KNEPP CASTLE ESTATE

River Adur Floodplain Restoration

Pre-feasibility study of river restoration

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1 Summary

River restoration provides a mechanism for integrating biodiversity enhancement, landscape improvements and flood risk management within the concept of returning catchments to a more self sustainable natural environment. It is also seen as a valuable tool for delivering government policy targets (national and European) relating to the above.

The landholding of Knepp Castle Estate, near Horsham in West Sussex contains a 2km length of the River Adur and tributaries. The river is over wide and deep and has undergone major engineering changes over many centuries, but still flows through a wide grassland floodplain.

Re-wilding of the 3500Ha estate has introduced the possibility for lowland clay catchment river and floodplain restoration. Constraints and issues need to be built into the project and solutions identified as part of this study. The main constraints and issues are;

Channel

- Over-sized compared to the normal flows it carries and route realigned for a variety of reasons, with original planform lost;
- Large weir structures impacting the landscape, hydrology and fisheries potential;
- Lack of in-channel, marginal, bankside and floodplain habitat diversity;
- Maintenance implications for Environment Agency Operations staff (desilting and structures);

Floodplain

- The historically damp floodplain now sheds water quickly via ditches into the main Adur;
- Open landscape with a lack of vegetation diversity;

Flooding

- Low lying estate buildings located within the floodplain (flooded as often as every 10 years);
- A24 dual carriageway culvert at downstream limit of restoration reach;
- Two minor road bridges, both of which currently flood, at upstream limits of project reach.

To ensure this project is state-of-the-art, based on current best practice and demonstrates innovation in the field of river restoration, the RRC fielded a team of experienced experts. Expert judgement and available data have been applied to propose a project ‘vision’ of what is desirable, given the constraints and obvious opportunities. A summary of the discussion underlying this visioning process is given in Section 3, but principally considers:

1. Land ownership (landuse and landscape (open/ wooded/ mosaic));
2. Topography;
3. Catchment, floodplain and channel geomorphology;
4. Hydrology and hydraulics;
5. Channel ecology (fish, mammals, etc.);
6. Floodplain ecology;
7. Engineering (structures/services).

The aim of the vision is:
“To enhance the channel and floodplain habitat diversity by physical manipulation of channel planform, bed levels and flow patterns with a particular emphasis on reconnecting the floodplain to the river channel.”

Objectives (stakeholder, local and national) have been set and targets identified to aid in the vision design. The vision is summarised in three Plans (A, B and C), with additional explanation provided in the text. The proposal is to return the river to a more appropriately dimensioned channel, dominated by woody debris, within an active floodplain, allowing increased floodplain wetting and supporting greater biodiversity potential.

Approx 1750m of new channel will convey low to moderate river flows alongside the existing/modified or infilled old course. Flood flows will occupy the new channel, preferential flood routes (sections of existing course) and the floodplain. Indicative engineering ‘design’ sections for hydraulic modelling and contract drawings purposes have been suggested. Desired as-built cross sections have also been suggested, showing the variation from the ‘design’ required of the contractor to achieve a ‘natural’ new river. Log jams will be constructed within the new channel.

Basic flooding scenarios have indicated the need to convey floodwaters away from sensitive locations, and areas where shallow flooding can be better accommodated. Further detailed hydraulic modelling is required in the next ‘Technical Feasibility’ stage to juggle flood risk management requirements with the new channel dimensions and floodplain re-wetting. Properties and infrastructure must be well protected and suggestions for this have been included.

Minor tributary streams should be utilised to create saturated areas of floodplain, providing different habitat to other flood inundation areas. Whilst floodplain woodland is desirable in this location, its development will depend greatly on the grazing pressure of the varied wild stock roaming the estate.

Technical feasibility is now required to define the hydraulic constraints, derive the most appropriate routing of flood flows and thus identify if the proposed new channel dimensions are appropriate. From this modelling work, most current uncertainties can be removed or reduced. This will enable a more accurate estimate of quantities and costs to be attributed to a detailed design specification for tendering purposes.

Preliminary estimates, based on this pre-feasibility ‘vision’ suggest project costs in the order of £500,000. This includes technical feasibility and contract documentation, background data collection, monitoring, management and post works adjustments, as well as the implementation works. Funding for a project of this scale will require a strong partnership between the landowner and government agencies, as well as a degree of external matched funding.

This river and floodplain restoration project has the potential to be a valuable national demonstration site, delivering target floodplain and channel objectives. It also has the potential to add considerably to the value of the Estate’s re-wilding project, already keenly supported by English Nature and Defra. Technical feasibility is now required to finalise the design. At the same time funding initiatives and wider support needs to be identified, targeted monitoring begun and the required permissions identified.

2 Introduction

2.1 Background

The Landowner of Knepp Castle Estate is keen to maximise the biodiversity potential of the whole estate. Through discussions with Defra the estate will be entering the Adur and its floodplain into an Environmental Stewardship scheme. The reach to be entered is approx. 2.2km, with two main tributaries and their floodplains adding to the extent of land to be considered.

Various options for habitat enhancement and increasing biodiversity had been suggested to the Landowner by a variety of organisation, from re-wetting by the use of sluice boards to restoration of the old course of the Adur.

Problems and issues:

- Channel over-sized compared to the normal flows it carries;
- Route realigned for a variety of reasons, original planform lost;
- Large weir structures impacting the landscape, hydrology and fisheries potential;
- Low lying estate buildings located within the floodplain (flooded as often as every 10 years);
- High maintenance for Environment Agency Operations staff (desilting and structures);
- The historically damp floodplain now sheds water quickly via ditches into the main Adur;
- Lack of in-channel, marginal, bankside and floodplain habitat diversity.

The River Restoration Centre was asked to look at the problems and issues above. A brief options report (Appendix A) highlighted the restoration of the River Adur and its floodplain over the 2km length between Capps Bridge and the A24 road bridge (Bay Bridge). Figure 1 of Appendix A shows the possible scope of a Restoration Project at the Knepp Castle Estate.

2.2 River and Floodplain Restoration Opportunities

The River Adur at Knepp Castle Estate flows through a lowland England clay catchment. Such river systems are common, but they are nearly always heavily modified through centuries of alteration and management. Restoration usually requires a reference state to use as an analogue, but with these systems such a reference is very difficult to find. In its absence expert opinion, literature and other projects supply the necessary information.

At Knepp, the suggestion is that a smaller, more sinuous clay channel would better represent a previous River Adur. However, discussion around the actual size, shape and sinuosity needs to be related to lowland England woodland clearance, historic grazing pressures, present flooding regime and site constraints. Even the detail surrounding the most appropriate channel shape for a clay catchment river verses how this can best be portrayed to a contractor to actually dug such a profile has been discussed. With clay soils this type of small detail is very important, as often the excavated shape is the final shape as very little adjustment occurs in these river types.

2.3 Project Scoping and Feasibility

The scoping study (Appendix A) concluded that additional work was required to assess the pre-feasibility of different options, based on expert input and additional information. Three stages were identified.

Stage 1 Information collection (to inform stages 2 and 3)

The recommendations of this stage included:

- *Topographic level survey of the river and floodplain, its features and extent between the A24 and Pound Lane*
  Helps to define realistic options for consideration and to ensure that any backwater effect of a newly designed channel does not worsening flooding potential of property and communication links. Detailed topographic survey at this stage also provides the basis for more detailed hydraulic modelling in the later feasibility stage.

[Survey carried out 2005 and data available]

- *Brief overview of historical data*
  It was proposed that a search of County and Estate archives, etc. should quickly indicate any evidence of historic channel routes across the floodplain.

[Brief overview carried out, little additional information gained]

- *Geomorphological assessment and comparison with surrounding catchments*
  Defining the accurate and most appropriate size, shape and sinuosity of a 'restored' river is essential. E.g. too small a cross-section could result in flood storage issues whilst too large could equate to a waste of time, effort and funds.

[Forms part of this pre-feasibility report]

- *Fisheries*
  The river reportedly supports a Sea Trout run, as well as a variety of coarse fish. As a fishery the river is known to be poor through the estate reach, but as a fisheries resource it could be valuable for salmonids
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[Information received as part of this study]

Stage 2 Pre-feasibility (this report)

Following the successful completion of the topographic survey RRC has been requested to field a small team of its 'Advisors' to work up the outline options for the estate, Defra and other potential partners to consider. This pre-feasibility stage will produce a detailed justification for the various options, based on the information available. It will give rough costings and form the basis of a brief for consultant engineers to carry out a technical feasibility study of the favoured option(s).

Stage 3 Technical feasibility (following this report)

The final stage will be essential to:

- Provide the required assurances for the landowner and Environment Agency flood defence team, to enable consent to be gained;
- Calculate accurate material quantities timescales and costings involved;
- Provide the tender drawings and documentation (bill of quantities, etc. needed to let the contract to contractors).

This pre-feasibility report uses information gained from Stage 1 (information collection) to propose the details for a restoration project (Stage 2; pre-feasibility). Stage 3 (technical feasibility) will need to be undertaken by an experienced consultancy team. It is recommended that RRC should be involved throughout the design and implementation stages to ensure that the design produced by the consultants is true to the client's original perception of the project, and hence provide project continuity.

2.4 The RRC Project Team

The Centre has considerable experience in advising on large scale innovative river restoration demonstration projects across the UK. As an independent advice and information centre, the RRC's core role is to be aware of, and share knowledge of, river and floodplain projects past, present and planned. The Centre maintains a support network of expert advisors who can input into specific projects should such knowledge and experience be required.

The RRC Project Team comprises of:

Martin Janes	RRC Centre Manager
Dr Jenny Mant	RRC Projects Advisor
Alice Fellick	RRC Information Officer
Richard Vivash	Advisor – River engineering
Dr David Sear	Advisor – Fluvial Geomorphologist
Karen Fisher	Advisor – Hydraulics
Dr David Gowing	Advisor – Wetland Ecology

Short CV's for each of the above can be found in Appendix B

2.5 This Pre-feasibility Report

Detailed discussions of number of channels, channel size, shape and sinuosity, related to lowland England woodland clearance, grazing pressures, present flooding regime and site constraints are summarised in Section 3, each sub-section adding more information, helping to reduce the uncertainty surrounding a single/or set of 'vision' option(s).

From this discussion and background information a 'vision' is proposed, with aim, objectives and measurable targets (Sections 4 and 5). These objectives and targets inform the data requirements for monitoring and evaluation purposes (Section 6). Such a process in vital to enable management of the project to adapt to necessary changes as they occur and as more accurate information becomes available.

Section 7 lays out the detail within the vision and the three annotated Plans. General principles for the whole site are given, then supplemented with detailed information for specific areas, tasks and features.

Preliminary costs estimates are provided in Section 8 to enable initial discussion of the amount and possible sources of funding required. This needs to be looked at further in parallel to the technical feasibility stage outlined in Section 9.

The final section proposes the way forward, suggesting what can be done now and what needs to be done in preparation of later stages. With a project of this size and importance it is vital to gain a strong partnership early on and to keep momentum going.

As much relevant information as possible has been summarised in the report and further details provided in the appendices. Where not provided RRC, the landowner and the Environment Agency can supply all other data.

3 River Restoration at Knepp Castle

Any channel and floodplain 'restoration' of the River Adur must incorporate the wider catchment objectives for the Adur system and the Knepp Castle Estate re-wilding programme. The project must work within any identified constraints whilst also demonstrating the opportunities for enhancement work to deliver landscape, biological, ecological, morphological and hydraulic enhancements. Furthermore, since the project will potentially be demonstrating a range of innovative restoration techniques, it is essential that project assessment becomes an integral part of the project so that both the Estate owner and the Environment Agency can gauge its success.

The following section describes the rationale underpinning the project that leads towards the proposed vision described in Section 7 and the stated aims and objectives (Section 4). The points listed here are the key issues that needed to be taken into account;

1. Land ownership (landuse and landscape (open/ wooded/ mosaic));
2. Topography;
3. Catchment, floodplain and channel geomorphology;
4. Hydrology and hydraulics ;
5. Channel ecology (fish, mammals, etc.);
6. Floodplain ecology;
7. Engineering (structures/services).

It is essential that all points are considered. Land ownership and use was the original driving force behind this project and it is this together with the local topography, which is fundamental in defining the project parameters. Geomorphological and hydrological considerations are then used to outline a restoration plan that provides the conditions to enhance channel and floodplain ecology whilst ensuring structures and services are not adversely affected by re-wetting the floodplain.

3.1 Land Ownership

The landowner is committed to 're-wilding' the entire 3,500ha Knepp Castle Estate. This will take the form of ceasing all cultivation of farmland, opening up the estate internal boundaries and promoting the free reign of already stocked fallow deer, wild pigs, ponies and longhorn cattle (Greenaway 2005).

The concept of restoring the River Adur and its floodplain to a more natural form with associated riverine processes of erosion, shallow floodplain flooding and deposition fits well with the Estates re-wilding concept. The Landowner is keen to pursue this route and demonstrate the benefits to the estate and environment of river and floodplain restoration.

Ownership extends to a wider area than just the 2km which forms the core of this project. For practical purposes the river between the A24 culvert (Bay Bridge) and Capps Bridge, including the Lancing Brook to Tenchford Bridge has been chosen as the project site.

Constraints to the project include Estate owned property at Kneppmill House and Tenchford Cottage both within the immediate floodplain.

3.2 Site Topography

An initial appraisal of general restoration concepts was undertaken based on a close examination of floodplain topography using contoured plans, cross-sections and long-section. This work looked at localised evidence for an appropriate form, location and size of the River Adur, and practical restoration potential. The following conclusion was used to help guide further discussion.

3.2.1 River Channel and Floodplain

Gradient of main River Adur

A mean gradient of 1 in 900 appears applicable throughout the site (Longitudinal Section attached). This was derived by adding a profile representing the lowest floodplain levels. This profile is generally below the top of bank levels plotted by surveyors. The existing river bed profile runs at least 2m below the floodplain profile, or 2 ½ m below, following the deepest bed levels plotted by surveyors. Channel depths of 3m are evident between highest bank and lowest bed.

Some interesting 'irregularities' are evident within the profile of the lowest floodplain grade of 1:900. Upstream of the Lancing Brook confluence the natural grade runs 20 cm above mean for 500m or so. This is roughly coincident with a lateral embankment crossing the floodplain at the footpath. Old structures within the embankment suggest floodwater could, historically, have been held back to deposit silt. Conversely, there is a marked 'hollow' downstream of the cottages abutting Knepp Mill Dam. The floodplain of the Lancing Brook, upstream of Trenchford Bridge, is markedly below the 1 in 900 mean grade of the Adur, by c.40 cm, however this appears to be a local feature.

Upstream of the Lancing Brook confluence the floodplain is markedly different than downstream. It runs north-south for about 800m with a consistent width of c.70m, whereas the latter varies in width considerably, up to 140m. The upstream floodplain is also much flatter than downstream with few clearly defined low spots.

Initial planform design suggestion based on local floodplain topography

For the purposes of planning channel restoration *a 'design' mean depth of between 1.0 and 1.2 m* appears reasonably practical. A 1 in 900 grade at this depth is coincident with the paved invert of the ancient Trenchford road bridge (see Long section). It also just clips the crests of each of the existing four sluices/weirs.

Furthermore, channel restoration would best be practically achieved by cutting a new meandering route. A study of well defined floodplain contours highlights a potential meandering route through the low points on the left bank floodplain between the sluice just below the Lancing Brook and a point 200m upstream of the sluice close to the A24 (Plans A, B and C). This lower sluice could be retained to serve as the transition between existing and restored channels – with enhancement to the structure. The retained channel upstream should help intercept initial sediments loads from the restored reach.

At the Lancing Brook confluence the existing channel needs to be retained to avoid raising flood levels but better use of the floodplain seems feasible. The restored reach could start close to the confluence, but a parallel reach of the existing channel may need to be kept open to convey floodwaters also. Lower down, the existing reach could be backfilled or ponded.

Initial cross section design suggestions
The cross sectional design will require a relatively standard 'engineering' section to enable multiple sections to be generated for hydraulic models, volume estimations and the final works tendering process. Such a design must be capable of being excavated as a bulk dig exercise. Additional detail and site supervision will be required to ensure local variation and a more 'natural' appearance is achieved on the ground.

3.2.2 Tributary Streams

Only two of significant size exist. It may be possible to close the outlets to the river and turn both to discharge directly onto the Adur floodplain to sustain wetlands that will vary in extent seasonally. A third tributary that flows into Knepp Mill Pond currently bypasses the site but if more surplus water is 'bled' through the dam an additional wetland site at Kneppmill Cottages could be sustained.

Though valuable as an indicator of the site practicalities and current system, analysis of the topographic information does not provide an insight into the historic functioning of the river. To gain this an assessment of the geomorphology of the site is required.

3.3 Fluvial Geomorphology

As well as looking at the existing site, a wider catchment geomorphology overview is essential to understanding the functioning of the river currently and historically. Geomorphology of these lowland systems is poorly understood and almost certainly owes much to processes that were more active than currently supported by the catchment. The role of the geomorphology input is to:

- Provide boundary conditions in terms of appropriate processes and features to the conceptual model (vision);
- Provide guidance on the dimensions of morphological features in a format that can be applied to any scale (e.g. width:depth ratios rather than absolute widths or depths). This acknowledges that the hydrological and hydraulic functionality has to be based on current and future flow regimes NOT past flow regimes;
- Provide Geomorphic Targets for the restoration that will be picked up in subsequent monitoring and adaptive management programmes.

The above are based on the notion of a reference condition, where this is not simply a set of features but also the processes that create and maintain these (unless both are relic and no longer active). Defining these reference conditions uses:

- Scientific/grey literature examples of similar stream types;
- Selection of suitable existing natural analogues which are either local to the catchment or use river habitat survey (RHS) to identify candidates;

- Analysis of palaeoenvironmental record at the site;
- Application of geomorphological models where appropriate.

An initial assessment of the river at Knepp Castle and its upstream tributaries indicates that the current channel is overlarge for the flows and size of catchment. The appropriate form of the Adur at Knepp was discussed. Two scenarios were proposed on the basis of scientific literature and knowledge of lowland England rivers:

- Multiple channels.
- Single channel.

3.3.1 Multi-channel vs single channel

The notion of multiple channels is valid conceptually, in lowland British landscapes. How they function in reality is not so well known. Work in the New Forest (our best lowland wet woodland analogue) suggests that multiple main channels are rare, but that multiple floodplain channels (range from 0.1-0.8m deep – main channel is 0.8-1.2m deep) are common, and effectively create a complex network of faster floodplain flow routes. Lower down the system, palaeoenvironmental evidence clearly points to multiple channel systems where the channels are similar in dimension. These are collectively referred to as ANASTOMOSED systems. Multiple channels are either braided or anastomosing. These two are discussed in Appendix C.

A site inspection was then undertaken to provide expert opinion as to whether one or both of these options were historically accurate and realistic, substantiated by observation and limited coring, such that a decision could be made as to which options should be pursued further.

3.3.1.1 Multi-channel option assessment

A purely multi-thread channel is unlikely (post forest clearance), although it may have been an option prior to that period. Any landscape finger prints for this option have long since been lost. Such an option would certainly achieve the overall objectives of the project, but the design may be so out of character with lowland clay rivers that uncertain guesstimates would need to be made in terms of channel dimensions and planform.

As a demonstration project, in terms of variation in habitat, it could be argued that a multi-thread channel is of most potential benefit – especially if these threads interact at different levels. It may also be easier to manage flood capacity problems and conveyance issues.

3.3.1.2 Single thread option assessment

Geomorphological literature suggests that since the Bronze Age period of mass floodplain tree clearance in Lowland England, the majority of such river systems would have been single thread with large quantities of woody debris. This concurs with the evidence from a brief field visit. In this clay catchment, the single thread river would most likely have been smaller in cross section than its current form. Clay rivers tend to be incised; they lack the hard material to form a protected (armoured) bed, and will form typically vertical banks due to the cohesive nature of the bank/floodplain material.

Whilst the physical channel dimensions may not have differed hugely from its current form the main change will have been the regular removal of accumulations of woody material. It is likely that the low gradient River Adur would have accumulated much fallen woody debris, which lodged in the single channel. This natural long term build up of wood and vegetative matter would have formed blockages, pools and had the effect of raising the water surface promoting more frequent overbank flows.

3.3.2 A geomorphologically appropriate channel

An effective restoration option would be the creation of woody debris structures and wooded riparian margins / floodplain. The hydraulic effects are likely to be increased roughness rather than physical loss of capacity. Wooded structures have high Mannings roughness values (they vary but 'n' values of around 0.5 - 1.5 span most that the project should need to consider).

By adding large woody 'blockages' and the associated increase in roughness, effectively raising water levels locally, the river would have a greater propensity to flood at more regular intervals. This would alter the current appearance of a channel oversized for the 'average' flow, and introduce geomorphological and habitat diversity.

Re-introducing woody debris into the system (and restoring the meander bends) could contribute towards achieving the goals of this project and would provide a good demonstration of how a clay river catchment might have looked at a specific historical point; post tree clearance[1]

It is essential that the contractor and site supervisor appreciate the level of fine detail that must be apparent within the finished as-dug channels shape. This could be formally specified as a % variation around a mean design cross section, or provided on-site through expert supervision.

3.3.3 Observations on conveyance

Adding debris to the main water course will result in a capacity reduction and this will have implications for larger flows. It is therefore necessary to:

- Establish the impact of reducing channel capacity on flood levels and frequency; and
- If necessary provide a technical solution to any unacceptable increases in flood levels given constraints outlined in section 3.4.2 that will still meet the environmental targets.

From a flood conveyance perspective, any single thread design would also need to consider additional (multiple) channels at sensitive locations. It is necessary to look at the hydraulics of the site to answer the questions posed above and refine an appropriate design.

[1] There is still much debate as to whether lowland Europe would have been extensively wooded, especially on floodplains. It is also proposed that the grazing and rooting of large herbivores may have dominated the landscape and kept woody vegetation to a minimum. As an integral part of the Estate's re-wilding programme, these same herbivores will have free access to the Adur floodplain. This provides an ideal study opportunity to look at the interaction between animals and floodplain woodland colonisation.

3.4 *Hydrology and hydraulics*

A brief assessment of scope and opportunities, constraints and information needs was undertaken, based on a discussion of topographic and geomorphological information.

3.4.1 Opportunities

- The river is over deep all through the reach from the A24 road Bridge upstream to Capps Bridge. Raising levels throughout the reach would allow more water onto the floodplain;
- Opportunities for meandering along the reach upstream of the A24 (see area and note 24 on plan maps). This could also incorporate the Jackson wood tributary (27 on map) on the right bank;
- Where the channel changes direction and runs north to south between Capps Bridge and Tenchford bridge, there is potential to create a wetter floodplain on the left bank and raise the bed through this area using woody debris. The tributary on the right bank just downstream of Capps Bridge (14 on site map) can be incorporated to provide a wetted area or feed water into a wetted area on the left floodplain;
- At the confluence between River Adur and Lancing Brook there may be scope for moving the confluence downstream (13 on map).

3.4.2 Constraints

- All properties under risk of flooding are owned by the estate, so increase in flood levels are not considered a major threat to the project but nevertheless this issue needs to be considered within the scheme and appropriate action taken;
- At some of the access points, especially to Pound Farm cottages, and along some of the paths, on the left bank between Capps Bridge and Tenchford Bridge, access would need to be maintained which may affect what can be done on the floodplain at these locations;
- The water levels at the A24 road bridge must be no higher than in the existing situation;
- The peak flows (or time to reach peak flood flows) being passed down under the A24 road bridge must be no greater than in the existing situation. (This is thought to be unlikely as it is planned that more water will be held back on the floodplain, but nevertheless needs to be considered);
- The flood levels at the Tenchford Bridge and Capps Bridge sites must not be increased;
- There is a pipe crossing the river 300m downstream of Capps Bridge which might create an additional constraint.

3.4.3 Hydraulic implications

3.4.3.1 Initial assessment

The points that need to be considered relate primarily to the road and property flooding and whilst raising flood levels within the estate has not been considered as a major constraint nevertheless, the properties just downstream of Kneppmill Pond might experience some increase in flooding; this would need to be investigated and some flood protection given. Similarly, the cottage by Tenchford Bridge is already prone to flooding and although the risk may or may not be increased by the river restoration, the project provides a good opportunity to provide some protection – bunding or flood proofing.

The flood levels at the roads – A24 and at Tenchford Bridge and Capps Bridge are considered the major constraints as they must not be made worse by the restoration. The planned restoration is mainly downstream of the bridges but water levels should not "backup" and cause problems from downstream.

The overall gradient in terms of water levels through the site is approximately 1 in 950 which concurs with initial topographical interpretation of 1 in 900 gradient on the floodplains. The water levels are controlled all the way up the reach by a series of sluices and weirs. By modifying the structures and raising the bed by 1m the gradient would still be the same and the river would be more free flowing.

In addition, raising the bed levels, possibly removing some of the weir and sluice structures and putting more water onto the floodplain with some increased floodplain planting will generally cause a slowing down of the flows and encourage water to come out onto the floodplain sooner. With the bed being raised some conveyance would be lost within the channel. The floodplain is already being used for flood storage so the levels on the floodplain are likely to increase to provide additional storage for the conveyance lost within the channel. The shape of the hydrograph will change. It is anticipated that the peak of flood flow hydrographs may be reduced but the hydrograph will be longer and flatter.

3.4.3.2 Initial model run

To inform this pre-feasibility study an initial 'broad brush' hydraulic model was run (Appendix D). The hydrology and hydraulic modelling work give indications of the total volumes of water which are passing along this reach of the River Adur during flood conditions. The initial analysis shows that the channel is over-sized, agreeing with the geomorphological assessment.

The impact of raising the bed levels will be to reduce the capacity of the channel by approximately $10m^3/s$ on average along the reach. The effect of this in a flood situation will be to raise the extreme flood levels by up to 0.125m downstream of the Lancing Brook confluence and by up to 0.065m upstream of the confluence.

The indicative rise is significant but by creating additional channels, creating wetland areas, floodplain scrapes and floodplain channels, it should be possible to reduce the impact of raising the bed level and not increase the flood levels, particularly at the vulnerable Tenchford Bridge at the confluence of the Lancing Brook and River Adur.

3.4.3.3 Technical feasibility modelling

The impact of three additional issues needs to be explored when undertaking full feasibility modelling:

- Impact of sea level rise. Will this impact the site by elevating the backwater effect of downstream levels? Currently this is not the case.
- Flood magnitude and frequency due to climate change. Current guidance is to allow a 20% increase in runoff with increased intensity. This may lead to higher flood peaks, though the floodplain storage proposed should have the opposite effect on flood peaks.
- Flood peak synchronisation. Changes to the time to peak of the floods at Knepp Castle could impact downstream if they combined with peaks from the East catchment. This would need to be discussed with the Environment Agency.

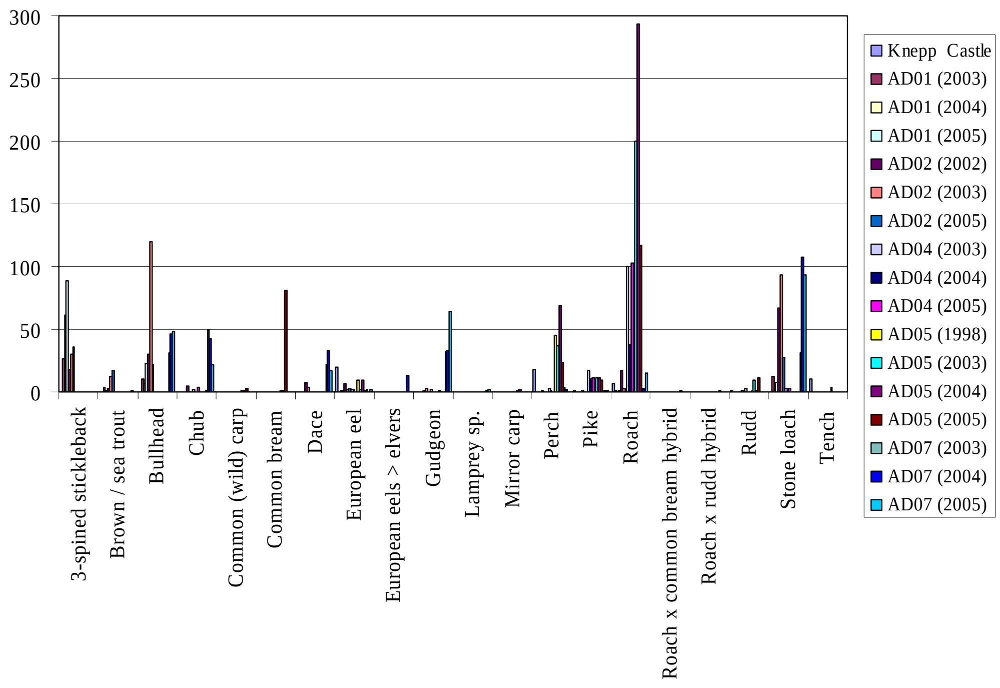
Final detailed design will need to carefully balance the physical channel modifications/additions with capacity and conveyance of flood flows. This is likely to be an iterative process at the detailed modelling stage. The resulting 'canvas' should be morphologically varied to provide the greatest possible physical habitat diversity to maximise ecological habitat potential.

3.5 Channel Ecology

3.5.1 Fish

EA survey data is available for the Knepp reach of the Adur. The following provides a brief summary of the data. Sites are shown in figure 3.5.1.

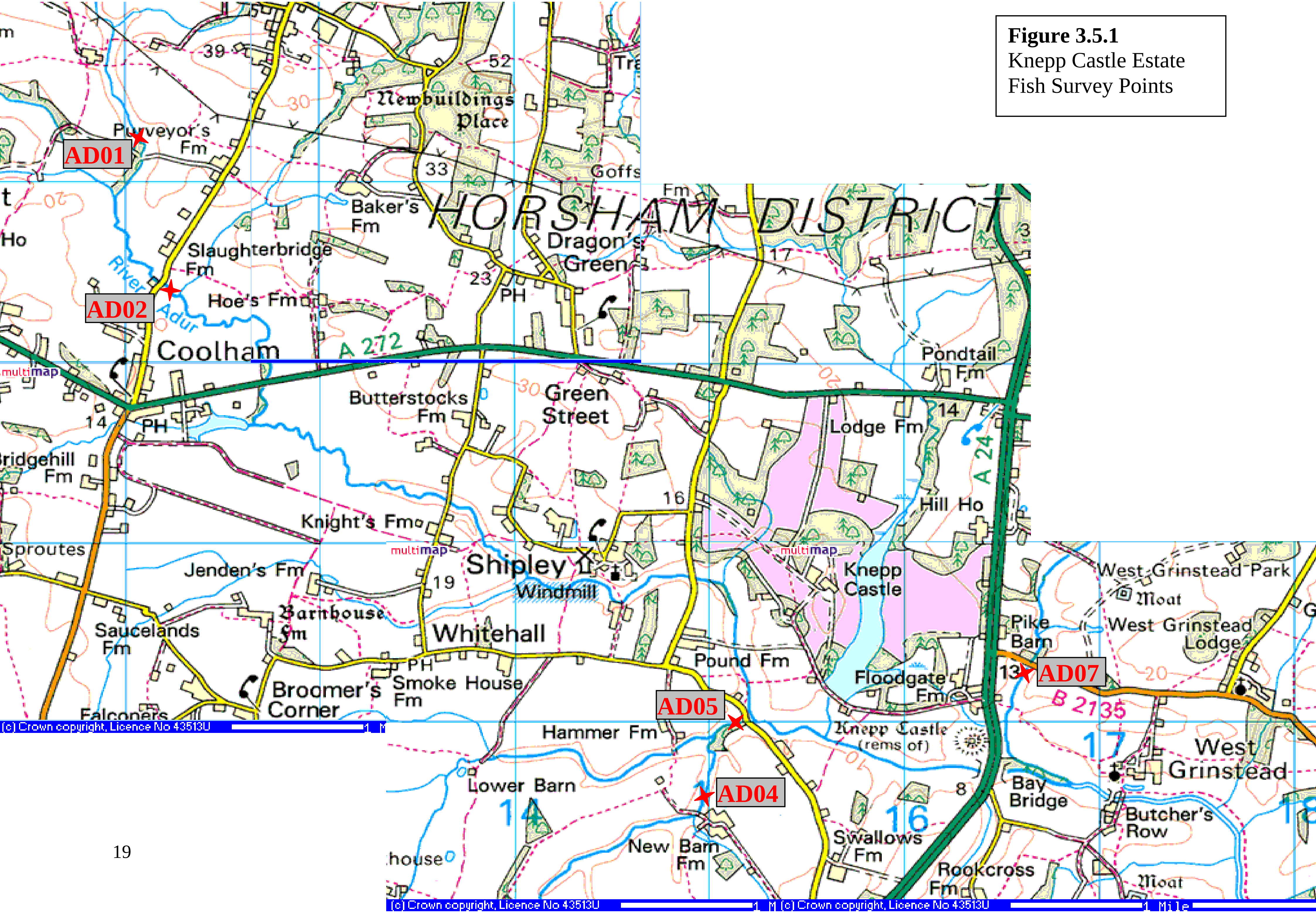
Fish species records for the River Adur Catchment



Sites AD01 and AD02 are both upstream of the Knepp Castle Estate, AD01 is located on Parsons Brook, a tributary to the Adur, and AD02 is located on the main channel. Sites AD04 and AD05 are on the Lancing Brook, another tributary which drains into the main channel within the Knepp Castle Estate and site AD07 is downstream of the Estate at Scolliers Bridge.

It is acceptable to assume that species found upstream of the Knepp Castle Estate could also be present further downstream, even though in some instances they were not recorded in the samples collected. The main trends to note are where species are absent upstream of the site as it may be that their presence is restricted by obstructions within the channel - such as four sluices located along this stretch of the Adur. Such species include Common Carp, Mirror Carp, Common Bream, Roach x Common Bream hybrid and Roach x Rudd hybrid which are only present in the Lancing Brook; Tench which is present within the Knepp Estate and the Lancing Brook but not further upstream; and Elvers and Lamprey which are only present downstream of the estate.

Figure 3.5.1
Knepp Castle Estate
Fish Survey Points



Other species of note are the Bullhead and Lamprey as these are covered by English Nature's species recovery programs which aim to achieve long-term self-sustained survival in the wild of species currently under threat from extinction. Although these species were recorded in the surveys, neither was found in the Knepp Castle reach of the River Adur. The incorporation of habitat improvements for both of these species is something that should be considered in the design phase of this river restoration scheme.

Sea Trout are a priority species for the Adur. The Environment Agency is keen to see enhancements to the river to improve the habitat for Sea Trout. The key limiting factors on the Adur are impassable structures, low flows and spawning substrate. The Adur at Knepp Castle Estate does not provide good spawning substrate, but could allow access to better substrate further up the system if the structures were made passable. The possibility of bypassing some of these would increase passage, as would enhancements to the remaining structures.

3.5.2 Water Vole

A brief Water Vole survey was undertaken in 2005 to ascertain the presence or absence of this species (Figure 3.5.2). A further, more detailed, study should be undertaken at Knepp Castle to confirm the presence and location of Water Voles and relate this to the proposed vision. If Water Voles are present on-site then the most up to date method of excluding voles from the works are should be used. Currently this would require excluding the voles from the works area prior to their beginning of the breeding season (early March) by strimming in the direction of the new habitat, re surveying and then removing the turf layer to prevent re-colonisation.

3.5.3 Otter

Unconfirmed otter sightings have been recorded downstream of Knepp Castle. Otter are present further down the river so it would be prudent to design the restoration works to be as otter friendly as possible, including enhancement work where possible. Given the above discussions, this is likely to be the case (e.g. riparian and floodplain woodland, better fish habitat/passage, less maintenance, general re-wilding of the estate, etc).

3.5.4 Macrophytes

In August 2005 a Botanical survey of the River Adur and Lancing Brook was undertaken by Dolphin Ecological Surveys (Ryland 2005). The survey covered the Adur from Shipley Windmill to the A24, and Lancing brook from its confluence with the Adur, up to the Hammer Pond. The main study reach exhibited good stands of marginal, emergent vegetation with little bank vegetation due to steep, collapsing clay banks. The survey was undertaken in a period of very low water levels in a dry year. Floating pondweed and other slow water plants were recorded, illustrating the sluggish nature of the river.

3.5.5 Signal Crayfish

It is thought that Signal Crayfish have colonised a downstream tributary of the Adur. Though structures exist on the Adur, it is unlikely that they would pose much of a barrier to advancing Signal Crayfish. This species is adept at bypassing such small structures. The suggested enhancement of the Castle Mound sluice to improve fish passage should not be viewed as opening up the upper reaches to the crayfish.

3.5.6 Invertebrates

It is important to note the presence of the invertebrate family Coenagriidae since *Coenagrion mercuriale* (Southern damselfly) is a UK BAP species and is listed as vulnerable by the IUCN categories, though its preferred habitat is chalk stream margins and heathland mires. Coenagriidae has been recorded consistently at Bay Bridge, where the A24 crosses the River Adur (TQ 1645020710), and Tenchford, where the Lancing brook joins the main channel (TQ 1520021000). It is not found downstream of the Knepp Castle Estate at Scolliers Bridge (TQ 1666021300).

3.6 Floodplain Ecology

3.6.1 Current biodiversity

The floodplain is predominantly well-established permanent grassland with a high diversity of grass species, including:

Alopecurus pratensis Meadow Foxtail	*Phleum pratense* Timothy	*Hordeum secalinum* Meadow Barley
Festuca arundinacea Tall Fescue	*Festuca pratensis* Meadow Fescue	*Festuca rubra* Red Fescue
Agrostis stolonifera Creeping Bent	*Agrostis capillaris* Common Bent	*Deschampsia cespitosa* Tufted Hair-grass
Holcus lanatus Yorkshire Fog	*Lolium perenne* Perennial Rye-grass	*Cynosurus cristatus* Crested Dog's-tail

However, the herb component was very small. The only frequent species noted were:

Cardamine pratensis Lady's-smock	*Rumex acetosa* Common Sorrel	*Rumex crispus* Curled Dock
Taraxacum officinale agg Dandelion	*Ranunculus repens* Creeping Buttercup	

This combination of grass species richness, paucity of herbs and near absence of sedges (scattered *Carex hirta* only) suggests a high fertility, productive system with adequate surface drainage for the most part. There was significant topographic variation on the floodplain enhanced by the excavation of drainage features. These shallow ditches held wetland species such as:

Juncus effusus Soft Rush	*Juncus inflexus* Hard Rush	*Glyceria fluitans* Floating Sweet-grass
Carex acutiformis Lesser Pond-sedge	*Oenanthe crocata* Hemlock Water-dropwort	

The only area where the vegetation indicated permanent moisture through the year was at the base of the embankment containing Kneppmill pond, where *Juncus articulatus* was present. Much of the river channel above Tenchford was bordered by a linear stand of woody species, the most frequent species of which were:

Alnus glutinosa Alder	*Salix cinerea* Grey Willow	*Acer campestre* Field Maple

Corylus avellana	*Fraxinus excelsior*	*Prunus spinosa*
Hazel	Ash	Blackthorn

3.6.2 Soil profile

Four exploratory auger holes were made along the floodplain. All gave similar results. The texture of the soil was overwhelmingly clay with higher silt contents in the surface layers at some points. In two of the four positions, there was a defined A-horizon coloured by organic matter as expected, but this was absent in the other two, suggesting soil disturbance of some kind. Where an A-horizon was present, there was well structured soil to a depth of approx 25 cm. Water will probably move laterally within this layer. The B-horizon showed strong mottling reflecting fluctuating water tables. The predominantly oxic zone typically went to 40 cm depth, then a transition zone between 40 and 60 cm, below which the soil was predominantly anoxic in terms of colour.

Holes were bored to 120 cm and at no location were any coarser sediments found.

3.7 Structures, services and archeaology

A number of additional constraints have emerged that need to be considered alongside the restoration proposals.

3.7.1 Powerlines

A high voltage cable follows the bridleway from Swallows Lane North to the river bridge and on to Kneppmill House. At the house a low voltage cable crosses to Charlewood Barn where it ends. EDF Energy have supplied details of these locations (Plan B). The only change to the supplied details is the apparent re-routing of the low voltage cable underground. The high voltage cable is likely to impact on the options for the properties, and will also have implications for the new channel where it crosses beneath them. Further technical information would be required on good working practice and works carried out in accordance with HSE guidance document HS(G)47. Knepp currently receive payment from EDF to allow the poles on their land. The landowner is happy to request that the remaining powerlines be buried.

3.7.2 Archaeology

Knepp Castle Estate contains the mound and ruins of a motte castle dating from after the Norman Conquest (Scheduled Monument No. 12861). The castle ruins are surrounded by a silted up moat (7-11m wide), and a low bank (6m wide). The castle is joined to high ground by a causeway 70m long to the west of the ruin. The site includes a 2m boundary around the features protected by the Schedule.

Proposals near this site need to be discussed with the West Sussex County Council archaeologist and English Heritage. This may include possible alterations to the downstream sluice structure if it is tied into higher ground on the left bank.

3.7.3 Rights of Way

Two rights of way cross the Adur floodplain within the project reach; a bridleway crossing the lower section from Swallows Lane North to the river bridge and up to Castle Lane, and a footpath which crosses the upper section from Trollards Barn to Tenchford Cottage. Currently the bridleway is raised above the floodplain and crosses a concrete footbridge. The footpath appears once to have been a series of mounds and raised walkways across the floodplain, but these structures have long since fallen into disrepair.

In addition, a track crosses the upper section above the footpath, linking the estate road with Pound Farm Cottages.

As one of the objectives is to increase floodplain wetting and flood storage, these three crossings will need special attention to maintain their usability. The two rights of way will need design specifications to be submitted to the Rights of Way Officer, Chichester.

4 Vision

A 'vision' of the restoration project has been proposed to help define how the river system should function and what it should look like. The channel and floodplain 'restoration' of the River Adur must incorporate the wider catchment objectives for the Adur system and the Knepp Castle Estate re-wilding programme. The project must work within the site constraints and demonstrate the opportunities for enhancement work to deliver landscape, biological, ecological, morphological and hydraulic enhancements. To demonstrate the success of the project objectives monitoring must be a key element.

Plans A, B and C illustrate the vision for the restoration of the River Adur and its floodplain.

4.1 Aim

To enhance the channel and floodplain habitat diversity by physical manipulation of channel planform, bed levels and flow patterns with a particular emphasis on reconnecting the floodplain to the river channel.

4.2 Objectives:

Landscape

- Provide the riverine element of the Knepp Castle Estate concept of a 'wilderness' Sussex landscape, requiring minimal intervention.

Geomorphology

- Increase physical habitat diversity within the river channel by manipulating the spatial structure of the channel form and hydraulics across the flow range, and by the introduction of Large Woody Debris (LWD);
- Increase the physical habitat diversity of the floodplain by manipulating the temporal and spatial structure of soil moisture conditions, modifying grazing regimes, and increasing the frequency and duration of fluvial flooding;
- To achieve the above 2 issues through physical manipulation in the first instance, but recognising that post-manipulation the restoration will be sustained by natural processes of debris accumulation and decomposition, channel migration (anticipated to be limited) vegetation colonisation and succession and variability in flow regime.

Hydraulics and Engineering

- Ensure that the flooding at the three road bridges is no worse than in existing situation, either from increased frequency or depth of flooding;
- Ensure protection for floodplain properties and infrastructure from any potential increase in flood frequency, duration and extent;
- Ensure that the flooding extent and duration upstream and downstream of the site is not adversely affected;
- Optimise the design to provide the best conditions for in-channel and floodplain flows for the required habitats;
- Provide conditions at the downstream end of the site to allow passage of fish.

Ecology

- Increase the diversity of riverine and floodplain habitats;
- Provide species specific enhancements where appropriate (Sea Trout passage, Water Vole, Otter, Bullhead and Lamprey habitat).

Determining project success

- Implement a monitoring strategy that will establish the relationship between new floodplain and river hydromorphology and successful habitat enhancement, and enable any necessary post project adaptations to be identified.

5 Targets

Through the discussion in Section 3, the following targets have evolved to achieve the vision and measure outcomes:

- To increase naturalness of the landscape and habitat;
- To increase the frequency of Large Woody Debris (LWD) based physical habitats throughout the reach, to levels that are typical for such river types;
- To increase channel sinuosity and to reduce channel cross-section area throughout the reach such that these match the characteristics of adjacent semi-natural reaches;
- To create a variable cross-section form with bank angles reflecting bend curvature in the first instance followed by adjustment in the post-construction phase;
- To develop a mixed sandy-silt substrate with intermittent LWD and vegetation;
- To develop a wooded riparian margin, affording shading along the newly constructed channel;
- To develop a succession of wet floodplain habitats with some wet woodland, sustained by a mixture of flush and flood hydrology;
- To maintain existing flood levels and frequency at three bridge sites and downstream of restoration site;
- To increase frequency of over bank flooding;
- To enable free passage for Sea Trout and increase passage of coarse fish species;
- To increase Water Vole habitat;
- To create habitat suitable for Otters;
- To increase diversity and abundance of typical floodplain plant and invertebrate species;
- To demonstrate appropriate restoration techniques.

The precise method for measuring some of these targets will not be able to be specified until the detailed design stage has been completed. For example, floodplain plant diversity will largely depend on the hydrological regime and associated grazing management, defined by the final design.

6 Adaptive management and restoration success evaluation

The EU Water Framework Directive (WFD) is aimed at protecting and improving all waterbodies with the ultimate goal of reaching 'good ecological status'. To achieve this it is stated that monitoring programmes should be an integral part of the enhancement process so that successes and failures can be identified. In addition it is recognised that monitoring programmes need to be reviewed and adjusted accordingly to ensure that best practice measures can be identified. Evaluating the Knepp Castle Estate project is therefore an essential part of this project not only to gauge ecological improvement but also to enable adaptive management to be incorporated so that any further enhancement measures deemed necessary over and above the initial design can be made, where appropriate.

Setting an appropriate evaluation programme should consider:

- The selection of the variables that are appropriate to measure sensitivity to change and provide indicators of both positive and negative change;
- The monitoring locations to ensure they are appropriate to measure against initial targets and that control sections are included;
- The frequency, location and timeframes of measurements so that the rates of change and driving forces behind them can be determined;
- The duration of the monitoring programme which will need to be of a sufficient period to indicate change and stabilisation of both ecological variables and geomorphological processes.

To evaluate the project effectively will require the collection, management, analysis and reporting of relevant information, including attributes of the physical and biological environment both prior to, and after, the restoration works. This can be undertaken at a variety of levels but one should not be seen as adequate over and above another.

6.1 Level 1

This will need to include baseline pre- and post-work surveys of any target species and the current morphological and hydrological characteristics of the river (including GPS referenced photographic monitoring). This will provide quantitative indicators to the qualitative restoration targets and enable:

- A benchmark to be set against which change is measured;
- Changes that have occurred within the restored area to be documented and compared with non-restored reaches;
- Evaluation of the success (or failure) of achieving the ecological and physical objectives set;
- Recommendations to be made for adaptive management, during and after the project timescale, that enables further changes to be made to include site conditions, new innovation, assessment feedback, etc if the restoration objectives have not been fully achieved;
- Identification of those initial targets that need longer term measuring strategies;
- The restoration project outcomes and lessons learnt to be communicated to others.

6.2 Level 2

The initial evaluation of the site should enable an assessment of the short term success of the scheme to be made, but will not allow for an assessment of longer-term recovery to be determined. Previous studies on other restoration sites have already begun to show that in most circumstances, whilst some major changes will occur in the short-term, much of the recovery takes place years or even decades later. A second level of evaluation should help to identify these longer term trends and is of particular importance in the Knepp Castle Estate case where success or failure is equally likely to be related to floodplain grazing management as it is to in-channel river processes. A framework of physical and ecological monitoring is therefore suggested that is initially completed annually for the first 5 years and then after 10 years to assess changes. This will continue to identify any necessary management of the site during the period when the restoration is still adjusting to a new river and floodplain regime. This phase is expected to be based on more detailed physical habitat mapping (including for example, feature inventories and data collection of both hydro-morphological and ecological attributes) with locations being informed by level 1. The continuation of repeat photography is also essential. This level of information would need to be resourced via a combination of contracted work and agency staff resources.

6.3 Level 3

This level of detail should run coherently with levels 1 and 2 and would provide for a more scientific, in-depth study of processes and habitats to be completed in addition to assessing original objectives and providing a tool for the adaptive management approach. This is essential to help to explain the major successes and understand those areas where success has been more limited. In research terms this level of appraisal can not only help assess the overall value of the scheme but also start to identify practices that are applicable to other areas. The level of commitment to such monitoring is high, so would need to be part of a University research exercise and would most likely form the basis of a PhD studentship.

Such an integrated approach would support the optimum habitat and river processes gain, ensure that the original targets have been achieved and that the requirements of current legislation are being delivered.

7 Restoration Vision

The following sections outline the proposed vision for the restoration project based upon the outline discussions in Section 3. Firstly the key concepts for the entire site are outlined in terms of channel morphology, floodplain rewetting, woody material, landscape, habitat and management. Where the concepts require further explanatory information this is provided in the relevant appendices.

This is followed by a more detailed proposal of specific works to the 'upper' and 'lower' sections, defined as Capps Bridge to Lancing Brook/Adur confluence and Tenchford Bridge to the A24 (Bay Bridge), respectively. These should be read in conjunction with the three layout plans, Plan A (upper), Plan B (middle) and Plan C (lower).

7.1 Whole Site

7.1.1 River morphology

The river should be relocated within its floodplain along a more geomorphologically typical sinuous course. The topography of the site and historical information provide a template for returning some sections to their original planform and linking these via low lying hollows and depressions into a continuous channel. In one location the new channel will cross the existing course. The 'restored' new channel will run for a distance of approx. 1750m from Pound Farm access track to the Castle Mound weir structure.

It is the intention of this scheme to restore the fluvial processes of an 'active' river, albeit low gradient and clay dominated. Many other enhancement projects simply achieve physical relocation of a still 'fossilised' or inactive watercourse; one where the active processes of erosion and deposition of material are not restored.

7.1.1.1 New channel

The new channel will demonstrate a more appropriate cross sectional profile. The constructed width and depth should be variable, but based around a design bed depth of approx. 1.5m below mean floodplain level and a width of 5m. This bed level may be hard or 'soft' such as the top of a woody debris layer, but in both cases is indicative of the capacity available for conveyance.

The proposed sizing reflects the current cross sectional measurements of the Castle Mound sluice. In some locations the channel may be able to be reduced in width if hydraulic modelling suggests this (possibly where multiple channels provide additional conveyance), or in the upper section where the new channel is in additional to the retained course.

Figure 7.1 indicates a typical 'engineering' cross section. The actual dug channel should vary around these typical dimensions, providing physical diversity of bank slopes, depth and width. Variation by up to 15% should provide adequate diversity of form (but a minimum cross sectional size should be specified (depending on the feasibility modelling), for conveyance purposes and to instruct the contractor). Figures 7.2 and 7.3 illustrate variation around the design cross section for both symmetrical and asymmetrical (bends) cross sections. This wider illustration should form part of the final detailed design specification to the workforce. This is

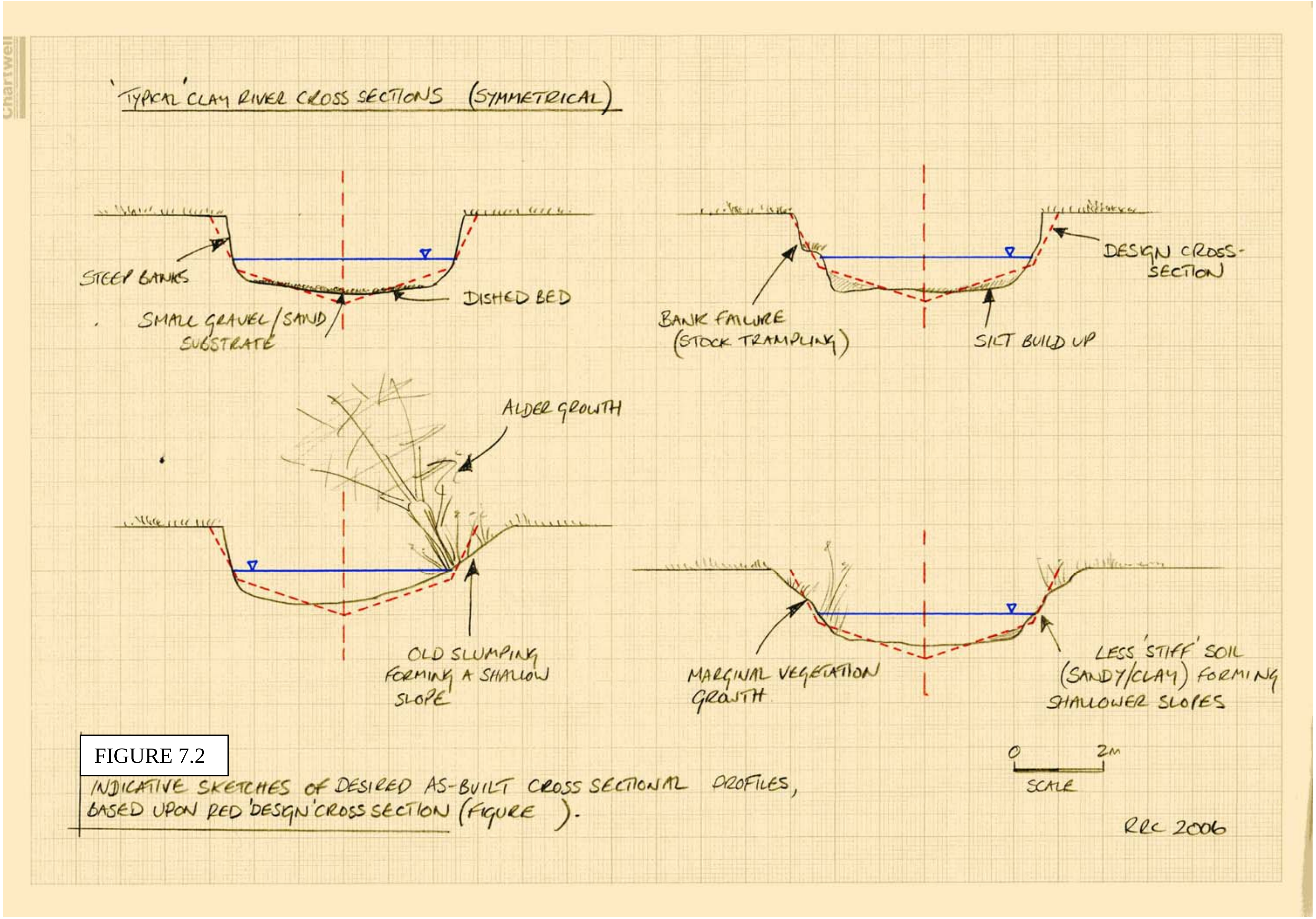
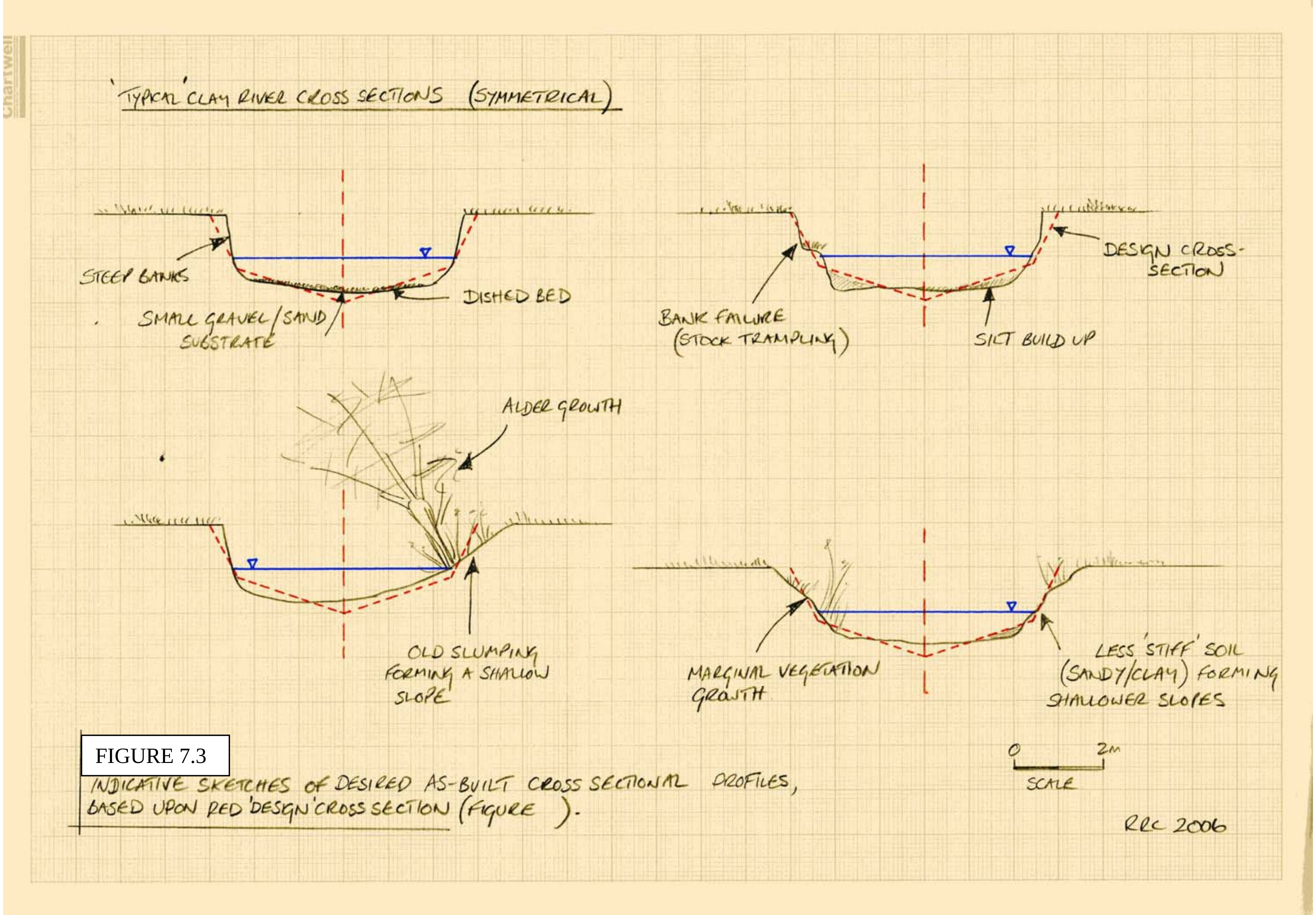


FIGURE 7.2

INDICATIVE SKETCHES OF DESIRED AS-BUILT CROSS SECTIONAL PROFILES, BASED UPON RED 'DESIGN' CROSS SECTION (FIGURE).



'TYPICAL' CLAY RIVER CROSS SECTIONS (SYMMETRICAL)
STEEP BANKS
DISHED BED
SMALL GRAVEL/SAND SUBSTRATE
BANK FAILURE (STOCK TRAMPLING)
DESIGN CROSS-SECTION
SILT BUILD UP
ALDER GROWTH
OLD SLUMPING FORMING A SHALLOW SLOPE
MARGINAL VEGETATION GROWTH
LESS 'STIFF' SOIL (SANDY/CLAY) FORMING SHALLOWER SLOPES
0
2M
SCALE
INDICATIVE SKETCHES OF DESIRED AS-BUILT CROSS SECTIONAL PROFILES, BASED UPON RED 'DESIGN' CROSS SECTION (FIGURE).
RRC 2006

FIGURE 7.3

important in clay river systems as it is desirable to avoid cutting a very engineered channel as subsequent self adjustment is often negligible. Thus detail must be built in.

On site supervision will also be critical to inform the workforce of the exact location of significant features and variations in width, depth and bank slope (associated with log jams, etc). A cost has been built in to the budget for such expert input as well as general site supervision.

As well as an appropriate form, the channel should demonstrate an appropriate substrate. In this clay catchment such material is the fine gravel and sands seen in the faster flowing reaches. The channel should be seeded with this material, where appropriate.

7.1.2 Floodplain rewetting

The new channel morphology will result in a smaller channel with proportionally less conveyance than existing. This will increase the frequency and duration of water overtopping the banks as well as increasing local watertable levels. Both of these outcomes contribute to the objectives of the overall scheme, in order to sustain the envisaged varied floodplain habitat communities and supported species.

Variation in floodplain hydrology is likely to include the following three scenarios. It is possible that all three scenarios could co-exist on the floodplain. Which of the three dominate and their spatial distribution will depend on the hydraulic design of the river restoration scheme:

1. Areas of prolonged, or permanent seepage (e.g. tributary streams directed onto floodplain with percolation through the soil profile);
2. Areas experiencing regular inundation (e.g. floodplain areas that receive out-of bank flooding in most years and which may occur as late as April or May; floods would be typically followed by rapid drainage, by which all surface water returns to the channel within 3 days of the flood receding);
3. Areas subject to temporary ponding (e.g. low spots and hollows within the floodplain that hold water following either heavy rain or a flood and where surface drainage is absent. Water is principally lost by evaporation and surface water may be present until July).

To achieve this within the constraints of the flood capacity of the site requires careful consideration of sensitive areas, total storage and total conveyance.

7.1.3 Woody material

Woody material will be incorporated into much of the new and old (where retained) courses. In clay river systems where gravel beds are uncommon, small woody blockages and accumulated material form the main drivers for variation in channel dimensions, flow, habitat and in-stream cover. Figure 7.4 illustrates a constructed log jam.

In addition, woody material supports biological activity and invertebrate life cycles and provides carbon storage. Initially the material can be placed, but this should be superseded in time by the availability of material along the new river, either riparian, floodplain or both.

The Wildlife Trust booklet ‘Managing Woody Debris in Rivers and Streams’ provides an introduction to the value of these features (see H1, Mott 2005).

Appendix H2 gives more detail on the success of woody debris structures and the design of such features.

7.1.4 Landuse and landscape character

The floodplain will be open to grazing animals. Presently this is grassland with light grazing. The removal of all fence lines and stock barriers may lead to an increase in grazing. The eventual vegetation type will be largely dependent on the degree of grazing pressure, which in turn will depend on the preference of the various grazers for the floodplain vegetation as opposed to that of drier areas of woodland, parkland and arable reversion areas across the remainder of the estate.

The projected maintenance of the site does not include any cutting and therefore hay-meadow or fen communities are not appropriate targets. All vegetation management will be via grazing. The possibilities in terms of floodplain vegetation at Knepp Castle Estate are summarised below (see Appendix F for full details).

Floodplain woodland: woodland is likely to occur spontaneously, given the proximity of seed source, if grazing pressure is low.

Swamp communities: Where surface water is retained beyond the end of May. If grazing pressure is moderate, then the sedges will predominate over the reeds, if grazing is sustained then a low flote-grass sward may be favoured.

Grassland communities: High grazing pressure is likely to maintain grassland communities irrespective of hydrological scenario.

Open vegetation: Where grazing pressure is very high (particularly pigs) and flood durations are prolonged.

It is suggested that floodplain woodland would be appropriate for this setting, but the establishment of such a vegetation community is uncertain. Expert judgement, literature and the experiences of the landowner suggest that this is greatly dependant on grazing and browsing pressure from the large herbivores. As a ‘demonstration’ project, it would be valuable to allow natural colonisation as well as a more controlled (perhaps fenced or even planted and fenced) means of establishment.

To avoid unnecessary fencing, but to encourage woody vegetation growth, a mix of blackthorn, buckthorn and hawthorn could be planted in small fenced enclosures, creating a self protecting ‘stockade’ once the fence falls into disrepair. The enclosure should also allow Alder, Ash, Field Maple and White Willow to regenerate within its protection. Planting of these latter species could also be undertaken if desired.

7.1.5 Habitat and Ecology

The scheme proposes a varied mosaic of habitat types, channel, riparian, floodplain. In-stream, diversity will be provided by woody material, bankside shade and cover and variety in width, depth and flow. Fish passage will be increased with the aim of habitat improvements being beneficial to key species such as Sea Trout. Woody material will also increase the available habitat and food supply for invertebrates.

Utilising the various physical differences of the floodplain, habitats will initially reflect the climate, soil and water conditions available. For example, low depressions in the clay soil may retain rain and floodwater until it evaporates, whereas areas fed by tributary streams will remain wetter for longer.

Table 7.1 Matrix of possible vegetation types establishing in the first 10 years following restoration based on hydrological scenario and degree of pressure from grazers and browsers.

	Grazing pressure	High		Low	
	Browsing pressure	High	Low	High	Low
Hydrological scenario	1	Open vegetation and bare mud		Sedges and other fen species	Willow carr with alder invading
	2	Mixed grasses, similar to current situation	Mixed grasses with scattered thorny shrubs	Tussocky grasses and tall herbs	Blackthorn scrub with ash invading
	3	Open water and mud with amphibious plants and rushes		Large rush tussocks	Rush tussocks with willow invading

Retention of the existing ditch network will continue to provide habitat for Water Vole, with more varied vegetation growth providing better cover.

7.1.6 Management

Management of the site is being reduced significantly in favour of open ‘wilderness’, so the above habitats should be as self sustaining as possible. Some management of the level of wild animals (as discussed above) may need to be considered either as part of this project, or in the longer term.

The areas of management that will need to be monitored and maintained are mostly to be the fixed structures and other physical elements of the site/works. It is envisaged that management will in most cases be the responsibility of the landowner.

Operational maintenance may be required for certain elements such as the flood proofing of the cottages. This would be the responsibility of the landowner and/or tenant.

7.2 Upper Section (Capps Bridge to Lancing Brook)

A combination of new channel creation and increased wetting of the floodplain is proposed to enhance this reach. The three principal constraints comprise the road bridge, the access track to Pound Farm and the footpath route from Trollards Barn to Tenchford Cottage.

7.2.1 Floodplain wetting

Within two hundred metres of Capps Bridge a tributary stream (Spring Wood Stream) joins with the main river from between Capps and Charlwood woods. It is reported by the landowner that this tributary flows for much of the year, but no data is available. Above the farm track, enhancement work will centre on diverting this tributary stream onto the eastern side of the floodplain, following the low areas identified in the topographic survey (Plan A). Initially a shallow 'swale' may need to be excavated to provide a route for this diverted flow, but in general the principle is to allow shallow surface wetting by overland flow. At times of high flows the increased volume of surface water may flow far enough to the south to rejoin the (new) River Adur, just above the access track. At other times evapotranspiration may exceed inflow and only keep wet the upper floodplain.

7.2.2 New Channel

Just above the weir at Pound Farm, a new channel will lead off to the left of the existing course. This is shown following the low depressions and old drainage network on a sinuous course across the floodplain. This new course picks up an area where standing water persists after high flows and heavy rainfall. In some areas the new channel will invariably drain these communities, but similar hollows and depressions can be excavated in the adjacent floodplain. Although the main depression in this area currently holds vegetation of wetland interest, such as water crowfoot (*Ranunculus peltatus*) and water starwort (*Callitriche* sp.), it is expected that such species will colonise similar wet depressions created to the north by the diversion of Spring Wood Stream.

The new channel will re-enter the Adur approx. 50m further downstream from the Lancing Brook confluence. This entry point needs to be designed to reduce headward erosion if bed and flow levels differ significantly between the two channels.

Along the new channel, two woody debris jams will be constructed from whole trees, branches and twigs. These features will require a 'standard' design for costing and construction purposes. On-site supervision will be needed to ensure that this basic design is interpreted into the naturalistic features envisaged (Figure 7. 4)

7.2.3 Footpath and farm access track

Shortly after the start of the new channel it will cross the existing access track to Pound Farm. A ford will need to be constructed to maintain continued access.

Half way along the new channel, at approx. chainage 1350, the footpath crosses the floodplain. Old structures indicate that the footpath may have been raised above the floodplain level to allow access when the surface was waterlogged. Reinstatement of this raised footpath, in conjunction with a bridge over the new channel is likely to be necessary to accommodate the requirements of the West Sussex Rights of Way Officer. This will provide a restored and (for the purposes of those who now use the path) a significantly more usable route.

7.2.4 Old course

Ensuring that Capps Bridge and the road are no more prone to flood risk than at present requires careful siting of the off-take to feed a new channel. Currently a weir exists at the farm access crossing. This crest level will define the overspill into the new channel. Above the weir, no major alterations will be undertaken that could affect the potential for river levels to back up and impact on the bridge. Small woody material, twigs and branches will be incorporated into this section to provide source material for the new channel (Appendix F2).

Below the farm sluice the old course is retained. This channel is still valuable as an additional flood channel in flood flows, and as a still/slow water habitat. The existing riparian trees will continue to provide leaf litter, branches and the occasional whole tree to the river system. This is important in the short to medium term as any new planting/colonising growth will take at least 10 years to provide such input to the river system.

7.2.5 Tenchford Cottage

Tenchford Cottage requires flood proofing to protect it from current and future flood risk. A specific study of the property, flooding routes and possible solutions should be undertaken. It is likely that a flood bund and a small sump and pump system will be needed to manage risk to the property. A brief inspection of the cottage revealed an existing barn in a state of disrepair with signs of road runoff entering the garden from the road through the barn wall. There appears to be room to create a flood bund around the property tying in with the high ground, except where the barn sits tightly between the cottage and road. It may be necessary to rebuild the barn, incorporating a low floodwall into the structure to link in with the bunds.

As the cottage is outside the project floodplain boundary, detailed solutions for its protections have not been drafted. Such bunding, etc. is likely to be undertaken locally to the property.

7.3 Lower Section (Tenchford Bridge to A24, Bay Bridge)

A new channel is planned for almost the entire length, using the middle and lower control structures to control flows. A section of the old course will be retained to aid flood capacity. Constraints include Kneppmill House and Cottage, the bridleway, power lines and the up and downstream bridges (Tenchford and the A24 Bay Bridge).

7.3.1 Flood routing

The confluence of the Adur and Lancing Brook is the most sensitive location with respect to flooding. The broad brush model undertaken in this study indicated that reducing the overall capacity of the river would impact greatest on this area; the greatest flood level height rise. Though only indicative this ties in with the observed flood prone nature of Tenchford road bridge. Such a rise would be unacceptable.

If the aim of restoring appropriate channel dimensions is to be achieved, an additional flood route is needed to convey the extra floodwaters away from this confluence area. Plan B shows the proposed ‘new’ channel exiting the current course at approx. chainage 1110.

The current course is retained as a flood channel. This course continues until it reaches the existing footbridge and powerlines. Just beyond the bridge the old course is filled and a new cut excavated to divert flows into the new channel, and in floods, onto the floodplain. All of this is subject to detailed hydraulic modelling.

The existing sluice structure at the brook/river confluence is needed to control the flow of water between the new channel and the existing course (now flood channel). At low to moderate flows the majority of water will pass down the new channel. At flows greater than the designed threshold the flood channel will come into play and flows will overtop the fixed crest to enter this additional route. The flood channel will be ‘seeded’ with small woody material such as branches and twigs to provide material for the new channel (see Appendix F2).

In addition, a low depression (possibly an old meander route) will be reconnected to the river by a shallow dished ‘swale’. This too will help convey floodwaters once they overtop the bank.

This combined use of the new channel and a flood channel should ensure flood flows are conveyed far enough downstream to avoid unduly impacting the Tenchford area, whilst still enabling the new course to function in isolation at low to moderate flows.

The floodplain soil is estimated to be adequately impermeable to prevent excessive lateral movement of water from the new channel to the existing, deeper flood channel (this may need to be checked at the feasibility stage).

7.3.2 New channel

Plans B and C show the proposed route of the new channel. Land adjacent to this channel is often wet or damp, with the Estate actively raising the water table by ditch blocking in previous years. Seepage may also be entering this area from the Kneppmill Pond, as well as via the sluice structure.

The new channel continues past Kneppmill House before crossing beneath the power lines and across the bridleway.

Past the bridleway the new channel continues for a distance of 500m before crossing the old course and linking into the low depressions in the southern floodplain. A 200m section of new channel, prior to crossing the old course, will be seeded with small woody material (Appendix F2). This section of floodplain is proposed as a potential site for establishment of floodplain woodland. As the trees mature, these will impart debris to the channel to sustain and create more of such features.

The existing course will become a mixture of infilled and open sections, providing deep, shallow and temporary pools. Where low lying floodplain exists, this could be linked to the new channel by partially infilling the old course, or kept separate. Initially three woody debris log jams are proposed for the new channel, shown on Plan B. Similar to those in the Upper Section, they will be constructed to impede flows and encourage the spilling of water onto the floodplain (Figure 7.4).

Once across the old course, the new channel passes through low lying depressions evident on site and clearly marked on aerial photos. Some of these depressions also tie in with the 1754 Crow map of the estate showing a more sinuous River Adur (Figure 7.5). The new channel will follow one of these depressions, whilst the Jacksons Wood tributary stream is diverted to wet the more southern series of hollows. Similar to the Spring Wood Stream upstream, this tributary confluence with the Adur will be blocked and the flow fed via an excavated swale into the hollows. It is reported that this tributary dries up much earlier than the Spring Wood Stream which should lead to the development of a more inundation/ drought-tolerant vegetation community. The new channel then continues along the main depression until it rejoins the existing course just before the downstream sluice.

7.3.3 Lower (Castle Mound) sluice

This sluice structure will be retained and used to return bed levels back to the old course, prior to the river entering the A24 culvert. In addition, and in combination with the new channel it will act to raise the depth of floodwater stored in the floodplain. In order for this storage to be effective some minor works will need to be undertaken. Currently the track to the bridge from the right bank passes through a low depression in the floodplain. This needs to be blocked to prevent floodwaters by-passing the structure, and may require a low embankment to tie in with the valley side.

Photo 7.1. Castle Mound sluice structure

Similarly on the left bank a shallow embankment (likely to be around 200-400mm in height) will be needed to tie in the sluice structure with higher ground. From a practical viewpoint this would best be achieved by tying in with the Castle mound; such work would not require any excavation or disturbance of the mound and would represent a very subtle land height increase. Such works would need approval by English heritage and the County Archaeologist. If this is not permissible, a longer length of embankment should be used to tie in with the A24, avoiding the Castle Mound.

The sluice bridge is part of the estate's access route for daily stock checking. It is important that this access is maintained. The route from high ground N. West of the bridge could be given a stone base to maintain its usability even when under shallow surface water, and the route from the bridge to southern high ground could be taken along the shallow embankment proposed above.

Cross sections 1.001 and 1.002 (Plan E) outline the proposed works to this structure and the river between it and the A24 bridge. Currently the structure is impassable to fish in the majority of flow conditions and its primary purpose is to retain water levels in the river behind the structure and any additional sluice boards inserted. As a result of the proposed works the artificial retention of high water levels is no longer necessary, nor is the need to manage levels via the boards. Instead the structure will have the role of returning flows from the new channel back to the existing course, prior to Bay Bridge. By using the sluice location, there is approx. 100m of river in which flood flows can return to the over-sized old course, before the road culvert.

As fish passage is severely restricted by this structure, it is proposed that the 1.5m (approx.) difference in height between top of structure and downstream bed level is utilised over a 75m length immediately downstream of the sluice. By re-grading to a design gradient of 1 in 50, the 1.5m drop can be used to provide easier access to the upper reaches (Plan E). Bulk fill material could be used to fill the bed to the required new bed grade. At another restoration site in West Sussex, crushed sandstone fill was successfully compacted as part of a ford. Care must be taken to ensure that the material is sufficiently well secured to prevent migration downstream due to high velocities in flood flows.

The cross sectional dimension of the weir structure is similar to the proposed new channel cross section. Some minor adjustments may need to be made to the structure for aesthetic purposes.

7.3.4 Kneppmill Cottages

Plan D illustrates potential options for flood protection at Kneppmill Cottages. This location is particularly problematic, and will require a co-ordinated approach to achieve flood risk management, working within the vicinity of the power lines.

Plan D shows the potential 'worst case' scenario (1) in terms of land take and embankment creation. The area illustrated in green shows the new shallow (1 in 7) sloped embankment required to provide 1 in 100 year flood protection. This assumes that the cottage gardens are to remain untouched by the works.

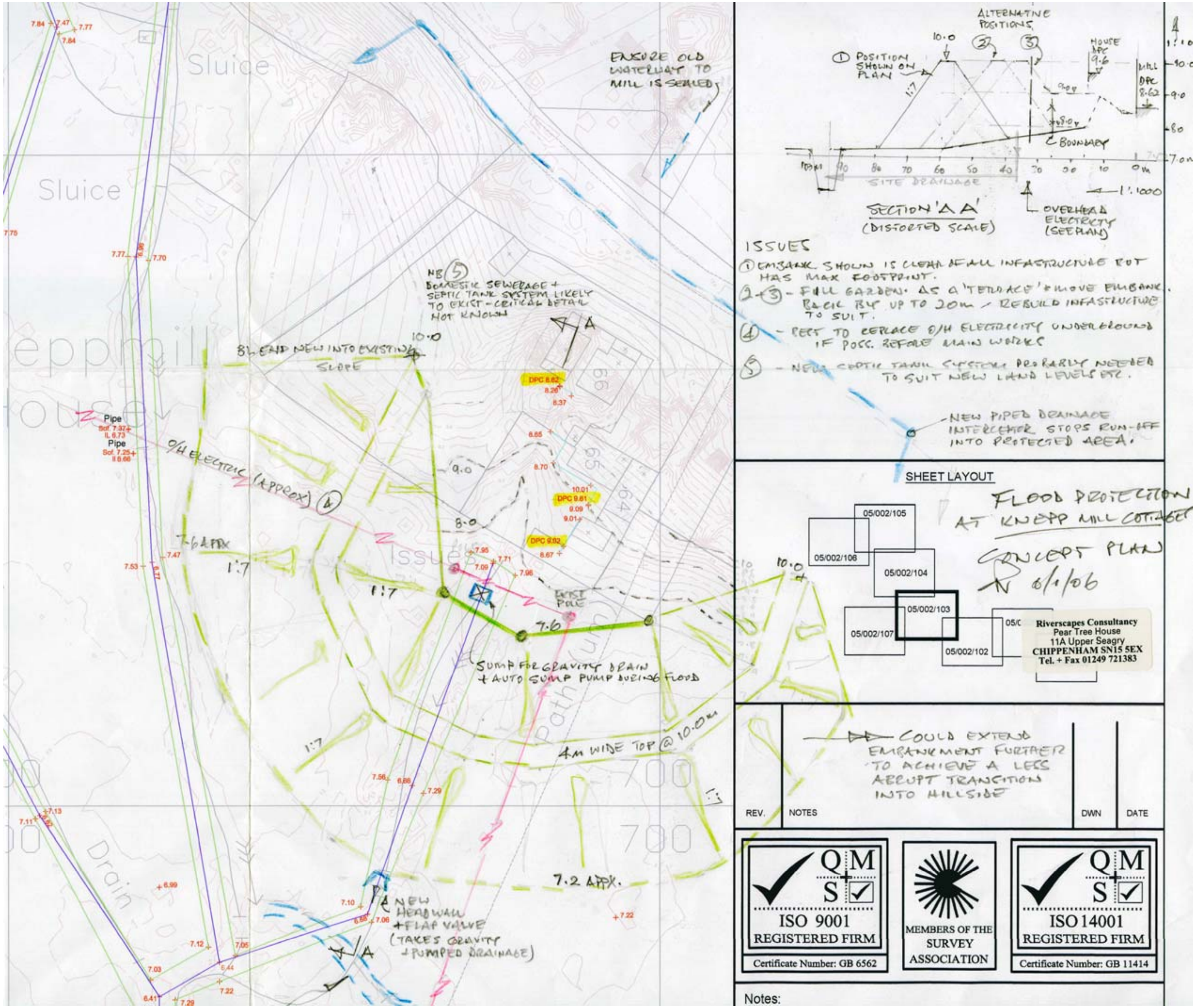
Alternatives (2) and (3) provide for a similar 1 in 7 riverward slope face, but require works to Kneppmill House gardens. Option (2) raises the House's garden to 8.0m AOD, this contour is marked on the plan. This would entail some 'terrace' works to a small area of the garden, but would reduce the footprint of the embankment into the floodplain by approx. 15m. In this option both the House and Mill damp proof course levels remain above the terrace level (9.6 and 8.6m respectively), though the Mill already has a bund of sorts surrounding it as indicated on the sketched cross section.

Option (3) is similar in that it reduces the footprint by another 5m in return for raising the House garden to 9.0m AOD. The contour, marked on the plan, shows that this terracing would have a much greater impact on the garden (approx. 80%), but could be seen as an improvement as it 'levels up' the garden.

Photo 7.2. Rear garden of Kneppmill House, looking towards the low lying Mill Cottage

The top of the embankment is shown at 10.0m AOD with a 4m top and 1 in 7 side slopes. The embankment keys into high ground against the dam wall and road on both sides. This arrangement could be varied as necessary. The embankment size location and top level will need to be run as part of the hydraulic modelling to determine the final design height and volume of material required.

Plan D
Flood protection at Kneppmill House and Cottages



On site it is apparent that steep slopes abound the property and the footprint for the embankment may be significantly reduced without undue landscape issues. The Landowner is happy to consider such options and wishes to minimise the land take to avoid impacting the floodplain.

As the properties are being protected from the river, it is also important to check their protection from the lake and old mill channel. The channel should be properly sealed, and a ‘simple’ interceptor drain may be required along the road verge to collect and divert local runoff, to avoid the possibility of pluvial (rainwater) flooding within the protected area.

In all options a small electric sump pump is desirable to deal with any water that does become trapped within the protective bund during short periods of river flooding.

All of this work would entail working within the immediate area of the high and low voltage cables. Discussion should be sought with EDF energy to look at the implications of such work and the possibility of routing the high voltage cables below ground level. This would need to be undertaken prior to the embankment works. The low voltage cables, now buried, would need to be correctly located to avoid disturbance during the works.

The need for replacement of septic tank and sewerage systems is likely. This will require detailed inspection of the house and cottages by a suitably qualified drainage contractor.

7.3.5 Bridleway and Footpaths

Bridleway downstream of Kneppmill Cottage
The bridleway crosses the floodplain from east of Kneppmill house to Swallows Lane North. This right of way must remain accessible and any proposed works should not significantly affect users. The proposal is to create seasonally wet areas and a new channel on the left floodplain. The most likely option would be to create fords for horse/vehicular access across the new channel(s), with additional raised walkways, similar to the upstream footpath, for walkers. After prolonged periods of rainfall, the floodplain will become damp to wet, as it does at present after shallow flooding from the river. The existing bridge over the old river course will remain.

Further discussion is required with the West Sussex Rights of Way officer to explain this option, in order to achieve the desired shallow flooding of the floodplain and maintain access.

Access track to Pound Farm
It is essential that this access track remains usable. A ford crossing over the new river channel that retains the current track levels is the landowners preferred option. The implication of this in terms of the hydraulic modelling needs to be considered. The impact may be to slightly pond water upstream, which could be beneficial to the overall project aim. The track should overtop in a controlled manner to reduce the risk of erosion. The ford needs to be sufficiently wide to convey low to moderate flows. During a high flow event the track would act as an obstruction and water would “weir” over the top which is not dissimilar to the current scenario. It would be a sensible precaution to protect the downstream edge of the track with larger stone to prevent this edge being ‘plucked’ away by floodwaters. No significant rise in predicted vs current water levels on or over the track during larger floods is expected as the downstream raised footpath already acts to pond water back locally in over-bank conditions.

Footpath across left floodplain on north-south channel

This footpath should be reinstated on the old, but currently redundant raised platform. This may cause some ponding upstream of the raised platform during floods. In exceptionally high flood situations the water will "weir" over the raised footpath and some ponding will occur upstream. This is undoubtedly the case at the moment; pedestrians would not be expected to be walking across the floodplain in a 1 in 100 year event. An opening will be required through the raised platform for the new channel. This can be designed to pass or hold back water as required similar to the existing design. No significant rise in water levels on or over the footpath during larger floods is expected.

Photo 7.3. Derelict structures associated with raised footpath

7.3.6 Kneppmill Pond seepage

Kneppmill Pond occupies the course of a further tributary of the River Adur at Knepp. The ponding of this tributary has resulted in a man made lake (hammer pond). There are three outlets for the pond: the main sluices at Floodgates discharge excess water into a brook which passes under the A24 prior to rejoining the Adur via the Southwater tributary; a penstock in the dam allows water to be bled off from the pond into the ditch network by Kneppmill House; and a series of overflow pipes release water from the pond before it reaches levels that might overtop the dam wall, also discharging onto the floodplain below the dam.

By controlling the outflow at Floodgates, it would be possible to crack open the penstock and bleed more water onto the floodplain via the ditch system. This would provide another feed to help establish further semi-permanently wet floodplain. In dry summers the pond level may drop and would require all sluices to be closed, but this would coincide with the other two tributaries ceasing to flow as well. A hydrological management plan will be needed to enable the Estate to manage the penstock and sluices optimally.

7.3.7 Spoil Disposal

Spoil disposal should be on-site. As there is a desire to retail some elements of the old channel as flowing, ponded or shallow waterbodies there may be an excess of spoil. This is roughly estimated in Section 8, including likely quantities from excavation and capacity of infill for old course, Kneppmill House and Tenchford Cottage embankments and lower sluice embankments.

If an excess is confirmed at detailed design and re-use elsewhere on the estate is not possible, landforming the valley side at specific locations could provide local disposal. This would also result in a net gain in flood storage capacity on the floodplain. The Landowner has indicated that this is acceptable.

7.3.8 Summary of major vision components

Upper section (Capps Bridge to Tenchford Bridge)

Feature	Works proposed	Objectives	Measurements
Spring Wood Stream [Plan A]	Steam blocked as it enters the floodplain. Stream flow diverted to left through a series of shallow scrapes. Scrapes tie in with low contours along left side of floodplain. Locally enhance floodplain levels to encourage retention of stream water, rainfall and floodwater. Drain along slope of valley side blocked with earth plugs at intervals.	Permanent or prolonged seepage, saturated and overland flow and floodwater retention. Create mosaic of floodplain habitat.	Approx 450m length of floodplain with increased wetness, by 50 to 80m wide. (up to 2.7 ha of floodplain wetland)
Capps Wood Drain [Plan A]	Drain at foot of slope infilled and flow allowed to spill over floodplain. Increased wetness of floodplain soils and enhanced habitat potential.	Increased periodic wetting of the floodplain following rainfall and out of bank flows	Approx 180m of infilled ditch, by 50m wide floodplain.
Pound Farm Sluice [Plan A]	The sluice may need to be modified, but currently sets the level at which the Adur will overspill into the new channel.	Allow controlled overspill into the new channel whilst retaining a flood route down the old course.	Immediate area around the structure
New Channel (upper) [Plans A and B]	Divert the majority of normal flows down a new, smaller and more sinuous channel.	More appropriate channel dimensions and greater connectivity with floodplain.	Approx. 550m length of new channel by 4x1m. See Figures 7.1, 7.2, 7.3
Log Jams [Plan B]	Construct two log jams on the new channel. Secure several large tree limbs and add smaller woody debris to form a low level obstruction within the watercourse. Over-widen/deepen the immediate downstream channel profile.	Provide structural and flow diversity, create habitat, promote local out of bank flows, re-wet the floodplain.	Immediate area around the constructed feature.
Pound Farm Track [Plan A]	Ensure a sound surface to the farm access track. Construct a ford crossing of the new channel.	Retain access to the Farm and Cottages, allowing deep flooding to overspill the track as at present.	70m of track. 15m of constructed ford.
Footpath [Plan B]	Reinstate the old raised footpath (structures still in existence – state of disrepair).	Provide a restored/better footpath than is currently available.	75m of footpath, some earth mounds and some wooden and brick structures.
Tenchford Cottage	Flood embankment tied into high ground (incorporating flood	Provide a suitable level of flood	Approx. 100m of flood

[Plan B]	wall as part of barn renovation). Sump pump installed to remove local drainage.	protection to the property.	embankment and flood wall.

Lower section (Tenchford Bridge to Bay Bridge (A24))

Feature	Works proposed	Objectives	Measurements
Flood channel [Plan B]	Shallow swale excavated on right hand floodplain downstream of the Adur/Lancing Brook confluence, connecting low hollows to form a flood route at high flows.	Reduce flooding pressure on the Tenchford area by increasing conveyance along multiple channels.	225m long flood route, requiring some 50+m of shallow excavation.
Tenchford Sluice [Plan B]	Existing structure retained. Overtopping will occur at moderate+ events. Some local modifications to the structure and appearance.	Provide mechanism for directing flow into the new channel. The old course will provide additional flood capacity.	Immediate area around the structure
New Channel (lower) [Plan B and C]	Divert all low to moderate flows along a new smaller sinuous channel.	More appropriate channel dimensions and greater connectivity with floodplain.	Approx. 1250m of new channel by 5x1.5m. See Figures 7.1, 7.2, 7.3
Log Jams [Plan B and C]	Construct three log jams on the new channel. Secure several large tree limbs and add smaller woody debris to form a low level obstruction within the watercourse. Over-widen/deepen the immediate downstream channel profile.	Provide structural and flow diversity, create habitat, promote local out of bank flows, re-wet the floodplain.	Immediate area around the constructed feature.
Seepage wetland [Plan B]	Utilise the lake penstock to provide a further source of water to the floodplain below the dam wall. Locally block ditch network to encourage shallow ponding. Excavate additional shallow scrapes in the floodplain. Retain ditch network as potential Water Vole habitat.	Permanent or prolonged seepage, saturated and overland flow and floodwater retention. Create mosaic of floodplain habitat.	Approx. 1.5-2 ha of wetted floodplain, with a matrix of depressions and blocked ditches.
KneppMill House [Plan B and D]	Shallow embankment surrounding the properties, tying into the dam wall/valley side. Sump pump installed and sewerage system upgraded.	Provide a suitable level of flood protection to the property.	Up to 90m length of embankment. (up to 4300m^3 of material)
Bridleway [Plan B]	Construct ford and raised footpath access across the new channel.	To provide similar level of access as is currently available.	Approx. 140m of bridleway crossing the floodplain. Up to 3

			crossing points @ 10+m.
Old/new course connection [Plan B]	Excavate a new cut between the existing course downstream of the bridleway bridge and the new channel.	Provide an outlet for flows routed along the old course.	Approx. 60m of new excavated channel, 5x 1.5m
Old Course infilling [Plan B and C]	Fully/partially infill old course between link to new channel and Castle Mound sluice. Degree of infilling will be determined by excess of spoil and cost of disposal elsewhere on site (see ‘Landforming’ Feature).	Force flows into the new channel and remove the visual impact of the old course.	Approx. 650m of old channel to be infilled. Potential volume of 11700m^3, but see below.
Backwaters [Plan C]	Retain some areas f the old course (above) as connected backwaters and unconnected ponds and shallow pools. Re shape banks to add shallow slopes and increased wettable margins.	Provide backwater/ponded habitat. Fish and invertebrate refuge in high flows; fry habitat in low flows.	Include backwaters and shallow pools (say 150m or 3000 m^3 unfilled old course volume).
Landforming valley slope [Plan B]	Re-profiling of valley slope at Tenchford. Topsoil stripping, material spreading, re-topsoiling and making good.	Excess spoil disposal if cut significantly greater than fill and other earthworks.	Volume of spoil to be spread such that landscape character is retained.
Jacksons Wood stream [Plan C]	Stream outlet to old course to be blocked with earth bund. Shallow scrapes to be excavated to link stream with existing hollows (old meander route).	Intermittent flows to provide seasonal wetland habitat.	Approx. 0.5ha linear wetland feature (new and existing scrapes/hollows).
Castle Mound Sluice [Plan C]	Sluice structure retained, but modified in operation. Aesthetic/landscape enhancements to the structure.	Control rate at which flood volumes return to the old course prior to entering the A24 culvert.	Immediate area around the structure
Floodwater bund [Plan C]	Construct a low earth bund from the sluice across the right hand floodplain to tie into the valley slope, and across the left hand floodplain (avoiding the Castle Mound) to tie into the A24 embankment.	Raise the floodplain ground level by approx. 300mm to retain floodwater on the floodplain and surrounding the Castle Mound.	Approx. 175m length of low bund, by 0.3-0.6m.
Fish Passage [Plan C and E]	Re-grade the existing bed with locally sourced sandstone to provide a mean 1 in 50 gradient. New bed level ties in to existing weir crest and existing bed at A25 culvert. Local variations in width, bed, and banks.	Passage for Sea Trout (prioirity species), and potential passage for other fish species including Lamprey and Bullhead.	100m between sluice and A24 culvert. 75m of bed fill material (350m^3).

8 Costs and Funding

8.1 Preliminary Estimate

The following provides a preliminary estimate of the costs involved with the major elements of the vision. These costs are based on predicted quantities associated with the accompanying plans and prices/estimates from other works.

As the vision has still to undergo technical feasibility, the costs should be taken as indicative, with changes to the final design requiring a more accurate costing exercise.

These figures give an indication of the likely scale of funding required to complete the current project vision.

Detailed modelling, feasibility and design Hydraulic modelling, detailed design (including detail for flood proofing cottages) and estimating, tender report and drawings.	£30000
Tender documentation Bills and specifications, additional detailed drawings, CDM requirements, etc.	£5000
Construction	
• Create tree/debris dams in new and existing river channels. Allow £1500 per dam, 5 dams	£7500
• Excavate new north/south meandering channel from Pound Farm sluice to d/s of Tenchford Bridge, approx. 550m in length. Introduce bed gravels. Locally block drainage network with earth from new excavations	£30000
• Dispose of excess spoil by landforming a section of valley slope.	£10000
• Re construct footpath crossing of the new channel and old course.	£7500
• Construct ford crossing of the new channel along the Pound Farm access track.	£7500
• Bury high voltage electricity cable (EDF Energy)	Foc?
• Excavate new east/west meandering channel from Tenchford sluice to Castle Mound sluice, approx. 1300m in length. Introduce bed gravels. Locally block drainage network and partially infill existing channel with earth from new excavations	£75000
• Construct footbridge and ford crossing of the new channel along the Kneppmill House bridleway.	£15000
• Embankment and flood proofing of Kneppmill House buildings and Tenchford Cottage.	£25000
• Landforming, access and modifications at Castle Mound sluice	£10000
• Fish passage enhancements between Castle Mound sluice and Bay Bridge (A24), bed regrading using appropriate stone base.	£30000
Sub total works	£217500
Add 20% multiplier for contract preliminaries	£43500
Add 20% multiplier to reflect nature of estimate	£43500
Suggested budget for construction works	£304500

Supervision of Contract Works	
Local engineering supervision/administration on part-time basis for 6 months	£25000
Allow for support from specialists in response to on-site conditions and supervisory support arising as works proceed	£10000
Adaptive Management and Project Evaluation	
Level 1 - Initial baseline data and sampling sites, post works re-survey, analysis and reporting; What targets will this allow us to measure?	£15000
Level 2 - Detailed monitoring programme covering all of the project targets, allowing true reporting of success and failure over a longer time period (say 5 years post works	£45000
Level 3 – PhD; a more scientific, in-depth study of processes and habitats to be completed in addition to assessing original objectives, providing a tool for the adaptive management approach.	£60000
Post Works Adjustments	
Allow for adaptive management changes following initial level 1 monitoring and analysis in years 2/3.	£15000
TOTAL	**£509500**

SUMMARY OF ESTIMATE	
Feasibility, design and contract docs	£35000
Construction works	£304500
Works supervision	£35000
Monitoring	£120000
Post works adjustments	£15000
TOTAL	**£509500**

8.2 Funding

Funding of this nature, *c*.500,000, will require a large commitment from the landowner in terms of time, support (financial and otherwise) and flexibility in how the project is 'marketed'. Reducing the level of flexibility may often reduce the potential for different funding streams. Projects of this nature often require a partnership approach to gain sufficient funding.

Partner organisations should include the Environment Agency, English Nature and Defra RDS (both to become Natural England in 2006) and the Landowner.

Other interested parties might include:
County Council;
Wildlife Trust;
RSPB;
Reaserch Institutes (Univerities, etc);
Highways Agency;
EDF Energy;

Parish Council;
Etc.

Funding for river restoration and biodiversity projects has recently become more common, but also appeals to a wide audience. As such it is more closely contested. The above ‘partners’ should be in a position to offer *some* financial support as well as considerable in-kind support, but there is usually a significant shortfall between this and the final total. In some instances the merits of the project may deliver sufficient National objectives to warrant greater Agency (EA, EN, Defra) funding, but this is not the norm.

Funding bodies (local, national and EU) represent a good opportunity to bridge this shortfall and to provide matching funding to achieve their spend on programmed activities.

Sources include:
- Heritage Lottery Fund (various levels of funding available);
- EU LIFE Environment;
- Interreg (multi region EU funding);
- Office of the Deputy Prime Minister (ODPM);
- Research Councils (for scientific monitoring);
- And a large range of other large/small opportunities.

The Environment Agency has dedicated regional ‘external funding’ staff tasked with advising Agency staff and project partners on appropriate funding sources and the current requirements for projects to qualify. Many programmes are reviewed and changed regularly, thus these staff should be able to provide an up-to-date summary of current opportunities. There is already some National interest in the potential River Adur Floodplain Restoration Project and its potential to offer biodiversity gains over and above that being explored elsewhere in England and Wales.

8.2.2 Qualifying elements

Most funding bodies have a key set of criteria that environmental projects must ‘tick’ before they would be considered for support. These may include:

- Biodiversity gain
- Public access and site interpretation
- Demonstration of nationally applicable outcomes
- Linkages with current government policies and incentive schemes (e.g. Environmental Stewardship).

Some programmes (EU LIFE Nature) apply only in qualifying areas (designated Special Areas of Conservation (SAC)) and most require defined targets for biodiversity gain. Many require a commitment to some degree of accessibility for the public to benefit from the funding (in particular HLF).

8.3 Memorandum of Understanding

With sufficient information and commitment from various parties to produce a project vision and seek a detailed design, it is imperative to maintain and focus this commitment through a

Memorandum of Understanding (MoU). Such a document is a non-legally binding ‘hand shake’ agreement between the various interested parties.

This short document should set out;

- The vision, aim and objectives;
- Key partners, their interest and any proposed commitment, if known (in-kind or financial);
- Basic outline of costs to highlight the scale of the project and the funding need;
- The resources/expertise that each partner could bring to the partnership (e.g. the site (landowner), advice on biodiversity enhancement (the Environment Agency), etc.

The MoU should be signed by the parties to engage each and show a level of commitment to overcome issues and obstacles as they arise. This type of agreement often differentiates between schemes where one lead organisation has to push others for support and consent and those where the partnership works as a team to actively maintain momentum and push forward the project.

8.4 Consents and permissions

Various consents and permissions will be required for the project. These will include:

- Environment Agency land drainage consent (involve Flood Risk Management and Development Control staff in the project design);
- Local Authority planning permission;
- Landowner agreement to increased flooding and potential flood risk to properties/land;
- English Heritage consent to work within the vicinity of the Castle Ruins;
- WSCC Rights of Way officer consent to proposed changes affecting the footpath and bridleway;
- EDF Energy commitment to undertake works to the high voltage cables;
- Highways Agency agreement to the level of investigation and modelling to show no adverse impact on roads and bridges.

The vision enables dialogue to be entered into now to work with the various organisations and to address concerns and constraints as they are raised. This gives the time to incorporate solutions into the design and avoid finding a ‘killer’ constraint at a later stage. Discussions should at this stage centre on identifying who?, how? and when?

9 Project feasibility stage

This report highlights the vision for the River Adur Floodplain Restoration Project. Whilst the pre-feasibility stage has been based on expert judgement, some limited modelling, field data and more extensive topographic information, the technical feasibility of the project now needs to tested (stage 3 as defined in the original scoping study Appendix A).

9.1 Technical Engineering Consultant

The project 'vision', as outlined in this report, addresses the main issues related to the various stakeholders. A technical feasibility study is now required to test the assumptions made and to fine tune the size, shape and functioning of the various new and retained river channels under varying flow conditions. This modelling will be able to inform the detailed design of the new channels (width and depth, extent of retained old course, etc).

Therefore the requirement is for technical assessment of the feasibility of the option proposed, looking in detail at the sizing of channel dimensions and impact of obstructions (log jams) on flood flows. Within this context the project must deliver its target biodiversity and landscape objectives.

The broad scope of the feasibility study is to:

- Liaise with the RRC team and stakeholders to quickly confirm project objectives and major site constraints;
- Model the proposed 'vision' to identify its suitability under a range of flows (storage, conveyance and impact on highways.
- Modify the interaction between the new channel and existing retained length to ensure flood risk constraints are addressed, whilst maximising potential for river and floodplain restoration.
- Derive the impact of the new regime on site features (access routes, properties, structures) and detail how these may need to be modified to cope with the new conditions.
- Adapt the 'vision' to ensure all constraints are met and target objectives are still achievable.
- Produce a detailed design and summary report of the final project.
- Produce contract drawings and tender documentation.

The consultant should have capabilities in:

- Hydraulic Modelling (Unsteady state) of multi thread channels and floodplain interaction;
- Detailed river restoration design;
- Contract documentation and tender drawing preparation;
- Working with an expert advisory team.

9.2 Information available

A large collection of information is available for the site, much of it summarised or mentioned in this report. Key elements include:

- **Project report outlining vision development process (RRC)**
- **Fisheries data (EA)**

- **Invert data (EA)**
- **Topographic survey data (Knepp)**
  Typical topographic survey data and LIDAR overlay.
- **Hydrographic data**
  There is information available from the gauging station at Hatterall Bridge just downstream of the A24 road bridge, including the following:
    Stage - Daily Means & 15 min from June 81 – Present;
    Flow - Daily Means From June 61 - Present & 15 min from June 81 – Present;
    Structure is a 3 channel flume where the central flume is used for measuring normal flow;
    Ratings = 2;
    Flow Duration Curve = whole record or a particular season;
    Survey Drawings - there are quite a number including the most current.

  The data provided shows that the peak daily mean is around 11 cumecs. The gauge is bypassed at high flows so the 11 cumecs is what is going through the gauging station but there is more flow going around on the floodplain. The peak flows therefore will be slightly higher than 11 cumecs, but the information provides a good idea of the size of flows with estimates of the Q10 and Q95 being 3.564 and 0.025 cumecs respectively.
- **Flooding photographs**
  Available from Knepp Estate.
- **Wildlife surveys**
  Ryland 2005 – Phase 1 Knepp Castle Estate botanical survey.
  Greenaway 2005 - Phase 1 survey of Knepp Castle Estate for naturalistic grazing regime.

9.3 Further information

Further information will be required to test the feasibility of the vision, mostly relating to the hydraulic modelling requirement. An initial assessment suggests the need for:

Hydraulic and Hydrological Information

- Any information on sizes and shapes of new channels, new structures, footpaths or bridleway crossings for the new or restored channel will be required in order to model the effects of the restoration scheme;
- Investigate and clarify high flow gauging reliability and accuracy at Hatterall Bridge gauging station;
- Select three flood events from the gauging record for calibration/verification;
- Events should have rainfall, flow and level records and if possible photographs and anecdotal evidence of flood levels through reach;
- The three flood events should range from a very rare event to a just out of bank event;
- Create hydrographs, from rainfall data, at upstream boundary and for tributaries for flood events chosen using FEH;
- Use flood hydrographs in hydraulic model to calibrate it, comparing model flood level results with measured levels and adjusting parameters as necessary.

10. Conclusion and Way Forward

10.1 Conclusion

This pre-feasibility study indicates that their much to gain from the restoration of the river and floodplain at Knepp Castle Estate. The proposed vision's aim and objectives all appear to be viable, based, at this stage, on expert opinion.

The issues and constraints that have arisen thus far, identified by the key stakeholders, would seem to be surmountable. The work required to achieve the vision is complex, in part due to the clay catchment; the need to 'engineer-in' fine detail, and the flood risk management constraints imposed by the upper and lower road boundaries. Further technical feasibility is now required to confirm the achievability of the vision.

At *c.* £500,000, the overall cost is likely to require significant partnership and external funding, but the project offers considerable demonstration potential, relating to current policy and environmental targets. As part of an estate wide goal for a 3500Ha wild Sussex landscape, the river and its floodplain is a major focal element.

10.2 Way forward

The following list illustrates the work that needs to be carried out to progress the project in the near future:

- Feasibility study:
  Specify the scope of the works, invite relavant engineering consultants to tender, organise a visit to the site to explain the scope and vision and appoint the successful firm;
- Background monitoring:
  Work up a planned approach to a standard monitoring programme (involving currently monitored sites and other opportunities, pre funding), allocate tasks;
- Memorandum of Understanding:
  Draft document and get support of signatory organisations;
- Funding opportunities:
  Early dialogue with EA national and regional funding advisors, evaluate likely sources and work required to apply;
- Permissions and consents:
  Begin to allocate responsibility for finding the correct contact and deciding the best way to explain the proposals that affect that organisation, etc;
- Interim works possibilities:
  Identify the capacity of Estate staff to undertake some of the minor works to kick-start the project. Possibilities include:
    - Seeking advice on the flood proofing of Tenchford Cottage and Kneppmill House buildings;
    - Re-wetting the floodplain below the dam by increasing seepage through the penstock and blocking ditches;
    - Alterations to Jacksons Wood stream to divert flow onto the right hand floodplain;

    - Defining short to long term floodplain woodland options within current agreements, constraints and management.
- Ensure consistency:
  Involve RRC team as advisors when necessary, to retain a watching brief over the feasibility/design, implementation, monitoring and evaluation stages.

Appendix A. Options Report

KNEPP CASTLE ESTATE

River Adur

Options for Restoration and Enhancement

March 2004

Prepared by Martin Janes
RRC, Silsoe, Bedford. MK45 4DT
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1. Preamble

The River Restoration Centre is a not-for-profit information and advice centre, providing non-consultancy services to the UK statutory environment agencies, river managers, land owners, practitioners and interest groups. RRC, founded in 1992, has a wealth of experience through staff and its network of Advisors (UK and internationally recognised experts who support the concept of river restoration and an RRC, and who provide services through the Centre's 'teams'. The RRC promotes the concepts of river restoration, sustainable river management and incorporation of multi-functional benefits from single function activities.

As the Centre is reliant upon subscribers, 'clients' will be asked to join for a small annual fee, to be eligible for 'member' rates for site visits, reports, etc. RRC's continued existence and promotion of river restoration depends upon this support.

The following report is based on a one day visit to the Estate, and some follow-up enquiries.

Present:
Charlie Burrell, Owner
Jason Emrich, Estate Manager
Martin Janes, RRC
Jenny Mant, RRC

2. Introduction

Knepp Castle Estate is keen to maximise the biodiversity potential of the whole estate. Through discussions with Defra the estate will be entering the Adur and its floodplain into a Countryside Stewardship scheme. The reach to be entered is approx. 2.2km, with two main tributaries and their floodplains adding to the extent of land to be considered.

Various options for habitat enhancement and increasing biodiversity are apparent, from re-wetting by the use of sluice boards to restoration of the old course of the Adur.

3. Description

The floodplain is very distinct, rolling valley sides meet the flat floodplain lags with a convex slope, one of the practical reasons behind the Estate's hammer ponds found on a number of tributary valleys. The catchment is clay, with much fine sediment being deposited in both the ponds and the main river. Some gravels are apparent within the channel, though these are most probably derived from isolated lenses and have been distributed widely over time.


The River Adur flowing through its flat floodplain

The lowland southern England landscape provides the Adur with very little gradient, thus the river is typical of this part of the county; flat and silty with a naturally steep clay bank, dominated by marginal vegetation established on the silt berms (ledges).

Through the centuries works have been undertaken to 'manage' the river for agriculture, industry, (ore for the hammer pond mills and foundries) flooding and fisheries. On rivers such as the Adur this has taken its toll and the channel is now vastly different to what it once would have been. The main river through the estate is, at its lower section, approx. 10m top width, 4-6m wide at water level, with 3m high banks. In places the actual flow (on a dry day) passes gently through sections 1.5m wide and 20cm deep.

The present course is interrupted with structures to impound water levels for the benefit of fish, such that in summer low flows (reported to be often) they are provided with deeper holding pools along the river.

However, the angling club currently renting the fishing rights have indicated their desire not to renew the rights due to poor catch returns.

The downstream border to the estate is bounded by the A24 Worthing to Horsham duel carriageway. The river passes under the road in a semicircular culvert, approx. 8 wide by 4m high. This culvert is the route for the river under the road (a secondary or original culvert is present but was blocked off as part of the duelling of the A24). In flood events (Feb. 2004) the river backs up from the culvert and floods over the lag, sometimes isolating the castle hill. The owner reported that the depth was such that boats could be used on the lag.


Siltation and reed growth narrowing the channel

It is not known whether the duelled A24 has ever flooded as a result of backing up, but reportedly in the floods of 2000 water was lapping at the road in a low spot by the Kneppmill Pond outlet stream.

The purpose of the hammer ponds, such as Kneppmill, was to provide mill power for ironworks. The ore, and presumably goods produced, would have been transported up the Adur which was navigable almost up to the estate. A complex series of locks and structures (a derelict examples remains east of the A24) must have been installed along the river to enable this and the river would have been regularly managed (deepened then dredged) to ensure adequate depth for the barges. This management would have significantly altered the natural planform (shape), size and character of the river.

Above the House, the importance of agriculture would most probably have been the driver for works to the river. Above Tenchford Bridge the river turns north/south and curiously hugs the western edge of the lag, tight against the valley slope. Though not uncommon, or even unnatural, this could indicate re-alignment of the river to avoid the difficulties of farming on both sides of the flat floodplain. From historical maps (Crow map of 1754) it can be seen that the river is positioned here at that time, so any re-alignment would have been before then, when the river was a much smaller and (in terms of moving it) a more manageable size.


The river hugs the bank to the left of the lag

From aerial photos (c. 1960's) evidence of possible meander routes is visible, though how old these are cannot be verified at this stage. A further study of historical archives may indicate further previous channels. As mentioned above the course may have been moved centuries before, but the bulk of the dredging and deepening would probably have been more recent.

4. **Problems and Issues**

- Channel over-sized compared to the normal flows it carries;
- Route realigned for a variety of reasons, original planform lost;
- Large fisheries weir structures impacting on the landscape;
- Low lying estate buildings located within the floodplain (flooded as often as every 10 years);
- High maintenance for Environment Agency Operations staff (desilting and structures);
- The historically damp lags now shed water quickly via ditches into the main Adur;
- Lack of in-channel, marginal, bankside and floodplain habitat diversity;

5. Key interests in the Adur at Knepp Castle

i) Flooding already occurs on the lags, as a result of impoundments and flashy peak discharges. This flooding provides benefits in the form of;

- flood storage for downstream;
- nutrient and sediment recycling, utilised by the grass and benefiting grazing;
- shallow flooding of the grassland for wading birds;
- wetting of the floodplain and retention of temporary pools for invertebrates and wet meadow plant species.

Fisheries weirs help impound low flows in summer

ii) Fisheries improvements have been made in the recent past to protect the populations from low flows. This work has involved the construction of several large weir structures in the river, the most recent being in the 1990's, when a meander was cut-off to construct the weir structure in the dry. Though the weirs do provide a backwater effect and a 'pool' within the channel at low flows, they still do not address the inherent problem of a massively oversized channel. A more appropriate answer may be to simply restore (or recreate) a more appropriate channel size along the old (or an approximation of the old) route.

iii) General biodiversity and wildlife friendly management practices are being implemented by the Estate (Countryside Stewardship; changing the surrounding valley side agriculture to grassland; improvements to the hammer ponds to provide refuge and support for wintering wildfowl; etc). These estate instigated changes are consistent with the policies of Defra and the statutory environmental agencies (English Nature, Environment Agency).

As well as recognising the past damage done by some 'improvement' works, the Environment Agency's approach to river management is changing to look at sympathetic management of the system and more sustainable 'restoration' of natural form and processes. Knepp Estate is well placed to demonstrate how to achieve this over a reasonable length of main river which has been harshly managed in the past.

6. Opportunities for restoration and enhancement

Opportunities exist throughout the low lying lags and further up the tributary streams, though funding will need prioritisation of these, based on technical feasibility and value for money.

The key areas are:

- Main river;
- Tributary streams;
- Ditches.

These areas of opportunity will also compliment the ongoing/planned works to the hammer ponds and the estate's changing agricultural practices.

7. Main River Adur

Options exist for enhancing the river right through to restoring its former course. Techniques used on other river systems are equally applicable here, and each will have an impact on the funding required. The main options are:

1. Enhance the present course between weir structures:
    a. Re-profile banks;
    b. Create berms to narrow the low flow channel;
    c. Allow vegetation growth to further narrow the channel;

d. Restrict weed cutting and desilting operations.

2. Raise the bed of the present course to promote increased frequency of flooding of the lags, and to reconnect the river with its floodplain. This may necessitate redundancy or removal of some/all of the fisheries structures;
3. Recreate a more natural channel planform and cross-sectional profile in the surrounding floodplain, bypassing the present river course;
4. Restore the ‘original’ course of the River Adur and its original dimensions.

Each of the above have advantages and disadvantages, which can be discussed briefly, but with enough certainty to rule some out as low VFM and/or impractical.


Re-profiling the River Rhee to a shallow slope (60^{o} to 20^{o})

8. Discussion

In the case of Knepp Castle estate, works to the present channel to achieve a worthwhile degree of enhancement are likely to be as, or more, expensive as restoring the original, or a more natural channel alignment and size through the floodplain. Given the height and depth of the river, any bank re-profiling would need to be a major undertaking to create a secondary floodplain within the canal that exists at present. Narrowing to form pinch points would have to be significant, and the whole works would need to be protected from possible damaging high flows for the 1st few years as the vegetation establishes to cover bare soils. The technical difficulty of such an approach is quite high, and would need to involve a lot of detailed design works and engineering to achieve a stable result. Even if the resulting works is successfully completed within budget, the overall result will only be partially successful in terms of the potential for the site. This will not address the planform, the impact of the structures, the depth of the channel bed, the lack of connectivity with the surrounding floodplain or the desire of the landowner to do something ‘exciting’.


River Cole. A smaller channel is cut across.

The 2nd option, does in part address the issues of the present channel, however the technical works needed to infill a watercourse (whilst it is flowing) to a degree where the material will not simply be washed away would be considerable. This has been achieved before, but on chalk streams where infilling with gravel is the natural choice and can be stabilised, and only to a achieve bed raising of a small increase in height. This is a costly option, necessarily using non-native substrate. A conservative estimate would be approx. $10m^2$ over 2.2km, giving a volume of granular fill of $22,000m^2$. At a cost of say £10 per m^3 this would be in the order of £220,000 just for the material. Once again this option does not address the straightened channel course, and the risk is that the material could be conveyed


Re-meandering the River Cole with a higher bed level

downstream and lost, or worse still, become a flood risk were it to be deposited near bridges and flood prone urban areas.

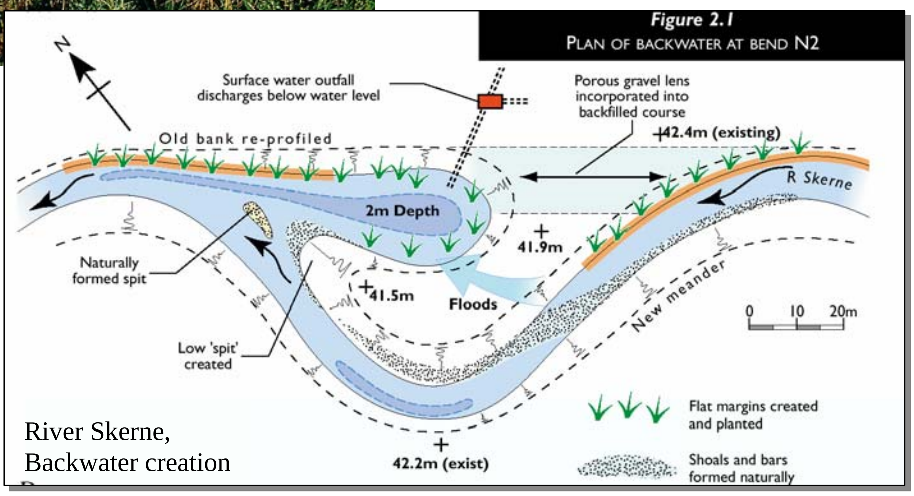
Option 3 removes the constraints of working within a flowing channel. It provides time and dry working conditions to excavate an appropriately sized channel, and establish bank side vegetation cover to prevent bare earth banks being eroded by the first high flows. Importantly, however, it would not be possible to recreate the original course of the river, as this we know would have crossed the present course at several points.


The Gaywood Stream, re-meandering over 1km, Kings

Option 4, restoration of the original course, is the preferred option from a purist approach, and one that the RRC aims to promote *where practical*. In the case of the Adur at Knepp Castle, the historical records concede a long history of management, with some glimpses of the previous course(s?). It is likely that a significant element of the old course is followed by the present channel (especially as the present watercourse's 'footprint' is massively wider than the original would have been). For this reason the works would need to involve significant elements of option 1, already argued to be costly and difficult.

__Potential option__
Perhaps the best 'design' approach (at this early stage) for consideration of the most achievable way forward would be a compromise between the relative ease and flexibility of option 3, and the desire to restore the original course of option 4. The re-meandering would simply entail carving the 'new' Adur through dry ground, away from problems of flowing water and fluctuating levels. The course could, where appropriate, follow the old visible meanders (subject to confirming their authenticity) crossing the present course, rather than incorporating significant lengths of it. Figure 1 shows an annotated map of the lower 1+km of the river, with suggestions of the type of works that may be achievable. Assuming a cost per m3 for bulk earthmoving of £8, the cost of cutting the new course would be around £32K. Crossing the old course is a more technically difficult procedure, and might cost an additional £50K. Landscaping and planting should be budgeted as an additional £20K, suggesting a (very crude) budget of ~£100,000. At this stage it should be noted that monitoring of the


River Skerne,
Backwater creation



River Skerne,
Backwater creation

site, works and results is a very valuable exercise and should ideally be assigned its own budget. Funding for this is available through government and university research bids, though often fiercely contested!

This compromise between 3 and 4 also has benefits that each would not necessarily deliver on their own. The old channel could be utilised to continue to provide refuge for fish in low flows, as well as acting as a sheltering backwater in floods. Backwaters also provide habitat for invertebrates, plants and mammals, and protection for fish fry, and have historically disappeared from many river reaches (convenient dredging spoil tips). These are now commonly introduced into river systems by the Environment Agency, sometimes called ORSU's (off-river support units). The extent of backwaters depends upon cut and fill budgeting, but clearly there would be a deficit of fill material (possibly as much as 60%) if it is intended to dig the new channel significantly smaller than the present one (figure 2). The old channel that remains could include temporary ponds (with no direct connections to the river), ponds linked by pipes to ensure river dependant levels, and backwaters connected at one end only. All of the above provide for different communities and species, and add to the diversity of habitat available.

Works to the main river should be able to be carried out on the lower west-east section, prior to Lancing Brook joining the river (the gradient is thought to be approx. 1:1000). Above this the Adur flows north-south, and the gradient of the river here will be the deciding factor for design of river works.

9. Tributary Brooks

Two main tributaries join the Adur within the estate grounds, the Lancing Brook and a smaller one just downstream of Capps Bridge. Lancing Brook contributes significantly to the flow of the Adur. On these two smaller watercourses the impact of management, and in particular dredging, is visible but to a lesser degree than on the main river. Here, options for enhancement of the channel, much of which is likely to still follow its original course, are more viable. This should be in conjunction with limited and sympathetic ditch management, allowing the watercourses to develop an appropriate vegetation structure and allowing the build-up of silt where the present course is over-sized.


Narrowing of the upper reaches through deposition

Once again flood defence issues must be considered and any design must not be to the detriment of people or property.

10. Ditch Network

Throughout the lags within the estate grounds, ditches convey surface water to the river and brooks, draining the grazing land. One of the goals of the estate is to increase surface water, both from flooding and retention of precipitation. The ditch (or possible meander route) in the four acre field by Tenchford Bridge shows the possibilities for retaining surface water, encouraging Rush dominated pasture and providing feeding habitat for wading birds. This 'ditch' is blocked at the downstream end and retains rainfall until it evaporates. Infiltration through the soil is likely to be minimal due to the heavy clay nature of the catchment.


Damming the ditches will create wader habitat

This approach could be copied across the remaining floodplain, such that every ditch, instead of draining the lags, is actively re-wetting the surface. This approach is more beneficial than completely filling in the ditches, as it is less labour intensive (so less costly), and provides temporary shallow open water for birds and invertebrates. Studies have shown that the increase in habitat and biodiversity achieved through adding shallow temporary wet scraps to floodplains can be far greater than that achieved by in-channel river habitat enhancement/restoration. In part this is due to the greater potential for colonisation by wetland, terrestrial and semi terrestrial plants and invertebrates, but shows the potential increase in biodiversity available by very simple techniques.

As well as blocking the drains, opening out the linear shape of them to provide shallower slopes will provide more shallow margins, as will gradual poaching by sheep, horses, deer and cattle.

11. Additional works

With the shift from arable practices to grassland reversion over the estate, a strategy of blocking field drains should also be considered. Early drainage in the 1800's and later in the 1950's and 60's has dramatically increased the 'time to peak' of rivers. On clay catchments this is particularly noticeable, as the field drains would have been spaced only a few meters apart, to make the fields workable for longer. By cutting out and plugging the drains, siltation, nutrient transport and excessive runoff will all be countered to some degree. By employing this approach over much of the estate, the effect could be quite considerable, and a programme of monitoring should be encouraged to assess the benefits. This same approach was used to aid reversion from arable farming to hay meadow, as part of a Countryside Stewardship scheme adjacent to the River Cole (river restoration demonstration site, Oxon/Wilts)

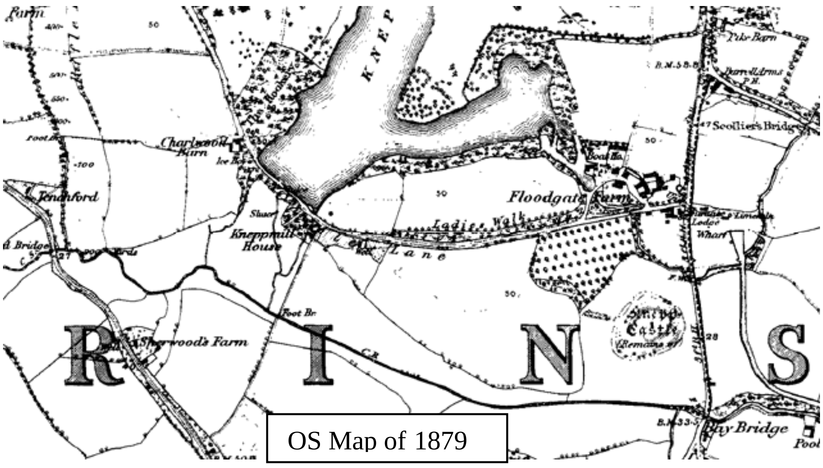
It is unlikely that such field drainage blocking works will unduly affect the rewetting of the lower floodplain, it will merely slow the passage of surface runoff to the lags and river.

12. Pre-feasibility works

Stage 1. Necessary works and surveys required to propose detailed options for consideration
Various unknowns exist at present;

- *Topographic level survey of the river and floodplain, its features and extent between the A24 and Pound Lane*
  This is the most important element of the pre-feasibility works. It will inform the applicability of the options for the main river and help define the realistic options for consideration. The effects of any proposed works on river levels would need to be analysed to ensure that the backwater effect of the new channel will not adversely affect the upper limit of Pound lane bridge. Gradient is known to be limited, but accurate levels are needed to ensure no worsening of flooding potential for property and communication links. Pound Land and Swallows lane both flood at present, though this is thought to be due to inadequate capacity of the bridge structures. Tenchford and Kneppmill cottages will need to be protected from increased flood risk, perhaps by bunding. This will also require accurate floodplain level information and potentially, hydraulic modelling at the later feasibility stage. The survey brief will depend on the scale and extent of the scheme envisaged, however it is always worthwhile having a more (rather than less) detailed study done at the outset.

- *Brief overview of historical data*
  A search of county archives, Estate archives, etc. should quickly indicate whether there is any further evidence of previous routes across the floodplain. This information will feed into the proposed option for works to the River Adur. This could be carried out by the Estate.



OS Map of 1879

- *Geomorphological comparison with surrounding catchments*
  Defining the accurate and most appropriate size and sinuosity of the ‘restored’ river is a careful balance between historic information, overviews of the surrounding catchments and an assessment of the current hydrological information for the river. Though shallow flooding of the lags is desirable, prolonged deep flooding resulting in the deterioration of the meadows is not. Too small a cross-section could result in the above whilst too large could equate to a waste of time, effort and funds. Understanding, designing and prediction how ‘natural processes’ will behave requires and experienced fluvial geomorphologist.

- *Fisheries input*
  The river supports a Sea Trout run, as well as a variety of coarse fish. As a fishery the river is known to be poor through the estate, but as a fisheries resource it may be valuable for salmonids. This may explain the large and costly structures installed by the water board, NRA and Environment Agency. This information needs to feed into any outline design options at an early stage.

Stage 2. Following the successful completion of the topographic survey, RRC could (if required) field a small team of its ‘Advisors’ to work up the outline options for the estate, Defra and other potential partners to consider. This stage would produce a reasonably detailed justification for the various options, based on the information available and that proposed above. It would give rough costings and suggestions of techniques to be used and examples from elsewhere. This report could form the basis of a brief for consultant engineers to carry out a technical feasibility study of the favoured option(s).

Stage 3. Further ‘technical feasibility’ would:
- provide the required assurances for the Environment Agency flood defence team, to enable consent to be gained;
- calculate accurate material quantities timescales and costings involved;
- provide the tender drawings and documentation (bill of quantities, etc. needed to let the contract to contractors.

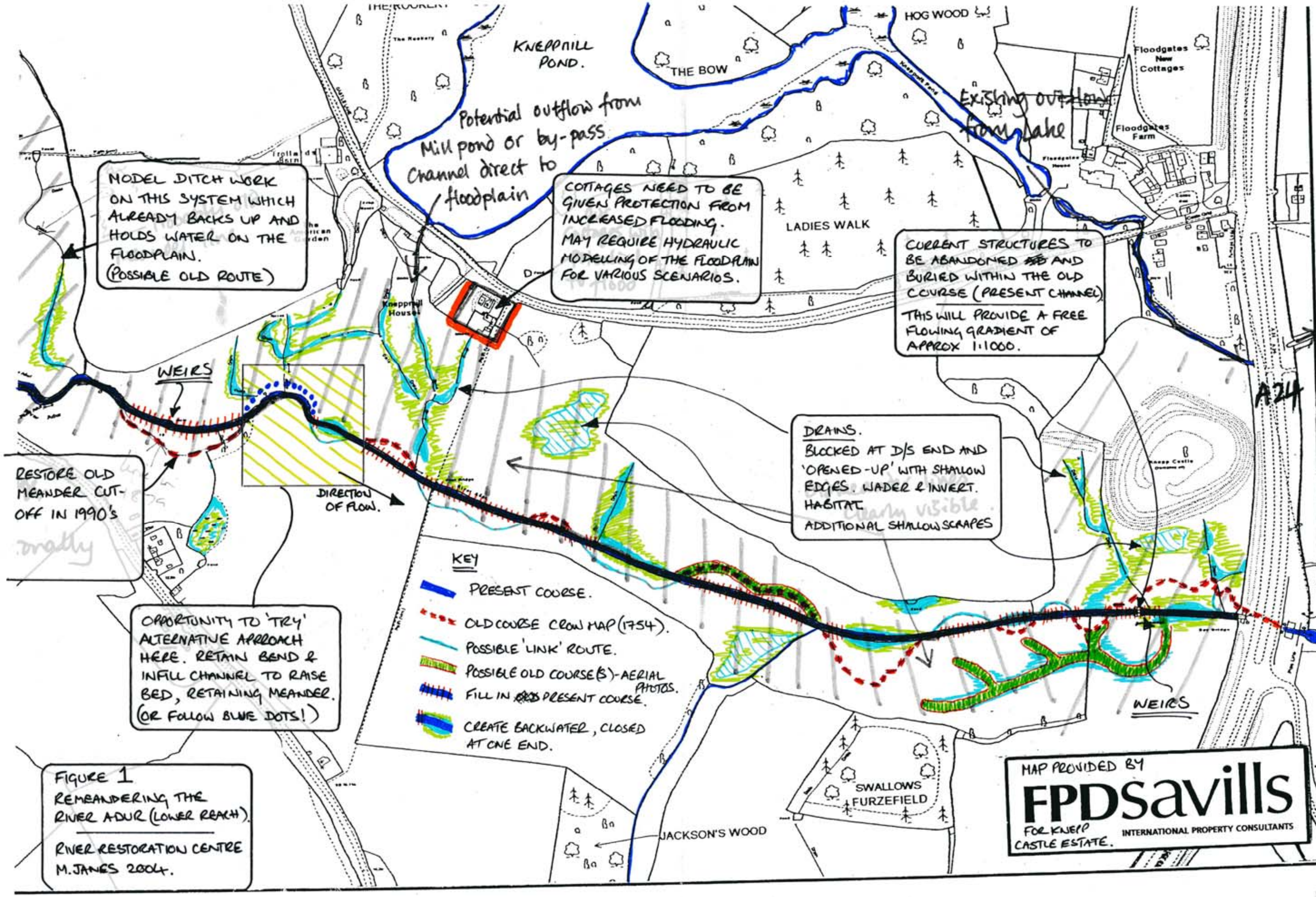
RRC normally suggests it be involved at the design and implementation stages to ensure that the design produced by the consultants is true to the client’s original perception of the project output, as this is not always the case! The Centre has a formal written framework agreement with the Environment Agency covering all of the above, and considerable experience in advising on large scale innovative river restoration demonstration projects.

Further Reading;

- Manual of River Restoration Techniques 2002 Update (2002), published by RRC, May 2002.

- Manual of River Restoration Techniques (1999), published by RRC, February 1999.

[Both can be found as pdf’s at: http://www.therrc.co.uk/manual.php]



KNEPPMILL POND.
THE BOW
HOG WOOD
Floodgates New Cottages
Floodgates Farm
Potential outflow from Mill pond or by-pass Channel direct to floodplain
Existing outflow from lake
MODEL DITCH WORK ON THIS SYSTEM WHICH ALREADY BACKS UP AND HOLDS WATER ON THE FLOODPLAIN. (POSSIBLE OLD ROUTE)
COTTAGES NEED TO BE GIVEN PROTECTION FROM INCREASED FLOODING. MAY REQUIRE HYDRAULIC MODELLING OF THE FLOODPLAIN FOR VARIOUS SCENARIOS.
LADIES WALK
CURRENT STRUCTURES TO BE ABANDONED AND BURIED WITHIN THE OLD COURSE (PRESENT CHANNEL)
THIS WILL PROVIDE A FREE FLOWING GRADIENT OF APPROX 1:1000.
Knepp Mill House
WEIRS
A24
RESTORE OLD MEANDER CUT-OFF IN 1990's
DIRECTION OF FLOW.
DRAINS. BLOCKED AT D/S END AND 'OPENED-UP' WITH SHALLOW EDGES. WADER & INVERT. HABITAT
ADDITIONAL SHALLOW SCRAPES
Knepp Castle
KEY
PRESENT COURSE.
OLD COURSE CROW MAP (1754).
POSSIBLE 'LINK' ROUTE.
POSSIBLE OLD COURSE(S) - AERIAL PHOTOS.
FILL IN PRESENT COURSE.
CREATE BACKWATER, CLOSED AT ONE END.
OPPORTUNITY TO 'TRY' ALTERNATIVE APPROACH HERE. RETAIN BEND & INFILL CHANNEL TO RAISE BED, RETAINING MEANDER. (OR FOLLOW BLUE DOTS!)
WEIRS
SWALLOWS FURZEFIELD
JACKSON'S WOOD
FIGURE 1
REMEANDERING THE RIVER ADUR (LOWER REACH).
RIVER RESTORATION CENTRE
M. JANES 2004.
MAP PROVIDED BY
FPDsavills
INTERNATIONAL PROPERTY CONSULTANTS
FOR KNEPP CASTLE ESTATE.

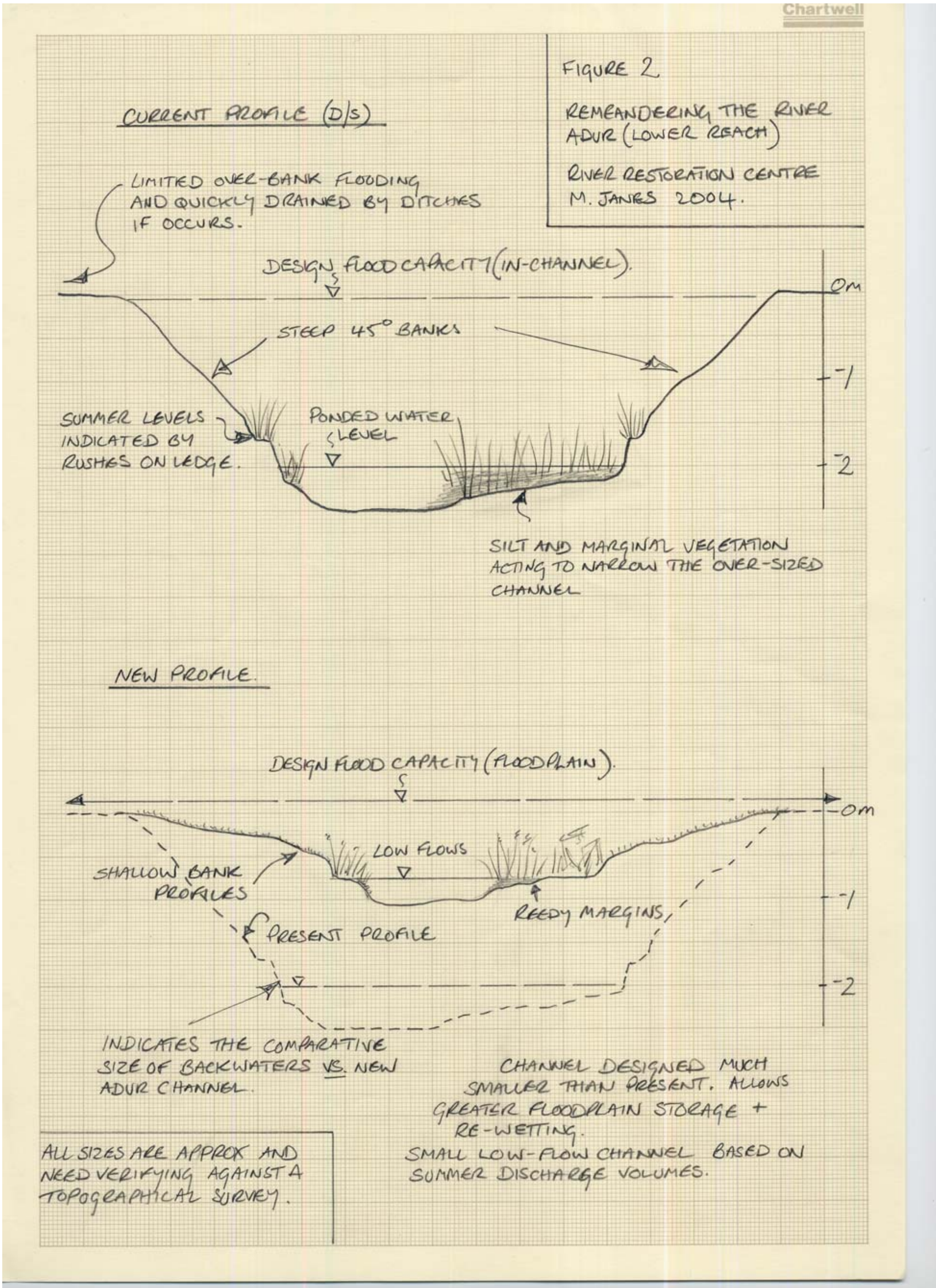


FIGURE 2
REMEANDERING THE RIVER ADUR (LOWER REACH)
RIVER RESTORATION CENTRE
M. JANES 2004.
CURRENT PROFILE (D/S)
LIMITED OVER-BANK FLOODING AND QUICKLY DRAINED BY DITCHES IF OCCURS.
DESIGN FLOOD CAPACITY (IN-CHANNEL).
0m
STEEP 45° BANKS
-1
SUMMER LEVELS INDICATED BY RUSHES ON LEDGE.
PONDED WATER LEVEL
-2
SILT AND MARGINAL VEGETATION ACTING TO NARROW THE OVER-SIZED CHANNEL
NEW PROFILE.
DESIGN FLOOD CAPACITY (FLOODPLAIN).
0m
LOW FLOWS
SHALLOW BANK PROFILES
REEDY MARGINS,
-1
PRESENT PROFILE
-2
INDICATES THE COMPARATIVE SIZE OF BACKWATERS VS. NEW ADUR CHANNEL.
CHANNEL DESIGNED MUCH SMALLER THAN PRESENT. ALLOWS GREATER FLOODPLAIN STORAGE + RE-WETTING.
SMALL LOW-FLOW CHANNEL BASED ON SUMMER DISCHARGE VOLUMES.
ALL SIZES ARE APPROX AND NEED VERIFYING AGAINST A TOPOGRAPHICAL SURVEY.

Appendix B. RRC Project Team

Richard Vivash, River Engineer:
A civil engineer with over 40 years operational experience in the field of river engineering and management across most of England and Wales. Richard was employed by the Environment Agency's predecessors until 1993, when he established his own consultancy, Riverscapes, with the aim of furthering his lifelong conviction that river engineering objectives are best achieved through environmentally sensitive methods. Richard was the General Manager of the River Restoration Project and is currently the River Restoration Centre Director of Projects.

Karen Fisher, Hydraulic Engineer:
A chartered civil engineer with over 15 years of experience in the river engineering environment. She is now a Director of KR Fisher Consultancy Ltd and has been involved recently in the hydraulic modelling of a number river restoration projects. She has continued her interest in research, developed as a Senior Engineer at HR Wallingford and Visiting Fellow at University of Birmingham, and is involved in ongoing research projects on sediments and habitats within rivers and catchment management. Karen is a Director of RRC.

Dr David Sear, Fluvial Geomorphologist:
A Reader in Physical Geography at the University of Southampton since 1994 having previous worked with Malcolm Newson on the application of geomorphology to river channel management. Current research interests relevant to the Knepp Castle Estate project include: river channel management and restoration and developing protocols for monitoring physical habitat in cSAC rivers (EU funded project on th Hants, Wilts, Dorset Avon). He is also one of the lead authors of the Handbook of Applied Geomorphology for river management and is currently involved with a further EU LIFE funded river project in the New Forest devoted to achieving sustainable wetland and river restoration; monitoring woody debris.

Dr David Gowing, Wetland Ecologist:
Dr David Gowing is a Senior Lecturer at the Open University, a Visiting Research Fellow of Cranfield University and a member of the European Science Foundation's EuroDiversity scientific committee. He has 15 years' research experience in the field of ecohydrology. His particular contribution has been to quantify the soil water requirements of plant communities. This knowledge has been applied to a wide variety of sites throughout lowland England via research and consultancy work with organisations such as RSPB, Environment Agency, Defra, English Nature, WIldfowl and Wetland Trust, Rural Development Service and various Environmental and Engineering consultants. He has written over 40 refereed publications on the topic, has advised on numerous habitat restoration projects and is regularly consulted by statutory agencies with respect to assessing impacts of altered hydrology on floodplain habitats.

Martin Janes, RRC Centre Manager:
Gaining an MSc in Environmental Water Management from Silsoe College in 1993, Martin has previously worked for the Royal Society for the Protection of Birds as Assistant Wetlands Advisor and Project Officer on the New Rivers and Wildlife Handbook. From 1994 - 1998 Martin worked for the River Restoration Project Ltd as Project Coordinator, principally co-ordinating the two EU LIFE funded demonstration projects on the Rivers Cole and Skerne. He took up the position of Centre Manager in April 1998 when the River Restoration Centre was

formed. Work is now divided between running the Centre and advising on potential river restoration and enhancement project throughout the UK.

Dr Jenny Mant, RRC Projects Advisor:
Gained a PhD looking at the effects of vegetation on sediment movement and its sensitivity to flows in S.E Spain in 2002. Jenny also has previous experience of EC funded projects in this interest area and has been involved in geomorphological assessments and designing restoration schemes as part of Environment Agency consultancy projects. She joined RRC in 2002. As RRC's Projects Advisor she advises on 20+ restoration and enhancement projects per year.

Alice Fellick, RRC Information Officer:
Since graduating from the University of Southampton with a BSc in Environmental Science, Alice has gained experience in riverine ecology and management of the wider catchment area. This includes experience working for the Environment Agency in the Sussex Fisheries, Recreation and Biodiversity Team and voluntary experience with A Rocha, Canada, working to improve salmonid spawning habitat in British Columbia. As Information Officer Alice manages and updates the Centre's project database as well as the website and library of river restoration material.

Appendix C. Braided and Anastomosed Channels

Braided channels

Braiding occurs when the transport capacity of a river is exceeded by the sediment supply, or when transport rates are typically very high (Figure C1). The response of the river channel is to deposit sediment in bars (shoals) that are inundated at higher discharges and subjected to sediment transport. During higher flows, channels may be cut across shoals or blocked by aggrading sediment, leading to a planform that is characterised by a dynamic network of channels and bars. Braided channels are typified by relatively high bankfull channel width, and low bankfull depth (see below). Braided rivers occur across a range of valley slopes, depending on the grain size of the bed material in transport. Steep braided streams are characterised by relatively large grain sizes; lower gradient braided rivers tend to form in sand sized bed material.

Figure C1 Braided River Reach; River Swale, Yorkshire. Note multiple channels flowing between active gravel shoals within a channel bounded by a vegetated and elevated floodplain surface.

The description of braided channel planform is based on the total length of channel per unit valley length, or some measure of the number of bars per unit channel length (Thorne 1997). Variability in these measures defines the extent to which a braided river is bar or channel dominated. Channels that locally widen around a central bar are not braided rivers. However sections of a river network may be braided. These are diagnostic of a change in bed load transport or sediment supply, often associated with changes in gradient.

Braided rivers were once more common in UK rivers, a fact attributed to the recent management of bank erosion, but also due to increased flood frequency and channel activity during the 17th – 19th centuries. Braided planforms often occur in response to increased sediment transport during extreme floods in upland watercourses, only to return to a meandering planform once the sediment supply and transport rates decline. Channels that exhibit this switching of planform morphology are termed wandering, and are close to the threshold of channel planform change.

Vegetation of bar surfaces is one of the main mechanisms by which natural braided rivers become stabilised. This occurs following incision of the river channel into the bed, progressively abandoning the bar surfaces and enabling colonisation by plants. In natural braided systems, Large Woody Debris helps create bars and islands by acting as local sites for sedimentation.

Anastomosed channels

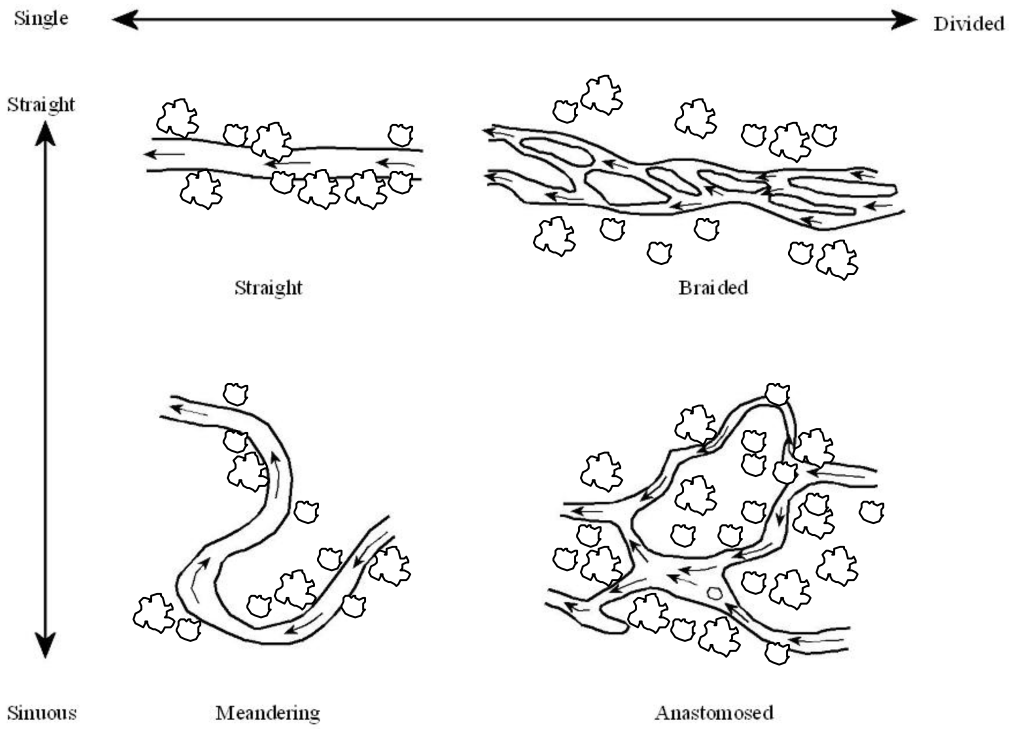
Anastamosis, is a medical term that refers to the branching of arteries in the body. The formation of anastomosed rivers would appear to be variable. Vegetation plays a key role with island formation occurring where woody debris or vegetation colonisation on bar heads promotes deposition of fines downstream and formation of a large island that subsequently vegetates and stabilises. Another mechanism is via blocking of the main channel by woody debris dams, and the dissection of the vegetated floodplain into multiple channels.

Anastomosed river channels are distinct from braided rivers for several reasons:

1) The channels are separated by vegetated surfaces of the same elevation as the floodplain (and in fact form the floodplain surface)
2) Anastomosis occurs in low gradient valleys experiencing long-term aggradation of fine sediment.
3) The individual channels function and appear like separate river reaches, with channel geometry and features adjusted to the flow and sediment load in each branch.
4) The planform activity of anabranched channels is typically low
5) The number of channel junctions per valley length is much lower than equivalent braided channels.

Anastomosed rivers are most clearly identified in lowland UK river channels, but are difficult to distinguish because of the history of channel management in these environments. Multiple channels across UK lowland floodplains may therefore retain old river branches, or may appear anastomosed as a result of valley drainage schemes. The characteristic feature of anastomosed rivers is the deposition and accretion of the floodplain by fine sediments. Therefore one indicator of anastomosis is a depth of fine cohesive sediments in the floodplain.

The branching of river channels to form anastomosis reduces the capacity of each channel, and therefore the sediment conveyance. Stream energy is therefore focused into smaller channels that can retain their form. Management of anastomosed river systems typically revolves around balancing the hydrological demands of each branch. The plugging of one branch will obviously lead to adjustment in the remaining branches as flow and sediment loads are re-apportioned.


Single
Divided
Straight
Straight
Braided
Meandering
Anastomosed
Sinuous

Appendix D. Preliminary Hydrology and Hydraulics study

Preliminary Hydrology and Hydraulics study

As a result of initial hydraulic assessment and discussion of the restoration concepts for the geomorphology of the channel and floodplain it was decided that preliminary modelling work on the hydraulics and hydrology of the site should be undertaken to try and "narrow down" the options as early in the process as possible.

This work has included:

- Some initial hydrological analysis to determine the volumes of water in a 1 in 100 year flood and 1 in 2 year flood;
- some initial modelling work on the channel and floodplain areas to determine the existing flow capacity;
- an initial assessment of the "excess" volume of water needing to be stored if the bed level was raised by 1 to 1.5 m (to the estimated practical depth of 1.0m gained from the topographic survey information – Section River Channel and Floodplain) along the entire channel.

The hydrological work was carried out using FEH methodology. The peak flows generated used in a simplified hydraulic model of the site. The results of both sets of work are described here briefly.

Hydrology

Some Flow Estimation Handbook (FEH) hydrological modelling has been carried out, to estimate the hydrology and provide some hydrographs and flood events at the upstream end, upstream of Capps Bridge, on the Lancing Brook and tributary draining Southwater.

The downstream boundary of such a model would be the gauging station at Hatterell Bridge. There is another tributary which joins the Adur just upstream of the Hatterell Bridge gauging station which drains Southwater. The hydrology of this tributary to the north was assessed using FEH to determine the contribution which that area makes to the flows going through the gauging station.

The following were generated using the FEH method:

1 in 100 year flow hydrograph
1 in 20 or year flow hydrograph
1in 10 year flow hydrograph
1 in 2 year flow hydrograph

These hydrographs were generated for the following locations:

514200 121750 Upstream of the village of Shipley
515050 120900 Lancing Brook – a tributary
516800 120800 The tributary which comes in just downstream of the A24 bridge
517850 119700 Hatterell Bridge gauging station

The 1 in 100 year flood hydrographs are shown in Figure D1

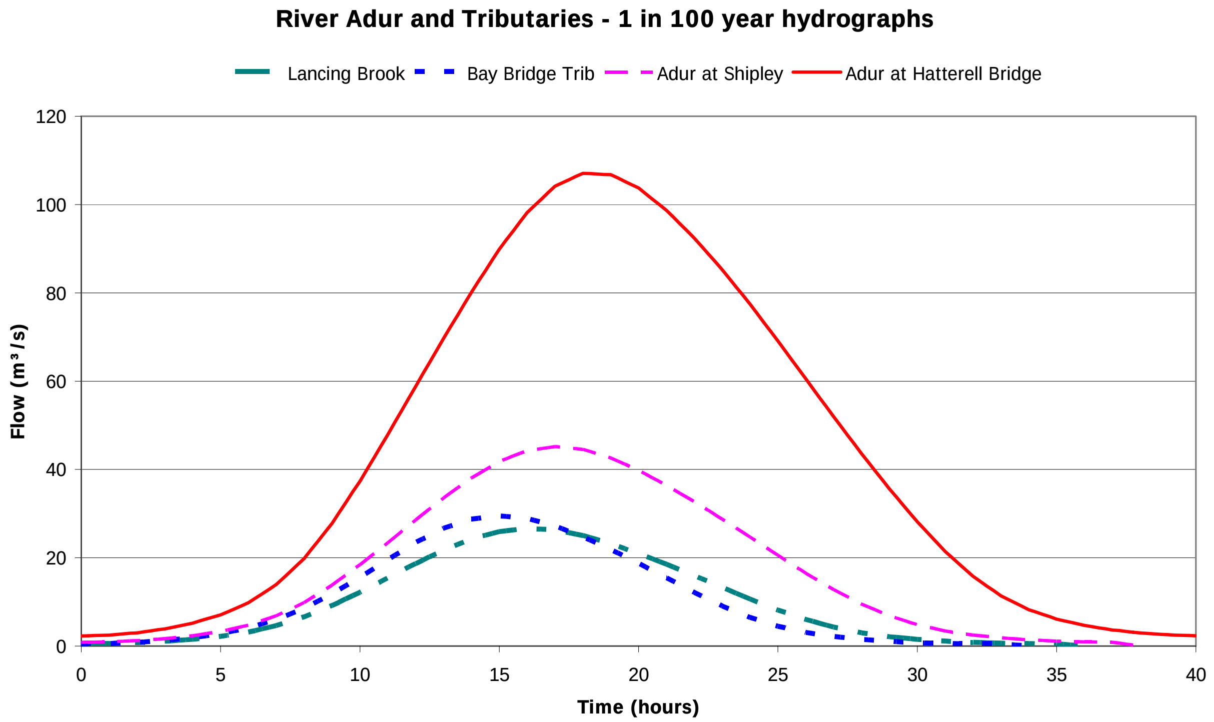


Figure D1 1 in 100 year hydrographs from FEH analysis

The 2 km study reach is on the River Adur between Shipley and upstream of where the Bay Bridge Tributary joins the River Adur. From the FEH analysis the peak flows at Shipley (the upstream end of the site), just downstream of the Lancing Brook confluence at Tenchford and at Bay Bridge (at the downstream end of the site) are given in table ?

Location	1 in 100 year peak flow (m^3/s)	1 in 2 year peak flow (m^3/s)
River Adur, Shipley (upstream end of site)	45	13
River Adur, Tenchford (including Lancing Brook component)	71	21
River Adur, Bay Bridge (downstream end of site)	85	25

Table C1 Peak flows at key locations along the R. Adur

The total volumes of water during a 1 in 100 year and 1 in 2 year flood at the downstream end of the site are:

1 in 100 year flood: 4.9 Million m^3
1 in 2 year flood: 1.6 Million m^3

This information helps to determine how much water we will need to store if we lose capacity in the channel if the bed is raised by 1-1.5m to a depth of 1m by the restoration work.

Hydraulic analyses

Cross-section data (topographic survey information undertaken by Maltby Land Surveys) was used and overlain with LiDAR data for the floodplain areas. This cross-section data was put into INFOWORKS hydraulic model and a simple model of the river, without bridges, sluices or tributaries constructed to enable a steady state model to be run. A steady state, simple model allows the capacity of the channel to be investigated as well as the impact of, for example, raising the bed level on the water levels. This allows a 'broad brush' investigation, without structures, to see what might be possible.

Based on the simple cross-sections in the model, the bankful capacity of the River Adur between the Lancing Brook tributary and the Bay Bridge is, on average 26 m^3/s. Upstream of the Lancing Brook confluence the bankful channel capacity is $23m^3/s$. Bankful discharge is often approximated to the 1 in 2 year flood. When comparing this value with the 1 in 2 year flood estimate at Bay Bridge of 25 m^3/s and just downstream of Lancing Brook, the estimate of 21 m^3/s, shows that this model predicts that the channel carries slightly more than the 1 in 2 year flood.

By raising the bed to a depth of 1m (see section 3.2.1) on average $10m^3/s$ conveyance from the channel would be lost which would need to be either stored in an alternative location or placed into another channel, or the water attenuated on the floodplain by planting of floodplain forests etc.

Analysis of the hydrographs show that the volume of water being carried by the **channel** in a 1 in 100 year flood between the Lancing Brook and the Bay Bridge on the River Adur is $2.5Mm^3$. Therefore the volume on the **floodplain** is 2.3 Mm^3 and the total is $4.9Mm^3$, as stated above. The "extra" volume of water which would be on the floodplain by raising the bed to a depth of 1m would be approximately $0.5Mm^3$ over the 2km in a 1 in 100 year flood. Therefore the channel would carry $0.5Mm^3$ less, and the floodplain $0.5Mm^3$more, water for the 19 hours that the floodwater would be on the floodplain in a 1 in 100 year flood.

This can be considered as a depth of water using Manning's equation, assuming a floodplain width of 100m and a roughness of 0.05. The additional depth of water on the floodplain to carry the 'lost' capacity of $10m^3/s$ would be a uniform 0.19m. This is a very simple approach and in some areas the water would be spread over a larger area. In addition to these hand calculations, INFOWORKS was run for pre and post restoration cases to look at the predicted increase in level when the bed level in the channel is raised by approximately 1.2m. Table 5.4.5.2 shows the increases in maximum water level at the sections for a 1 in 100 year flood.

Section (from survey)	Post Restoration Max Stage (m AD)	Pre Restoration Max Stage (m AD)	Differences Max Stage (m AD)
1.001	7.846	7.846	0
1.002	7.883	7.883	0
1.003	7.886	7.883	0.003
1.004	7.902	7.897	0.005
1.005	7.921	7.914	0.007
1.006	7.944	7.937	0.007

1.007	7.966	7.953	0.013
1.008	7.999	7.981	0.018
1.009	8.028	8.006	0.022
1.010	8.066	8.040	0.026
1.011	8.038	8.021	0.017
1.012	8.239	8.115	0.124
1.013	8.330	8.205	0.125
1.014	8.330	8.205	0.125
1.015	8.396	8.304	0.092
1.016	8.491	8.415	0.076
1.017	8.587	8.520	0.067
1.018	8.743	8.684	0.059
1.019	8.735	8.670	0.065
1.020	8.851	8.798	0.053
1.021	8.938	8.875	0.063
1.022	9.017	8.962	0.055
1.023	9.114	9.062	0.052
1.024	9.175	9.142	0.033
1.025	9.300	9.267	0.033

Table C2. 1 in 100 year increases in water level post works (modelled).

The maximum rise is 0.125m just downstream of the Lancing Brook confluence, with a lower rise of approx. 0.05m between Tenchford and Capps Bridge.

These results are both preliminary and indicative as the model does not include any bridges or structures and it is steady state so does not include any storage areas.

Appendix E. Floodplain Vegetation Scenarios

The projected maintenance of the site does not include any cutting and therefore hay-meadow or fen communities are not appropriate targets. All vegetation management will be via grazing. The possibilities in terms of floodplain vegetation at Knepp Castle Estate are:

Floodplain woodland: initial colonisation by *Salix cinerea* (Scenario 1) or *Prunus spinosa* (Scenario 2) with gradual succession to *Alnus glutinosa/Fraxinus excelsior* woodland is likely to occur spontaneously, given the proximity of seed source, if grazing pressure is low. Such woodland could dominate the floodplain, except where surface water is retained at least into midsummer most years, thereby hampering establishment of woody seedlings (Scenario 3).

Swamp communities: Where surface water is retained beyond the end of May in an average year (Scenario 1 or 3), it is likely that specialist wetland vegetation will be encouraged. Possible dominants are reed canary grass (*Phalaris arundinacea*), large pond sedges (*Carex acutiformis/riparia/acuta*) or flote-grass (*Glyceria fluitans*.) There is little common reed (*Phragmites australis*) on the site; *P. arundinacea* is favoured by the nutrient-rich, fine-textured soils with variable water-tables.   If grazing pressure is moderate, then the sedges will predominate over the reeds, if grazing is sustained then a low flote-grass sward may be favoured.

Grassland communities: High grazing pressure is likely to maintain grassland communities irrespective of hydrological scenario. Increasing wetness will encourage the rush species (*Juncus* spp.) already on site. Seepage (Scenario 1) or inundation (Scenario 3) throughout the year will favour the soft rush (*J. effusus*) whilst floods confined to winter/spring will favour the hard rush (*J. inflexus*.)   If the drainage of the floodplain becomes more impeded then the more tussocky species such as tufted hair-grass (*Deschampsia cespitosa*) and tall fescue (*Festuca arundinacea*) are likely to increase in frequency, especially as they are not generally favoured by grazing animals.   Herb richness may increase over time if nitrogen becomes increasingly limiting in the wet soils (and assuming large nutrient loads are not being delivered by organic debris/sediment from higher in the catchment.). One might expect leguminous species such a meadow vetchling (*Lathyrus pratensis*) to become more widespread within the floodplain. Under Scenario 2 combined with high grazing pressure, the floodplain vegetation may not change much in appearance in coparison to its current state, with *Hordeum secalinum* and *Festuca pratensis* much in evidence.

Open vegetation: Where grazing pressure is very high (particularly pigs) and flood durations are prolonged (Scenarios 1 & 3), then it is likely that there will be a high proportion of bare mud for most of the year and the vegetation will fall into the category labelled "Open Vegetation" by the National Vegetation Classification (NVC.) These communities are characterised by sprawling species that can rapidly recolonise bare mud once surface water has retreated, e.g. creeping bent grass (*Agrostis stolonifera*) and creeping buttercup (*Ranunculus repens*) or by annual species with persistent seed banks such as water pepper (*Polygonum hydropiper*) and knotweed (*Polygonum aviculare*).

Additional interest could be introduced into the system where Scenario 1 can be encouraged via manipulation of the tributaries or inflow from Knepp Mill Pond. These areas ideally would have moisture percolating through the more permeable surface horizon. Such hydrology in combination with significant grazing pressure would favour species such as:

Carex nigra Common Sedge	*Carex disticha* Brown Sedge	*Juncus articulatus* Jointed Rush
Carex hirta Hairy Sedge	*Cardamine pratensis* Lady’s-smock	*Caltha palustris* Marsh-marigold
Mentha aquatica Water mint	*Eleocharis palustris* Common Spike-rush	*Potentilla anserina* Silverweed
Polygonum amphibium Amphibious Bistort		

Such systems would be reliant on the water being of appropriate quality. Heavily enriched water would probably result in further flote-grass stands.

Appendix F. Woody debris

F1 Managing Woody Debris in Rivers and Streams

A hard copy is attached and the document can be viewed or downloaded from the following link http://www.staffs-wildlife.org.uk/.

F2 Woody debris dams

Introduction

The origin, functioning and habitat value of floodplain features is revealed during flooding. The ephemeral channels confine flow, producing faster streams running between slower, ponded areas. Fast flow can scour the floodplain surface to produce hollows and pools and can reactivate and maintain abandoned channels, although these may also be filled in depending on the specific pathways of water and sediment over the surface. The location of each ephemeral channel is controlled by existing topography including trees, woody debris and patches of dense vegetation. A patchwork of fast and slow flow therefore occurs across the floodplain, creating a variety of temporary flow habitats that may, in the case of pools, persist for several days after the floodwater has receded. The pattern of sediment deposition after each flood is variable, and the amounts also vary intensely, ranging from zero to up to 26 kg m-2 across distances less than one metre (Jeffries et al., 2002). Apart from the role this deposition plays in maintaining the ephemeral channels (through, for example, wake deposits behind trees confining flow), a wide variety of bare surfaces for vegetative colonisation occurs after each flood.

Flooding links the channel and the floodplain with transfers of energy, water and sediment. Debris dams reduce channel capacity, ponding flow and thereby dramatically increasing the area flooded and the duration of overbank flow. Jeffries et al., (2002) found that a single dam increased the duration of overbank flow from 0.2 to 42% of a six month study period. The localised ejection of water, energy and sediment results in patches of the floodplain that are subject to increased geomorphological activity and therefore provide an intermittently wetter and more variable habitat, with complex areas of inundation, scour and sediment deposition.

The size of the floodplain changes downstream in both catchments, reaching a maximum towards their confluence. Floodplain geomorphology is therefore constrained by valley floor width, and the nature of the connectivity between the river channel and the floodplain, itself heavily dependent on the presence of debris dams and channelisation.

Impacts of debris dams on channel and floodplain process

The impacts of debris dams on coarse sediment transport have been documented in a range of streams, though most are steeper than the Adur at Knepp Castle Estate (Assani, and Petit, 1995, Beschta, 1979). Beschta (1979) found that the removal of large organic debris dams accelerated downcutting of previously stored sediments. As a result, turbidity and suspended sediment levels increased during several storms after debris removal. Streamflow eroded more than 5,000 m3 of sediment along a 250m reach the first winter after debris removal. Assani and Petit (1995) undertook bedload transport in a steep gravel-bed open ditch with debris dams. It emerged from these experiments that the debris dams contribute to the reduction of bed-load evacuation by decreasing the total available shear stress for sediment transport. Conversely removal of the debris dams, increased the available shear stress for sediment transport and increased sediment transport rates for a given discharge.

Dudley et al., (1998) document the effect of woody debris entrapment on flow resistance. Hydraulic measurements obtained in a channel prior to and following the removal of woody debris indicated that the average Manning's n value was 39 percent greater when woody debris was present. An examination of the drag-velocity relation for vegetation indicated that an increase in the frontal area of debris and/or vegetation results in a nearly proportional increase in Manning's n. The influence of debris on flow resistance decreased as flow depth increased. Gippel, (1995) has shown that hydraulically, debris acts as large roughness elements that provide a varied flow environment, reduce average velocity, and locally elevate the water-surface profile. This can significantly increase flood travel time. The significance of debris is however, scale-dependent. For example, the hydraulic effects are often drowned out in a large flood on a large river. Gregory (1992) has shown a reduction in flood travel time on the Highland water associated with the removal of debris dams.

Jeffries (2002) conducted an intensive study of a large debris dam on the Highland Water at Millyford. This work demonstrated the significant role larger Active dams play in controlling floodplain processes and process rates (Figure F2.1). Overbank flood frequency and sedimentation rates were significantly enhanced over reaches without debris dams. Furthermore, interaction between sediment laden water and the floodplain forest structure created a diverse topography and suite of erosional and depositional environments.

Figure F2.1 A Large Hydraulically effective Debris Dam in the Highland Water.

Debris Dam distribution

Large Woody Debris (LWD) is an important component of natural river ecosystems and its role in physical, chemical and hydrological processes is complex (Gurnell, Gregory & Petts, 1995). Large Wood (LW) in rivers have been shown to increase the diversity of in-stream habitats (Lehane et al 2002), provide refugia for fish and invertebrates (Lang), increase retention times of organic detritus (a critical source of energy in low order streams) and provide substrate for aquatic organisms which are involved in the decomposition processes of wood. Moreover, LWD is an important element of floodplain surfaces, for the same reasons cited above. An additional role of in-stream LWD is the provision of points of high channel-floodplain coupling where the woody elements are formed into dams (Jeffries et al 2003).

LWD is a feature that is either absent or much lower in abundance than would naturally be the case in most UK rivers. This arises for two reasons; 1) direct removal of woody debris (de-snagging) is a routine maintenance operation on most main river and; 2) removal of riparian vegetation to supply the woody debris from the catchment. The occurrence of woody debris in New Forest streams is an important part of their geomorphology and ecology. Gregory et al (1993) report debris dam densities from some mountain rivers of up to 40 per 100 metres of channel. Variations in debris dam density have been ascribed to distance downstream (fewer as the ratio of channel width to tree length falls), channel width (fewer with increased width), to land-use effects, to felling, and to the management of coarse woody debris in streams. Their study of the Lymington Basin, showed that the input of storm debris resulting from blow down accounted for 45% of the gross debris load. The remaining 55% net load varied according to distance downstream and land use, with the greatest loads in deciduous woodland areas. Removal of debris from the streams significantly impacted debris dam density. Gregory et al., (1993) deduced that as a consequence of long-term management the present channel debris may be as little as 7% of the total net load that could have been present if no management had occurred.

Debris dams were classified in the field based on the typology of Gregory et al., (1985):

- High water dam (tree fallen across channel. Minor hydraulic influence during overbank flow)
- Partial dam (small accumulation that partly spans the channel and slightly disrupts flow hydraulics, usually reducing the cross sectional area)
- Complete dam (accumulation that spans the channel and affects hydraulics but DOES NOT pond water at time of survey)
- Active dam (accumulation that spans the channel and ponds water. i.e. a real dam!)
- Other dam (either unidentifiable due to map, or some other hydraulic influence such as a clay plug)

At the time of survey, 90% of geomorphological reaches contained a dam of some sort (Table 6.6). A dam occurred on average every 76m, with the most common being partial dams, spaced around 170m apart. Complete and active dams both occurred less frequently, with around 4 per kilometre observed. High water dams (fallen trees) were the least frequent, and their spacing varied much more than any other type.

Debris Dam location

A common example of a jam point is a meander inflection that is confined by trees on either or both banks. Gurnell & Sweet (1998) report that an analysis of geomorphological maps of the Highland Water channel surveyed in 1982 and 1996/97 shows an overall decrease in the number and size of pools along the section that was cleared of LWD dams. This is supported by the relative lack of active and complete dams in the Blackwater and the absence of deeper glide and pool habitats reported in this survey.

Specific guidance on the restoration of Large Woody Debris Dams – The New Forest project

The introduction of woody debris and debris dams is now an established element in stream restoration (Gippel et al 1994), although its use in UK rivers is somewhat limited and tends to focus on cover for fish. A major woody debris restoration project has been undertaken in the

New Forest funded under the EU LIFe-3 programme. The main reasons for debris restoration is two-fold; 1) to increase physical habitat diversity and ecological function to disturbed watercourses and; 2) to provide bank protection. However, one of the functional characteristics of debris dams particularly, is to increase upstream water levels and generate local points for the transmission and exchange of water, sediment, nutrients and seeds/propagules on to and off the floodplain. The natural density of woody debris dams in the New Forest streams is open to debate, although Gregory et al. (1993) indicate that current debris dam density may be much lower than natural. The problem with the two catchments is that removal of debris has reduced recruitment, furthermore, absence of riparian sources of indigenous species must also have reduced debris loadings and dam frequency within potential semi-natural analogues. Jeffries (2002) documents average debris dam frequency of 1.7/100m for semi-natural reaches of the Highland Water, compared to 0.8/100m for channelised reaches, and this report further indicated much higher potential for jam point development than is currently the case.

Two important factors in restoring natural debris loadings and debris dam density in New Forest streams are: 1) the restoration of debris supply through development of appropriate riparian woodland, and 2) restoration of the jam points formerly present in the watercourses. This latter factor includes restoration of meandering planform, but also riparian trees and appropriate width/depth ratios for the channel cross-sections. This is best achieved wherever possible by restoring the abandoned watercourses. To facilitate debris loadings in the short term, it may be possible to augment debris loadings in these channels using indigenous riparian timber.

Dooley & Paulson (1998) report the following functional characteristics of LWD dams and which may be used to guide their design:

- Interrupt the stream flow to trap coarse and fine sediment upstream of the LWD
- Modify stream flow to create pool habitat upstream and downstream of LWD
- Provide cover and shade for juvenile and adult salmonids
- Direct high-water flow to support hydraulic routing to floodplain
- Trap and hold small organic materials (leaves, needles, carcasses, etc.)
- Provide hydraulic roughness to the stream during high flow conditions
- Provide habitat and perches for aquatic insects, amphibians, birds and riparian mammals
- Provide structure and nutrients for microbiological organisms important to the aquatic ecosystem
- Provide habitat for aquatic and semi-aquatic plant communities by providing crags and silt traps within the structure
- Provide a continuing flux of organic carbon and decay products to a stream system

In order to perform these functional requirements an engineered LWD dam would be subject to physical parameter constraints such as the following:

- Cross-section and length are proportional to stream channel and high flow conditions (proportional length and diameter is better)
- Mass, specific gravity or other features to keep LWD in place during all but most severe flows (heavier is better)
- High hydraulic roughness (higher drag is better – keep the branches on)
- High physical surface roughness to trap sediments, debris, etc. (rougher is better)
- Maximum surface area (more surface area per unit volume is better)
- Natural appearance after placement (blends with the natural scene)

- Natural appearance of debris when structure fails during extreme flow event (no square edges)
- Minimum impact of debris on downstream public works (smaller debris size is better & larger elements are stable over time).

The 1998 annual report on the Natural Resources Status for the Oregon Fish & Wildlife Service documents the effectiveness of woody debris restoration in streams of comparable size and slope to those within the New Forest. The report makes the following conclusions:

The majority of placed wood remained stable through two large (5yr & 100yr Recurrence Interval) flood events. Some 75% of wood showed no noticeable movement and only 10% of wood moved more than one bankfull channel width from emplacement site.
The stability of debris dams was greatest where trees with natural rootwads were used, and anchored into the banks.

Mobility of debris is of concern to downstream flood protection, thus information on debris movement is a necessary goal of project monitoring.

Options for restoring debris dams
This study has concluded that LWD loadings and debris dam frequency are lower than would be the case in the undisturbed floodplain forest condition. The reason is three-fold:
1) reduction of debris supply through clearance of floodplain woodland;
2) reduction in jam points arising from channel straightening and modification to width:depth ratios;
3) clearance of existing dams/LWD.

The options for restoring debris dams and LWD loads within the forest streams include the following:

- Engineered debris structures – LWD is physically manipulated to create structures that provide the functionality of debris dams.
- Debris loading in channels – LWD is placed in the channels and allowed to be transported to natural jam points to develop debris dams.
- Jam point seeding – LWD is placed in the channel in the vicinity of a jam point and allowed to develop naturally into debris dams.
- Natural recruitment – LWD is allowed to naturally accumulate over time within the newly restored channels

Woody Debris is supplied to a reach from upstream as well as by input from the riparian margins. Such debris comes in many sizes from leaf fragments up to whole trees. The finer material provides a valuable source of carbon and acts as a substrate for in-stream biota, whilst the larger material also creates diverse physical habitat through interaction with the flowing water. Restoration of woody debris therefore depends in the long term on the establishment of a debris source, and the cessation of debris management (removal).

Specific guidance on the restoration of Large Woody Debris Dams – River Adur Restoration Project

At Knepp Castle, there is an upstream source of woody debris, and some limited sources of riparian debris. In order to sustain woody debris into the future it will be necessary to establish this riparian source through planting and natural deposition of propagules and seeds. In the short-medium term, the absence of large woody debris can be offset by selective introduction of branches and trees located at points where tree fall and debris are most likely to occur / accumulate. These would be upstream of obstructions, and where trees collapse into the channel. In the Adur, this will largely be driven by undermining and bank collapse (limited owing to stability of channel banks) and windthrow (direction prevailing from SW). Thus debris jam points are identified at which point a mature tree (Alder/Willow/Oak) should be collapsed across the channel such that the root bole is pushed into the surface of the right bank, and the bole of the tree and branches pushed into the channel so that the structure is wedged tightly inside the channel, lying diagonally across and downstream. Additional branches could be laid against the upstream side of the jam.

Debris accumulations should initially be of the Partial dam (small accumulation that partly spans the channel and slightly disrupts flow hydraulics, usually reducing the cross sectional area) and Complete dam (accumulation that spans the channel and affects hydraulics but DOES NOT pond water at time of survey) type. These will change as debris decomposes or is trapped. At high flows they will afford additional flow resistance resulting in locally elevated upstream flood levels, accumulation of sediment on the channel bed, and trapping of debris. As the dams develop, they may begin to create scour downstream of the structure. This can result in collapse of the dam, but the large debris is unlikely to travel far before becoming trapped again. If there is any concern about debris mobility then steps should be taken to anchor the tree/branches.

Recent and on-going research at Southampton University School of Geography (Sear et al 2005) is quantifying the flow resistance of different debris dams. Preliminary analysis shows that as the blockage affect of the debris increases, flow resistance changes from form drag to spill resistance dominated and the dams behave like broad crested weirs. Values for Darcy-Weisbach friction factor f, of natural debris dams range from 1 – 500, with an average for the types of debris accumulation proposed at Knepp Castle of around f = 50-200.

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