River Chess Knowledge Creation

Part H - Sediment source apportionment

Smarter Water Catchment Programme

March 2024

Working in partnership

Contents

Figures

Executive summary

The River Chess is a Chalk stream located in the Chilterns. Thames Water has set out a 10-year plan to help to protect and enhance the River Chess catchment. This review forms part of a package of works which was set up to investigate fine sediment issues within the catchment. The study concerns 'Milestone Che045a - Review evidence and scope options from sediment source apportionment project'.

Previous datasets and studies undertaken to help investigate fine sediment within the catchment have been reviewed. The studies included in this review comprise a fine sediment study, a sediment apportionment exercise and an urban pollution study. Additional datasets reviewed include Citizen Science Mud Spotter surveys and outputs of investigations using SCIMAP (Sensitive Catchment Integrated Modelling Analysis Platform).

The results reveal that fine sediment concentrations are similar to neighbouring chalk stream catchments. Whilst it is not possible to determine how this relates to natural characteristics of the river due to a lack of reference data, the catchment has been extensively modified (reach homogenisation, installation of weirs, widening for watercress beds and land-use changes in the wider catchment). It is therefore likely that fine sediment storage within the River Chess is higher than it would be naturally and would benefit from measures to help reduce concentrations within the gravel bed.

The existing evidence suggests that the current source of fine sediment within the river and catchment is likely to mostly originate from bank erosion. Surface runoff is not believed to represent a significant sediment source due to the limited pathways connecting these sources to the river. Despite this, Mud Spotter survey evidence reveals instances of highly turbid water during heavy rainfall along specific tributaries. Furthermore, water quality and sediment quality sampling reveals high organic levels which cannot be explained by sewer misconnections. This data suggests that surface runoff to river connections do exist during heavy rainfall.

Following this review, it is suggested that interventions revolve around three themes: (1) reducing sediment inputs at the source; (2) improving downstream conveyance of sediment; and (3) improving local sediment storage. To make sure the most suitable interventions are placed in the most effective location, additional analysis is recommended which should include investigations into the geomorphological baseline of the river, stream power analysis and a site walkover to constrain erosion locations.

The negative effects of elevated fine sediment on chalk streams is well-documented. Based on the existing data and analysis, there are likely to be various opportunities to provide effective improvements to the River Chess that ensure the natural biota can flourish, whilst improving resilience to further degradation in the face of climate change.

1 Introduction

The River Chess is a vulnerable chalk stream habitat located in the Chilterns Area of Outstanding Natural Beauty (ANOB). It has been classified as having moderate ecological status (under Water Framework Directive Cycle 3 classification). This is due to a variety of causes including physical modifications to the river, high phosphate concentrations from sewage effluent discharges, and riparian and instream activities causing bank erosion (Environment Agency, 2021).

Thames Water has set out a 10-year plan to help to protect and enhance the River Chess catchment. As part of this, the Chess Smarter Water Catchments funding has resulted in the establishment of a partnership which runs a comprehensive Citizen Science program to provide an evidence-base for the catchment management.

This review forms part a package of works which was set up to investigate fine sediment issues within the River Chess Catchment. As part of the Smarter Water Catchments Programme, several milestones have been set. This study concerns 'Milestone Che045a - Review evidence and scope options from sediment source apportionment project' within the Water Quality Theme. The study has included critical analysis of recently commissioned work on fine sediment and re-analysis of existing data. The initial aim of this work is to provide an independent review of the existing studies that have been undertaken to help understand fine sediment pollution in the River Chess. The second aim is to devise an action plan that targets high priority areas and scopes the next steps associated with each.

2 Catchment context

The River Chess includes a 95km^2 catchment located within the Chilterns ANOB. It originates from springs at the base of the hills around Chesham. From here, it flows for 18km through Buckinghamshire and Hertfordshire before reaching the confluence with the River Colne in Rickmansworth.

The geology of the catchment comprises chalk of the Upper Cretaceous Chalk Group (Figure 2.1), overlain by alluvium in the valley bottoms, representing recent (Holocene) deposition of the River Chess. Superficial deposits are also seen in the upper parts of the catchment, commonly referred to as Clay-with-Flints (Gallois, 2009), presumably of Pleistocene age. These are effectively karst deposits, formed by dissolution and decalcification of the soluble carbonate within the chalk, leaving behind the insoluble impurities (clays)and flint nodules. Other superficial deposits include Pleistocene gravels, which form terraces in the lower parts of catchment, deposited by historic courses of the River Thames (Aston and Mason, 2023).

The superficial deposits would naturally have contributed very little to the sediment budget; however, with land-use changes this may no longer be the case and these deposits could represent an important source of fine sediment if artificial surface drainage pathways now exist connecting these to the river.

The permeable geology means most of the water that falls on the ground naturally seeps into the soil, eventually reaching the chalk aquifer. This limits overland flow and potential drainage pathways in the upland areas are typically dry. Many of the smaller streams emerge from springs in the lower parts of the catchment. These are often ephemeral, locally known as 'winterbournes', responding to seasonal variations in groundwater levels. The underlying chalk provides a flow in the river which is naturally dominated by groundwater, resulting in a very high base flow index (0.95) at the Rickmansworth gauge (UK Centre for Ecology & Hydrology, 2024). Mean flow at this gauge is 0.542m^3/s, whilst QMED is 1.14m^3/s.

The River Chess catchment has been affected by significant historical modification. Land use within the catchment currently comprises 12% urban, 36% arable/horticulture, 34% grassland and 18% woodland (Rothamsted Research, 2023). Numerous mills and associated structures were constructed on the river, many of which remain today. These have modified the natural grade of the river, reducing flow velocities and impounding water behind the structures. In addition, watercress farming became an important local industry throughout much of the 20th century. In places, the river was widened or diverted to provide flow for these beds. The river has likely undergone significant straightening and channelisation and the resultant planform is likely to be in contrast to its natural state.

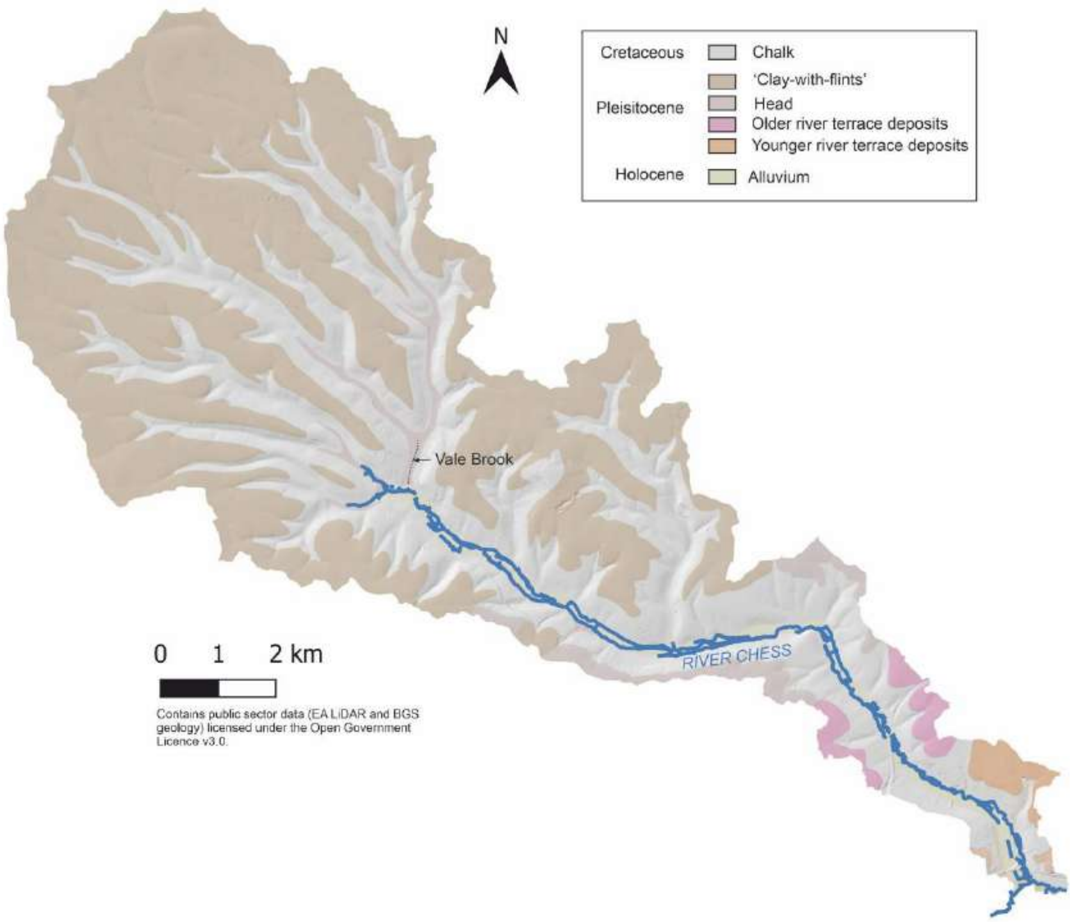

Figure 2.1: Maps showing the catchment geology

3 Theoretical background

Chalk streams are groundwater-dominated systems where the majority of the water is fed from underground. The water is filtered as it passes through the subsurface lithologies. As such, the water emerging from these sources tends to be very clean, with low proportions of suspended sediment (Heywood and Walling, 2007; Walling et al., 2007). The stable flow conditions limit bank erosion, and therefore in-channel sediment inputs tend to also be low.

Chalk streams often have complex catchment histories. For centuries they have been recognised as economically important resources for activities such as milling and watercress production. Such activities have caused significant changes to chalk streams, particularly surrounding how water and sediment moves through the system (Grabowski and Gurnell, 2016).

As well as direct changes to the rivers themselves, many catchments have been subjected to significant land use changes. There is an increasing body of evidence highlighting the significance of bronze-age deforestation and the rise of land cultivation on fine sediment fluxes (Brown et al., 2018; Castro and Thorne, 2019; Cluer and Thorne, 2014). The effects of land cultivation are still being seen particularly with the expansion and intensification of winter-sown cereal production, the amalgamation of fields, and increases in field-channel connectivity. As such, an estimated 72% of fine sediment entering watercourses in England and Wales is thought to originate from diffuse agricultural sources (Zhang et al., 2014).

The picture in chalk stream catchments is more complex. Chalk catchments are naturally permeable which means that most of the water that falls on the ground infiltrates into the underlying aquifers. Whilst the Clay-with-Flints likely reduce permeability where present, surface flow tends to be minor, and the intense drainage connectivity of more permeable catchments is often not present. As such, there are normally less flow paths capable of transferring sediment. However, one of the consequences of groundwater-fed systems is that they tend to be less 'flashy[1]' than other fluvial systems which can limit the higher flows capable of mobilising and transporting sediment, commonly referred to as bed mobilising flows (Mondon et al., 2021; Sear et al., 2005). Therefore, if excess sediment finds its way into the channel, there are less opportunities to move the sediment downstream.

Fine sediment dynamics within the channel have been affected by often extensive modification, including straightening, re-sectioning, impoundment and embankment. One impact of this is the 'homogenisation' of many of our chalk streams. Vegetation and large wood naturally creates flow variations which traps sediment in some locations but promotes scour in others (Heppell et al., 2009). Clearance of such vegetation removes the pockets of 'clean' gravels and local sediment stores, reducing the natural variability that allows sensitive species to flourish.

Natural sinks of sediment have also been removed, particularly a reduction in floodplain connectivity reducing the potential for the settling of sediment on the floodplain. Compounding fine sediment inputs are pressures from groundwater abstraction which reduces summer flows (Bickerton et al., 1993), whilst the introduction of weirs and mills cause impoundment which further encourage fine sediment deposition and limit the potential for bed mobilising flows (Wohl, 2015).

Sedimentation is a natural process and can be part of natural river recovery following modification. However, there is now a substantial body of evidence that elevated levels of fine sediment (defined as inorganic and organic particles < 2mm in diameter) can cause degradation to freshwater ecosystems (Malmqvist and Rundle, 2002; Mondon et al., 2021; Wilkes et al., 2019). Effects can happen both through increased turbidity within the water, which limits the light available for processes such as photosynthesis, or through increased saturation of fine sediment stored within bed forming gravels, often referred to as 'colmation' (Velickovic, 2005). The increased fine sediment saturation blocks the pore space within the gravels, removing valuable niches for biota to live. The lack of hyporheic flow (surface water to groundwater connectivity), reduces dissolved oxygen and the removal of metabolic waste, effectively suffocating the organisms living in these areas. Finally, the organic matter often associated with fine sediment tends to decompose within the water, further decreasing dissolved oxygen concentrations and compounding ecosystem disruption.

A conceptual framework for the fine sediment budget for the River Chess is shown in Error! Reference source not found.1. The River Chess represents a fairly typical chalk stream within the Chilterns AONB. Given its extensive catchment modification, it is expected to be affected by activities which have perturbed the fine sediment budget, resulting in negative consequences for the ecosystems within the river.

[1] Flashy rivers respond quickly to rainfall events and are characterised by a steep rising limb and short lag time on a hydrograph.

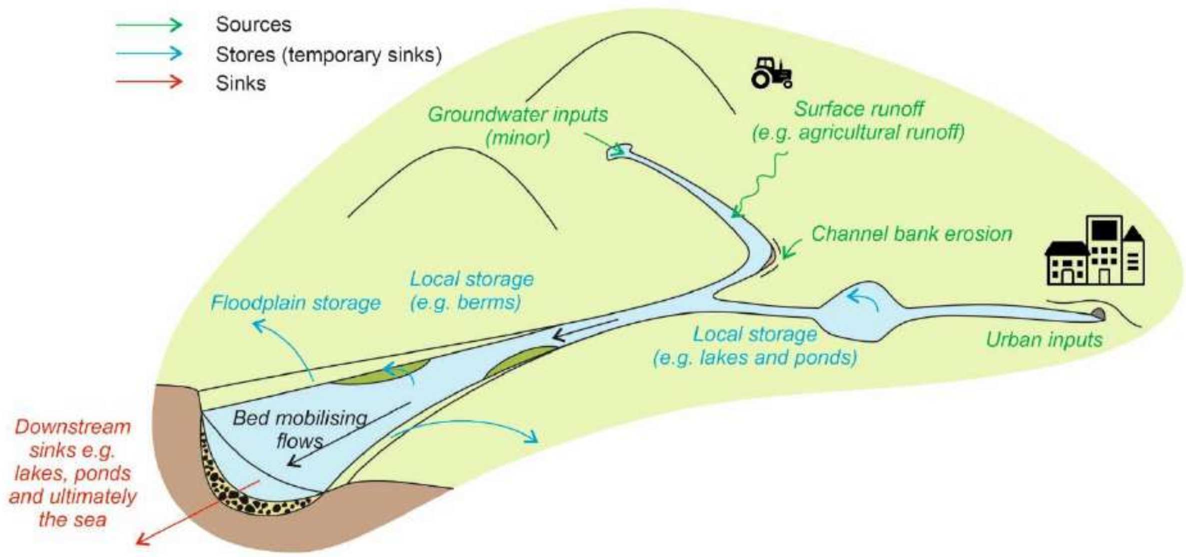

Figure 3.1: Conceptual sketch of the River Chess catchment showing the relationship between sources, stores and sinks of fine sediment.

Sediment within the River Chess can be thought of in terms of inputs, stores and sinks. Inputs include surface runoff from the land surface (Figure 3.1). This can include natural sources, such as that from woodlands, grasslands as well as anthropogenic such as those from cultivated land and urban areas. Bank erosion can also deliver sediment to rivers, Whilst livestock poaching is noted at several locations within the River Chess, bank erosion within chalk streams should naturally be very low due to the stable flow conditions.

The predominant sink of sediment is essentially the removal of sediment downstream. However, additional temporary sinks of sediment can occur on the floodplain, and/or on top of berms within vegetation and large woody debris. These temporary sinks or 'stores' will likely eventually be remobilised downstream on longer term timescales but represent important opportunities for sediment removal in the shorter term. Other stores of sediment include sediment stored within the bed gravel (culmination) or sediment stored in low flow areas within the channel.

When these variables are in equilibrium, there is no change in sedimentation within the system. However, if one of these variables change e.g. bed mobilising flows decrease or sediment inputs increase, the sediment budget can become imbalanced which can manifest as increases in bed storage. This conceptualisation can be used in relation to potential mitigation activities discussed in Section 6.

4 Review methodology

A summary of the review methodology is provided in Appendix 1. The review includes a critical analysis of the previous studies and collected data on fine sediment pollution in the River Chess catchment. The aim is to bring the analysis together and highlight gaps, conflicting results and thereby provide additional insight into the studies that enables an action plan to be developed.

The studies and datasets which are included in this review are outlined below:

- Fine sediment analysis of both suspended and bed sediment (APEM, 2023)
- A sediment apportionment exercise (Rothamsted Research, 2023)
- An urban pollution study (Jacobs, 2023)
- Citizen Science Mud Spotter surveys
- Analysis through SCIMAP (Sensitive Catchment Integrated Modelling Analysis Platform)

As part of this review, questions are asked about the purpose of the study, limitations of the chosen methodology, relevance and reliability of the conclusions and overall impact on the River Chess. In order to add value to these studies, some additional analysis was undertaken as part of the review process and is outlined in Appendix 1.

5 Study review

A summary of the individual studies in this review are provided below. Whilst the results of some additional analyses undertaken as part of this review are also outlined, the section mostly covers the main conclusions of the author(s) in the individual studies. Additional interpretations in light of this review are provided in Section 7.

5.1 Fine sediment analysis

A fine sediment analysis study was undertaken in 2023 by APEM (APEM, 2023). The aims of the study were to calculate fine sediment storage within the bed of the River Chess. The aims were also to understand the potential impact of the composition of the bed material on target plant, fish and invertebrate species.

Bed samples were taken from eight sites along the River Chess between Chesham and Rickmansworth. Three samples were taken from each site to make sure potential variations in channel bed characteristics were captured. The study utilised the stilling method for calculating the stored mass of fine sediment (Lambert and Walling, 1988), but bulk sediment samples of the bed were also collected following standard techniques. The particle size distribution (PSD) of the bulk sediment samples were analysed, whilst the mass of fine sediment was extracted from the stilling samples to provide the fine sediment storage within the gravel bed.

As part of this review, the results of the fine sediment storage were integrated into GIS and the average results plotted on a catchment map in Figure 5.1. Fine sediment storage was found to be variable with individual results between 0.82 and 40.9g/cm^2. Some sites displayed a large variation in fine sediment storage, most notably at Meades Water Gardens, Broadwater Bridge, Watercress Beds, and to a lesser extent on the Main Chess at Restore Hope Latimer. The results reveal that the worst areas for average fine sediment storage were Chesham Moor (15.2g/cm^2) and Elms Lake (12.9g/cm^2) (Figure 5.1). These samples were at opposite ends of the study area, and there doesn't appear to be any downstream patterns in fine sediment storage.

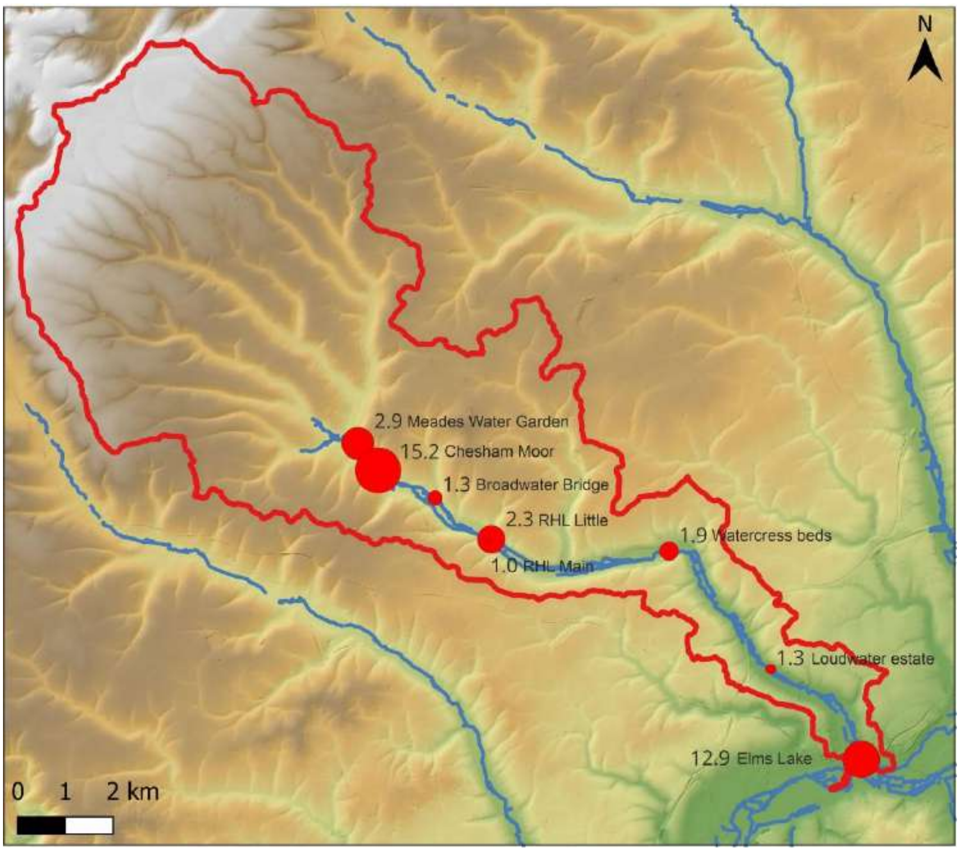

Figure 5.1: Downstream variation in fine sediment storage. The River Chess catchment is shown in Red overlain on to LiDAR Data.

Other data to enable reliable comparisons on fine sediment storage within chalk streams is unfortunately lacking. Whilst there is some existing data, the methodologies are slightly different meaning direct comparisons cannot be drawn. When compared with other river types, the fine sediment storage is probably low. However, these results are largely expected as chalk streams are naturally cleaner systems due to the high base flow (groundwater) component. Some broad comparisons can be made to neighbouring chalk streams including the Upper River Tern, River Pang and River Lambourne. These suggest the River Chess suffers from lesser amounts of fine sediment storage.

One of the complexities is that finding 'reference reaches' that are unmodified is difficult, particularly in a chalk stream such as the River Chess. Whilst potentially not as high as some neighbouring chalk streams, the results are variable and highlight areas with high amounts of fine sediment storage. Given the general understanding that the majority of chalk streams are more saturated in fine sediment than they should naturally be (Mondon et al., 2024), efforts to improve fine sediment concentrations will be of benefit.

Whilst elevated fine sediment storage within chalk stream gravels is widely attributed to adverse effects on the geomorphology of the riverbed with consequent effects upon biota (Wood, 1997), determining the specific effects on biota on the River Chess is problematic. Without continued monitoring it is difficult to link changes in fine sediment concentration with biotic indicators. However, there is some correlation between fine sediment concentrations and changes in some of the biotic indices within the River Chess, specifically the Biological Monitoring Working Party (BMWP) scores and Whalley Hawkes Paisley Trigg (WHPT) metrics. These may suggest that improvements to fine sediment storage as part of catchment interventions will lead to improvements in invertebrate numbers.

5.2 Sediment apportionment

A sediment apportionment study was undertaken in 2023 by Rothamsted Research (Rothamsted Research, 2023). The aim of the work was to trace the sources of fine-grained sediment in the River Chess. Whilst agricultural runoff was historically considered the most important source of fine sediment to

UK rivers (Walling et al., 2007; Walling and Collins, 2005), more recent work has suggested sources to be much more variable (Pulley and Collins, 2021). Therefore, determining what these sources are helps focus what interventions may be applicable to help reduce fine sediment pollution.

The study employs a relatively new technique to look at provenance[2] involving simple colour-based analysis. Traditional sediment provenance or 'fingerprinting' techniques typically require complex analysis using specialist equipment, and technical expertise for interpretation (Owens et al., 2016). As such, it is considered costly and not currently routinely used for catchment management. The colour technique was proposed by Pulley and Collins (2021) to provide an accessible and inexpensive tracer.

The study collected both suspended sediment and bed samples (see locations in Figure 5.2), following standard sampling techniques. Suspended samples were collected using traps, sampled for a year, between June 2022 and May 2023. The study also collected 117 samples from potential sources, comprising all major land uses as well as channel banks. Organic matter has the potential to affect sediment colour, so to remove this, the samples were treated with hydrogen peroxide. The samples were dried and disaggregated, and images were taken using a document scanner. The study also included measurements of turbidity and flow.

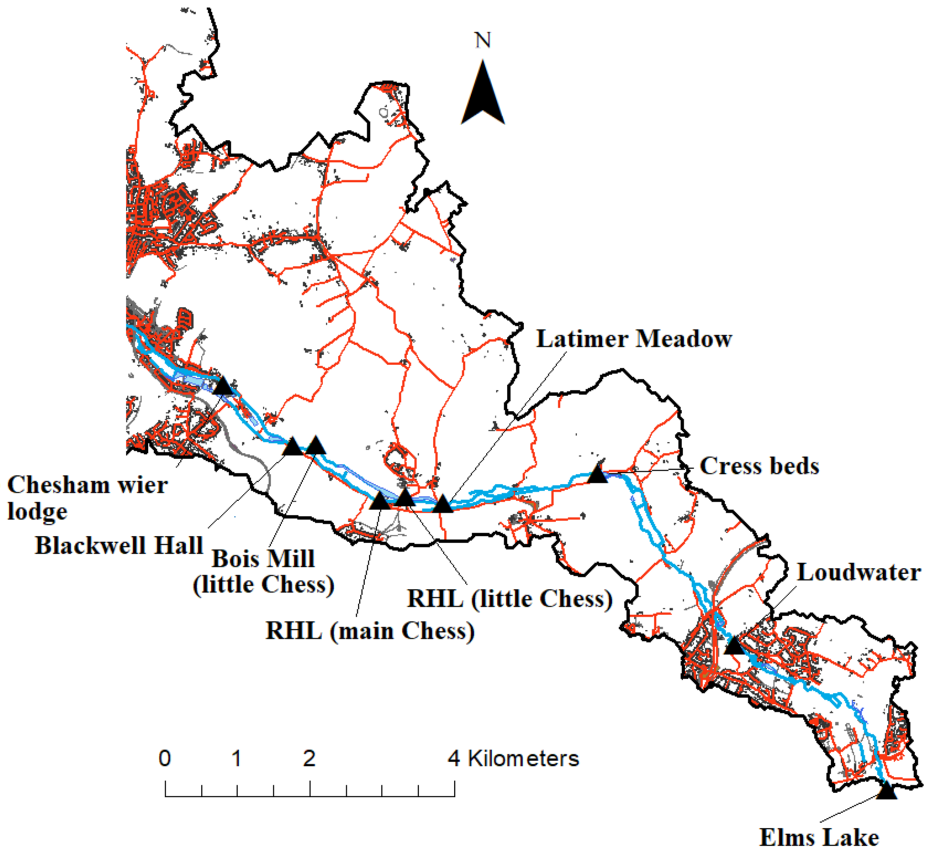

Figure 5.2: Sample locations from the sediment apportionment study, from Rothamsted Research (2023)

Colour was found to be able to discriminate between the source areas well, with the different potential sources mostly clustering in different parts of the biplots (Figure 5.3). The colour of all suspended sediment and channel bed sediment fell between the urban, road dust and channel bank sources. There were some differences noted spatially in the results with darker colours noted in the upper parts of the catchment at Chesham Weir Lodge, Blackwell Hall and downstream at RHL Main Chess, interpreted to reflect a mixed urban and channel bank sediment provenance. The blue value of the sediment is higher in relation to red in the sediment samples than in the woodland, grassland and cultivated sources suggesting no significant contributions from surface runoff to any sediment sample.

[2] Provenance means where the sediment comes from and how it got where it is today.

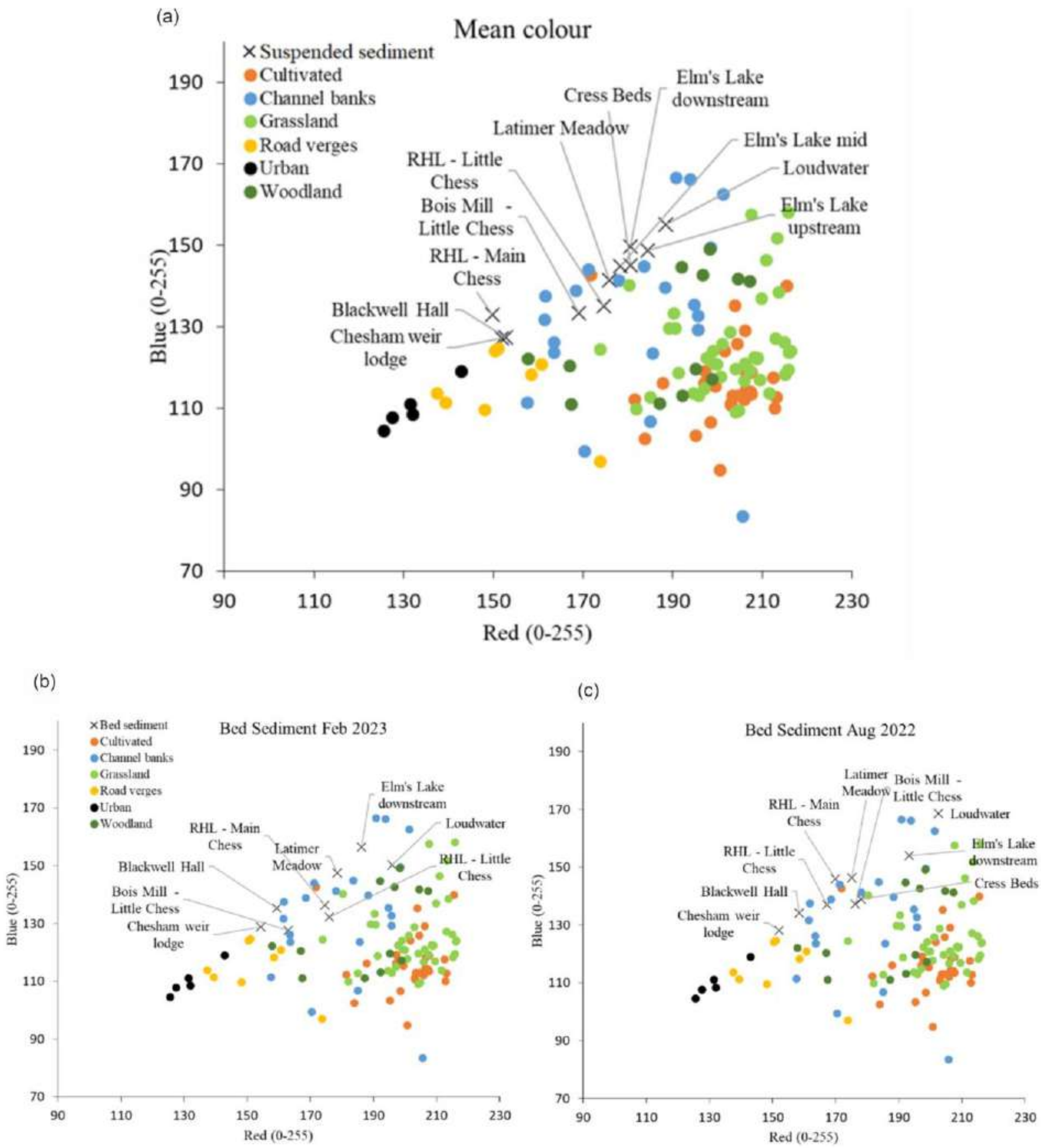

Figure 5.3: Biplots showing the results of the colour-based apportionment exercise. (a) Average results from the suspended sediment analyses. (b) Results from bed sediment collected February 2023. (c) Results from bed sediment collected August 2022.

The results of the turbidity measurements showed seasonal variation, as expected, due to increasing contribution from overland flow associated with winter rainfall events. However, there was generally poor correlation between the highest flow events and turbidity. Samples from higher in the catchment showed better correlation, possibly relating to a higher component of surface runoff from these areas in relation to base flow. Overall, the suspended sediment yields were very low, as typical of chalk streams.

The results suggest that most of the fine sediment found both within the water and on the channel bed is sourced from bank erosion. Whilst there is potentially a high concentration from urban runoff upstream, these inputs are being diluted and are becoming insignificant downstream. As such mitigation that focusses on these urban runoff sources are likely to only have localised benefits in the upper reaches of the river. The authors suggest that whilst soil erosion (via surface runoff) is noted by citizen science groups, the volumes needed to deliver the measured sediment loads would be implausible and therefore mitigation should focus on efforts to improve downstream sediment conveyance.

5.3 Sediment and water quality

Chesham has previously been identified as a priority area for understanding the impact of pollution of the River Chess and there are visible differences in the turbidity of the water between summer and winter conditions. A water and sediment study was undertaken by Jacobs in 2023 (Jacobs, 2023). This study focused on a tributary to the River Chess called Vale Brook (see Figure 2.1 for location) which largely runs beneath Chesham town centre and is thought to have issues with sediment pollution. An example of fine sediment pollution in Vale Brook is shown in Figure 5.4. The main objectives of this work were to determine whether sewer misconnections could be affecting water quality, investigate differences between high and low flow conditions, and identify any longitudinal variability in the data upstream and downstream.

Figure 5.4: Fine sediment pollution at Vale Brook

The study analysed water samples at various points along Vale Brook (Figure 5.5). It also included analysis of samples upstream and downstream of the Vale Brook confluence to see the impact the tributary has on the River Chess. The study analysed a number of parameters in the laboratory which represent water quality including, ammoniacal nitrogen, Highways runoff (cadmium, copper and zinc concentrations), conductivity, orthophosphate, microbiology (Escherichia coli, faecal coliforms, total coliforms, total suspended solids and organic matter dissolved organic carbon, chemical oxygen demand, biochemical oxygen demand). Particle size distribution (PSD) and turbidity data were also analysed.

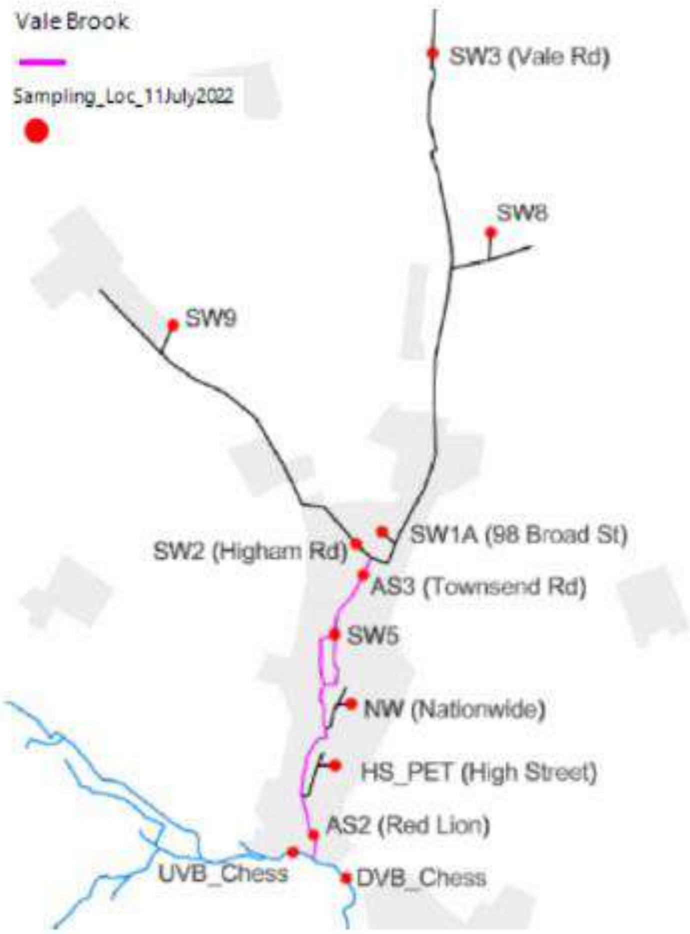

Figure 5.5: Sample locations of the sediment and water quality study in the Vale Brook

The study examined flows during both dry and wet weather. The dry weather results recorded a decline in water quality after the confluence of Vale Brook within the River Chess, suggesting the tributary has a negative impact on water quality. Copper, lead, zinc and poly aromatic hydrocarbons (PAHs) were all recorded in concentrations above safe standards, making them pollutants of interest. There was variation upstream and downstream with lead being particularly high at some locations. High amounts of organic pollution (e.g. dissolved organic carbon) as well as relatively high total nitrogen and total organic carbon were recorded. Whilst this could be indicative of misconnections, the bacterial count was mostly low suggesting no sewer misconnections. It is most likely that these pollutants are derived from a combination of urban run-off sources from Chesham and agricultural land upstream.

Rainfall events typically resulted in the dilution of the pollutants; however, some pollutants (e.g. chloride) are temporarily elevated during the initial flush events related to winter salt spreading. Total suspended solids show an increase associated with the first flush following rainfall, indicating erosion and runoff from agricultural fields. This is evidenced by variations in orthophosphate concentrations which seem to be related to surrounding agricultural land, rather than from urban runoff.

The results suggest that agricultural land and in particular surface runoff were a cause of the sediment pollution issues within the Vale Brook. The study concluded that reducing sediment from the Vale Brook into the River Chess is a priority either by directly tackling the sources or by removing polluted sediment already accumulated on the river bed.

6 Additional data review

The additional datasets included in this review are outlined below. New interpretations of these data are provided in the context of fine sediment within the River Chess.

6.1 SCIMAP

The catchment partnership has previously undertaken analysis in Sensitive Catchment Integrated Modelling Analysis Platform (SCIMAP) and the outputs of this work are utilised in this review (Figure 6.1). SCIMAP is a sediment risk assessment model and is used here to identify potential sediment source areas and pathways across the landscape. The aims of the work were to get an indication of where the highest risk of sediment erosion occurs within the catchment. This allows mitigation to be more effectively targeted and areas that require further investigation to be identified.

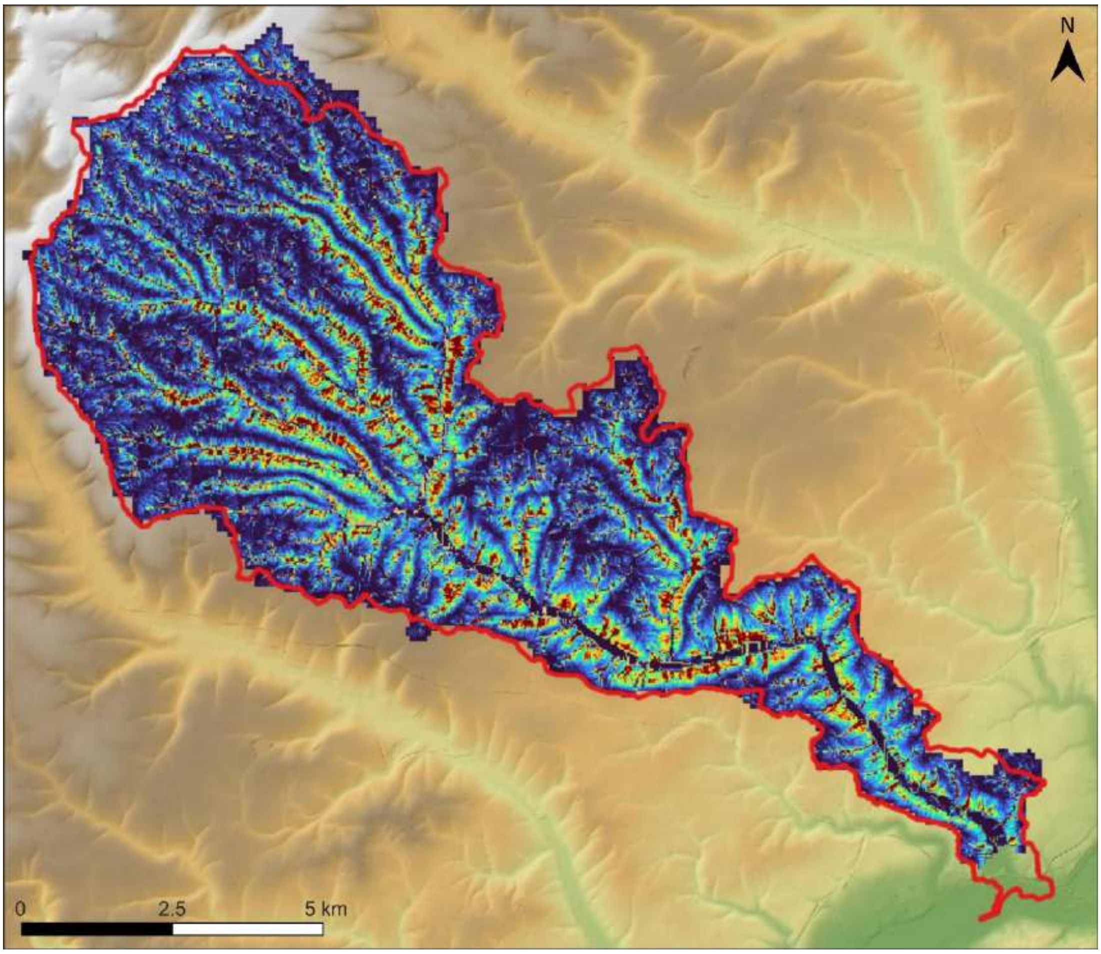

Figure 6.1: Map showing the erosion risk map outputs from SCIMAP. Red colourations represent the areas at highest risk of erosion whilst blue represents the lowest risk.

SCIMAP uses digital elevation models (DEMs), land-use data and rainfall information to give an indication of areas at most risk of soil erosion. SCIMAP works by first identifying areas where sediment is most likely to be available to be mobilised, through analysis of the land use maps. This is combined with information on the hydrological connectivity of the watercourse to give an indication of how likely sediment will be mobilised to a receptor / water body (i.e. the River Chess).

Previous interpretations of the SCIMAP outputs were not available for this review. However, the outputs from the SCIMAP analysis, illustrating fine sediment erosion risk, are shown in Figure 6.1. The following interpretations are based on analysis undertaken as part of this review.

The SCIMAP analysis reveals that some areas of the catchment have the potential for fine sediment mobilisation. The relatively steep gradients within the catchment, combined with the presence of arable land with winter-sown cereal production, puts the River Chess catchment at relatively high risk for agricultural runoff. The highest risk areas appear to be those on the steeper land adjacent to the River Chess.

It is important to note that SCIMAP does not take into account the geology of the catchment. The analysis identifies surface water pathways based on the topographic LiDAR data. The permeable nature of the chalk catchment naturally limits these surface water pathways; therefore, caution should be applied to the interpretations of sediment connectivity.

The results do however suggest that there are areas within the River Chess catchment that are at high risk for sediment erosion. These areas typically include the steeper areas immediately adjacent to the floodplain in the lower parts of the catchment and the dry valleys in the upper parts. If surface flow pathways are found for these sources then these areas can be prioritised for further analysis and potentially the implementation of measures to reduce sediment erosion.

6.2 Citizen Science (Mud Spotter)

Mud Spotter is a surveying technique developed by Queen Mary University of London that enables non-specialists to gather scientific data on sediment entering river systems (Figure 6.2). Previous interpretations of the Mud Spotter outputs were not available for this review. The resulting interpretations are based on analysis undertaken as part of this review.

Figure 6.2: Photographs of fine sediment inputs taken during Mud Spotter surveys at (a) Vale Brook and (b) Cannon Mill Stream.

Mud Spotter evidence reveals episodes of increased turbidity which correspond to delivery of fine sediment into the River Chess from its tributaries. Some of the sediment inputs come from unknown culverts where the source cannot readily be determined.

Three locations within the upper catchment have been identified where sediment inputs from surface runoff are observed following heavy rainfall: (a) Vale Brook, (b) Blackwell Hall and (c) Bell Lane. Of those, Vale Brook in particular has been repeatedly recorded as being subjected to episodes of fine sediment delivery. Additional tributaries noted include Cannon Mill Stream.

7 Discussion

A discussion of the results of the studies in relation to the River Chess are outlined below.

7.1 Is fine sediment a problem for the River Chess?

The results of the fine sediment study suggest that sediment concentrations at the sample sites are relatively low. This is expected given that chalk streams typically have much lower fine sediment concentrations than other catchment types. Some data was available from neighbouring chalk streams; however, there are differences in the methodology of the surveys so direct comparisons cannot be made. In general, the data would appear to suggest the River Chess has similar, if not lower, suspended sediment concentrations than other chalk streams.

The number of sample sites within the fine sediment study was relatively low and the wide variety of results from individual sites demonstrates significant variability within the River Chess. The results are probably highly dependent on the locations of the samples being taken, with samples taken from the centre of the channel being most likely to have lower sediment storage, whilst samples closer to berms or backwater areas are likely to show higher sediment storage. Without undertaking a more systematic sampling strategy, in particular recording specific details about the characteristics of each sample location, the strength of the conclusions are limited. However, it seems sensible to conclude that in general, the fine sediment concentrations are fairly typical of chalk streams.

Whilst fine sediment storage is not recorded as particularly high throughout the sampling locations, this doesn't necessarily mean that local concentrations are not problematic. Determining 'natural' fine sediment concentration in chalk streams within the UK is difficult. One of the issues is that almost all chalk streams have undergone some form of modification that has likely altered the sediment budget compared to their natural state. Furthermore, fine sediment concentrations can be highly dependent on catchment geology and hydrology. Rarely are catchments composed purely of chalk, and even within the chalk there is lithological variation. Superficial geology is also likely to contribute, with the occurrence of glacial deposits and valley alluvium causing variation in sediment supply.

The occurrence of different lithologies within the catchment are likely to vary the natural sediment budget within the system. The hydrological and hydraulic conditions will impact the ability of the river to supply fine sediment and transport it through the system. These factors will naturally cause variability in fine sediment concentrations within rivers. Therefore, determining a threshold for ecological degradation induced by elevated fine sediment is unlikely to be possible without knowing the natural reference state for that particular river.

Despite this, various studies have concluded that chalk streams are being affected by high levels of fine sediment. Mondon et al. (2024) concluded more than 75% of the chalk streams examined, as part of the freeze core database, exceed thresholds for ecological degradation. Given the extensive catchment modification including a reduction in sediment mobilising flows related to the creation of weirs, mills, channel straightening, and groundwater abstraction, as well as the evidence for fine sediment inputs from the Mud Spotter and water quality studies, it is highly likely to be experiencing higher levels of fine sediment than would naturally be present within the river. This is likely to be having negative ecological consequences for the biota that have evolved to the natural conditions.

7.2 Where does the fine sediment come from?

The results of the sediment apportionment exercise suggest that bank erosion is the predominant source of sediment within the River Chess. Surface runoff and agricultural land use were not deemed to be an important source and it was suggested that efforts for mitigation should focus around reducing livestock poaching (reducing bank erosion sources) and improving the conveyance of sediment downstream.

The lack of surface runoff sources can be explained by a lack of pathways connecting the agricultural land to the River Chess. The permeable catchment generally limits surface runoff and water readily infiltrates into the ground. Extensive field drains are typically absent within the upland areas, and field connectivity is expected to be low. As such, whilst there may be opportunities for fine sediment generation through agricultural practices (e.g. tilling), the lack of transport pathways generally limits naturally connectivity, and there are less opportunities for transfer to the River Chess.

The lack of a soil erosion signature could also have alternative explanations. Whilst the apportionment study suggests river banks are the predominant source of sediment, it is important to note that the river banks comprise mostly alluvium. This alluvium is itself effectively a sediment store, which has been previously deposited by the river and not a distinct source. Unless the provenance has changed since it was deposited, one would expect the current bed and suspended sediment to share provenance characteristics with this material, and a matching provenance does not necessarily mean that this was the sediment source.

The river bank material (i.e. alluvium) does not appear to match any of the sources on the biplots (Figure 5.3). This could either be explained by alternative sources which were historically present when this sediment was deposited, or it highlights other factors which have affected sediment colour since deposition on the floodplain.

An alternative explanation is that colour changes have taken place sometime during transportation, erosion or shallow burial. Sediment colour can be affected by the redox[3] conditions of the waterbody (Statham et al., 2019). This is particularly important where sediment is stored, as it may encounter reducing conditions and be chemically altered.

Redox conditions within rivers can be variable, and it is likely that any stored sediment could be chemically altered or reduced. Alternatively, the floodplain sediments could have undergone chemical alterations on the floodplain in-situ following deposition. This could provide an explanation for the higher blue values and lower red values (Figure 5.3).

Given that sediment colour can be changed by chemical reactions, an alternative explanation for the results which indicate a bank erosion source could be that the sediment within the water samples has started to undergo chemical alterations, inducing colour changes. Whether there is sufficient time for these changes to occur is not known, but this could cast doubt on whether sediment colour alone is providing sufficient characterisation of provenance, to discount surface runoff as a source.

Further evidence for surface runoff inputs are provided by the water and sediment quality study. This revealed the Vale Brook has elevated organic sources, which could not be explained by sewer misconnections. The most likely explanation is through surrounding agricultural land and local soil erosion. Whilst pathways that deliver nitrates does not necessarily mean there are also pathways that deliver sediment, it does suggest a degree of connectivity to agricultural land.

In addition, there is evidence on the ground that fine sediment from agricultural sources is reaching the main channel at some locations. Mud Spotter reveals notable tributaries to the River Chess are delivering apparently significant sources of turbid water during heavy rainfall. Data collected from the River Chess also suggests there have been significant increases in turbidity downstream of the tributary with the Vale Brook during heavy rain. This highlights a potentially significant component of fine sediment being transported along this tributary, most likely linked to agricultural runoff.

SCIMAP analysis of the Vale Brook catchment reveals the presence of numerous high risk areas for erosion. It is important to note that whilst SCIMAP highlights potential for erosion, it does not take into account the permeable nature of the catchment which limits the potential for overland flow. Whilst the high risk areas exist, the risk does not appear significantly different to other tributaries on the River Chess. It is possible that specific agricultural activities may be ongoing within this sub-catchment and/or the current land management has created sediment transport pathways.

In summary, in-channel sources are likely contributing a significant proportion to the overall fine sediment budget and interventions should be instigated to reduce those sources. Further data collection is

[3] Chemical reaction that takes place between oxidizing substance and reducing substances

necessary to determine reaches likely to be undergoing bank erosion. Whilst agricultural runoff is not identified as a major source according to the provenance method used, it is recommended that agricultural sources should not necessarily be discounted. This is particularly important as those sources may also be affecting water quality.

7.3 How can fine sediment be managed?

Fine sediment concentrations within the River Chess are likely to be a function of the inputs of sediment to the system, the availability of local stores of sediment and the transfer of sediment downstream (Figure 3.1). Potential interventions that target these are discussed below.

7.3.1 Reducing sediment inputs at the source

Whilst sediment supply to the River Chess from surface runoff is debatable, there is evidence to suggest that bank erosion provides an important input. Interventions which target bank erosion could include:

- Fencing to prevent livestock poaching,
- Bank protection e.g. coir rolls, bank stakes, faggots and brushwood, willow spiling, large wood and vegetated rock rolls.

It should be noted that bank erosion is a natural geomorphological process and is generally considered a normal response to channel modification (Florsheim et al., 2008). The alluvium that exists along the River Chess is likely to include coarser sediment (e.g. gravel), in addition to fine sediment, which may be of benefit. Additional investigations should be undertaken as to the current trends of the river system, and its state in response to historical catchment changes. Until this is undertaken, careful consideration should be applied to interventions that reduce natural bank erosion, as this may disrupt the natural trends occurring in the river.

Priority areas for reducing bank erosion include areas where bank poaching by livestock is actively observed. Disturbed bank faces have been previously noted downstream of Sarrattmill Bridge, Blackwell Farm and downstream of Loudwater. This should be confirmed with a full river walkover (Appendix 1).

Given the evidence for agricultural runoff from certain sub-catchments and the potential links between these sources and water quality, the implementation of interventions that target agricultural runoff are also recommended. These could include:

- Working with land owners to improve agricultural practices e.g. restricting operations at high risk times, better soil management, cover crops and land-use changes, and
- Installation of measures to trap sediment at or close to the source e.g. installation of Sustainable drainage systems (SuDS), sediment traps, ponds, wetland areas, riparian buffers around fields and watercourses and breaking up larger slopes in high risk areas.

Priority areas for reducing agricultural inputs could include Vale Brook, Blackwell Hall and Bell Lane and Cannon Mill Stream.

7.3.2 Improving downstream conveyance of sediment

Whilst reducing fine sediment inputs should reduce any additional sediment being stored in the gravels, it will have little impact on what is already there. To manage the sediment already in the bed, in-channel measures are recommended to improve the downstream conveyance of sediment.

Stream power is considered to have an important control on fine sediment concentrations (Mondon et al., 2024) and there is negative correlation between stream power and fine sediment concentration in rivers (McKenzie et al., 2022; Naden et al., 2016; Sear et al., 2008). Increased flow velocities associated with higher stream powers likely influences sediment storage by improving fine sediment transport, infiltration of fine sediment into the gravel bed and mobilisation of fine sediment out of the bed

(Mondon et al., 2024). Creating areas of higher flow velocities are therefore more likely to create 'cleaner' gravel beds.

Measures to increase stream power and flow velocities within the channel include:

- Channel narrowing,
- Berm creation,
- Flow structures (e.g. deflectors) and creation of scour pools, and
- Weir removal.

As well as increasing the potential for the downstream conveyance of sediment, the above interventions will help create flow diversity within the channel. Local areas of high velocity, flow diversity and scour (e.g. behind flow structures) are created, within which sediment mobilisation is enhanced, keeping the gravels clean and clear of interstitial fine sediment. In other areas (e.g. backwater zones and within deep pools) fine sediment concentrations may increase. Such interventions are likely to create a mosaic of bed types, which benefit a broad range of biota and deliver the most benefits to the river system.

Priority areas for improving the downstream conveyance of sediment include areas where the channel is artificially widened, has a low gradient, or is being affected by significant impoundment of flow. The fine sediment storage analysis revealed particularly high sediment storage at Chesham Moor and and Elms Lake. Further investigation into these areas should be undertaken to determine their suitability for improvements to downstream conveyance.

7.3.3 Improving local sediment storage (or sinks)

The interventions discussed above should help to improve the downstream conveyance of sediment. Once entrained, this sediment should eventually either reach sections of the river which are less susceptible to fine sediment (e.g. clay catchments) or should reach natural sinks within the system. Additional interventions to remove fine sediment from the system could also include creating or enhancing the opportunities for local sinks and storage within the fluvial system. Such interventions could include:

- Opportunities for floodplain storage and floodplain reconnection (e.g. bed raising, embankment removal), and
- Improved opportunities for in channel storage (e.g. berms, pools, backwater areas)

Priority areas for improving local stores of sediment include areas where the channel has been straightened and 'homogenised' and has little flow diversity. Reaches with potential for other storage include those with adjacent land suitable for floodplain reconnection or associated activities like wet woodland creation.

8 Gaps in data and knowledge

In this section, the gaps in our understanding are discussed and additional investigations are recommended to help characterise fine sediment in the River Chess, help determine suitable interventions and help prioritise areas which are likely to have the most significant benefit.

The River Chess is likely undergoing long-term changes in response to the extensive modification that has occurred within the catchment. Direct changes to the river channel probably date back to medieval times with mill creation and damming. Straightening and re-sectioning has also likely occurred, and associated land drainage has probably lowered water levels in the surrounding areas as well as increased the contribution of flows to runoff. Unless the effects of such changes are understood, it is difficult to interpret baseline conditions.

Furthermore, the study has recognised the importance of high flows both in preventing fine sediment accumulation, and helping to clear fine sediment already deposited within the gravels. The erosive power of the river is likely to be dependent on flow and width. It is important to be able to calculate which areas currently show preferential trends towards sediment deposition versus erosion. Prioritisation of specific reaches that will benefit most from improvements to downstream sediment conveyance are not possible until this is undertaken.

Based on this, it is recommended a hydrological and geomorphological baseline study of the River Chess is undertaken. This study should include the following:

- A desk-based investigation of longer-term trends occurring in the river in response to historical modification within the catchment. This should include analysis of historical maps, LiDAR data, borehole data, geological maps and published studies.
- A field-based geomorphological assessment of current patterns of erosion and sedimentation within the river. Given the results of the provenance study, this should have a particular focus on areas which are currently undergoing bank erosion.
- Investigations of downstream variation in gradient and channel width and ultimately the hydrodynamics of the river system. This would include stream power calculations and investigation of how stream power changes downstream. This will enable interventions to be targeted in the low stream power areas to increase flow, whilst bank protection may be recommended in the higher stream power areas to reduce the potential for erosion.

Once this study has determined areas with potential issues with fine sediment, suggested interventions can be developed. Further prioritisation of works at specific reaches cannot be undertaken until the above study is completed.

9 Action plan

An action plan listing the recommended next steps is provided in Appendix 2.

10 Conclusions

This report has critically reviewed the existing studies that have been undertaken on fine sediment pollution in the River Chess. The work has identified further gaps in the understanding of the system and has recommended additional work that should be undertaken to allow the scoping and prioritisation of potential interventions to progress. An action plan has been developed outlining the recommended next steps. The main findings from this study are outlined below:

- Investigation into the fine sediment storage of the River Chess reveals levels similar if not slightly below neighbouring catchments. Determining whether the observed storage is likely to result in negative effects on the river ecology is problematic due to a lack of reference data. However, given the historical modifications which have occurred in the River Chess, it is likely that higher proportions of fine sediment are present than would naturally occur, which is expected to have negative effects on aquatic biota.
- The existing provenance data suggests that channel banks are the predominant source of fine sediment in-channel and that existing pathways for fine sediment from agricultural land are not well developed. However, the Mud Spotter data and the water quality investigations highlight that tributaries do have a role in fine sediment pollution, particularly the Vale Brook tributary. These studies suggest that there is some connectivity with agricultural land which warrants further investigation and potential mitigation.

- Interventions should not only include measures that reduce the contributions of fine sediment to the system, but those that aim to increase bed mobilising flows that can remove the sediment already present on the channel bed. Recommended interventions revolve around: (a) reducing sediment inputs at the source, (b) improving the downstream conveyance of sediment and (c) improving flow diversity and the local storage of sediment.
- Further analysis is recommended prior to the implementation of mitigation which should include investigations into the existing geomorphological and hydrological trends within the river in response to catchment modification, longitudinal stream power calculations to determine variation in bed mobilising flows and a geomorphological walkover survey to identify areas of existing sedimentation and erosion.

References

APEM. 2023. River Chess Fine Sediment Analysis

Aston ER, Mason PJ. 2023. The distributions and variations of Quaternary Thames River Terrace deposits of Greater London. Quarterly Journal of Engineering Geology and Hydrogeology 56 : qjegh2023-016. DOI: 10.1144/qjegh2023-016

Bickerton M, Petts G, Armitage P, Castella E. 1993. Assessing the ecological effects of groundwater abstraction on chalk streams: Three examples from Eastern England. Regulated Rivers: Research & Management 8 : 121–134. DOI: 10.1002/rrr.3450080115

Brown AG, Lespez L, Sear DA, Macaire J-J, Houben P, Klimek K, Brazier RE, Van Oost K, Pears B. 2018. Natural vs anthropogenic streams in Europe: History, ecology and implications for restoration, river-rewilding and riverine ecosystem services. Earth-Science Reviews 180 : 185–205. DOI: 10.1016/j.earscirev.2018.02.001

Castro JM, Thorne CR. 2019. The stream evolution triangle: Integrating geology, hydrology, and biology. River Research and Applications 35 : 315–326. DOI: 10.1002/rra.3421

Cluer B, Thorne C. 2014. A stream evolution model integrating habitat and ecosystem benefits. River Research and Applications 30 : 135–154. DOI: 10.1002/rra.2631

Florsheim JL, Mount JF, Chin A. 2008. Bank Erosion as a Desirable Attribute of Rivers. BioScience 58 : 519–529. DOI: 10.1641/B580608

Gallois RW. 2009. The origin of the clay-with-flints: The missing link. Geoscience in South-West England : Proceedings of the Ussher Society

Grabowski RC, Gurnell AM. 2016. Diagnosing problems of fine sediment delivery and transfer in a lowland catchment. Aquatic Sciences 78 : 95–106. DOI: 10.1007/s00027-015-0426-3

Heppell CM, Wharton G, Cotton JAC, Bass JAB, Roberts SE. 2009. Sediment storage in the shallow hyporheic of lowland vegetated river reaches. Hydrological Processes 23 : 2239–2251. DOI: 10.1002/hyp.7283

Heywood MJT, Walling DE. 2007. The sedimentation of salmonid spawning gravels in the Hampshire Avon catchment, UK: implications for the dissolved oxygen content of intragravel water and embryo survival. Hydrological Processes 21 : 770–788. DOI: 10.1002/hyp.6266

Jacobs. 2023. River Chess Urban Pollution Study (Phase 2): Water Quality and Sediment Sampling Results

Lambert CP, Walling DE. 1988. Measurement of channel storage of suspended sediment in a gravel-bed river. CATENA 15 : 65–80. DOI: 10.1016/0341-8162(88)90017-3

Malmqvist B, Rundle S. 2002. Threats to the running water ecosystems of the world. Environmental Conservation 29 : 134–153. DOI: 10.1017/S0376892902000097

McKenzie M, England J, Foster IDL, Wilkes MA. 2022. Abiotic predictors of fine sediment accumulation in lowland rivers. International Journal of Sediment Research 37 : 128–137. DOI: 10.1016/j.ijsrc.2021.06.003

Mondon B, Sear DA, Collins AL, Shaw PJ, Sykes T. 2021. The scope for a system-based approach to determine fine sediment targets for chalk streams. CATENA 206 : 105541. DOI: 10.1016/j.catena.2021.105541

Mondon B, Sear DA, Collins AL, Shaw PJ, Sykes T. 2024. The sedimentology of gravel beds in groundwater-dominated chalk streams: Implications for sediment modelling and management. River Research and Applications n/a DOI: 10.1002/rra.4250 [online] Available from: https://doi.org/10.1002/rra.4250 (Accessed 23 February 2024)

Naden PS et al. 2016. Understanding the controls on deposited fine sediment in the streams of agricultural catchments. Science of The Total Environment 547 : 366–381. DOI: 10.1016/j.scitotenv.2015.12.079

Owens PN, Blake WH, Gaspar L, Gateuille D, Koiter AJ, Lobb DA, Petticrew EL, Reiffarth DG, Smith HG, Woodward JC. 2016. Fingerprinting and tracing the sources of soils and sediments: Earth and ocean science, geoarchaeological, forensic, and human health applications. Earth-Science Reviews 162 : 1–23. DOI: 10.1016/j.earscirev.2016.08.012

Pulley S, Collins AL. 2021. The potential for colour to provide a robust alternative to high-cost sediment source fingerprinting: Assessment using eight catchments in England. Science of The Total Environment 792 : 148416. DOI: 10.1016/j.scitotenv.2021.148416

Rothamsted Research. 2023. Sources of fine-grained sediment in the River Chess and potential options for mitigation of the sediment problem

Sear D, Newson M, Old J, Hill C. 2005. Geomorphological appraisal of the River Nar Site of Special Scientific Interest. N684

Sear DA, Frostick LB, Rollinson G, Lisle TE. 2008. The significance and mechanics of fine-sediment infiltration and accumulation in gravel spawning beds

Statham PJ, Homoky WB, Parker ER, Klar JK, Silburn B, Poulton SW, Kröger S, Pearce RB, Harris EL. 2019. Extending the applications of sediment profile imaging to geochemical interpretations using colour. Continental Shelf Research 185 : 16–22. DOI: 10.1016/j.csr.2017.12.001

UK Centre for Ecology & Hydrology. 2024. 39088 - Chess at Rickmansworth [online] Available from: https://nrfa.ceh.ac.uk/data/station/info/39088 (Accessed 26 February 2024)

Velickovic B. 2005. Colmation as one of the processes in interaction between the groundwater and surface water. Facta universitatis - series: Architecture and Civil Engineering 3 : 165–172. DOI: 10.2298/FUACE0502165V

Walling DE, Collins AL. 2005. Suspended sediment sources in British rivers. Sediment Budgets 1 (Proceedings of symposium S1 held during the Seventh IAHS Scientific Assembly at Foz do Iguaçu, Brazil, April 2005). 291

Walling DE, Webb B, Shannon J. 2007. Investigations into the use of critical sediment yields for assessing and managing fine sediment inputs into freshwater ecosystems

Wilkes MA et al. 2019. Physical and biological controls on fine sediment transport and storage in rivers. WIREs Water 6 : e1331. DOI: 10.1002/wat2.1331

Wohl E. 2015. Legacy effects on sediments in river corridors. Earth-Science Reviews 147 : 30–53. DOI: 10.1016/j.earscirev.2015.05.001

Wood PJ. 1997. Biological Effects of Fine Sediment in the Lotic Environment. Environmental Management 21 : 203–217. DOI: 10.1007/s002679900019

Zhang Y, Collins AL, Murdoch N, Lee D, Naden PS. 2014. Cross sector contributions to river pollution in England and Wales: Updating waterbody scale information to support policy delivery for the Water Framework Directive. Environmental Science & Policy 42 : 16–32. DOI: 10.1016/j.envsci.2014.04.010

Appendix 1 - Review methodology

Name of study	River Chess Fine Sediment Analysis	Sources of fine-grained sediment in the River Chess and potential options for mitigation of the sediment problem	Mud Spotter	River Chess Urban Pollution Study (Phase 2)	SCIMAP
Type of study	Sediment characteristics and bed storage	Sediment apportionment	Citizen science surveys	Sediment and water quality	Erosion risk maps
Authors and date	APEM, October 2023	Rothamsted Research, October 2023	Citizen scientists, ongoing	Jacobs (February 2023)	Catchment partnership, ongoing
Additional actions as part of review process	Replotting and sense checking data against recent freeze cores	Replotting data and map visualisation, literature review on technique methodology	Analysis of existing data in context of other studies	Sense checking and reinterpretation in the context of other studies.	Analysis of SCIMAP outputs in context of other studies
What is the study trying to determine?	The fine sediment storage within the bed of the River Chess. The aims were also to understand the potential impact of the composition of the bed material on target plant, fish and invertebrate species.	The sources of fine-grained sediment in the river.	Sources and pathways of mud being transported into rivers during or shortly after rainfall.	Whether sewer misconnections could be affecting water quality, investigate differences between high and low flow conditions, and investigate any longitudinal variation in the data upstream and downstream.	Where the highest risk of sediment erosion occurs within the catchment.
What was the approach?	Stilling method for sample collection. Particle size distributions and sediment storage calculations.	Sediment colour analysis of both potential source areas, bed samples and water samples. Suspended sediment load measurements.	Recording of water and mud inputs from individual mud sources such as culverts, pipes, ditches, overland flow pathways and eroding river banks by citizen scientists via the Mud Spotter App.	Sediment and water samples along Vale Brook, and upstream and downstream of the confluence on the River Chess. Multi proxy laboratory analysis of various parameters relating to water and sediment quality.	Automatic GIS-based classification based on digital elevation models, land use data, and rainfall data.
Are there any limitations in the methodology chosen which affect interpretation of the results in relation to sediment?	Fine sediment storage likely to be highly dependent on sample location (e.g. position in relation to berms, structures, pools and riffles). Sample locations are not well defined, preventing reliable replication of results. Number of study sites following methodology is limited. There is currently a limited dataset to which to compare results to which makes it difficult to assess the condition of the	Sediment colour is a relatively new technique to look at provenance and could be considered less robust than the more traditional, albeit more, expensive fine sediment tracing techniques. There are known issues with organic matter (resolved by treatment with acid during processing) and potential issues around chemical alterations and colour changes during transportation and burial.	Data is largely qualitative and possibly subjective to the person doing the survey.	The study only looked at one tributary of the River Chess (Vale Brook), so perhaps difficult to draw conclusions about the rest of the catchment. Sources of water quality pollution don't necessarily correlate with sediment due to potentially different transport pathways.	SCIMAP does not take into account catchment geology, and the impact of infiltration on hydrological connectivity.

Name of study	River Chess Fine Sediment Analysis	Sources of fine-grained sediment in the River Chess and potential options for mitigation of the sediment problem	Mud Spotter	River Chess Urban Pollution Study (Phase 2)	SCIMAP
	River Chess in comparison to other chalk streams.	Ideally the bed storage samples would have been utilised for analysis and this could have provided more of a direct indication of where the fine sediment that is stored within the gravel bed has come from.			
What are the conclusions in relation to sediment?	The sediment storage within the gravels is about the same or slightly lower than neighbouring chalk streams	Most of the fine sediment both found within the water and on the channel bed is sourced from bank erosion.	*Data not previously interpreted*	There are high amounts of organic pollution within the water samples, which cannot be attributed to sewer misconnections and are most likely to be sourced from agricultural land.	*Data not previously interpreted*
Following review, what are the implications for the River Chess?	Whilst the fine sediment storage appears comparable or lower than other chalk streams, there is sufficient evidence to show that the vast majority of chalk streams are affected by high sediment saturation. Further work is needed to determine longer term trends but given the extensive catchment modification, it is highly likely the River Chess is being negatively affected by elevated fine sediment.	Reducing bank erosion and encouraging the downstream conveyance of sediment are likely to have the biggest impacts on fine sediment reduction. However, based on the limitations of this technique, other sources should not be discounted.	Some of the tributaries, particularly Vale Brook appear to have elevated levels of fine sediment, the colour of which suggests agricultural sources.	Water quality within the Vale Brook sub-catchment is shown to be affected by agricultural runoff. Whilst sediment is likely to have different pathways to water, the study suggests methods to reduce agricultural runoff should not necessarily be discounted.	Many of the arable fields surrounding the River Chess are potentially at high risk of erosion and could deliver fine sediment to the river if there are active surface water pathways that connect this sediment to the main river.

Appendix 2 – Action plan

Action number	Topic	Action	Methods	Justification	Action owner	Outcomes	Timeframe
1	Developing the baseline	Undertake a geomorphological baseline study of the River Chess	Desk-based and GIS analysis of LiDAR,	An understanding of the current trends within the river in response to historical modification is critical to the implementation of effective mitigation for sediment management	tbc	A geomorphological and hydrological baseline report	0-12 months
2	Developing the baseline	Undertake a walkover of the River Chess to collect field data on the geomorphological processes with particular focus on the state of banks within the catchment	Walkover survey(s)	Following the findings of the sediment studies, bank erosion is considered to be an important source of fine sediment. The location of existing areas of bank erosion needs to be identified.	tbc	Data to feed into AP 5,6,7 and 8 - Catchment prioritisation and scoping exercise	0-12 months
3	Developing the baseline	Undertake longitudinal stream power calculations	Channel dimensions taken from LiDAR or MoRPh surveys where available	There is good corelation between stream power and bed mobilisation flows. An understanding of stream power variation will enable reaches to be targeted where stream power is low.	tbc	Data to feed into AP 6,7 and 8 - Catchment prioritisation and scoping exercise	0-12 months
4	Catchment prioritisation and scoping exercise	Prioritisation of areas to decrease source inputs from agricultural runoff	Using land-use data, Mud Spotter, SCIMAP and potentially a Farm Scoper exercise.	In order to prioritise areas for reducing agricultural runoff, we need to know which areas are currently inputting sediment. We can then focus our interventions at areas most likely to make a difference.	tbc	Shortlisted options for mitigation to decrease source inputs	12-18 months
5	Catchment prioritisation and scoping exercise	Prioritisation of areas to decrease source inputs from bank erosion – poaching by livestock	Aerial photos, land-use data and site walkover data, Mud Spotter.	In order to prioritise areas for bank poaching, we need to identify areas where it is actively occurring or is at risk of occurring in the future. To do this, land use information is important as it will allow us to identify which fields have livestock.	tbc	Shortlisted options for mitigation to decrease source inputs	12-18 months
6	Catchment prioritisation and scoping exercise	Prioritisation of areas to decrease source inputs from bank erosion – fluvial and geotechnical bank erosion	Stream power calculations, historic maps, aerial photos, LiDAR data analysis, site walkover and local knowledge, Mud Spotter	In order to prioritise areas for fluvial/geotechnical bank erosion, we need local site information about where banks are currently failing which we can get from AP2. We can use stream power calculations (AP3) to help us with this as it shows which areas of the river have enough energy to be actively eroding the channel.	tbc	Shortlisted options for mitigation to decrease source inputs	12-18 months
7	Catchment prioritisation and scoping exercise	Prioritisation of areas to improve downstream conveyance	Using site walkover data, MoRPh surveys and stream power calculations	Stream Power calculations (AP3) will allow us to determine areas where deposition is likely to be occurring. We can then focus interventions in these areas to improve the downstream conveyance of sediment (e.g. channel narrowing, berm creation and flow deflectors). We can then focus our interventions at areas most likely to make a difference.	tbc	Shortlisted options for mitigation to decrease source inputs	12-18 months

Action number	Topic	Action	Methods	Justification	Action owner	Outcomes	Timeframe
8	Catchment prioritisation and scoping exercise	Prioritisation of areas to improve storage	Using site walkover data, land-use data, LiDAR, MoRPh surveys and stream power calculations	We can use site data (e.g. bank height, land-use, floodplain characteristics) to determine which areas might be most suitable for floodplain reconnection. We can also use the channel characteristics to determine areas where in-channel storage could be implemented (e.g. berms and backwater areas).	tbc	Shortlisted options for mitigation to decrease source inputs	12-18 months
9	Stakeholder engagement	Involve potential stakeholders as early in the process as possible	Stakeholder meetings.	Land ownership is often one of the biggest barriers to the delivery of schemes. Having early stakeholder engagement ensures landowners that are amenable to the schemes can be identified.	tbc	Agreement with landowners on mitigation options	Ongoing
10	Interventions	Design and installation of measures to reduce source Inputs	Potential delivery by a combination of volunteers and contractors	Interventions should be appropriately designed and installed to make sure they are effective	tbc	Installation of options to decrease source inputs	18-36 months
11	Interventions	Design and installation of measures to increase downstream conveyance	Potential delivery by a combination of volunteers and contractors	Interventions should be appropriately designed and installed to make sure they are effective	tbc	Installation of options to increase downstream conveyance	18-36 months
12	Interventions	Design and installation of measures to increase local storage	Potential delivery by a combination of volunteers and contractors	Interventions should be appropriately designed and installed to make sure they are effective	tbc	Installation of options to increase local storage	18-36 months
13	Monitoring	Continued water and sediment quality analysis	Various	Allow the baseline characteristics to be understood and allow the impact of any mitigation efforts to be assessed	tbc	Data for subsequent analysis	Ongoing
14	Monitoring	MoRPh surveys of selective reaches to monitor the effects of interventions	Citizen Science surveys	Allow the baseline characteristics to be understood and allow the impact of any mitigation efforts to be assessed	tbc	Data for subsequent analysis	Ongoing
15	Monitoring	Continue Mud Spotter analysis	Mud Spotter Citizen Science surveys	Mud spotter data provides useful information of the locations and characteristics of fine sediment inputs and should be continued. This helps with scoping of potential areas for intervention.	tbc	Data for subsequent analysis	Ongoing
16	Monitoring	Repeated bed storage measurements post-implementation	Bed sample PSD and fine sediment storage measurements	Allow the baseline characteristics to be understood and allow the impact of any mitigation efforts to be assessed	tbc	Data for subsequent analysis	36 months +

River Chess
Smarter Water
Catchment