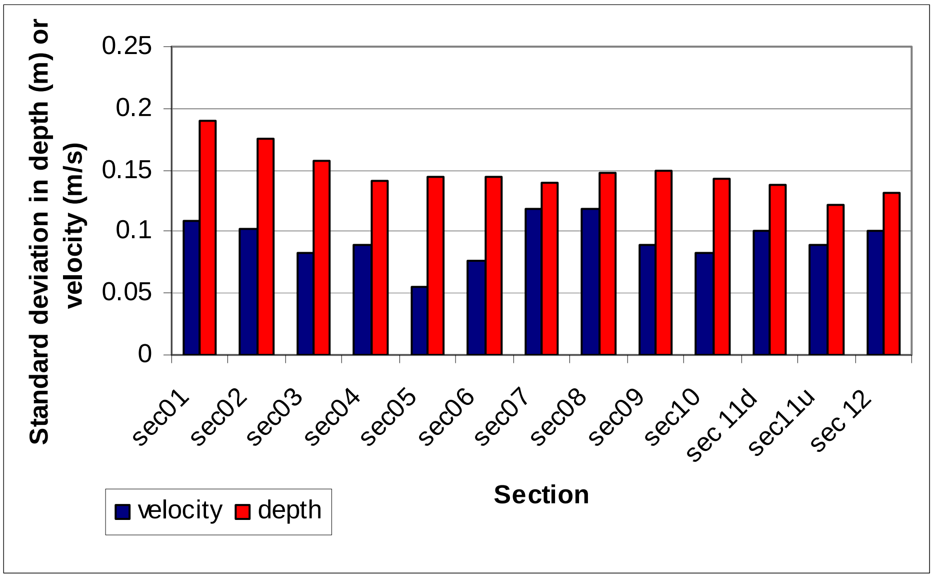

Figure 3.8 Standard deviation of depth and velocity over an annual cycle for 2005 cross-section survey

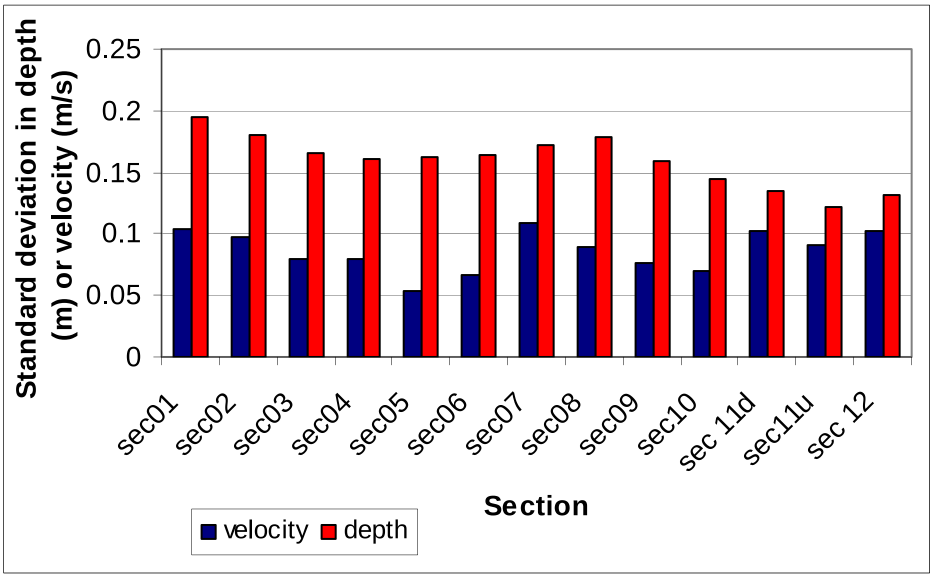

Figure 3.9 Standard deviation of depth and velocity over an annual cycle for 2007 cross-section survey

Figures 3.8 and 3.9 show the standard deviation in depth and velocity for the 2005 and 2007 surveys which are very similar over an annual cycle. The changes in hydraulic roughness between 2005 and 2007 only have a minor impact on the standard deviation of the depths, causing a small increase generally and a small decrease in the standard deviation of the velocity.

Figures 3.10a to c show the variations in velocity over an annual cycle at each section for the 2005, 2007 and 20 years on from 2007. For each section a line with a central box is given on the graph. The upper point of the line is the maximum velocity and the lower point on the vertical line, the minimum velocity at that section. The box in the centre is the range of the 75 percentile to 25 percentile. The mid point of the box represents the median velocity.

A number of observations can be made from these Figures.

- The median and range of velocities in Sections 1 to 6 are very similar for 2005 and 2007 with a slight decrease in range and median from 2005 to 2007
- The larger differences are between Sections 9 and 10 where the medians and 25th and 75th percentile spread is greater in 2007 than in 2005.
- Comparison with the 20 years on from 2007 model run shows that the spread between 25th and 75th percentile is very much wider than in 2005 and 2007 and the maximum values of velocity are also higher.
- This indicates a higher range of velocities, with generally higher values, through the year due to the increased roughness values.
- The reach between Sections 4 and 6 show a lower variation and range of velocity with much lower median values. This reflects the narrow deep channel in this part of the reach and ponded water which creates little velocity variation and less variation in habitats.

Figures 3.11a to 3.11c show the variations in shear stress over an annual cycle at each section for the 2005, 2007 and 20 years on from 2007. These figures show similar trends to those for the velocity variations.

- The median shear stresses are generally higher in 2007 than in 2005
- There has been an increase in the maximum shear stresses at most sections from 2005 to 2007, especially at Section 4 and between Sections 8 to 11d
- The largest change in shear stress between 2005 and 2007 is at Section 4. This is due to the changes in slope between Section 4 and 5 and the increase in roughness at this section, see Plate 3.3.

For the simulation 20 years on from 2007, the shear stresses are generally much greater, with greater median values, ranges in shear stress and maximum values. These increases are due to the increased roughness values and the changes in depth and slope that these create.

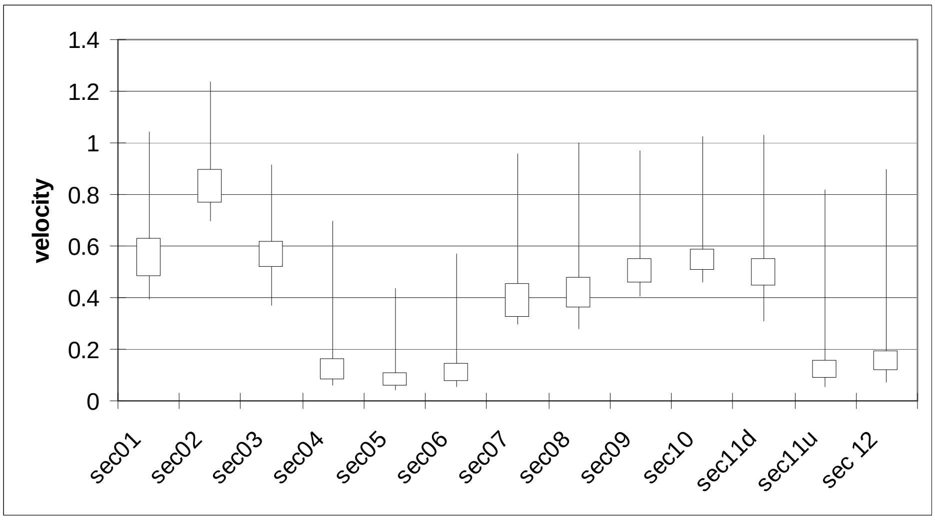

Figure 3.10a 2005 survey, velocity variations

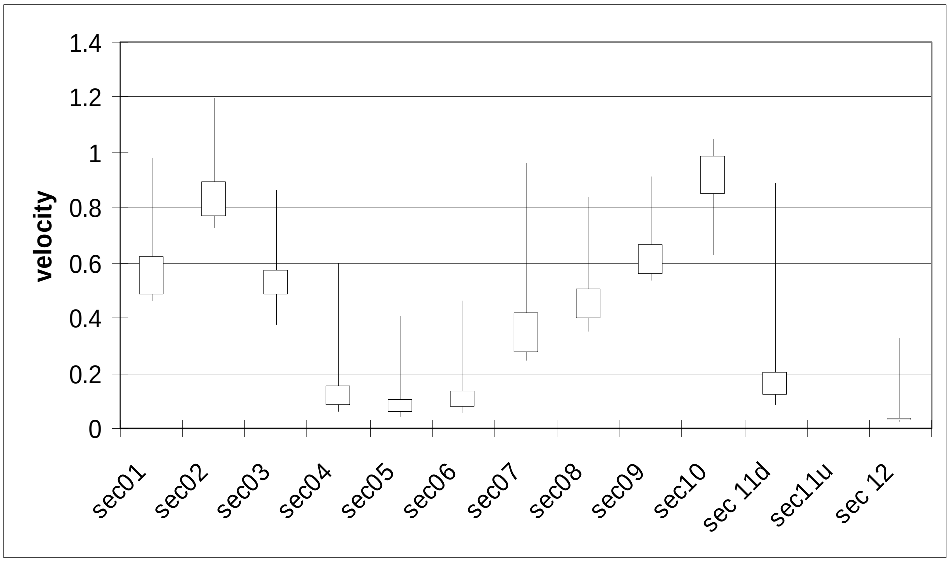

Figure 3.10b 2007 survey, velocity variations

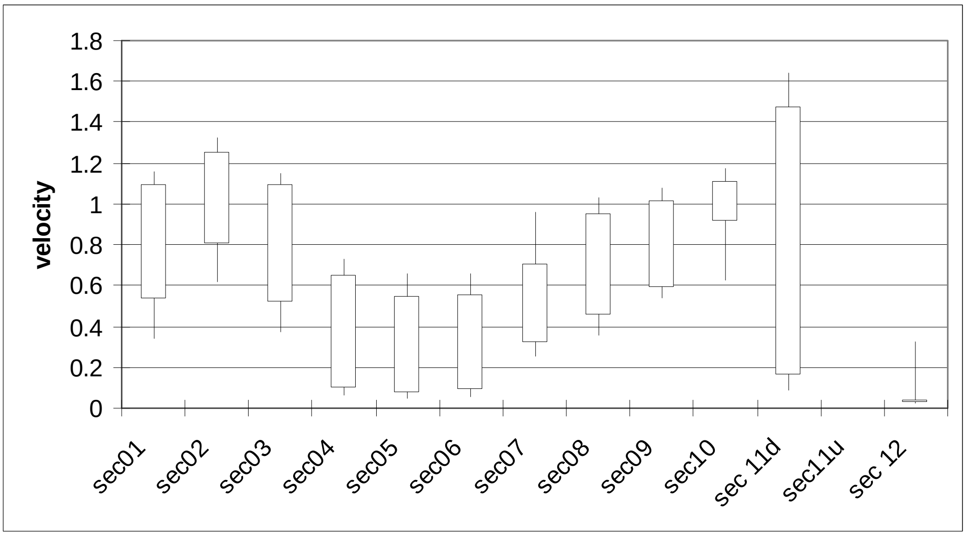

Figure 3.10c 20 years on from 2007 survey, velocity variations

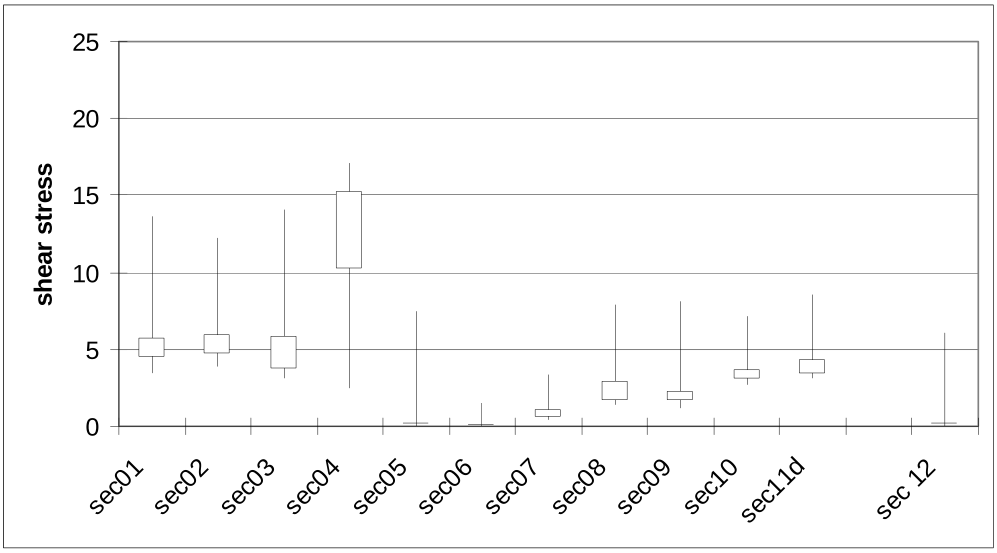

Figure 3.11a 2005 survey, shear stress variations

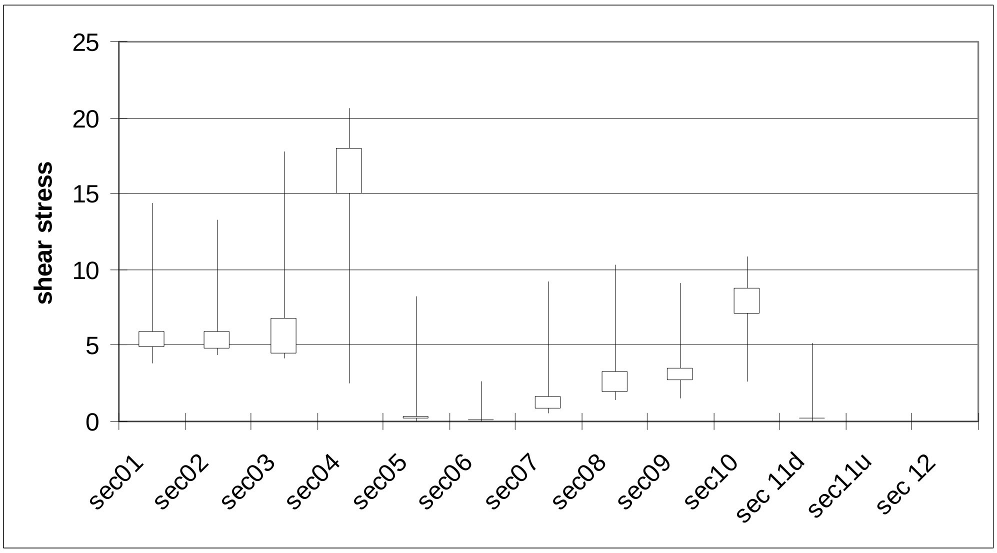

Figure 3.11b 2007 survey, shear stress variations

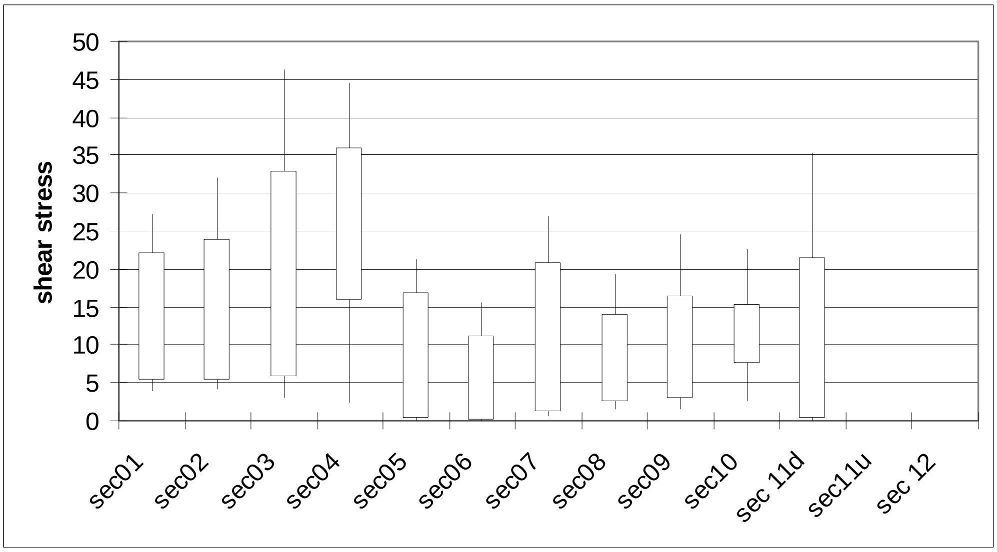

Figure 3.11c 20 years on from 2007 survey, shear stress variations

4. River Eden

4.1 DATA COLLECTION AND COMPARISON

Cross-section surveys have been taken through a reach of the River Eden in Kent, see Figure 4.1. The purpose of the surveys was to determine the changes in cross-section over a period of time on the river reach. Surveys were taken in 2005 and twice in 2007 for the Sediments and Habitats project. In addition a Section 105 survey was used from 2001. In this section the surveys are compared to investigate the temporal changes that have taken place and to relate these both to channel management actions and the information from the geomorphological and habitat surveys.

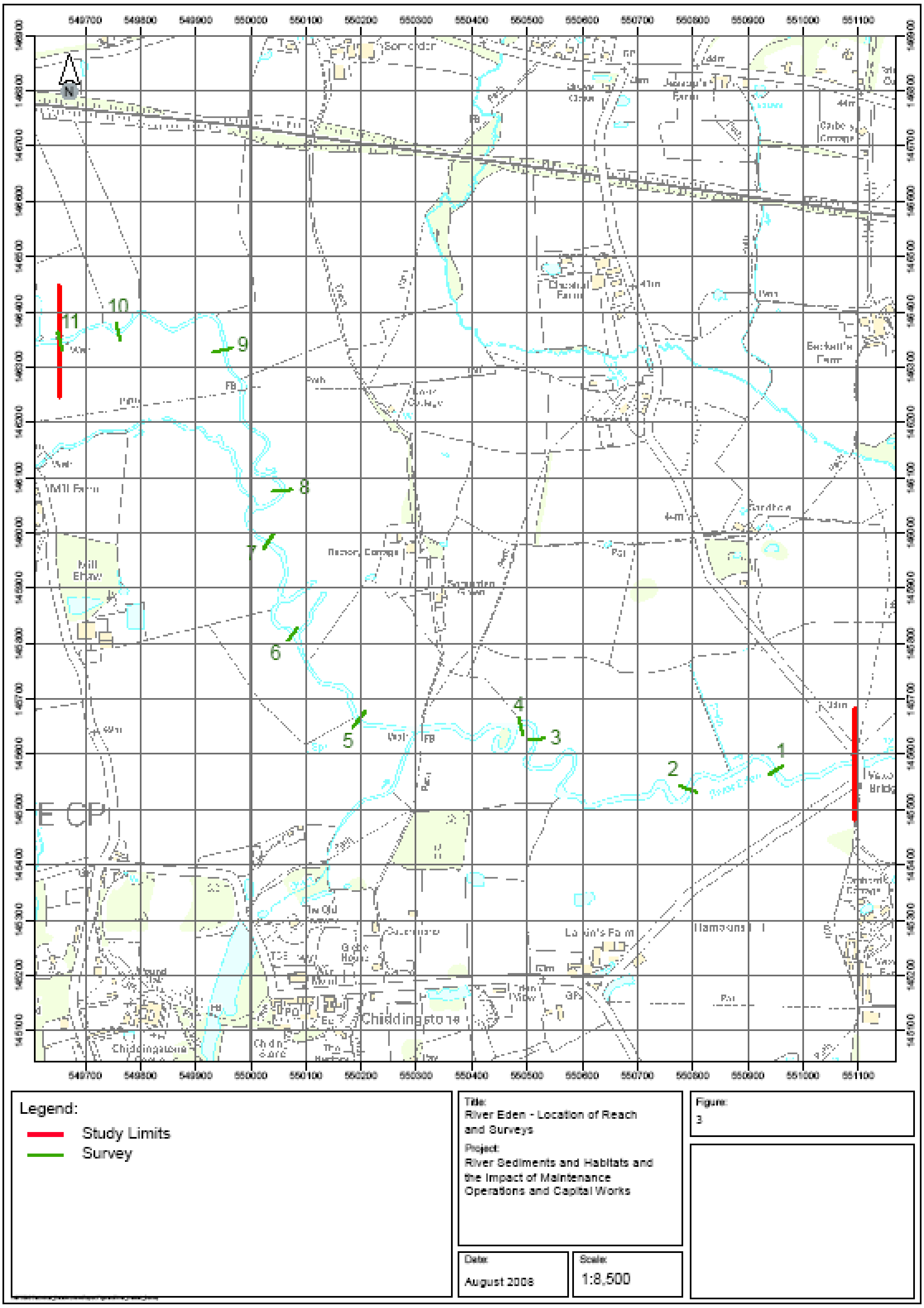

Figure 4.1 Location of cross-sections

The survey positions of the 2001 cross-sections do not exactly match with the other surveys. The 2005 survey and the November 2007 surveys match exactly in the position of the sections. The table below gives the relative positions and different names of the sections with the distance given from the upstream weir, at TQ497463.

Table 4.1 Comparison of labels and lateral distances from upstream weir for three surveys

2001 section 105		2005/Nov 2007		Sept 2007	
Section label	**Distance from upstream weir (m)**	**Section label**	**Distance from upstream weir (m)**	**Section label**	**Distance from upstream weir (m)**
25A	0	11d	0	11d	0
24	282	10	118	10	85
22	454	9	390	9	331
21	797	8	689	8	445
20	1011	7	796	7	649
19	1186	6	972	6	903
18	1360	5	1170	5	986
15	1607	4	1468	4	1210
14	1825	3	1505	3	1266
12	2330	2	1896	2	1640
11BU	2512	1	2069	1	1812

Figure 4.2 shows a plan view comparison of location of sections for 2005/Nov2007 and September 2007 surveys. As the September 2007 survey was not in exactly the same place as the 2005, the 2007 survey was repeated in November 2007 and this has been used for comparison purposes. A comment on the differences between the September and November 2007 surveys, and the implications of these differences, is made in the sections below.

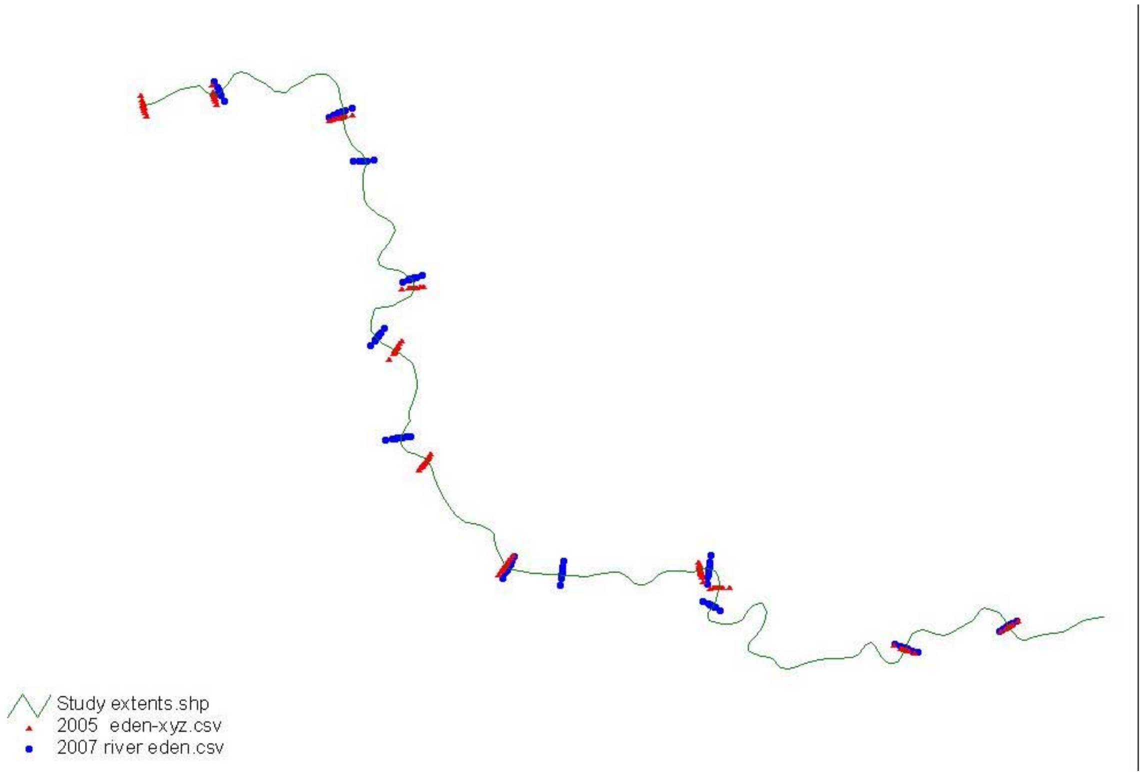

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Figure 4.2 Location of cross-sections for 2005 and Sept 2007 surveys

4.2 DISCUSSION OF TOPOGRAPHIC SURVEYS

The minimum bed levels measured in the topographic surveys of 2001, 2005 and November 2007 are shown in Figure 4.3. The differences between 2005 and November 2007 are slight but those between 2001 and 2005 show a difference of up to 0.5m in places. This may be as a result of a number of factors:

- Dredging between 2001 and 2005 in the areas between Sections 8 and 10 and 1 and 3.
- The cross-sections were taken in different places in 2001 and 2005 which could have resulted in changes of up to 0.5m due to local variations

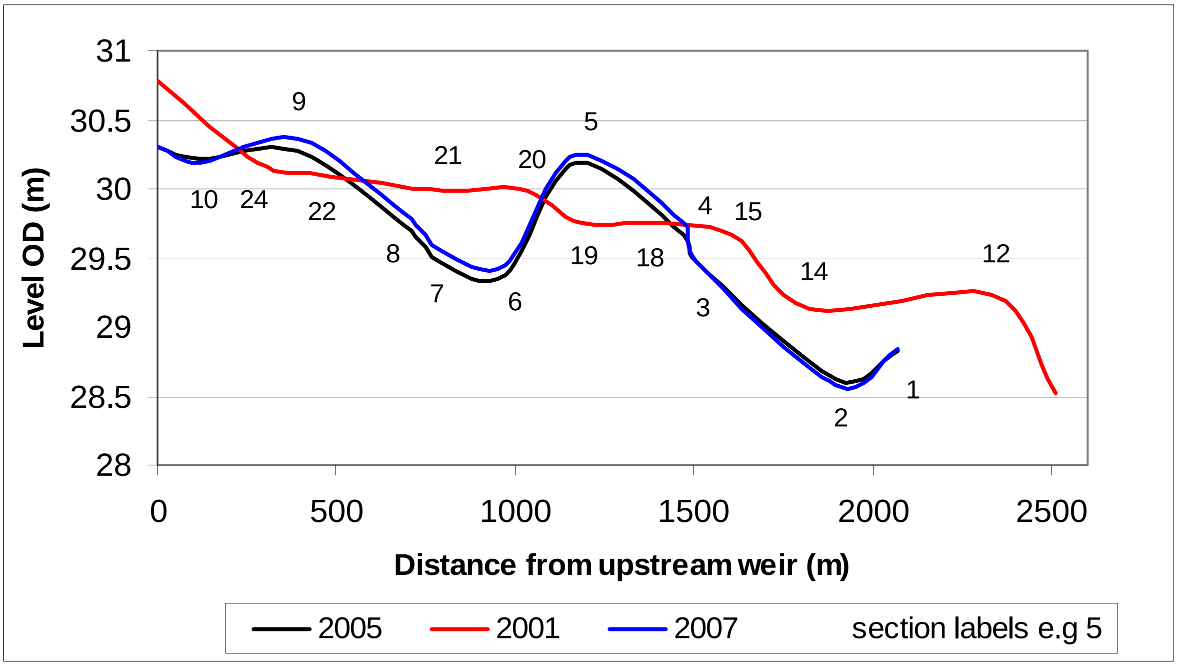


Figure 4.3 Comparison of bed levels for 2001, 2005 and 2007 surveys

The results in Figure 4.3 show a number of features:

- Between 2001 and 2005, the river was dredged in the upper reaches between Sections 8 and 10 (2005 survey). This is shown in Figure 4.3 although the bed may have recovered in this area by 2005 shown by the bed level at Section 9.
- There is some anecdotal evidence and evidence on the ground that the bed downstream of Section 4 (2005 survey) was dredged between 2001 and 2005. Figure 4.3 shows that the bed level in this area is lower in 2005 than in 2001.
- The bed level between Sections 6 and 8 is lower in 2005 than in 2001 but it is unclear whether this is due to dredging or a result of erosion stimulated by the dredging further upstream.
- Figure 4.3 shows deposition around Section 5, in the reach upstream of the footbridge between 2001 and 2005. This is borne out by evidence on the ground where shoals and berms are forming upstream of the footbridge.
- Figure 4.3 shows that the differences between the bed levels in 2005 and 2007 are minimal with small amounts of deposition between Sections 4 and 5 and also between Sections 6 and 9.

- The bed levels between Sections 5 and 9, (2005 survey) have increased to above the bed levels of Section 105 survey in 2001.
- Between Sections 4 and 5, for the 2005 and 2007 survey, upstream of the footbridge the slope has become much steeper and there has been erosion between Sections 4 and 3 below the 2001 levels, although this might be as a result of the dredging.

It is possible however that the changes in minimum bed level between 2001 and 2005 may be because the survey points are not coincidental. The necessity of comparing like survey position with like survey position can be explored further when looking at the differences between the September 2007 and November 2007 surveys. Some of the sections in the September 2007 survey were taken at incorrect locations. Often these locations were only a few metres apart, as given in Table 4.1 and Figure 4.2, but the change in minimum bed level was as much as 0.5 m, as shown in Figure 4.4.

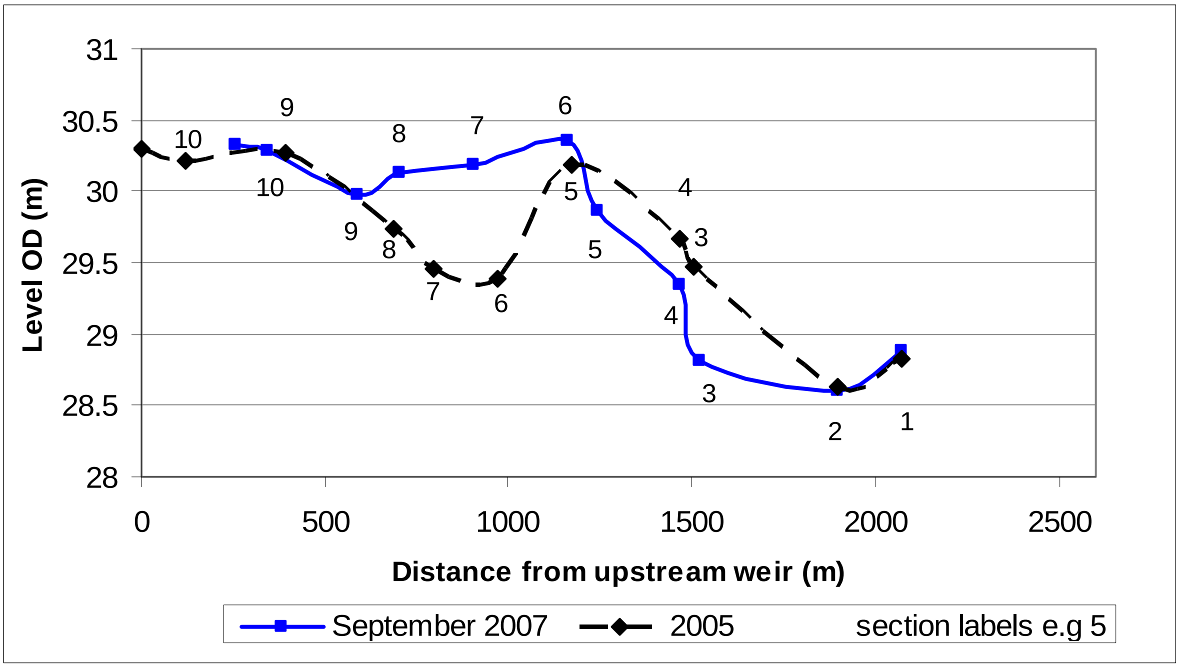


Figure 4.4 Comparison of bed levels for 2005 survey and September 2007 surveys

As the topographic survey shows the minimum bed levels as shown in Figure 4.4 give a very misleading impression of the bed level as the surveys points were taken at different points from the 2005 survey. The September 2007 survey suggests that there has been significant deposition, over 0.5m in the part of the reach between Sections 5 and 8 and erosion in the area between Sections 2 and 5. When the sections are taken at identical points as in November 2007, the bed levels at those points are almost identical to 2005 as shown in Figure 4.3.

These differences in bed topography show the importance of having coincidental and identical survey information when comparing data and drawing conclusions.

4.2.1 Hydraulic Modelling

Three INFOWORKS models were established using each of the topographic bed surveys, 2001, 2005 and November 2007.

Data

The cross-section surveys, in 2001, 2005 and November 2007, of ten cross-sections and one weir crest were used to construct the three hydraulic models.

Section spacing
The general cross section spacing is approximately 150 metres, although there are a few reaches with distances of over 300 metres without any cross-sections. Between Sections 9 and 8 the distance is 300 metres, between Sections 5 and 4 the distance is 300 metres, between Sections 3 and 2 the distance is 400 metres. The average channel width is approximately 15 metres.

Long profile
The reach slope is relatively low, 1 metre in 1400 metres.

Roughness
Hydraulic roughness zones were created using the CES roughness advisor. Survey photographs of the Eden have been compared to the standard examples in the roughness advisor and used to estimate the unit roughness at each cross section.

Sinuosity
The sinuosity, calculated as a reach average, is 1.14.

4.3 FLOOD MODELLING

To determine the impact of the changes in bed levels, the models were run for a 1 in 100 year flow and the results are shown in Figure 4.5. The flow with an annual probability of exceedence was estimated as being 72 m^3/s.

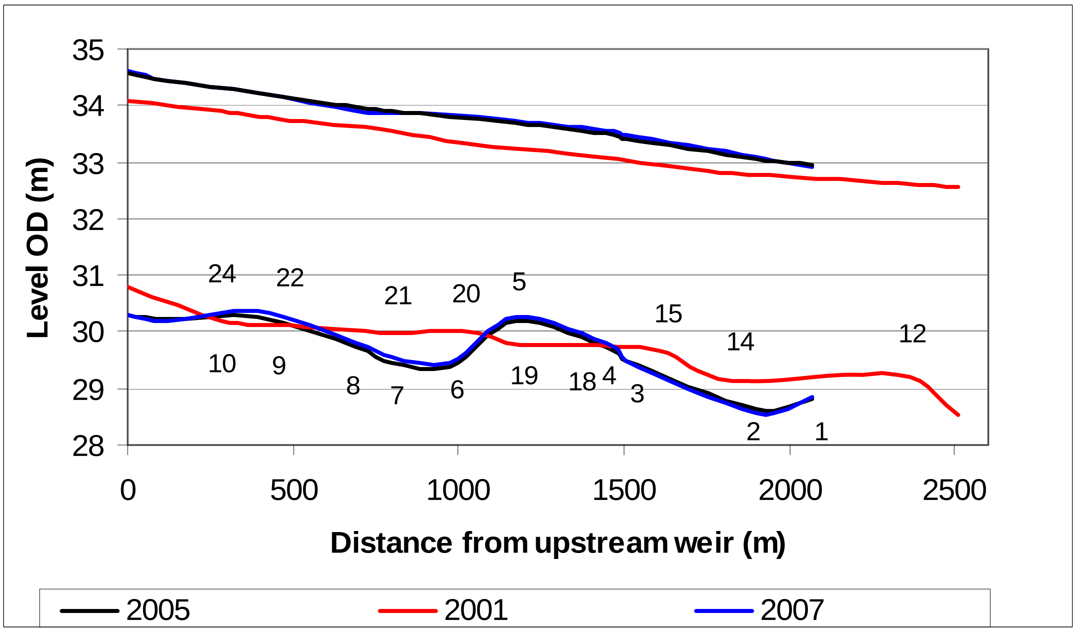


Figure 4.5 Comparison of bed levels and water levels for flow with a 1% annual probability of exceedence, for 2001, 2005 and 2007 surveys

4.4 DISCUSSION OF RESULTS FROM FLOOD MODELLING

The results in Figure 4.5 show a number of features:

- Figure 4.5 shows the differences in bed and water levels for 2001, 2005 and 2007 surveys for the flow with a 1% annual probability of excedence.
- The water levels for 2007 are very similar to 2005 water levels in a flow with a 1% annual probability of excedence. In the downstream parts of the reach, from Section 6 downstream, the water levels are increased in 2007 by up to 7cm (Section 4). This increase is due to the conveyance generally between 2005 and 2007 being reduced.
- This reduction in conveyance is shown in Figure 4.6, the cross-section profile for Section 5, where a berm has started to form on the right edge of the channel and has narrowed the channel.
- In the upper parts of the reach the water levels are generally lower in 2007 than in 2005 by up to 7cm at Section 8, although the bed levels are slightly higher in 2007 than in 2005. This arises as the channel width at higher water levels is greater in 2007 than 2005. The processes occurring are that sediment is depositing in the base of the channel but the banks are slightly eroding, see Appendix 6.
- Figure 4.7 shows a cross-section profile of Section 9 where there deposition on the bed and erosion on the banks is occurring.

In summary the dredging, around 2004, initially created a deeper channel, in the upper part of the reach, which reduced water levels locally. The dredging in the lower part of the reach had no impact on the water levels as these are controlled by Vexour bridge. This raises the issue of the value of carrying out dredging upstream of structures if the water levels upstream are controlled by the structure rather than the channel conveyance.

Over a short period of time (2-3 years) the dredged parts of the reach in the upper Sections 5-9, (2005 survey) have been filled in with sediment and the bed level has increased to above the pre-dredged level. This shows a relatively rapid increase in bed levels following the dredging that has been carried out. The middle parts of the reach around Section 5, 4 and 3 have seen some erosion, creating a steeper slope in this area. There are sediment features which are developing in this area and berms being created as shown in Figure 4.6 of cross-Section 5. The combined impact of the steeper slopes and the deposition upstream have raised water levels upstream.

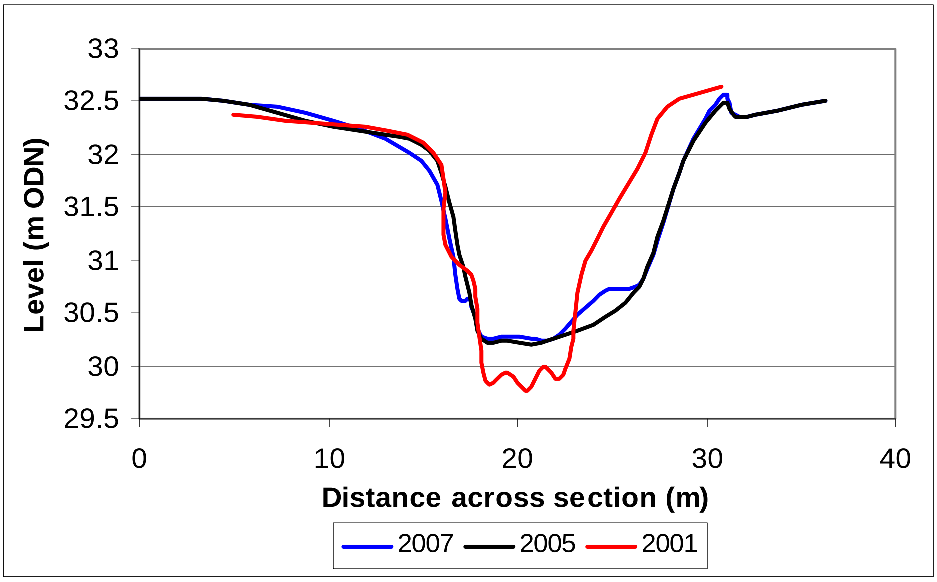


Figure 4.6 Cross-section 5 and 19: 2001, 2005 and 2007 bed level profiles

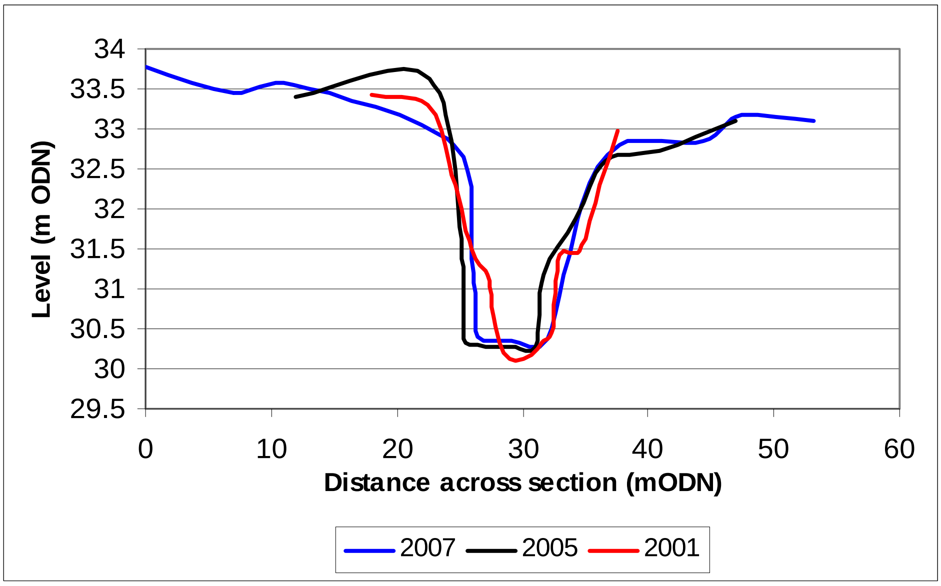


Figure 4.7 Cross-Section 9: 2001, 2005 and 2007 bed level profiles

There are further impacts on the shear stress and velocities which will impact upon the sediments and habitats which are described below.

4.5 DEPTH, VELOCITY AND SHEAR STRESS VARIATIONS OVER AN ANNUAL CYCLE

The Infoworks models using the three different surveys in 2001, 2005 and 2007 were run for an annual cycle using flow information for 2005 from a nearby gauging station. By using the results from these runs we can compare how the velocity, depth and shear stress varies over a year, and how the changes in bed levels due to the dredging and the subsequent recovery of the channel impact upon the hydraulics.

Figures 4.8a-c show the standard deviation of stage and velocity over the 2005 annual flow sequence with the cross-section geometries taken from the 2001, 2005 and 2007 surveys, respectively. The flows from 2005 were used as being representative of a typical flow year. Comparing Figures 4.8a and 4.8b for the 2001 and 2005 surveys, the standard deviation in the stage is greater in the upper parts, Section 9-11d, of the reach for the pre-dredged situation, 2001, than after the dredging, 2005. These upper parts of the reach were where the major part of the dredging occurred in 2004 and this has led to less variation in water depth through Sections 5-9. In the lower parts of the reach, Sections 1-4, the variation of water depth is very similar for both 2001 and 2005. In this lower part of the reach the water levels are more influenced by backwater effects from Vexour bridge than by the bed levels and so one would expect the water depths to be similar for the different years.

Overall the standard deviation in velocity in 2005 is greater than in 2001 and this is most noticeable for Section 5, 2005 when compared with Section 19, 2001, Figure 4.8. The channel has begun to recover from the dredging in 2004 and where berms and shoals are beginning to form the section is more varied leading to greater variation in velocity

In 2007, the standard deviation in velocity and stage are noticeably greater in the middle parts of the reach, Sections 4-7, than in both 2001 and 2005. At the downstream end (Sections 1-3), the standard deviations are similar to the 2005 and 2001 values. At the upstream Sections 8-11, the standard deviation in depth in 2007 is generally similar to that

2005, reduced from 2001 but the standard deviation in velocity in 2007 is larger than in 2005 at Section 10.

Figures 4.9a, b and c show a more detailed picture of the velocity variation. For each section a line with a central box is given on the graph. The upper point of the line is the maximum velocity and the lower point on the vertical line, the minimum velocity at that section. The box in the centre is the range of the 75 percentile to 25 percentile. The mid point of the box represents the median velocity.

A number of observations can be made from these diagrams:

- The average of the median values of velocity for 2001, 2005 and 2007 do not change substantially, being around 0.22m/s. The variation around the median values is different between 2001 and 2005/2007.
- The pattern of variation of velocities at each of the cross-sections is very similar in 2005 and 2007 which should not be surprising as the bed levels in 2005 and 2007 are very similar.
- The differences in velocity variation between 2001 and 2005/2007 should be read with a note of caution as the cross-sections are not coincident.
- The velocities at Section 5 are greater in 2005 than the corresponding Section 19 in 2001. This shows that in some parts of the reach, especially the middle parts, recovery from the dredging was occurring.
- Overall in 2005 and 2007 the median values of velocity are higher than in 2001 showing that although the reach was dredged in 2004 the recovery, in terms of creating a channel with higher velocities, has been generally good.
- In the 2007 survey, the velocity medians and range in the middle parts of the reach, Sections 5-7 are much greater than using the 2005 and 2001 surveys. The increased slope due to deposition upstream and erosion downstream has created this impact.
- In the downstream reach, Sections 1-4 the velocity range is greater in 2005 and 2007 but the median velocities are similar or lower to 2001.

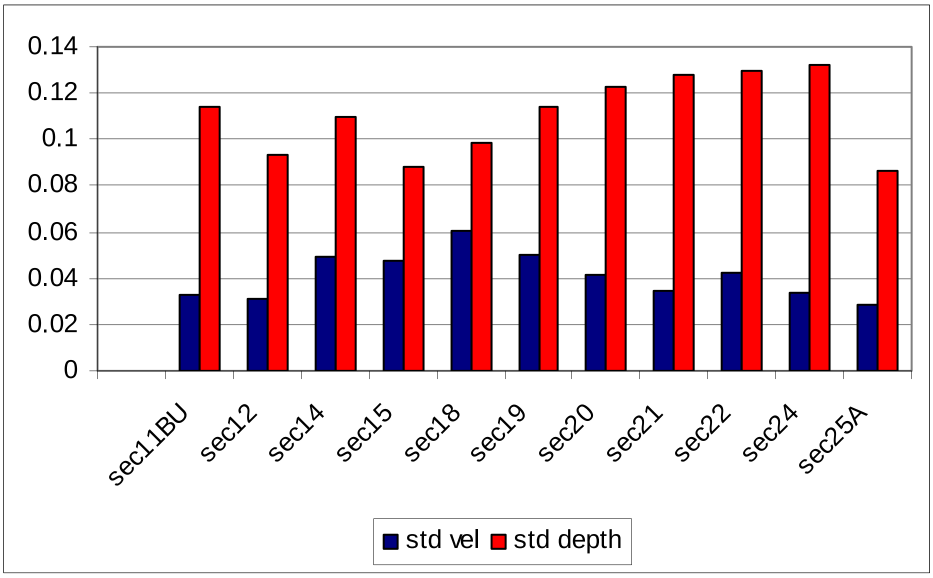


Figure 4.8a 2001 survey, standard deviation of depth and velocity

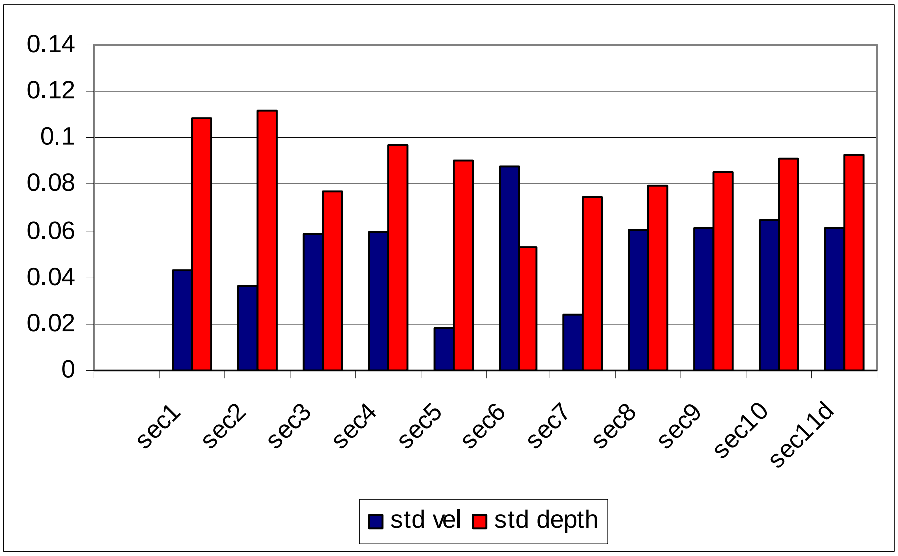


Figure 4.8b 2005 survey, standard deviation of stage and velocity

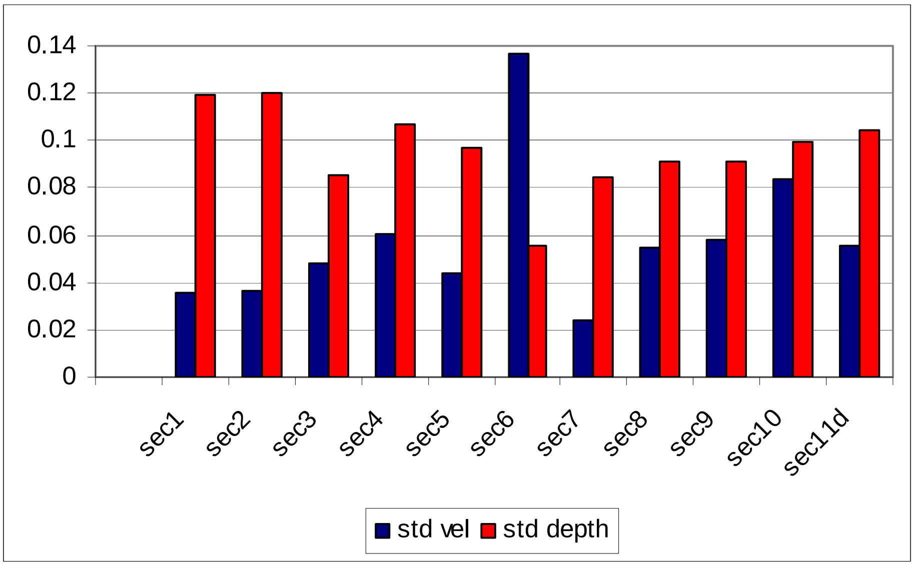


Figure 4.8c 2007 survey, standard deviation of stage and velocity

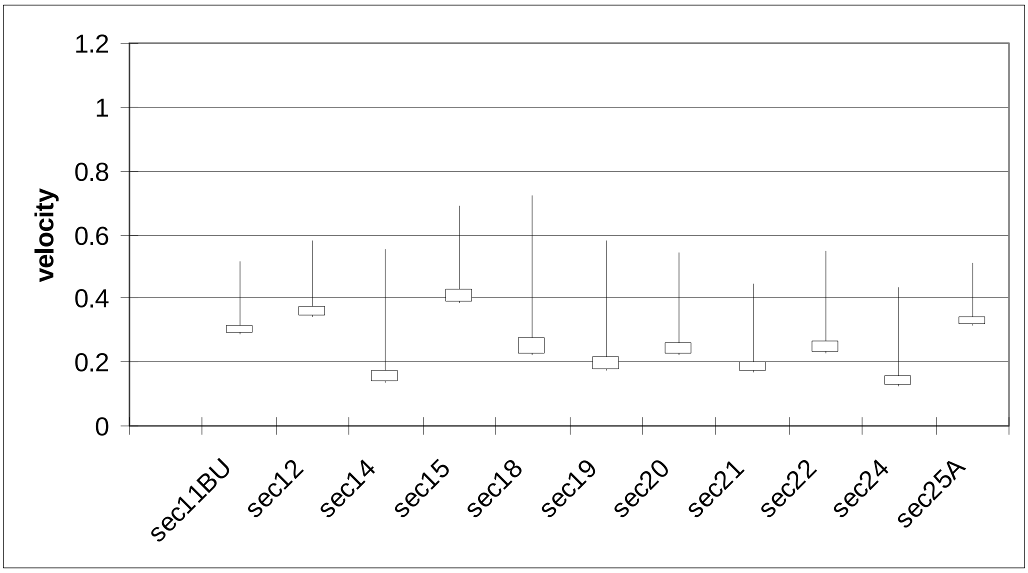


Figure 4.9a 2001 survey, velocity variations

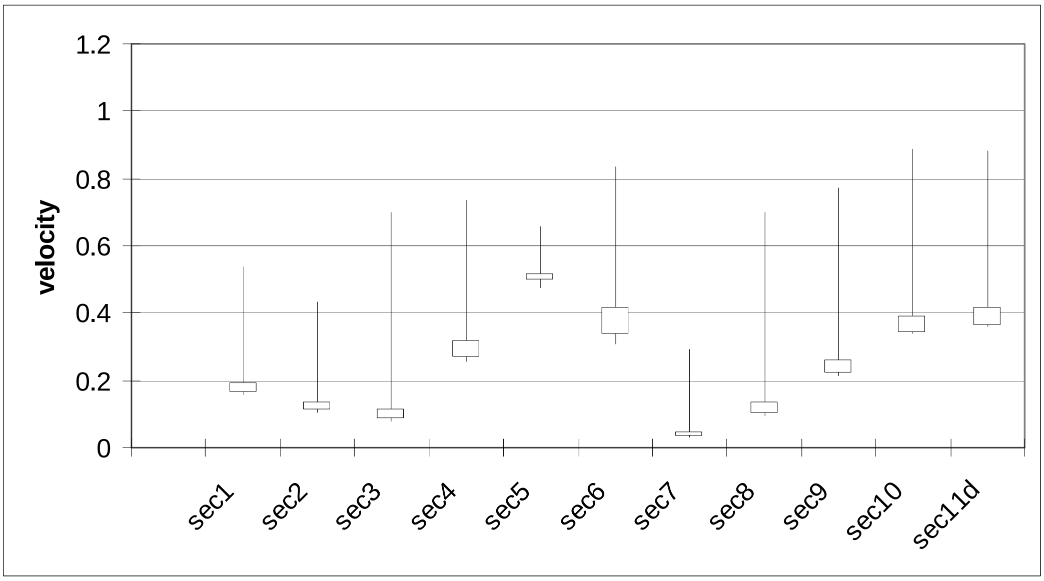


Figure 4.9b 2005 survey, velocity variations

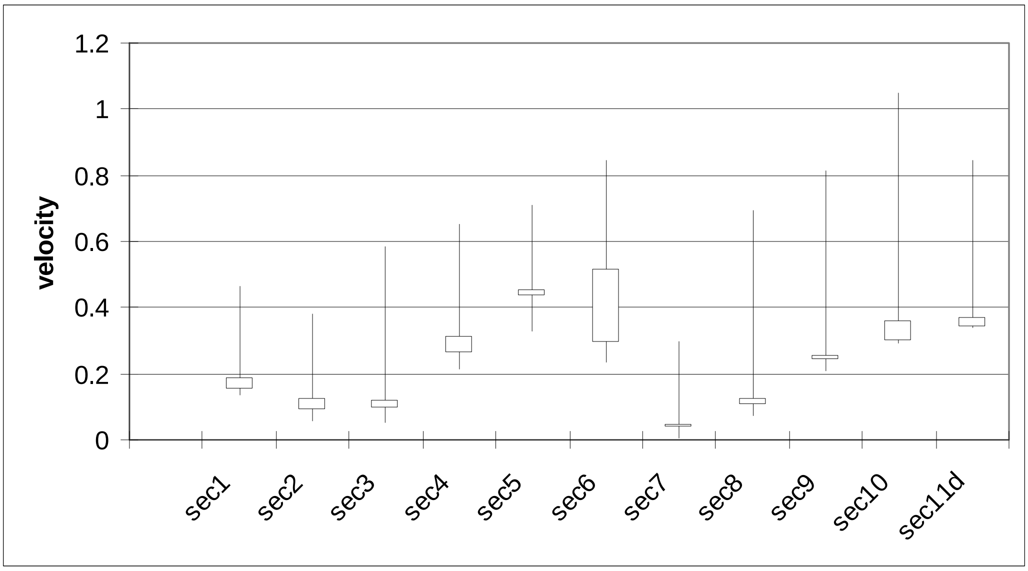


Figure 4.9c 2007 survey, velocity variations

Figures 4.10a to 4.10c show variations in shear stress for the 2001, 2005 and 2007 surveys, respectively. From 2001 to 2005 the average shear stress along the reach is very similar, although the median shear stresses reduce between 2001 and 2005 in the upper parts of the reach, due to the dredging. The maximum shear stresses slightly decrease from 2001 to 2005 except at Section 6 where there is an increase in slope downstream and the greatest activity in terms of berm creation and habitat formation.

For 2005 and 2007, the average shear stresses are similar but the variability along the reach is much higher in 2007, especially in the central part of the reach. The range of shear stresses is generally higher in 2005 than in 2007. At the upstream part of the reach, between Sections 8-11, the shear stresses continue to be very low due to the shallow water surface slope generated in the backwater created by Sections 6 and 5.

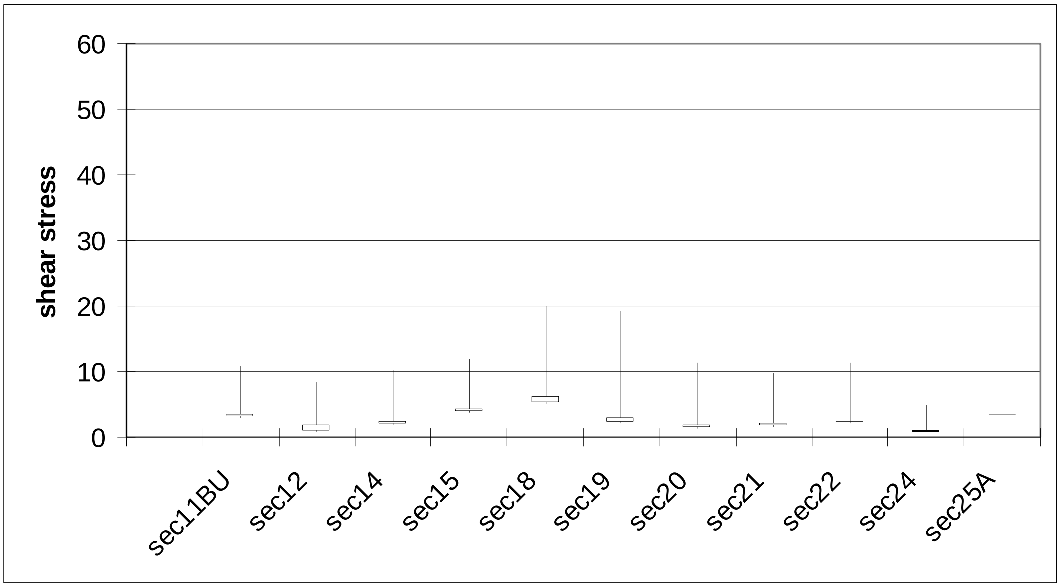


Figure 4.10a 2001 survey, shear stress variations

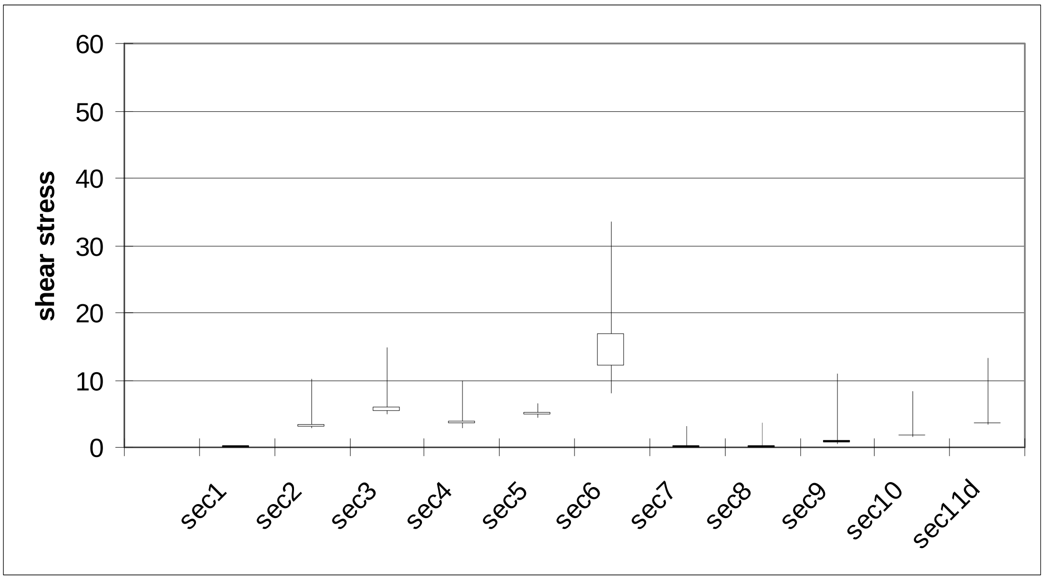


Figure 4.10b 2005 survey, shear stress variations

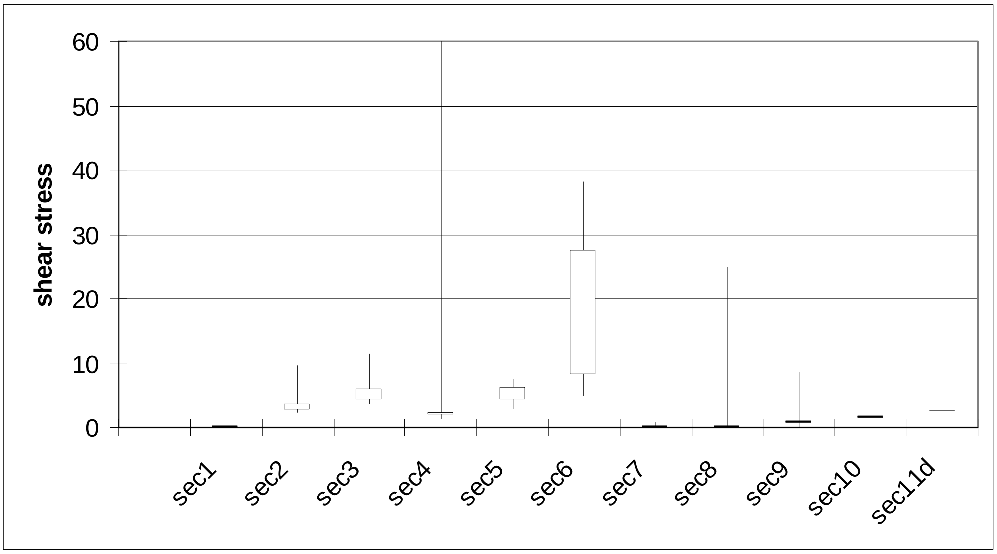


Figure 4.10c 2007 survey, shear stress variations

5. River Harbourne

5.1 BACKGROUND

A recent flood alleviation scheme on River Harbourne has included construction of a flood storage reservoir upstream of Harbertonford village. The reservoir was built across the valley with the embankment tying into the valley sides and stores water for floods in excess of those with a 10% annual probability of exceedence to take the peaks off the hydrograph. The river flows through twin box culverts which are gated with penstocks which operate automatically from a telemetered system.

The works through the village have involved some widening of the channel, regarding of the bed, bank protection and replacement of weirs with riffles. The scheme was completed in 2002 and there has been at least one significant flood event since that time when it is understood that the scheme operated as expected.

Maintenance
There is no maintenance carried out on the river and it is designed as a self-sustaining system. There was little/no maintenance carried out prior to the scheme being installed.

Data availability
There are *pre-construction cross-sections* available for the scheme and *as designed drawings and cross-sections*, although no as built drawings.

Site features
The river has a gravel bed. Just downstream of the reservoir site the channel has remained as it was before the flood alleviation scheme. Under the main road bridge the channel was regraded and bank protection placed along both banks. A riffle was installed with a low flow notch, a distance of 20m downstream of the road bridge. The Harberton stream flows in on the left bank just downstream of the riffle. Downstream of the riffle, the channel passes behind a row of houses. It is tree lined for approximately 100-200m down to a riffle which replaced a weir. There is a mill leat offtake on the right bank which was narrowed and concrete lined during scheme to take a sweetening flow but to flow more efficiently during floods. Approximately 100m downstream of the riffle the channel has been widened for 200-

300m alongside Bow Road. At the upstream end of this there is a sediment bar which was placed where vegetation has established. This bar or shoal was designed assuming that sediment would deposit and there is some evidence of sediment accumulation on the right bank with the channel narrowing in this area. The channel widening finishes at a foot bridge where the channel returns into a “natural” size and over another riffle just upstream of a road outfall on the left bank. The scheme finishes at the footbridge.

The evidence for sediment accumulation appears to be clearer from comparing historic photographs with present conditions than by comparing the various cross-section information. This is in part a reflection of the uncertainty in the placing and surveying of cross-sections and partly a reflection of the sensitivity of the eye to detect small changes in a visual picture.

Appendix 9, Figures 27 and 28 shows the plan of the river through the village.

5.2 HYDRAULIC MODELLING

5.2.1 Data

A hydraulic model of the reach using the 2005 survey data was constructed using the data described below.

Cross-section data
A cross-section survey of eleven cross-sections and one weir crest was used to construct the hydraulic model, see Figure 5.1 for the location of the cross-sections.

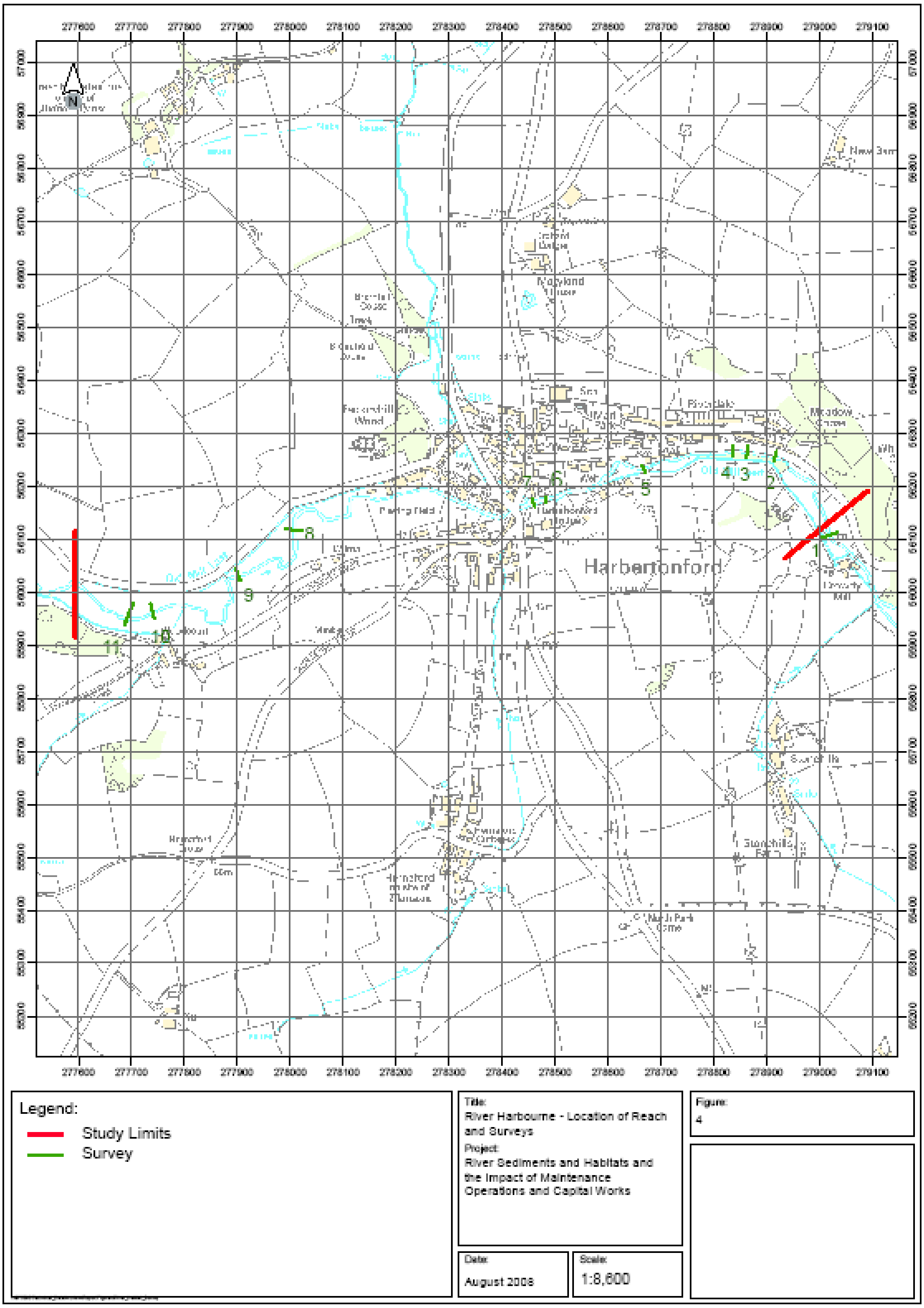


Figure 5.1 Location of cross-sections

Section spacing

The general cross section spacing is approximately 150 metres, although there are a few reaches with distances of over 200 metres without any cross-sections. Between Sections 10 and 9 the distance is 250 metres, and between Sections 8 and 7 the distance is 500 metres. The average cross-section width is approximately 8 metres.

Long profile
The long profile of bed levels has few discontinuities. The reach slope is relatively steep, 1 metre in 200 metres.

Hydraulic Roughness
Hydraulic roughness zones were created using the CES roughness advisor. Survey photographs of the Harbourne have been compared to the standard examples in the roughness advisor and used to estimate the unit roughness at each cross section.

Sinuosity
The sinuosity has been calculated as a reach average of 1.14.

Downstream boundary
The downstream section has been copied and moved downstream so that its bed level is 1 metre lower than that of the true section. The distance moved has been calculated assuming the average reach slope and a 1 metre change in elevation. In this case the cross section is 200 metres downstream of the last cross-section in the reach. This is to ensure that any errors in the downstream boundary do not affect water levels in the reach. The downstream boundary used was a normal depth rating curve generated from the cross section properties.

5.2.2 Flood Modelling

The hydraulic model was run for flood with a 1% annual probability of exceedence, which has a peak discharge of approximately 51m^3/s. The runs were for the 2005 cross-section survey data and then the cross-section profile around Section 2 was changed to reflect what might happen if the shoal at Bow Road were to increase in size. Figure 5.2 shows the section as in 2005 and then with raised shoal and raised bed and raised shoal.

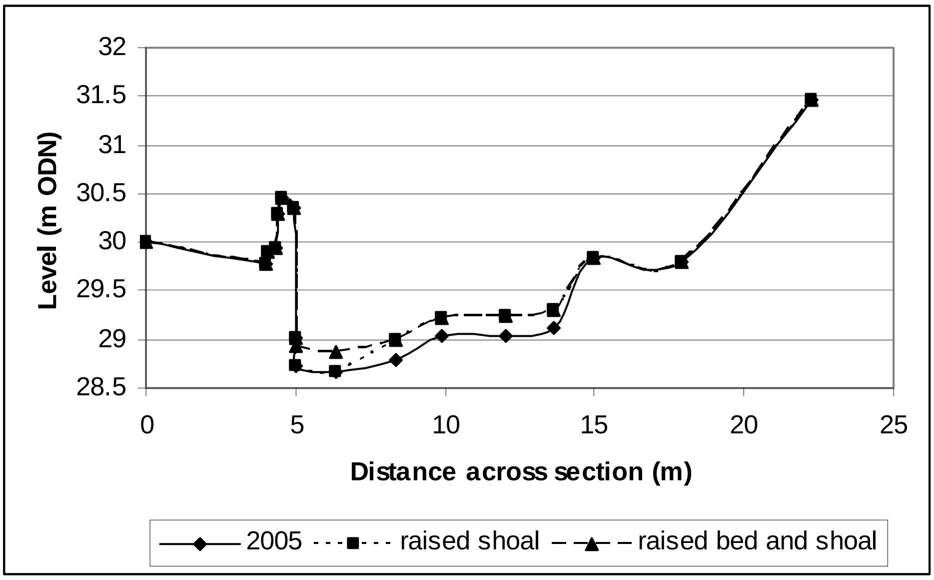


Figure 5.2 Cross-Section 2 at shoal, Bow Road

The model was run under these different scenarios for a flow with a 1% annual probability of exceedence of 51m^3/s. Figure 5.3 shows the results of these runs.

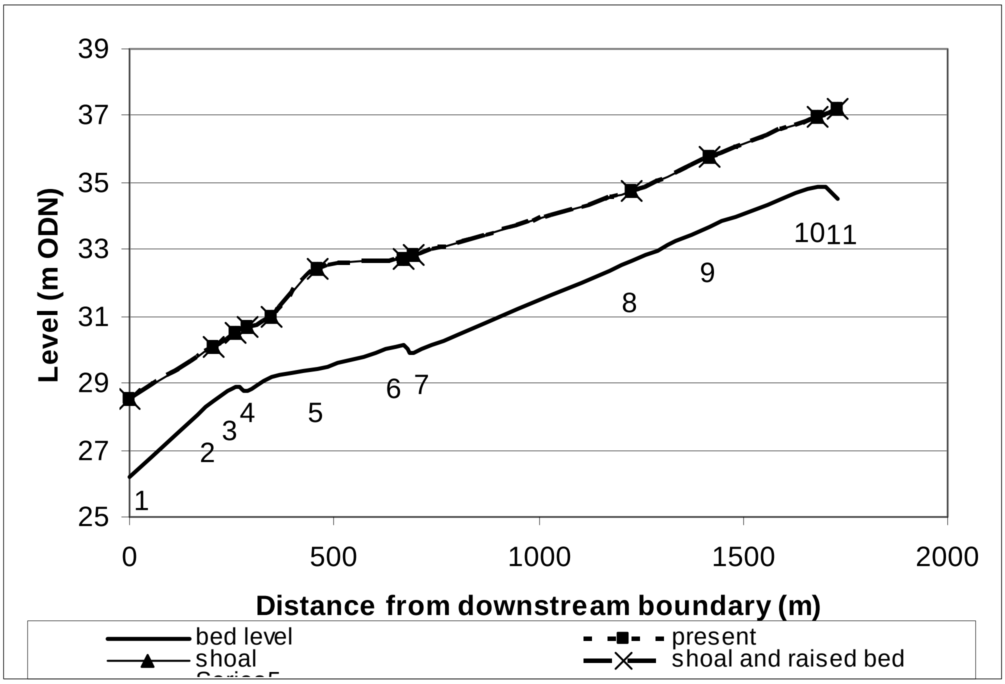


Figure 5.3 Water levels for flow with a 1% annual probability of exceedence for different scenarios

There is a rise in water level, for both the raised shoal and raised bed and shoal scenarios of just under 3cm in the flood with a 1% annual probability of exceedence. This slight rise in water level is local around Section 3, just upstream. With the riffle in place at Section 4 the local rise is lost around this point and upstream of the riffle there is no rise.

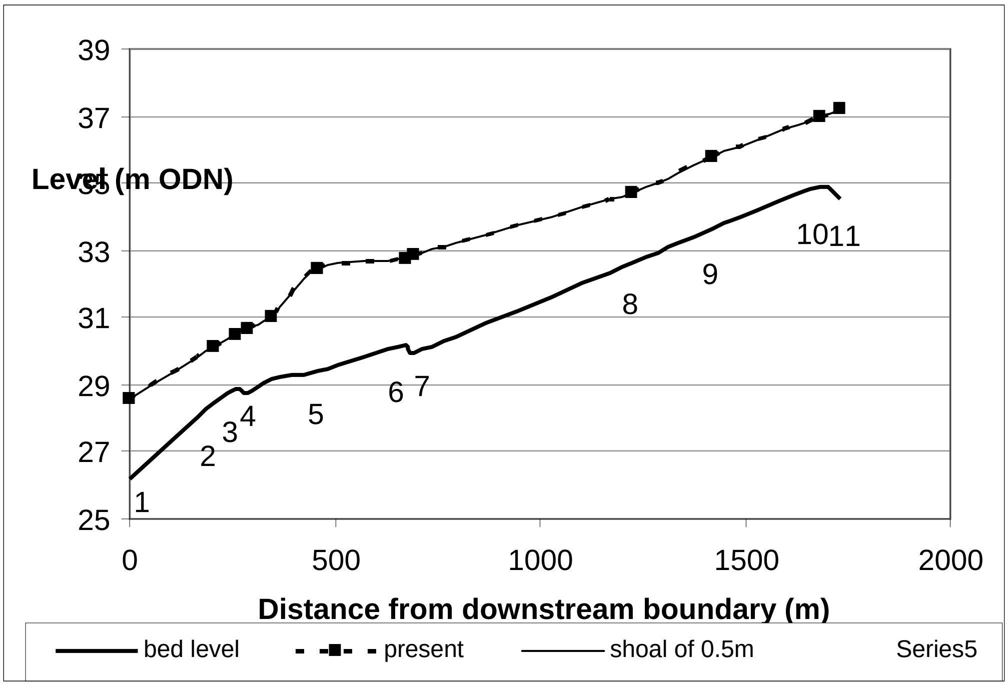


Figure 5.4 Water levels for flow with a 1% annual probability of exceedence with shoal of 0.5m

In the model the shoal was raised to 0.5m and Figure 5.4 shows the water levels for flow with a 1% annual probability of exceedence in this situation. The water level rise locally upstream of the shoal is shown to be approximately 7.3cm, with a small rise of just over 1cm upstream of the riffle which is reduced to zero at Section 5, further upstream. This shows that if the shoal height increases over 0.5m above 2005 levels then the water level increase is greater locally but also the levels upstream of the riffle may begin to rise.

6. River Kent

6.1 BACKGROUND

The reach of the River Kent that was studied forms a high-energy gravel bed river through the centre of Kendal. The river channel has been subject to major changes in the past and now has artificial banks while the bed level is constrained by a number of weirs. There has been a history of fluvial flooding in the urban area and a flood scheme was implemented in the 1970s. In the reach through the centre of Kendal sediment is deposited in the form of gravel shoals within the channel and these have to be removed relatively frequently to control the flood risk.

Compared to the reaches upstream and downstream of Kendal, the re-aligned channel through Kendal is straighter than would be expected. The channel has been enlarged to convey floods and appears to be too deep and wide for the present flow and sediment regimes. Through the centre of Kendal the bed level is stabilised by a sequence of low weirs or bed sills. The crests of these are horizontal and, therefore, they not only stabilise the bed but also ensure that the bed levels are uniform across the width of the channel. If allowed to adjust it is expected that the river channel would silt and narrow through vertical and lateral accretion of sediment in middle and point bars.

The study reach extends downstream of Kendal where the river is in a more rural setting and the bed and banks of the river are not constrained.

6.2 DATA FOR HYDRAULIC MODELLING

6.2.1 Cross-section data

A cross-section survey of twelve cross-sections along the reach and one weir crest was used to construct the hydraulic model, see Appendix 1. The locations of the cross-sections are shown in Figure 6.1.

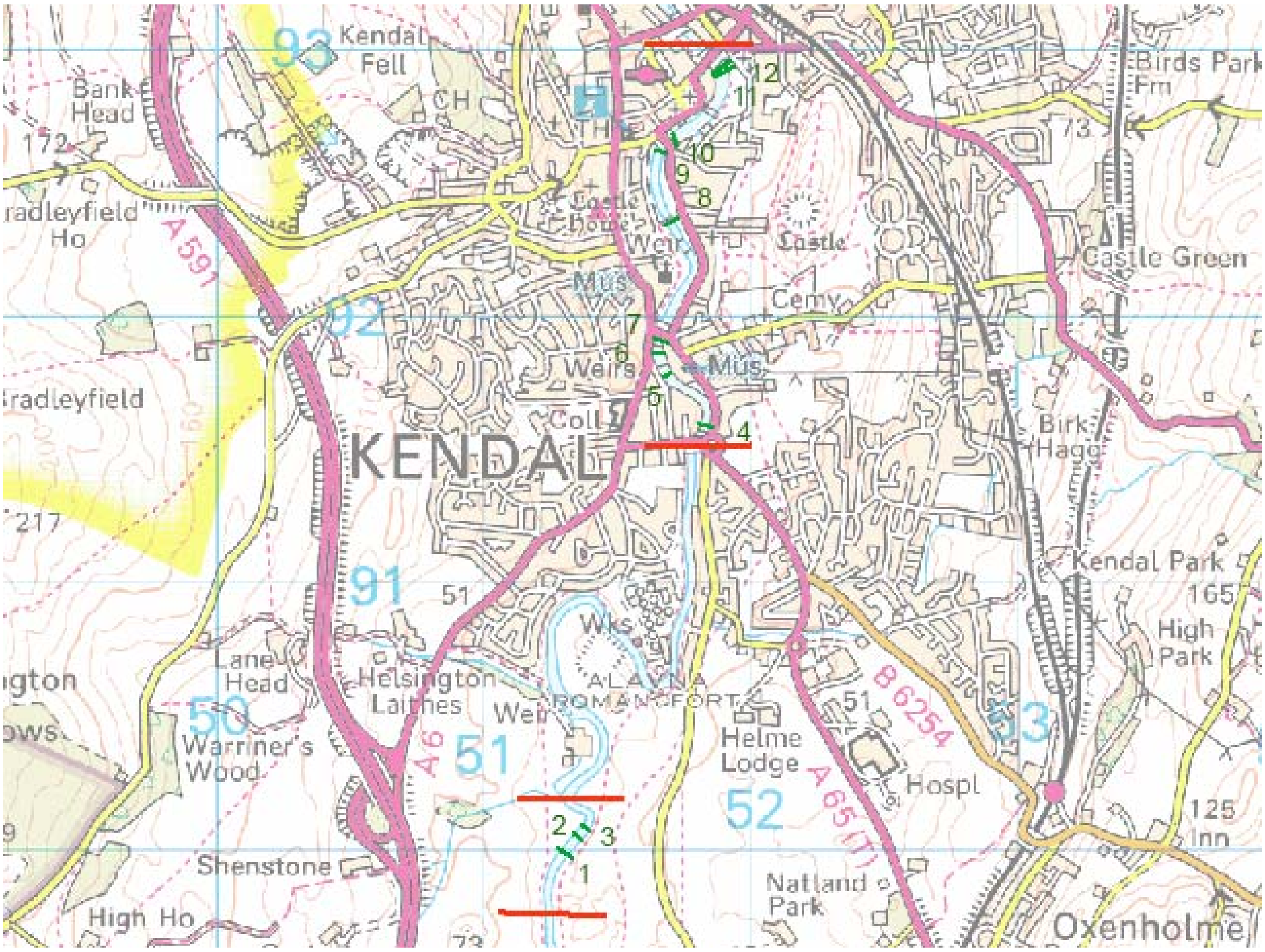


Figure 6.1 Location of cross-sections

6.2.2 Long profile

The reach slope is relatively steep, 1 metre in 500 metres.

6.2.3 Hydraulic Roughness

Roughness zones have been created using the CES roughness advisor. Survey photographs of the Kent have been compared to the standard examples in the roughness advisor and used to estimate the unit roughness at each cross section.

6.2.4 Sinuosity

The sinuosity has been calculated as a reach average and is 1.20.

6.2.5 Downstream boundary

The downstream section has been copied and moved downstream so that its bed level is 1 metre lower than that of the true section. The distance moved has been calculated assuming the average reach slope and a 1 metre change in elevation. In this case the cross section is 464 metres downstream of the last cross-section in the reach. This is to ensure that any errors in the downstream boundary do not effect water levels in the reach. The downstream boundary is a normal depth rating curve generated from the cross section properties.

6.3 HYDRAULIC MODELLING

6.3.1 Sediment modelling

The hydraulic model was run with a mobile bed and a long flow record was simulated. The results of this modelling are described in Appendix 7 but are summarised here. The model results showed that without sediment removal the bed levels in the centre of Kendal would rise by approximately 0.4 m but would stabilise after a period of approximately 6 years. There would be a corresponding increase in water levels. The magnitude of the increase in water levels is of a similar order of magnitude as the increase in the bed levels, that is approximately 0.4m.

With no sediment removal in the centre of Kendal, the numerical model predicted an increase in bed levels in the downstream reach suggesting that the sediment removal is starving the downstream reach of sediment.

6.3.2 Variation in depth, velocity and shear stress over an annual cycle

The hydraulic model was run for a typical annual flow period and the temporal variation in depth, velocity and shear stress were determined. For each variable the maximum, 75%ile, mean, 25%ile and minimum values during the period were determined. In addition the standard deviation of the variable was determined over the annual period.

The shear stresses and flow velocities in the River Kent were larger than in the other rivers modelled which is consistent with the River Kent being a high energy system. Figure 6.2 shows the calculated vales of the shear stress along the reach, with Section 13 being at the upstream end and Section 1 at the downstream end. The results show that the shear stress at the upstream end of the model is lower than in the rest of the reach, which is consistent with this being the location of sediment deposition. To make the channel self-sustaining the water surface slope would have to increase to increase the shear stress to ensure that sediment is passed to the reach downstream.

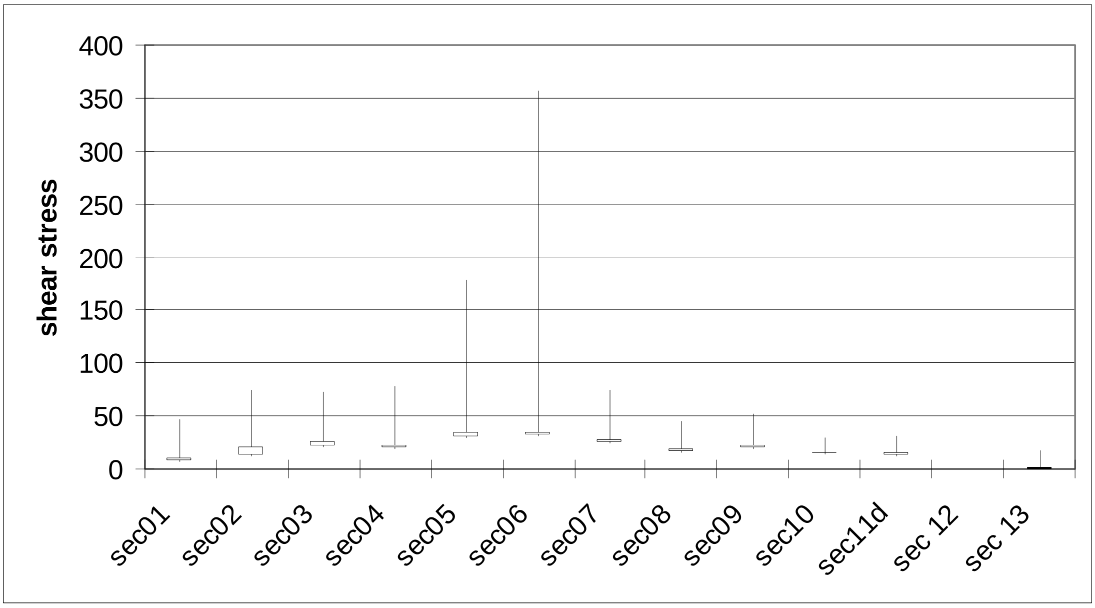


Figure 6.2: River Kent: Longitudinal variation in shear stress

The shear stress is larger through the middle part of the reach but decreases again at the downstream end. This pattern of shear stress is consistent with the predicted sedimentation in the downstream part of the reach if sediment removal through Kendal were to cease or be reduced. The variation in shear stress is greater in the downstream part of the reach than in the upstream part which likely reflects the more natural channel shape that is to be found in the downstream part of the reach. The high shear stresses occur in the middle of the reach were the bed is stabilised by a sequence of weirs which inhibit erosion of the bed material.

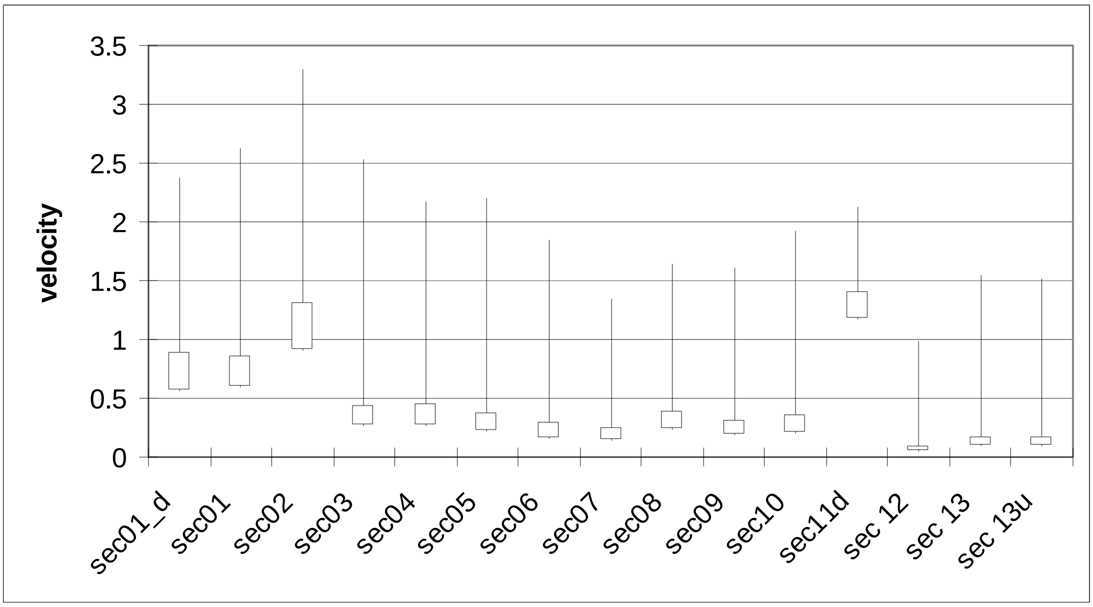


Figure 6.3 River Kent, Longitudinal variation in velocity

Figure 6.3 shows the longitudinal variation in velocity. At the upstream end there are low velocities due to the influence of Stromongate weir. The velocities are largest in the most downstream part of the reach where the channel is more natural. In the constrained part of the reach the velocities are lower and show less variation. This is consistent with the observation that through the centre of Kendal the river channel has been over-widened in comparison with the width that one would expect in an unconstrained channel (see Appendix 6). It is noticeable that in the most downstream part of the reach there are the largest differences between the 75 and 25 %ile values.

Similar patterns to those described above are seen in Figure 6.4 which shows the standard deviations of the values of the velocity, shear stress and depth. The values of the standard deviation for the depth show a lower variation in depth upstream of Stromongate weir. In this area the water level is controlled by the weir. This also has an impact on the variation in the shear stress.

The conclusions are that at the upstream end of the reach the weir is constraining the variability of the velocity and shear stress. The area immediately downstream of the weir is an area of low shear stress consistent with the observed sediment deposition. The constrained reach through Kendal shows lower variability in velocity and shear stress then the more natural downstream part of the reach. Thus the combination of permanent works in the form of low weirs or bed sills and periodic sediment removal leads to more uniform flow conditions than one would expect in a more natural channel system. The low weirs and artificial banks through the centre of Kendal promote more uniform flow conditions than one would expect in a natural channel.

Some of the uniformity within the channel system could have been reduced by installing the low weirs or bed cills with variable height crests. This would have promoted greater lateral variability of velocities and depths

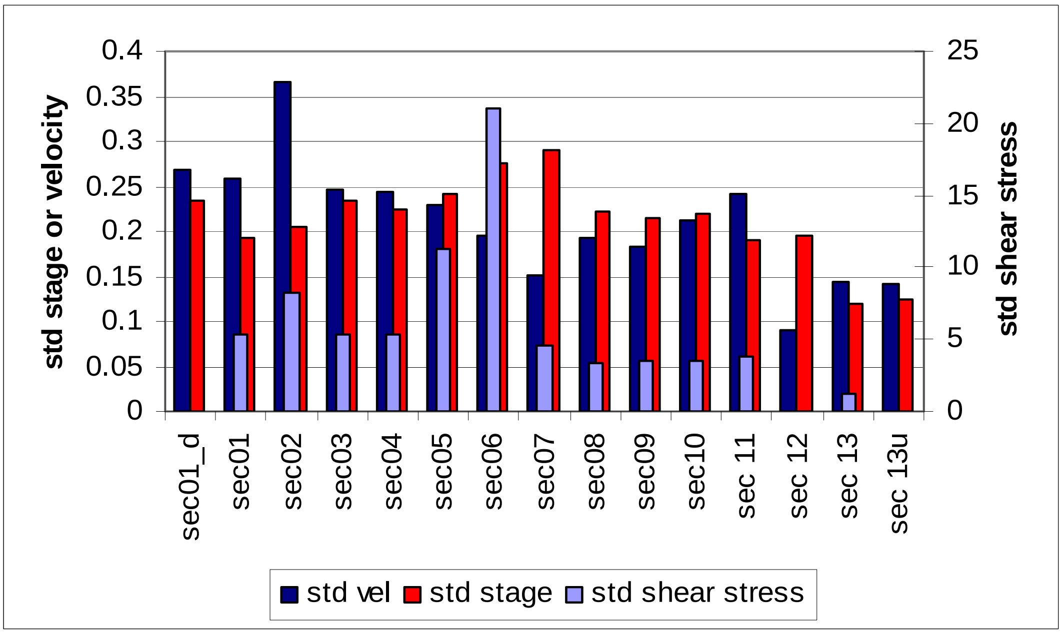


Figure 6.4 River Kent: Standard deviation of velocity, stage and shear stress

The hydraulic calculations are consistent with the collected habitat data which implied that the most downstream part of the reach provided a wider range of habitats, see Appendices 3 and 4.

The work shows that there is greatest flow diversity in the downstream reach which is least impacted by channel maintenance. It also shows that the weirs act to locally reduce flow diversity.

7. Analysis of spatial characteristics of flow

7.1 INTRODUCTION

There is strong belief that a diverse physical habitat in terms of flow characteristics such as flow depth and velocity will provide richer habitats in terms of biota. In the context of this study there was an interest to explore:

a) whether sediment management altered the flow diversity within a reach and
b) whether there was any correlation between the quality of the habitats in terms of the RHS results and the diversity of flow characteristics.

To investigate these aspects the spatial distribution of flow velocities and depths was investigated using a numerical model. The results of this analysis were then compared with the results of the RHS surveys for the reaches.

The approach has similarities to that that underpins habitat modelling such as PHABSIM. The philosophy of such modelling is that the flow conditions are modelled in some way to determine the spatial variability of flow velocity and depth. In PHABSIM the combinations of flow velocity and depth that are favourable to certain species and life stages are known (preference curves) and so proportion of the area of the river bed that has favourable conditions ca be determined. This approach can be used to assess the impact of proposed changes on the target species.

A similar approach is used in this study to determine the distribution of flow velocities and depths. Instead of assessing conditions in terms of some preferred set of conditions, preference curves, the metric is based on the overall diversity of flow conditions. This is based on the belief that the wider the range of flow velocity and depth conditions then the richer the habitat is likely to be in terms of the range of species found. The implied belief behind this assumption is that high diversity can be equated to good ecological condition. This may not always be the case. An alternative approach is that of defining 'reference condition' for particular river types, that is, what range of diversity one would expect for particular river types. The analysis described below could be used both to establish reference conditions and to compare actual reaches against such conditions. At the moment there is not the information available, however, to establish appropriate reference conditions for specified river types.

7.2 METHODOLOGY

The size and shape of the channel was described by the cross-sections that had been collected for each reach. A number of discharges were selected to represent typical flow conditions within the river reach. It should be noted that whereas flood risk management is concerned with flows with relatively high return periods, the flows that dominate the ecological characteristics of a channel occur much more frequently. As a result the following discharges were used in the analysis: Q_{95}, Q_{75}, Q_{50}, Q_{25} and Q_5, where Q_n denotes the discharge that is exceeded n% of the time.

Each discharge was run in the numerical model as a steady discharge. At each cross-section the Conveyance Estimation System (CES) was used to determine the lateral distribution of velocity and depth. It was assumed that this was representative of the reach containing that cross-section. Each point on the cross-section was then allocated a velocity-depth combination based on 0.1 m steps in the depth and 0.1 m/s steps in the velocity. Thus in a cross-section of a given width one could allocate lengths of cross-section to different categories of depth and velocity. For example one could determine that for 1.3 m of the cross-section the velocity and depth were on the range 0 to 0.1 m/s and 0 to 0.1 m respectively while for 0.8m of the cross-section the ranges were 0.2 to 0.3 m and 0.1 to 0.2 m/s. Assuming that this cross-section was representative of that reach one could determine the area corresponding to each class by multiplying these lengths measured laterally by half the sum of the distances to the adjacent cross-sections. By taking the overall area of the reach one could determine the percentage of the area of the bed corresponding to the different combinations of flow and velocity.

To illustrate this one can consider two different channels. One is rectangular while the other has a less regular cross-section. In the case of the channel with a rectangular cross-section, the majority of the area of the bed will have the same combination of velocity and depth In the case of the less regular channel, there will be a wider distribution of values.

The above area data was derived for each flow condition. The data for each discharge was then combined and multiplied by a weighting corresponding to the percentage of time relevant to that discharge to determine a percentage of each class taking account of both temporal and spatial variations.

The analysis was carried out for the three reaches on the River Eden and the River Dearne.

7.3 RESULTS

7.3.1 River Eden

The results are very detailed and difficult to assimilate and so attempts have been made to derive simple metrics to assess diversity. These involve counting the number of different positive entries for each flow condition and in addition counting the number of entries for the '% average of area factored by time'. These have been selected on the basis that the larger the number of entries then the greater is the variety of flow conditions present in the channel.

Tables 7.1 to 7.3 show the results for the three reaches of the River Eden. Comparison of Tables 1 and 3 show that the results for the upstream Reach and the middle reach are very similar in terms of the number of entries in the tables. The total number of different combinations of velocity and depth for the three reaches are as follows: Upstream Reach 33, Middle Reach 27 and Downstream Reach 21.

% Average of area factored by time

		Maximum depth (m)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Maximum	**0.1**	4.363978	0	0	0	0	0	0	0	0	0
velocity	**0.2**	25.0536	18.29734	0.126799	0.032956	0	0	0	0	0	0
(m^3/s)	**0.3**	0.862531	13.15057	4.61921	0.434001	0.009565	0.039166	0	0.187284	0	0
	0.4	0.372977	1.429365	3.444901	4.47092	0	0	0.17482	0.045396	0	0.159739
	0.5	0	0.196303	5.411619	8.533943	0	0	0	0.2108	0.296426	0
	0.6	0	0.195832	0.098152	3.967863	0.762447	0.798695	0.361182	0	0.665668	0.432388
	0.7	0	0	0	0	0	0.793573	0	0	0	0
	0.8	0	0	0	0	0	0	0	0	0	0
	0.9	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0

Table 7.1: River Eden: Upstream sub-reach showing percentage of area weighted by time of different combinations of velocity and depth.

% Average of area factored by time

		Maximum depth (m)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Maximum	**0.1**	16.11626	0	0.422166	0	0	0	0	0	0	0
velocity	**0.2**	9.287869	0.78097	14.13946	6.328519	4.763591	0	0	0	0	0
(m^3/s)	**0.3**	0	2.189707	0.166356	1.207868	10.07949	7.717131	1.458177	0.022219	0	0
	0.4	0	0	0	0	0	0.116369	0	0.22473	0.201476	0.44457
	0.5	0	0	3.151075	5.685693	0.172791	0.112171	0	0	0	0
	0.6	0	0	0	1.215428	9.706177	0.32577	0	0	0	0
	0.7	0	0	0	0	0	2.77769	1.186274	0	0	0
	0.8	0	0	0	0	0	0	0	0	0	0
	0.9	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0

Table 7.2: River Eden: Middle sub-reach showing percentage of area weighted by time of different combinations of velocity and depth.

% Average of area factored by time

		Maximum depth (m)									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Maximum	**0.1**	24.58823	23.33972	3.401068	0	0	0	0	0	0	0
velocity	**0.2**	4.728016	0.730799	15.80385	14.76107	4.552418	0	0	0	0	0
(m^3/s)	**0.3**	0	2.827737	0.374102	0.003628	1.222613	1.470406	0.223961	0.591625	0	0
	0.4	0	0	0	0	0	0	0	0.090496	0.335786	0.475951
	0.5	0	0	0	0	0	0	0.15346	0.024828	0	0
	0.6	0	0	0	0	0	0	0.30024	0	0	0
	0.7	0	0	0	0	0	0	0	0	0	0
	0.8	0	0	0	0	0	0	0	0	0	0
	0.9	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0

Table 7.3: River Eden: Downstream sub-reach showing percentage of area weighted by time of different combinations of velocity and depth.

The downstream reach shows less variety in terms of flow conditions. This contrasts with the overall results of the RHS survey data which shows the best HQA scores for the downstream reach. This may not be surprising as the RHS takes into account many more factors. But there still does not appear to be any correlation with the sub-score relating to Channel Features though there is similar type of behaviour with the Flow type sub-score.

River Eden: Comparison of flow variability with RHS scores

Reach	Flow variability	Av HQA score	Av Channel Features sub-score	Av Flow type sub-score	Av HMS score	Av Resection sub-score
Upstream	33	43.3	3.3	7.67	2660	2413
Middle	27	37.7	1.67	7	2583	2573
Downstream	21	46	3	6.67	2305	2213

7.3.2 River Dearne

A similar analysis was carried out for the River Dearne.

Reach	Flow variability	Av HQA score	Av Channel Features sub-score	Av Flow type sub-score	Av HMS score	Av Resection sub-score
Upstream	29	10.3	2	8.3	2870	2800
Middle	21	10.7	0	4	2832	2800
Downstream	27	11	2	7.67	3349	2800

A similar pattern emerges for the Dearne with similar type of behaviour between the flow variability derived from the numerical modelling and the Flow type sub-score.

7.4 CONCLUSIONS

It would appear that the analysis of the spatial variability of the flow provides little indication of the quality of the habitat as assessed by the RHS score or the degree of modification provided by the HQA score. There appears to be qualitative agreement between the flow variability derived from the numerical modelling and the RHS Flow type sub-score. It should be noted, however, that the RHS score is derived more quickly and with significantly less data input than the analysis of the flow variability. Thus it would appear that a simple visual inspection is as effective as a more complex quantitative analysis.

A number of conclusions can be drawn from the above. It would appear that the cross-sections used do not provide a sufficiently detailed picture of the flow characteristics in the channel. This suggests that the features of habitat value have a spatial scale that is smaller than the typical distance between cross-sections. Thus it would appear that to encourage good habitat quality one needs to encourage the development of features with relatively short spatial scales.

The need to have features with small spatial scales has implications for the specification and implementation of channel management actions. It is important, therefore, that in any advice or specification, such as for example the Environmental Options manual, there is appropriate guidance given on longitudinal variation in conditions. It may be that the type of guidance such as that given under Environmental Options W5 should be reviewed.

8. *Conclusions*

8.1 TEMPORAL CHANGES IN CHANNEL CROSS-SECTIONS

The analysis of the cross-section data confirms the observations made during the geomorphological study and the other study on the changes that are taking place in the shape of the river channels. For example, on the River Eden comparisons of the river surveys show that sediment is being eroded from the upper bank of the channel and being deposited in the lower part of the cross-section. It is more difficult to confirm the absence of change but comparisons of the cross-sections surveys are consistent with the level of change being noted by the other field work that has been carried out. On the River Harbourne there is no cross-section evidence for bed level increases but at the downstream shoal where it was intended that sedimentation should take place it would appear from photographic evidence that limited sediment deposition has indeed taken place. This highlights the uncertainty in comparing cross-section data taken a number of years apart and the sensitivity of the human eye to detecting small changes in images.

8.2 IMPACT OF CHANGES IN CHANNEL CROSS-SECTION ON FLOW CHARACTERISTICS

The flow modelling has shown that the channel cross-section changes discussed above have an impact on the flow characteristics in terms of velocities, depths and shear stresses. These are detectable both in the 1-D model results and in the CES analysis. Thus the development of sediment related features within a channel are both detectable by hydraulic modelling and have a measurable impact on flow diversity within the channel. This means that both 1-D modelling and CES modelling can play a useful role in assessing the potential impact of both maintenance and capital works of flow and hence habitat diversity within a reach.

8.3 CORRELATION OF FLOW CHARACTERISTICS WITH HABITAT CHARACTERISATION

For the River Eden it is possible to compare the RHS survey data (Appendix 2) and the flow analysis and spatial variability analysis described above. The RHS survey indicated greater flow variability in the upstream reach and least flow variability in the downstream reach. Considering the numerical flow modelling results, a similar trend is also displayed in the values of the standard deviation in the velocity in Figures 4.7b and c. Figures 4.8 a to c show increasing flow variability generally as the sediment related features develop in the channel following the dredging that had taken place. The greatest variability is shown at Sections 5 and 6 where the greatest morphological and habitat changes were observed. The smallest changes appear to be in the downstream reach, where the hydraulics are controlled by the Vexour bridge and where the geomorphology study suggested that there was less active development of sediment related features. The spatial variability analysis also shows greater variability in the upstream reach and least variability in the downstream reach. This shows that the model results do reflect such variability and provide evidence that such models could be used to predict the likely impact of works on spatial flow variability.

8.4 RELATIONSHIP BETWEEN SHEAR STRESSES AND CHANNEL CHANGES

The estimation of shear stresses in the River Eden show that, at Section 6 there appears to be a correlation between high shear stresses and berm and habitat formation. The mechanism driving such a correlation would appear to be that the high shear stresses cause bank or bed erosion modifying the channel shape and releasing sediment into the system which encourages the development of sediment depositional features. In the River Dearne at Sections 7 and 8 there also appears to be a correlation between increasing shear stress and greater depth variability. In this case this may be associated with increased hydraulic roughness as a result of the development of vegetation.

8.5 RELATIONSHIP BETWEEN CHANNEL MANAGEMENT AND FLOW DIVERSITY

In analysing the River Dearne model runs were carried out to simulate the impact of 20 years of vegetation growth with no management. This results show a significant increase in velocity variation but in addition a significant reduction in channel conveyance. This demonstrates the need to strike a suitable balance between management to promote habitat diversity and management for flood risk.

8.6 RELATIONSHIP BETWEEN FLOW CHARACTERISTICS AND RHS DATA

Comparison of the analysis of the flow modelling results and the overall RHS values of HQA and HMS show little correlation. This is to be expected as in assessing habitat quality the RHS surveys take account of many more factors than just the nature of the flow. There does appear to qualitative agreement, however, between the flow variability derived from the modelling and the RHS Flow Type sub-score. This provides the confidence that one can use modelling to investigate the potential impact of changes on flow diversity and hence on the potential to provide a wider range of habitats.

8.7 IMPACT OF VEGETATION MANAGEMENT ON FLOW

The temporal variation in the hydraulic roughness of vegetation has a significant impact on flood risk through a year. It is thus important, when modelling flood risk that the hydraulic roughness appropriate to a particular time of year is used. The work on the Long Eau showed that vegetation cutting not only has an impact on flood risk for high flows but affects the water depth and lateral distribution of velocity. If when cutting vegetation margins are left along the bank then this results in low velocities adjacent to the bank. This can encourage the development of sediment related features. The impact of vegetation cutting depends upon the nature of the cross-section and the flow that is being considered. Cutting vegetation at different times affects the overall flood risk but has only a small impact on the overall, annual flow regime of the channel.

Appendix 6 Geomorphology

1. Introduction

The geomorphological element of the project focused on the field identification of morphological features in the maintained and unmaintained sub-reaches at the five project sites, coupled with interpretation of the links between channel morphology, sediment dynamics and maintenance practices. The aim was to establish the impacts of past and current maintenance regimes on channel morphology and evaluate the potential for morphological features and sediment forms to recover if maintenance ceased or was modified to allow or even promote the development of sediment features and the physical biotopes they provide.

The study approach employed geomorphological field reconnaissance to assess the morphological features and forms in the watercourses[1]. This involved filling-out check-sheets for the study sub-reaches following a site walk-over to gain a general overview of the morphologies of the sub-reaches. Separate sets of reconnaissance sheets were completed for all the sub-reaches. The check sheets comprise of 17 sections, which include spaces for notes, field sketches and site photographs. The sheets are grouped under the following headings:

Scope and purpose of the investigation (problem statement, logistics and general comments);

Region and valley description (vertical and lateral context for the current channel in relation to it valley and floodplain/margins);

Channel description (characteristics, bed sediment, physical biotopes); and,

Bank assessment for left and right banks individually (characteristics, vegetation status, profile, evidence of erosion/failures and accumulation).

Sites were visited at least twice, with the more dynamic watercourses being inspected on multiple occasions.

The completed sheets for all five project sites are voluminous and are unsuitable for inclusion in a project report, but they may be viewed and downloaded from the project website. They are supported by textual documents that interpret the results of the stream reconnaissance and account for the morphological features and sediment forms observed in all the sub-reaches at each site. In this Appendix the main findings of the reconnaissance surveys are summarised and used to support a wider discussion of the impacts of maintenance and the potential for recovery of a more natural morphology in streams with different fluvial attributes, morphological characteristics and maintenance histories.

In considering the results obtained at the project sites, the overriding factor governing the potential for morphological recovery appears to be the stream power possessed by the watercourse and consequently the order in which the project streams are discussed goes from the stream with the lowest power (Long Eau) to that with the highest (River Kent).

[1] Thorne, C R (1998) *Stream Reconnaissance Guidebook: Geomorphological Investigation and Analysis of River Channels*, Wiley, Chichester, ISBN 0-471-968560, 127p.

2. Summary Geomorphological Descriptions

2.1 LONG EAU

2.1.1 Regional Description

The Long Eau is a tributary of the Great Eau river system, draining an area of predominantly agricultural land in the Manby area of east Lincolnshire. The Long Eau lies in western part of the catchment, which bounded along its western margin by a chalk escarpment. From the escarpment the land surface falls gently eastwards to the North Sea Coast. Between the escarpment and the coast is an extensive, low-lying coastal plain, most of which lies below sea level and is which is consequently protected by extensive coastal flood defences.

2.1.2 River valley, valley sides and floodplain

There is no interaction between the Long Eau the valley side slopes at the project site due to the continuous, broad, coastal plain isolating the channel from the chalk escarpment. The very low gradients in the coastal plain significantly reduce the stream power available to the Long Eau to do geomorphic work and, consequently, reworking of the floodplain is almost entirely associated with human activities, most notably farming and the construction of settlements, infrastructure (such as Manby Aerodrome), and engineering works for land drainage and flood control, rather than the natural accumulation and re-erosion of sediments.

Historically, the channel has been constrained by artificial embankments along both banks, disconnecting the Long Eau from its floodplain. However, while this has had some positive effects in buffering the channel from agricultural activities and surface runoff that erodes soil and delivers it and associated pollutants to the drainage network, agricultural and suburban runoff still entered the Long Eau via land drains, sewer outfalls and ditches. More recently, the embankments in part of the project site have been repositioned, reconnecting part of the channel to specially designed, off-line flood basins in the floodplain.

2.1.3 Catchment sediment sources

Catchment sediment sources are mainly associated with agriculture, although the watercourse also receives sediment carried by runoff from the nearby village of Manby and its aerodrome (now converted into a business park). Land use in the area comprises mainly of arable cropping, and the potential for raindrop detachment and sheet erosion in arable fields is very high, although the sediment transport capacity of tributaries and ditches appears low. Delivery of sediment to the study sub-reach occurs mainly via the drainage ditches, which supply fine sediment in the silt, sand and clay size particle size ranges to the Long Eau.

2.1.4 Downstream Sub-Reach: Footbridge to culvert

In the downstream sub-reach, the channel has no terraces, indicating that the river has not experienced marked vertical instability in the past through prolonged aggradation or degradation. Similarly, the single thread, meandering channel planform is stable, due to the low stream power of the stream and the relatively high erosion resistance of its cohesive, vegetated banks. Given its location on the coastal plain, it would be expected that longterm evolution of the stream would be led by net accretion of sediment due to the storage of soil particles washed into the channel from the surrounding fields. However, the channel has been impacted significantly by past capital works and maintenance for land drainage, mainly through channel over-deepening, widening and embanking. The current maintenance regime for the Long Eau continues to affect channel morphology in the sub-reach by perpetuating the over-deep and over-wide cross-section and the channel remains disconnected from its floodplain by embankments along the majority of its length in this sub-reach.

Sediment supplied to the channel from the catchment is mainly derived from agricultural sources (arable cropping, vehicle movements). Along most of the sub-reach, crops are grown on the land adjacent to the channel right up to the flood embankments. The potential for raindrop detachment and sheet erosion of the fine-grained soils in the arable fields is high, and drainage ditches, farm tracks and tributary streams provide efficient transport pathways linking diffuse sediment sources to the channel.

The naturally low gradient of the Long Eau limits the extent and intensity of geomorphological activity in the fluvial system. Historically, over-deepening of the channel, coupled with the construction of high flood embankments, has reduced floodplain connectivity. However, this situation has changed where part of the flood embankment has been removed as part of the rehabilitation scheme in the upper part of the sub-reach.

The morphology of the channel is the outcome of the low gradient and velocities that characterise the watercourse, coupled with extensive re-sectioning in the past to create an enlarged, trapezoidal channel for land drainage and flood control. The result is a simple channel geometry with a limited range of sediment features and a lack of morphological diversity. The only exceptions to this general condition are two pool/riffle units, which appear highly unnatural and are likely to be artificial. Apart from at these gravel riffles, flows throughout the sub-reach are uniform and tranquil, with limited diversity in flow velocities, monotonous physical biotopes and a limited range of functional habitats. There are no natural or artificial controls stabilising the channel boundaries, though the high erosion resistance of cohesive bed and bank materials combine with extensive herbaceous and shrubby plants provide a degree of natural stabilisation.

In-channel sediment sources in the sub-reach are limited to just two or three cut banks exhibiting localised erosion, mainly at the outer margins of tightly curved meander bends. Tree roots exposed in these banks suggest that bank erosion is a semi-continuous but slow process. It appears that the supply of sediment from in-channel sources is low in the sub-reach.

The left bank is formed in cohesive sediments and is backed by a flood embankment along the entire length of the sub-reach. Bank angles are spatially variable and include some steep sections of bank. Bank vegetation consists of continuous grass/flora but no trees. Although bank maintenance (through vegetation cutting and sediment removal at the bank toe) occurs in this sub-reach, the toe of the bank still exhibits some recent deposits of sediment and emergent reeds in the vicinity of the artificial pool-riffle features. It is clear that these bankside reeds and sedges are very effective in trapping fine sediment. These observations indicate some potential for recovery of a more natural bank profile should maintenance cease or be modified.

The right bank is also formed in cohesive sediments, backed by a continuous flood embankment. The bank is vertical in places, although it is generally less steep, especially at the inner margin of channel bends. The right bank is generally well vegetated and while bushes, sedges and reeds predominate, there are occasional overhanging trees, some with exposed roots, suggesting slow bank erosion.

2.1.5 Study Sub-reach 1: Footbridge to gate

This part of the study reach is disconnected from its floodplain by flood embankments. However, the embankments appear to be slightly lower than those in the downstream sub-reach and they also feature wider riparian buffer strips along the left bank, colonised by reeds and grasses.

At low flow, the channel exhibits uniform/tranquil flow, with very slow velocities. There is little evidence of lateral instability, with only localised areas of toe erosion and sediment accumulation. However, the bed width appears slightly narrower than in the downstream sub-reach, associated with berm accumulation along the edges of the channel particularly in the downstream part of the sub-reach where marginal reed beds are highly effective in trapping fine sediment.

The sub-reach features four gravel riffles, similar to those in the downstream sub-reach downstream and also constructed artificially. The riffles create pools upstream by ponding the flow, to widen the range of physical biotopes, which otherwise consist of monotonous glides.

The left bank has a continuous flood embankment along the entire length of the sub-reach, but the bank is fenced-off to create a narrow (2-3 m) buffer strip at the top of the bank. Fencing, together with a less intensive maintenance regime is resulting in more the marginal vegetation being untouched along the left bank.

The right bank also has a continuous flood embankment. The angle of this bank is more variable, including some vertical profiles due to bank erosion and toe scour. The right bank has a greater range of mature vegetation, consisting of mainly bushes, sedges and reeds, with occasional patches of overhanging trees.

2.1.6 Study Sub-reach 2: Little Carlton Road Bridge to Footbridge

Conditions in this sub-reach are influenced by the weir upstream, which is an artefact of past use of the river to support milling activities. The weir is a fixed structure that stabilises the bed elevation and planform position of the channel locally and limits the potential for vertical adjustments to the long profile and lateral shifting of the channel more generally. The potential for vertical or lateral morphological changes in the sub-reach is further reduced by the presence of the Little Carlton Road Bridge and an under road culvert, which also fix the planform position and bed elevation of the watercourse.

Notwithstanding the relative stability of the channel, there are localised areas of slow but active channel shifting through bank retreat, mainly at outer margins of bends along both banks. Additionally, there is a relatively large area of active erosion in the downstream part of the sub-reach due to poorly managed access to the watercourse by livestock (trampling, poaching) and farm vehicles using a ford to cross the stream (bed disturbance, compaction and mechanical erosion of the bank, vegetation destruction).

There are very few in-channel, fluvial features, although some limited silt deposits were noted along the right bank, at locations immediately downstream of the areas of localised bank and toe erosion. These deposits showed some evidence of stabilisation and encroachment into the channel through reed colonisation, although this occurs along only a limited proportion of the right bankline.

Flows are uniform and tranquil, resulting glides being the only physical biotopes.

The left bank is stable along most of its length and is covered with extensive stands of herbaceous and shrubby vegetation. There are only a few areas of localised bank erosion, mainly at the outer margins of bends. The right bank is steeper in the upper part of the sub-reach, with profiles being sufficiently steep to trigger bank slumping in some places.

Generally, however, the right bank is covered by grassy vegetation from bank top to toe along the sub-reach.

2.1.7 *Commentary and recommendations*

The channel of the Long Eau currently fulfils land drainage and flood control functions mainly to support agriculture, and the existing maintenance regime is geared towards these functions. Negative impacts on the geomorphological functioning of the watercourse result both directly and indirectly from past and current maintenance actions. Direct impacts occur because the maintained channel:

- is over-wide and over deep for its flow and sediment regimes,
- has a simple trapezoidal shape that lacks the morphological diversity found in a natural stream in the same fluvial environment,
- lacks the variety of bank and sediment balance conditions at its margins expected in a natural channel,
- is disconnected from its floodplain along the great majority of its length,
- receives an elevated supply of fine sediment from catchment runoff which it lacks the capacity to store through overbank deposition in an active riparian corridor backed by a floodplain.

Indirect morphological impacts also occur because maintained channel:

- lacks natural vegetation assemblages in-stream, at the channel margins and on the banks, along the riparian corridor and in overbank areas,
- has had gravel riffles artificially installed to try to offset the effects of past capital works and maintenance by restoring lost functional habitats.

Lack of natural vegetation is important as vegetation plays multiple roles in the geomorphic functioning of low power fluvial systems like the Long Eau, including providing flow resistance, trapping fine sediment, stabilising sediment features and deflecting flows to promote constriction/local scour and so provide a wider range of physical biotopes than would occur otherwise. The constructed riffles are significant because they indicate recognition that the current morphological condition of the watercourse is unsatisfactory and signal a desire to restore lost habitats that is well intentioned, although the outcomes appear highly unnatural and inappropriate to the environmental setting.

Other restorative measures – particularly the gaps in the embankments and the off-line flood basins, may be more appropriate, but it is too early to judge their success in terms of morphological adjustments and recovery of more natural morphological forms and functioning.

Maintenance issues centre on sediment and vegetation management. If the supply of fine sediment to the channel could be reduced, the frequency with which desilting is necessary to meet land drainage and flood control functions should be reduced. Therefore:

Recommendation 1: thought should be given to buffering the channel from surface runoff and aeolian processes that deliver sediment derived from catchment erosion – especially in arable fields. Measures might include set back drain outfalls with reed beds between them and the channel, and the creation of a continuous, broad riparian corridor along the course of the Long Eau.

Problems with the capacity of the watercourse to carry water at high stages due to the comparatively high flow resistance of natural vegetation should be addressed using approaches capable of meeting land drainage and flood control objectives while also minimising the need for maintenance and avoiding negative impacts on the natural functions of the channel. Therefore:

Recommendation 2: depending on post project appraisal of the existing schemes, thought should be given to retiring the embankments along much greater lengths of the watercourse to make space for the stream to convey water and sediment during runoff events, and store sediment in overbank areas between events without compromising the conveyance capacity and functional habitats in the low flow channel.

A problem with the recovery of low power systems like the Long Eau occurs due to the low capacity of the flow and sediment regimes to restore natural forms and functions and the long time taken for discernible outcomes to emerge. Therefore:

Recommendation 3: Lessons learned from the installation of artificial riffles should be taken on board in proposals for further river restoration through structural interventions that are better attuned to the lowland setting of the watercourse and designed to better mimic features that would be found in undisturbed streams with similar stream powers and fluvial regimes.

2.2 RIVER DEARNE

2.2.1 Region and Valley Description

The River Dearne is a tributary of the River Don in Yorkshire. It rises southeast of Huddersfield before joining the River Don at Conisbrough, near Doncaster. The majority of the catchment constitutes a lowland, relatively low stream power system, with Coal Measures being the most prominent surface geology. The Dearne catchment is mostly rural, with land use comprising mainly of arable croping, but there are isolated properties, small settlements and larger, urban conurbations scattered throughout the basin.

2.2.2 River valley, valley sides and floodplain

There is no channel-slope coupling within the sub-reaches due to the broad floodplain that separates the channel from the valley sides. The low gradient of the valley floor reduces the power available for fluvial reworking of the floodplain. Consequently, lateral activity is mainly attributable to past fluvial responses to human activities, most notably mining, rather than natural processes. The channel is constrained and disconnected from its floodplain by artificial embankments along both banks.

2.2.3 Catchment wide sediment sources

Catchment wide sediment sources are mainly associated with agriculture and runoff from the village of Harlington. Land use comprises mainly of arable cropping, and the potential for raindrop detachment and sheet erosion in arable fields is high. The delivery of sediment to the upstream sub-reach occurs mainly via drainage ditches and tributary streams, which supply fine sediment (mostly silt, sand and clay size particles) to the River Dearne. However, control structures (sluice gates) on many drains and tributaries reduce their connectivity in terms of sediment transfer through the drainage network and to the main river.

2.2.4 Upstream Sub-reach: Weir to Footbridge

The position of the channel in the upstream sub-reach is fixed by engineering structures (embankments, weirs and gated sluices) and there no signs of lateral or vertical instability.

High flood embankments along both banks disconnect the channel from its floodplain and the sub-reach is further stabilised by a crump weir at its upstream limit.

The channel planform and cross-sectional morphology are heavily influenced by past flood defence works. The upstream sub-reach features uniform, tranquil flow in a single threaded, slightly sinuous course that has little scope for lateral activity due to the low power of the fluvial system, continuous vegetation cover on both banks and narrowness of the riparian strips between the banks and the flood embankments. Sediment is mainly fine grained (sands, silts and clays) being sourced from catchment-wide, diffuse processes of soil erosion together with sediment derived from localised bank erosion.

The channel throughout the upstream sub-reach is much wider than in the sub-reaches downstream, but is adjusting through narrowing under the current flow and sediment regimes. This is indicated by the stable condition of the banks and the existence of berms at the toe of the both banks. These berms are not only accreting but are also becoming progressively more stable through vegetation colonisation, mainly by reeds, sedges and grasses. In time, it is likely that they will significantly reduce the channel bed width.

Biotopes are mostly glides, with some deadwater zones associated with the heavier patches of marginal vegetation.

The banks are formed in cohesive sediments with steep slopes and heights between 1 and 2m. Generally, the banks are stable and along most of their length they are covered by mixed vegetation consisting of extensive herbaceous and shrubby plants. Extensive accumulations of fine sediment and debris at the bank toe have built berms in the lower part of the upstream sub-reach. Reed beds on the berms in the lower part of the upstream sub-reach are trapping sediment and promoting accretion and encroachment into the channel.

The exception to generally stable or accreting conditions along the banks occurs at areas of localised erosion at the right bank due to trampling and disturbance by anglers accessing the river at fishing pegs. Erosion around the pegs creates point sources of fine grained sediment spaced fairly evenly along the upstream sub-reach. Bank vegetation adds to stability and reduces the erosive potential of the near-bank flow, but there is also potential for tree fall (due to disease, age or wind throw) leading to disruption of the bank form and promoting localised erosion.

2.2.5 Study Sub-reach: Footbridge to Road Bridge

The floodplain surrounding this sub-reach shows little evidence of natural channel shifting, filling or incision in the context of the wider valley. However, the course of the river prior to its artificial realignment and re-positioning as part of a past flood defence scheme can be identified. Historical maps show that the old channel in this sub-reach exhibited a meandering planform with a more irregular planform than that of the floodway. The condition of the old channel therefore suggests that the local catchment characteristics (unmodified) provide the necessary conditions for an active channel migration.

The current planform features an artificially narrow, sinuous, low flow channel within the wider, flood control channel. The effect is to produce a 2-stage channel. Movement of the inner channel within the wider floodway is restricted because the sinuous channel has been 'locked' in place using rock and, secondly, because the flood embankments prevent the channel shifting or interacting with its floodplain. The capability for the channel to be active laterally is further reduced by extensive vegetation colonisation of the artificial berms, riparian strip and flood embankments.

The current morphology results from channel narrowing through the artificial construction of rock berms as part of the 1990s habitat creation scheme, coupled with natural processes of reed establishment and fine sediment trapping along the channel margins that concentrates flows and increases local velocities. In addition, some firmer and coarser bed materials (gravel deposits) were identified within the sinuous part of the sub-reach and there appears to be a bed control (it is unclear whether this is an artificial structure or a natural outcrop of geologically resilient material) midway along the sub-reach. The presence of erosion resistant materials in the bed further restricts the potential for morphological adjustment.

There appeared to be a lack of sediment features in the channel, suggesting that this is a sediment throughput reach, where bed material load is transported but does not long reside as it is transferred downstream efficiently.

This condition seems to be the outcome of narrowing of the channel for habitat creation, coupled with subsequent accretionary advance of one or both banks along much of the project sub-reach, which is encouraging the development of self-cleansing conditions within the inner channel. Although the resulting channel fails to display pronounced in-channel fluvial features, narrowing does appear to have reduced the requirement for frequent and/or intense of channel maintenance to manage sedimentation within the project sub-reach of the River Dearne.

The banks are 0.5 to 1m high and are protected by rock revetments at the toe, which preclude undermining by the flow. The banks are stable, with extensive vegetation cover in the form of herbaceous bushes and shrubs growing at intervals along the bank top and berms. Some of these plants have started to lean into the channel, trailing branches in the water and, thereby, inducing some variability to the flow velocity and physical biotopes. Leaning appears to be the result of wind-throw process rather than active bank instability.

The artificial berms along the right bank appear to have been colonised by a greater variety of vegetation types than along the left bank. These berms provide a wide riparian buffer from runoff from the steep flood embankments, further limiting erosion and sediment delivery to the channel.

2.2.6 Commentary and recommendations

The channel of the River Dearne has been heavily modified by past engineering interventions, first in response to the effects of mining subsidence and later for habitat creation. The current maintenance regime is geared towards sustaining the conveyance capacity of the flood control channel between the high embankments. Negative impacts on the geomorphological functioning of the watercourse that result from the past capital works are, to an extent, unavoidable given the limited space available for the watercourse within the flood channel. However, the recovery of some more natural attributes observed in the upstream sub-reach suggests that modification to maintenance activities would assist the river in reaching its maximum ecological potential, as required under the Water Framework Directive. Direct negative impacts occur because the channel is:

- disconnected from its floodplain hydromorphologically throughout the project site,
- morphologically constrained by embankments and, in the study reach, fixed rock berms,
- locked into a slightly sinuous planform that fails to provide the degree of morphological diversity associated with the pre-disturbance, irregularly meandering stream,
- lacking in-stream sediment features (for example bars) due to sediment flushing by flows funnelled between the artificial rock berms.

Indirect morphological impacts also occur because the river:

- throughout the project site, has only limited space within which to develop a riparian corridor between the low flow channel and the flood embankments.
- within the study reach, lacks the capacity to periodically wash out and renew vegetation assemblages at the channel margins and along the banks due to bankline fixing by rock revetments,
- within the upstream sub-reach, experiences localised instability and erosion around fishing pegs.

In the upstream sub-reach, reductions in the intensity of maintenance appear to be allowing a degree of natural, geomorphological recovery. Morphological adjustments involve development of low berms along both banks that narrow the low flow channel and promote development of a wider range of flow velocities and variation in near ban depths. Vegetation colonisation of the berms in the upstream sub-reach appears to be highly effective as a driver of morphological recovery, through trapping sediment and debris by emergent and trailing stems. This is reflected in the presence of additional physical biotopes in the upstream sub-reach compared to the downstream sub-reaches. The naturally deposited berms in the upstream sub-reach contrast with the artificially constructed, rock armoured berms in the downstream sub-reaches in that they are self-formed and self-adjusting. Consequently, they are better attuned to the flow and sediment regimes, are more responsive to the occurrence of channel-forming flows, are able to interact with the sediment features in the low flow channel and are capable of providing a wider range of habitats.

While the river remains locked between its flood embankments, opportunities for recovery of a more natural morphology are severely limited. However, based on observations made in the upstream sub-reach during this study, it appears that the River Dearne does have the capacity to recover at least some of the natural geomorphological forms and functions expected in a sinuous river if it is allowed to do so. Hence, if applied over a longer reach of river, reductions in the intensity and frequency of maintenance operations should prompt improvement in the morphological condition of the channel through ‘allowed recovery’. In time, this would lead to development of a slightly sinuous low flow channel meandering between the embankments that would recovery some (but by no means all) of the morphological diversity exhibited in the abandoned former course of the river identified in the field and from old maps. Therefore:

Recommendation 1: maintenance in the upstream sub-reach should be modified to allow further recovery of natural forms and features in the cross-sectional and planform morphologies of the channel while ensuring that, (1) the flood control channel continues to meet the minimum standard of service required for flood defence and (2) the stability of the flood embankments is not reduced.

In contrast to the observed tendency for natural recovery in the upstream sub-reach, the presence of fixed berms in the downstream sub-reaches limit the degree to which ‘allowed recovery’ is capable increasing the range of physical biotopes and the functional habitats they provide. Hence, the rock berms may limit the maximum ecological potential that the river can attain with its heavily modified hydromorphology. This is the case because the immobile boundaries presented by the berms prevent natural adjustments to the morphology of the low flow channel and renewal of vegetation in the riparian corridor while creating fluvial conditions that preclude the development of sediment features within the low flow channel. Therefore:

Recommendation 2: Ideally, the rock berms should be modified throughout the downstream sub-reaches to reduce their rigidity and restore the capability for fluvial processes to interact with the morphology of the low flow channel. This would introduce opportunities for natural morphological adjustments, deposition of in-stream sediment features and the creation of increased morphological diversity in the cross-sectional and planform attributes of the low flow channel within the embankments. In contrast to the habitat creation scheme of the 1990s, this would represent restoration of fluvial *functions*, rather than fluvial forms. The habitats creation scheme has had some benefits, but it has created form without function and so its success is limited. Any, modifications should be made incrementally and monitoring would be necessary to identify any undesirable morphological developments and provide the basis for managing changes adaptively.

Implementation of Recommendation 2 would require further heavy engineering and a paradigm shift in the approach adopted to management of the river for biodiversity and WFD purposes, a less radical alternative would be to use additional structural measures to promote habitat creation in the downstream sub-reaches. Therefore:

Recommendation 3: thought should be given to the construction of ‘Newbury Riffles’ in the low flow channel to create pool and riffle biotopes and increase the range of habitats. These riffles are hydrodynamically designed to avoid any raising of flow levels during flood events and so have zero impact on the conveyance capacity of flood control channels. They have a 30 year track record of success in improving habitats in heavily modified watercourses while meeting goals for channel stability and flood control and therefore present minimal risk.

The right bank in the upstream sub-reach is currently being damaged due to anglers accessing fishing pegs. This is detrimental to bank stability, creates opportunities for local erosion and elevates the supply of sediment to the river. Therefore;

Recommendation 4: bank instability, erosion and the sediment it generates could certainly be reduced or eliminated by appropriate bank management and the appropriate measures should be taken immediately through, for example, construction of stabilisation features around fishing pegs, changes to the behaviour of anglers, and conservation of bank vegetation in the upstream sub-reach.

2.3 RIVER EDEN

2.3.1 Regional description

The River Eden is a tributary of the River Medway in Kent. It rises south of Caterham and flows eastward through the Wealden Clay to join the River Medway near Penhurst. The majority of the catchment is a lowland, low power system, with weathered soils predominating in the surface geology. The Eden catchment is mostly rural, with land use comprising of cultivation: mostly arable crops and improved pasture. In addition, there are small settlements and areas of woodland scattered throughout the Eden catchment.

2.3.2 River Valley, Valley Sides and floodplain

There is very limited channel-slope coupling at this study site due to the continuous, broad valley floor isolating the channel from the valley sides. The only location where the river undercuts the valley side is along the right bank near Vexour Bridge, Here, and more generally, well developed slope profiles formed in weathered, well drained soils limit the effectiveness of hillslope processes. The Riparian corridor is, however, narrow and highly fragmented, with agricultural cultivation extending right up to the channel margins in places. There are no natural or artificial levees and so the channel is fluvially connected with its floodplain. Consequently, there is little buffering of the channel from agricultural activities and surface runoff that delivers eroded soil and agri-chemicals to the watercourse.

2.3.3 Catchment sediment sources

Catchment wide sediment sources are mainly associated with the extensive cultivation of arable crops and improved pasture. The potential for raindrop detachment and sheet erosion in arable fields is high, and drainage ditches, farm tracks and tributary streams provide efficient transport pathways linking these sediment sources to the river in this sub-reach of the river. The dominant type of sediment supplied by field erosion will be fines, consisting mainly of particles in the sand, silt and clay size fractions. Also, improved pasture generates enhanced quickflow, which also leads to elevated sediment yields.

2.3.4 Downstream project sub-reach: CSA 1- 5 (Vexour Bridge to Footbridge)

Trash lines and silt deposits on the floodplain establish that out-of-bank flows do occur within the sub-reach. This suggests that the notably low width/depth ratio of the channel in this sub-reach may be a product of past capital dredging for land drainage and flood control, rather than natural incision. The channel does not appear to be incising at present, but is, if anything, aggrading slowly. The channel also appears overly-narrow and may be tending to widen, although sporadically and at a slow rate.

There is little evidence of fluvial reworking of the valley floor in this sub-reach through either lateral or vertical instability. The planform displays a single thread, meandering channel with a mixture of regular and irregular bends. Generally, lateral erosion is slow and is irregularly distributed throughout the sub-reach. Cohesive bank materials and binding together of the banks by extensive bank side vegetation (in areas where there is a riparian fringe) reinforce the banks locally and clearly limit meander migration and evolution. There is an ox-bow left by a meander cut-off near CSA 4, but may well be artificial.

Channel morphology in this sub-reach has been influenced by past dredging and de-silting, with clear evidence of bed lowering compared to the oxbow channel near CSA 4. Flow is influenced in the downstream part of the sub-reach by the back water effect of Vexour Bridge. Elsewhere, flow is mainly uniform, tranquil flow, with no natural bed controls and only occasional width controls (mainly in the form of mature trees with particularly extensive roots).

Sediment is predominantly fine grained (sands, silts and clays) derived from catchment runoff and localised bank erosion. Fine sediment is supplied naturally by,

(i) surface runoff during storm events,
(ii) re-mobilisation of ditch and tributary deposits and,
(iii) in-channel, fluvial processes in the form of bank erosion and remobilisation of berm deposits.

Exposed tree roots, trees with leaning and/or bent trunks and limited retreat of the bank near the footbridge at CSA 5 indicate that bank erosion is a slow process. This may be attributed to the low stream power of the system, the high erosion resistance of the bank materials and the presence of trees that provide natural bank protection though root reinforcement and flow retardation.

Bank erosion occurs mostly at outer margins of tight bends, where near bank flow velocities are highest and flow impinges against the bank during high, in-bank events. In the downstream part of the sub-reach (immediately upstream of Vexour Bridge) there is some evidence of channel/slope coupling as the channel abuts against the right valley side and bank erosion leads to undercutting of the valley side hillslope.

Sediment is stored in the channel in berm and bench features rather than bars. Berms form by deposition of sediment along the channel margins. Benches form through basal accumulation of failure blocks of bank material. Extensive in-channel vegetation cover and reed beds have resulted in the trapping of fine sediment from the sediment load carried by the river and gradual accumulation of sand, silt and clay on berms, driving contemporary narrowing of the channel at formerly over-wide locations, including some bend apices. Other situations where sediment accumulates include fines settling in slack and backwater areas, coarser sands accreting on point bars at meander bends, and sediment depositing on the floodplain during overbank floods.

Physical biotopes are limited to glides and marginal dead water zones. Some diversity in biotopes results from encroaching in-channel vegetation, especially where this interacts with the flow, sediment load and bank processes on actively accreting berms.

The banks in this sub-reach are approximately 2m high and may be close to the limiting unsupported height for geotechnical stability. Evidence of failure by soil fall, rotational slip and shallow slides was observed in the field. Shrubs and deciduous trees are extensive along the banklines. Some trees exhibit exposed roots and/or curved trunks. Exposed roots indicate a slow rate of erosion and curved trunks suggest gradual slumping of the bank in the past. Many trees have severely undermined roots, however, and their future stability cannot be relied upon. Trees located in the ox-bow channel (which is not incised into the flood plain) illustrate the original, lower relationship between the roots and the channel and are not undercut. This provides further evidence that the active channel has either degraded or been over-dredged in the past.

Contemporary bank failures are located at the outside of meanders, because of toe scour and undercutting by parallel and/or impinging flows. The banks at other locations are accreting through berms and bench growth. Most commonly, berms are found at the outer banks of very tight meander bends, due to flow separation.

2.3.5 *Middle Sub-reach: CSA 6 to 9*

Trash lines and overbank deposits in this sub-reach suggest that the incised morphology of the channel is recovering naturally through in-channel siltation that has been allowed to continue due to lack of maintenance. There is no evidence of extensive vertical or lateral channel instability.

The planform features irregular meanders, possibly due to outcrops of erosion resistant materials in the banks, coupled with past re-alignment of the river as part of channel improvement works for land drainage and flood control. There is one prominent ox-bow in the middle sub-reach, which probably results from an artificial cut-off. Lateral activity and planform development appears to have been limited by extensive vegetation in the riparian corridor and on the banks along both sides of the river.

Channel morphology in the middle sub-reach appears to have been influenced by past maintenance and capital works (including bend cut-offs). There is evidence of bed lowering in that the elevation of the current bed is notably lower than in the abandoned oxbow channel near CSA 7. This may be due either to: (i) fluvial incision triggered by de-silting/straightening, or (ii) mechanical lowering of the bed by over-dredging. However, the channel appears to have at least partially recovered from past maintenance actions through in-channel siltation, mainly through berm formation. Apart from in the vicinity of the weirs, flow is uniform and tranquil, with no natural bed controls and only occasional width controls (mainly in the form of trees with particularly extensive roots).

Sediment in the channel is predominantly fine grained (silts, sands and clays), being derived from catchment wide and local bank erosion sources. Bank sources include both fluvially eroding areas associated with meandering and trampled/poached areas where stock and/or anglers gain access to the river.

Currently, trees along the middle sub-reach appear to relatively stable and provide significant natural bank protection, although this protection may not be reliable in future should slow but progressive erosion of the banks continue to expose the roots of bank side trees, or should soil creep cause them to lean further into the channel.

Bank erosion there is concentrated at the outer margins of meander bends but in addition to this natural erosion, accelerated erosion results from damage to the right bank due to poorly managed stock access and trampling by anglers around fishing pegs. Elevated supplies of catchment derived fine sediment also result from absence of a riparian fringe due to cultivation right up to the bank tops and uncontrolled flow in tributary drainage ditches, both of which increase the potential for sediment input from the floodplain and wider catchment. Conversely, a series of weirs immediately upstream of the middle sub-reach may reduce the supply of relatively coarse (bed) sediment. Also, the maintenance regime for the project sub-reach upstream includes desilting, which limits morphological adjustment and probably results in that sub-reach acting as a sediment sink as it recovers a more natural morphology between maintenance events, through berm building. Mechanical removal of sediment further prevents the channel becoming more active through lateral shifting of the channel and interaction with the floodplain, which will also tend to reduce the sediment supply to the middle sub-reach.

In-channel sediment storage occurs in heavily vegetated berms and benches, a process probably assisted by lack of recent maintenance operations. Very few sediment bar features were observed. Benches have also formed (and are still forming) through basal accumulation of failure blocks of channel bank material that have not been removed by fluvial processes. Berms and bench growth is causing a general narrowing of the channel, widening the range of flow types and physical biotopes. Other situations where sediment accumulates include fines settling in slack and backwater areas, coarser sands accreting on point bars at meander bends, and sediment depositing on the floodplain during overbank floods.

There is, however, some variation in the physical biotopes in this sub-reach, which include glides, runs, boils, pools and marginal dead water zones. Runs and glides are most pronounced in the lower part of the middle sub-reach, where the channel appears steeper and has a much straighter planform alignment approaching the footbridge. Notably, in this sub-reach the vegetation cover is sparser than in the project sub-reach downstream, which reduces the degree of channel shading and shelter.

The banks are formed in the cohesive clay/silt with some exposed gravels mixed into the finer alluvium. They are lower than in the project sub-reach downstream and are generally less densely vegetated. River cliffs are formed where fluvial shear is eroding the banks at the outer margins of meander bends.

Significantly, the trees along the left bank are much straighter in this sub-reach than there are in the sub-reach upstream. Lack of bent trunks indicates greater long-term geotechnical stability in the left bank in this sub-reach, but there is evidence of past geotechnical bank instability at both the inside and outside of tight bends. Basal accumulation of failed material at the bank toe has formed benches that are almost continuous along the left bank. These benches have been colonised by grasses, flora, reeds and sedges, leading to trapping of some of the suspended sediment load and conversion of benches into more extensive berms.

The right bank has no artificial protection, but is naturally stabilised to a degree where vegetation is well established. Relict failure scars and scarps indicate that in the past geotechnical failures occurred through sliding and soil fall. Upper bank retreat is, in places, still contributing to narrowing of the channel bed width through basal accumulation of failed bank material to form benches. However, unlike the left bank, basal accumulation and bench building are not continuous along the right bank. In fact, the bank toe sediment balance appears to alternate between areas in excess basal capacity (in areas of swift or impinging flow where scour potential exceeds sediment supply) where the banks are actively eroding, and areas of net basal accumulation (slower or slack water areas near the bank, with sediment supply exceeding the capacity of the flow to remove sediment), where benches and berms are actively accumulating.

2.3.6 Upstream project sub-reach: CSA 10-13

Fresh trash lines and overbank sediment deposits illustrate that that out-of-bank flows occur in this sub-reach, which is consistent with the present morphological status of the channel in the project reach as a whole as being incised but naturally, though very slowly, recovering through in-channel siltation that has occurred since the last maintenance activity. The floodplain in this sub-reach shows more evidence of lateral channel shifting but, no signs of longterm vertical instability.

The river at the upstream limit of the sub-reach is stabilised by a weir, but despite this the channel is able to erode its banks and shift its planform position. This may be accounted for by the series of de-silting operations which appear to have lowered the bed through over-dredging, thereby increasing the risk of geotechnical failure due to bank over steepening and/or over heightening. Evidence of past bank instability is present in the form of benches, while intermittent berms along both banks indicate a tendency for natural recovery of channel form following maintenance.

Flow throughout the sub-reach (apart from in the vicinity of the weir) is nearly uniform, tranquil flow, with no natural bed controls and only occasional width controls (mainly in the form of trees with particularly extensive roots). The weir at the upstream limit of the sub-reach creates a pooled, back water condition in the approach channel upstream that both controls the long profile gradient and probably limits delivery of the relatively coarse (bed material) fraction sediment load supplied to the project sub-reach from channel upstream. It is likely, therefore, that the majority of channel-derived sediment supply to the sub-reach is derived from bank erosion, while finer, catchment-derived sediment comes mainly from soil erosion in arable fields. The sediment delivery ratio (ratio of soil erosion in arable fields to sediment yield to the channel itself) is elevated where farming extends right up to the channel margins and there is no buffering effect due to the lack of a riparian corridor.

Relatively small amounts of sediment are stored in the channel in discontinuous berms and benches along the toes of both banks. Very few bar features are observed in the channel. At some locations, narrowing of the channel due to berm building is accelerated by vegetation encroaching into the channel and trapping sediment at the flow margins. This creates of a greater variety of flow and biotope types within the sub-reach. Other locations where sediment was observed to be accumulating included areas of dead or slack water where fines are able to settle out, together with over bank (floodplain) deposits on the valley floor along both banks.

This sub-reach exhibits a limited range of physical biotopes with glides, pools and deadwater areas predominating, although one pool-riffle unit was observed. The low number of physical biotopes and their limited range of types may be attributed to the limited supply of sediment from upstream (due to sediment trapping at the weir), periodic de-silting, and vegetation clearance.

The banks have a range of profiles ranging from steep river cliffs at the outside of bends, to gentle slopes inside the bends. Banks are formed mainly in cohesive alluvium in the clay/silt size ranges, with some exposed gravels. Erosion occurs mainly at the outer margins of meander bends but rates appear to be low. Single trees, or rows of trees, are located along the bank top in places. These are mature plants generally with straight trunks but exposed roots, which suggest that banks are stable geotechnically, but eroding very slowly under the combined action of fluvial processes and sub-aerial weathering.

Erosion of the right bank is accelerated and the supply of sediment elevated due to the activities of anglers. Damage is concentrated around fishing pegs located at regular intervals along the right bank. Vegetation loss (leading to loss of root reinforcement, exposure of the soil surface to fluvial erosion and enhanced sub-aerial weathering) and damage to the bank by trampling (leading to mechanical erosion and surface compaction – which in turn leads to increased runoff and concentrated flow erosion) are mainly caused by anglers climbing up and down the bank to gain access to the water's edge from the top of the bank.

2.3.7 Commentary and recommendations

The channel of the River Eden currently fulfils land drainage and flood control functions to support agriculture, and the existing maintenance regime is geared towards these functions. Direct and indirect, negative impacts on the geomorphological functioning of the watercourse result, particularly as a legacy of past maintenance actions. Direct impacts occur because the maintained channel:

- is over deep for its flow and sediment regimes,
- has an over-wide bed width,
- lacks the degree of morphological diversity expected in a natural, meandering stream with the same planform attributes,

- receives an elevated supply of fine sediment from catchment runoff,
- experiences accelerated bank retreat and an elevated supply of bank-derived sediment where poorly controlled stock access and the activities of anglers damage the banks and destroy bank vegetation.

Indirect morphological impacts also occur because maintained channel:

- lacks natural vegetation assemblages in-stream, at the channel margins and along the banks,
- lacks a riparian corridor where arable farming encroaches up to the bank top.

Lack of natural vegetation assemblages in-stream and at the channel margins is important as they play multiple roles in the geomorphic functioning of medium/low power fluvial systems like the River Eden, including providing flow resistance, trapping sediment, stabilising sediment features and deflecting flows to promote constriction/local scour and so provide a wider range of physical biotopes than would occur otherwise. Lack of a riparian corridor is significant because it exposes the channel to elevated sediment deliver from the surrounding arable fields and reduces momentum export from the channel to the floodplain (by large eddies) during overbank floods.

Reductions in the intensity of maintenance in the middle sub-reach appear to be allowing a degree of natural, geomorphological recovery. Although it is not easy to discern marked differences between the sub-reaches, close inspection indicates that morphological adjustments (recovery from past incision, berm building, bed narrowing) and recovery of more natural geomorphological functioning (in-channel sediment storage, increased frequency of overbank flows, momentum exchange between the channel and floodplain flows during floods) do appear to be occurring in the middle sub-reach when it is compared to the sub-reaches up and downstream. Also, the vegetation on berms in the middle sub-reach does appear more mature than in the sub-reaches upstream and downstream, and it is therefore more effective as a driver of morphological recovery. This is reflected in the slightly wider range of physical biotopes (glides, runs, boils, pools and marginal dead water zones) observed in the middle sub-reach compared to the sub-reaches upstream and downstream(glides, pools and dead water zones).

Maintenance issues centre on sediment management. In this context, it would be more sustainable to treat the causes of the problems rather than the symptoms. For example, if the supply of sediment to the channel were reduced, the frequency with which desilting is necessary to meet land drainage and flood control functions should be reduced. Therefore:

Recommendation 1: thought should be given to further buffering the channel from surface runoff and aeolian processes that deliver sediment derived from erosion of the surrounding arable fields. Measures might include set back drain outfalls with reed beds between them and the channel and, particularly, creation of a continuous, broad riparian corridor along the course of the River Eden to replace the fragmented and discontinuous corridor that currently exists.

Recommendation 2: the supply of sediment from bank erosion is currently elevated due to poor control of stock access and damage to the banks around fishing pegs along the right bank. These problems can certainly be reduced or eliminated by appropriate bank management and the appropriate measures should be taken immediately (discussion with riparian land owners and stakeholders using the river, control of stock access, construction of stabilisation features at stock access points and around fishing pegs, changes to behaviour of anglers, conservation of bank vegetation).

Based on observations made during this study, application of the stream power screening tool, channel resurveys and anecdotal evidence from local stakeholders, it appears that the River Eden does have the capacity to recover at least some of the natural geomorphological forms and functions expected in a lowland, meandering river if allowed to do so. Hence, if applied over a longer reach of river, reductions in the intensity and frequency of maintenance operations like those trialled in the middle sub-reach should lead to improvement in the morphological condition of the channel through ‘allowed recovery’. However, the legacy of past capital works is such that ‘allowed recovery’ alone is unlikely to be sufficient to return the stream to a satisfactory condition with respect to the range of physical biotopes, the functional habitats they provide and the ecological status that the river can attain based on its hydromorphology. This is the case because due to the on-going impacts of past channel straightening (bend cut-offs) and bed lowering (incision/over-dredging). In this context, a problem with the recovery of medium/low power systems like the River Eden occurs due to the limited capacity of the flow and sediment regimes to restore natural forms and functions and the long time taken for discernible outcomes to emerge. Therefore:

Recommendation 3: Consideration should be given to river restoration throughout the study site, through interventions attuned to the lowland setting of the watercourse and designed to reinstate the sinuosity and bed elevations of the pre-disturbance channel. Development of more natural in-stream, marginal and riparian morphological features may then be allowed to occur through ‘prompted recovery’.

2.4 RIVER HARBOURNE

2.4.1 Background: the 2002 Flood Alleviation Scheme

The river at the project site was the subject of a flood alleviation scheme 2002 that was designed to provide the required standard of service for flood defence in Harbertonford, while conserving the habitat and aesthetic values of the channel within the settlement. The scheme involved improvements to the channel through the settlement coupled with creation a flood retention basin upstream. Specific flood defence measures within the settlement included lowering flow lines by reducing the height of Crowdy weir and re-aligning a tight bend that was causing excessive head losses, and increasing conveyance capacity by improving the channel beneath the A391 road bridge and alongside the Bow Road. Habitat conservation measures in the flood defence channel within Harbertonford consisted of creating a series of rock riffles spaced at approximately 6 times the width along the channel downstream of the A391 road bridge. Upstream of the village a flood retention area was created through construction of Palmer Dam. The land upstream of the dam was purchased to create a seasonally flooded area within which the channel, riparian corridor and floodplain could re-nature itself and the pasture in the area was replanted for nature conservation.

2.4.2 Region and Valley Description

The catchment characteristics are listed in Table 2.1, which is taken from a Catchment Baseline Survey performed as part of a Fluvial Audit which was performed in 2001 as part of planning and design for the flood alleviation scheme.

Table 2.1 Catchment characteristics (after BDB Associates 2001)

Catchment area	*ca*. 35 km^2 at Harbertonford
Stream length	*ca.* 12km for Harbourne River from source to Harbertonford *ca.* 50km for Harbourne River plus tributaries
Stream order	4th (Strahler); two 3rd order tributaries in the lower reaches, Ashwell Brook and Beenleigh Brook
Relief	Source (SX 695 651) 340m O.D.; Dartmoor National Park Harbertonford (SX 784 562) 40m O.D.; 5m south of Totnes
Topography	Gently sloping ridges dissected by narrow, steep valleys commonly with convex slope segments with angles up to 20^0; limited floodplain
Rainfall	Long term average rainfall ca. 1500mm p.a.
Geology	Upper reach: Upper Devonian slates and thin limestone Lower Devonian Dartmouth slates Volcanic tuffs and lavas Middle reach: Middle Devonian slates and shales Lower reach: Volcanic tuffs and lavas
Soils	Predominantly Trusham Association - typical brown earths/stony clay loams Pockets of Yeollandpark Association - gleyed brown earths/clay loams
Land use	*ca*. 80% grassland - livestock farming *ca*. 15% crops and fallow - maize, cereals, fodder beet *ca*. 5% farm woodland/other Evidence for hedgerow removal

The river rises on Dartmoor (within the National Park) and flows through a valley that is incised into the surrounding moorland. The catchment area is relatively small, but it receives abundant rainfall, including heavy downpours associated with frontal depressions. The steep valley sides, thin soils and impermeable underlying geology make runoff naturally flashy and recent agricultural practices may have exacerbated this behaviour. There is a widespread belief that frequent flooding in Harbertonford in recent years may be related to post World War 2 land use changes involving intensification. The potential exists for climate change to further increase runoff and soil erosion, with implications for downstream flood risk.

2.4.3 River valley, valley sides and floodplain

The river has a continuous floodplain along most of its length, but this is limited laterally by the width of the valley floor and, consequently, the capacity for natural storage of flood waters and sediments in the catchment is also limited. Riparian woodland and buffer zones are narrow because the majority of the floodplain has been converted to pasture. The channel planform is of medium sinuosity, with localised straight sections and actively eroding meander bends. The valley gradient is moderate, with a fall of around 300m along its length. Historically, low stone weirs have been constructed in many places to power mills and these are responsible for local reductions in channel gradient, velocity and stream power in the backwater reaches upstream, and concentrations of velocity and stream power immediately downstream. The river exhibits a dynamic, meandering, and largely unmanaged course, though examination of historical maps indicates slow rates of lateral migration (0 to 1 m/yr).

2.4.4 Catchment wide sediment sources

Given that catchment land use is dominated by improved pasture, it is likely that sediment transport is dominated by sands, silts and clays (wash load) moving in suspension, although the appearance of the bed and the periodic need for gravel removal as part of maintenance of the channel just downstream of the A381 road bridge (prior to the 2002 FAS) indicate that the gravels of the bed are also mobilised frequently. In common with much of the UK, agricultural use of the land appears to have intensified in recent times through, for example, increased stocking densities, under field drainage, expanded cultivation and hedgerow removal. These changes have been shown to lead to reduced infiltration capacity, increased runoff and elevated sediment yields, coupled with channel incision in headwater streams. These land use changes would tend to have promoted quick flow and enhanced both the production of sediment and its delivery to the river. Hence, it is likely that catchment-derived wash load and bed material loads have both increased since intensification.

The channel banks are erosion resistant, due to their cohesive nature and the presence of vegetation along most of their length. However, there are actively eroding bank lines associated with actively migrating meander bends (though migration rates are low) that probably contribute significantly to sediment loads in the River Harbourne.

2.4.5 Study Sub-reach: A381 road bridge to Bow Road

There is no natural floodplain surrounding channel in the study sub-reach as the river flows through the settlement of Harbertonford. Consequently, the channel is artificially disconnected from its floodplain, and encroachment by buildings and infrastructure leaves no opportunities for lateral shifting. The long profile through the study sub-reach is also controlled in places, most obviously by the sill below the A381 road bridge at the upstream limit of the sub-reach and by Crowdy weir in the middle of the sub-reach. The channel has also been re-aligned in the past, mainly in connection with the weir and head works for the leat serving Crowdy Mill. It appears that the channel was straightened and enlarged upstream of the offtake when the weir was built, to improve water availability and the approach conditions to the structure. The re-occurrence of flood events in the village in the late 20th century led to construction of a flood alleviation scheme (FAS) in 2002, which included engineered improvements to the channel through the village so that it can now convey the 5-year flood without inundating properties, larger floods being detained by Parker dam upstream. Hence, the channel is clearly oversized compared to that expected for a 'regime' channel and compared to the channel in the sub-reach upstream.

Hard bank protection along most of the channel has eliminated the ability of the river to shift laterally. The sill beneath the A381 bridge and Crowdy weir has acted to stabilise the bed profile. The channel planform has long been affected by re-alignment to allow floodplain development and exploitation of the river for water power. The channel is in the upstream half of the sub-reach is much wider than would be the case naturally, and even along the Bow Road it is somewhat wider than in the upstream sub-reach, due to past engineering for water power generation and flood control.

In 2002, the morphology of the channel in the downstream sub-reach was directly altered by engineering work performed as part of the flood alleviation scheme (FAS). Specifically, the invert below the A381 road bridge was lowered, to increase the capacity of the bridge to convey flood water, the bed was lowered along between the bridge and Crowdy weir, the elevation of the weir was reduced (the weir was lowered initially as part of the scheme and then it was lowered further following a subsequent flood), an artificially tight bend that was causing excessive energy losses was re-aligned onto a smoother planform, and the channel running alongside the Bow Road was enlarged and stabilised. To enhance the habitats and improve the aesthetics of the new channel, rock riffles were introduced into the reach between the A381 bridge and Crowdy weir. The aims of the FAS were to improve the hydrodynamics and transport of sediment through the sub-reach, to meet the required 5-year flood flow conveyance capacity and reduce the frequency with which gravel extraction is necessary as part of channel maintenance.

Compared to the reaches up and downstream, the channel in the sub-reach is straighter than would be expected, but despite this, historically, the channel has been prone to siltation. Modelling conducted as part of the design process for the FAS revealed that this was due to a combination of the backwater effects of Crowdy weir and excessive energy losses at an artificially tight bend between Crowdy weir and the Bow Road reach. Modelling further indicated that the tendency for siltation would be reduced (though not eliminated) following the FAS and that, consequently, there would be a reduction in the frequency at which gravel extraction would be necessary to maintain the capacity of the channel to convey the 5 year flood.

Local channel and catchment sediment sources have practically been eliminated by channel stabilisation. However, sediment still enters the sub-reach from upstream and from tributaries, drains and urban run-off. In this context, it should be noted that the outlet of the Palmer Dam (the flood detention structure upstream) can convey flows up to the 5 year event with minimal back watering and has been designed to pass gravel and cobbles through it. As in most alluvial streams, around 90% of sediment is transported by flows with return periods of 5 years or less, it should be the case that bed material is still being delivered to the study reach at about the same rate as prior to installation of the FAS and that some gravel extraction may still be needed in future when trigger bed elevations are exceeded. During periods when the bed is recovering from maintenance, gravel supply to the reaches downstream of Harbertonford may be reduced to some degree, although the trap efficiency of this sub-reach is probably quite low.

Clearly, the overall form of the channel has been significantly influenced by the past and recent engineering and management. The river displays a rather rectangular cross-section that is over-sized compared to the channel in the upstream sub-reach and which is flanked by very steep banks formed by masonry walls in many places. If allowed to do so, the channel would probably reduce its cross-sectional area, with a tendency to adjust its dimensions to contain the 2-year flow. The channel would develop riffle bars and berms along the bank lines, built through the deposition of first coarse and later fine sediment, with some recovery of sinuosity. The upper bar and berm surfaces would likely be further stabilised through vegetation colonisation. Clearly, the resulting loss of conveyance for flood flows would be likely to compromise the performance of the channel as a flood defence asset and the risks associated with allowing recovery of a more natural form in this urban sub-reach would be unacceptable in terms of the public interest.

Bed sediment mainly consists of gravel and cobbles, with pockets of finer material in places. Sediment is spatially arranged into riffles and point bar features throughout the study sub-reach. The riffles downstream of the A381 bridge are artificial – being covered by large rock that is grouted into the bed and dressed with gravel. The remains of Crowdy weir act as a riffle, although again one formed in artificially large material. In the middle part of the sub-reach gravel point bars predominate while downstream, alongside Bow Road, the channel features pools and riffles that are weakly, but naturally, developed. There is one middle bar, where the channel first approaches Bow Road. This is emergent at low flows and is topped by dense vegetation during summer.

The channel exhibits a variety of different physical biotopes, including areas of uniform/tranquil, riffled and steep/tumbling flows, and marginal dead water zones. Variability results from a combination of natural and managed processes. For example, the natural deposition of coarse bed material within the flood control channel disrupts the water surface in places. In addition, artificial riffles increase habitat diversity, enhance in-stream ecology and improve aesthetics. Marginal bars that have been colonised by vegetation further improve the range of biotopes in the channel. Bank side trees – some in unmanaged areas, others in gardens, provide shade and root reinforcement of the banks. Overall, the natural and artificial sediment features present in the study sub-reach provide a better range of functional habitats and refugia than might normally be expected in an urban flood alleviation channel.

Both banks throughout this sub-reach are dominated by hard bank protection, which appears to be in good condition. The height of the banks ranges from 0.5 to 2 metres, reflecting the highly urbanised state of the floodplain in this sub-reach. Nevertheless, there are natural sections of bank in front of flood walls and where gardens or unmanaged areas abut the channel. At these locations, the banks feature extensive, dense vegetation including mature trees, interspersed with herbaceous and shrubby plants. The trunks of many of the larger trees are curved, indicating that there has been instability in the banks in the past. However, there is only one area of active erosion – along the left bank upstream of Crowdy weir, where local bank protection at the end of a private garden has failed.

2.4.6 Upstream Sub-Reach: Parker Dam to Harbertonford

The channel in the upstream sub-reach appears to be in a near natural condition that is adjusted to the surrounding valley terrain and flow and sediment regimes. Sediments (sand and pea gravel) freshly deposited on the floodplain and a clear trash line were identified during reconnaissance, indicating a recent overbank flood event. As the recent flow record does not indicate any extreme flows, this suggests that overbank flow is common and that the channel is not incised. The channel meanders across the full width of the floodplain, only being constrained laterally at 3 locations, where it encounters the valley sides. There is no evidence of recent shifting or avulsions in the topography of the floodplain, suggesting that the channel is quite stable laterally.

The channel is markedly smaller than in the study sub-reach downstream, principally because it is narrower. The channel features an irregular, meandering planform with long straight reaches separated by tight, short radius bends. Channel width varies in an irregular manner, with no tendency to be wider at bends (as would be expected in an actively meandering stream). The indications are that lateral activity in the current channel is limited by its small size (meaning that stream power is exported to the floodplain by overbank flows under quite modest events) and the high erosion resistance of its banks (which are cohesive and, for the most part, thickly vegetated).

The bed is formed in gravel and cobbles and it displays a distinct pool/riffle sequence. Deep pools are associated with the outer margins of tight meander bends. In some of the long, straight reaches the bed is more uniform, producing a continuous riffle effect on the flow.

Sediment is supplied to the upstream sub-reach from upstream as the outlet of Palmer Dam was designed to avoid interrupting the sediment transfer system, including the capability to transmit coarse sediment (gravel and cobbles). The presence of fresh overbank deposits in the upper part of the upstream sub-reach demonstrates that abundant finer sediment (sand and pea gravel) certainly passes through the structure.

Within the upstream sub-reach, sediment is sourced from bed scour, re-mobilisation of riffle sediments and erosion of the banks. The supply of sediment from the banks is elevated by the effects of poaching by livestock, especially along the left bank – which has a fragmentary riparian fringe. Poaching is concentrated around stock access points, where destruction of vegetation and localised erosion has allowed concentrated overland flow erosion to create gullies. The eroding water may be rain water drainage from the surrounding floodplain, but could also be river flow returning to the channel during overbank events. There appears to be good sediment connectivity in this sub-reach – both in the long stream direction and between the channel and its floodplain.

This, mainly natural, sub-reach provides a wide range of physical biotopes thanks to its morphological diversity coupled with the variety of vegetation found along the course of the stream. Biotopes include riffles, pools, runs, tumbling flow and dead water zones. Bank vegetation, especially along the right bank, provides tree trunks and branches that trail in the flow to create complex velocity fields. Vegetation also shades the channel in many places, further enhancing in-stream habitats.

The left bank is almost uniformly steep, while the profile of the right bank is more variable, its local value reflecting the planform position of the bank and the type of vegetation on the bank face. In general, the right bank is steep at the outer margins of tight meander bends, where trees growing at mid-bank height provide natural reinforcement. In contrast, the bank slopes more gently along those straight reaches where the riparian fringe is missing and grass extends down the bank face. Both banks vary in height between about 1 and 1.5 m. The floodplain is in pasture – which may have been improved in the past. However, on the day of the reconnaissance the ground was extremely wet and boggy – suggesting poor under drainage. Lack of a riparian fringe makes the bank vulnerable to erosion, especially where water drains over the bank and into the channel. Low spots in the banks – some natural (due to the terrain), but more commonly caused by trampling around places where stock access the channel – exhibit significant gully erosion. It appears that gullying is driven by runoff from the floodplain in combination with overbank flow returning to the channel during and following out of bank events.

Fluvial erosion is concentrated around stock access points and the outer margins of meander bends. However, rates of natural erosion are low – as evidenced by the curved trunks of trees growing at mid-bank heights in places along this bank. Although the relatively high flow stage obscured the bank toe in many places, where the toe was visible there was a surprisingly small amount of sediment stored there. This might be the result of basal clean out during the recent high flow event.

2.4.7 Commentary and recommendations

The River Harbourne at the project site in and upstream of Harbertonford presents the opportunity to assess the impact of major capital works designed to reduce the probability of flooding in the urban settlement while protecting the aesthetics of the riverscape, enhancing in-stream habitats and reducing the need for maintenance in the form of gravel extraction.

The post-project history of flood management in Harbertonford indicates that the scheme as initially constructed did not operate as intended. This is the case because a high flow event in 2003 flooded some properties and threatened others even though it should have been contained within the flood control channel. To address this situation, the crest level of Crowdy Weir was further lowered and this seems to have solved the problem. In summer 2007, discharge rose sufficiently to necessitate operation of the control gate at Parker Dam. When this was not actioned by the Environment Agency, local residents raised the alarm and the necessary gate adjustments were made in time to control the flood and prevent any properties from being inundated. This demonstrates that, provided that active participation in flood management by local residents and stakeholders can be assured, the modified FAS is able to provide the required standard of service for flood defence.

Discussion with residents of Harbertonford during post-project appraisals performed on the flood retention basin in 2002, 2004 and 2006 reveal that the scheme is popular with its beneficiaries. Generally, local stakeholders appreciate the measures taken to conserve the aesthetics of the riverscape and they find the post-project appearance of channel acceptable. Moreover, the flood control channel displays variety of physical biotopes, including areas of uniform/tranquil and steep/tumbling flow, riffles, pools, and marginal dead water zones. The range and types of biotope compare favourably with those in the upstream sub-reach, where riffles, pools, runs, tumbling flow and dead water zones were observed. Hence, the FAS is providing the range of functional habitats intended in the design and found in the sub-reach upstream. One possible area of concern relates to a perceived need for vegetation management, with some people living right next to the river taking matters into their own hands by removing vegetation from the mid-channel bar in the channel approaching Bow Road during summer 2006. It therefore seems that the scheme has been successful in conserving the aesthetic and amenity value of the river within the settlement of Harbertonford.

The third major design aim of the FAS was to reduce the frequency with which gravel extraction and other maintenance operations are necessary in the reach between the A381 road bridge and Crowdy Weir. Historically, shoal accumulation and siltation in pools had often reduced conveyance capacity in the sub-reach necessitating dredging/desilting to maintain the required standard of service for flood defence. This caused repeated damage to benthic and in-stream ecosystems and serious disruption to village life. Since construction of the FAS, and excluding further lowering of Crowdy Weir to correct a design limitation, no maintenance has been necessary in the channel. Inspection of the artificial riffles and intervening bed during this study revealed little or no gravel accumulation on riffles, shoals or marginal bars, while the pools between the riffles appeared to be storing finer material temporarily between transport events - as intended in the FAS design. Downstream, in the Bow Road reach, a single mid-channel bar appears to be being colonised by woody vegetation. This would encourage further accumulation of sediments, including seeds and propagules that would promote stabilisation of the feature and increased flow resistance. It represents, therefore, the one location in the FAS reach where maintenance should be undertaken to ensure that the channel continues to meet the required standard of service for flood control.

Based on the reconnaissance inspections performed in this study, it may be concluded that the FAS is currently achieving its objectives, including those related to sediments, habitats and maintenance. However, it is not yet clear whether gravel is travelling through the study sub-reach, as there have been too few transport events to establish this conclusively and the concerns of residents about colonisation of berms and bars by vegetation must be taken seriously. Therefore:

Recommendation 1: 5 years on from construction, post-project appraisal should now be performed in the study sub-reach to establish whether gravel accumulation and pool filling is significant or is approaching trigger levels for maintenance action to sustain the flood conveyance capacity.

Recommendation 2: the results of computations using the Conveyance Estimation System should be used to investigate the contribution of vegetation to flow resistance in the study sub-reach. On the basis of the results, a strategy for vegetation management should be formulated. Management should ensure that the flood control channel meets the minimum required standard of service, while due regard is given to river aesthetics, habitats and ecology.

The river in the upstream sub-reach is not in a natural, pristine condition being impacted by agricultural land use on its floodplain. It does posses a high degree of morphological diversity and it appears to be functioning adequately in terms of sediment connectivity in the longstream and lateral dimensions. These geomorphological forms and functions provide a good range of biotopes, but there are opportunities for enhancement and reduced maintenance. Therefore:

Recommendation 3: the riparian corridor is currently fragmented and reinstating it would bring multiple benefits. To achieve this it would be necessary to fence off a continuous riparian corridor that is several times the width of the channel, create properly controlled and stabilised stock access points, and construct stable fords.

It is unclear at present whether coarse sediment is moving through the retention basin and Parker Dam in the manner intended in the design of the FAS. In this context, it is vital to restoring long stream connectivity in the sediment transport system that this part of the scheme is operating as intended. Therefore:

Recommendation 4: gravel and cobble movement through the flood basin, Parker Dam and the upstream sub-reach should be monitored with the option of managing bedload dynamics adaptively if this is required to achieve long stream connectivity in the fluvial system.

2.5 RIVER KENT

2.5.1 Background

The context for this project site is that flood defence and, subsequently, habitat improvement works were performed upstream of and through the town of Kendal in 1970s and management of the coarse load and gravel bars in the upstream sub-reaches is on-going as part of maintenance performed to ensure that the channel provides the required standard of service for flood defence.

2.5.2 Region Description

The River Kent rises in the Lake District National Park, where it flows through the town of Kendal before reaching the Irish Sea at Heversham. It drains the Borrowdale Volcanic geology of the central Lake District Dome, with most of the upper and middle catchment flowing on Silurian slates and gritstones. Below Kendal the solid geology is limestone. Structurally, the area is intensely folded and faulted.

The catchment is characterised by its ancient glacial legacy (glaciated valleys, terraces, drift deposits, drumlins and moraines) and its recent industrial history, with mining in the upper reaches (quarries, spoil heaps), water mills in the middle and lower reaches (weirs, control structures and leats) and extensive channelisation (for flood defence and land drainage). The planform pattern and potential for lateral shifting of the channel are constrained along most of the length of the river either naturally (by high river terraces and drumlins) or artificially (by channelisation, hydraulic structures or embankments). Consequently, the scope for the channel to adjust to the action of natural channel processes is restricted.

The yields of both coarse and fine-grained sediment from the catchment are high naturally due to effects of heavy precipitation on the steep and relatively unstable terrain. Yields have been further elevated anthropogenically, through land management problems (over-grazing, poaching due to uncontrolled access to the banks by stock, damage by visitors to the National Park through trampling etc.) and site-specific impacts (mining spoil) at a number of key locations. Mining waste continues to constitute a significant source of coarse sediment in some reaches of the river, while bank erosion in those reaches are able to shift laterally supplies both fine and coarse sediment to the river.

2.5.3 Catchment and valley description

In the project area, the river is characterised by its high stream power, which results from the steep gradient and abundant runoff. The high transport capacity of the flow, coupled with the high yield of sediment from the catchment, produce substantial sediment loads that lead to active reworking of sediments residing temporarily in the channel (in bars) and stored in system as floodplain deposits. The channel is in many places coupled closely to the surrounding, upland terrain. This provides extensive scope for geomorphic work through landslides and other less violent but highly efficient slope processes, such as slope wash and soil creep.

The study area is located immediately downstream of the confluences of the River Mint and River Sprint tributaries. The Mint particularly is geomorphologically active and adds significant amounts of sediment to the River Kent. The River Kent is also coupled to the slopes of its valley side walls in places, although channelisation and the construction of flood embankments have reduced the length of channel along which the modern river interacts with the valley sides.

2.5.4 Catchment sediment sources

Catchment sediment sources include reworking of sediments in previously mined areas upstream, runoff from agricultural areas, erosion of valley side slopes and terraces, bed incision in reaches channelised or embanked for flood defence purposes, and inputs from tributaries. In this last respect, the River Mint is especially important, as it confluences the River Kent at the upstream limit of the study area.

Parts of the catchment feature improved pasture for intensive sheep farming (which is known to elevate runoff and sediment yields) while along significant lengths of the Kent and some of its tributaries uncontrolled livestock access has resulted in significant bank erosion through trampling and poaching of the river banks.

These factors result in abundant sediment entering the channel from erosion that extends across a large percentage of the catchment and which is particularly effective during major flow events, when in-stream, floodplain, colluvial and artificial (mine spoil) stores of sediment are extensively reworked, and slopes throughout the catchment are heavily destabilised by processes such as landsliding, sheet wash, rilling and gullying.

However, the sediment transfer system in the River Kent is complex and there are significant sediment sinks at intermediate points in the fluvial system. These include natural and artificial lakes as well as opportunities for sediment to be stored on the floodplain, due to deposition during overbank flow events, in those reaches where flooding is not prevented by naturally high terraces or artificial embankments. In this context, it is important when considering how sediment sources and sinks may be linked, to establish the degree to which sediment connectivity exists in the fluvial system. For example, Kent Mere Tarn and the gravel trap immediately upstream of Kendal both act to punctuate the sediment transfer system, at least for coarse sediments moving as bedload or near-bed suspended load, and in this respect sediment pathways through the drainage system are discontinuous.

The size distribution of sediment supplied to the river channel is strongly bimodal. The coarse fraction consists of coarse material in the gravel and cobble size ranges derived from bed scour, bank erosion and valley floor reworking. The fine fraction consists of silts and clays derived from erosion in agricultural fields, on slopes and along stream banks.

2.5.5 Upstream study sub-reach: Gravel Trap to Victoria Bridge

Several trash lines and overbank sediment deposits provide evidence that out of bank flows do occur in this sub-reach. The bed profile is controlled by bedrock outcrops and very large boulders that have fallen into the channel where it runs at the foot of a steep, potentially unstable, valley side slope. Prior to artificial stabilisation, fluvial processes undercut the cliff, and weathering then resulted in boulders falling into the river. These boulders have subsequently remained in place in the channel due to lack of a mega-flood of sufficient magnitude to entrain and carry them downstream. The presence of rock outcrops and boulders has a stabilising effect, effectively preventing degradation. The evidence suggests that, though the river may have experienced marked vertical instability in the past, at present it is neither incising nor aggrading in this sub-reach.

Outcrops of rock in the valley sides, together with artificial rock revetments and embankments, also control lateral shifting of the river at many points, resulting in the channel being effectively constrained throughout this sub-reach.

The planform in this sub-reach features a single thread, sinuous channel that has been re-aligned in places. It is apparent from inspection and discussion with EA staff that, despite the presence of a gravel trap in the upstream part of the sub-reach, the sediment load in this sub-reach is still high. Where the banks are formed in mainly non-cohesive materials and, in places, those banks that are unprotected are eroding. This is especially the case immediately upstream of the sub-reach, around the Mint confluence, where poaching by livestock has exacerbated the situation, leading to elevated rates of bank retreat. More generally, mature trees along both banks provide a degree of natural protection from erosion.

The geomorphology of the channel has been influenced by previous primary industries (mining, milling and farming), and it continues to be affected by management actions, including the gravel trap. This trap is intended to reduce the supply of sediment into the middle (urban) study reach downstream and so reduce the frequency with which maintenance is needed. However, EA staff present during the reconnaissance visit (Mike Fell and David Brown) estimate the efficiency of the trap in retaining gravel as 50-70%, depending on how much gravel has accumulated in the trap since it was last emptied. Trap efficiency will be much lower for the fine fraction of the sediment load. Within Kendal, gravel is extracted to manage the heights of gravel bars in the urban reach, with the aim of maintaining the conveyance capacity of the flood control channel at the level required to meet the required standard of service. The fact that gravel extraction is on-going proves that coarse gravel is still continuing to be transported through this sub-reach and into the middle (urban) study sub-reach.

The high energy of the flow in this sub-reach interacts with the significant load of coarse sediment, to produce a range of in-channel bars. In the downstream part of the sub-reach, bar heights are periodically reduced by gravel extraction, but they are then rebuilt during subsequent transport events that deliver more gravel.

Flow variability in the sub-reach is high, being associated with the frequent bedrock outcrops, boulders and gravel bars. Consequently, the sub-reach exhibits varied flow types, mainly consisting of areas of uniform/tranquil flow interspersed with areas of steep/tumbling water. The river displays a variety of physical biotopes including broken standing waves, rippled flows, steep/tumbling and uniform/tranquil flows.

The left bank has artificial bank protection with geometrically simple bank profiles along much of its length in this sub-reach. Heavy, structural protection is required to prevent bank retreat from threatening adjacent flood embankments, an industrial estate and urban development. Where the embankment that protects the industrial estate is slightly set-back (in the vicinity of the gravel trap), this allows more floodplain conveyance and negates the need to armour the bank. The left bank within this area ranges from 1m to 2m in height and is formed in non-cohesive material, consisting of a cobble/gravel matrix with isolated boulders with sand filling the intestacies. Vegetation in the vicinity of the gravel trap is non-existent; but a narrow band of riparian vegetation exists along the sub-reach between the gravel-trap and the urban area of Kendal. This riparian fringe consists of herbaceous and shrubby plants, covering the whole bank profile, together with mature, deciduous trees that appear to be healthy. However, even this narrow riparian band has been artificially removed to improve the conveyance capacity of the flood control channel approaching Kendal.

Overall, the left bank appeared to be stable downstream of the Mint confluence. However, lateral gravel bars are forming along the left bank in some areas, suggesting that bank accretion through the growth of attached point bars would occur if gravel trapping and extraction were to cease. This would be expected because depositional centres such as bars usually expand in response to an increase in sediment supply.

The right bank is also heavily protected along most of this sub-reach. In the upper part of the sub-reach, immediately downstream of the gravel trap, the right bank is very steep (vertical in places), and is approximately 3m high, where the river encounters the valley side and makes an abrupt left turn. The bankline here is stabilised by a large rock revetment.

In the middle part of the sub-reach, the bank is not as high and is slightly less steep, being backed by an area of former floodplain that provides space for several private houses. Hard bank protection, using a variety of materials, and an embankment have been implemented along this part of the sub-reach to reduce the risk of flooding to the properties and to maintain a stable bankline. The hard protection is continued into the urban area of Kendal in the form of masonry block walling that extends along the riverside path all the way downstream to Victoria Bridge.

As was the case for the left bank, the right bank throughout most of the sub-reach is in a stable, intact condition. There is slight displacement of the rock within some of the revetments and, historically, boulders have fallen from the rock face exposed in the right valley side where, in the past, it was actively undercut by the channel. Vegetation along the top of the bank is extensive, consisting of grasses/flora mixed with herbaceous and shrubby plants and some trees, except where the floodplain has been covered in tarmac as a walk way.

2.5.6 Middle study sub-reach: Stramongate Bridge to Romney Bridge

Exposure of bedrock outcrops, coupled with a series of weirs constructed as part of flood defence works for Kendal has stabilised the long profile of the River Kent throughout this sub-reach. Hard bank protection along extensive lengths of the channel and, especially, around in-channel structures has eliminated the ability of the river to shift laterally. The planform has long been affected by re-alignment to allow floodplain development.

In the urban area of Kendal buildings, roads, paths and other infrastructure are located at the channel edge along both banks. Compared to the reaches up and downstream, the re-aligned channel is straighter than would be expected. The channel has been enlarged to convey floods and appears too deep and wide for the flow and sediment regimes. If allowed to adjust, the river channel would silt and narrow through vertical and lateral accretion of sediment in middle and point bars.

Local channel and catchment sediment sources have largely been eliminated by urbanisation and channel stabilisation. However, sediment still enters the sub-reach from upstream and from urban run-off. While the supply of coarse sediment (gravel and cobbles) from upstream must be diminished by the gravel trap, it is evident that a high bedload is still being delivered because gravel bars continue to grow in height, representing a perceived risk to the operation of the flood defence channel that triggers gravel extraction when trigger elevations are exceeded and some reduction in the supply of gravel to the reaches downstream of Kendal.

The geomorphology of the river is significantly influenced by the past and current channel management. The channel has a deep (approximately 2m in places), rectangular, over wide channel.

Bed sediment is mainly gravel and cobbles, with exposed bed rock outcropping in places. Sediment is spatially arranged into middle and point bar features. The larger gravel bars are frequently reduced in height down close to the water level because of the perceived increase they cause in flood risk. In the upper part of the sub-reach the extent and height of gravel bars is greater, compared to downstream, and the sediment sizes appear to reduce significantly approaching Romney Bridge.

The channel exhibits uniform/tranquil, rippled and steep/tumbling flows. Variability results from a combination of natural and managed processes. For example, the natural deposition of coarse bed material within the flood control channel disrupts the water surface in places. In addition, following the completion of the flood defence scheme, large boulders were placed in the channel to enhance ecology. These boulders increase the range of functional habitats and refugia.

Both banks are artificially protected, and appear to be very good condition with no areas of instability. Bank heights range from 2 – 4 metres. Overall, vegetation cover is more extensive on the left bank including occasional mature trees, interspersed with herbaceous and shrubby plants. For part of its length, the left bank is formed in a park area (formerly the town ‘pitch and put’ course), which provides a narrow riparian buffer between the river channel and the road way.

2.5.7 Downstream Sub-reach: Downstream of Helsington Weir

Both natural and artificial bed controls exist within this sub-reach, in the form of bedrock outcrops, and a weir plus artificially placed stone, respectively. The bedrock outcrops suggest that the channel has incised through the valley fill (glacial and alluvial deposits), but also indicate that further incision of the river would be a very slow process. Helsington Weir, at the upstream limit of the sub-reach, and the introduction of placed stone in the bed both act to stabilise the long profile. The presence of placed stone suggests that local scour may have caused problems in the past. There are no signs of lateral channel movement. The river has a meandering planform, but the bends appear in places to be locked in place through interaction with the valley sides. It may be concluded that the channel in the downstream sub-reach is stable, due to a combination of geological, topographic and anthropogenic controls.

The River Kent within this sub-reach has a relatively natural morphology when it is compared to the sub-reaches upstream. A significant amount of coarse sediment is stored in a lateral bar that extends along the right bank, downstream of the weir. This may have been released from long-term storage behind the weir as its condition has deteriorated due to lack of maintenance. However, bank erosion and bed scour at the channel margins (especially at the outside of bends) are the primary sediment sources for this sub-reach.

The river in this sub-reach flows through a mainly rural area, and there is significant channel-slope coupling, especially on the left descending bank. The surrounding land-use is improved pasture, with intensive livestock grazing in parts. The terrain is particularly steep and therefore the energy available for geomorphic work is high. The riparian corridor is narrow and highly fragmented, with agricultural activities encroaching right up to the channel margins in places. There are no artificial bank protection measures or embankments and so the river is hydrologically and morphologically connected with its floodplain, reducing the buffering capacity of the channel from agricultural runoff, fine sediment delivery and agri-chemicals.

Catchment sediment sources are mainly associated with sediment transport from upstream (though it is unclear how much coarse sediment travels through the urban reach upstream), together with local inputs from tributaries and agricultural drainage.

In-channel sediment storage within this sub-reach is quite extensive, mainly consisting of the gravel/cobble sized particles, with some fine gravel/silt storage at the channel margins and in slack water areas. The bars are vegetated to various degrees, indicating that the upper, exposed parts of bars in this river are naturally colonised by vegetation if they are stable for any substantial period of time.

The channel displays a greater variety of in-channel bed and bar features than in the urban reaches. However, geomorphology is unnatural due to the effects of Helsington weir and the associated channel stabilisation measures. Away from the weir, flow is largely uniform and tranquil, with some tumbling flow over and around the bars. Dead water zones are associated with bar accretion and merging along the right bank that is creating localised pool habitats.

The left bank is highly unstable just downstream of the weir. Generally, the bank there is nearly vertical and formed in weakly-cohesive sediment, making it prone to fluvial erosion and mass failure. The bank is located at the outer margin of a bend and appears to have experienced retreat through fluvial undercutting followed by collapse of the over-steepened bank. The steep bank profiles are only sparsely vegetated, with only grasses and flora being present along the bank top. This retreating bank may be providing a significant source of sediment supply to the river. Some attempt had been made to mitigate bank retreat by placing large boulders in front of the section experiencing toe scour.

Further downstream the channel is located against the valley side, and the left bank is both steep and high (approximately 3m). In this area the bank is thickly vegetated with a cover of mature trees and herbaceous and shrubby plants, but some of the mature trees are leaning towards the channel, possibly indicating that the valley side at this point is unstable geotechnically. Further evidence of instability in the valley side where it is actively interacting the river through slope-channel coupling is the presence of large boulders at the toe of the bank slope. These boulders are too large to have been carried to the site by the flow, but have remained *in situ* after falling from the slope above. This suggests that the slope weathering and failure by rock fall have occurred in the past and it is possible that the slope is still active geomorphologically.

The right bank immediately downstream of Helsington Weir has been artificially constructed. It is relatively high and has a very extensive grass cover, which seems to be maintained by sheep grazing and appears relatively stable. Downstream the right bank consists of simple gentle slopes, giving easy stock access to the watercourse. As a result the right bank has been poached and trampled by stock. Consequently, the bank is devoid of extensive vegetation, but there is a significant amount of sediment stored along the right toe, which lies at the inner margin of a meander bend in this part of the downstream sub-reach.

2.5.8 Commentary and recommendations

The sediment transfer system in the River Kent is complex and is made up of multiple sediment source, transfer and storage reaches. Broad scale modelling of the sediment transfer system in the River Kent (using SIAM and REAS from the FRMRC sediment toolbox: see www.floodrisk.org.uk for details and publications) shows that there are significant sediment sinks at intermediate points in the fluvial system, which punctuate sediment movement from headwater sources to the coast. These include natural features of the glacio-fluvial landscape as well as artificial features related to primary industries and river management. It is important to consider the study sub-reaches within this wider context. Particularly, it appears that sediment sinks along the River Kent may disconnect headwater and upstream sources from the study reaches, indicating that the coarse sediments deposited in the flood control channel may be sourced more locally. In this respect, the River Mint may be a source that supplies significant quantities of coarse and fine sediment into the upstream study sub-reach. Therefore:

Recommendation 1: further investigations should be performed to identify the sediment sources responsible for supplying coarse material to the study reaches as a first step in considering 'sediment source control' as an alternative maintenance strategy to gravel trapping and extraction. Source control should be more sustainable, according to Defra guidance in 'Making Space for Water'.

While achieving sediment connectivity in the fluvial system is a factor in attaining good ecological status in a water body, in planning river management generally and the programmes of measures required to achieve good ecological status or maximum ecological potential by 2015 (and so avoid fines or other sanctions) in particular, it is also important to consider how sediment sources and sinks occur and are linked in the system in question *naturally*. For example, Kent Mere Tarn and the gravel trap immediately upstream of Kendal both act to punctuate the sediment transfer system, at least for coarse sediments moving as bedload or near-bed suspended load, and in this respect sediment pathways through the River Kent drainage system are discontinuous not only because of artificial interventions in the fluvial system. This should be borne in mind when planning the changes to maintenance activities in the study reach that are now necessary under English environmental law. These changes will be geared either to achieving maximum ecological potential should the watercourse be declared to be 'heavily modified' or will seek to achieve good ecological status if the River Kent is not declared to be heavily modified. In either case, there will changes to the maintenance regime.

This is the case because during periods when the gravel trap is retaining sediment and bars are rebuilding following gravel extraction, gravel supply to the reaches downstream of Kendal must be curtailed to some degree. Only when the trap efficiency of the gravel trap decreases as it fills and bar heights approach their equilibrium values would accumulation begin to be replaced by reworking, to provide a significant source of coarse sediment to downstream reaches. Hence, maintenance must to some extent disrupt long stream sediment connectivity and transfer in the fluvial system.

Within the study reaches, in-channel structures and bank protection affect hydrodynamics and the sourcing, transport and storage of sediment within each sub-reach. In its current condition, the channel in the middle sub-reach lacks the morphological complexity and range of physical biotopes present in the downstream sub-reach and other more natural reaches upstream. It is difficult to say how much geomorphological processes and morphological diversity are affected by sediment depletion due to coarse sediment being retained in the gravel trap and extracted from the study sub-reaches. This also makes it difficult to predict how biotope diversity would respond if sediment management practices were modified or ceased entirely. This is the case because biotopes depend on complex interactions between meso-scale controls such as the channel planform, channel gradient and flow regime, and local controls such as bar elevation, bed topography and disruption of the flow field by isolated boulders.

Probably, the bars would grow in elevation and extent for some way before re-working during medium and high flow events resulted in the bars establishing a new equilibrium height. This would result in some loss of flood conveyance capacity due to increased bar and vegetation roughness.

The wider morphological outcomes of a reduction in gravel extraction or some degree of allowed recovery in the channel would probably involve development of a 'two-stage' or compound cross-sectional shape, with an inner 'regime' channel adjusted to the prevailing inputs of water and sediment under 2 to 5-years flows, inset within the larger floodway. The inner channel would be flanked by attached bars and berms built through the deposition of first coarse and later fine sediment along one or both banks. The upper bar and berm surfaces would likely be further stabilised through vegetation colonisation and would, in time, acquire the attributes of a proto-floodplain, unless managed to prevent this. These wider morphological changes would also tend to reduce the conveyance capacity for water (while increasing it for sediment) with implications for flood risk management.

Clearly, the loss of conveyance for flood flows due to bar growth and channel evolution might compromise the performance of the channel as a flood defence asset and the risks associated with allowing recovery of a more natural form in this heavily urbanised sub-reach would have to be investigated very carefully. The conclusion reached based on geomorphological investigation of the study reaches (within the wider context provided by catchment, fluvial and sediment transfer studies) is that multi-dimensional, mobile boundary, hydrodynamic modelling (including large eddy simulation and sediment transport) would be necessary to assess the impact of bar growth on flood capacity is necessary to assess the response of the River Kent in the study reaches to a change in maintenance regime. This is the case because the meandering planform, variable, three dimensional geometry of the bars, the heavy interaction between bars, widely graded sediment load and vegetation during high flow events, and generation of deadwater zones by large eddies with vertical axes at various points in the channel (observed directly in the field reconnaissance) mean that the results of 1-dimensional models and conveyance estimation techniques are useful but indicative. Therefore:

Recommendation 2: the need to manage flood risk in Kendal while also achieving the environmental standards required under WFD raise questions that cannot be answered fully using the models and approaches routinely applied by consultants engaged by the Environment Agency. The Kent and Kendal has been a high profile example of the tensions between environmental management and flood defence for decades and this is unlikely to change in the future. Hence, the site should be used as the vehicle for advanced research into how apparent conflicts between the needs of people and the environment can best be resolved during an era of rapid climate change and socio-economic growth. Research should focus on achieving goals for flood risk management (using non-structural measures as well as hard defences) sustainably – including achieving statutory goals for environmental standards.

3. General Conclusions

The recommendations and conclusions relevant for each project site are included with the summary geomorphological descriptions. In this section of the annex the wider messages stemming from the geomorphological element of the project are summarised in relation to the relevant objectives of the project as a whole.

Objective 1: Impacts, benefits and influences of maintenance on sediment and habitat features

On-site impacts

The impacts of maintenance have been found to be detrimental to the geomorphology of the watercourses at the project sites. When comparing the study reaches to more natural reaches nearby it emerged that the maintenance as practiced currently leads to:

- simpler channel geometries;
- reduced morphological diversity;

than would be expected in a natural channel with the same flow and sediment regimes, boundary characteristics and catchment context.

The geomorphological impacts of maintenance have been demonstrated to result in:

- Less desirable physical biotopes in study compared to control reaches;

- A narrower range of physical biotopes in study compared to control reaches.

Off-site impacts

While the geomorphological impacts of maintenance are strongest and most direct in the channel where the disturbance actually takes place, indirect impacts occur off site, both up and, especially, downstream as well.

Downstream impacts occur primarily due to disruption of continuity and connectivity in sediment transfer system. Sediment connectivity is a major element in the hydromorphological assessment of waterbodies that is performed when establishing their ecological status for WFD purposes. There are two dimensions to sediment connectivity: lateral and longstream. Maintenance activities or capital works that isolate the channel from its floodplain preclude sediment transfer/exchange laterally, leading to on-site impacts that are usually adverse. Maintenance or capital works that prevent the downstream transfer of sediment disrupt or punctuate long stream connectivity. A major risk is that sediment removal or retention in a reach subject to maintenance or capital works may lead to:

- reduction or elimination of the sediment supply to reaches downstream;
- sediment depletion or starvation in downstream reaches;
- channel instability through bed scour, bar loss, degradation, width change, changes in migration rate or planform metamorphosis;
- damage to infrastructure (including flood defences);
- detrimental impacts on in-stream, riparian and floodplain environments and ecosystems.

Response of the watercourse to downstream impacts depends on the catchment context. For example, if gravel is trapped or removed by maintenance in a gravel sink reach close to the downstream limit for gravel transport, downstream response will be muted or insignificant. Conversely, if sediment is retained or extracted upstream of a transfer reach, this may trigger coarsening of the bed or even degradation, and habitat loss.

As maintenance is performed periodically rather than continuously, it introduced unnatural variations into the dynamics of sediments, with the potential for sediment slugs to be generated when large events flush through sediment that has accumulated in a flood control channel but not yet reached a trigger level for mechanical removal from the maintained reach. This sediment is more mobile than would otherwise be the case due to its loose state and the lack of vegetation to bind it. Generation of sediment slugs will impact downstream reaches and may lead to:

- unnatural elevation of the sediment supply to reaches downstream;
- sediment over loading in downstream reaches;
- channel instability through pool/bar accretion, aggradation, width change, changes in migration rate or planform metamorphosis;
- damage to infrastructure (including flood defences);
- detrimental impacts on in-stream, riparian and floodplain environments and ecosystems.

Upstream impacts may also occur depending on the hydrodynamics of the waterbody affected. For example, steepening of the energy slope approaching the maintained reach may increase sediment transport potential and so trigger an imbalance between sediment supply and transport upstream of the project reach. Conversely, the construction of control structures may reduce the energy slope, leading to sediment accumulation in the reach affected by backwater the effect.

Objective 2: Recovery and self regulation of sediment processes

The response of geomorphological processes, forms and functions to modification or cessation of maintenance depends broadly on the catchment context and condition of the fluvial system. More specifically, the potential for geomorphological recovery is conditioned by the:

- sediment supply from upstream,
- stream power available in the project reach,
- erodibility/transportability of the bed and bank materials,
- presence of any natural or artificial constraints on channel adjustment (vertical, lateral, planform),
- the space available to the river within which the channel may evolve.

Typical changes to sediment processes and channel morphology that occur during recovery include:

- deposition at channel margins to build continuous or discontinuous berms along the toe or one or both banks,
- accumulation of failed bank materials as benches at the toe or one or both banks,
- growth of point, middle and side bars through deposition of sediment supplied from upstream,
- development of riffles in coarser bedded watercourses,
- fines deposition and stabilisation of berm, bench and bar surfaces due to colonisation by vegetation,

- accumulation of woody ‘debris’ that creates flow and morphological diversity, enhances sediment storage capacity and provides habitats,
- concentration of flow by sediment and vegetative features to sustain a low flow channel within a larger flood control channel, scouring away fines in the bed and revealing the coarser substrate.

In attaining a new self-regulating condition the role of vegetation and its interactions with hydraulics, morphology and sediment dynamics is crucial in rivers of all types and stream powers. This is most obviously the case in low energy systems, but evidence from this and other recent studies demonstrates the importance of vegetation in high power systems as well. Vegetation has been termed a ‘geomorphological engineer’ (Professor Angela Gurnell, personal communication, 2008) and a better understanding the interactions between live and dead vegetation is needed to optimise maintenance practices and management of channel recovery processes in multi-functional channels.

The outcomes of recovery include:

- increased morphological complexity and diversity,
- reconnection to the adjacent floodplain (if there is one)
- improvement in downstream connectivity in the fluvial system,
- increased capacity of the channel to remobilise and transfer sediments during floods,
- improvement in the capacity of the channel to store sediments and woody debris in organised sediment features between transport events,
- increased retention of woody debris jams,
- reduced in-channel capacity to convey floods,
- increased flood flow and storage on the floodplain (depending on constraints left in place),
- increased value and range of morphologically-related physical biotopes and functional habitats.

It must be understood that the ‘self sustaining’ condition attained in a channel recovering from maintenance will be geomorphologically dynamic. Periodic and sometimes marked morphological adjustments may continue as the channel responds to the sequence of channel forming events that it experiences. This is the case because in alluvial (self formed and adjusting) streams, even the equilibrium condition that the recovering channel approaches is meta-stable, meaning that the channel will continue to evolve in perpetuity. The best way to accommodate this condition is by ‘making space for the river’, as advised in the latest Defra guidance and promoted by advocates of sustainable river management nationally and internationally. Some low power and heavily modified channels lack the capacity to recover without further structural interventions because they lack the energy to erode their boundaries and/or the sediment supply to build in-channel features. Under these circumstances, recovery is likely to be too slow as to be perceptible and some form of ‘prompted recovery’ will be necessary.

It follows that potential for recovery of more natural attributes in a maintained is limited mainly by the constraints on its geomorphological functioning that remain after maintenance has been modified or ceased. These depend on the other on-going functions required of the channel in the project reach (for example, flood control or land drainage) site and the catchment context (defined by conditions and functions in the wider catchment and fluvial system). For example, the potential for recovery in watercourses flowing through urban areas and high value agricultural land is likely to be constrained by on-going flood defence and land drainage functions. Hence, when assessing the potential for recovery, it is essential to establish clear goals for multi-functional management of the project reach and to ensure that these are consistent with goals for the watercourse as a whole – as set out in the relevant Catchment Flood Management Plan (CFMP).

Objective 4: New approaches to maintenance and channel design

The sub-reaches compared and contrasted in this study reveal encouraging evidence that new, more environmentally-aligned approaches to maintenance can be effective in allowing partial recovery in alluvial watercourses. In this context, the degree of recovery and the environmental benefits achieved depend primarily on the degree to which reductions in channel conveyance capacity and land drainage efficacy compromise the flood defence and land drainage functions of the channel. In designing new approaches to channel maintenance it is therefore vital to take a multi-functional approach, with maintenance designed to be sustainable in terms of value for money, the needs of society and environmental legislation.

In this study, investigation of the River Harbourne at Harbertonford has highlighted the potential for new approaches to the design of flood control channels to meet multi-functional goals in sustainable river management. It emerges that the Flood Alleviation Scheme (FAS) is achieving its aims for flood defence, aesthetics, habitats and low maintenance, although as the scheme has only been in place for 6 years it is as yet too early to declare it a complete success.

Nevertheless, the results of the geomorphological investigation at Harbertonford suggest that it is possible to design capital works in a multi-functional way provided that environmental and habitat features are designed in from the outset. In this context, new build offers much better opportunities than attempting to retro-fit habitat features to existing flood defence channels.

Objective 6: Adaptive management of flood control and restored channels

Recent research on the prediction of channel response to changes in climate, land use or maintenance performed under this project and by the Flood Risk Management Research Consortium (www.floodrisk.org.uk) has demonstrated that future morphological adjustments cannot be predicted deterministically over anything but the shortest time scales due to the stochastic nature of channel forming events. The only possible conclusion to be drawn from this finding is that the management of maintained and restored channels must be adaptive.

In terms of geomorphology, the basis for adaptive management lies in post-project appraisal (PPA). PPA relies on monitoring and so monitoring programmes must be put in place for all maintained and restored watercourses. However, monitoring must be linked first to appraisal, to identify unanticipated adjustments/changes early in their development, and second to effective mechanisms for invoking adaptive management actions that deal with unanticipated developments before they cause problems to the key functions of the watercourse (such as land drainage, flood control, conservation, recreation).

Appendix 7 Sediment management

1. Introduction

1.1 AIMS

Different forms of sediment management are carried out within watercourses in England and Wales either to maintain the conveyance of the channel or to prevent excessive erosion. The sediment management may take different forms depending upon the nature of the river system.

Sediment related features occur naturally in alluvial channels and are responsible for providing the wide range of habitats that are to be found in rivers. Their presence may not have a significant effect on channel conveyance, indeed, in some cases the presence of local bed features may increase channel conveyance. Sediment features will only begin to affect the channel conveyance if they occupy a significant portion of the channel over a significant distance. There should only be a need to carry out sediment removal for flood risk management purposes if the overall channel conveyance is affected and if such removal is the only means of achieving an acceptable flood risk. It is important in terms of flood risk management that the floodplain and channel system is considered as a whole. Thus control of flood risk may be achieved by using floodplain management in addition to in-channel works rather than just in-channel works alone. It also needs to be considered that sediment removal at one location will affect the channel upstream and downstream. Lowering the bed level at one location increases the upstream bed slope and hence increases sediment transport and may cause erosion while downstream the sediment supply is reduced potentially also causing erosion.

The removal of sediment causes an immediate disturbance to the area and may lead to the release of fine sediment downstream. This can have a significant impact on habitats downstream, see Appendix 8. The removal of sediment features alters the normally results in a more uniform channel shape. This results in a reduced flow diversity in terms of the range of flow velocities and depths. Removal of sediment also alters lowers the water level and hence alters the relationship between water level and any remaining sediment features. This can have a significant impact on their habitat value.

In some locations sediment erosion can be an issue as it may threaten structures adjacent to or in the river and may precipitate bank failures. Stabilising the river bed level to inhibit bed erosion may reduce the sediment transport rate downstream and so initiate erosion downstream.

The aims of the work related to sediment management were:

a) to understand more on how sediment management influences sediment movement
b) to understand more about how changes in sediment management may impact on flood risk
c) to investigate the potential impact of capital works on sediment movement.

1.2 DATA COLLECTION

In addition to the collection of data for the hydraulic modelling, as part of this work, bed sediment data was collected for the sites. This was a coordinated effort by this project and the Flood Risk Management Research Consortium (FRMRC) and their efforts are gratefully acknowledged. The FRMRC project also carried out modelling of longer reaches of some of the rivers in which the present project reaches were embedded. This provided a valuable insight into the setting of sediment boundary conditions for the present studies.

1.3 MODELLING APPROACH

To understand more about the impact of sediment management numerical models were used to predict the movement of sediment through the reaches and the impact of changes either to the management regime or the channel. A number of different numerical models were used depending upon the nature of the problem that was being investigated. Infoworks RS was used to investigate the long-term development of bed levels and the corresponding impact on flood risk. The Conveyance Estimations System (CES) was used to investigate the impact on lateral velocity distribution and using SHARC the impact of changes in the velocity distribution on sediment transport of different management strategies was investigated.

2. Long Eau

2.1 BED SEDIMENT SAMPLING

The project took three bed sediment samples from the Long Eau and details of these are given in Annex 1. The results show that the sediment in the Long Eau is generally fine but with a sand component and that the size of the sediment is spatially variable. This is consistent with the low energy nature of the river.

2.2 NUMERICAL SEDIMENT MODELLING

An Infoworks RS model was set up to simulate flow and sediment movement within the river system. The model was based on the available cross-sections. It is clear from the longitudinal bed profile shown in Figure 2.1 that the cross-section spacing was too large to pick up all the artificial riffles in the reach but the cross-sections do appear to include two riffles at chainages of approximately 1,200 m and 2,000 m. It is noticeable that the cross-sections do not reflect all the riffles in the lower part of the reach.

In the Infoworks model the riffles were represented as 'Hard beds' in which the level of the bed cannot be lowered below its initial value. Figure 2.1 shows a longitudinal profile of bed levels showing the initial bed profile and the model predicted bed levels after a period of 7 years. This shows some limited sediment accumulation during the period but there is only a limited change in bed levels.

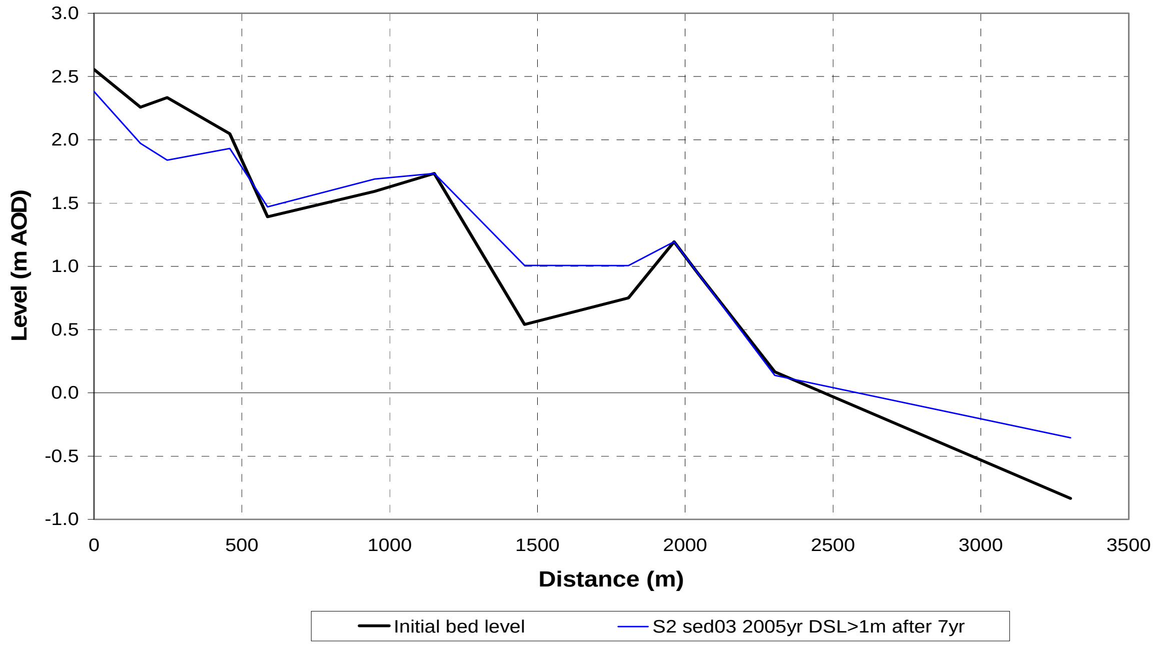


Figure 2.1 Long Eau, longitudinal profile of initial bed levels and model predicted bed levels after 7 years

The analysis described in Section 7 below indicates that during the summer period the amount of sediment transport depends upon the amount of the vegetation cutting that takes place with the sediment transport rate increasing as a greater proportion of the channel width is cut. Analysis of the distribution of sediment transport through the year showed, however, that over 94% of the annual sediment movement took place during the winter period when vegetation growth is low. In this situation the nature of vegetation management during the summer is unlikely to impact significantly on the overall annual sediment movement or deposition within the channel. For sediment that is deposited during the summer period, however, the nature and distribution of vegetation cutting is likely to influence the locations of local areas of sediment deposition. As shown in Section 7, the amount of vegetation cutting affects the nature of the flow and will influence local sediment transport. Thus sediment is more likely to deposit in marginal areas where vegetation has been left than in areas where the vegetation has been cut. Leaving the same areas uncut each year will encourage sedimentation in those particular locations.

From the model results it is not clear that the numerical model is fully representing the impact of the artificial riffles but the model results do suggest that the construction of artificial riffles do have the potential to impact on bed levels upstream. This should be considered when consideration is being given to the introduction of artificial riffles within river channels. This potential impact is likely to have been exacerbated by the low energy nature of the river channel. It is likely that artificial riffles in higher energy streams would have a lesser potential impact.

3. *River Dearne*

3.1 BED SEDIMENT SAMPLING

The project took three bed sediment samples from the River Dearne and details of these are given in Annex 2. The River Dearne bed sediment samples showed bed material with D_{50} in the range 1 to 3 mm and D_{95} in the range 8 to 10 mm.

3.2 NUMERICAL SEDIMENT MODELLING

An Infoworks RS model was set up to simulate flow and sediment movement within the river system. The model was used to simulate the evolution of the bed levels in the River Dearne.

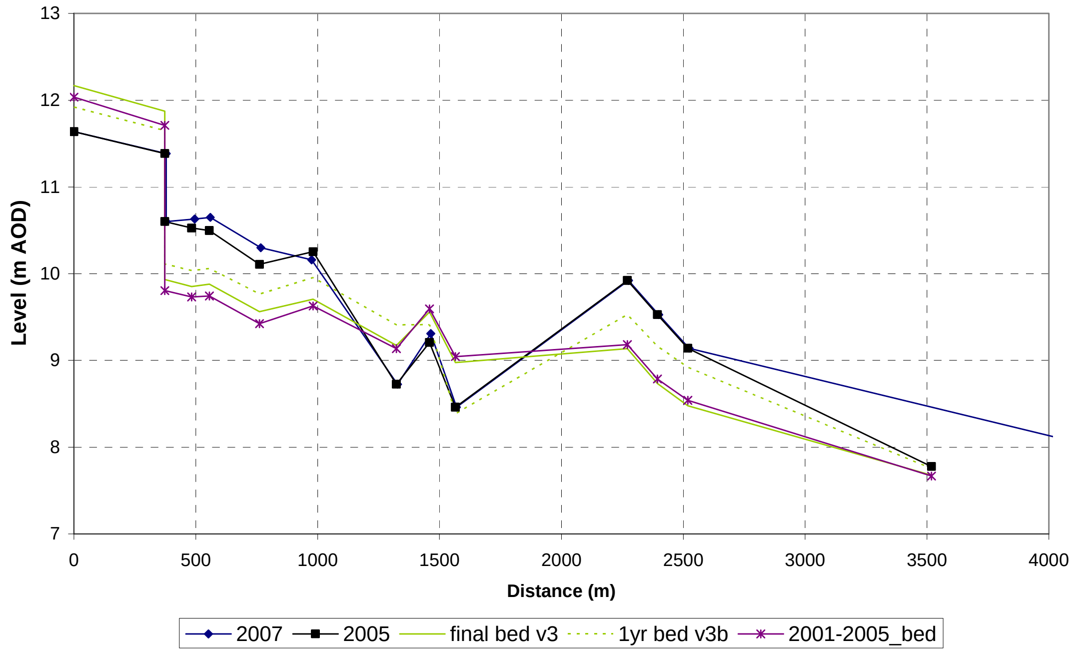


Figure 3.1 Longitudinal bed profile showing bed development with no sediment maintenance

Figure 3.1 shows observed bed levels and three different model predicted bed levels after 5 years representing three different assumed upstream sediment boundary conditions. The model predicts long-term accretion upstream of the weir near the upstream model boundary and degradation immediately downstream of the weir. This would appear to contradict the observations within the system. In modelling terms, the accretion upstream of the weir could be reduced by reducing the sediment inflow to the system at the upstream boundary but this would exacerbate the predicted degradation downstream. Meanwhile the degradation downstream of the weir could be reduced by increasing the sediment inflow at the upstream boundary but this would exacerbate the predicted accretion upstream of the weir. The present imposed upstream sediment boundary condition would appear to represent the best present compromise but the result is that the model does not seem to be modelling the development of bed levels satisfactorily at the present. The model is predicting erosion at the upstream and downstream reaches and accretion in the middle reach but no such changes are reported from the field.

In the light of the disparity between the model predicted bed levels and the observations it is difficult to draw any firm conclusions about sediment movement within the study reach. The model predicted bed levels in the lower part of the reach are steeper than those upstream which may reflect the reduced channel widths in this sub-reach, though the observed bed slope downstream of chainage 1000 m is just as steep as the observed bed slope downstream.

The response one would expect to channel narrowing depends upon the previous channel width. If a channel is initially in equilibrium and the width is confined then one would expect the longitudinal slope of the channel to increase. If the channel had been over-widened in the past, however, then narrowing the channel width towards its original equilibrium value could lead to a reduction in the longitudinal slope.

3.3 INTERACTION BETWEEN SEDIMENT AND VEGETATION MANAGEMENT

In the upstream sub-reach of the Dearne sediment features are developing within the channel as a result of the disturbance to the flow caused by marginal trees. This leads to the deposition of fine sediment in the lee of such features and these fine sediment deposits are being colonised by reeds. These processes lead to the development of distinct habitats. Meanwhile the constriction of the main flow resulting from the formation of these marginal habitats has led to coarsening on the bed material in the main flow part of the channel. This underlines the need for vegetation and sediment management to be considered together rather than in isolation. Appropriate vegetation management can promote the development of sediment related features. In turn sediment management can have a significant impact on the availability of suitable macrophyte habitat. Inappropriate sediment management may significantly affect the macrophyte populations.

4. *River Eden*

4.1 BED SEDIMENT COMPOSITION

The FRMRC project took bed sediment samples at eleven sites on the River Eden. The sediment grading curves are given in Annex 3 below. The data shows that the bed sediments of the River Eden vary significantly in size, ranging from fine silts to gravels while it is also spatially very variable. The D_{50} size of the bed samples varies from approximately 32 mm for sample 3 to approximately 0.12 mm for samples 5 and 10. This wide variation may be the results of different effects. It may be that the samples were taken from different features within the river and so some represented depositional features, while some of the coarser material may reflect underlying sediment that has been exposed by dredging activity.

4.2 NUMERICAL MODELLING OF SEDIMENT MOVEMENT

An Infoworks RS model was set up to simulate flow and sediment movement within the river system. The model was used to simulate the evolution of the bed levels in the River Eden in the absence of any sediment removal.

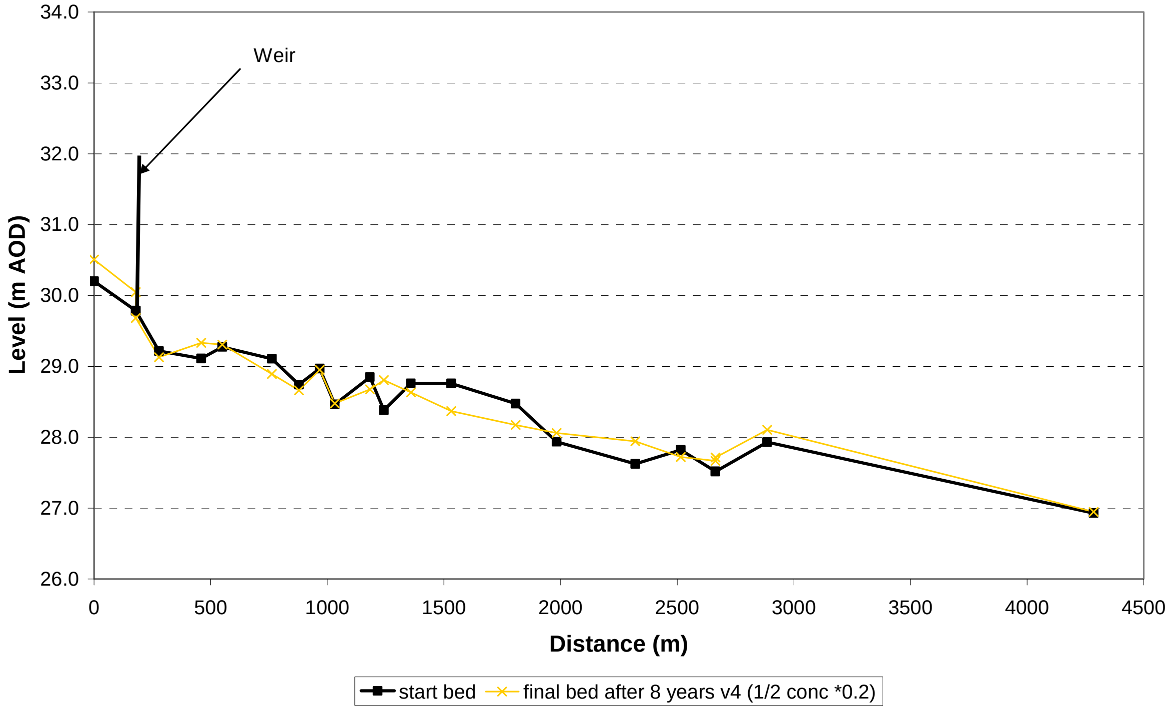


Figure 4.1 Longitudinal profile of bed levels showing initial bed levels and bed levels after 8 years with no sediment maintenance

The model results show the impact of no maintenance over a period of 8 years. The model indicates that overall bed level changes through the reach with no maintenance will be limited. The model shows that the rate of response of the River Eden to stopping sediment maintenance is slower than for the River Kent. This is to be expected as the Kent is a higher energy watercourse which is carrying significantly higher sediment loads. The low response of the River Eden reflects the low energy of the system and the limited sediment inputs from upstream.

The absence of accretion of the bed does not imply that sediment related features will not develop in the channel. Though there is little overall predicted change in bed level there is a significant sediment load passing through the reach. This will result in the development of localised sediment features as observed in the channel. Provided that such sediment features are small and isolated they will not impact on the overall conveyance of the river channel. If such features are removed by dredging then they will reform.

5. *River Harbourne*

5.1 BED SEDIMENT COMPOSITION

The FRMRC project took sediment samples at seven sites on the River Harbourne. The sediment grading curves are given in Annex 4 below. The sediments in the River Harbourne are predominantly coarse with the D_{50} sizes typically being in the range of 30 to 90 mm. This reflects the fact that it is a high energy river.

5.2 SEDIMENT MODELLING

An Infoworks RS model was set up to simulate flow and sediment movement within the river system. The model was used to simulate the evolution of the bed levels in the River Harbourne.

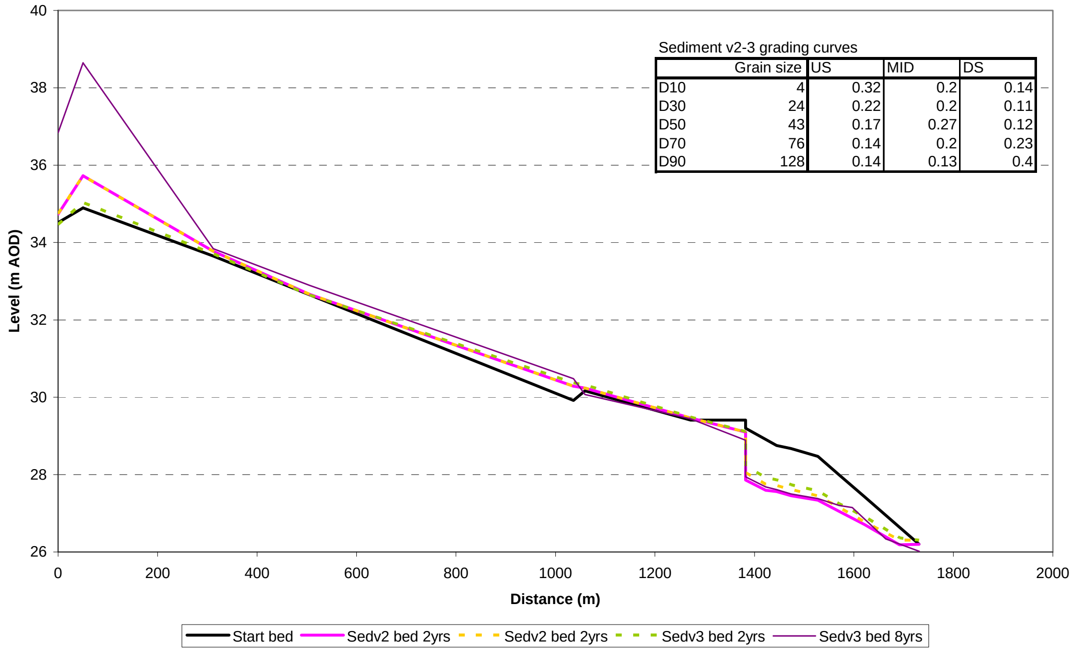


Figure 5.1 River Harbourne: Longitudinal bed profile showing future development of bed levels through the Flood Alleviation Scheme

Figure 5.1 shows the model predicted bed levels through the flood alleviation scheme. In the scheme design in part of the lower section of the scheme the channel was deliberately widened to deliberately promote limited sediment deposition. The intention was to use the numerical model to look at likely development of the bed levels in this area. Unfortunately the numerical model results show significant degradation in the lower part of the reach. This is not consistent with observations of the bed levels since the scheme was implemented. In general the bed levels have been stable and limited sediment deposition has occurred in the deliberately widened section. The numerical model results are thus significantly at variance with the observations. This may be due to problems with the bathymetric or sediment data. The numerical model results indicate that the model is not providing a satisfactory model of the sediment processes through this reach of the river.

6. *River Kent*

6.1 INTRODUCTION

To carry out an investigation of sediment movement through the study reach sediment was included in the Infoworks flow model. The sediment data used in the model was derived from sediment sampling and analysis that had been carried out by the Flood Risk Management Research Consortia (FRMRC) project.

6.2 SEDIMENT DATA

The FRMRC project took bed sediment samples at eleven sites on the River Kent. To provide an indication of the nature of the bed sediment sizes the properties of the combined sample are given below in Table 6.1 and Figure 6.1.

Table 6.1 Properties of combined bed sediment sample for the River Kent.

Size class (finer than)					
Mm		**Ψ**	**n**	**%**	**Cumulative**
2	-1.0	1.0	1	0.1	0.1
2.83	-1.5	1.5	0	0.0	0.1
4	-2.0	2.0	0	0.0	0.1
5.66	-2.5	2.5	11	1.0	1.1
8	-3.0	3.0	15	1.4	2.5
11.3	-3.5	3.5	27	2.5	4.9
16	-4.0	4.0	67	6.1	11.0
22.6	-4.5	4.5	145	13.2	24.2
32	-5.0	5.0	209	19.0	43.2
45.3	-5.5	5.5	250	22.7	65.9
64	-6.0	6.0	189	17.2	83.1
90.5	-6.5	6.5	118	10.7	93.8
128	-7.0	7.0	51	4.6	98.5
181	-7.5	7.5	9	0.8	99.3
256	-8.0	8.0	7	0.6	99.9
362	-8.5	8.5	1	0.1	100.0
512	-9.0	9.0	0	0.0	100.0
724	-9.5	9.5	0	0.0	100.0
1024	-10.0	10.0	0	0.0	100.0

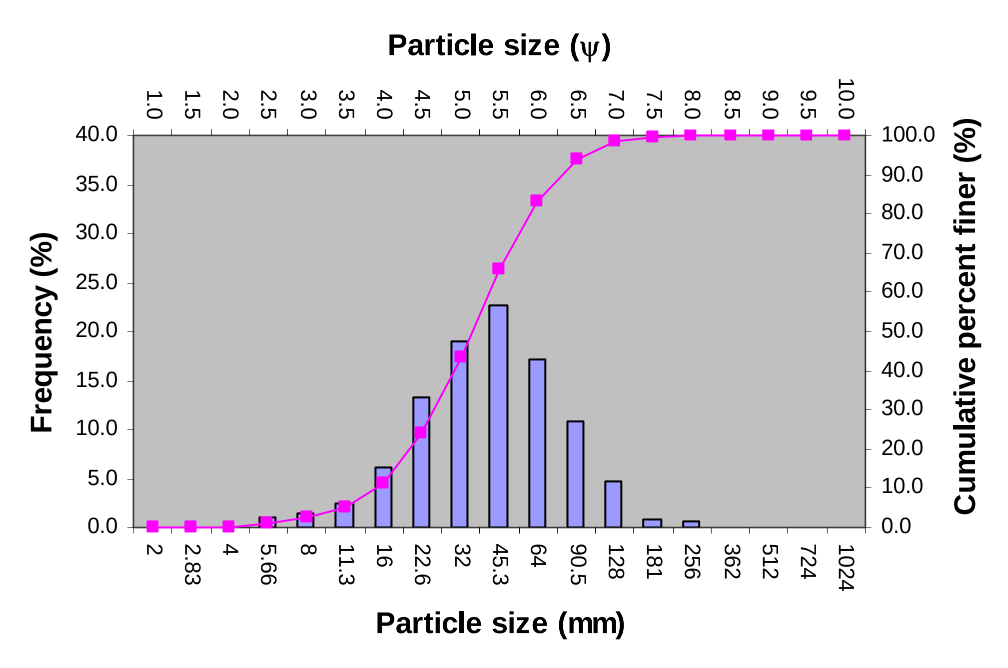


Figure 6.1 Particle size distribution for the combined bed sample for the River Kent.

Table 6.1 and Figure 6.1 indicate that the bed sediment in the River Kent is predominantly a uni-modal gravel with a D_{50} size of approximately 45 mm.

6.3 SEDIMENT MODELLING

On the River Kent periodic sediment removal takes place from the reach through Kendal. The Environment Agency provided details of the periodic sediment removal over the last five years. This information was used in the calibration of the numerical model to ensure that the sediment deposition matched this removal rate.

The numerical model was then run for a period of 8 years with no sediment removal through Kendal. The longitudinal bed profile is shown in Figure 6.2

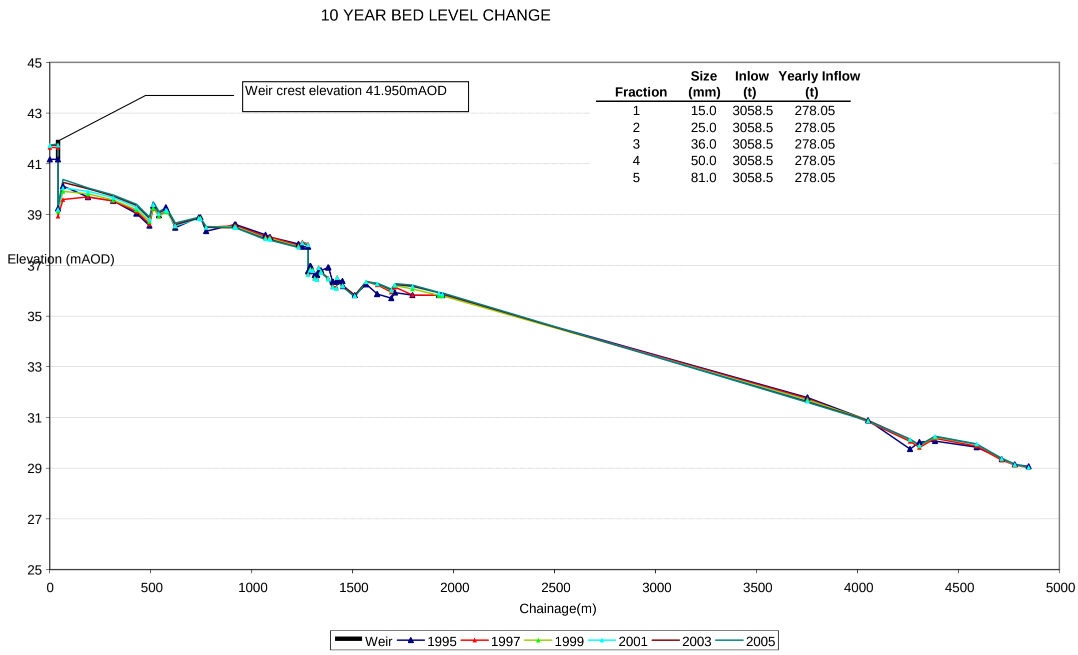


Figure 6.2 Longitudinal bed profile of River Kent through Kendal showing accretion immediately downstream of weir at upstream end of reach.

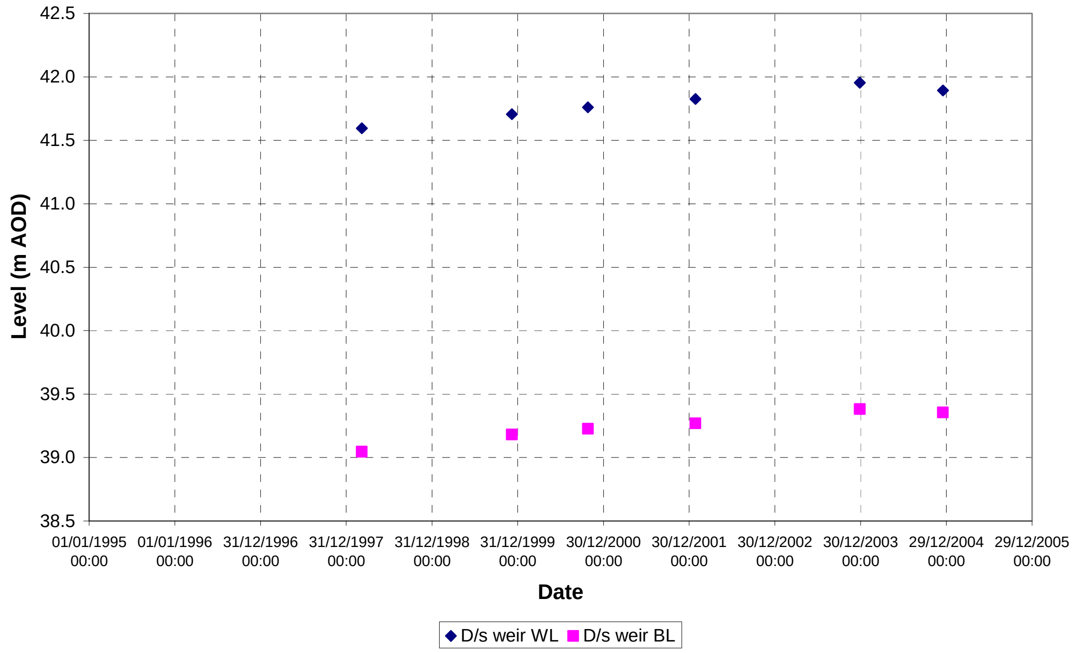


Figure 6.3 Temporal change in the bed levels and water levels for the same discharge immediately downstream of the weir.

It can be seen from Figure 6.3 that the bed levels immediately downstream of the weir increase initially but appear to stabilise after a period of approximately 6 years. This suggests that if the level of maintenance is reduced or stopped then after a number of years the bed levels will stabilise but at a higher level that presently. After this period it is likely that the bed level will fluctuate due to variations in the flow and variations in the upstream sediment load.

It can be seen from Figures 6.3 and 6.4 that the increase in bed levels leads to corresponding increases in water levels.

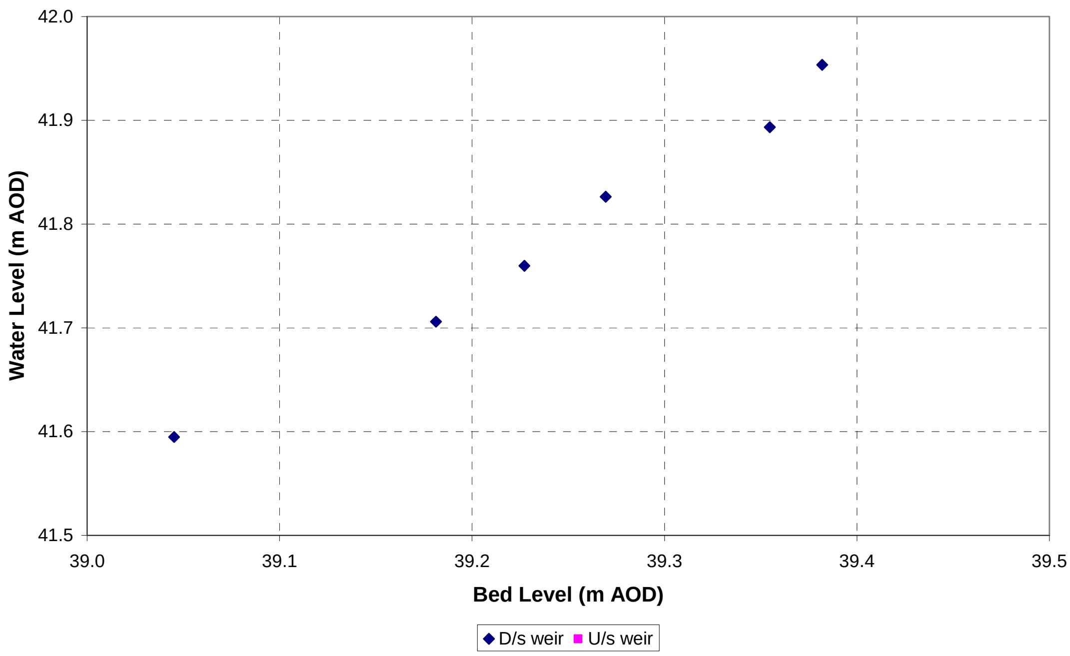


Figure 6.4 Plot of bed level and corresponding water level change immediately downstream of weir.

The picture that emerges is typical of the impact of reducing sediment maintenance in rivers where sediment removal currently takes place. If sediment removal ceases or is reduced then bed levels will increase. The rate of adjustment to the new equilibrium conditions depends upon the nature of the river and the amount of sediment that was being removed as a ratio of the total sediment load. In high energy systems such as the River Kent through Kendal one would expect that the speed of adjustment would be relatively rapid and take a number of years, as indicated by the results shown above. In lower energy systems then the rate of adjustment may be much slower and the time period for adjustment may be measured in decades or longer.

The changes in bed level that result from changes in sediment maintenance result in changes in water level. The relationship between the two depends upon the nature of the river. As can be seen from Figure 6.4 in the River Kent the increase in water level for a given discharge is smaller than but comparable with the increase in bed level. In more lowland rivers the increase in water level will be less than the increase in water level.

The length of river over which water levels will be raised will depend upon a number of factors including: the steepness of the river and the presence of any strictures. In general if bed levels are raised over a limited length then water levels will be raised over that length and also further upstream. The length of the impact upstream depends upon the slope and depth of the river, see Samuels (1989) discussion of backwater lengths. The increase in water levels upstream has an impact on sediment transport, which causes sedimentation to progress upstream. This can be halted, however, by the presence of structures. In the case of the River Kent, the presence of the weir immediately upstream limits the upstream impact of increased water levels as a result of reduced sediment removal downstream.

The results at the downstream end of the modelled reach show increased bed levels as a result of ceasing sediment removal in the upstream part of the reach through Kendal. This demonstrates how sediment removal can impact downstream reaches and inhibit or prevent the development of sediment related features in the downstream reaches. Thus in considering the potential impact of sediment removal or ceasing sediment removal it is important that potential downstream impacts are considered.

It may be possible to reduce the need for the removal of sediment at a particular location for flood risk management purposes by determining and addressing the sources of sediment upstream. It may be easier to treat the source of the sediment upstream than to treat the depositional problems that are generated downstream. Where deposited sediment is difficult or damaging to remove the use of a sediment trap can be considered. The use of a sediment trap may make sediment removal easier but still results in loss of habitat and impacts downstream.

7. Relationship between vegetation cutting and sediment movement

7.1 INTRODUCTION

There is an interaction between in-channel vegetation management and the movement of sediment within a channel. The presence of vegetation within the channel affects the distribution of flow velocities and hence the depth of flow in the channel for a given discharge. Vegetation management, by altering the spatial distribution of hydraulic roughness, alters the lateral distribution of flow velocities and the overall depth. This impacts on the sediment transport within the channel.

To investigate the impact of different vegetation management options numerical modelling was used to investigate the change in sediment transport rate that would result from different sediment management options.

The issue is complicated by temporal changes in the hydraulic roughness due to in-channel vegetation and the flow frequency. Sediment transport is a highly non-linear function of flow velocity and, hence, discharge, with the sediment transport rate increasing rapidly with discharge. Thus, commonly, the bulk of sediment movement takes place during flood events. It is commonly found that proportionately more sediment moves during flow events with probabilities varying in the range of occurring two or three times a year to an annual probability of exceedence of 0.2%. For events with greater probabilities, the flow velocity is often so low that the sediment transport rate is low and for events with smaller probabilities, the probability of the event is so small that it doesn't contribute significantly to the overall sediment load.

The hydraulic roughness due to vegetation is normally greatest in late summer and is smallest in the winter period. In many rivers in the UK floods occur more frequently during the winter months. As the vegetation has normally died-back during this period, the impact of vegetation on sediment movement is less than it might be at other times.

In the following summer vegetation conditions have been assumed and so the impact of vegetation management may be exaggerated by the results that are presented.

7.2 METHODOLOGY

The Conveyance Estimation System was used to determine the lateral velocity and depth distribution for a given discharge and vegetation condition. The values of velocity and depth on a large number of verticals across the cross-section were the extracted from the CES results and used in the modified Ackers and White sediment transport theory to determine the sediment transport rate associated with each vertical. These sediment transport rates were then integrated over the width of the cross-section to determine the overall sediment transport rate for the cross-section.

To apply the sediment transport theory a sediment size has to be selected. As is shown by the results presented below the impact of different vegetation management on the sediment transport rate depends upon the sediment size selected.

Typical cross-sections were selected in the upper part of the Long Eau reach and these were input into CES. Three different vegetation cutting regimes were simulated:

a) cutting centre one third of channel
b) cutting centre half of channel
c) cutting centre two thirds of channel

For these configurations the lateral distribution of velocities and depths were determined using CES for the following discharges:

Q -50% (discharge that is exceeded 50% of the time)
Q – 5% (discharge that is exceeded 5% of the time)

The velocities and depths on verticals spaced every 200 mm were determined. The velocity and depth results are shown in Figures 7.1 and 7.2. It can be seen that going from a one-third cut to a half channel cut increases the flow velocities. There are also corresponding changes in flow depths. It should be noted that these changes in flow depth will affect the overall flood risk.

For selected sediment sizes the sediment concentration was determined at each vertical and the corresponding sediment transport rate for that vertical determined by multiplying by the discharge through that 'panel'. The sediment transport rates on each vertical were then summed to determine the overall sediment transport rate for the cross-section for that discharge for that flow condition.

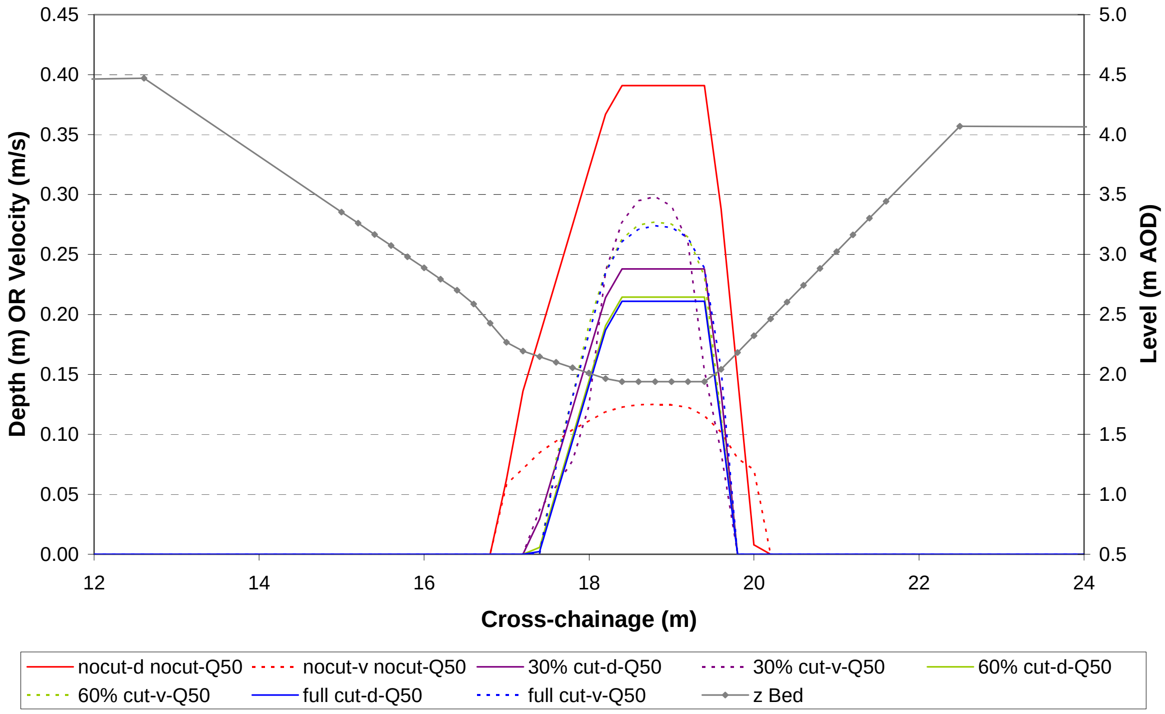


Figure 7.1 Predicted velocities and depths for the Q50 discharge with different vegetation cutting strategies

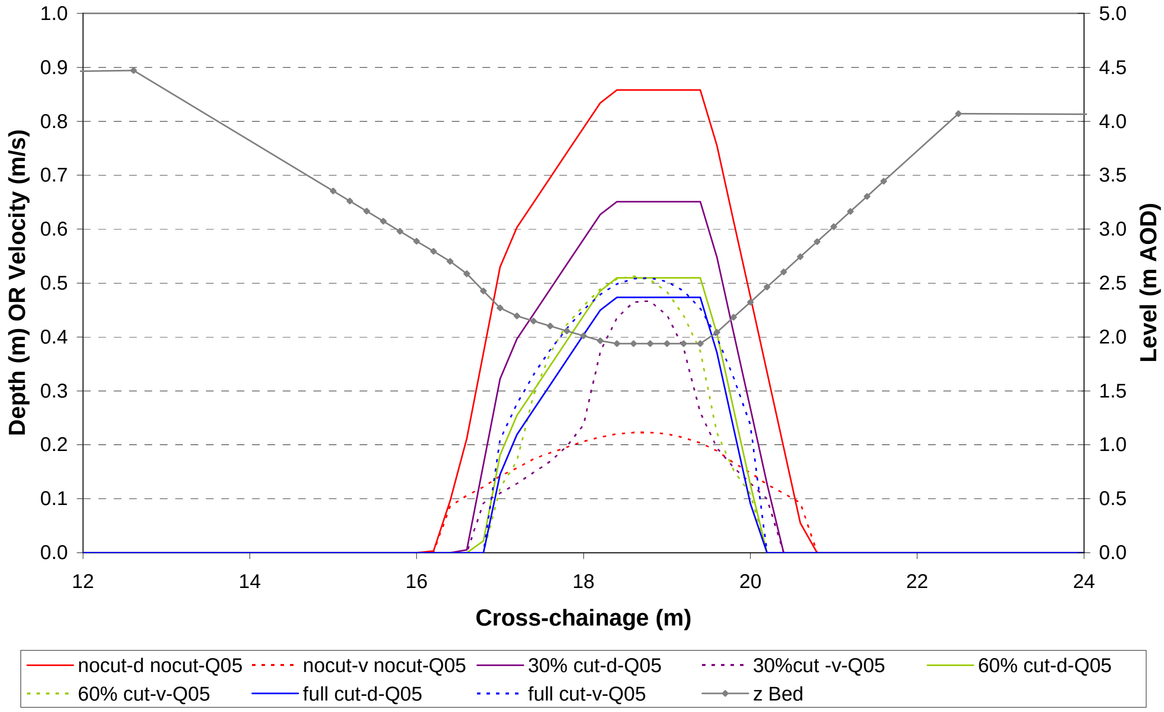


Figure 7.2 Predicted velocities and depths for the Q5 discharge with different vegetation cutting strategies

Table 7.1 Predicted sediment transport rate for the Q-50% discharge assuming different vegetation cutting regimes

	Qs (D = 0.2mm) (kg/s)	% increase from (a)
cutting centre one third of channel	0.09	0
cutting centre half of channel	0.13	55
cutting centre two thirds of channel	0.14	66

The impact of the vegetation cutting is to reduce the water depth in comparison with the fully vegetated channel and to increase the flow velocities in the centre of the channel. The flow velocities at the margin are reduced. This leads to a reduction in sediment transport in the channel margins but an increase in the central portion of the channel. The greater the proportion of the perimeter of the channel that is cleared of vegetation then the greater these effects become. As can be seen from Table 7.1 the change in sediment transport going from a one-third cut to a half channel cut is much larger than going from a one half cut to a two-thirds cut.

For the Q-5% flow results sediment calculations were carried out for two sediment sizes. A larger sediment size was selected to illustrate the point that due to the fact that the shear stress increases with an increase in the amount of vegetation cut then there are always some sediment sizes which will move if more vegetation is cut but for which little or no sediment movement will take place if less vegetation is cut.

Table 7.2 Predicted sediment transport rate for the Q-5% discharge assuming different vegetation cutting regimes

	Qs (D = 0.2mm) (kg/s)	% increase from (a)
cutting centre one third of channel	1.2	0
cutting centre half of channel	1.6	31
cutting centre two thirds of channel	2.6	114
	Qs (D = 1.5mm) (kg/s)	% increase from (a)
cutting centre one third of channel	0.002	0
cutting centre half of channel	0.014	595
cutting centre two thirds of channel	0.063	3134

As can be seen for Table 7.2, by judicious selection of the sediment size an arbitrary large difference can be found between the sediment transport for a particular size although the actual sediment transport rate is small.

7.3 TEMPORAL VARIATIONS IN VEGETATION AND SEDIMENT TRANSPORT

The calculations described above show that vegetation cutting can have a significant impact on the ability of a channel to transport sediment. It has to be remembered, however, that normally significant vegetation is only present for part of the year, from Spring through to late Autumn. During the winter vegetation dies back and its contribution to the overall hydraulic roughness of the channel is small. During the winter months the discharges are normally greater than in the summer. As sediment transport is a non-linear function of the discharge it is found that typically the bulk of the sediment movement takes place during the winter period when the vegetation is low. The annual flow record for the long eau was divided up into a winter and summer period and a sediment rating curve derived from the numerical model results was used to determine the percentage of the annual sediment movement that took place in the winter and summer period. The results showed that approximately 94% of the sediment movement took place during the winter with only approximately 6% during the summer period. The precise figures depend upon the nature of the river and the particular flow sequences experienced but the general conclusion that one can derive is the bulk of the sediment movement takes place during the winter when the hydraulic roughness of the vegetation is low.

This implies that though the above analysis showed that cutting vegetation has an impact on sediment movement, the impact of vegetation cutting on the overall sediment movement in a river is small. Thus the impact on sediment transport cannot be used as a justification for cutting vegetation during the summer period.

7.4 CONCLUSIONS

Comparison of the sediment transport rates for the Q-50 and Q-5 flows demonstrates that much more sediment movement takes place during the higher flows.

The results show that the amount of sediment transported by a channel increases monotonically with the amount of vegetation cut. Cutting vegetation can lead to significant changes in the sediment transporting capacity of a channel. This implies that reducing vegetation maintenance in a channel will reduce its capacity to transport sediment and may lead to sediment deposition.

It should be remembered that in many UK rivers the bulk of the sediment movement takes place during winter floods when the vegetation has often died back. During such winter floods the influence of the vegetation management on the sediment transport rates is very small. Thus though cutting vegetation has an impact on sediment movement, the impact on the overall sediment movement in a river is small. The impact on sediment transport cannot be used, therefore, as a justification for cutting vegetation during the summer period.

It should be noted that the results do not take account of longitudinal variations in sediment transport rate and so do not indicate the impact of vegetation in trapping sediment. Turbulent diffusion within the channel will tend to provide lateral mixing of the flow. Turbulent mixing will occur at the boundary between the central cut portion of the channel and the uncut portion at the edges. This will mean that water with higher sediment concentrations will be transferred from the central portion of the channel to the vegetated margins. As the flow velocities in these margins are lower than in the central portion, sediment deposition will take place. Thus vegetation in channels tends to act as a sediment trap. This is a subject which requires further research.

None of the available models could be used to investigate this phenomenon but some observations relating to it can be made. The amount of sediment deposition is likely to be related to the strength of the turbulent exchange rather than the lateral extent of the vegetation. The turbulent exchange will depend upon the magnitude of the velocity gradient at the edge of the vegetation. Examination of the velocity profiles suggests that the velocity gradient is larger if more vegetation is cut. Since the sediment concentrations in the central part of the channel will also be greater if more of the vegetation is cut it would appear that more sediment will be trapped by the vegetation if more of the vegetation is cut. Eventually there will be a cutting regime for which the amount of sediment trapped by the vegetation will reduce as the amount of cutting is increased.

8. Dredging and self-sustaining conditions

One of the methods for increasing the flow conveyance of a channel is to increase the size of the channel cross-section by dredging material from the bed of the river. This increases the depth of flow and hence cross-sectional area for a given stage. Assuming that the hydraulic roughness of the channel does not change there is an associated reduction in the water surface slope. These two effects combined leads to a reduction in the sediment transport rate within the dredged section in comparison with the sediment transport in the original channel.

Dredging may be carried out in a number of different situations. In some circumstances the channel may originally have been in equilibrium and the dredging is carried out to increase the flood conveyance through a particular reach. In other circumstances the river channel may not be in equilibrium and if no works were carried out sedimentation would normally occur. In this case dredging may be carried out to prevent future changes to the river system. A particular form of this is the removal of sediment at a deliberately constructed sediment trap, as, for example, upstream of Kendal.

If, in the pre-dredged condition, the channel was in equilibrium then the reduced sediment transport rate through the dredged section will lead to sediment deposition. This will typically take place at the upstream end of the dredged reach and gradually progress downstream. While dredging takes place the sediment load entering the reach downstream of the dredged section will be reduced leading to changes in the morphology of the downstream section. In an infinitely long, uniform channel these effects will progress downstream uninterrupted. In practice the extent of downstream influence is limited in extent either by incoming tributaries contributing significant amounts of sediment or some downstream boundary such as a lake or the sea. The starving of downstream reaches of sediment can be a significant impact and was, for example, observed in the Kent downstream of Kendal.

The impact of dredging may also extend upstream of the dredged section. The lowering of bed levels through a reach will lead to an increased water surface slope upstream which will locally increase the sediment transport rate and may cause erosion of the bed.

In considering sediment maintenance an issue arises where sediment has traditionally been removed from the river system as to what the impact of reduced sediment removal or the total cessation of sediment removal. Any such reduction in sediment maintenance will lead to increases in stage for a given discharge and increases in the water surface slope of the river. The freedom to be able to contemplate such changes in sediment management will depend greatly, therefore, upon the existing flood risk and its acceptability. In the case of the River Kent through Kendal there is an existing flooding problem and so the latitude to relax overall sediment removal is limited though there may be different approaches to managing the removal of the sediment. In other areas where flood risk is less acute it may be possible to consider overall reductions in the amount of sediment removed or even the complete cessation of sediment removal.

In considering changes to sediment removal it is important to remember that the sediment transport rate is very sensitive to small changes in the flow conditions. This is illustrated in the following table

Table 8.1 Sensitivity of sediment transport rate to changes in flow depth

Discharge (m^3/s)	Depth (m)	Velocity (m/s)	Slope	Sediment Concentration (ppm)
5.0	0.85	0.930	0.003	3727
5.0	0.55	0.840	0.0022	2241
5.0	0.6	0.765	0.0016	1391
5.0	0.65	0.701	0.00125	885
5.0	0.7	0.646	0.00097	575

Table 8.1 shows that a 20% increase in the depth leads to over a 50 reduction in the sediment transport rate. This demonstrates that what appear to be minor relaxations in sediment management may lead to significant increases in the amount of sediment passing through a reach and downstream. Thus it is possible that quite minor changes may lead to significant steps towards making a channel system self-sustaining.

To determine the degree of latitude available for changing sediment management in specific sites requires detailed studies related to that site it is possible to contemplate the formulation of indicative guidance. An important parameter is the difference between the rate of sediment removal and the unmodified rate of sediment transport in the channel. As is suggested by Table 8.1 above a 50% increase in sediment transport rate can result from small changes in the hydraulic parameters. This suggest that if the ratio of the rate of sediment removal and the unmodified sediment transport rate is less than approximately 50% then small changes in the flow conditions will significantly reduce the need for sediment maintenance. It must be appreciated, however, that any such change in flow conditions will increase the flood risk.

Where sediment removal does take place there are different options related to the frequency and amount of sediment that is removed. To maintain a given level of flood risk smaller amounts of sediment may be removed at shorter intervals or larger amounts of sediment may be removed at less frequent intervals. Removal of sediment at less frequent intervals implies the over removal of sediment, to allow for the build up of sediment over the period between maintenance. This will result in greater quantities of sediment having to be removed. The decision as to the appropriate frequency and quantity of sediment to be removed will depend upon local circumstances.

9. General conclusions

The modelling results for the River Kent through Kendal show how reducing sediment removal rates increases bed levels. The model results indicate that this impact on bed levels gradually propagates down the reach over a period of time. Under normal conditions one would also expect the impact on bed levels to propagate upstream but in the case of the River Kent in Kendal this is inhibited by the presence of the weir upstream which limits the extent of the upstream impacts.

The increase in bed levels has an impact on water levels and raises water levels for a given discharge locally. The relationship between the increase in bed levels and the increase in water levels depends upon the nature of the river, particularly factors such as the slope and the presence of structures.

The results from the Kent demonstrate that if sediment maintenance is reduced or removed then the river will move from the present equilibrium condition to another, future equilibrium condition. This is not to suggest that the river will be constant as the bed level will fluctuate dependent upon the flow and the incoming sediment load from upstream. The modelling results suggest that, in the case of the River Kent this new equilibrium would be achieved in perhaps 8 to 10 years but there would be a corresponding increase in water levels. The speed of response will depend upon the nature of the river and also in the change in the sediment regime that is carried out. High energy rivers which have high sediment loads will respond more quickly than low energy rivers with lower sediment loads. The larger the change in the sediment conditions as a function of the overall sediment load in the river than the longer will be the time period required for adjustment.

If sediment maintenance is reduced then bed levels will rise and this will impact on water levels. Any increase in flood levels will impact on flood risk. In locations where there is already a severe flood risk, for example, the River Kent in Kendal, any reduction in sediment management will exacerbate the flood risk. It is possible that in other locations, the change in flood risk resulting from sopping or reducing sediment maintenance may be more acceptable. The Environment Agency currently are developing a Performance-based Asset Management System (PAMS) and under this proposed approach there will be a need to establish the performance that is required from all Flood Risk Management assets, including water courses. It is hoped that under this approach it will be possible to identify maintenance requirements based on the flood risk associated with individual reaches. Under this approach it should be possible to identify reaches were reducing or ceasing sediment maintenance will be possible consistent with appropriate flood risk management.

The investigation on how vegetation management influences sediment transport was carried out using information on flows and using the Conveyance Estimation System and standard equations of sediment transport. The results showed that as the amount of vegetation cutting in a channel is increased then the sediment transport rate is increased. The corollary of this is that if vegetation cutting is carried out on a smaller proportion of the width of a channel then the sediment transport rate will reduce. If the incoming sediment load from upstream this will lead to increased sediment deposition within that reach. An investigation of the temporal variability of the sediment transport rate showed that approximately 94% of the sediment was moved during the winter period when vegetation was low. In this situation vegetation management during the summer is unlikely to have an impact on the overall annual sediment movement of the overall amount of sediment deposition in a given reach over a year.

Vegetation also acts to trap sediment, particularly fine sediment. The prediction of how the amount of sediment trapped will vary with vegetation density and thickness is difficult and the topic requires further research.

This part of the project looked at the case of the River Harbourne at Harbertonford where a Flood Alleviation Scheme has been carried out. The intention was to look at the impact of the capital works on sediment movement through the use of sediment modelling. As described above the predictions of the numerical model are currently not consistent with the observed behaviour in the river system. Since the scheme was constructed it has been observed that the bed levels have been generally stable but with some slight sediment deposition in an area where it had been intended to encourage such deposition. Currently the model is predicting significant sediment erosion in this reach. This is currently being investigated further.

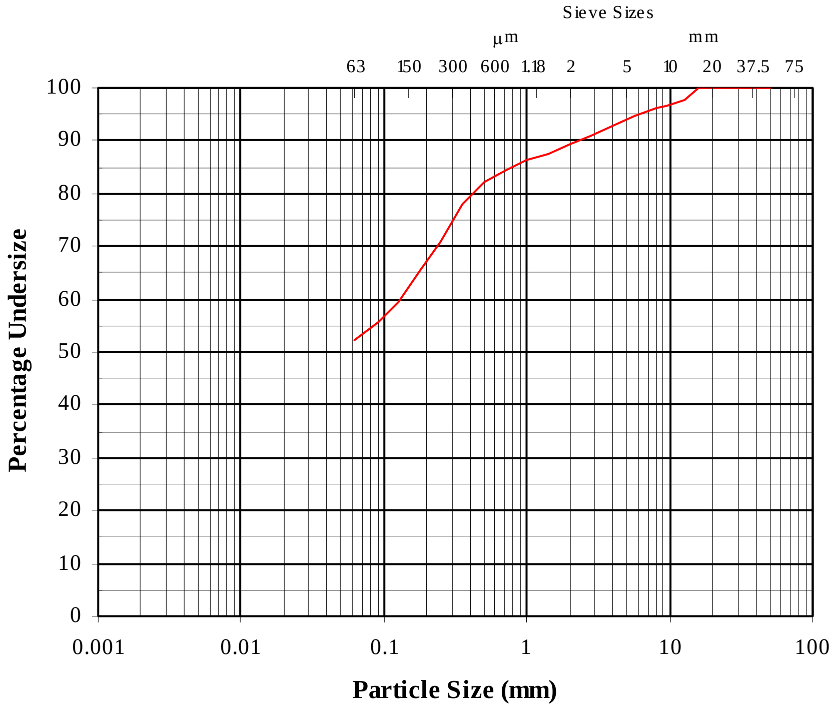
Sensitivity calculations showing the impact of flow depth on sediment transport rates shows that modest changes in depth can lead to significant increases in sediment transport rate. This implies that quite minor changes in sediment management might lead to significant movement towards channel being self-sustaining.

It is suggested that a parameter that can be used to assess the potential for making channels self sustaining is the ratio of the sediment removed to the overall sediment load within the system. If this ratio is less than 50% then quite modest changes in flow conditions might lead to the sediment in the channel achieving a natural equilibrium and becoming self-sustaining.

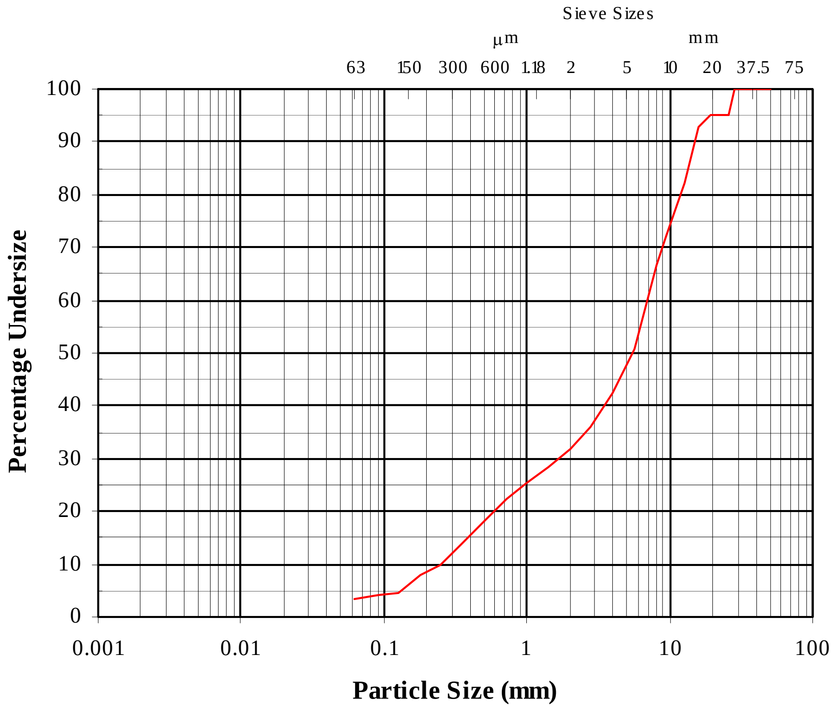
References

Samuels, P. G. 1989. Backwater lengths in rivers, *Proc. Inst. of Civil Engineers*, Part 2, Vol. 87, pp 571-582.

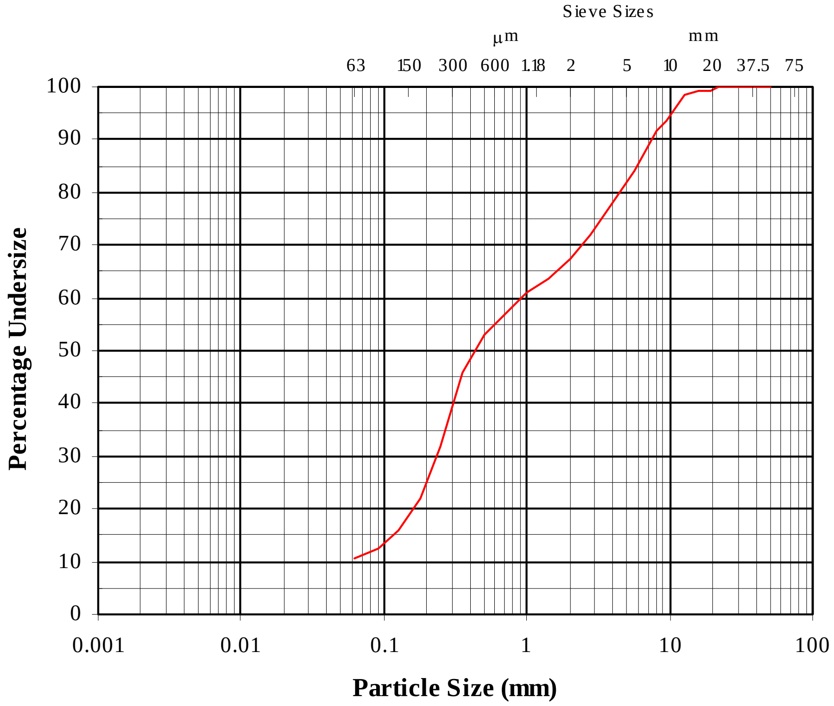
Annex 1Long Eau : bed sediment composition



Long Eau: Sample 1 Downstream from Old Eau confluence and Section 8 (TF40380 85850)

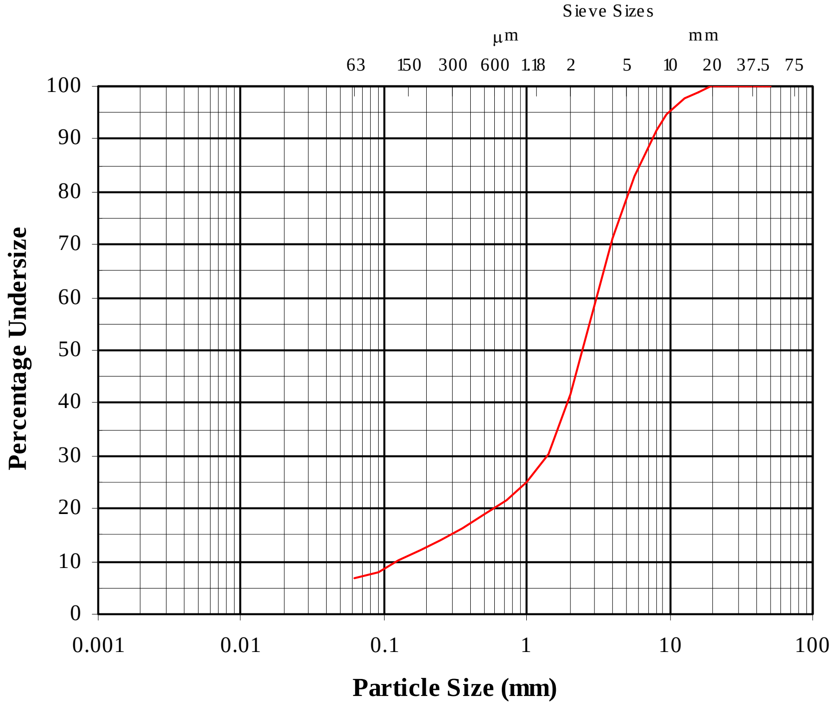


Long Eau: Sample 2, cross section 10 (TF40140 85760)

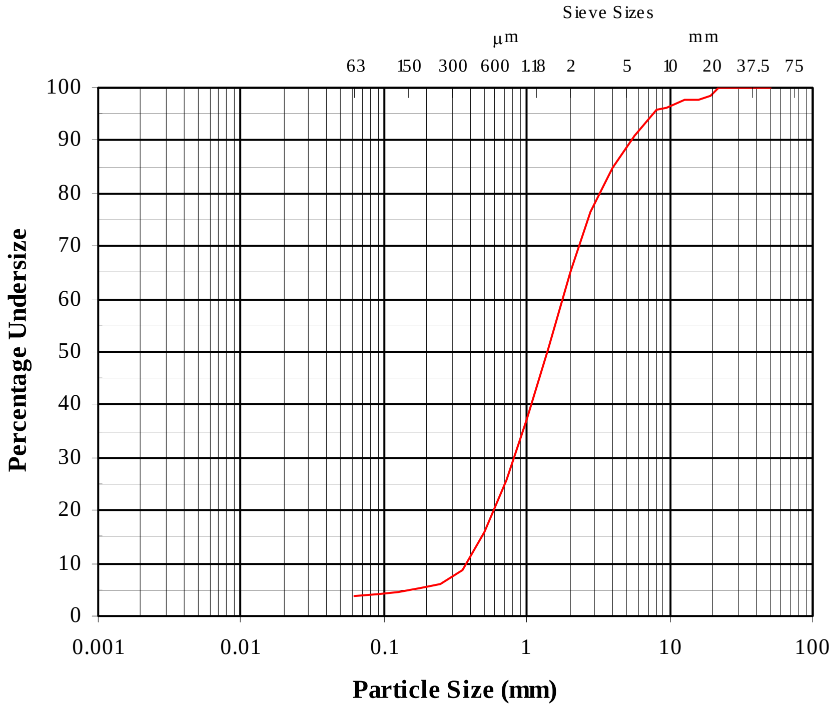


Long Eau: Sample 3, Upstream from Section 12 (TF40100 85590)

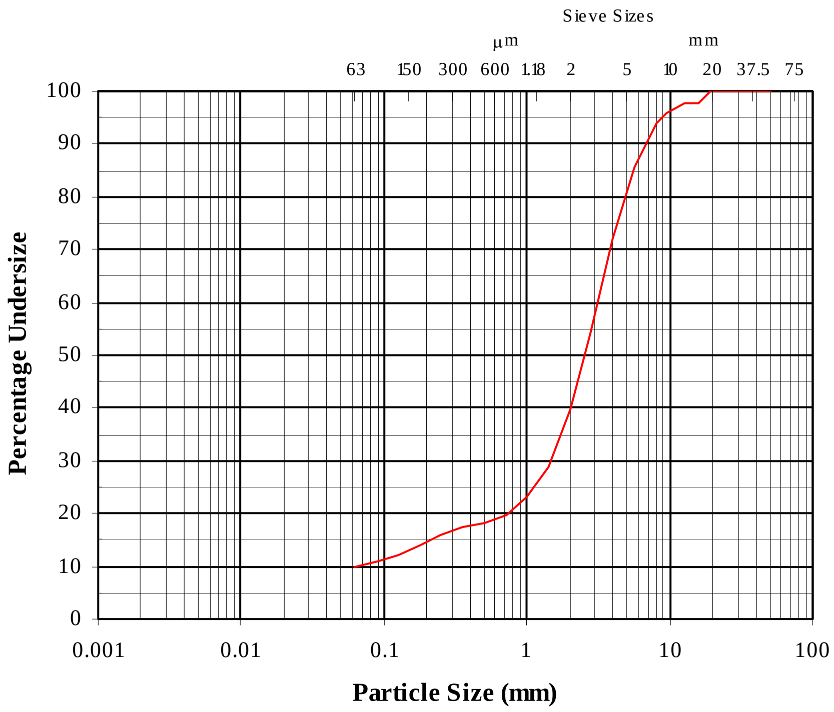
Annex 2 River Dearne: bed sediment composition



River Dearne: Sample 1, Footbridge at end of Mill Lane between Sections 6 and 7 (SE48370 01770)

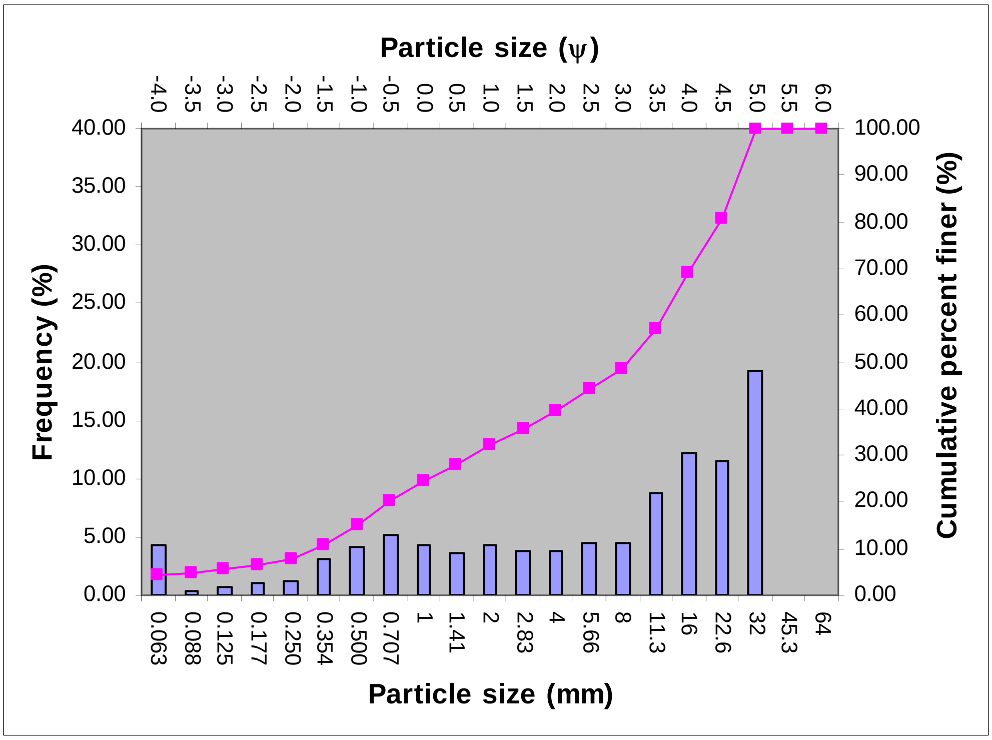


River Dearne: Sample 2, Pastures Lane bridge, downstream from Section 1 (SE49752 00748)

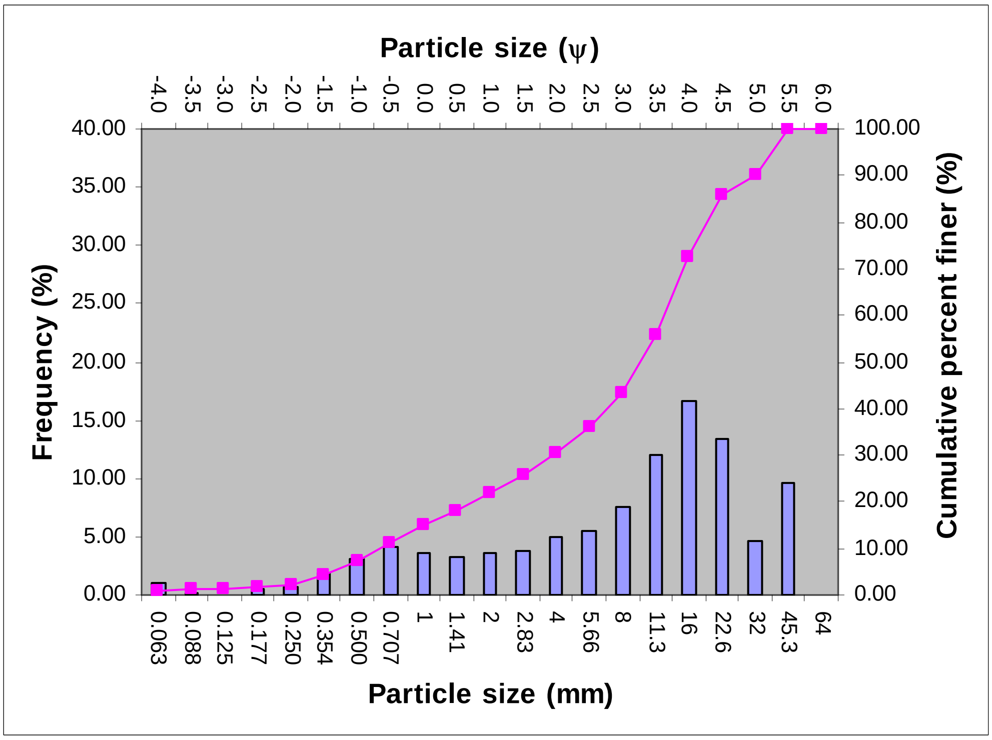


River Dearne: Sample 3, Pastures Lane bridge, downstream from Section 1, 1/3 channel width from right bank (SE49752 00748)

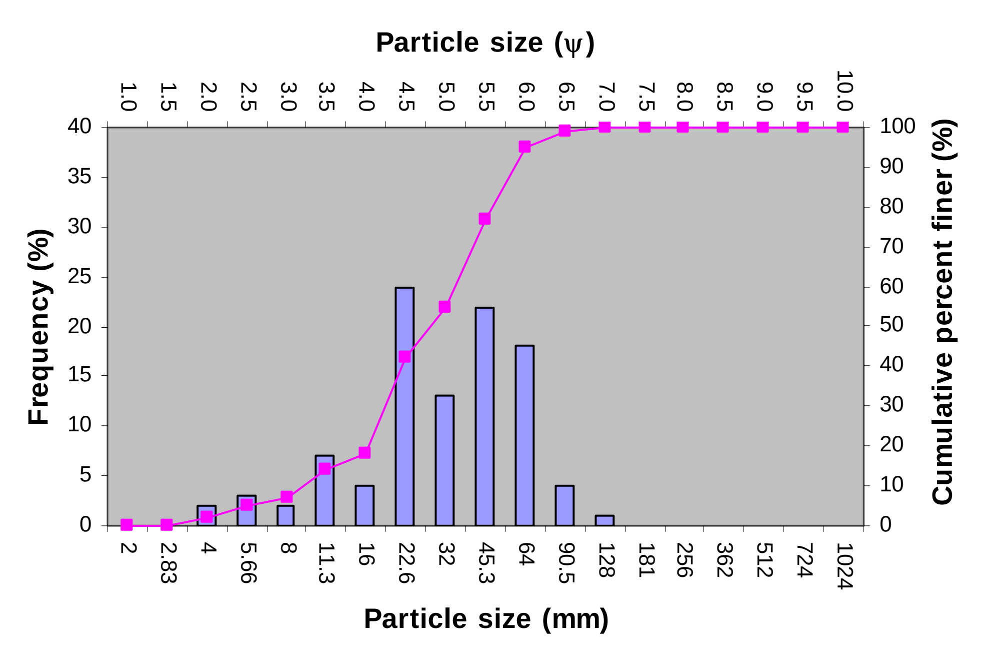
Annex 3 River Eden: Bed sediment composition



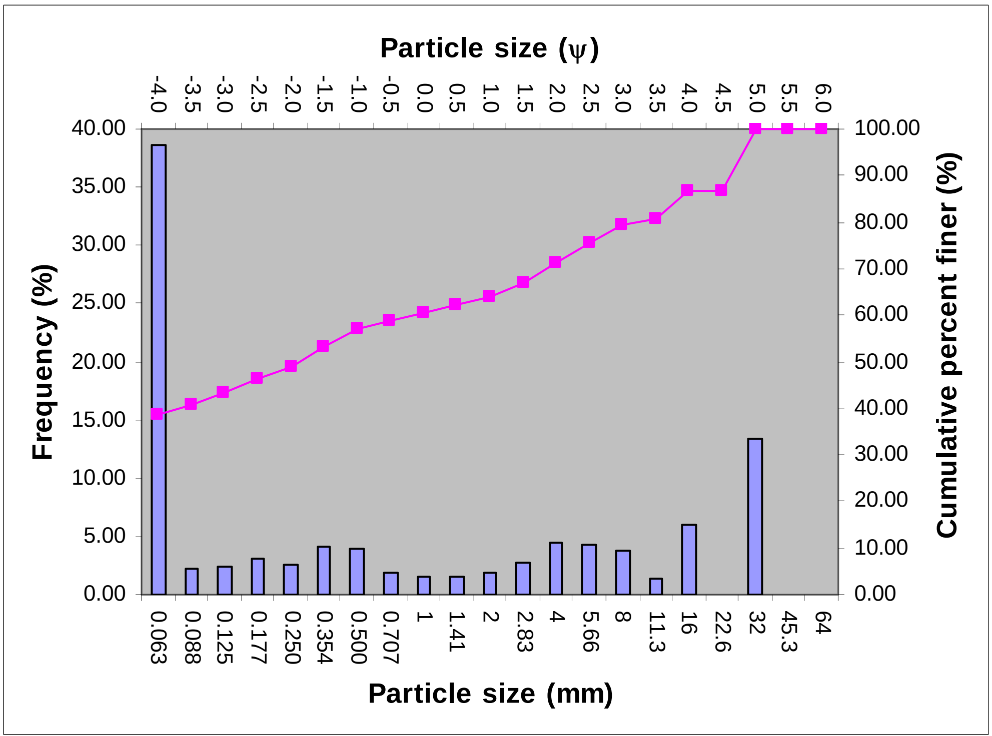
River Eden: Site 1: Mill Farm Bridge (Grid ref: 549520, 146200)



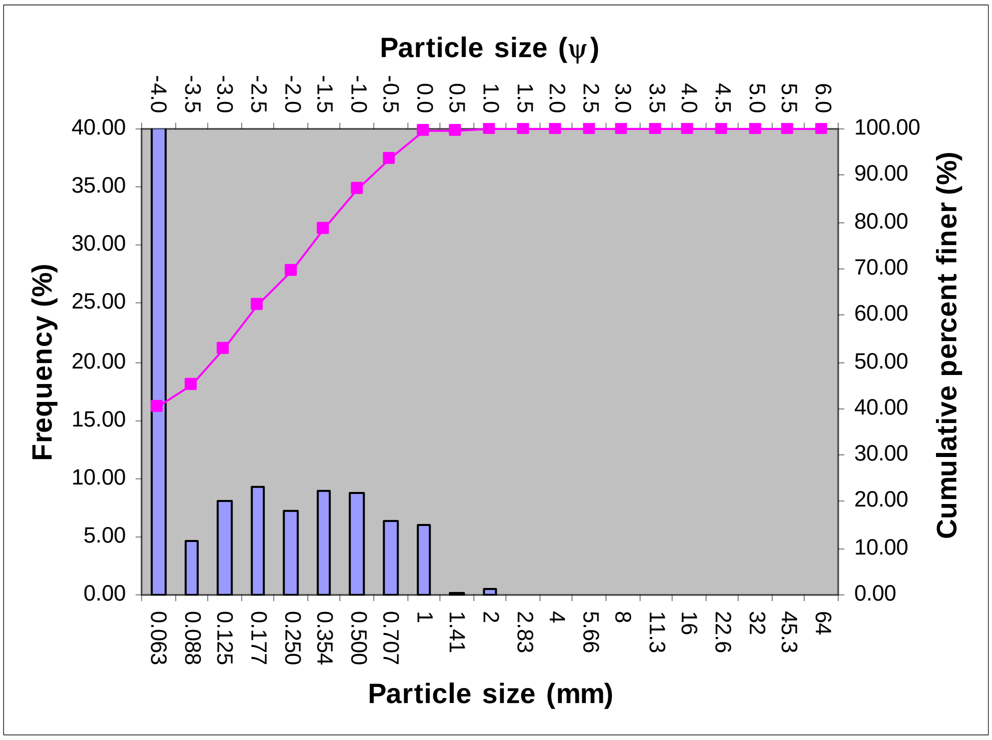
River Eden: Site 2: Cross section 13 - upstream of weir (Grid ref: 549668, 146360)



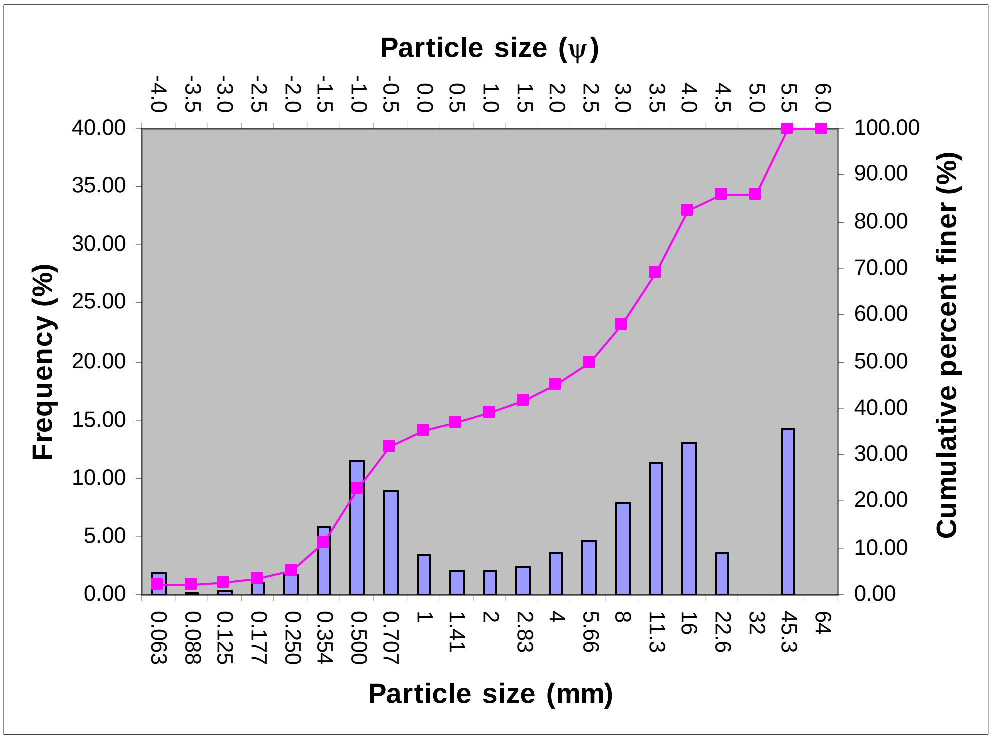
River Eden: Site 3: Cross section 11 (Grid ref: 549976, 146361)



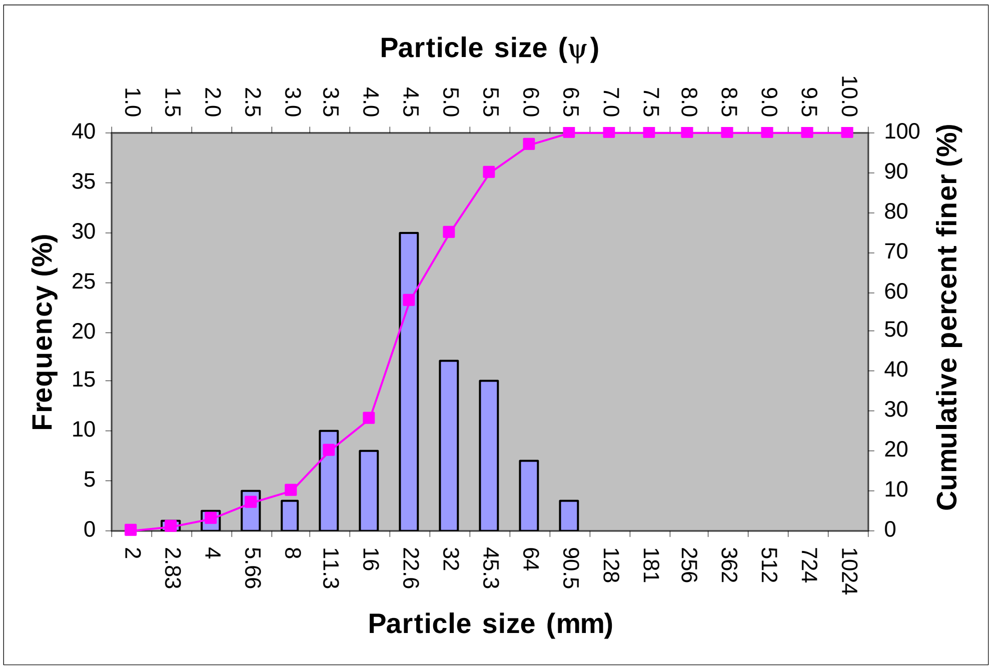
River Eden: Site 4: Upstream of cross section 10 (Grid ref: 549976, 146281)



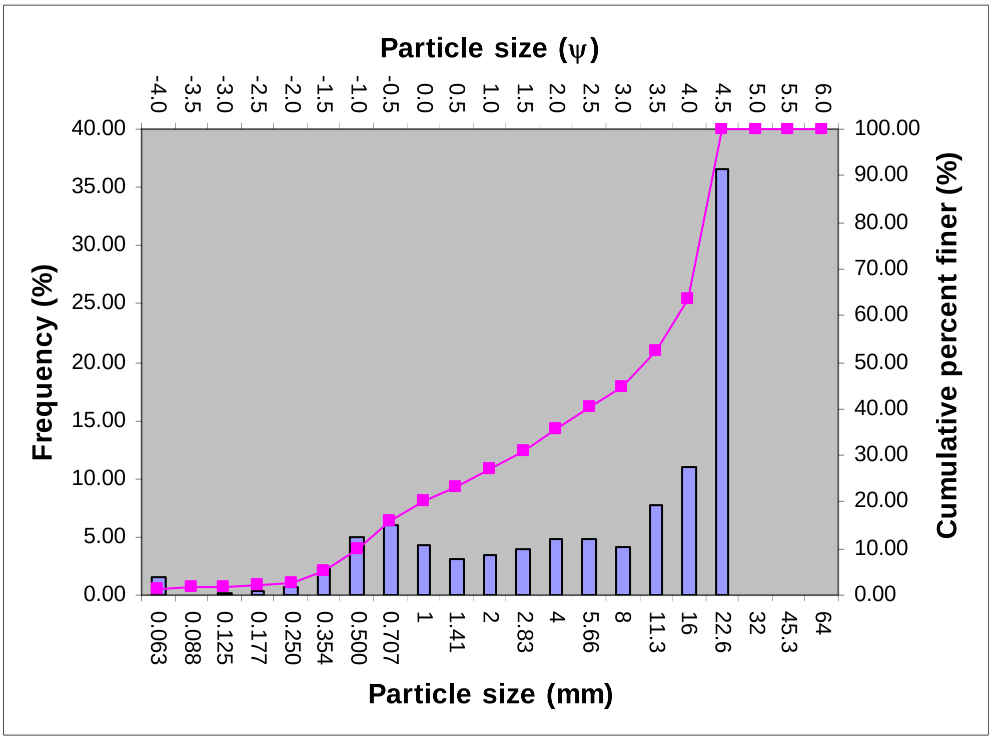
River Eden: Site 5: Cross section 8 (Grid ref: 550020, 145992)



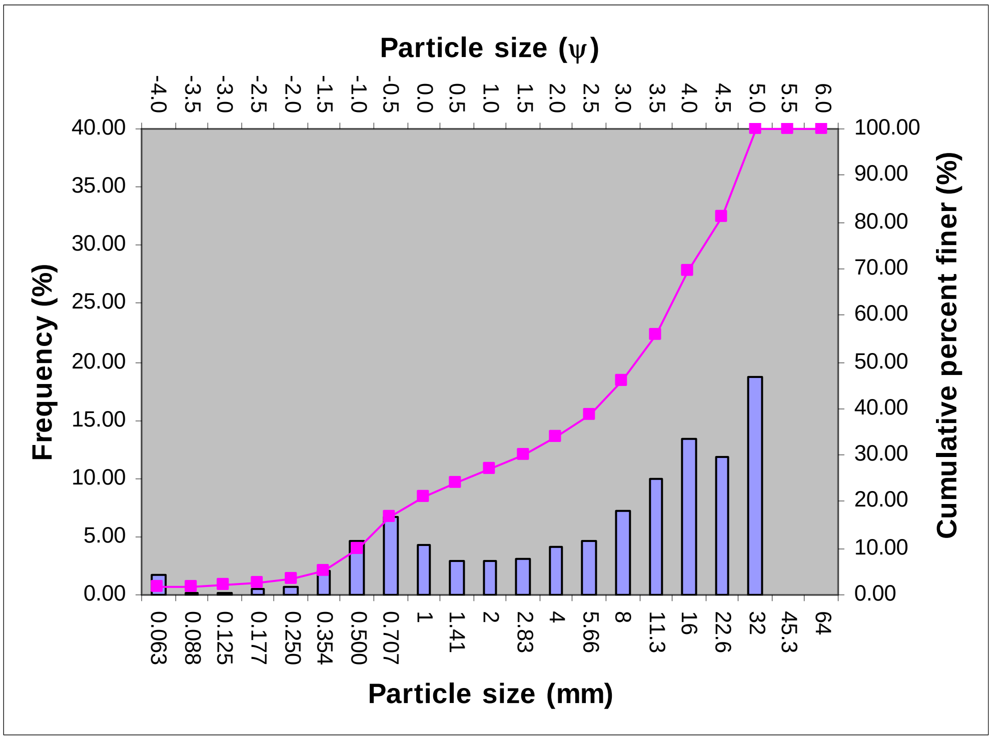
River Eden: Site 6: Cross section 6 (Grid ref: 550192, 145666)



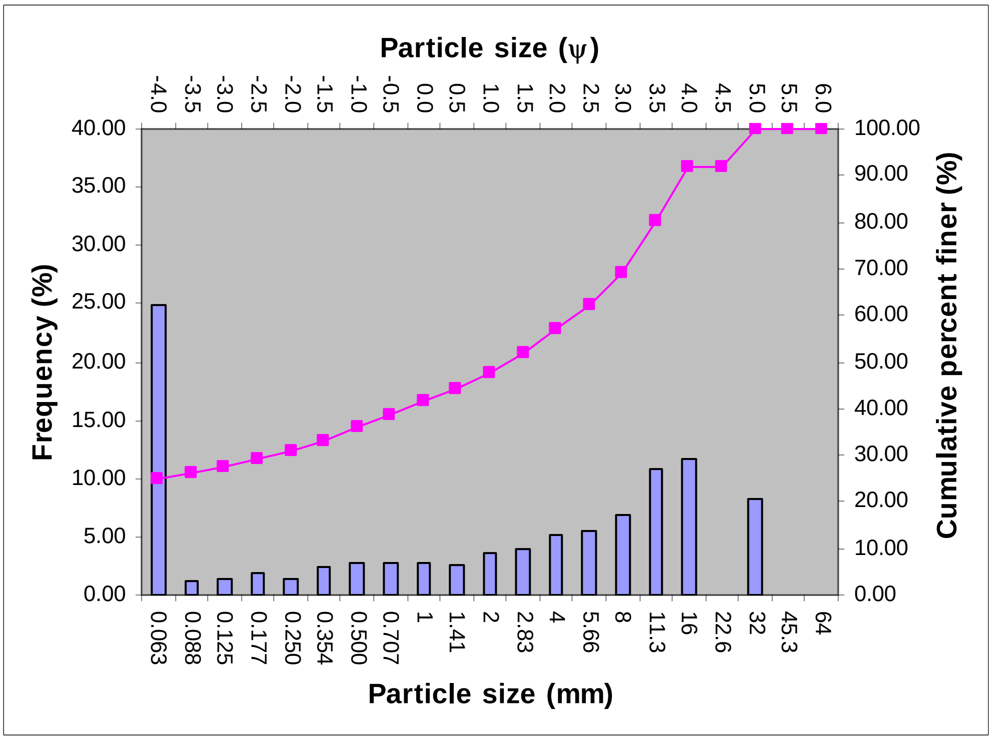
River Eden: Site 7: Upstream of cross section 5 (Grid ref: 550277, 145646)



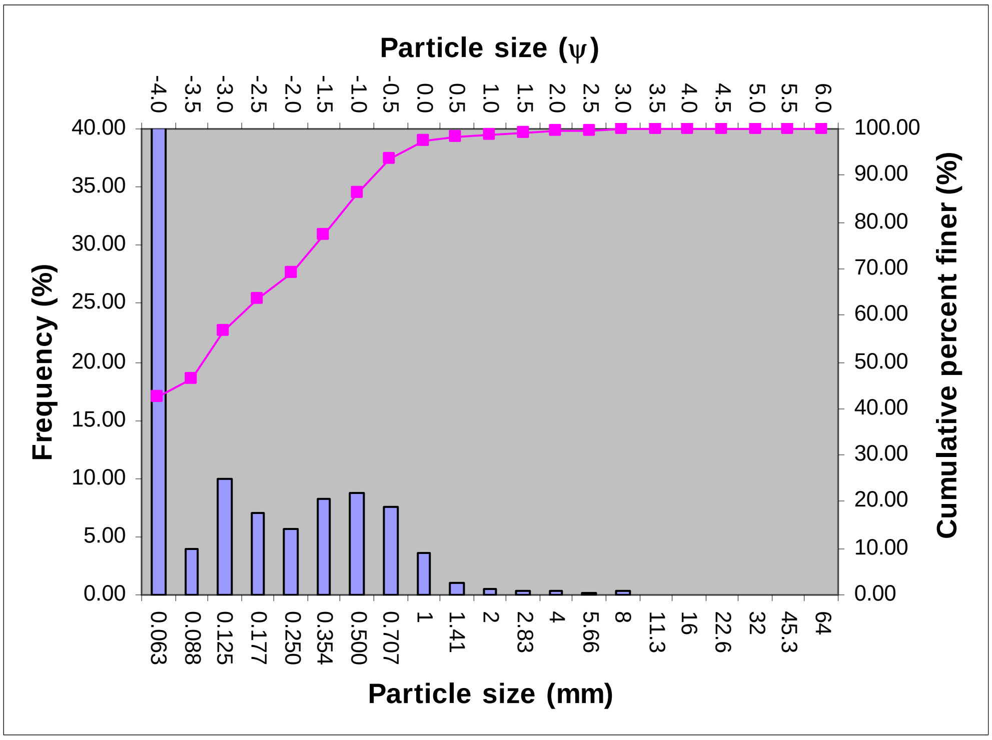
River Eden: Site 7: Fines on surface upstream of cross section 5 (Grid ref: 550277, 145646)



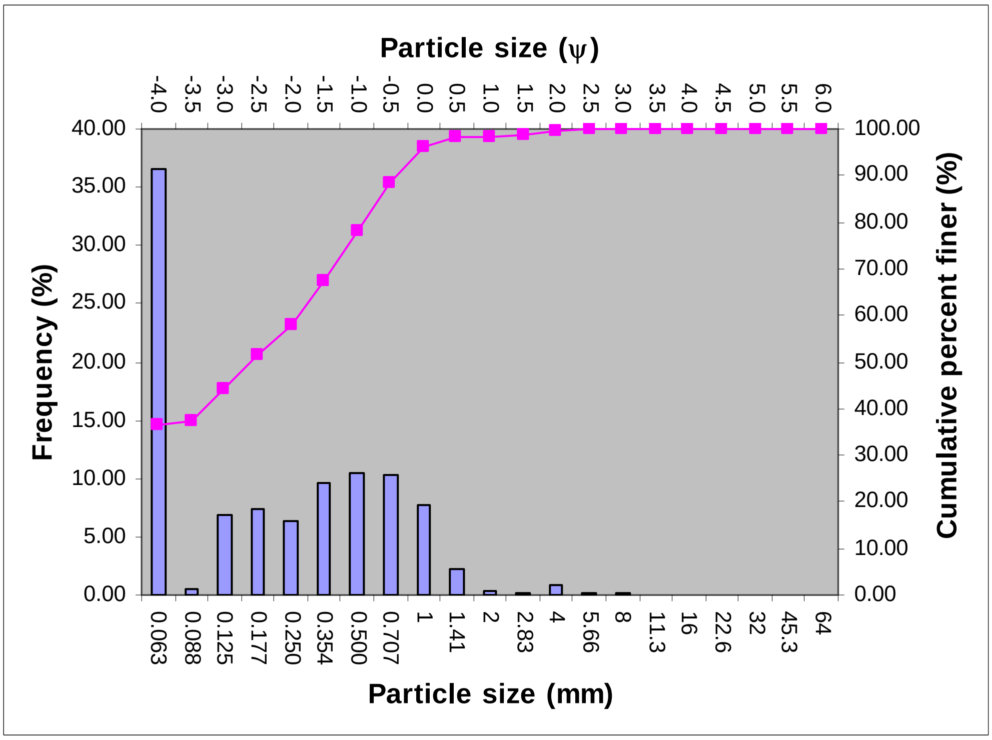
River Eden: Site 8: Cross section 4 (Grid ref: 550489, 145663)



River Eden: Site 9: Cross section 3 (Grid ref: 550518, 145629)

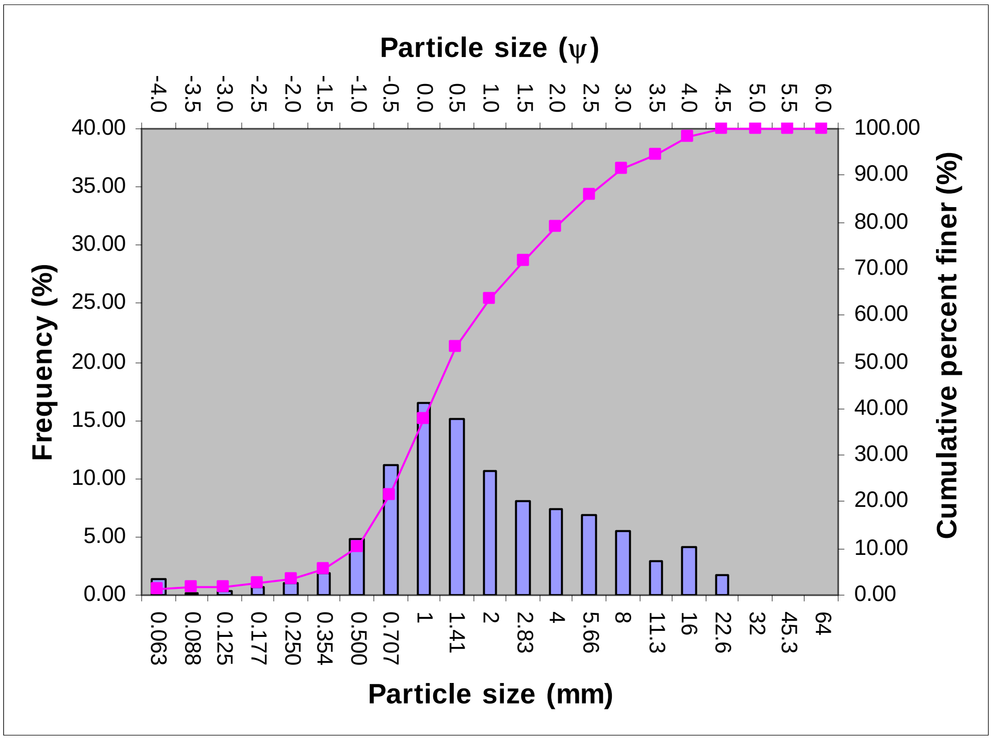


River Eden: Site 10: Cross section 2 (Grid ref: 550880, 145560)

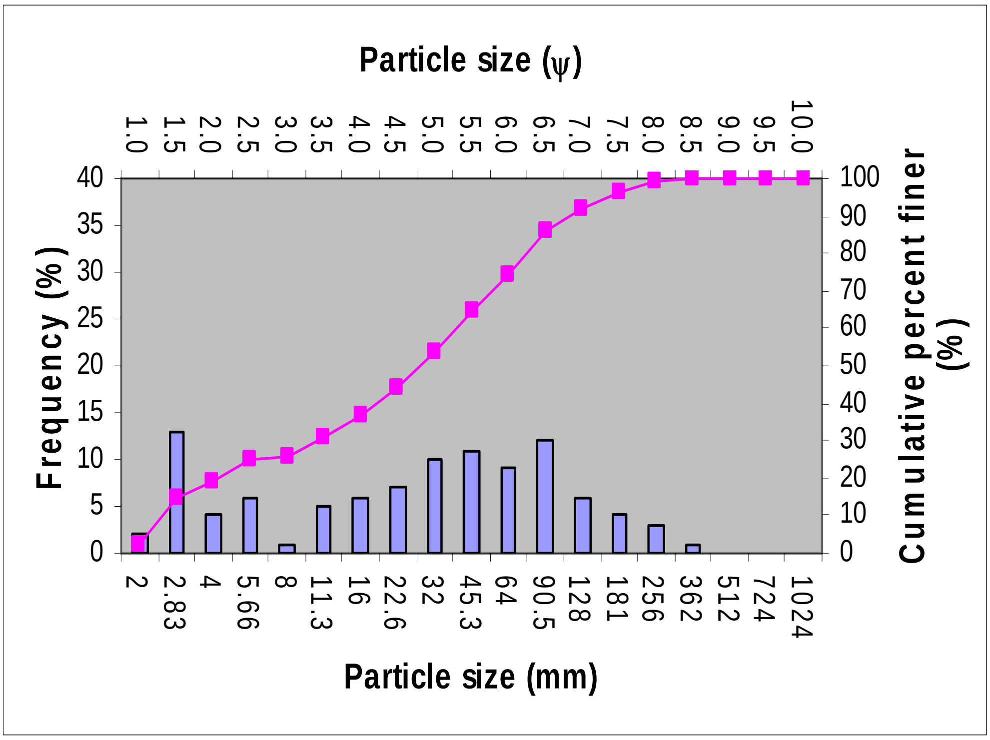


River Eden: Site 11: Vexour Bridge (Grid ref: 551080, 145590)

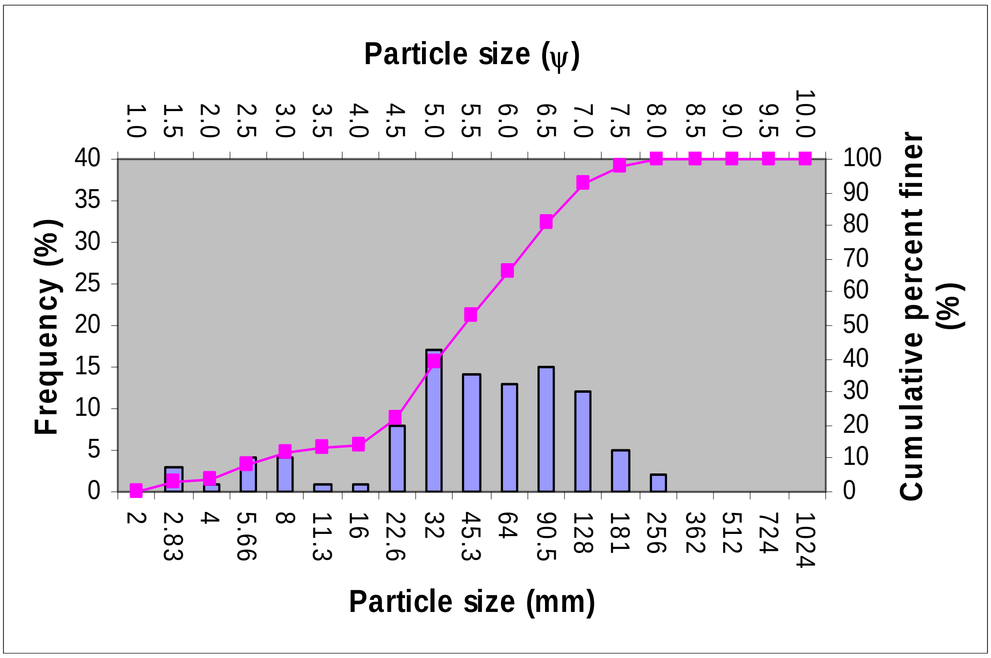
Annex 4 River Harbourne: Bed sediment composition



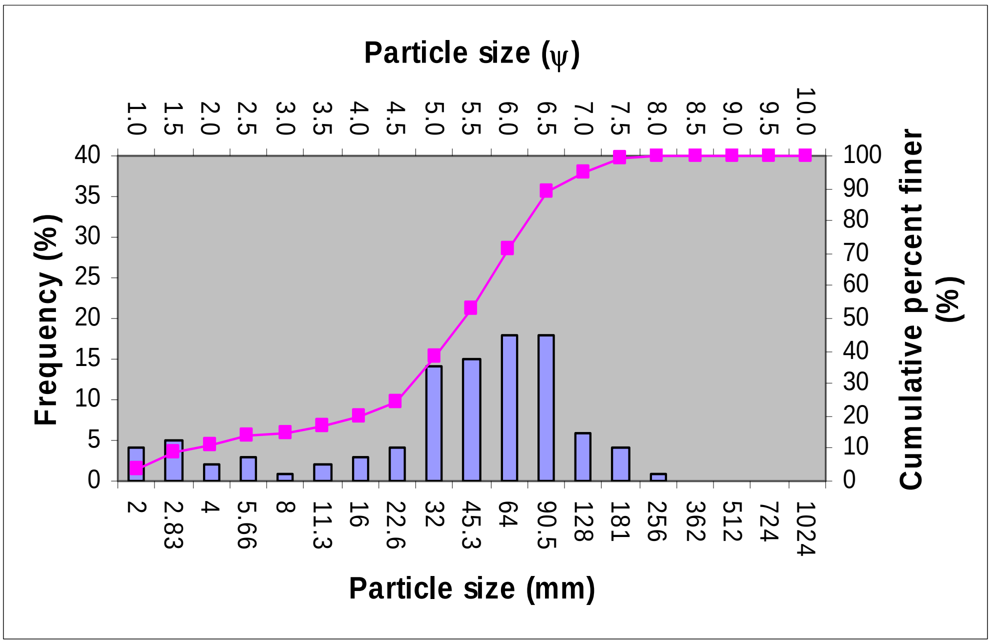
River Harbourne: Site 1 (Grid ref: 277697, 55956) - sample obtained from pool downstream of flood control structure



River Harbourne: Site 2 (Grid ref: 277739, 55975)



River Harbourne: Site 3 (Grid ref: 277904, 56047)



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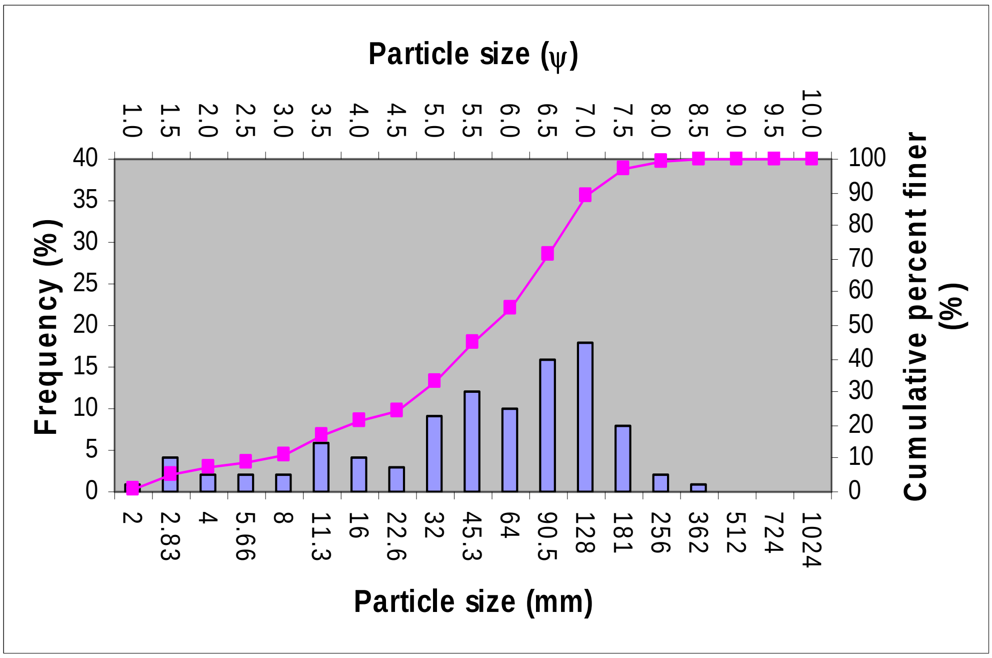

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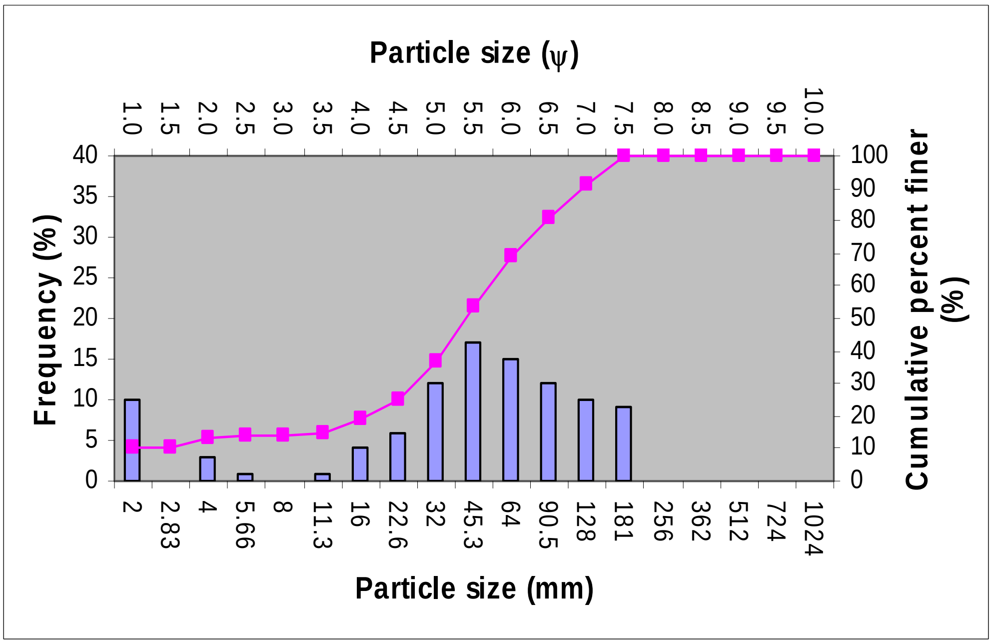

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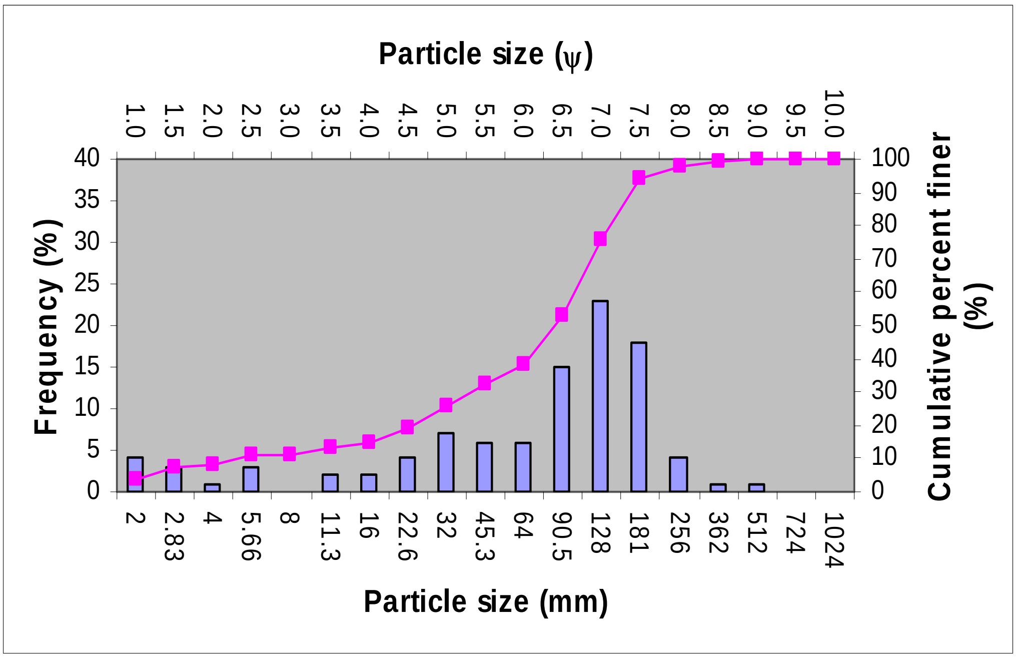

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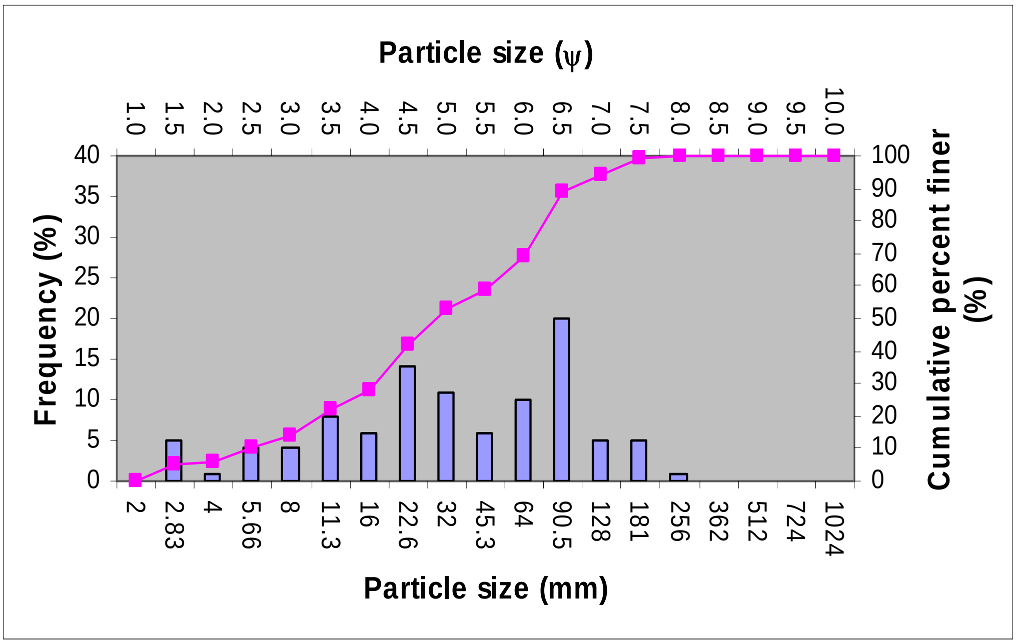


River Harbourne: Site 10 (Grid ref: 278919, 56263)

Appendix 8 Summary of Environment Agency maintenance manuals and other related documents provided by EA area offices

1. Aim of Task

The main aim of this part of the project was to provide an assessment of local area Environment Agency office river management protocols by contacting each area office.

Completing this task provides an overview of the different approaches to river maintenance adopted in different areas and, more importantly, associated local documents. This provides a support document of the main core site analysis of this project in terms of the practical outcomes of the research when compared to current on-the-ground practice.

2. Key Aspects of Appendix

The Appendix provides a summary of collated documents related to the river maintenance. These have been collected through River Restoration Centre's main Environment Agency contacts database. The main contacts, area offices and key responses are highlighted in Table 2.1. Overall the response was reasonable good with about 80% of areas responding and all but 30% of respondents providing information that was specific to that area. Interesting, only one area referred specifically to the "Environment options for flood defence maintenance works" (Environment Agency, 2003), whereas one might have expected most areas to have identified this as a key maintenance text. That said, some areas have clearly extracted specific parts of this document as was felt appropriate for a specific area's river type and maintenance issues. Area specific documents have then been formulated. This is not, however, the case in all areas and additional discussion with operational delivery personal, suggests that in many areas river maintenance is based on individuals local knowledge and past experience; thus often protocols remain in those individuals heads/vision rather than being clearly documented.

The appendix has been divided into three main sections comprising:

a) A general overview of weed cutting recommendations based on area Environment Agency protocol but (including the main outputs from the Environment Agency 2003)
b) Other reference material including scientific literature relating to specific habitat issues and maintenance commissioned for specific rivers;
c) A small section on gravel removal issues.

The written text is supported by various tables including Tables 3.2 and 4.1 which provide specific information relating to watercourses as provided by Environment Agency staff over and above that discussed in Sections 3, 4, and 5 below.

3. Environment Agency internal references

3.1 ENVIRONMENT AGENCY (2003) REFERENCE MANUAL

"Environment options for flood defence maintenance works" (Environment Agency, 2003) is a reference manual that collates the EA recommended options for weed control and de-silting works. Generic site specifications have sometimes been developed especially for those areas where rare or sensitive species are identified.

Three weed cutting techniques are proposed in the EA recommendations: weed cutting, weed-cutting by boat and weedraking. These guidelines vary depending on the “water course conservation value”. The higher this conservation value is, the lower the impact of the maintenance works. A brief summary of the recommendations is provided in the following paragraphs:

Weed cutting scenarios (W1-W9)
Text recommends that the works is carried out in summer. In all there are 9 weed cut scenarios, see Figures 3.1 and 3.2 as examples. However, the amount of weeds left remaining depends on the conservation value of the watercourse as summarised below

A. High flood risk areas: weed cut should be carried out on one bank only. Refuges areas are to be created where possible. Works should be carried out to prevent any top or bank soil being exposed and ensuring bed material is not disturbed. Weed cutting is carried out up to 1 m from the summer water level and the weed is cut back to within 75-100 mm of the bank surface.

B. High conservation value: an uneven margin to be left on one side and maintenance is carried out on the other side. A minimum of 10% retained margin should be left and vegetation inside the channel should not be cut if depth is less than 150 mm.

C. Highest conservation value: the retained margins are left on both sides and are cut on rotational 3 to 5 year basis. Weed-cuttings are always placed as far from the channel as possible.

Weed-cutting by boat (WB1- WB2)
Here the weed cut is within the 80% central area of the river. A minimum of 10% retained margin is left when the channel width is less than 10 m and 20% if the channel is greater than 10 m wide. For watercourses with higher conservation value, weed will be removed from 2/3 of the wetted perimeter annually and infrequent cuts will remove 4/5 of the wetted perimeter. Weed-cuts will not be carried out at channel level; 100 mm height will always be left.

Weedraking (WR1- WR2)
Where this is recommend as a maintenance option it is suggested that it is carried out in 100 m sections on 3 to 5 year basis.

The manuals other key recommendations
The manual is comprehensive in its maintenance work options and includes options for tree cutting along banks (i.e. removal of lower tree branches and bush removal on embankments and banks; pollarding and desilting). Of particular note is that the guidelines state that all desilting options must be accompanied by a detailed environmental specification.

Increasing Conservation Value

OPERATION	ENVIRONMENTAL OPTIONS								
Mowing	M1			M2	M3			M4	M5
Mowing Raised Banks	ME1			ME2	ME3			ME4	
Mowing Tidal/ Sea Banks	MS1			MS2	MS3			MS4	
Weedcutting	W1	W2	W3	W4	W5	W6	W7	W8	W9
Weedcutting by Boat				WB1	WB2				
Weedraking				WR1	WR2				
Desilting	D1			D2	D3	D4			
Pollarding								P1	
Tree and Bush Management Embankment	BE1			BE2	BE3				
Tree and Bush Management	B1			B2	B3	B4			

The Environment Agency has been provided with advice on how our routine maintenance can incorporate best practice for the following protected species: bats; birds; otters; water voles; amphibians and reptiles. Where possible we have incorporated this advice into the environmental options. Where we have not incorporated this advice we have indicated that carrying out an option can have a high risk of adverse impact upon protected species and recommend effort is made to identify potential habitat and carry out mitigation/ enhancement measures where present.

Key
High risk of adverse impacts upon protected species
Medium risk of adverse impacts upon protected species
Low risk of impact upon protected species

Figure 3.1 Summary of key operations in outlined in the 'Environment options for flood defence maintenance works'

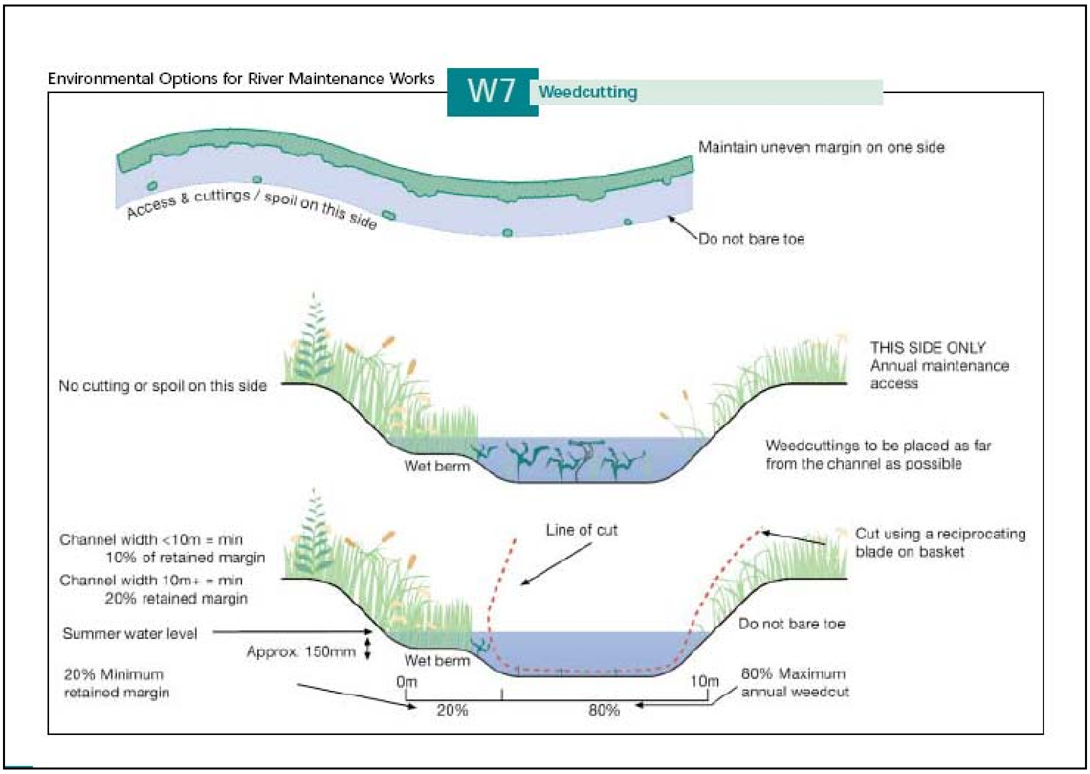


Figure 3.2 Example of weed cutting regime (W7)

3.2 SUMMARY OF WEED CUTTING SUGGESTED OPTIONS FOR SOUTHERN REGION (2004)

Whilst this manual is based, and indeed reiterates many of the points outlined in the above manual, the Environment Agency (2004b) Southern Region manual provides additional practical guidance for maintenance works carried out in its region. The document highlights that, when planning the annual maintenance programme, the contractor must be advised to:

- Survey the site to establish the presence, location and extent of wildlife.
- Be aware of the crayfish plague (how to prevent it from spreading)
- Prevent the spread of invasive weeds.
- Not to carry works at specific times of the year that may that may alter the habitat of fish spawning (October-April for salmon, trout and sea trout, and April-June for dace and chub), water vole (March-October) and breeding birds (15th March to 15th July).
- Avoid water pollution as a result of de-silting, oil leaks or decomposing vegetation.

The good practice guide mentions three possible ways to manage weeds in rivers; cutting, spraying and de-weeding. When weed-cutting is applied, the work is carried out from mid-July/August through to November to minimise disturbance to wildlife. The cut material is placed on the banks. The aquatic margins must be retained to take into account the conservation interest of many watercourses. A minimum vegetated margin of 20% across the water surface is recommended to be retained. Where possible, the cutting should be alternated between banks: the bank that remained un-cut the previous year will be cut in the subsequent year. This will help to reduce the chance of margins becoming too consolidated with depositing silt. A set of diagrams similar to those in Environment Agency (2003) are provided for weed cutting.

Weed spraying must be timed properly according to the habitat requirement of wildlife. The majority of emergent and floating weeds are treated by direct spray application. The ideal timing is mid to late summer to avoid birds and insects breading seasons. Submerged weeds and algae are treated in the spring or early summer when they are young and more susceptible. Limited recommendations are provided for de-weeding.

Environmental impact assessment procedures (EIA)
A flow chart is included in this document to ascertain the need for an EIA. In addition a table is included which clearly states the appropriate level of EIA and consenting regime for agency projects which include activities such as watercourse dredging and channel works.

3.3 REVIEW MAINTENANCE AND OPTIONS FOR THE LAMBOURN (2004)

The Environment Agency and English Nature (2004a) carried out a study to identify the potential impact of weed-cutting on Brook Lamprey, the Bullhead and the Ranunculus communities in the Lambourn River. For the Brook Lamprey and Bullhead the expected impacts were:

direct physical damage to spawning gravels by the operations,
disturbance of spawning adults,
disturbance and damage to occupied nursery sediment beds,
loss of macrophyte cover in the absence of stony substrate,
loss of invertebrate food items in the absence of macrophyte invertebrate habitat and
loss of heterogeneity of channel habitat structure.

Ranunculus communities were expected to have a stimulation of the growth rate (e.g. cuts before flowering can lead to growth increase in the following winter) and a reduction of the biomass of the population by self-shading and natural wash-out. The study showed that many of the reaches observed have been cut for decades without any observable reduction in plant vigour. A set of guidelines were drawn up after analysing all the potential impacts and each specific maintenance reach is identified with guidelines tailored to particular needs.

3.4 REVIEW OF MAINTENANCE AND RECOMMENDATION FOR THE AVON (2000)

Menendez (2000) produced a review and recommendations on routine main river weed cuttings carried out by the Environment Agency on the Avon River. The works considered are routine main river weed cuts on the Lower Avon and free weed cuts by fishermen on the Upper Avon and tributaries. In 1998 there were 6 routine weed-cutting works in the Lambourn and a monitoring programme was carried out on the banks during two of the cuts. The impacts of the works on habitat and species were assessed. Results showed that the impact can be more harmful than beneficial and so a set of guidelines to decrease the impacts of weed-cutting works were developed. The main impacts identified were:

- Decimation of Ranunculus beds.
- The communities identified in the areas were free weed-cutting has been implemented since 1830 are a product of the weed cutting regime (Lewis, 1997 in Menedez, 2000). A 50% of Ranunculus biomass loss is expected if the weed-cuttings are stopped for four years (Dawson, 1978 in Menedez, 2000). An impact on Ranunculus communities will also be expected. If weed-cutting is stopped on shallow reaches, the system will revert to very narrow channels within swamp and wet woodland with a totally changed aquatic community.
- The weed cuts drained adjacent land and drains affecting important habitats (e.g. Marsh Stitchworth).
- Weed-cutting (Green et al, 1986 in Menedez, 2000) will reduce food and refugia available for the spawning and recruitment of coarse fish. Green et al (1986 in Menedez, 2000) found a rapid decline in planktonic Caldocera due to weed-cutting, followed by a rapid decline in the growth rate of Roach. The major food source of coarse fish is macroinvertebrates, which are generally found in aquatic weed. Weed-cutting removes considerable number of macro-invertebrates, this having a detrimental impact on survival and growth of fish.
- An increase in mortality of Brown trout and fry due to weed-cutting was reported
- Weed-cutting favours uniform flow and scour (Ward et al 1994 in Menedez, 2000) not favouring the salmon populations of the Avon.
- Weed-cuttings increases the water flow, favouring the Ranunculus, but only if the Ranunculus can survive the cuts, the deeper silty river bed and the competition from other re-growing plants.

3.5 RIVER STOUR MAINTENANCE (2006)

Impacts during and after the 2005 weed control works in the Kent area have also been reported by the Environment Agency (2006). The propeller during the weed cutting works disturbed the silt riverbed and caused a depletion of oxygen levels. Fish stress incidents and more than 100 dead fish were observed. This impact is greatest in warm weather and in slow / low flow rivers with silt substrate. In the Little Stour, weed was traditionally removed annually or biannually for the full width of the river. These issues have resulted in the maintenance manual for the Stour catchment that also provides details of when it is appropriate to carry out weed cutting to ensure that fish habitat is not adversely affected, see Figure 3.3, and this information is supplemented with maps providing information about how management at different reaches should be administered, see Figure 3.4. The weed cut management was changed so a wide marginal fringe and submerged plants were left uncut. Water crowfoot appeared after the management change; water velocity in the narrowed channel scoured out lanes creating habitat for water crowfoot. A pilot study was proposed for a 700 m stretch at the Little Stour to see the effects that weed cutting has on biological communities and the geomorphology of the river channel. No information has been collated regarding this study.

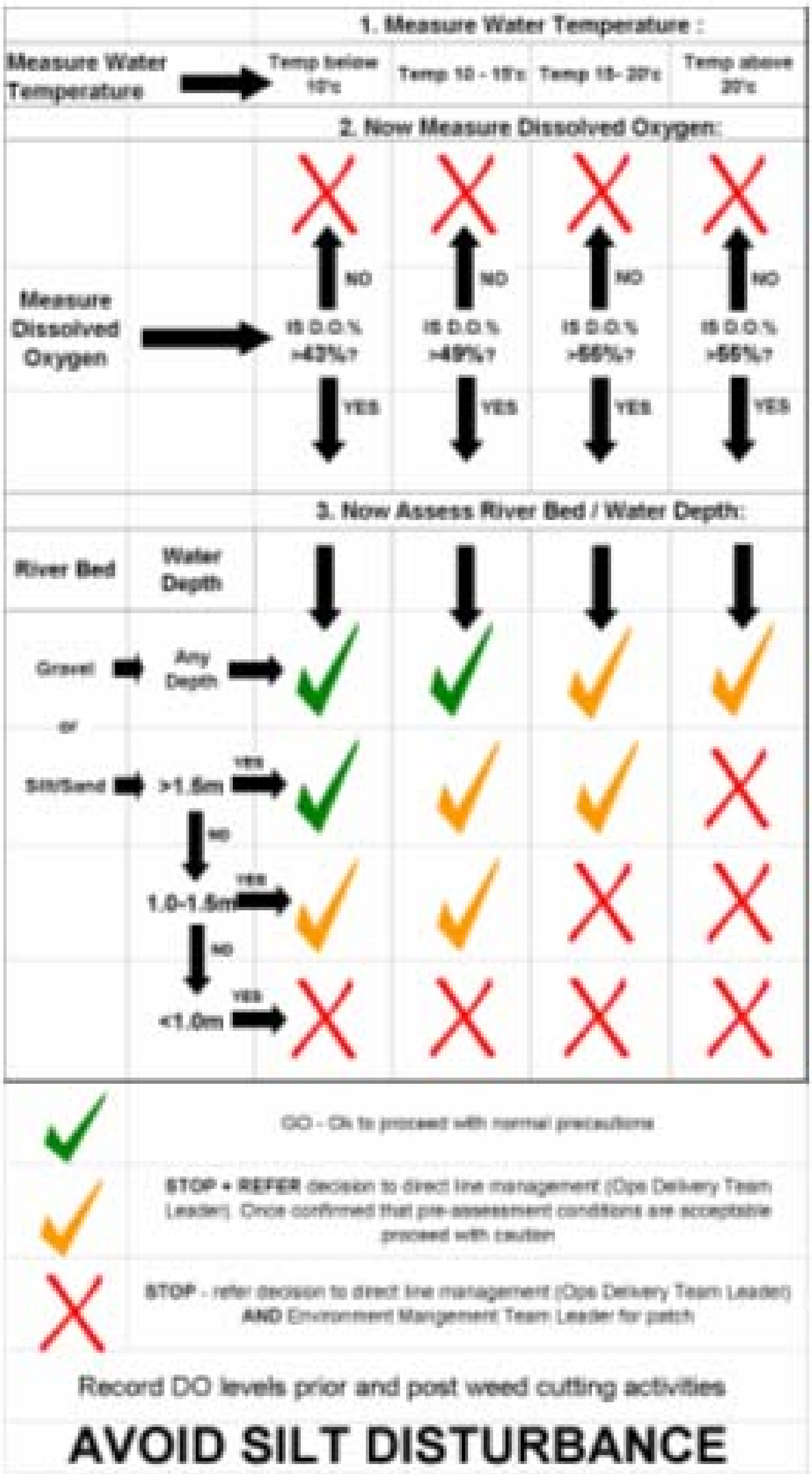


Figure 3.3 Example from the River Scour maintenance recommendations to ensure fish habitat is not adversely affected

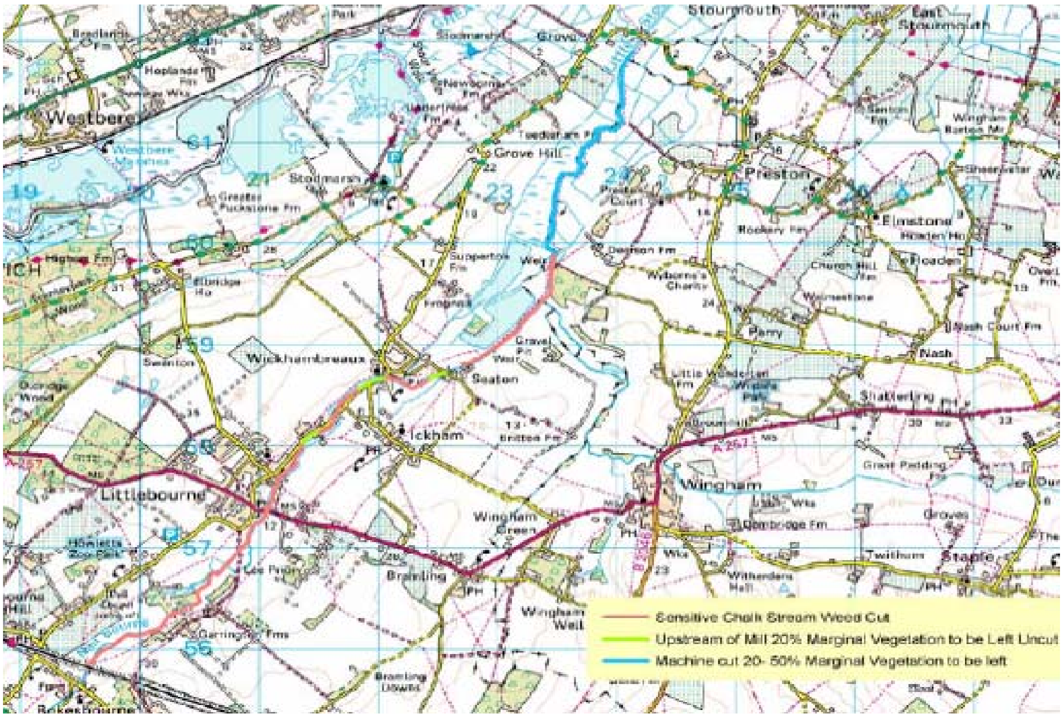


Figure 3.4 Maps providing information about how management at different reaches could be approached

3.6 SOMERSET RIVERS AND COVE BROOK FLOOD STORAGE AREA, LONDON

In many areas maintenance is based on a series of spreadsheets and grid references rather the map references to reach, see Table 3.1. Most of the rivers in the Somerset area are maintained in this manner with recommendations included for weed cut types based on the Environment options for flood defence maintenance works (2003) and sections of that text used as an example, see Figure 3.5. Cover Brook takes a similar format, although in this system there is more emphasis on specific management on a reach by reach basis.

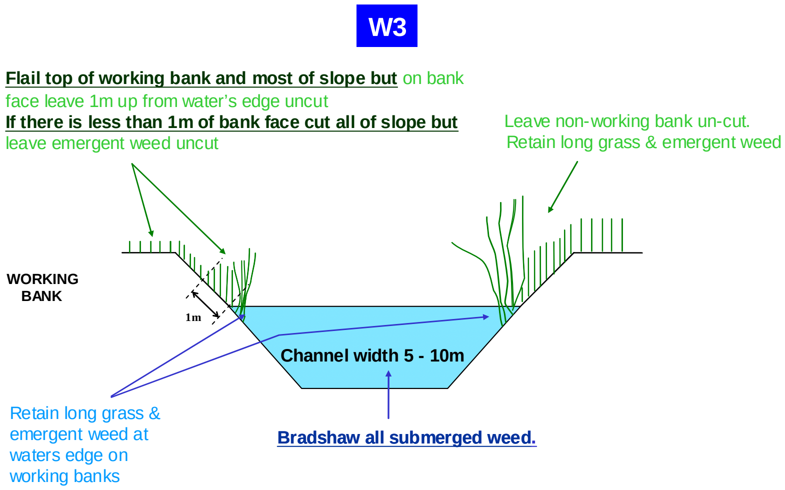
3.7 KEY NOTES FROM SECTION 3

There is a wide range of approaches adopted throughout area offices in terms of current maintenance options, see Tables 3.2 and 3.3. Whilst many have adapted Environment Agency's Environment options for flood defence maintenance works (2003) for their specific range of river types and many have aimed to take account of habitat requirements there has been little internal assessment of what these maintenance regimes actually imply in terms of linkage between flood risk management objectives and the morphological/ecological regime which adds further credence for this piece of R&D work.

LENGTH		DESIGNATED SITE			WEEDCUTS				FLAIL CUTS			
metres	**Channel width (m)**	Designation	OLD SPEC	**SPEC**	No. cuts per year	1ST CUT	2ND CUT	MACHINE(S)	BANK No. cuts LEFT	BANK No. cuts RIGHT	MACHINE(S)	**COMMENTS**
2480		No	L	W5 (FB)	1/2	JUN	SEP	50' (small bucket) or 40' (13t)	1	1	Flail	Possibly 10.1m - 13T tele slew after Hixham Rhyne
220		No	L	W5 (FB)	2	JUN	SEP	50' (small bucket) or 40' (13t)	1	1	Flail	
6720		No	L	W1	1	AUG / SEP		Hand strimmed	1	1	Strimmer	No machine access (gardens). Channel <2m wide & important for flood evacuation, hence W1.
4320		No	L	W1	1	AUG / SEP		Hand strimmed	1	1	Strimmer	No machine access (gardens). Channel 2-3 m wide & important for flood evacuation, hence W1.
2480	**0-5**	No	K	W6 (FB)	2	JUL	SEP	Herder	1	1*	Flail	* OR cut alternate banks so that each bank is cut once per year

Table 3.1 Example section of spreadsheet use in Somerset area

NO FLOODBANKS
BRADSHAW WEED CUTTING & TRACTOR FLAILING



NO FLOODBANKS
BRADSHAW WEED CUTTING & TRACTOR FLAILING

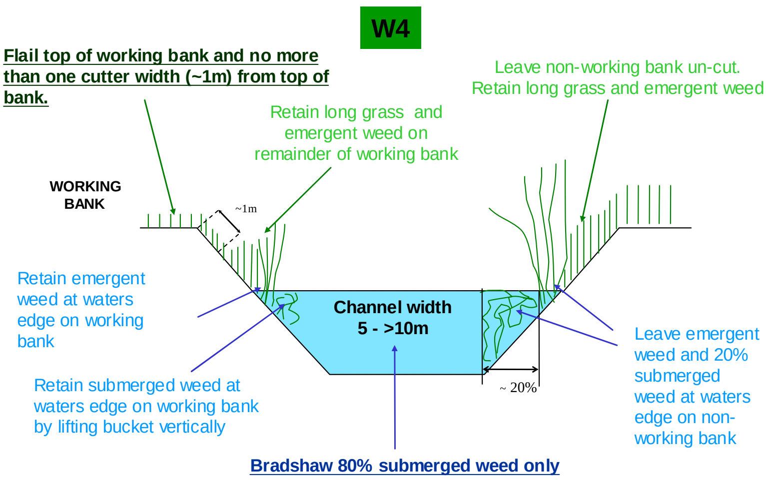


Figure 3.5 Example of diagram adapted from the Environment options for flood defence maintenance works for Somerset area

Table 3.2 Summary of discussion above regarding maintenance of various rivers systems within the Environment Agency areas

Document	Key points	Benefits	Suggested Limitations
Environmental options for river maintenance work (EA 2003)	Provides guidance on weed cutting (W1-W9) weed boat cuts (WB1- WB2); weed raking (WR1-WR2) plus tree and bush management and desilting for a range of environments	1. Provides a good overall summary and a clear focus and guidelines for work	1. Looks at current sensitivity of site – not necessarily aimed at improving site 2. Diagrams are very generic in design – some photos would enhance document 3. Basis of document – i.e. scientific basis not clear from information 4. How widespread this concept is being used (on the ground) within the Environment agency is unknown
Conservation and the flood defence maintenance programme: Southern Region (EA 2004)	Provides local guidance on weed cutting. Based on EA 2003 (as above). Additional information in appendices related to when an EIA may be necessary and the implication of maintenance on SSSI	1. Provides a good overall summary and a clear focus and guidelines for work 2. Useful appendices for permissions and EIA requirements	1. Looks at current sensitivity of site – Key information (i.e. EIA assessment etc that might result in site enhancement is housed as appendices rather than integral to document – might lead guidance not always being used a frequently as could be? 2. Diagrams are very generic in design – some photos would enhance document 3. Basis of document – i.e. scientific basis not clear from information
Lambourn (2004)	Manual designed to protect Brook Lamprey, Bull Head and Ranunculus. Maintenance specified for different reaches (e.g.) 1) Rack Marsh (Bagnor) weed cut only marginal vegetation; no Ranunculus cut. 2) Bagnor Manor/Woodspeen - minimum 30% macrophyte growth retained; where cress is dominant Ranunculus not cut. 3) Boxford - cuttings carried out 2 -3 times/year; minimum 25% macrophyte growth retained.	1. Provides precise guidance for specific reaches 2. Designed to used in conjunction with EA 'Environmental options for river maintenance work'	1. Requires understanding of specific river system
Stour (2006)	Rivers in region classified by flood risk risk: High (retain 20% of the vegetation) Medium (20-50% of the vegetation cut); Low Flood (+ 50%). Guidelines based on hydraulic efficiency V percentage weed cut graphs. Sensitive weed cuts are applied in specific sites (e.g. chalk rivers). The	1. Details guidance including information about fish benefits 2. Aiming to improve river course rather	1. Guidance diagrams still from the 'Environmental options for river maintenance work' on weed cutting specification and would benefit from some real example photographs

	Little Stour River considers water voles, Ranunculus, Bull Head and Brown Trout habitat so weed cut carried out to modify the channel and restore water depth and flow and prevent drying up. In general for Nairbourne and Little Stour: 1) No maintenance works carried out between the 15th March to 15th July 2) Weed cut not undertaken from November to April to protect trout spawning. 3) Minimum 20% wet channel should remain uncut. 4) Margins left uncut one year then cut following year to reduce silt consolidation. 5) Cut vegetation and spoil not be placed on the retained margins, but place on the top of the bank. 6) No weed removed if %DO <43% or in channels shallower than 1 m. (matrix provided	than keep status quo 3. Good maps and more detailed insert specifying what is required at different reaches 4. Clear guidance on the need to include the biodiversity team if options differ on site.	
Somerset Rivers	A spread sheet that summarises maintenance requirements and machinery required	1. Clear instructions on a reach by reach basis	Would benefit from photos to illustrate sensitivity

4. Independent environmental guidelines

4.1 VEGETATION MANAGEMENT IN CHANNEL

In additional to the manuals outlined above, a limited amount of independent guidelines and studies have been completed that should also be mentioned.

Ward (1996a, 1996b) provides a set of guidelines to facilitate the selection of vegetation maintenance practices which are best for wildlife. The first step of these guidelines is to determine the "wildlife quality" and the river category. "Wildlife quality" is assessed by completing a checklist form with riverine features that indicate high quality and comparing the reach with reference photographs. The river category is assessed from the gradient and the bed width. A list of maintenance practices is scored and classified into "unacceptable", "poor", "acceptable", "best" and "very best" for each "wildlife quality" and river category.

In addition the effects or potential effects of weed control on fauna, flora and river habitat is documented in several studies and impact assessments (Environment Agency, 2004a; Menendez, 2000, Environment Agency, 2006a and 2006b, Garner et al, 1996, Aldridge, 2000, Kaenel et al, 2000 and Dunderland and Morris, 1996). These research studies have been completed by organisations that are independent of the EA are summarised below:

Garner et al (1996) studied the effect that macrophyte removal had on zooplankton distribution and 0+ roach (*Rutilus rutilus*) distribution, diet and growth. The study was carried out in the River Great Ouse (UK). Monitoring took place before, directly after and a few weeks following weed-cutting operations. Results showed that removal of all but a 2 m marginal strip of macrophytes decreased the mean densities of planktonic Cladocera and a rapid decline in the growth rate of roach as they started to feed on less nutritious aufwuchs. The study suggests that weed cutting adjacent to one bank in alternate years is enough to prevent loss of channel capacity and will provide refuge for fish and zooplankton.

Aldridge (2000) studied the impact of dredging and weed cutting on the population size, structure and distribution of four species of unionid mussel. The study was carried out at Wicken Lode (Cambridgeshire), a watercourse that flows through Wicken Fen National Nature Reserve. Results showed that dredging caused reduction of up to 23% of the population for some species whilst weed cutting removed a maximum of 3% of the population of any species. However, the higher frequency of weeding works resulted on a decrease of the population similar to dredging. The impact in the case of unionid mussel can be reduced by cutting only within the centre of the channel and cutting marginal vegetation to 5 cm above the river bed.

Kaenel et al (2000) studied the impact of macrophytes removal on stream metabolism and oxygen balance. The study was carried out in two Swiss streams. The concentration of dissolved oxygen was monitored before and after removal and the gross primary production and ecosystem respiration was calculated. Results showed that only one site showed impacts to weed removal; gross primary production and ecosystem respiration were reduced by about 70%. Only moderate increase in nocturnal oxygen concentration was observed. This suggests that the increase in the oxygen concentration after weed cutting is transient in unshaded, nutrient-rich streams.

Dunderland and Morris (1996) developed guidelines to enable Flood Defence staff to justify and prioritise maintenance programmes and to determine best environmental practice for river maintenance. For this purpose a study of the impacts of maintenance works was carried out on 12 river sites in 5 NRA regions in England and Wales. HR Wallingford developed a numerical morphological model to assess the impacts of maintenance works on sediment movement, erosion and deposition. Widening, deepening and weed-cutting were the maintenance works simulated by the model in idealised sand, silt and gravel bed channels. The impacts on water discharge and water depth over a 30 year period were assessed. A set of tables were provided to determine for how long and by how much deepening and widening the benefits of reduced water depths and increased bankful discharge are retained after the maintenance works. The type and extent of potential impacts on aquatic and bankside vegetation, adjacent and field natural vegetation, aquatic invertebrates, fisheries, birds and mammals were assessed from River Corridor Surveys. The RCS was carried out at each river at a 500 m section and concentrated on the immediate corridor of adjacent land (50 m either side of the banks). The impacts assessed were: change in cross-section, predominant bed material, degree of irregularity of channel sediment, relative effects of obstruction, vegetation, degree of meandering and groundwater - drainage impacts. RCS pre and post maintenance are presented within the scheme reports.

4.2 KEY POINTS FROM ABOVE

- Work in Ward 2006a and 2006b provide an example of how ‘real’ examples might be able to help in terms of having a better idea of what is meant by guidance diagrams.
- Keeping one marginal edge intact each year should be sufficient to prevent loss of channel capacity and will provide refuge for fish and zooplankton.
- For some species, higher frequency of weeding works can result in a decrease of the population similar to dredging but reducing cutting to the centre of the channel and cutting marginal vegetation to 5 cm above the river bed may help significantly.
- Increase in the oxygen concentration after weed cutting is transient in unshaded, nutrient-rich streams.

5. Gravel removal

Part of the flood risk management maintenance works is the removal of gravel from the river bed to increase the discharge capacity. The potential impacts of gravel removal are site specific but, in general, include:

changes in the flow and velocity regimes,
turbidity,
siltation,
physical damage,
toxicity,
habitat loss and simplification of habitat,
destabilisation of channels,
increased and unpredictable rates and patterns of incision/erosion/deposition and mobilisation of heavy metals and nutrients due to re-suspension of sediments (poor water quality).

This may affect species of special interest such as: Bullhead, River Lamprey, Brook Lamprey, Atlantic Salmon, Ranunculus and otter. The alteration of the sediment regime of the river may affect habitats (e.g. salmon and lamprey spawning and nursery habitats, lying up sites for adult fish and invertebrates) through erosion and sedimentation. Breeding birds that nest in gravel banks at the margins of rivers (e.g. oystercatcher, redshank, common sandpiper, little ringed, grey plover, sand martin and kingfisher) may be affected by the removal of gravel bars and shoals required for their survival. Alien invasive species (e.g. Japanese knotweed) may take advantage on exposed shingle banks and colonise these areas. The Environment Agency has started a geomorphological investigation to establish the effect of gravel removal on the sediment regime and morphology of the river.

The Environment Agency policy on the removal of gravel from rivers (Environment Agency Policy number 359-04) states that the EA is generally against the removal of gravel from rivers. Gravel removal is only allowed for navigation or where proven essential for flood risk management or water supply purposes. In those cases, studies that ensure that the practice is sustainable and environmentally acceptable over the long term will be developed. Best practice guidelines will be developed for gravel removal for each particular case. These guidelines must include the following information:

- A demonstrable strategic approach to the problem.
- The consultation and liaison procedures to be followed
- Pre-works surveys to define the location/extent of biodiversity interests
- Assessment of impact on geomorphology
- Location, extent and timing of works
- Method for working and use of machinery
- Specific measures to minimise the mobilisation of sediments
- Restoration measures
- Disposal of material and
- Appropriate monitoring programme to assess the impact of works and aim achievement.

Table 5.1 summarises the sites for where specific information regarding gravel removal has been collated.

Environment Agency (2004b) provides a “good practice guide” for shoal digging and gravel removal in rivers. The guide recommends:

(i) to carry out pre-work surveys to establish the location and extent of biodiversity interests,
(ii) to assess the geomorphological impact and
(iii) to define the location, extent and timing of works.

Works should be carried out between the 14th of August and the 30th of September to avoid disturbances to spawning fish and breeding birds. The dredging must be carried out in as small and shallow an area as practicable, not removing material below summer water levels and moving along one bank only. A proportion of the gravel shoal must be left untouched so re-colonisation can be granted. Specific measures should be taken to minimise the mobilisation of sediments and restoration measures considered when the works have finished. The extracted material must be disposed and re-use of gravels for biodiversity projects considered. The guide of good practise provides a set of tables where the appropriate level of Environmental Impact Assessment is defined for each of the maintenance actions (i.e. control of aquatic vegetation and gravel removal). A chart diagram that informs of all the legal steps/ legal documents to be completed before each activity is also provided.

6. Summary

Some of the key findings from this trawl of literature based on local Environment Agency area offices recognise that there appear to be two primary ways of going about maintenance. In essence these either relate to using the key Environment Agency Flood management text (2003) and adapting it to specific usage within the area, or, alternatively, management relates to individuals knowledge of catchment and what is perceived to be the best management of particular sites. This is presumably based on what has happened before and thus may result in a system of status quo rather than analysing whether or not a change of maintenance that more directly takes account of the morphological and ecological regime of a river system.

Some of the independent research has suggested, however, that, depending on the frequency of weed cutting, it can, in some cases, be almost as detrimental to some species as dredging.

This review is primarily meant to bring together an overview of current practice across the Environment Agency area offices to help to put this R&D project into context in terms of what is happening on-the-ground outside those sites chosen for the detailed investigation which forms the basis of this project.

The survey of the advice currently available shows a number of features. There appears to be no centrally available advice on sediment issues and desilting. A number of regions of the Environment Agency have prepared their own advice or procedures but these do not seem to have been universally adopted. The practises appear to vary across the Environment Agency. This may not be surprising as the sediment related problems vary widely across the different regions of the Environment Agency. For example, the sediment issues faced in steep gravel rivers in Wales differ markedly from those to be found in low energy artificial channels in East Anglia. Thus it may not be necessary or appropriate to have national guidelines.

There is currently a lack of guidance on sediment issues and sediment related maintenance in a number of key areas which include:

a) when and how to remove sediment from a river channel
b) the impact in terms of both geomorphology and environment of removing sediment, both within a reach and upstream and downstream
c) impact of not removing sediment on flood levels
d) the relationship between vegetation management and sediment.

It should be noted that a number of these issues should be addressed under the ongoing development of the Performance-based Asset Management System (PAMS). It is recommended that the Environment Agency provide guidance on these issues for

Table 3.3 Specific guidelines for weed cutting collated in this literature review

River	Comments	EA office
Sussex Rifes	Three different types of weed cutting regimes have been implemented at the Sussex Rifes (south of Chichester, West Sussex) according to the degree of flood risk associated with each water course. These regimes have been implemented for the last 2 years. • Cut type 1: regime associated with high flood risk. An intensive cut along one or both banks is carried out with the cutting blades set to 10-15 cm. The vegetation is removed from the majority of the river channel and 20 % of the vegetation is retained in the margins. • Cut type 2: regime associated with medium level of flood risk. Intensive cuttings are carried out in only one of the banks. A narrow fringe of vegetation is retained. 30 % of the vegetation is retained. The opposite bank is left un-cut and a 50-75% of the in-channel vegetation is removed. • Cut type 3: regime associated with a low level of flood risk. Both banks are left intact or there is one bank cut every two year rotation. 50% of the vegetation is retained and only the vegetation from the centre of the channel is removed. A sinuous meandering course is created and the self-cleansing of any silt is encouraged.	(Charlote Murray) Charlotte.murray@envirnment-agency.gov.uk
Nidd	Weed-cutting works must be dones between start of July and end of September. For grass-cutting onecut is done after the end of July.	(Sue Penn) sue.penn@environment-agency.gov.uk
Derwent	Weed-cutting works must be done between start of July & end of September. Specifications for grass-cutting: SSSI grasslands cut after the end of July, Derwent at low marishes undertake 2 cuts (mid-July and end of July). Check the management plan for the Barmby Barrage Amenity Site where different cutting regimes are provided.	
Wharfe	Weed-cutting works must be done between start of July & end of September. Bowlam banks must not be cut until 1st July since they are within Kirkby Wharfe SSSI.	

Ouse	Weed-cutting works must be done between start of July & end of September. First grass-cut may take place in May. Any grass-cutting works on Fulford Ings SSSI, Naburn Marsh SSSI and also Clifton Ings, Rawcliffe Meadows and associated meadows should take place after 1st July.	
Ure	Weed-cutting works must be done between start of July & end of September. Any grass-cutting works on Ripon Parks and Ure Bank SSSI, Hack Fall Wood SSSI, Mar Field Fen SSSI, Ure Grasslands SSSI, Wanlass Grasslands, SSSI, Freeholders Wood and Aysgarth SSSIs should take place after 1st July.	
Swale	Weed-cutting works must be done between start of July & end of September. Any grass-cutting works on the Lower Swale Woods and Grasslands SSSI, Swale Lakes SSSI, Park Hall Meadows-Healaugh SSSI, upstream of Gunner Bridge, flood bank on west bank of Swale opposite Helperby and High Amenity/Urban sites should take place after the 1st July.	
Tees	Weed-cutting works must be done between start of July & end of September. At Lustrum Beck a reedbed was planted in 1999 and thus, reeds must not be cut without advice from Ecologists. The sites at Cowbridge Beck, Billingham Beck, Lustrum Beck, River Tame, Tanton area, Clow Beck, Hutton Magna area, River Skerne, Woodham Burn, Rushyford Beck, Mainsforth Stell, Baydale Beck, Cocker Beck and West Beck have watervoles and thus, specific care must be taken; at least 10% of the vegetation must be left uncut at the margins along the length of the watercourse. Grass-cuts in general must be done between start of June and October. In the low Beck and Tees floodbanks (Croft) it is necessary to carry out a first cut during the second half of April and a second cut during August. Weed-cutting must be carried out at the same time as grass –cutting and no cutting must be done in May, June or July. At the Tees floodbank next to the County Wildlife Site it is required not to encroach onto foreshore during the first cut. The management plan of River Restoration Project for the Skerne River (Darligton) must be checked to determine when grass-cut is required. At Newsham Grange the Tees floodbanks must have a first cut before mid-May and a second after the end of September; the landowner prefers this option for game bird reasons. At Neasham, Lustrum Beck and Stokesley	

	the first cut can be done in May. At Baydale Beck there are water voles so special action must be taken; the first cut will always be a partial cut.	
Lower and Upper Avon + tributaries (Nadder and Wylye)	Weed cutting is carried out once per year. The operations are carried out by weed cutting launches and commence at the beginning of June. In those sections where wildlife is greater, weed cutting does not start until July. Marginal reed is retained 1 to 1.5 m from each bank except where special agreements are drawn. In these locations compensatory reed fringe widths will be adopted on one of the banks. River bed is left uncut beyond these reed fringes. The weed cut is left to flow to the nearest boom where it is removed. Weed fringes are cut back completely along 200 m upstream of boom sites. Some of the streams require weed raking on alternate years. Weed raking commences in October and is carried out machines that track along one side of the river and are proceeded by tractor flailing of the vegetation.	Environment Agency - South West Region South Wessex Area Office (Allan Frake) allan.frake@environment-agency.gov.uk
Little Stour River	For this region rivers are classified as High, Medium or Low Flood risk. High risk systems retain 20% of the vegetation uncut, medium risk systems retain from 20-50% of the vegetation and low risk systems retain more than 50%. These guidelines are obtained from hydraulic efficiency against percentage weed cut graphs. Sensitive weed cuts are applied in specific sites (e.g. chalk rivers). The Little Stour River is a chalk stream that has the following species of interest to nature conservation: water voles, Ranunculus, Bull Head and Brown Trout. A sensitive cut is carried out at the Little Stour. Weed cutting is carried out to modify the channel and restore water depth and flow. This is necessary because due to anthropogenic modifications the riverine gravels are above the water table and the site is particularly vulnerable to drying. The general guidelines for weed-cutting at the Nairbourne and Little Stour site are: no maintenance works should be carried out between the 15th March to 15th July so breeding birds are protected. Weed cut works must not be undertaken from November to April so the trout spawning season is protected. A minimum of 20% of the wet channel should remain uncut.	Kent (Claire Munday, Paula Wadsworth) Environment Agency (2006a) paula.wadsworth@environment-agency.gov.uk
River Cray	No cuts except where there are specific issues.	Kent (Claire Munday, Paula Wadsworth) paula.wadsworth@environment-agency.gov.uk

River Darent	The aim is to obtain a self maintained channel so no weed-cutting is being undertaken. Weed-cuts are carried out only when the weed covers bank to bank or at sections upstream of mills and weirs.	Kent (Claire Munday, Paula Wadsworth) paula.wadsworth@environment-agency.gov.uk
Humber Estuary	Grass cutting is undertaken between June-September. Critical areas may have up to 3 cuts starting in April. The cuttings will be carried out from 1st Januray 2008 to 31st December 2009.	Environment Agency - North East Region (Elly Andison; Richard Jennings) richard.jennings@environment-agency.gov.uk
Wensum	Weed cutting can start on the 2nd week of June. Generally 2 cuts are carried out per year. 50% of the vegetation is retained along fast flowing reaches (e.g. downstream structures and bridges) and only 25% is retained in impounded sections of channel. 100% of the vegetation is cut in critical stretches. No cutting of bankside vegetation is carried out except around gauging stations. Margins of emergent vegetation are retained along both banks and a minimum of 100 mm height of vegetation is retained on the bed of the river.	Environment Agency - Anglian Region Eastern Area Office, (Julia Stansfield) julia.stansfield@environment-agency.gov.uk
General	No works should be carried out between id-March and mid-July to protect breeding birds. If water voles are present the period must extend until September. One third of the channel (10 -20% if watervole is not present) vegetation must remain uncut to retain the range of plants and species present and the habitat for aquatic invertebrates, water voles and waterfowl. An uncut strip must be retained along the lower bank/water margin to provide refuge for aquatic invertebrates, water vole and birds. Only one bank is cut annually. Cut material must be disposed avoiding damage to herb-rich areas; the material should be remover from the site to prevent soil enriching.	Environment Agency, Thames Region, South East Area Office (Dave Webb) david.webb@environment-agency.gov.uk
General	Works must be carried out between June and October. If only grass cutting is required then this will be carried out in September/October. Grass cutting will precede aquatic weed cutting by up to 2 weeks. The working area must be checked for environmental problems before starting the daily works. During the works dissolved oxygen and temperature readings must be taken ahead of the machine every 2 hours and logged. If environmental problems are noticed, works must stop.	South West Region, North Wessex Area Office (Francis Farr) francis.farr-cox@environment-agency.gov.uk

	Weed-cutting will start only if DO is >20% in all of the top 0.5 m of water. If oxygen levels ahead of the machine are falling below the day's initial reading cutting should stop. Where the weed density is high, works must concentrate on removing the surface weed. Cuts must be high so disturbance of the bed channel is avoided. These areas are particularly at risk of de-oxygenation. Cut vegetation must be deposited on the working bank. Bankside vegetation is to be cut to the highest setting the plant will allow.	
General	Works must be carried out at normal flows and avoided during hot days. The best time to carry the works during sunny days in the early-mid afternoon when the oxygen levels are at their highest. Cutting with the weed-boat minimises the disturbance of silt. If machinery is required to do the works then, special measure should be taken to minimise silt disturbance.	Environment Agency - Midlands Region Upper Trent Area Office (Andrew Crawford) andrew.crawford@environment-agency.gov.uk

Table 5.1 Specific guidelines for gravel removal collated in this literature review.

River	Comments	EA office
River Roach	A complete gravel management plan is available for the river Roach. Increase in gravel deposition suggests that the flood risk is increasing. As a consequence gravel shoals are removed to reduce bed level and increase channel capacity. The maintenance is often undertaken in a reactive manner rather than as part of a prepared strategy. The Environment Agency prepared the gravel management plan for the river Roach to adopt a more sustainable approach to sediment management (integrated catchment scale approach). The study area is the River Roch catchment from source to the downstream limit of Blackford Bridge at the confluence with the River Irwell. The main fluvial flood risk sites in the Roch catchment are located at: Whitworth (River Spodden), Milnrow (River Beal), Rochdale town centre (River Roch), Heap Bridge (River Roch) and Gigg (River Roch). A specific action plan has been designed for each of the sites: the maintenance actions vary from site to site as does their urgency. The document provides a description of the methodology used for prioritisation.	Gary Morris Environment Agency - North West Region Southern Area Office Appleton House 430 Birchwood Boulevard WARRINGTON Cheshire WA3 7WD
Upper Irwell	As for the River Roach, a complete gravel management plan is available for the Upper	Gary Morris

	Irwell. The study area is the upper catchment of the River Irwell from source to the downstream limit of Blackford Bridge at the confluence with the River Roch. An integrated catchment scale approach is proposed as part of the management plan. The key issues identified in the catchment are: (i) constriction due to culverting, (ii) low channel capacity as a result of sedimentation, (iii) constrictions caused by bridges, (iv) condition of existing flood defences, (v) reduced channel capacity caused by tipped material (urban waste) and (vi) areas of low-lying land (floodplain development).	Environment Agency - North West Region Southern Area Office Appleton House 430 Birchwood Boulevard WARRINGTON Cheshire WA3 7WD
River Greta at the Pencil Mill, Keswick (2005)	It is proposed to restore the channel capacity of the River Greta by the Pencil Mill in accordance with the Environment Agency Policy on The removal of Gravel from Rivers, V1 (2004). In-channel gravel shoals (above water level) will be removed and two stage channel will be re-instated and maintained back to design level. The in-channel gravel shoals will be reduced in height to water level by an excavator. Silt build up on the berm, on the left bank, will be removed to design level. All material will be loaded into a dumper to transport to the designated storage area and removed off site by wagon to the contactor's recycling centre. The works are of a localised nature and will be completed in 3 weeks at low flows and between June and September. Mechanical digger will be checked for fuel leaks before work commences and bio-degradable hydraulic oils will be used. Recommendations: • Removal of the upper extents of the bars is better than wholesale removal. • a series of gaugeboards/marker posts will be erected to monitor the height and extent of the bars. • monitoring of the bed level downstream of Greta Bridge to ensure that gravel management at the pencil mill does not have a detrimental impact downstream After the proposed works the river will have the capacity for self-repair and self-renewal: dynamic conditions will be maintained within the constraints of this modified section.	Mrs Liz Dawson Environment Agency - North West Region Northern Area Office Ghyll Mount Gillan Way Penrith 40 Business Park Penrith Cumbria CA11 9BP
River Cocker at Low	The Agency has removed gravel from the River Cocker whenever it has become necessary to maintain the flood capacity of the channel through Low Lorton. This single	Mrs Liz Dawson Environment Agency -

Lorton (2004) River Derwent at Grange-in Borrowdale	episode of gravel removal is not believed to have an effect on site integrity as this is part of a pattern of management that has been on-going for many years. The in river work is undertaken using a 15 tonne tracked excavator that access the river via the existing ramp and then tracks across the river to the location of the gravel shoal. The gravel is excavated down to, but not below water level, with the edge of the shoal being left intact to reduce sediment input to the river. The excavator works from the downstream extent of the shoal: the excavated gravel is moved into a heap immediately downstream of the bridge on the left back. This heap is then re-excavated and transferred across to the right bank to form a heap on the right bank access ramp. The gravel is then loaded to 6 wheel wagons with a carrying capacity of 20 tonnes and transported to the Cockermouth area for re-cycling as construction material. A total of 500 tonnes are expected to be removed over a 5 day period. Recommendations: • Gravel is only to be extracted, from the un-vegetated shoals downstream of Lorton Low Bridge. • No gravel is to be extracted below water level. • Machine access to the shoals is via the existing permanent track down the right riverbank. Gravel shoals are also removed from the Greta at Keswick; and the River Derwent at Grange-in-Borrowdale (every 5 years). There is also a proposal to remove gravel on the River Derwent at Cockermouth (previously carried out approximately 40 years ago). Further studies are being considered to investigate the impacts of all these works. At the village of Grange-in-Borrowdale the river is very wide and large gravel shoals deposit in the area. There is a large vegetated island around the bridge and additionally numerous unvegetated gravel shoals build up within a few years. The Agency has cleared primarily un-vegetated gravel shoals when requested by the Parish Council.	North West Region Northern Area Office Ghyll Mount Gillan Way Penrith 40 Business Park Penrith Cumbria CA11 9BP
Cockermouth (2005)	The Agency evaluated the performance of the flood defences downstream of the confluence of the Rivers Derwent and Cocker. It was proposed to remove the in-channel gravel bar between Harris Bridge and Gote Bridge and the shoal on the right bank immediately upstream of Gote Bridge above water level in accordance with the	Mrs Liz Dawson Environment Agency - North West Region Northern Area Office

	Environment Agency Policy on the removal of Gravel from Rivers, V1 (2004). Vegetation should be strimmed from the shoals. During low flows the in-channel gravel shoals should be reduced in height to water level, by an excavator. All material should be loaded into a dumper to transport to the designated storage area. Material should be removed off site by wagon to the LDNP depot, recycling centre or waste facility.	Ghyll Mount Gillan Way Penrith 40 Business Park Penrith Cumbria CA11 9BP
River Caldew (2004)	The River Caldew has a restricted channel capacity through Carlisle. The Agency has periodically cleared all bushes/young trees from the lower riverbank throughout this part of the river and occasional gravel removal has been carried out. Larger shoals of pebbles/cobbles accumulated in the section of restricted channel through the middle of Carlisle at Victoria viaduct, foot bridge and Holmehead weir. Holmehead weir: the gravel trap immediately downstream of Holmehead weir is emptied as and when significant deposits of gravel build up (approximately once every couple of years). Large gravel shoals built up further downstream and where removed 10 years ago. Gravel from gravel trap and gravel islands is removed to maintain channel capacity to standard.	Mrs Liz Dawson Environment Agency - North West Region Northern Area Office Ghyll Mount Gillan Way Penrith 40 Business Park Penrith Cumbria CA11 9BP
Glenridding Beck (2005)	Removal of an un-vegetated gravel/cobble shoal from the section of river up and downstream of the main road bridge in Glenridding to reduce flood risk to adjacent properties. Silt disturbance should be relatively low as the gravel to be removed is large in size and has little associated fines with it. Only gravel above water level will be removed. A higher buffer along the edge of the beck is to be left during the working period and is to be regraded upon completion of the works. The works will be carried out in the salmonid spawning season but will be completed out of water. The potential impact of tracking across the beck will be minimal considering the amount of gravel movement during the recent 1 in 170 year flood. This work is not considered to have a potentially significant impact as it is so close to the lake which acts as a natural sink for sediment.	Mrs Liz Dawson Environment Agency - North West Region Northern Area Office Ghyll Mount Gillan Way Penrith 40 Business Park Penrith Cumbria CA11 9BP
Coledale gravel trap	The gravel trap at Braithwaite is designed to limit the amount of gravel in the reaches so flood risk is minimsed. Management of the trap by removing gravel is done on a regular basis when the trap becomes full (generally due to mine works). The trap was designed to be easily emptied with a plugged drain system in the bottom of the weir. The gravel trap is drained the day before works commence so silt pollution is minimised. Once drained, a digger will track onto the exposed gravel and remove gravel using a large	Mrs Liz Dawson Environment Agency - North West Region Northern Area Office Ghyll Mount Gillan Way Penrith 40 Business Park

	bucket to a wagon. The gravel will then be removed to an agreed site. The gravel can be removed virtually in the dry with minimal disturbance to the beck. The works are proposed for the end of May to avoid salmonid spawning season and the works will be completed at a period of low flow so that water entering the top of the gravel trap during the draw down period will be as low as possible. The gravel trap at Coledale Beck on the edge of Buttermere Fells SSSI. Removal of gravel from the trap involves draining down by initially removing the plugs from the weir. A digger machine enters the trap and removes he gravel build up to an awaiting wagon. This has the potential to create some silt and oil pollution. The silt pollution will be minimised by draining down the trap and using straw bales downstream if necessary. Oil pollution will be avoided by following Agency Pollution Prevention Guidelines for works in water and ensuring that all machines are well maintained and free of surface	Penrith Cumbria CA11 9BP
Gravel shoal at Hilton Beck, Coupland (2004)	The works are proposed for June 2004 and involve the removal of one un-vegetated gravel/cobble shoal from a section of river causing potential changes to riverine habitats in the area. Works will only remove gravel above water level. The majority of the works will take place out of the water but access will be required across the river to clear the silt bar from upstream of the culvert. There will be no machine access across the main river channel. The works can be carried out from the right bank so any direct damage to potential lamprey habitat is avoided. A buffer zone of approximately 1 metre will be left around the edge of the shoal. A crayfish rescue will be required for the shoal removal upstream of the culvert.	Mrs Liz Dawson Environment Agency - North West Region Northern Area Office Ghyll Mount Gillan Way Penrith 40 Business Park Penrith Cumbria CA11 9BP

Table 2.1 List of contactees and key responses

Area/Region	Name	Email	Key Response
Anglian Region, Central Area	Paul Jose	paul.jose@environment-agency.gov.uk	Use EA guidance (2003)
Anglian Region, Eastern Area	Julia Stansfield	julia.stansfield@environment-agency.gov.uk	Wensum
Anglian Region, Northern Area	Caroline Tero	caroline.tero@environment-agency.gov.uk	No reply
Midlands Region, Midland Regional	Tim Pickering	tim.pickering@environment-agency.gov.uk	no specific info

Midlands Region, Lower Trent Area	Anja Nonnenmacher	Anja.Nonnenmacher@environment-agency.gov.uk	No reply
Midlands Region, Upper Severn Area	Ros Challis	ros.challis@environment-agency.gov.uk	No reply
Midlands Region, Upper Trent Area	Andrew Crawford	andrew.crawford@environment-agency.gov.uk	See general info
North East Region, Northumbria Area	Anne Lewis	anne.lewis@environment-agency.gov.uk	Not specific
North East Region, Ridings Area	Elly Andison	eleanor.andison@environment-agency.gov.uk	See email and - follow up Richard and Caroline see Richard follow up
North East Region,Dales Area,	Liz Chalk	liz.chalk@environment-agency.gov.uk	Specific info on Nidd, Derwent, Wharfe, Ouse, Ure, Swale and Tees (weed cutting times)
North West Region, Northern Area	Liz Dawson	liz.dawson@environment-agency.gov.uk	Various gravel EIA assessment and gravel removal recommendations
North West Region, Southern Area	Gary Morris	gary.morris@environment-agency.gov.uk	Irell and Roch plans and maintenance guidelines
North West Region,Central Area	Lindsay Ward	Lindsay.Ward@environment-agency.gov.uk	No reply
South West Region, Cornwall Area	Sally Mitchell	sally.mitchell@environment-agency.gov.uk	No reply
South West Region, Devon Area	Mike Williams	mike.williams@environment-agency.gov.uk	No specific info
South West Region, North Wessex Area	Andy Baines	andy.baines@environment-agency.gov.uk	Francis Farr Cox- see general info
South West Region, Regional	Deborah Dunsford	deborah.dunsford@environment-agency.gov.uk	No reply
South West Region,South Wessex Area	Allan Frake	allan.frake@environment-agency.gov.uk	Avon and tributaries
Southern Region, Hampshire and Isle of Wight Area	Heb Leman	heb.leman@environment-agency.gov.uk	No specific info
Southern Region, Kent Area	Jeremy Burgess	jeremy.burgess@environment-	Claire Munday/Paula Wandsworth -

		agency.gov.uk	Cray, Darent, Little Stour
Southern Region, Southern Regional Office	Phil Griffiths	phil.griffiths@environment-agency.gov.uk	Referred to Sussex info
Southern Region, Sussex Area	Charlotte Murray	charlotte.murray@environment-agency.gov.uk	Sussex rifes
Thames Region, North East Area	Judy England	judy.england@environment-agency.gov.uk	No specific info
Thames Region, South East Area	Dave Webb	david.webb@environment-agency.gov.uk	Cove Brook FAS management plan
Thames Region, Thames Regional	Richard Copas	richard.copas@environment-agency.gov.uk	No reply
Thames Region, West Area	Graham Scholey	scholgd@environment-agency.gov.uk	Lambourn
Wales	David Mee	dave.mee@environment-agency.gov.uk	Nothing specific - little maintenance

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