Opportunities for further dredging in Somerset

Part 1 - River Brue and tidal sections of the Rivers Parrett and Tone

MCR5576-RT001-R03-00

October 2016

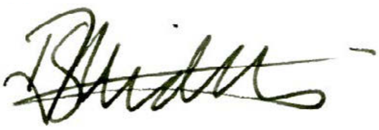
Document information

Document permissions	Confidential - client
Project number	MCR5576
Project name	Opportunities for further dredging in Somerset
Report title	Part 1 - River Brue and tidal sections of the Rivers Parrett and Tone
Report number	RT001
Release number	R03-00
Report date	October 2016
Client	Somerset Rivers Authority (SRA)
Client representative	Iain Sturdy and Nick Stevens
Project manager	David Ramsbottom
Project director	Mark Lee

Document history

Date	Release	Prepared	Approved	Authorised	Notes
27 Oct 2016	03-00	DMR	DSM	DMR	Addition of changes requested by the SRA
07 Jul 2016	02-00	DMR	MWL	DMR	Final version taking account of comments from the SRA
06 May 2016	01-00	DSM	DMR	DMR	

Document authorisation

Prepared	Approved	Authorised
		

Foreword

Dredging was included as part of a series of measures in the Somerset 20 year Flood Action Plan to help meet the challenges of repeated severe flooding, increased rainfall and run off as well as a public demand for better standards of flood protection. This report forms the first significant part of an investigation to produce a Dredging Strategy for the Somerset Rivers Authority (SRA) that was initiated by the SRA Board at their meeting in October 2015. At this meeting the Board requested that more cost-effective dredging techniques and sites were investigated before further dredging work was commissioned. This report, therefore, looks at locations and techniques for undertaking dredging activities. However it does not attempt to either identify or resolve any associated environmental impacts or draw conclusions about benefits versus costs (including long term costs). These aspects will be addressed in further work.

Due to constraints of time and priority the initial focus is on the intertidal and lower reaches of the Rivers Parrett and Tone as well as the downstream reach of the River Brue. A wider consideration of fluvial and main drain dredging may follow on.

We know from modelling and river monitoring undertaken by the EA that dredging of certain watercourses can make a significant difference. In places such as Northmoor, the dredging which has now been carried out on the Parrett and Tone would have been able to reduce the 2013/14 flood levels significantly reducing flooding to the A361, many properties and large areas of land. As a result of this investment, the SRA is minded to fund further dredging works on the tidal Parrett and Tone to secure this greater conveyance capacity by its continued maintenance as well as looking to see if there are further lengths of the tidal channel that could benefit from similar pioneer and maintenance works without increasing the flood risk elsewhere.

This report identifies locations for pioneer dredging which are most likely to reduce flooding and recommends further detailed modelling to more accurately quantify all the hydraulic outcomes. The report also recommends dredging methods that would reduce the costs and concurs with the need to undertake trials to establish the best methods.

The report also examines sediment movement trends, physical processes, and channel shape and form with the intention of identifying dredging techniques which will manage these aspects as sustainably as possible.

Whilst the initial focus of this work has been to identify whether there are further reaches of the tidal Parrett and Tone where dredging will reduce flooding, it is clear that if it is shown to be possible, further work will be necessary to assess the long term cost effectiveness, benefits, and environmental effects as well as any mitigation that may be necessary. The report makes reference to the environmental legislation that will have a bearing on planning, assessment and constraints that will have an impact on the timing and locations where dredging will be possible. However the presence of the internationally designated environmental sites and water bodies in the study area underlines the significant challenge involved in obtaining the necessary consents and permits to progress a programme of works.

We already know that these reaches of the Parrett and Tone adjust in shape and size rapidly in response to complex physical interdependencies. Monitoring of fixed location cross sections associated with the recent programme of works is already underway. This report examines whether a more comprehensive programme of monitoring should be considered and whether the use of contemporary survey technology would improve the data gathered and our overall understanding of these matters.

The report contains only limited reference to the possibility of dredging on the River Brue due to the lack of information on the hydraulic benefits resulting from the very limited amount of modelling that has been undertaken. This shortfall will be addressed in the additional modelling that has been commissioned.

Whilst the aim of this work is as discussed above, it does not seek to form the business case for dredging or conclude the environmental aspects, all of which will need to be developed with information contained in this report and the additional information that is being made available from the further modelling that is being undertaken.

This report is provided for the SRA Board who represent the full range of residents and businesses in Somerset and who will take into account a broad range of costs and benefits in making their decision to invest. The SRA's investment criteria are determined locally, and are therefore different from that of the Treasury and the Environment Agency.

Note:

The SRA Dredging Strategy Board are a group of officers and members who have been brought together to steer the work of the Internal Drainage Board (IDB) who are leading the work to develop a Dredging Strategy. Members comprise the Chairman and Vice Chairman of the SRA Board and officers from the SRA, Environment Agency, Somerset County Council, Natural England and the IDB.

Summary

The Somerset Levels and Moors Flood Action Plan includes a programme of dredging to reduce flood risk. Major dredging activities have been carried out on the River Parrett and the River Tone. This report describes opportunities for future dredging on the tidal River Parrett, the tidal River Tone and the River Brue from Glastonbury to Highbridge.

The purpose of the report is to identify opportunities for dredging for flood risk reduction with the intention of considering detailed requirements such as licensing and environmental assessment proportionately if the possibility of further worthwhile dredging is identified.

Hydraulic objectives are used to provide a rationale for deciding whether dredging would be worthwhile. These consist of flood levels on the moors for the Parrett and the Tone, and maintaining the channel capacity for flood flows on the River Brue. A benefits assessment has not been carried out.

The report has identified the following dredging activities to reduce flood risk :

- A programme of monitoring of the river channel bathymetry in order to assess the rates of accretion in the channels and the effectiveness of the dredging;
- Two sections of 'pioneer' (or new) dredging, on the Parrett downriver of the current dredging and on the Parrett upriver of the Tone confluence;
- Four areas of maintenance dredging on the Parrett and Tone, for the current and completed dredging on the Parrett, for the completed dredging on the Tone and for the two areas of pioneer dredging;
- One area of maintenance dredging on the Brue.

It is proposed that cross-section shapes for the new dredging are designed in such a way so that the amount of sedimentation that occurs after dredging is minimised as far as possible. This is intended to optimise the hydraulic benefit that can be achieved per unit volume of dredged material, and minimise the amount of future maintenance dredging that will be needed.

The proposed method of maintenance dredging is either by water injection or agitation, where the sediment is mobilised and dispersed downriver by the current. This avoids the need for disposal of the sediment by other means, but will require trials to identify the best method. Both methods will be included in the trials, and tenderers will be given the opportunity to propose other innovative techniques.

Trials are proposed at two locations: one in the dredged section of the Parrett downriver of the Tone confluence and the other in the dredged section of the Tone. This is because the sedimentation regime is different at the two locations, with more sediment movement at the downriver location. In addition, some interim maintenance dredging is suggested after the trials are completed if the river channel monitoring indicates that this is necessary and if the trials identify a satisfactory method for maintenance dredging.

The pioneer dredges on the Parrett downriver of the current dredging and upriver of the Tone confluence would be carried out using conventional methods similar to those already adopted, but the tender documents will include an option for tenderers to offer an alternative method based on different technologies. The dredging on the River Brue would also be carried out using excavators, either from the bank or from floating plant depending on where the dredging is to be carried out.

A provisional programme for a 10-year dredging programme has been prepared. The programme is intended to provide a reasonably even distribution of annual costs for the first three years, after which the activities will consist of regular monitoring and maintenance. However the actual dates of dredging at each location will be decided by the Somerset Rivers Authority based on their current programme, available budgets, the time needed for pre-dredge activities including environmental surveys, and the results of monitoring of the bathymetry of the river channels.

This programme assumes the following provisional frequencies of maintenance dredging, although this is likely to change as the results of the monitoring surveys of the rivers are reviewed:

- River Parrett downriver of the Tone confluence: annual maintenance of both the already completed and new dredging;
- River Parrett upriver of the Tone confluence and the dredged section of the Tone: maintenance every two years;
- River Brue between Glastonbury and Highbridge: maintenance every five years.

Environmental constraints have been taken into account and the dredging activities are planned for the autumn and early winter (September to December) as this is the period when adverse environmental impacts are minimised. There will however still be a need for environmental monitoring and mitigation measures as part of the dredging programme.

The proposed dredging programme is presented in Section 9, including the areas to be dredged, the methods of dredging, the timing and estimated costs.

Importance of monitoring

The monitoring is a vital component of the dredging programme. The results will be used to decide the timing, locations and amounts of future dredging in order to optimise the dredging programme and minimise the risk of unnecessary or not very effective dredging activities. This should help to maximise the cost effectiveness of dredging.

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1. Introduction

1.1. Context

During the winter of 2013/14 the Somerset Moors and Levels experienced a severe and prolonged flood. There have also been recent floods in summer 2012 and winter 2012/13. As part of the response to these floods the Somerset Rivers Authority (SRA) was formed. The SRA's purpose is to deliver higher standards of flood protection than would be funded nationally, and to create better flood protection and resilience against further flooding by joint planning and delivery (where possible).

The SRA has produced a Flood Action Plan which covers the next 20 years. One of the measures in the Plan to reduce flood risk is dredging of river channels. This report has been commissioned by the SRA and covers opportunities for future dredging on the tidal sections of the River Tone and River Parrett together with the non-tidal River Brue from Glastonbury to Highbridge. The report was prepared by HR Wallingford on behalf of the SRA.

The purpose of the report is to identify the possibilities of dredging for flood risk reduction with the intention of considering detailed requirements such as licensing and environmental assessment proportionately if the possibility of further worthwhile dredging is identified.

Hydraulic objectives are used to provide a rationale for deciding whether dredging would be worthwhile. These consist of flood levels on the moors for the Parrett and the Tone, and maintaining the channel capacity for flood flows on the River Brue. A benefits assessment has not been carried out.

1.2. Background

1.2.1. The River Parrett and River Tone: tidal sections

The River Parrett and the River Tone convey water through part of the Somerset levels to the Severn estuary. The floodplains (referred to as 'moors') are low-lying and river levels can exceed ground levels during high tides and high fluvial flows, and combinations of the two. The rivers have flood banks, which protect the land from being flooded by the high water levels in the river channels. The rivers are tidal from the estuary to the tidal limits at Oath on the River Parrett and Newbridge on the River Tone.

Both rivers have overflows (referred to as spillways) that remove water from the river channels during periods of high river flows. This prevents flooding further downriver, but water that leaves the rivers via the spillways can cause flooding during large flood events.

Allermoor spillway on the River Parrett is upriver of the tidal limit. It conveys water into the Sowy River, which flows into the Kings Sedgemoor Drain. The latter discharges back into the Parrett at Dunball, thus providing a flood relief route for the River Parrett. There is a second spillway on the River Parrett downriver of the tidal limit, Beazleys spillway. It is understood that this is intended to control water levels during high tide periods in order to limit river levels as a result of tide locking.

Hook Bridge spillway on the River Tone is downriver of the tidal limit. It conveys water from the River Tone into Curry Moor. When a threshold water level is reached in Curry Moor, surplus water overflows two spillways and then passes into North Moor. Water from Curry Moor and North Moor is pumped back into the River Parrett further downriver.

Figure 1.1 shows the main features of the system.

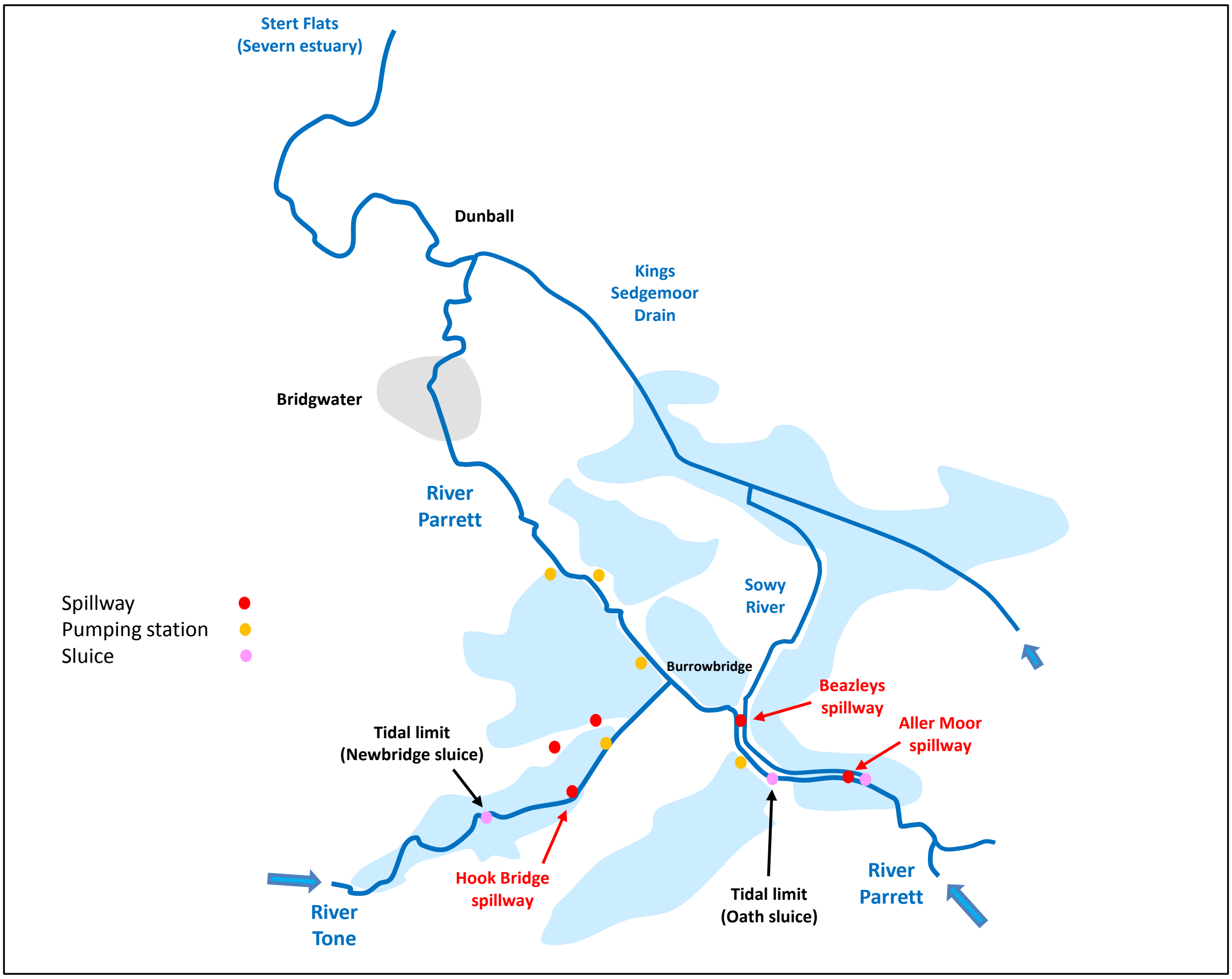

Figure 1.1: Main features of the Parrett and Tone river system

The rivers are subject to sedimentation, which reduces their effectiveness as flood channels. Marine sediment enters the river system from the estuary during incoming tides. The flood tide is much shorter than the ebb tide in duration and has much higher velocities. It carries more sediment than the ebb tide under some conditions, and sediment that settles in the river channels as the tide turns causes a net accumulation of sediment.

Fluvial flows reduce the effect of the tide and also can reduce the amount of sedimentation during high flow periods by eroding sediment and carrying it downriver. Thus during high flow periods, net erosion can takes place. However the duration of high fluvial flows is relatively short and there is an overall increase in sedimentation until an equilibrium condition is reached, particularly during the summer months. The sediment consolidates to form a bank of material that has an increased resistance to erosion.

The impact of marine sedimentation is to reduce the cross-sectional area of the river channels and therefore reduce their flow capacity. As a result, more water passes over the spillways leading to an increase in flooding. Vegetation growth causes the sediment to further consolidate and also traps more sediment. As a result the sediment becomes less erodible and more difficult to remove.

Fluvial sediments enter the tidal system at the tidal limits on the Parrett and the Tone. Most of the sediment arrives during high fluvial flows. However sedimentation in the tidal reaches is dominated by marine sediments. The amount of sediment movement increases towards the estuary as tidal activity increases.

An important feature of the river system is the confluence between the Parrett and the Tone. The river system is very flat, and high water levels in the Parrett cause water levels to back up in the Tone, reducing the flow and increasing the probability of water overtopping the Hook Bridge spillway.

The system is sensitive to changes in water levels, and therefore the amount of dredging that is carried out. Following the major floods of 2013/14, the River Tone and the River Parrett were dredged in 2014 from Hook Bridge spillway on the Tone to Northmoor pumping station on the Parrett, a distance of about 8 km. This work increased flood conveyance in the Parrett and Tone, which lowered water levels at Hook Bridge spillway and therefore flooding on Curry Moor and North Moor during periods of high river flow.

Maintenance dredging of the lower 2.2 km of this section took place in 2016, and a further length of dredging was undertaken downriver of Northmoor pumping station in 2016.

1.2.2. River Brue

The River Brue between Glastonbury and Highbridge is a flat river that that passes through the moors. Drainage systems discharge into the Brue, either by gravity or by pumping (North Drain). There are mitre gates at Highbridge Clyse that close during high tide periods and prevent tidal inflow. At high tide the river backs up when the gates close but at low tide the gates opens and the river discharges freely. Hackness sluice is used to maintain summer water levels further upstream.

Maximum flows in the river are limited by overflow into the moors during flood events. The River Brue modelling report shows constant river flows at Westhay of about 30 m^3/s for a range of flood return periods from 20% (1 in 5-year) to 0.1% (1 in 1000-year), indicating that excess water is discharged further upstream (Jacobs 2010).

Siltation has occurred in the river channel and a location has been identified where dredging may be required, as indicated on Figure 1.2. Detailed surveys of this reach have been carried out and a dredging method statement has been prepared. The findings of this study have however shown that this may not be the best place to dredge.

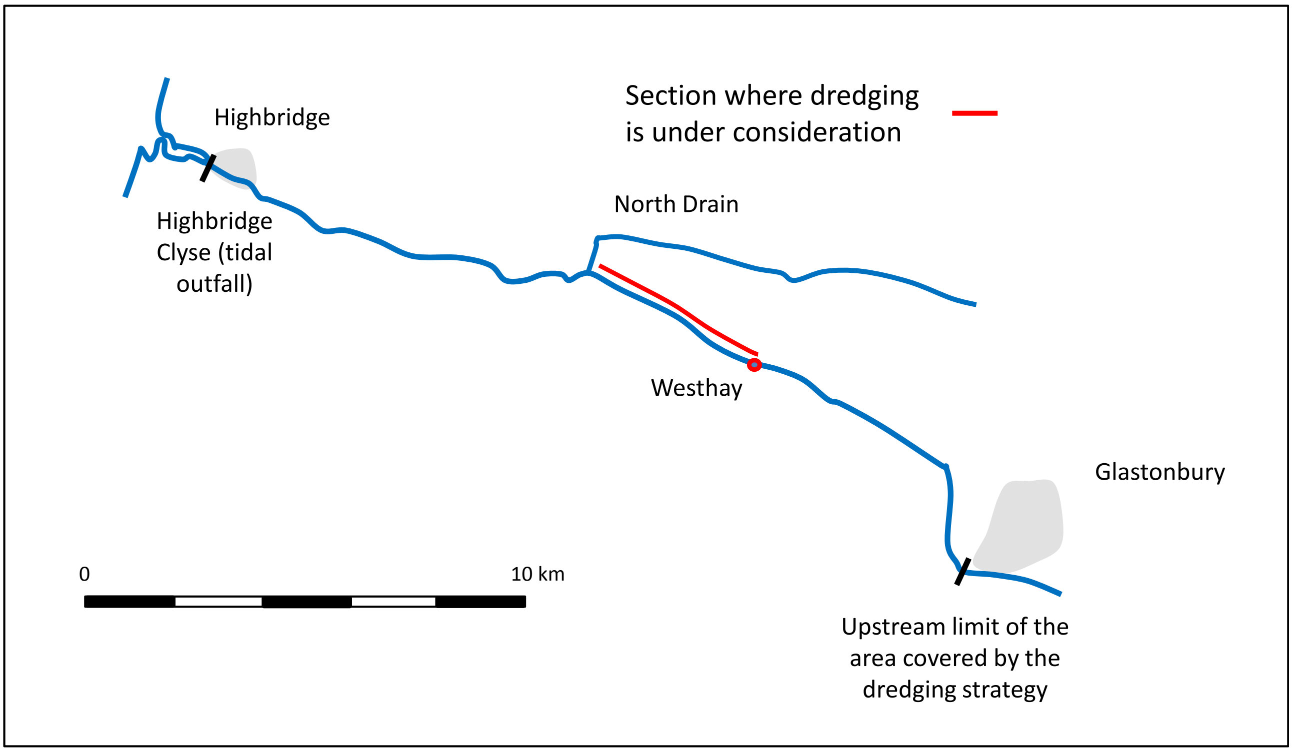

Figure 1.2: Section of the River Brue covered by the report

1.3. Development of the report

The objective of this document is to identify long term opportunities for the management of silt and vegetation within the tidal River Parrett and River Tone, and the River Brue from Glastonbury to Highbridge. The intention is to allow the SRA to work out what dredging needs to be done and how to deliver it sustainably whilst providing value for money.

In order to achieve the objective, it was necessary to find out what dredging has been carried out in the past including the methods used and the effectiveness. It was also necessary to investigate available dredging methods including those that have not been used before on the Somerset Levels.

Opportunities for dredging have been developed by reviewing previous work including reports and data, and by interviewing key stakeholders and other consultees. These included the SRA, the Environment Agency and Dredging Contractors.

The documents and data that have been reviewed are listed in **Appendix D**, including a brief summary of the contents. The consultees that have been interviewed are listed in **Appendix E**, including a brief summary of the consultation meetings. Section 2 discusses the key issues that have arisen concerning dredging, particularly on the River Parrett and the River Tone where the greatest problems exist.

Before preparing the report, it was necessary to understand the flood risk issues and the sediment regime in the river systems, particularly the Parrett and Tone which form part of a complex drainage system. An assessment of the hydraulics of the system was therefore carried out, which is summarised in **Appendix A**.

A conceptual model of the sediment regime was also developed in order to describe sediment deposition and erosion, as this affects the amount of dredging that will be needed in the future. The conceptual model is described in **Appendix B** and information on the sediment is provided in **Appendix C**.

The hydraulic analysis was used to develop the objectives of dredging (Section 3) and identify the locations of dredging (Section 4). The conceptual model was used to select dredging methods (Section 5). The timing of dredging and environmental mitigation is described in Section 6 and the proposed procurement approach in Section 7.

An approach to assessing the benefits of dredging is discussed in Section 8 and the overall opportunities for dredging are summarised in Section 9 including proposed activities, timing and costs. Thus the structure of the report is as follows:

Section 2: Background information on dredging

Section 3: Objectives of dredging

Section 4: Locations of dredging

Section 5: Selection of dredging methods

Section 6: Timing of dredging and mitigation measures

Section 7: Procurement approach

Section 8: Benefits of dredging

Section 9: Long term opportunities for dredging

The approach to dredging that has been developed includes:

- Monitoring of the river channel bathymetry;
- Trials for selected methods of maintenance dredging;
- Pioneer (new) dredging;
- Maintenance dredging.

2. Background to dredging and key issues

2.1. Sediment transport

2.1.1. The Parrett System

A review of the mechanisms delivering sediment in to Parrett System is provided in **Appendix B.** The key sediment transport processes are:

- The dominant source of sediment delivered to the tidal system is marine.
- Under lower freshwater flow conditions there is a net accumulation of material within the channel.
- Under higher freshwater flow conditions there is a net erosion of material from the channel.
- The specific condition, both spatially and temporally is dependent upon the balance of the freshwater and marine flows.

2.1.2. The River Brue

Sediment transport on the Brue System is dominated by fluvial flow. Peak sediment transport will occur during times of peak flow, with scouring of the river channel occurring during rising water levels and flow speeds and sedimentation occurring during falling water levels and flow speeds. Data provided by the SRA confirms that sedimentation has occurred downstream Westhay on the Brue for approximately 4km towards the confluence with North Drain near Burtle. The SRA have directed HR Wallingford to focus upon this section of the river in the study.

The presence of a tidal outfall at Highbridge will affect the local sediment transport regime such that, during the time when the outward facing mitre doors are closed, there will be a backwater effect that will reduce flow speeds and enhance deposition. When the tide flap is opened the flow will accelerate and relatively high flow speeds (estimated at around 1m/s) occur and re-erode the sediments that were temporarily deposited during the period the tide flap was shut.

2.2. Dredge material

The future material to be dredged on the River Parrett and the River Tone can be distinguished as pioneer and maintenance dredge material. The key differences between pioneer and maintenance dredge material are:

- Pioneer dredge material is more consolidated (stronger) than maintenance dredge material (owing to the relative age of the sedimentation).
- Pioneer dredging could involve the removal of a greater volume of material per metre length of river channel than maintenance dredging (owing to the duration of build-up).
- Different dredge methods could be appropriate to the two types of material based on their characteristics and disposal options.

For the River Brue, the material to be dredged is fluvial sediment that has accumulated in the bed of the channel.

2.2.1. Future dredge volumes

This section describes the methods used to estimate dredging volumes. The calculated volumes are included in the summary of dredging requirements (Table 4.2).

The potential pioneer dredging volumes have been estimated from a comparison of existing river cross-section information, and indicative design cross-sections.

The potential maintenance dredging volumes have been calculated from the available bathymetry data (in analysable form) for the stretch along the River Parrett covering the recent 2.2km maintenance dredge, and information on the flux of sediment, as derived by Partrac (2009).

Survey data for the April 2015, November 2015 and March 2016 surveys were analysed. The results of this analysis suggest that:

1. Sedimentation of around 1,700m^3/month occurred for the winter period 2014/15 (October 2014 to April 2015).
2. Sedimentation of around 1,900m^3/month occurred for the summer period 2015 (April 2015 to November 2015).

3. Sedimentation of around 900m^3/month occurred for the winter period 2015/16 (November to March 2016).

The variations in siltation rates along this reach are to be expected. Immediately following dredging the cross-section is enlarged leading to enhanced deposition. During the summer period the tidal flows (with high suspended sediment concentrations) will dominate – demonstrated by the highest sedimentation rates in this reach. The reduced sedimentation rates during the 2015/16 winter period are consistent with a reduced tidal influence due to the relatively reduced channel cross-section compared to winter 2014/15.

Sediment flux is the amount of sediment that moves through a river cross-section in a set period of time. The Partrac (2009) studies include estimates of sediment flux at different river sections. The estimates for summer conditions (i.e. no freshwater input) suggest the following:

- If the sediment flux value is defined as one unit in the Parrett and Tone Rivers, upstream of the confluence then:
  - In the upper reaches of the lower Parrett, near to the confluence with the Tone, the relative sediment flux value is estimated to be 2 units (i.e. twice as much sediment moves over a given time period than further upstream on either the River Tone or Parrett);
  - In the middle reaches of the lower Parrett, near to North Moor, the relative sediment flux value is 7;
  - In the lower reaches of the lower Parrett (M5 crossing) the relative sediment flux value is 35.

In order to provide a rough estimate of sedimentation rates, it could be assumed that the sedimentation rate is proportional to the sediment flux. This assumption has been used to estimate annual maintenance dredging volumes, by scaling measured sedimentation rates at the 2.2km maintenance dredge location. The relative flux value at this location is assumed to be 5, as it is just upstream of North Moor and still some distance from the confluence. Sedimentation values of 2,000m^3/month for summer and 1,000m^3/month per winter have been used. In the lower reaches of the Parrett, where the relative sediment flux is 35. Using this value would generate a large maintenance dredging volume. A lower estimate of the maintenance dredging volume using around half this flux value has been used in the calculations, so that the annual maintenance volume is consistent with the pioneer dredge volume.

These patterns and rates of sedimentation are consistent with the conceptual model of sediment transport discussed in **Appendix B**:

- Highest rates of sedimentation are expected at the downstream end of the Parrett System.
- Highest rates of sedimentation are expected to occur during the summer (lower freshwater) period.

2.2.2. Parrett System - sedimentation in the channel

After reviewing elevation cross-section information and inspecting potential dredge locations during site visits, the following concept is suggested as the mechanism by which material accumulates in the channels.

- Following dredging, sedimentation initially occurs across the full width of the channel, below the mean water level mark as evidenced in Figure 2.1. The specific location where sediment accumulates will be controlled by the local hydrodynamics, such that sediment will tend not to accumulate on the outsides of bends but accumulates on the insides of bends.
- Once the cross-section has been sufficiently reduced by sedimentation, the constriction will locally increase the flow speed and will therefore maintain the channel cross-section such that the absolute channel depth is not reduced significantly from the post-dredge condition.

- Further sedimentation tends to occur higher up the bank profile, creating a ‘terrace’ or ‘berm’ of sedimentation over time. This pattern, which results in a channel that has steeper sides and sediment berms on the flanks is shown in Figure 2.2.
- The precise cause of the pattern of sedimentation is not known, but the following hypothesis is suggested for straight sections of the channel (and can be modified accordingly for channel bends):
  - The dredged cross-section is initially smooth and too large for the mean flow and therefore sedimentation occurs, and is distributed relatively evenly.
  - Lower flow speeds are experienced at the edges of the channel due to the effects of friction. This friction can be enhanced by the presence of vegetation.
  - Lower flow speeds at the edge of the channel also offers a longer period of time for material to settle out of suspension, increasing rates of deposition.
  - As sedimentation occurs, the flow is more focussed in the centre of the channel due to the reduction in cross-sectional area. This in-turn reduces or stops sedimentation in the centre area of the channel.

Figure 2.1 shows cross-section P58 which demonstrates post dredge (pioneer), pre-dredge (maintenance) and post-dredge (maintenance) cross-sections and illustrates the accumulation of sediment across the full channel width (by comparison of the blue line to the green line).

Figure 2.2 shows cross-section P58 demonstrating the pre dredge (Pioneer) cross-section and the accumulation of sedimentation on channel edges creating ‘terraces’ or ‘berms’ of sediment (the red hatched area).

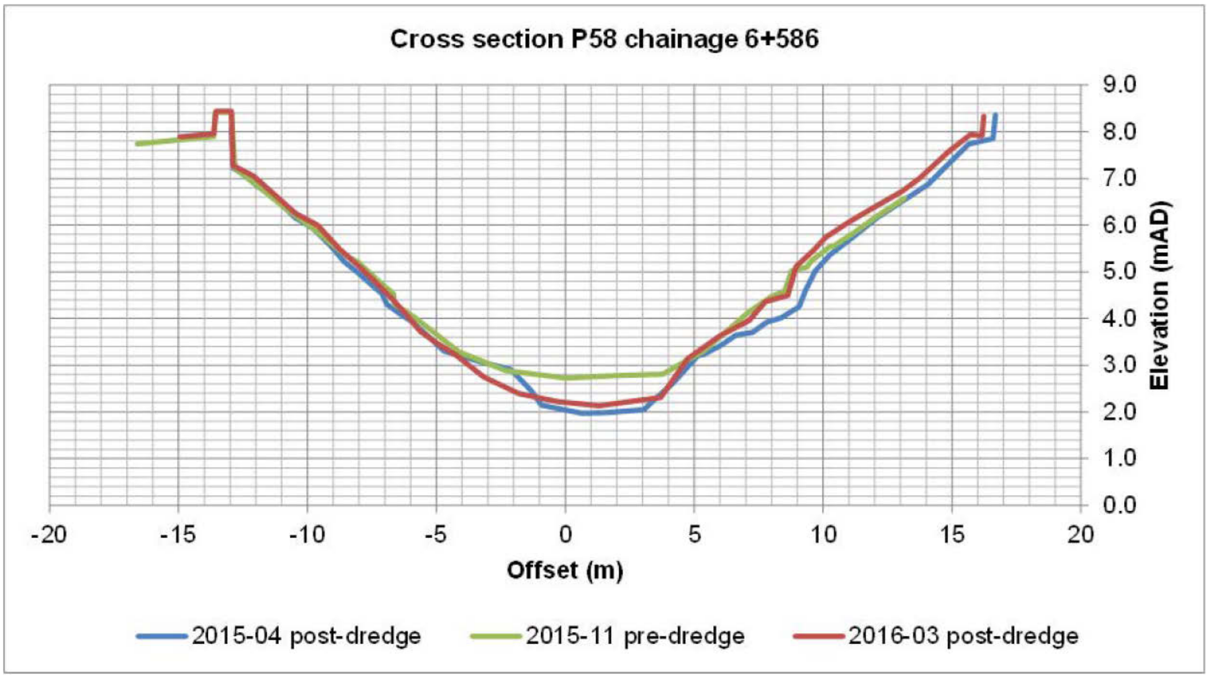

Figure 2.1: Example of channel survey data

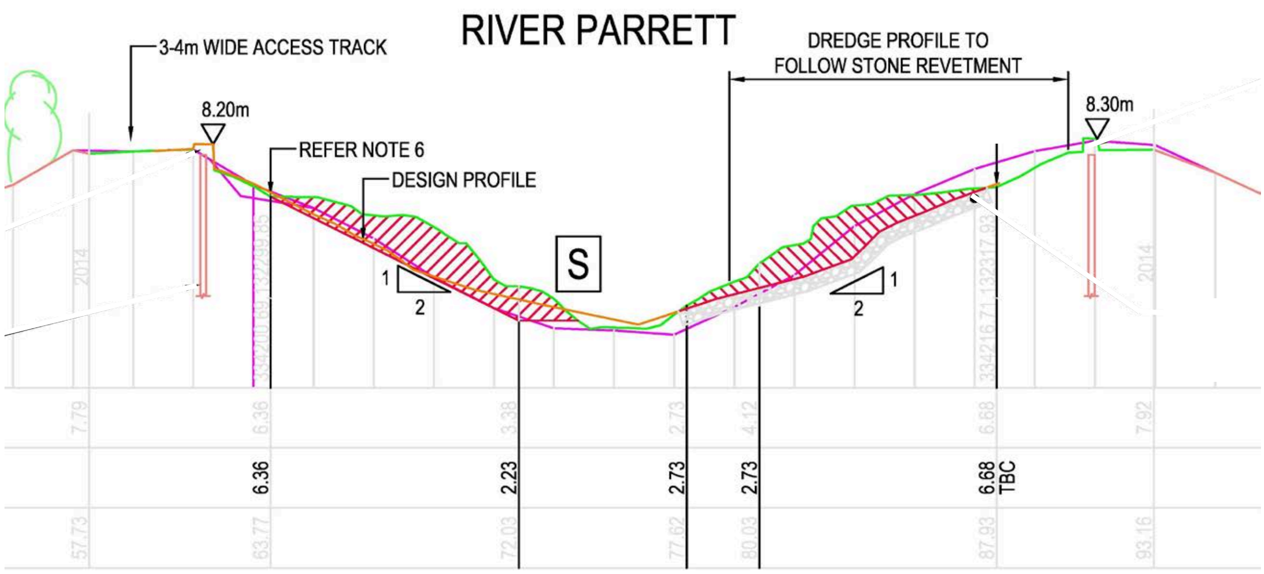

Figure 2.2: Example of the accumulation of sediment in a channel cross-section

2.2.3. Parrett System - Dredge material analysis

The material that required dredging for the 8km pioneer dredge has been investigated (Southern Geotechnical 2014). The material was sampled by means of piston sampler, in-situ shear value and dynamic probe super-heavy (DPSH) tests. Key findings include:

- The material is predominantly described as a ‘light grey’ or ‘light brown sandy clayey SILT’ on both the Rivers Parrett and Tone. Small differences in strength of the material were measured between the River Parrett and River Tone. In some locations ‘made ground’ (such as embankment reinforcements) was encountered during the dredging activity. This is consistent with the heavily modified watercourses.
- On the River Parrett sediment from near surface to 2.0m below ground level (BGL) is characterised as ‘very loose’ (‘N’ values of <5 where N is the number of blows needed in the test to drive a standard rod 100mm). However, some samples show a significant increase in strength immediately below the surface layer, before reducing in strength as distance BGL increases. Generally, from around 2.0mBGL the ‘N’ values increase with depth to an average of around 14 (‘compact’ material) at 4.5mBGL. Shear vane values of between 36kpa (kN/m^2) and 115kpa were recorded for the samples taken on the River Parrett.
- On the River Tone a slightly different profile was measured. The first 1mBGL produced ‘N’ values of around 8-10 on average (‘loose material’). Below this level there was a noticeable reduction in strength (‘N’ value on average <4 indicating ‘very loose’ material), before increasing back to an ‘N’ value of around 6-10 at 4mBGL. Data for the River Tone shows a greater spatial variance in ‘N’ values compared to the Parrett. Shear vane values of between 31kpa and 118kpa were recorded for the samples taken on the River Tone.
- Undrained triaxial compression tests on pioneer material suggested shear stress of order 30-70kpa for the samples taken on the Rivers Parrett and Tone, with a maximum value of 140kpa. This implies medium to high soil strength.
- Analysis of sediment samples collected along the River Tone and Parrett in preparation for the maintenance dredging works indicate that the material type can be classified as ‘non-hazardous’. The contamination levels are considered to be low, and all parameters measured were below the human health risk screening criteria.

Further summary information on the available geotechnical investigation of pioneer dredge material is provided in **Appendix C**.

An assessment of the channel bank material, including sediment grab sampling and a cohesive strength meter (CSM) tests representing autumn/winter and summer conditions was undertaken by Partrac (Partrac 2008 and 2009). Key findings include:

- Median (D50) grain size (summer) for the sampling locations along the River Parrett indicate values in the range of 33 to 46µm, with a general decrease in median grain size with increasing distance upstream. The material is described by Partrac as a ‘very fine sandy very coarse SILT’.
- D50 grain size (winter) for the sampling locations along the River Parrett indicate values in the range of 22 to 34µm, with a general decrease in median grain size with increasing distance upstream. The smallest D50 value (14µm) was recorded at a location above the tidal limit. The material is described by Partrac as a ‘very fine sandy very coarse SILT’.
- The D50 value for the summer sampling for two locations on the River Tone is 33 and 66µm. During the winter these reduced to 19 and 12µm. The material is generally described by Partrac as a ‘very fine sandy very coarse SILT’.

- CSM test results for the winter samples suggest that erosion of the bank material was typically initiated at around 6 to 40kpa.
- CSM test results were used to calculate entrainment thresholds for bank material, based on a flow speed at 1m above the bed (U_{100}). Typical calculated values were in the region of 0.2 to 0.7m/s for both winter and summer surveys. However, some isolated samples demonstrated higher entrainment threshold current speeds (measured at 1m above the bed) of >1m/s.
- Based on this information, the relative erosion potential for sediments decreases with increasing distance upstream on the River Parrett.
- CSM tests performed at different heights on the channel banks indicated increasing strength of the material higher up the bank.

2.2.4. Parrett System - Summary

Overall it is considered that:

- <u>Additional ground investigation work should be undertaken prior to commissioning future dredging work to confirm specific ground conditions at the dredge site.</u> This is particularly relevant in areas where dredging has not been completed before and historical geotechnical information is not available.
- For the purposes of assessing dredging needs and methods for dredging, the following are considered reasonable assumptions from the available information and comparison of similarities in environments.
- Future pioneer dredge material is *likely* to be a 'light grey' or 'light brown sandy clayey SILT':
  - Pioneer dredge material on downstream sections of the River Parrett is likely to be represented by the pioneer dredge material from the previous ground investigation on the River Parrett.
  - Pioneer dredge material on the upstream section of the River Parrett may be similar to the pioneer dredge material from the previous ground investigation on the River Tone because they will both be affected by a similar tidal regime.
- Maintenance dredge material can be represented by the sediment grab sample data collected by Partrac, and is described as 'very fine sandy very coarse SILT':
  - Maintenance dredge material is likely to be represented by the sediment (channel bank) grab sample data collected by Partrac.
- Based on the samples analysed, the pioneer dredge material strengths encountered i.e. with average 'N' values of 4-15, and maximum value of 25 and undrained shear stress values of <150kpa are well within the capabilities of conventional cutter-suction dredger, back-hoe (excavator) dredger or trailer-suction hopper dredger. Typical undrained shear stress limits for back-hoe (excavator) dredger is of order 2.5Mpa.
- 'Very fine sandy very coarse SILT', with shear stress values in the region of 6 to 40kpa have the potential to be mobilised by agitation, jetting or water injection dredging techniques.

2.2.5. River Brue

Exo-environmental (2014) undertook sediment sampling (using a piston sampler) and laboratory analysis for the River Brue. Details of the results of the analysis are presented in that report (including Particle Size Distribution (PSD), pH and density). Two samples were collected between Westhay and Burtle Moor. The sediment is described as a 'sandy clayey SILT'.

No further information on the material to be dredged is available, particularly in relation to the strength of the material, however subject to other controlling factors (such as access and disposal options), it is expected that this material type can be dredged using conventional cutter-suction dredger, back-hoe (excavator) dredger or trailer-suction hopper dredger.

2.3. Effects of vegetation

The occurrence of vegetation within the dredged areas is variable both spatially and temporally. Vegetation coverage increases with height up the channel bank, with areas that are submerged most frequently having none to very little vegetation cover. Vegetation cover is at its natural maximum prior to the winter season die-back (typically October).

The presence of vegetation has several impacts related to sedimentation:

- The vegetation increases local roughness of the channel, this in turn leads to a reduction in local flow velocities and contributes to increased rates of sedimentation.
- The vegetation provides protection to the existing bed surface, reducing the ability of flows to suspend (erode) sediment.
- The root network acts as a fixative, strengthening and consolidating the material further preventing erosion of sediment.
- The magnitude of the effects are likely to be seasonal – affected by seasonal growth and die-back as well as vegetation management activities.

The dredging method chosen can be sensitive to the presence of vegetation (in particular the strength of the material). Mechanical methods are typically insensitive the types of vegetation encountered on the banks of the channels in the Parrett System and River Brue. However, agitation (and hydrodynamic methods) along with hydraulic methods are likely to be sensitive for the following reasons:

- The presence of vegetation can ‘armour’ the channel bed and reduce the effectiveness of hydrodynamic methods;
- The presence of vegetation can cause an obstruction to pumps used in hydraulic dredging – reducing their effectiveness by increasing downtime.

Vegetation is environmentally important and dredging should be undertaken in such a way so that the adverse impacts are minimised. The need for vegetation management as part of dredging on the River Brue and the tidal River Parrett and River Tone is discussed in Section 4.3.

2.4. Historic Dredging

2.4.1. Parrett system

Based on historical and recent dredging on the tidal sections of the Rivers Parrett and Tone, the dredging activity can be defined in two ways:

- Pioneer dredging – this is considered to be dredging of an area / material that has not been dredged for several years, where the deposited material has consolidated and vegetation has become established.
- Maintenance dredging – this is considered to be dredging of an area / material that has been dredged relatively recently (perhaps within the last 2 to 5 years), and the material has not become consolidated and vegetated.

From discussions with stakeholders it became apparent that historically dredging was carried out more frequently than in the more recent past (last 10 years). It is understood that the time-line is a follows:

- First dredger purchased by the Somersetshire Drainage Commissioners around 1881/1882, this was a steam powered grab dredger with a working radius of around 5m and ½ ton lifting capacity. This was known as the 'Priestman Grab'.
- The 'Priestman Grab' appeared to have limited success, and therefore an alternative type of dredger, a 'scourer and weed destroyer' known as the *Pioneer* was used for trials after a competitive bidding process. The dredger used bottom, bow and side mounted jets to erode sediment from the river bed and banks. The original design also incorporated weed-cutting equipment – however, these proved to be a failure and were abandoned. The use of the *Pioneer* appears to have been largely successful, and she provided dredging services for over 20 years, from c1895 to c1917.
- The success of the *Pioneer* influenced the Port and Navigation Committee of the Bridgwater Corporation to try hydraulic erosion for maintenance of the navigable section downstream of the Parrett below Bridgwater, using a vessel called the *Eroder*. The vessel again used jets to dislodge material, both below and above the waterline for transport during the ebb tide.
- During the 1920's the use of plough dredging was trialled (using the *King Alfred*), however, mainly due to the poor performance of the dredging equipment the attempts to 'comb the bottom of the river' did not prove a success. However, 'some promise' was shown when the equipment was working correctly.
- During a similar period, the *St Dunstan* was used to hydraulically erode the river bed and banks using the wash from its propellers. However, due to severe mechanical failures this proved unsuccessful.
- In 1925 an improved Priestman grab was purchased. The machine could work from a pontoon or from the bank and was the only machine at the time to be able to do both and as such was retained for special jobs and seldom used. Eventually the pontoon fell into disrepair and was deliberately sunk.
- From 1932 through to 1952 a similar craft to the *Pioneer* was constructed, called the *Persevere.* It is understood that the Persevere was successful, but from 1939 it became increasingly difficult to find crew and stoppages for repairs became increasingly frequent. Eventually in 1952 her operation ceased and she was sold on.
- As a more economical alternative to the *Persevere*, a hydraulic erosion vessel was constructed from an ex-RAF scow hull, a second-hand Perkins marine engine and ex-NFS 'Godiva' fire pump.
- It is understood from Post WWII to the 1990's Dredging was undertaken using bankside draglines and small tenders with an on-board pump and monitor to direct a water jet.
- In the 2000's, dredging was undertaken by Contractors. Dredging was undertaken less frequently but probably with a larger volume per dredge.
- An agitation dredging trial was carried out in the reach downstream of Northmoor in 2005. Problems encountered included low depths for vessels, cohesive nature of material and low velocities. Increased bank instability was noted as flows were directed around sediment deposited within the channel and towards the banks.
- Significant pioneer dredging was carried out in 2014 (132,000m^3) along 8km of the Parrett and Tone, followed by a maintenance dredge (21,200m^3) along 2.2km of the Parrett in 2015/2016.
- Future planned pioneer work is for 0.75km (13,000m^3) along the Parrett, downstream of the recently completed maintenance dredge.

It is suggested that the reduction in dredging frequency during the late 2000's to early 2010's contributed to a significant build-up of siltation between dredges, necessitating 'pioneer dredging'. Prior to this time it is possible that the relatively continual nature of the dredging activity prevented significant accumulations of sediment negating the need for 'pioneer dredging'. It is therefore considered that prior to this date, the dredging activity was closer to a maintenance dredge activity in nature.

The frequency with which dredging occurs is significant for several reasons:

- Frequent dredging activity prevents accumulation of sediment over extended periods of time. This both reduces the effect on the channel cross-section, but also reduces the time available for the material to consolidate and vegetate.
- If the material is less consolidated and less vegetated it will be easier to remove with an alternative dredging method (e.g. hydrodynamic method).

2.4.2. River Brue

No historical information is available on dredging of the River Brue. However, from consultation with SRA members, it is understood that dredging has previously taken place and the Environment Agency is aware that dredging was carried out in the 1990s with disposal to the 'back of bank'. The wide banks on the Brue near Westhay Bridge indicate that dredging has been carried out with this type of disposal..

2.5. Dredging requirements and constraints

2.5.1. Relevant Legislation and Regulations

Dredging activity on the Parrett System and River Brue should comply with relevant legislation and regulations. These include:

- Water Resources Act (1991);
- Water Management Act (2010);
- Land Drainage Act (1991 and 1994);
- Wildlife and Countryside Act (1981);
- The Countryside and Rights of *Way* Act (2000);
- Salmon and Freshwater Fisheries Act (1975);
- The Water Environment (Water Framework Directive) (England and Wales) Regulations (2003);
- Natural Environment Rural Communities Act (2006);
- The Eel Regulations (2009);
- Environmental Permitting (England and Wales) Regulations (2010);
- Environmental Permitting Regulations (2010);
- The Conservation of Habitats and Species Regulations (2010);
- Environmental Impact Assessment (Land Drainage Improvement Works) Regulations (1999);
- Town and Country Planning Act (1990);
- Bathing Water Regulations (2013).

Future dredging activity (if using agitation techniques) may also be controlled by:

- Marine and Coastal Access Act (2009).

Future dredging activities must comply with legislative requirements.

2.5.2. Licencing and Permits

There are a number of licencing and permitting considerations when disposing of dredge material. A summary of the key consenting requirements is given below.

Waste exemptions

Several categories of waste exemption licence exist. The ones that are considered most relevant include:

- D1 – This exemption allows the deposit of dredge material from the dredging of inland waters and associated screening and dewatering, provided that:
  - The total quantity of deposited or treated over any 12-month period does not exceed $50m^3$ per metre of land on which the material is deposited;
  - The waste must be deposited on the bank of the water from where it was dredged;
  - The waste must be deposited on the land adjoining the water from where it was dredged by mechanical means in one operation.
- U10 – This exemption allows the spreading of waste dredging on agricultural land to confer benefit to the land for purposes of providing, maintaining or improving the soils ability to provide a growing medium, provided that:
  - Only (up to) 150 tonnes per hectare may be spread and up to 1250 tonnes per hectare may be stored;
  - The land must not have been frozen for 12 hours of the previous 24 hours, it must not be water-logged, frozen or snow covered;
  - The waste must be deposited on the land adjoining the water from where it was dredged.
  - The waste must have been generated by the following activities: from creating or maintaining habitats, ditches or ponds in parks, gardens, fields and forests only.
- U1 – This exemption allows the use of up to 1000 tonnes of dredging in any construction project over a three-year period. The waste can be stored for up to 12 months. It is also possible to store up to 5000 tonnes of dredging over the same period of time as long as the waste is used for work carried out for the purposes of the Land Drainage Act 1991, Water Resources Act 1991 and Environment Act 1995.

Disposal permits

Several categories of disposal permit exist. The ones that are considered most relevant include:

- SR2010 No.4 Mobile plant of spreading. This allows operators to obtain a mobile plant permit and then make a 'deployment' (of equipment) to spread the dredging. This permit is usually held by the plant operator /owner.
- SR2010 No. 9 and No.10 use of waste in the reclamation, restoration or improvement of land. These standard rules may be used in conjunction with the mobile plant for treatment of land for reclamation, restoration or improvement where there is a need to create a surface layer of soil to enable the land to be brought back into use for agricultural, ecological or amenity purposes. The total quantity of waste that can be stored and subsequently spread at the site under these standard rules shall not exceed 50,000 tonnes (No.9) and 100,000 tonnes (No. 10). However, the activities must not be carried out within 500 metres of a Ramsar site or a Site of Special Scientific Interest (SSSI). The activities must not be carried out within 50m of a Local Nature Reserve.
- SR2010 No. 12 Use of dredge material in the production of soil. These standard rules will allow the operator to store waste at a specified location and treat it to produce soil, soil substitutes and aggregate.

The total quantity of waste that can be stored and subsequently treated at the site under these standard rules shall be no more than 75,000 tonnes per year. However, the activities must not be carried out within 500 metres of a Ramsar site or a Site of Special Scientific Interest (SSSI). The activities must not be carried out within 50m of a Local Nature Reserve.

- SR2010 No.18 Dewater and storage of dredge material. These standard rules will allow the operator to temporarily store waste arising from dredging inland waters in lagoons. These standard rules also allow the treatment, by dewatering, of the waste in the lagoons. The total capacity of the lagoon used for the temporary storage of waste under these standard rules shall not exceed 125,000 cubic metres. However, the activities must not be carried out within 500 metres of a Ramsar site or a Site of Special Scientific Interest (SSSI). The activities must not be carried out within 50m of a Local Nature Reserve.

Use of Agitation Technique

If agitation or hydrodynamic methods are used then consultation with the MMO is required (the section of the Parrett System in question is submerged at mean high water spring tide).

It is probable that the MMO would require some form of plume dispersion evaluation and environmental impact assessment prior to use of this method as an on-going dredging technique (such as numerical modelling or monitoring of the plume during trials).

In order to establish the effectiveness of the technique, it could be possible to undertake a trial under an exemption (Article 18A of the 2013 Exempted Activities Order) within the Maintenance 1 and 2 areas:

- the dredging activity must have occurred at the site in question and be to a depth previously dredged within the last 10 years;
- the volume of material to be dredged as a result of the activity does not exceed 500m^3;
- no more than 1500m^3 of material has been dredged, including the volume to be dredged as a result of the activity proposed, in the previous 12 months;
- the activity is not likely to affect the status of the waterbody or prevent the achievement of any environmental objectives listed in the relevant River Basin Management Plan.

Notification of such dredging (trial) is required by the MMO.

Following evaluation of agitation or hydrodynamic dredging as a tool for maintenance dredging, further discussions with the MMO should be held to assess future maintenance dredging using this method under their Marine Licensing Regulations.

2.5.3. Environmental Impacts

Extensive environmental impact assessments (EIA) and statements (EIS) have been produced by the Environment Agency (February 2014) for the 8km pioneer dredge (EA 2014), and more recently an Environmental Impact Scoping and Assessment was completed by the IDB (November 2015) for the 2.2km maintenance dredge (IDB 2015).

Other assessments completed by the Internal Drainage Board include a Water Framework Directive (WFD) assessment and a Habitats Regulation Assessment (HRA). Whilst WFD requirements must be covered for the Parrett and the Tone, the rivers are not part of SSSI or other designated sites.

Potential environmental impacts identified include:

- Socio-Economic:

- Reduced access to public and private land and highways during dredging activities;
- Increased traffic;
- Damage to archaeology and areas of historical interest.

- Physical:
  - Impact upon water quality (increased suspended sediment concentrations);
  - Changes to river channel bank profiles (morphology).
- Ecological:
  - Destruction / modification of habitats and harm to species.

The EIA documents, including WFD and HRA assessments already completed for the 8km pioneer dredging and 2.2km maintenance dredging, provide a good and pragmatic starting point for future EIA investigations and studies that will be required prior to additional pioneer and maintenance dredging works.

There will inevitably be conflicts between dredging and environmental requirements, and it will be essential for teams to work together, identify environmental concerns as they arise and undertake proportionate mitigation activities. For example, where there is a conflict between the need to remove vegetation and the conservation of a habitat, one option would be to re-create the habitat elsewhere.

2.5.4. Sensitive receptors

A summary of the relative sensitivity of key physical conditions and flora and fauna to disturbance found in the Parrett System is given in Table 2.1. Species of particular importance include water voles and Hairy Click Beetles.

Table 2.1: Relative sensitivity of key physical conditions and flora and fauna to disturbance

	Environmental Constraints Calendar (irrespective of site)												
Environmental constraint	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Comments**
Water quality (bathing)	Low	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Effective 15th May - 30th Sept
Water voles	Medium	Low	Low	Low	Medium	Medium	Medium	Medium	Low	Low	Low	Medium	Exclusion work under class licence (15 Feb to 15 Apr & 15 Sep to 31 Oct); work under a bespoke species licence maybe an option
Badgers	Medium	High	High	High	Medium	Low	Low	Low	Low	Low	Low	Low	Work under class licence (except Feb to Apr)
Otters	Low	Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Low	Low	Low	
Tree and hedge management (incl. breeding birds and roosting bats)	Medium	Medium	Medium	High	High	High	Medium	Medium	Low	Low	Low	Medium	Bat survey maybe required in winter (roosts)
Wintering birds	High	High	Medium								Medium	High	
Breeding birds		Low	Medium	High	High	High	Medium	Low					
Glass eels	Low	Medium	Medium	Low									Glass eel fishery (14th February – 1st April)
Fish	Low	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	
Rare invertebrates (in channel)	Medium	Medium	High	High	High	High	High	High	Medium	Medium	Medium	Medium	
Rare invertebrates (riparian)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Low	

Sensitivity
- High
- Medium
- Low

Source: P. Brewin at Parrett IDB

2.5.5. Designations

The Somerset Levels is acknowledged as a region of national and internationally designated conservation sites. These designations include Special Protection Area (SPA) Ramsar and Sites of Special Scientific Interest (SSSI). Figure 2.3 provides an overview of the relevant designations around the Parrett System.

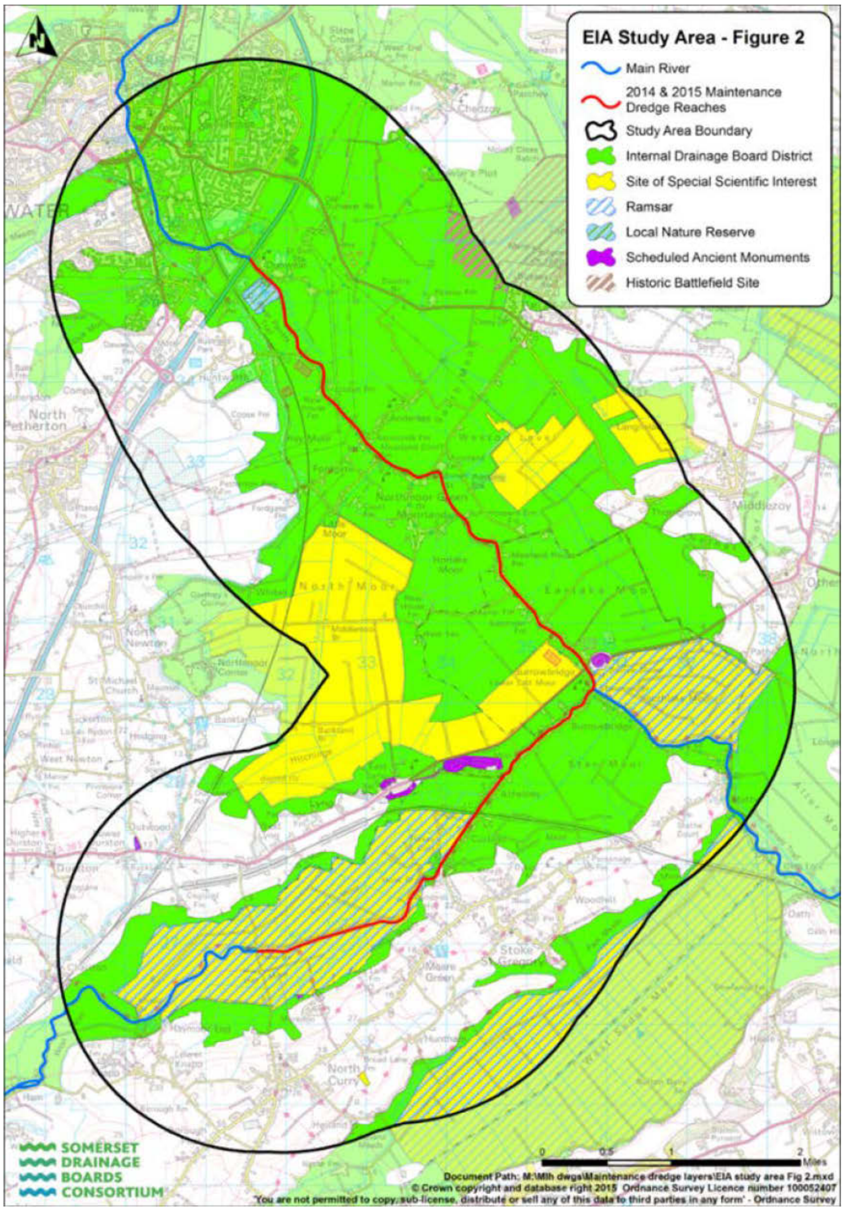

Figure 2.3: Overview map of relevant land designations around the Parrett System

Source: IDB HRA for maintenance dredging on the Parrett, November 2015

Future Pioneer dredging on the Parrett system could directly impact upon the following locations:

- The local nature reserve (Screech Owl Nature Reserve) located upstream of the M5 crossing on the west bank of the River Parrett;

- Ramsar and SSSI at Southlake Moor upstream of the Tone and Parrett confluence on the east bank of the River Parrett.

Future maintenance dredging on the River Brue could impact on the Catcott, Edington and Chilton Moors SSSI which extends on the right bank from Westhay Bridge to North Drain and also occupies land on the left bank of the same reach near Burtle. This is the area where the need for dredging has been identified by the SRA.

Pioneer dredging activities were previously undertaken along sections of the River Tone designated as both Ramsar and SSSI. Access was not permitted through designated areas and no spreading of dredge material was permitted within designated sites. However this precedent shows that arrangements can be made for dredging work in these sensitive areas.

2.5.6. Mitigation measures

General mitigation measures identified to reduce the effects of the previous pioneer and maintenance dredging works have included:

- Develop a Traffic Management Plan (TMP);
- Timing of dredging activity to avoid peak environmental sensitivity;
- Adoption of one-bank working and one bank dredging within 1-year in order to reduce environmental impact, mitigate impacts of working from the bank and aid ecological recovery;
- Leaving the upper portion of the channel banks untouched to prevent disturbance (where re-profiling is not required);
- Strip and recover / replanting of reed rhizomes (some locations);
- Undertake key sensitive species surveys prior to dredging works;
- Consider re-locating sensitive species if there is no other way of ensuring adequate conservation during dredging operations;
- Minimise disturbance to wintering birds, particularly in the SSSI areas;
- Check the salinity levels of material before disposal, to ensure that salinity levels in material that is spread on the land are acceptable;
- Water quality monitoring prior to, during and after dredging. This includes monitoring Dissolved Oxygen and temperature for fish populations;
- Water level management on the adjoining moors, to safeguard the necessary water supply and level control required to sustain the condition of protected wetland areas.

It is expected that these mitigation measures will be relevant for future pioneer and maintenance dredging work.

2.5.7. Physical constraints

Dredging within the Parrett and Tone system is affected by physical constraints, which include the following:

- Dredge material tends to accumulate on the banks and shoulders of the channel meaning the material to be dredged can be above the water-line during certain conditions;
- The channels of the Parrett system are relatively narrow, and incised with flood embankments on either bank complicating access issues for dredging equipment;

- Overhead cables that cross the rivers restrict the dredging methods and equipment that can be used at some locations (this also applies to the Brue);
- Access to the banks is not possible at some locations because of the close proximity of houses and roads to the banks (this also applies at some locations on the Brue, where bankside trees are also a constraint for access);
- Existing hard defences including walls and submerged/buried rock armour;
- The water depths within the channels are tidally and seasonally variable. This impacts the types of dredge methods and equipment which can be used (e.g. use of low draft vessels / equipment);
- Flow speeds and directions are tidally and seasonally variable. This places limits on the timing of the use of dredging equipment for maximum effectiveness (e.g. hydrodynamic dredging method);
- Delivery of dredging equipment to dredge site – this includes both access to the river channel from roads as well as launching sites for floating equipment. Currently some of the floating equipment is craned onto the waterway.

Issues related to physical access to dredging sites could be overcome by the development of dedicated deployment locations. An example includes Westonzoyland Pumping Station site, which has been used as a base for the recent pioneer and maintenance dredging operations. On the assumption that dredging operations were to continue in the same manner, e.g. use of bankside or pontoon mounted excavators, then it arguably makes sense for additional deployment locations to be identified upstream or downstream of sections where pontoon mounted excavation is required.

The use of agitation dredging techniques, which are vessel based, may reduce the need for permanent site compounds or extensive deployment facilities. It is possible that the vessel could be launched from an existing available jetty or slipway structures downstream of the currently dredged reaches (for example in Bridgwater). However, given the distance between the upstream and downstream dredged locations it would be advantageous to have at least one other jetty or slipway location on the Parrett or Tone.

3. Objectives of Dredging

3.1. Introduction

It has long been the perceived wisdom by many that removal of sediment accumulations from the upper reaches of the tidal parts of the River Parrett and the River Tone is advantageous in reducing flooding, and this has been confirmed during consultations with the SRA and other stakeholders. However the effectiveness of dredging as a flood reduction measure when compared with other methods (such as pumping) has been questioned.

The positive effect of dredging on water-levels within both rivers and their floodplains has been modelled in different combinations and reported on several occasions, particularly the hydraulic modelling reports by Black and Veatch referred to in Appendix D. For example, the modelling shows that the 8km dredge on the Parrett and the Tone would reduce peak flood levels on North Moor by 1.0 m for the 2013/14 event, and a greater reduction could be achieved in combination with pumping.

Dredging can affect different parts of the Parrett and Tone river and floodplain system. In order to decide where dredging should be carried out, the objectives of the dredging must be stated. For this study, hydraulic objectives have been used that are be expressed in terms of changes in flood water level on the moors. This also indicates the flood volume, as the moors are effectively large flood storage areas.

The River Brue is a non-tidal river that is subject to fluvial sedimentation. Objectives on the River Brue are related to the channel capacity needed to convey flood flows and enable more effective water level management for agriculture and nature conservation.

3.2. Development of objectives

The principle behind dredging, or de-silting, of the River Tone and River Parrett channels is that the larger cross-sectional area afforded by dredging increases the amount of (flood) water that can be discharged through the rivers, thus reducing the amount of water that overflows onto the floodplains.

The hydraulics of the river system are complex, and an assessment of the hydrology and hydraulics is provided in Appendix A. Some of the key points regarding the system are as follows:

- The river reaches have a relatively low capacity for the discharge of flood water compared to peak flows and flood volumes that enter the low lying areas during large flood events. This means that flooding will be a relatively frequent occurrence with or without dredging.
- For example, the 100-year flow on the River Tone at Taunton was about 170 m^3/s (based on the Taunton Valley scheme design) whereas the capacity of the tidal Tone downriver of Hook Bridge is of the order of 20 to 60 m^3/s depending on tidal conditions, even when dredged to the 1960s design capacity (see Appendix A, Figure A.6).
- Flood water overtops the river banks upriver of the tidal reaches, and therefore the amount of flood water that enters the tidal reaches is less than the flood flows upstream. Any hydrological analysis of the river systems should therefore take account of the impact of attenuation on flood flows.
- Flooding is primarily a function of flood volume and not peak flood flow. This is because the capacity of the rivers is low and any flow that exceeds the capacity can cause flooding. This means that prolonged periods of high flow can cause flooding even if the peak flow is not exceptional (as in winter 2013/14).
- The tidal reaches are affected by the tide. The rates of discharge are higher at low tide and lower at high tide. This means that it is not possible to assign a single ‘design flow’ for each reach of the river, and hydraulic modelling is needed to assess the overall capacity of the system.
- The tidal reaches of the Tone and the Parrett downriver of the Tone confluence are very constrained by flood banks, roads, buildings and other features. This means that the capacity of the river channels will be constricted, and there is a limit to the amount of enlargement that can be achieved by dredging.

Dredging of 8 km of the River Tone and the River Parrett has been carried out, which provides an enlarged channel from Hook Bridge spillway on the Tone to Northmoor pumping station on the Parrett. This reduces the amount of water that flows over Hook Bridge spillway and therefore the amount of flooding on North Moor.

However high flows on the River Parrett cause backing up of the Tone and increases the water levels at Hook Bridge spillway. This in turn increases flow over the spillway and therefore the amount of flooding on North Moor. If the capacity of the Parrett is increased upriver of the confluence, the amount of water that flows into the River Sowy system will decrease but the adverse effect on the River Tone will increase.

If an objective is to reduce flooding on Curry Moor, Salt Moor and North Moor, maintaining a high capacity channel on the Tone and the Parrett would be appropriate. This is the original approach adopted in the Tone Valley scheme in 1960 and also the approach adopted for the 2014 dredging on the Tone and Parrett. If however the objective is to reduce flooding on the Sowy River and on the Parrett upriver of Allermoor spillway, maintaining a high capacity channel on the Parrett from Allermoor spillway downriver would be the most suitable approach. It is understood that both objectives are important, and therefore a balance is needed between the two approaches.

Figure 3.1 shows the potential channel enlargements for the discharge of flood water. Channel enlargement 2 (Parrett downriver of the confluence) and Channel enlargement 4 (the Tone) have already been implemented in the 8 km dredge referred to above.

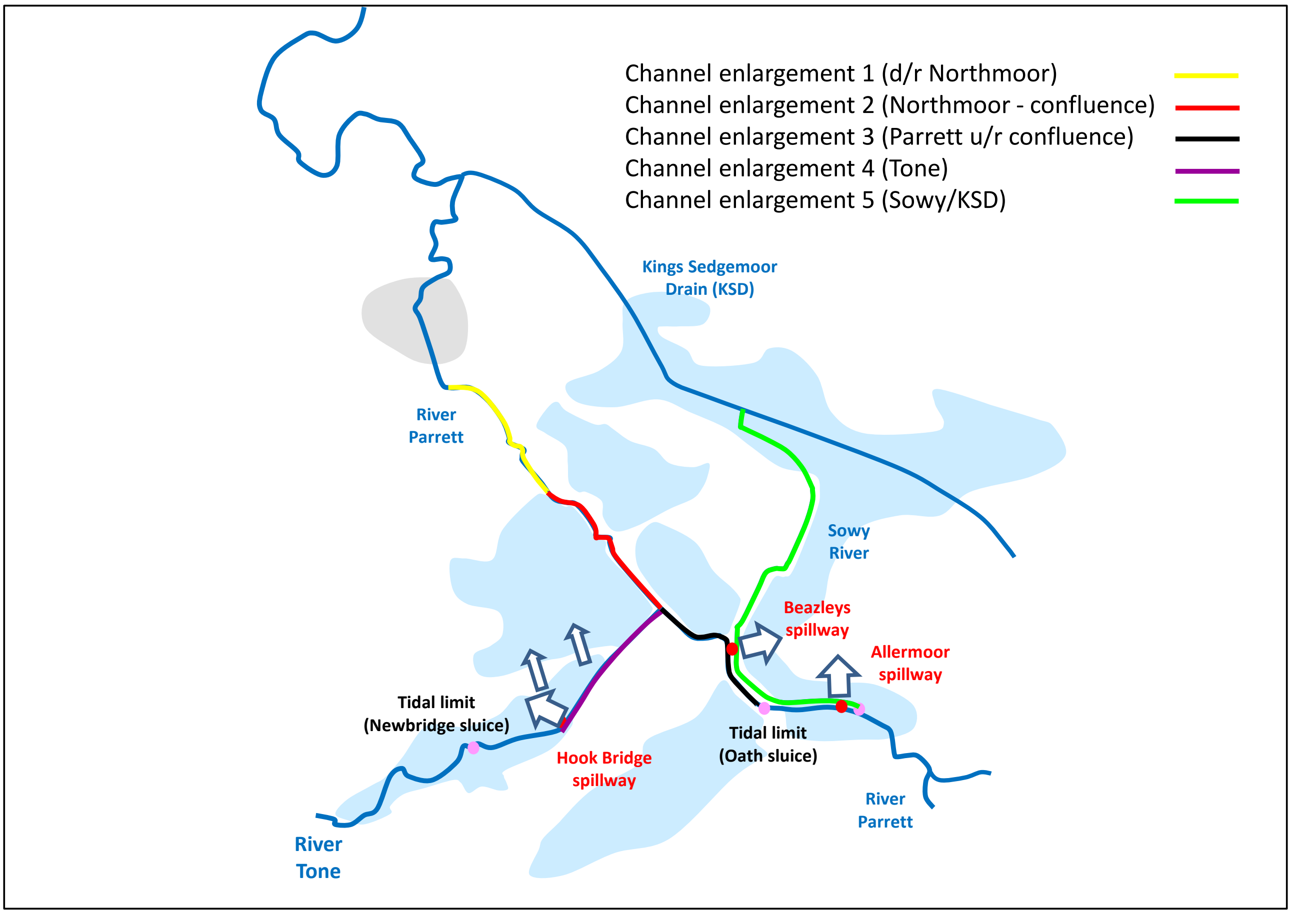

Figure 3.1: Potential channel enlargements

Options for combining these channel enlargements in order to discharge flood water via the river channels are as follows:

1. Parrett downriver of the confluence (enlargement 2) and the Tone (enlargement 4): This is the dredge that has already been carried out and reduces flooding from the Tone;
2. Parrett downriver of the confluence (enlargements 1 and 2) and the Tone (enlargement 4): This further reduces flooding from the Tone;
3. Parrett downriver and upriver of the confluence (enlargements 1, 2 and 3), and the Tone (enlargement 4): This reduces flood flows in the Sowy River and flood levels upriver of Allermoor spillway but increases flooding from the Tone compared with option 2;
4. Parrett downriver of the confluence (enlargements 1 and 2), the Tone (enlargement 4) and the Sowy (enlargement 5): This allows floodwater on the Tone to discharge via the Parrett and floodwater from the Parrett to discharge via the Sowy River;

5. Parrett downriver and upriver of the confluence (enlargements 1, 2 and 3), the Tone (enlargement 4) and the Sowy (enlargement 5): This utilises all flood channel options to reduce flooding on the Tone and the Sowy, and also reduce flood levels upriver of Allermoor spillway.

The objectives of dredging are described in terms of hydraulic benefits. For the Parrett and the Tone, the indicators used consist of flood water levels at key locations. The key locations selected are:

- North Moor, which represents the most important flood risk area in the western part of the system;
- Kings Sedge Moor, which represents flooding in the east part of the system;
- Muchelney Level, which is used to represent flooding in the river system upriver of Allermoor spillway.

It is accepted that the 8 km dredge on the River Parrett and the River Tone between Northmoor pumping station and Hook Bridge spillway in 2014 and the current (2016) 750m dredge will be maintained in the future. The main benefit of this dredging is to reduce water levels at Hook Bridge spillway, which in turn reduces the amount of water that enters Curry Moor and North Moor.

Further dredging options have been tested for the 2013/14 flood event (Black & Veatch 2014/15). Those on the tidal River Parrett and River Tone that have greatest impact on flooding are given below, compared with a baseline that assumes completion of the 8km dredge on the Parrett and Tone and the current (2016) 750m additional dredge on the Parrett. It is estimated that the original 8km dredge would have lowered water levels on North Moor by about one metre during the 2013/14 event.

- Dredging on the River Parrett downriver of Northmoor pumping station to the M5 motorway (enlargement 1 in Figure 3.1), as follows:
  - Scenario 1: dredging from the existing profile to a 1 in 2 side slope plus widening by 2m. This has the following effects on peak flood water levels:
    - North Moor – flood level reduction of 160 mm
    - Kings Sedge Moor – flood level reduction of 20 mm
    - Muchelney Level – no change in flood levels
  - Scenario 2: dredging from the existing profile to a 1 in 2 side slope plus widening by 4m. This has the following effects on water levels:
    - North Moor – flood level reduction of 240 mm
    - Kings Sedge Moor – flood level reduction of 20 mm
    - Muchelney Level – no change in flood levels
- Dredging on the River Parrett upriver of the River Tone confluence (enlargement 3 in Figure 3.1), as follows:
  - Scenario 1: increase the channel width by 2m from Great Bow Bridge (Langport) to Allermoor spillway. This has the following effects on water levels:
    - North Moor – no change in flood levels
    - Kings Sedge Moor – flood level increase of 10 mm
    - Muchelney Level – flood level reduction of 20 mm
  - Scenario 2: dredging from the existing profile to a 1 in 2 side slope plus widening by 4m from the Tone confluence to Allermoor spillway. This has the following effects on water levels:
    - North Moor – flood level increase of 300 mm
    - Kings Sedge Moor – flood level reduction of 80 mm

- Muchelney Level – flood level reduction of 30 mm

- Dredging on the River Parrett downriver of Northmoor pumping station to the M5 motorway combined with upriver of the River Tone confluence (enlargements 1and 3 in Figure 3.1), as follows:
  - dredging from the existing profile to a 1 in 2 side slope plus widening by 2m downriver of Northmoor pumping station (scenario 1) to the M5 motorway combined with dredging from the existing profile to a 1 in 2 side slope plus widening by 4m from the Tone confluence to Allermoor spillway (scenario 2). This has the following effects on water levels:
    - North Moor – flood level increase of 170 mm
    - Kings Sedge Moor – flood level reduction of 110 mm
    - Muchelney Level – flood level reduction of 30 mm.

These results are shown in Figure 3.2.

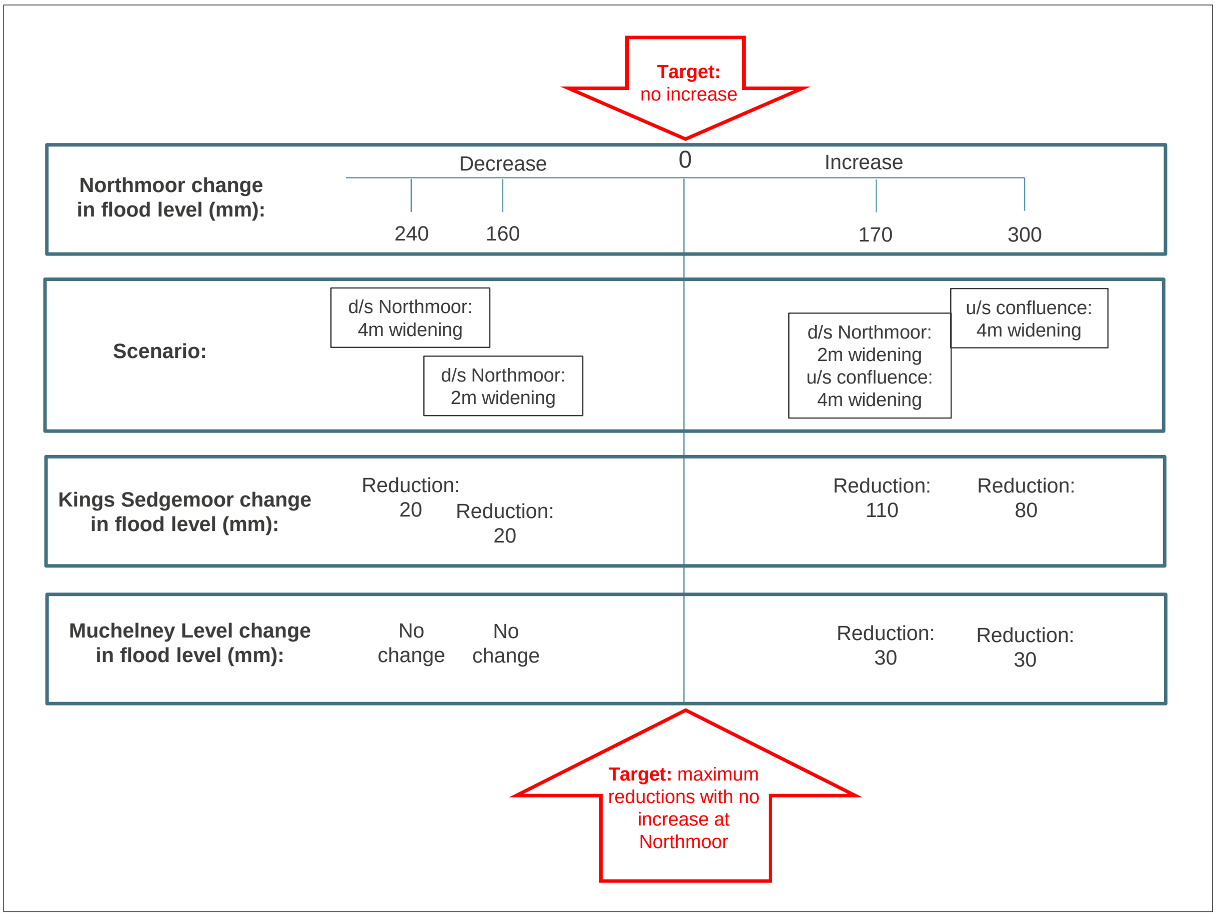

Figure 3.2: Impacts of model tests on flood levels

It is apparent from Figure 3.2 and the model predictions that there may be more efficient combinations of upstream and downstream dredging that would not worsen flooding on North Moor, for example a larger downstream widening combined with a smaller upstream widening, Figure 3.2 therefore also shows potential targets of dredging, which are to avoid increasing flood levels on North Moor but maximising the reduction in flood levels elsewhere. These contribute to the objectives identified in Section 3.3.

The objectives of dredging on the River Brue are to maintain the flood capacity of the river channel. In order to develop the objectives in detail, modelling of the river will be required to identify where the capacity is restricted. Previous work has already identified that there is a significant loss of cross section from silt deposits in the reach between Westhay Bridge and North Drain pumping station.

3.3. Objectives

The objectives of dredging are of two types: hydraulic benefit and efficiency of dredging. The objectives of dredging on the River Parrett and the River Tone are:

1. To avoid any increase in flood levels on North Moor with the 8.75 km existing dredge in place for a repeat of the 2013/14 event;
2. To maximise the reduction in flood level on Kings Sedge Moor;
3. To maximise the reduction in flood level upriver of Allermoor spillway;
4. To adopt the most efficient and appropriate methods for pioneer and maintenance dredging activities. This includes consideration of their legal, regulatory, financial and environmental requirements and impacts.

Objectives 1, 2 and 3 are hydraulic objectives which arise from the discussion in Section 3.2. It is recognised that there are other locations where reductions in water level will be beneficial, but these locations are considered to be representative of the most important flood levels in the Parrett/Tone river system.

Objective 4 covers the need for efficient and cost effective dredging methods.

The objective of dredging on the River Brue is:

- To maintain the capacity of the river channel for the conveyance of flood flows and enable more effective water level management for agriculture and nature conservation.

Further modelling for the River Parrett and the River Tone is proposed in order to identify the optimum combination of dredging downriver of North Moor and upriver of the confluence to achieve the hydraulic objectives.

Modelling of the River Brue is proposed to identify the current in-channel capacity and identify the areas where siltation causes the greatest restriction to the river flow.

4. Dredging requirements

4.1. Locations of dredging

4.1.1. River Parrett and River Tone

In order to achieve the objectives identified in Section 3.3, new ('pioneer') dredging is proposed on the River Parrett downriver of the completed and current dredging work and upriver of the River Tone confluence. No new dredging is proposed on the River Tone. The locations of the proposed new dredging are shown on Figure 4.6.

Figure 4.1 shows the cross-sectional area of the River Parrett channel from just downriver of Langport to Bridgwater. The areas are below 8 m AOD, which is the approximate bank top level. The figure also shows indicative design cross-sectional areas that maintain constant trapezoidal section shapes where the bed level is parallel to the existing bed.

It can be seen from Figure 4.1 that the cross-sectional area is low upriver of the Tone confluence, and there is a clear need for dredging in this area if the conveyance capacity is to be improved. The cross-sectional area is also low downriver of the completed and current dredging work, and there are areas with a low cross-sectional area both upriver and up to about 1 km downriver of the M5.

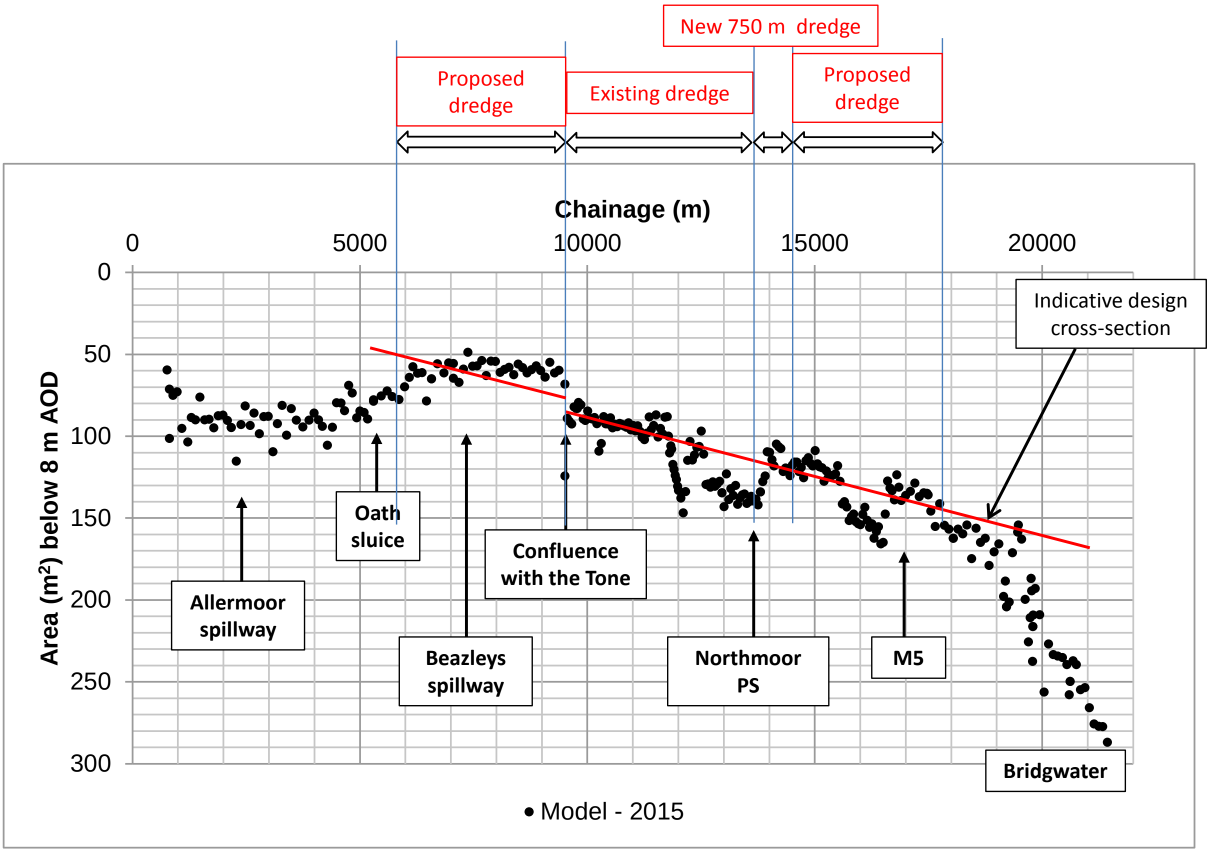

Figure 4.1: River Parrett channel cross-sectional area (below 8 m AOD)

It is therefore proposed that pioneer dredging is extended further downriver to provide a uniform cross-section with a bed level and bed width that is similar to the existing bed. The intention is to achieve a reasonably efficient hydraulic cross-section that is less likely to silt up quickly than a section with a wider bed. This will also reduce the required pioneer dredging quantities in this area.

Figure 4.1 also indicates the locations where pioneer dredging is proposed, upriver of the Tone confluence and downriver of the existing and current dredging areas. Maintenance dredging in areas where pioneer dredging has been carried out will also be required. This includes the River Tone, where dredging from Hook Bridge spillway to the confluence with the Parrett was carried out in 2014. No new pioneer dredging is proposed on the River Tone.

The cross-sectional area plot on Figure 4.1 provides a good indication of where dredging is needed and how much (in terms of m^3 per m of channel). However it provides a guide only as the area is affected by the width of the berms and other features. Design cross-sections will be needed to provide a reasonably uniform cross-section, as indicated on Figure 4.1. The hydraulic benefit of the design cross-sections will be determined by hydraulic modelling and the volume of dredging must be calculated by applying the design cross-section to each river cross-section.

Typical cross-sections of the upriver and downriver areas to be dredged are shown on Figure 4.2 and Figure 4.3 respectively. Further detail is provided in Appendix A.

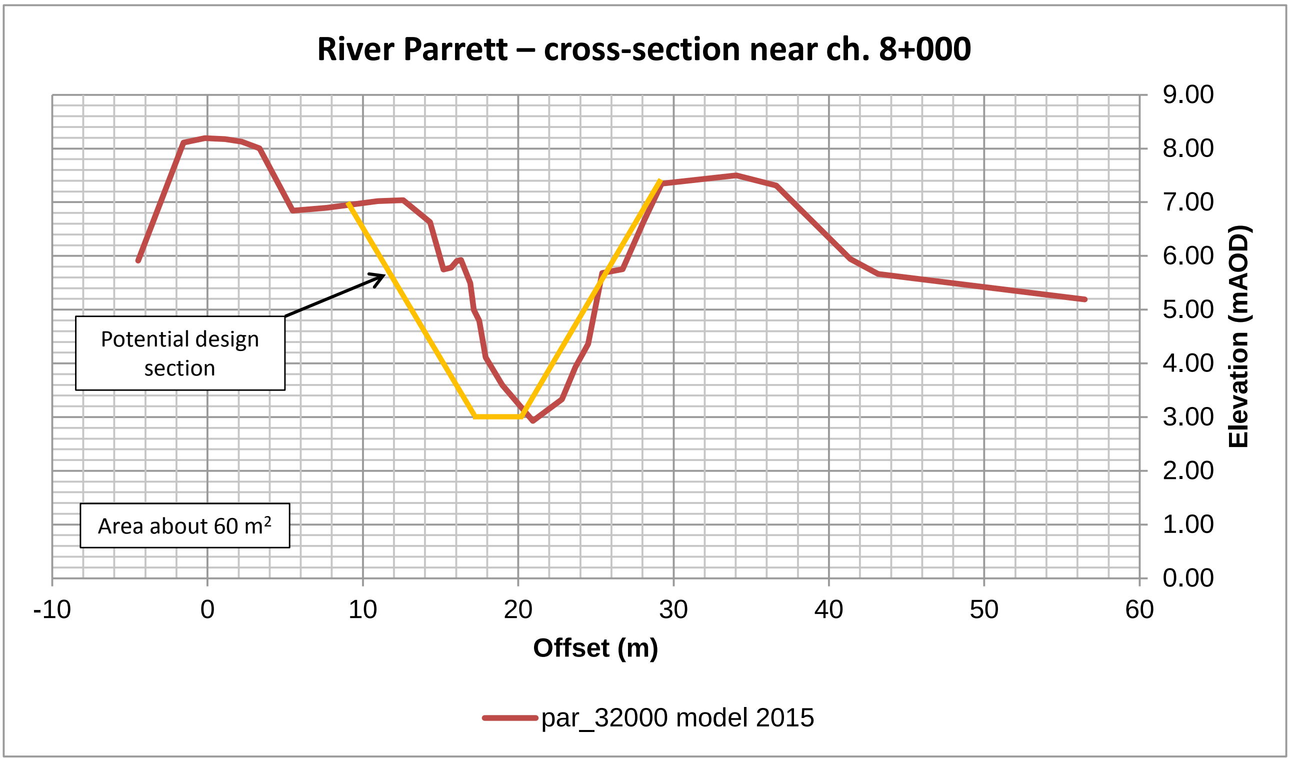

Figure 4.2: River Parrett channel cross-section upriver of the Tone confluence

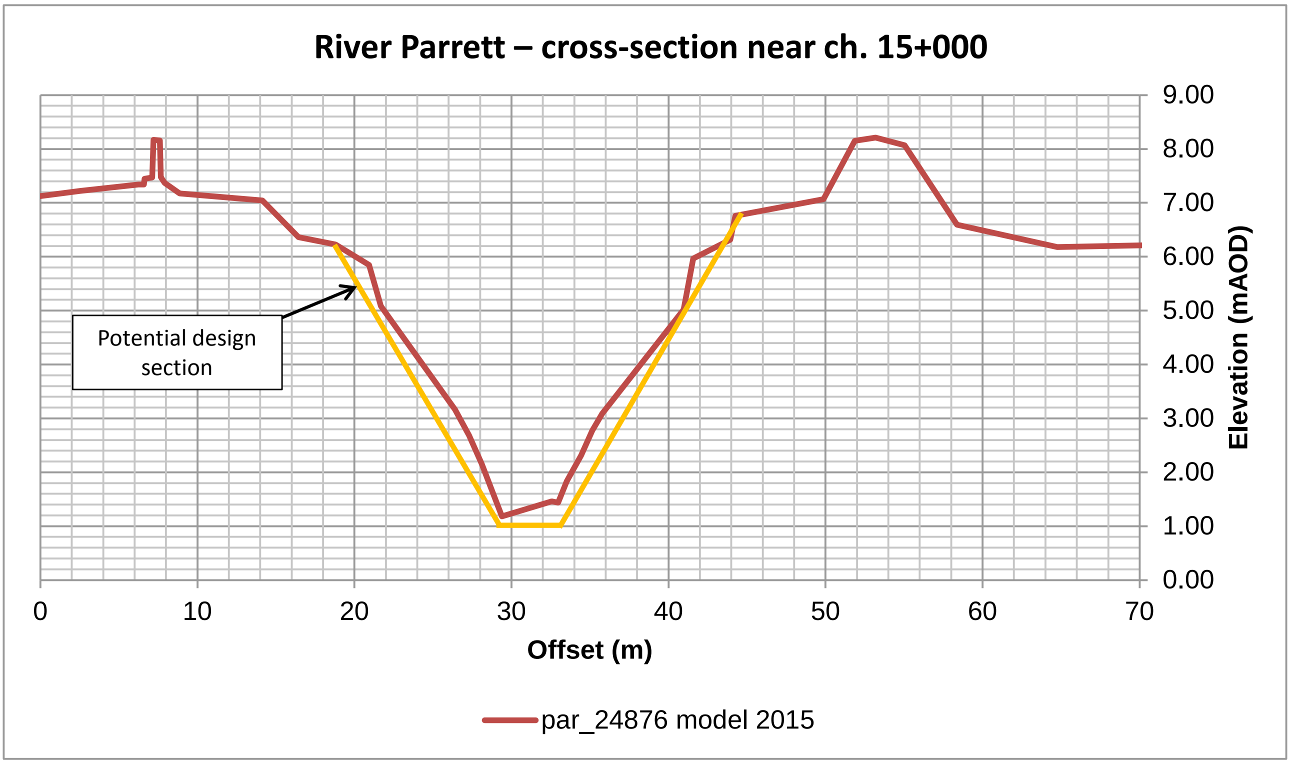

Figure 4.3: River Parrett cross-section downriver of the current 750 m dredge

4.1.2. River Brue

Figure 4.4 shows the cross-sectional area of the River Brue channel from just downriver of Glastonbury to Highbridge. The areas are below 3.8 m AOD, which is the approximate bank top level in the reach downriver of Westhay Bridge. Dredging of the 4.5 km reach between Westhay Bridge and North Drain is under consideration, and a detailed survey of this reach with and without silt has been undertaken.

It is however apparent from Figure 4.4 that the channel cross-sectional area is not constant and the main areas with a smaller cross-section are downriver of North Drain. Figure 4.4 also shows an approximate design cross-section that would convey the maximum flood flow of about 30 m^3/s (estimated in the Jacobs 2010 modelling report).

The information in Figure 4.4 indicates that the main priority for dredging should be downstream of North Drain, although some dredging would be required upstream of North Drain to achieve the potential design cross-section.

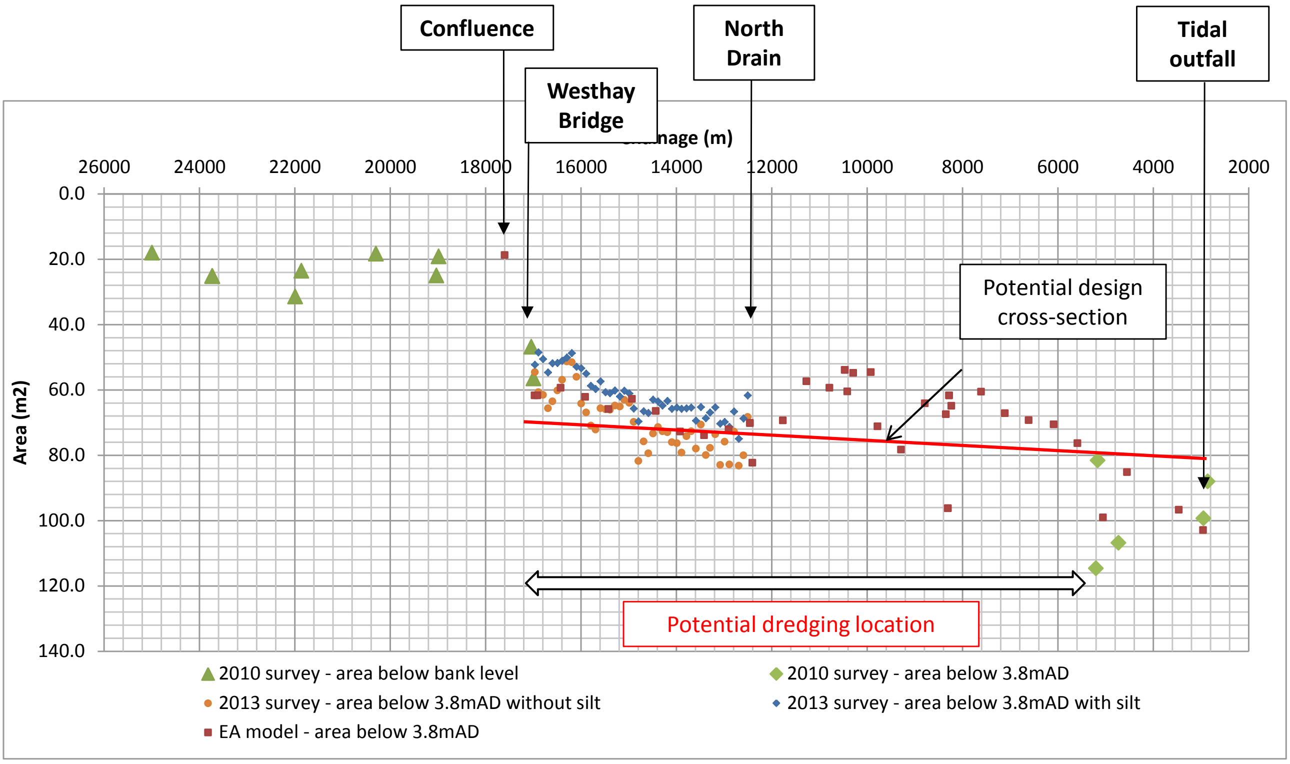

Figure 4.4: River Brue channel cross-sectional area (below 3.8 m AOD)

Figure 4.5 shows a longitudinal section of the river which has been prepared using all the available survey data. It is apparent that the bed level is higher downstream of North Drain compared with the 'without silt' sections upstream of North Drain. The channel is also narrower downstream of North Drain compared with upstream. Further downstream the channel bed level reduces but the channel continues to be narrower than upstream of North Drain. Selected cross-sections are shown in Appendix C, Section C.5.

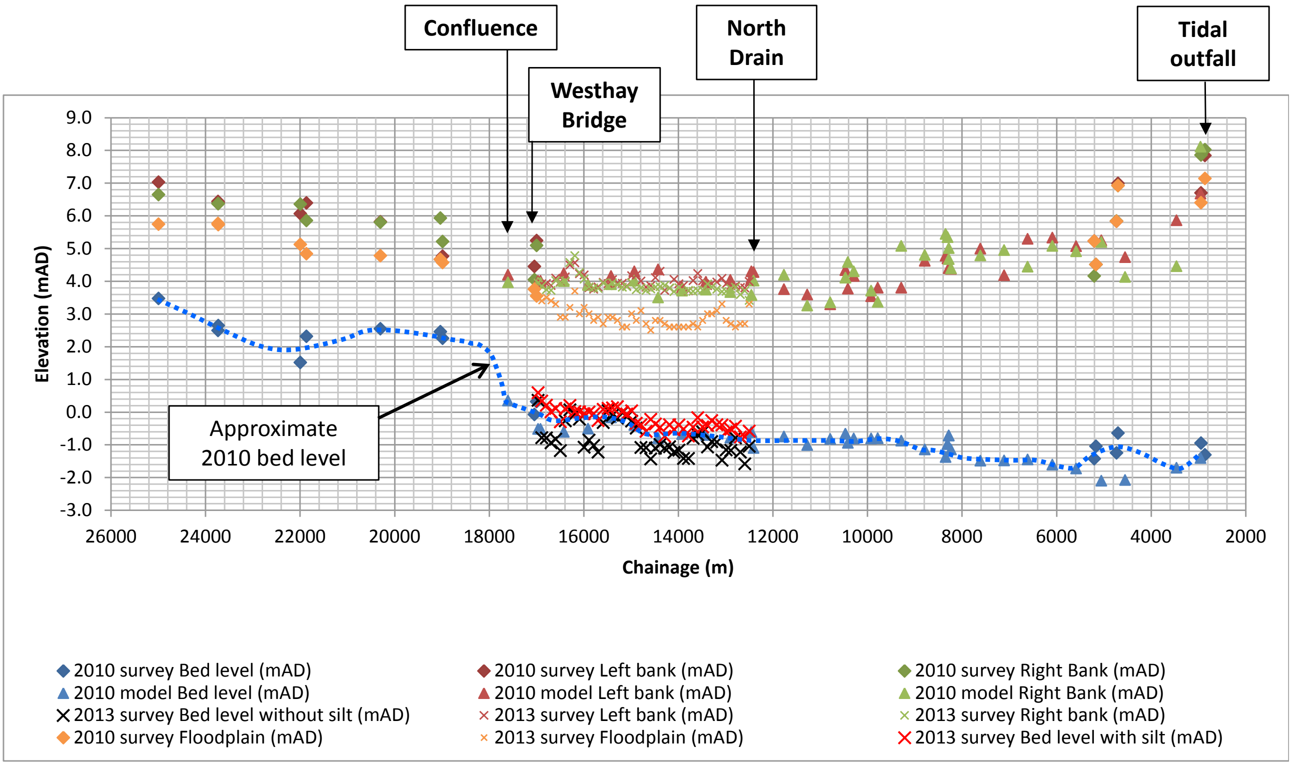

Figure 4.5: River Brue longitudinal section

Figure 4.4 provides a guide to the cross-sectional area that might be needed. However more detailed design work is needed to determine the design cross-section needed for planning dredging work. For example, a smaller section may be adequate for flood flows and some of the upstream sections may be oversized. It does however appear that constrictions in the channel downstream of North Drain contributes to high water levels further upstream.

It is therefore recommended that the proposed dredging locations on the River Brue are reviewed. Further survey should be carried out from Westhay Bridge to about Ch 5000 in order to check the findings shown in Figure 4.4 and Figure 4.5, which have used data from 2010 and 2013. It is also recommended that a hydraulic design for the river is formalised in order to guide decisions regarding future dredging.

4.2. Summary of dredging requirements

The general locations of dredging are shown on Figure 4.6 and tabulated on Table 4.1. This includes the proposed pioneer dredging on the Parrett, maintenance dredging on the Brue, and maintenance of all completed dredging on the Parrett and the Tone. Estimated dredge volumes for future pioneer and maintenance dredging based on the methods for estimating volumes outlined in Section 2.2.1 are shown in Table 4.2.

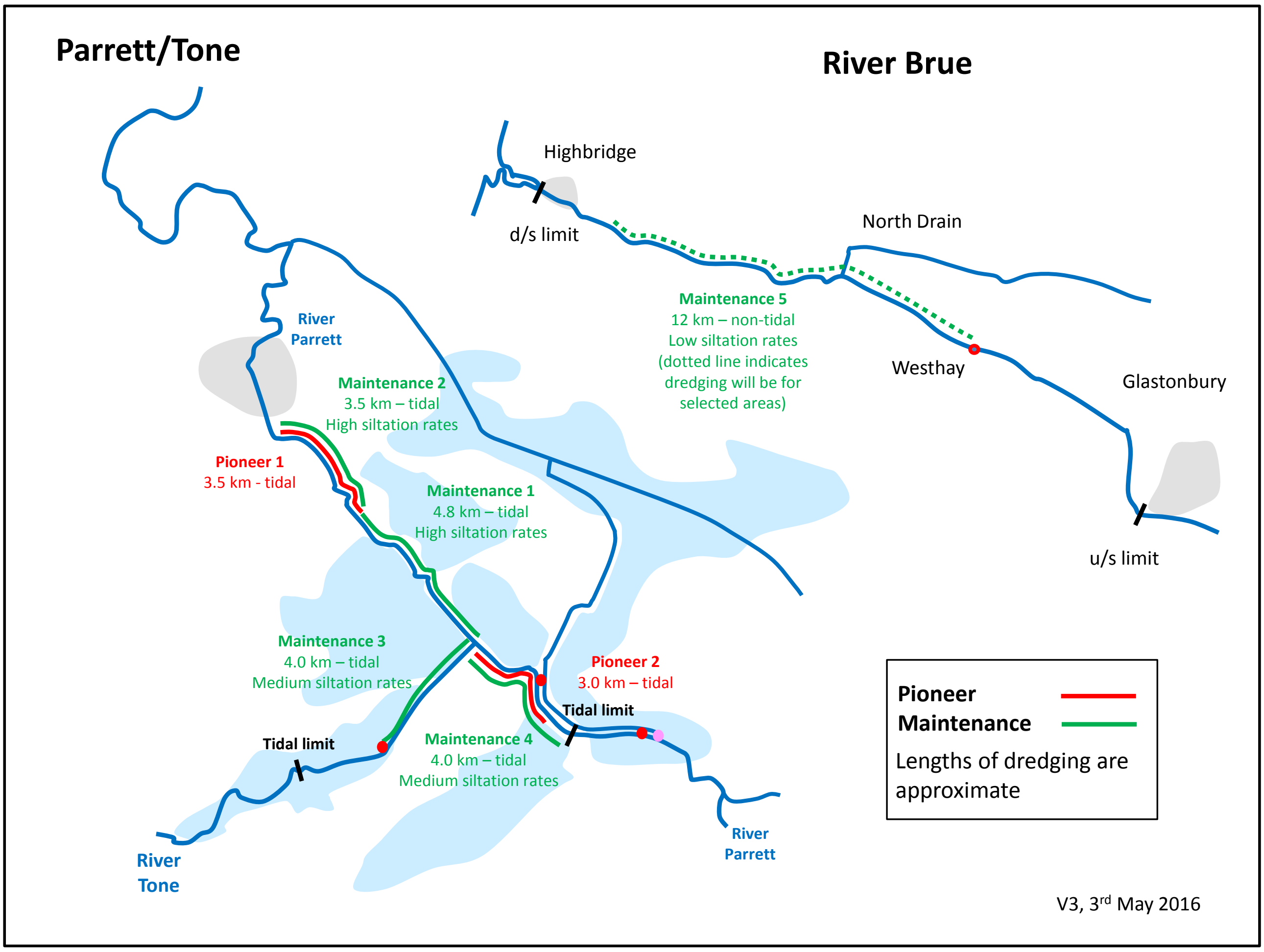

Figure 4.6: Proposed dredging locations: River Parrett, River Tone and River Brue

Table 4.1: Proposed dredging: River Parrett, River Tone and River Brue

River	Type / Ref	Length (km) (approx.)	Comments
Parrett	Pioneer 1	3.5	May include dredging downriver of the M5
Parrett	Pioneer 2	3.0	
Parrett	Maintenance 1	4.8	Maintenance of completed Parrett dredging
Tone	Maintenance 3	4.0	Maintenance of completed Tone dredging
Parrett	Maintenance 2	3.5	Maintenance of Pioneer 1
Parrett	Maintenance 4	4.0	Maintenance of Pioneer 2 (to Oath sluice)
Brue	Maintenance 5		Locations within the 12 km length on Figure 4.6 to be determined by further survey and hydraulic analysis

Table 4.2: Summary of future dredge volumes

Location	Estimated Volume (m^3)
Parrett – Pioneer 1: Downstream of existing dredge	50,000
Parrett – Pioneer 2: Tone confluence to Oath sluice	40,000
Parrett – Maintenance 1: Existing dredge from Tone downstream	35,000 per year
Parrett – Maintenance 2: Downstream of existing dredge	40,000 to 60,000 per year
Tone – Maintenance 3: Existing dredge upstream of confluence	13,000 every 2 years
Parrett – Maintenance 4: Tone confluence to Oath sluice	13,000 every 2 years
Brue – Maintenance 5: River Brue	40,000 every 5 years

4.3. Vegetation management

The effects of vegetation on the River Brue and the tidal River Parrett/Tone are discussed in the following sections together with the need for vegetation management.

4.3.1. River Brue

The River Brue is a freshwater environment with some tidal impact caused by backing up from Highbridge Clyse during high tide periods. The impact of vegetation will directly affect the conveyance of the river, particularly during flood periods when high water levels occur. Vegetation occurs both on the banks and in the channel.

Figure 4.7 shows the River Brue near Westhay in April 2016. It is apparent that the channel is well maintained and vegetation is not a major issue for flood conveyance. Vegetation will increase during the spring and summer and vegetation management may be required in order to maintain the flood conveyance capacity. This would be carried out in an environmentally sensitive way to minimise disturbance in accordance with normal good practice (for example, Environment Agency 2011A).

The proposed dredging in this area is to deepen the bed rather than widen the channel (Exo-environmental, 2014). The dredging should also be designed to avoid the risk of undermining the banks. It should be possible to minimise the impact of dredging on vegetation using such measures as dredging in the autumn and early winter (when in-channel vegetation will be low) and measures to minimise damage to the river banks. Dredging from one bank only may not be possible because of the width of the channel.

Further downstream from between River Bridge and Bason Bridge to Highbridge there is more bankside vegetation including trees. In the deeper section of the river through the higher ground near Highbridge, the banks are steep and vegetated. In these areas the bank vegetation will have a greater impact on flood conveyance.

Should dredging be required in these areas, it would involve deepening the bed and may have to be carried out from floating plant with disposal onto the banks where space permits in order to minimise damage to the bankside vegetation. Dredging in the autumn and early winter would minimise the impact on in-channel vegetation and habitats. Vegetation management would be needed if it is demonstrated by modelling that the vegetation will have a significant impact on flood conveyance. Vegetation management would be carried out in accordance with current good practice to minimise the overall impact on habitats, including the timing and sequence of maintenance operations.

Figure 4.7: River Brue downstream of Westhay

Source: Site visit, April 2016

4.3.2. Tidal River Parrett and River Tone

The situation regarding vegetation management is more complex on the Parrett and the Tone because vegetation occurs on the material that would have to be removed by dredging to create the required flood conveyance. Figure 2.2 shows the pattern of sedimentation that occurs, and Figure 4.8 shows the type of vegetation that becomes established on the sediment.

Both the sediment and the vegetation will affect flood conveyance and the greatest benefit will be achieved by removing sediment and vegetation on both banks, and then maintaining the section. This is essentially the method adopted in the Tone Valley Scheme, where a trapezoidal channel section is used for the channel design.

The effect of removing vegetation (and the reduction in channel roughness) has a significant impact on flood conveyance, as shown on Figure A.6 in Appendix A where two values of Manning's 'n' have been used to represent rough and smooth dredged surfaces.

The problem with dredging both banks is the adverse environmental impacts including the effects on habitats. An alternative approach would be to dredge on one bank only and widen the river bed. However it is apparent that the natural stable regime of the tidal rivers is to have a relatively narrow river bed, as shown on Figure 2.2 where sedimentation has occurred on the banks but not in the bed. Widening of the bed will encourage siltation, which in turn will lead to a greater requirement for future maintenance dredging.

This pattern of siltation can be seen in Figure 4.9 by comparing the design profile (red and black lines) with the profile in April 2015 (blue line), following the 8km dredge in 2014, and the green line, which shows the additional siltation by November 2015.

Figure 4.8: River Parrett downstream of Northmoor

Source: Site visit, March 2016

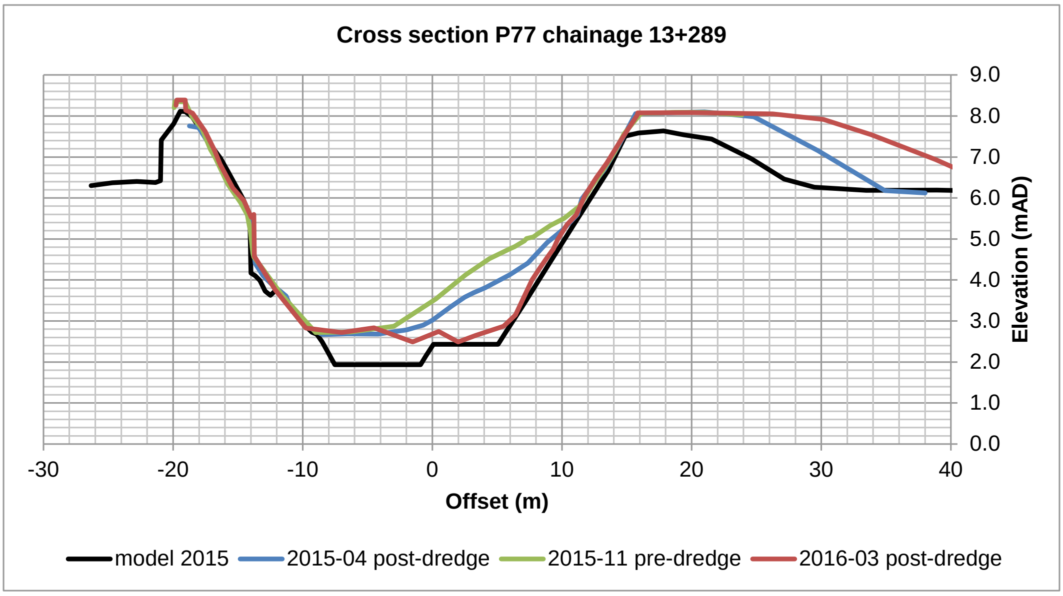

Figure 4.9: River Parrett cross-section showing siltation and maintenance dredging

Source: Data provided by the SRA

It is therefore recommended that a trapezoidal channel should be adopted with a relatively narrow bed width. This is the same approach to dredging as the Tone Valley Scheme. In this case it is likely that dredging will be required on both banks on the Parrett downriver of Northmoor, although this will depend on the detailed design. It may be possible to dredge one bank only on the Parrett upriver of the Tone confluence, as indicated in Appendix A, Figures A.12.and A.13. In both cases it will be necessary to minimise environmental impacts as far as possible, including undertaking dredging during the least damaging period (September to December).

If dredging is only undertaken on one bank of the river, vegetation management will be needed on the other bank to reduce the resistance to flow and the potential for trapping further sediment.

With regard to the maintenance of dredged channels, jetting or agitation techniques are proposed. Figure 4.10 and Figure 4.11 show sections of the River Tone and River Parrett that were dredged in 2014. The photographs were taken in 2016 and it is apparent that the amount of vegetation is limited and the effect on flood conveyance would not be large. This vegetation could be managed by regular maintenance, carried out in accordance with current good practice to minimise the overall impact on the environment.

There is a need to avoid or minimise the amount of consolidation of the sediment and vegetation growth so that the agitation/jetting methods are as effective as possible. This would require regular maintenance dredging to maintain the section shape including the bed and both banks.

Figure 4.10: River Tone upstream of the Parrett confluence

Source: Site visit, April 2016

Figure 4.11: River Parrett downstream of Burrowbridge

Source: Site visit, March 2016

4.4. Recommendations for hydraulic modelling

Hydraulic modelling is recommended in order to refine the design of the proposed dredging. The proposed tests are as follows:

4.4.1. River Brue

- Model the channel from upstream of Westhay Bridge to Highbridge with and without siltation to see the impact on bank full flow and, by implication, the impact on flood flows. This is proposed to see whether the currently proposed dredging would provide significant benefits. The modelling should take account of the trees and other vegetation in the lower reaches;
- Develop a hydraulic design for the river between Westhay Bridge and Highbridge in order to provide a river channel that can discharge flood flows without causing further flooding due to a restricted cross-section;
- Model the hydraulic design and then optimise the design based on the results of the modelling;
- Use the final hydraulic design to plan future dredging work.

The results for the River Brue should be presented in terms of water level profiles for specified design flows. The modelling should take account of tidal effects, and a mean spring tide is proposed at the downstream boundary. It is also proposed that steady fluvial inflows are used.

4.4.2. River Parrett and River Tone

- Develop hydraulic designs for the River Parrett both upriver and downriver of the confluence with the Tone. The designs will be as hydraulically efficient as is practically possible in order to avoid the need to continually remove sediment that re-accretes following dredging.
- Model the hydraulic designs to see the hydraulic benefits, particularly at North Moor, Kings Sedge Moor and upriver of Aller Moor.
- Model further combinations of dredging on the Parrett upriver of the confluence with the Tone and downriver of the existing and planned dredging near North Moor in order to determine the best combination of dredging at the two locations.
- Use the optimised combination of dredging at the two locations to plan future dredging work.

The results for the Parrett and Tone should include water levels at key spillways, overflow volumes and water levels in the main flood risk areas (including North Moor, Kings Sedge Moor and Muchelney Level).

4.5. Potential impacts of climate change

The potential impacts of climate change include increases in high river flows and increases in tidal water levels. These changes will increase flooding if mitigation measures are not implemented. The consequences of these changes on flooding in the Somerset Levels and potential mitigation measures are discussed in this section.

4.5.1. River flows

The latest projections provided by the Environment Agency for flood risk assessments are for increases in fluvial flows from the 1990s of 10% by the 2020s, 20% by the 2050s and 30% by the 2080s (Environment Agency 2016). The guidance also includes 'upper end' estimates of 25%, 40% and 85% respectively for the same three epochs. These increases are similar to those provided for scheme design and appraisal purposes (Environment Agency 2011).

Whilst there is considerable uncertainty in the estimates, it is clear that high fluvial flows are expected to increase. The Somerset Levels already experience frequent flooding and this problem is therefore likely to get worse.

Flows on the tidal Parrett, the tidal Tone and the Brue downstream of Glastonbury are unlikely to increase by these percentages because of the limited sizes of the river channels and the fact that more water will overtop the banks further upstream. However, increases in river flows will occur and flooding will become more frequent.

4.5.2. Sea level rise

The latest projections provided by the Environment Agency for flood risk assessments are for increases in sea level compared with the 1990s of 3.5 mm/year up to 2025, 8 mm/year up to 2050, 11.5 mm/year up to 2080 and 14.5 mm/year up to 2115 (Environment Agency 2016). These increases are similar to those provided for scheme design and appraisal purposes (Environment Agency 2011). This means that the projected rise in Mean Sea Level would be 0.87 m between 2016 and 2100.

The effect of sea level rise will be to increase tidal water levels on the Parrett and Tone, and cause fluvial flows to back up during high tide periods to a greater degree than at present. This will cause an increase fluvial flooding as a result of more overtopping of the spillways, and an increase in the risk of overtopping of the flood banks.

The effect of sea level rise on the River Brue will be to raise tidal water levels at Highbridge Clyse. This will reduce the available time when fluvial flows can discharge and increase the amount of backing up of fluvial flows in the river upstream of the Clyse. Ground levels are high upstream of Highbridge Clyse, and the effect of sea level rise on fluvial flooding will depend on the extent of backing up that occurs.

4.5.3. Mitigation measures

The general approach to managing increases in flood risk is by new or improved flood risk management measures including both structural and non-structural measures. These might include new or raised flood banks, new or enlarged flood storage areas, and improved flood resilience measures. Enlarging river channels is generally not considered to be a suitable measure because of the relatively low benefit cost ratio and also the high level of environmental impacts.

In the case of the Somerset Levels, channel enlargements have been used to reduce flood risk. The scope for further enlargement of the river channels in the tidal River Parrett and River Tone is very limited because of the limited width of the river corridor. Roads, buildings, flood banks and other features mean that these river channels cannot be easily widened without making changes to the existing buildings and infrastructure.

There is space to enlarge the River Brue over much of the length between Glastonbury and Highbridge. However it would be a relatively expensive operation for the amount of benefits that could be achieved. There would also be a need to maintain the enlarged channel. It is likely to be more cost-effective to provide improved flood protection for high risk areas and accept that low risk areas will flood more frequently.

There is an important opportunity to increase the flood resilience of the tidal River Parrett and the River Tone by the construction of a tidal barrier in the Parrett downriver of Bridgwater, and studies are currently in progress. Whilst the barrier is primarily for the protection of Bridgwater against tidal flooding, there are a number of ways in which the barrier could contribute to reducing the fluvial flood risk, as follows:

1. Closing the barrier at low tide during a fluvial flood event would create some flood storage in the River Parrett and the River Tone, thus reducing flood levels. The amount of storage that could be created and the impact on fluvial floods is under investigation, although previous work suggests that the flood reduction benefit may be small.
2. Closing the barrier during spring tides could help to reduce the amount of marine sediment that enters the system, thus reducing the amount of maintenance dredging that is needed. The use of existing sediment flux information together with additional monitoring could be used to identify when the sediment flux is greatest and when closure would be most beneficial. For example, the barrier could be closed during the rise of the largest spring tides each month. The barrier would be re-opened on the falling tide when upriver and downriver levels had equalised.

5. Dredging Methods

A review of established and novel dredging methods (including those used for the previous pioneer and maintenance dredging works) has been completed. The review included consultation with dredging contractors and dredging equipment manufacturers.

5.1. Overview of dredging methods

Dredging methods can be broadly characterised into three categories:

- Mechanical dredging – typically this involves excavation of the soil in its in-situ condition through the use of bucket dredgers, back-hoe or excavators.
- Hydraulic dredging – typically this involves disaggregation of the soil and subsequent transport as a slurry. This is often accomplished through the use of suction or cutter-suction dredgers.
- Hydrodynamic dredging – this technique involves the use of ambient currents or artificially generated currents to disperse dredge material created by disturbance, or fluidisation of the soil including bank silt. Agitation, water-injection dredgers and ‘jetting’ are in this category.

Dredging methods that fall into these 3 general categories have been considered in subsequent sections.

5.2. Comparison of appropriate dredging methods – Parrett System

An evaluation of potential specific equipment types that can be used on the Parrett System is given in Table 5.1. When evaluating the potential dredge and disposal methods the following *key* constraints were considered:

- Access to the dredging site – recent dredging operations have usually be achieved from the existing channel bank. However, in some locations the berm crest width is insufficient, or there is the presence of housing / infrastructure which does not allow working by bank-side excavator and therefore access from the water is required. Access is variable along both the Parrett and Tone and has been evaluated during previous pioneer and maintenance dredging works. There may be a need to identify locations where access improvements could be made to facilitate future dredging operations, but this will depend on the proposed methods. For example, there may be a need for a permanent access point for floating craft to undertake maintenance work.
- Operation – once the plant has been able to access the dredge site, the effectiveness of operation is affected by the type of excavation method employed (mechanical, hydraulic and hydrodynamic), the soil conditions, relative size of the equipment and other operational constraints (for example, is the equipment sufficiently manoeuvrable? Can it dredge above the water line as well as below the water line?).
- Environmental – There are several sensitive receptors in and around the Parrett System including protected nature conservation areas, rare invertebrates, protected mammal species, bird species and fish populations (including eels) – See Section 2.5.4. The process of dredging, irrespective of method chosen will impact upon these habitats and environments. However the choice and timing of methods can reduce these impacts. Mitigation measures have been identified in Section 2.5.6.
- Cost – where possible an appraisal of the relative costs of each dredging method has been undertaken. It is understood that the SRA is keen to identify ways in which dredging costs can be reduced.
- Disposal – in recent dredging operations the material has been excavated and either placed to the ‘back of bank’ or spread to farmer’s fields under various waste licences and exemptions. Some of the embankment structures are now estimated at ~7m wide at their crest and therefore the ‘back of bank’ disposal method is, in the longer-term, not considered sustainable. Specific consideration of the disposal methods has been made, and shown in Figure 5.2. Whilst disposal to agricultural land is potentially acceptable over the longer-term, there are costs associated with transportation of the dredge material and an element of investigation and planning is required to ensure that the material is spread in

compliance with regulations. Current practice also includes an element of transporting material to the site where the greatest benefit occurs, not to the nearest possible site.

- Specifically, with respect to maintenance dredging, the use of agitation and hydrodynamic techniques potentially offers a more sustainable dredge and disposal method compared to removing material from the system, however, its effectiveness needs evaluation.

5.3. Dredging methods - River Brue

No information is currently available with respect to the dredging methods that have been previously used on the River Brue. Exo-environmental (2014) has already produced a maintenance dredging method statement for dredging on the River Brue between Westhay and the confluence with North Drain. A review of this document has been made, and concludes that the use of bank side excavator with disposal using D1 exemption to 'back of bank' is an appropriate method.

5.4. Location specific considerations

Specific considerations for the future Pioneer 1 dredging from around Linden Farm to downstream of the M5 crossing include:

- Berm width – in some locations the berm crest or available bank space may be insufficiently wide for long-reach excavators to operate from. This will necessitate the use of floating / amphibious plant.
- Presence of overhead pylons upstream of Linden Farm. This would restrict dredging in these areas using long-reach excavators, although the pylons may be in the current (2016) 750m dredge.
- The River Parrett channel is constrained at the upstream and downstream end of this section, by the presence of Huntsworth Lane on the western-side of the channel and occasional farming and residential properties. This will mean that use of a D1 licence for disposal of the material will not be appropriate.
- For the majority of the section further downstream, where Huntsworth Lane leaves the River Parrett, bank working by long-reach excavators will be more practical – the flood bunds are set back from the channel edge.
- The channel once again becomes constrained downstream of the M5 by residential and other properties.
- Potential presence of key sensitive species, including water voles.
- Near to the M5 crossing, on the western side of the channel is "Screech Owl Nature Reserve", which is a local nature reserve. It is expected that access to the dredge site and disposal of dredge material through and in this area will not be permitted.
- Near to the M5 crossing, on the eastern side of the channel, River Lane and Dunwear encroach on the Parrett channel. Again this will mean that use of a D1 licence for disposal of the material may not be appropriate.

Specific constraints for the future Pioneer 2 dredge upstream of the Parrett and Tone confluence, along the River Parrett (a distance of around 4km) include:

- The River Parrett channel is constrained at the downstream end of this section, by the presence of residential properties along Stathe Road on the southern side of the channel. There are no properties along the northern side. This may require cross-channel or from within the channel working by a long-reach excavator.

- The northern side of the channel is bordered by a SSSI and Ramsar site (Southlake Moor). It is expected that access to the dredge site and disposal of dredge material through and in this area will not be permitted . The SSSI extends from the Tone confluence to Stathe, a distance of around 2.5km. This may mean that spreading of dredge material to fields will be the best available disposal method, using for examples a SR2010 No.9/No.10 permit allowing road transport or equivalent for the dredge material. However this assumption should be investigated in detail when planning this dredge because of the high cost of disposal and the need for suitable sites.
- Presence of Beazley's spillway between the River Parrett and River Sowy – disposal of dredge material to 'back of bank' will not be permitted at this location.
- Potential presence of key sensitive species, including water voles and hairy click beetle.
- Berm width – in some locations the berm crest may be insufficiently wide for long-reach excavators to operate from. This could require the use of floating / amphibious plant.

The proposed maintenance dredging activity on the Parrett and the Tone covers the entire reach of the previous and proposed pioneer dredge area. Therefore the constraints with respect to access, operation, sustainable disposal, environment etc. for the proposed pioneer dredging and the previously completed pioneer works will also apply to bankside operations and methods where disposal of material is required. However it is intended that much of the maintenance dredging will be undertaken using floating plant, thus avoiding many of these constraints. The effectiveness of these methods will be established by trials.

Location specific considerations for the River Brue will depend on the selected location of dredging. The main constraint for the reach between Westhay Bridge and North Drain is the SSSI. In addition, there are power lines that cross the river downstream of Westhay Bridge. Downstream of South Drain (Ch. 9000 on Figure 4.4) there are trees on both banks of the river which would severely affect dredging operations.

5.5. Beneficial re-use options for dredged material

Where possible sediment from dredging should be reused for beneficial purposes. The reuse of dredge material can have several benefits, including an increase in the sustainability of the dredging activity, reduction in overall cost of the dredging activity, and potential environmental enhancements (e.g. improvement in ecological status and provision of asset or amenity to local population).

It is important to establish whether the material is suitable for beneficial reuse. This could include assessment of the chemical, physical, biological and engineering properties of the dredged material and is dependent upon the intended use of the material. An important consideration is the cost benefit of using the dredged material, as some beneficial reuse options could increase the overall dredging costs.

A review of potential beneficial reuse options for the Parrett system and the River Brue has been made and the following observations are made:

- The land-use within the vicinity of the dredging is heavily controlled, it is principally agricultural land, with some areas designated as SSSI and/or Ramsar. This limits the options for developing material handling / processing facilities for disposal of large volumes of material. Specifically Standard Rules permits state that disposal to areas designated as SSSI and/or Ramsar sites is not permitted. However, there may be exceptions for particular cases where the impact can be accepted or mitigated. It is therefore suggested that discussions are held with the appropriate regulators to determine if exemptions can be made and bespoke permits issued for specific situations.

- The material type is predominantly silty – this generally makes the material unsuitable for extraction as an aggregate and subsequent resale to the construction industry.
- Presently there is no established industry able to accept the dredge material and process it for economic benefit (such as a soil processing facility or brick making factory). Development of this industry would require market assessment and capital investment. Whilst this investigation is beyond the scope of this report, there may be merit in exploring local opportunities for re-use.
- The dredge material has the potential of being reused locally in the following ways:
  - Repair and extension of existing river channel bunds – this would be covered under a U1 Waste Exemption. However the mass of material that can be disposed of in this way is relatively small compared to the pioneer dredge volumes;
  - Construction of new flood bunds around at risk properties or settlements – this would be covered under a Standard Rules SR2010 No.7 or No.8 (dependent upon the mass used);
  - Construction of new flood refuge areas (elevated sections) where farmers and the local population could store livestock or assets during flood periods - this could be covered under a Standard Rules SR2010 No.9 or No.10 (dependent upon the mass of material used for construction).
- At a broader scale, potential uses of silty dredged material on the Humber estuary include land raising, land improvement, aquaculture, topsoil, wildlife habitats and wetland restoration (Lonsdale, 2013). Some of these options are available on the Parrett, including land raising, land improvement and wildlife habitats/wetland restoration. In the latter case the material could be re-used in the construction of schemes designed to encourage or improve the ecological environment (such as bird habitat and wetlands). In this case the material would typically be used to raise the land levels to create a variety of habitat or used in the construction of bunds. However in all of these cases, the material would have to be moved from the site of dredging to the re-use site.

5.6. Recommended dredge methods

5.6.1. Pioneer 1

It is considered that generally the method adopted for the 8km pioneer dredge (i.e. long-reach excavator placing material to 'back of bank' using a D1 exemption or spreading to agricultural land using a 'SR2010 No.9/10') is likely to be the most appropriate method for future dredging works in the Pioneer 1 area. The justification for this is as follows:

- Trailer-Suction Hopper Dredgers are excluded on the grounds of access and operability at the dredge site.
- Cutter-Suction Dredger methods do not offer the required manoeuvrability and will have limited ability to dredge material above the waterline. The dredged material will be delivered hydraulically and the relatively large volumes of transport water will require management.
- Excavator methods offer distinct advantages when compared to these alternative methods:
  - It is expected that for the majority of the length of channel that requires dredging upstream of the M5 access from at least one bank will be possible. However, downstream of the M5 access is significantly more constrained.
  - As dredging has not occurred in this reach for an extended period of time, upstream of the M5 crossing there appears to be sufficient space along the bank for dredged material to be placed to the 'back of bank' in the majority of locations.

- In areas where bankside access is not possible (such as River Lane, Dunwear, the M5 crossing, potentially at Screech Owl Nature reserve and downstream of the M5 crossing), in order to reduce the additional mobilisation costs associated with pontoon work a recommendation would be to use amphibious excavators with adjustable spud-carriage. Barging of material and rehandling for disposal to agricultural land of this material would then be required (under a SR2010 No.9/10 exemption).

To reduce the amount of rehandling of the dredged material an alternative option could be to use a barge or small pontoon mounted hopper and pump, which is loaded by the amphibious excavator. The material is then pumped to and rehandled at site for disposal on to agricultural land (under a SR2010 No.9/10 exemption). The use of a piston pump would reduce the transport water required.

Confirmation of both the materials suitability for pumping in this way, and potential for reducing costs (pumping vs. barging and road transport) is required, and this alternative method could be trialled on a relatively small scale at the start of any future pioneer dredging operations. The use of a low-water content pump is considered as a sensitivity in the estimated costs.

A particular concern in this part of the river will be the salinity of dredged material, as this will affect disposal and use of the material. An assessment of salinity should therefore be made as part of the planning of dredging operations.

5.6.2. Pioneer 2

As with Pioneer 1, it is considered that generally the method adopted for the 8km pioneer dredge (i.e. long-reach excavator placing material to 'back of bank' using a D1 exemption) is likely to be the most appropriate method for future dredging works in the Pioneer 2 area. The justification for this is as per the Pioneer 1, plus:

- It is expected that for the majority of the length of channel that requires dredging, access from at least one bank will be possible.
- As dredging has not occurred in this reach for an extended period of time and there is sufficient space along the bank for dredged material to be placed to the 'back of bank' in the majority of locations.
- From site inspection, it appears that access to the dredge locations are possible from the bankside. However, disposal to back of bank in all locations may not be appropriate due to the presence of Southlake Moor SSSI and Beazley's spillway. Subject to suitability, in this case the dredged material could be disposed to agricultural land (under a SR2010 No.9/10 permit). If disposal to back of bank can be permitted in the SSSI, a D1 exemption could be applied. Disposal on the spillway is unlikely unless measures can be implemented to prevent erosion when overtopping of the spillway occurs.

As with the Pioneer 1 locations, to reduce the amount of rehandling (and cost) of the dredged material an alternative option could be to use a land based hopper and pump, which is loaded by a bankside excavator. The material is then pumped to and rehandled at site for disposal on to agricultural land (under a SR2010 No.9/10 permit).

The use of a piston pump would reduce the transport water required. Confirmation of the materials suitability for pumping in this way is required.

Table 5.1: Evaluation matrix – potential relevant dredging techniques for Parrett System

	Dredging Technique						
Category	**Trailer Suction Hopper Dredger**	**Cutter Suction Dredger**	**Long-reach Excavator (including Pontoon use)**	**Amphibious Excavator**	**Amphibious Excavator with Cutter-suction adaptor**	**Water Injection / Jetting Technique (Vessel Based)**	**Water Injection / Jetting Technique (Land Based)**
Site access	1) Scale of plant means requires access to Parrett and Tone from downstream end. 2) Min. draft of 2m loaded. 3) Bridges and other waterway obstructions (bend radii)	1) Launch / recovery location required. 2) Limited to water of sufficient draft. 3) Land support required.	1) Requires wide stable platform free of structures (observe weight limitations) 2) Large area within reach but only suited to lengths where both banks are accessible if full width dredging to be completed. 3) Needs supporting barge/truck for movement over larger distances (between dredge sites). 4) Launch / recovery location required for pontoon.	1) Launch / recovery location required. 2) Large area within reach and could work both banks from centre of channel (reducing size of machine) 3) Needs supporting barge/truck for movement over larger distances (between dredge sites). 4) Removes need for pontoon 5) Water depth not an issue if 'spuds' used 6) Launch / recovery location required for pontoon - more flexible than pontoon.	1) Launch / recovery location required. 2) Large area within reach and could work both banks from centre of channel (reducing size of machine) 3) Needs supporting barge/truck for movement over larger distances (between dredge sites). 4) Removes need for pontoon 5) Water depth not an issue if 'spuds' used	1) Launch / recovery location required. 2) Limited to water of sufficient draft. 3) No Land support required.	1) Relatively un-restricted (footprint equivalent to 4x4 plus trailer)
Operation	1) Smallest equipment too large to be used within existing channels and location of sedimentation (on banks) suggests this would be an inappropriate method.	1) Would only be able to dredge material at or below water line only (pumping limitation). 2) Material located on banks rather than bed of river means this method would be restricted in effectiveness.	1) Easily cope with both pioneer and maintenance dredge ground conditions (including vegetation) - including location of material relative to bank. 2) Can produce design slope easily and accurately. 3) Most convenient method if disposal to 'back of bank' 4) Consistent and manageable productivity	1) Easily cope with both pioneer and maintenance dredge ground conditions (including vegetation) - including location of material relative to bank. 2) Requires support barges / rehandling in wide channel areas. 3) Can produce design slope easily and accurately. 4) Most convenient method if disposal to 'back of bank' 5) Consistent and manageable productivity	1) Can cope with both pioneer and maintenance dredge ground conditions (including vegetation) 2) Cutting and pumping limited to areas at or below water line (pumping), but highly controllable below waterline. 3) Can produce design slope easily and accurately. 4) Optimum productivity developed through site experience. 5) Requires correct tidal and freshwater conditions for dispersion of material	1) Potentially high productivity when working. 2) Requires correct tidal and freshwater conditions. 3) Jetting above the waterline could be done using modified / specialist equipment. 4) May be used to instigate (controlled) slope collapse. 5) Limited use in vegetated areas. 6) Difficult to determine precise production without survey data. 7) Vessel can 'chase' dispersed material down channel to encourage flushing 8) Optimum productivity developed through site experience.	1) Lower productivity than vessel based 2) Requires correct tidal and freshwater conditions. 3) Can work above the waterline 4) May be used to instigate (controlled) slope collapse. 5) Material cannot 'chased' as effectively as vessel based method 6) Optimum productivity developed through site experience.
Environmental Impact	1) Generates increased suspended sediment concentrations.	1) Generates increased suspended sediment concentrations. 2) Proportion of dredged material could be spilt and could require clean up if not dispersed - reducing effectiveness	1) More control over losses of dredge material to system 2) Access along banks / slopes can cause local temporary damage	1) More control over losses of dredge material to system 2) Access along banks / slopes can cause local temporary damage	1) Access along banks / slopes can cause local damage 2) Dredge material dispersed to wider environment by ambient currents 3) Generates increased suspended sediment concentrations.	1) Generates increased suspended sediment concentrations. 2) Dredge material dispersed to wider environment by ambient currents	1) Generates increased suspended sediment concentrations. 2) Dredge material dispersed to wider environment by ambient currents
Disposal	1) Discharge to containment and dewatering facility. 2) Significant volumes of transport water to deal with. 3) Or disposal site at mouth of Parrett or offshore (dumping site) - order 4 times solids volume 4) MMO licencing possibly required for this activity.	1) Discharge to containment and dewatering facility. 2) Significant volumes of transport water to deal with. 3) MMO licencing possibly required for this activity.	1) Material can be placed to 'back of bank' (D1). (Pioneer work) 2) Material will require transport to disposal site if 'back of bank' is not an option (Maintenance work) 3) Material has low water content 4) Sediment removed from the system	1) Material can be placed to 'back of bank' (D1). (Pioneer work) 2) Material will require transport to disposal site if 'back of bank' is not an option (Maintenance work) 3) Material has low water content 4) Sediment removed from the system	1) Material dispersed by ambient currents for maintenance material 2) MMO licensing possible required for this activity 3) Material retained in the system, there no requirement of disposal facility / location	1) Material dispersed by ambient currents (specific conditions required) 2) MMO licensing possible required for this activity 3) Material retained in the system, there no requirement of disposal facility / location	1) Material dispersed by ambient currents (specific conditions required) 2) MMO licensing possible required for this activity 3) Material retained in the system, there no requirement of disposal facility / location
Relative costs (Pioneer)	N/A	N/A	1) High mobilisation cost (particularly for supporting equipment) 2) High transport costs for disposal material if 'back of bank' not used	1) High mobilisation cost (but less than pontoon) 2) High transport costs for disposal material if 'back of bank' not used	1) High mobilisation cost (but less than pontoon) 2) Specialist cutter adapter to excavator will cost a premium	N/A	N/A
Relative costs (Maintenance)	N/A	N/A	1) High mobilisation cost (particularly for supporting equipment) 2) High transport costs for disposal material if 'back of bank' not used 3) Cost per m3 dredged low if bankside, high if from pontoon	1) High mobilisation cost (but less than pontoon) 2) High transport costs for disposal material if 'back of bank' not used 3) Cost per m3 dredged low to medium	1) High mobilisation cost (but less than pontoon) 2) Specialist cutter adapter to excavator will cost a premium 3) Cost per m3 dredged potentially low - but depends how contractor recovers cost of cutter adapter	1) Low mobilisation cost - self propelled 2) Cost per m3 low	1) Low mobilisation cost 2) Cost per m3 low
General comment	Not a practical method	More practical than TSHD but disposal facility and transport water key issue. Unlikely to be practical unless disposal / dewatering facility available	Established method on Parrett and Tone. Effective at both maintenance and pioneer dredging but long-term disposal not sustainable to 'back of bank'	Method used on Parrett and Tone previously. Effective at both maintenance and pioneer dredging but long-term disposal not sustainable to 'back of bank'. Advantage of amphibious dredger is increased access.	Method considered to be most effective for maintenance dredging by when done 'little and often' to create a slurry ('agitating') dredge material that can then be released to river channel and dispersed under correct conditions (ebb tide / freshwater flow). Considered to be less effective than conventional excavator work for pioneer work where disposal to 'back-of-bank' is an option.	Method considered to be most effective for maintenance dredging when done 'little and often' to create agitate dredge material so that it can be dispersed under correct conditions (ebb tide / freshwater flow). Considered unsuitable for Pioneer work (strength of material and density of vegetation)	Method considered to be most effective for maintenance dredging when done 'little and often' in support of Excavator with cutter adaptor or convention WID. Considered unsuitable for Pioneer work (low production rate, strength of material and density of vegetation)
Potential Method?	**No**	**Unlikely**	**Yes - Pioneer** **Yes - Maintenance**	**Yes - Pioneer** **Yes - Maintenance**	**Yes - Maintenance** **Unlikely - Pioneer**	**Yes - Maintenance** **No - Pioneer**	**Yes - Maintenance** **No - Pioneer**

Table 5.2: Evaluation matrix – potential relevant disposal methods for Parrett System

Category	**'Back of Bank'**	**Spreading to field for agricultural improvement (mechanical)**	**Spreading to field for agricultural improvement (hydraulic)**	**Containment facility (mechanical)**	**Containment facility (hydraulic)**	**Dispersion in water course (both vessel and land based)**
Licencing	1) Performed under Environment Agency 'D1'	1) Performed under Waste Regulation exemption 'U10'	1) Unknown - requires consultation with the EA. 2) Potential variation of 'U10' exemption	1) Unknown - but possible exemptions include; SR2010 No. 9 and 10, SR2010 No. 11 and No.12 and SR2010 No.18	1) Unknown - but possible exemptions include; SR2010 No. 9 and 10, SR2010 No. 11 and No.12 and SR2010 No.19	1) Likely to require approval by MMO (and or EA) in tidal sections of Parrett and Tone
Benefits	1) Convenient method with little or no transport of dredged material	1) Convenient method when 'Back of Bank' not possible. 2) Longer-term disposal option - assumed that cycling of fields required to prevent excessive build up of salinisation.	1) Reduces transport costs compared to mechanical methods. 2) Longer-term disposal option - assumed that cycling of fields required to prevent excessive build up of salinisation.	1) Potential longer-term storage option - material could be reused (resold): e.g. processed, washed and then incorporation as topsoil / fill. Material used as construction material (fill for embankments or flood bunds).	1) Potential longer-term storage option - material could be reused (resold): e.g. processed, washed and then incorporation as topsoil / fill. Material used as construction material (fill for embankments or flood bunds).	1) Potentially most sustainable method - material not 'stored' for maintenance work
Constraints	1) 50m3/m of bank limit in 12 months. 2) Non-sustainable disposal option longer-term (berm width increased too much)	1) 150T/Hectare limit spread and 1250T/Hectare stored 2) Transport required 3) Material must satisfy requirement that provides an improvement to the quality of the land which it is being spread to	In addition to mechanical: 1) Material must be suitable for pumping - geotechnical assessment required 2) Transport water requires management. (This can be reduced using low water content slurries) 3) Pumping distance - limitation 4) Logistical consideration - pipelines creating obstructions	1) Requires longer-term commitment to facility (availability of land). 2) Supporting equipment and resources to transport, process and handle dredged material (costs) 3) Assumption there is a market for resale / reuse of material 4) Delivery of dredged material - facility(ies) will be focal point and therefore impact on traffic / local population required.	1) Requires longer-term commitment to facility (availability of land). Likely that smaller and more numerous facilities due to reduced pumping distances over road transport. 2) Supporting equipment and resources to transport, process and handle dredged material (costs) 3) Assumption there is a market for resale / reuse of material 4) Management of tailwater will be a key issue.	1) Specific hydrodynamic conditions required, most successful expected to be: a) (Spring) Ebb tide b) (with or conditions dominated by) Freshwater discharge 2) Dredging operations will need detailed planning as well as 'reactive' approach (unpredictability of freshwater discharge) 3) Adapted or specialised equipment required due location of sediment build up (can be above the water line)
Environmental considerations	1) Direct effect on existing embankment habitat (land side).	1) (Short-term) effect on salinity of land that material is spread on to. 2) Material only spread if proved to be of agricultural benefit	1) Effect on salinity of land that material is spread on to likely to be greater due to additional volume over mechanical method. (Larger area required and thinner spread of material)	1) Assumed permanent footprint - site selection assessment important 2) Longer-term effect on salinity of land (and water table) that material is spread on to it	1) Assumed permanent footprint - site selection assessment important 2) Longer-term effect on salinity of land (and water table) that material is spread on to it (likely to be greater than mechanical delivery due to increased volume of transport water)	1) Increased suspended sediment concentrations (should be assessed in context of very high levels of background suspended sediment load)
Cost considerations	1) Relatively cheap method - no transport and method is not a constraint on production. 2) Compensation to land-owners not required (Land Drainage Act)	1) Expense associated with transportation - assumption that landowners take material for 'free'. 2) Costs associated with planning of disposal and testing of material. 3) Not suitable if salinity is too high.	1) Reduction in cost associated with transportation but reduction offset by requirement to have methods to manage transport water (equipment, pumps, weirs). 2) Therefore cost neutral compared to mechanical (overall)?	1) Likely to be relatively significant investment (land purchase / rental plus equipment) 2) Is there a market for resale / reuse? 3) If market exists possibility to recover dredging costs	1) Likely to be relatively significant investment (land purchase / rental plus equipment) 2) Is there a market for resale / reuse? 3) If market exists possibility to recover dredging costs	1) Likely to require adapted or specialised equipment - cost premium associated with this, but can be offset over longer-term use 2) Both vessel and bank based methods would be relatively cheap to operate
Currently used?	Yes	Yes	No	No	No	No - used historically
General comment	1) Probably most cost-effective method for small volumes per m of channel. 2) Established method.	1) Option when material cannot be placed to back of bank (or not practical to do so). 2) Additional cost associated with transport (and compensation if agreed) - can be costly if haul distance is high 3) Assessment of material quality (salinity) required 4) Established method	1) Cost- benefit over mechanical method not clear 2) Material needs to be assessed for suitability for pumping 3) Likely to be location specific - i.e. where transport distance by road are too great / impractical 4) Licensing requirement not clear	1) Method requires further study and evaluation 2) Likely to require investment in handling equipment and resources 3) Method is probably for future longer-term consideration - viability affected by market demand for material.	1) Method requires further study and evaluation 2) Likely to require investment in handling equipment and resources 3) Method is probably for future longer-term consideration - viability affected by market demand for material.	1) Likely to be cost effective and sustainable method for disposal of maintenance material 2) Trials required to evaluate effectiveness as a total solution
Potential future method?	**Yes**	**Yes**	**Possible - requires further study.**	**Unlikely**	**Unlikely**	**Possible - trials required.**

5.6.3. Maintenance – Parrett System

The current maintenance dredging method is very similar to the pioneer dredge method (i.e. the use of bankside or pontoon mounted excavators with disposal under a D1 exemption or SR2010 No.9/10 permit). However, it is proposed that an alternative dredge method (agitation and hydrodynamic) could be trialled to evaluate its effectiveness for maintenance dredging.

It is expected that use of this dredging method will require a licence from the MMO and supporting environmental impact assessments, as this will affect water quality (suspended sediment concentrations) proportionally more than the dredging methods that have been used previously for the pioneer and maintenance works. However, as stated in Section 0 under Article 18A of the 2013 Exempted Activities Order it may be possible to undertake small scale trial (up to 500m^3) of this technique, without the need for a licence, provided the MMO is informed.

Justification for recommendation

There are several factors that suggest the use of agitation and / or a hydrodynamic method would be appropriate:

- The material type (predominately silt with fine sand) is suitable for dredging using this type of method. Specifically, the maintenance dredge material is expected to be less consolidated compared to the pioneer material. This will allow the maintenance material to be more readily excavated / eroded (i.e. less force is required);
- Evidence suggests that under the correct combination of conditions, flows within the Parrett system can be used to transport the maintenance dredge material away (downstream) from the dredge. However, the effectiveness of the technique will be very dependent upon the prevailing conditions.

Example equipment and methods

Two potential methods for undertaking maintenance dredging using an agitation / hydrodynamic technique have been identified:

- Use of a water injection dredger (WID) (Figure 5.1 andFigure 5.2) - the vessel could also include additional water jets (for use above the water surface) to spray / wash the banks in areas where the dredge material has accumulated above the waterline. The capability of a WID could be augmented by adding these above surface jets, and also increasing the directional control of the water jet from the spray bar.
- Use of a modified amphibious excavator dredger (MAE) with a cutter-pump attachment (Figure 5.3 and Figure 5.4).

The WID would be used to inject high pressure water into the river bed and mobilise sediment, which would then be dispersed by the prevailing currents. To increase the effectiveness, the dredge could also ‘chase’ the mobilised sediment downstream using the high-pressure water jets.

As an alternative to this method, an amphibious excavator fitted with a cutter-pump adapter could be used to disaggregate material from the bank and pump the slurry back to the water a short distance away (say 20-50m) for dispersion by the prevailing currents. Consideration should also be given to silt removal from the banks by a barge mounted excavator.

Each of these methods have different benefits and dis-benefits, for example:

- The WID can be used to ‘chase’ the dredged material downstream and encourage dispersion – this would be more difficult to achieve with the MAE.
- The MAE can be used to accurately control the bank profile created – the WID would have less control over the bank profile and dredged quantity released.
- The MAE would have more consistent and controllable production – the WID will be limited by the conditions suitable to dredging.
- With minor modification (additional jets) the WID would be able to dredge above the waterline – the MAE would not be able to dredge above the waterline (pump requirements).

Monitoring of the effectiveness of these methods is difficult because of the dynamic nature of the processes. It is recommended that the high resolution pre-and post-dredging surveys should be used for monitoring rather than attempting to use tracer technology.

Figure 5.1: Example small scale WID (not self-propelled)

Source: Image courtesy of Faversham Creek Trust

Figure 5.2: Example small scale WID (self-propelled)

Source: Image courtesy of GPS Marine

Figure 5.3: Example Amphibious excavator

Source: Image courtesy of Land and Water Services

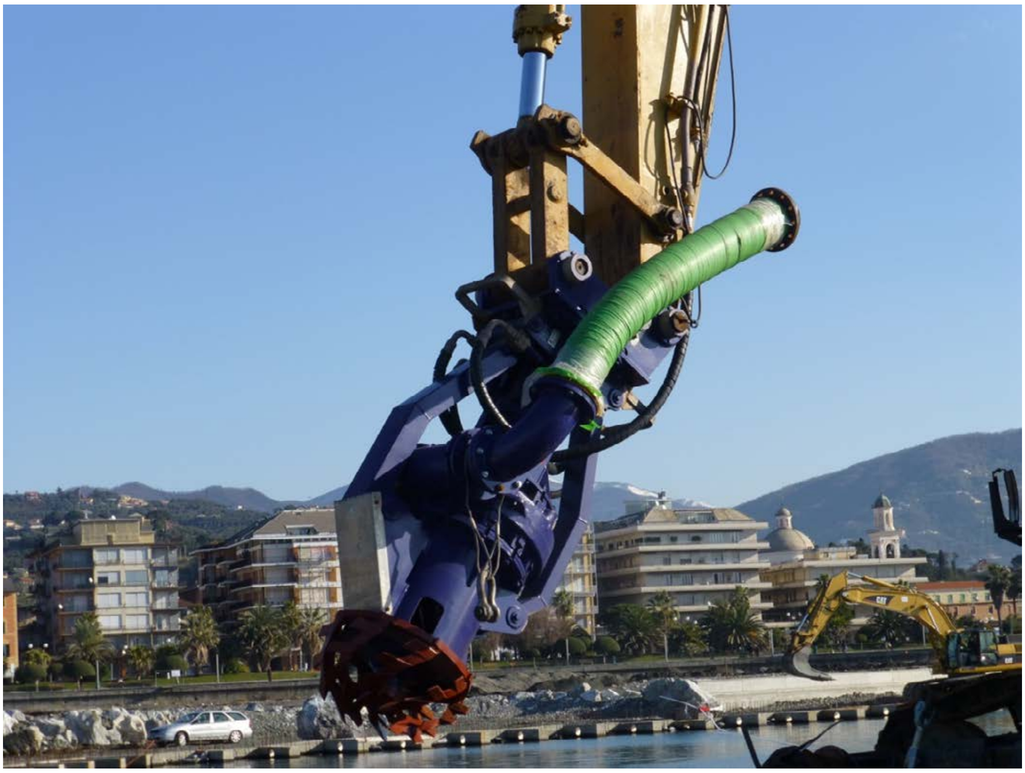

Figure 5.4: Example Cutter Pump adaptor for an excavator dredger

Source: Image courtesy of Italdraghe

5.6.4. Maintenance 1

This section of the maintenance dredge (4.8km) is located around the mid-reach of the Parrett system where previous pioneer and maintenance dredging has already been completed. Trials of an agitation / hydrodynamic method is recommended in this section as some areas are likely to be now due for maintenance dredging. Once the viability of this technique has been established it could be deployed to other sections of the Parrett system. Key considerations include:

- Locations where a WID vessel or similar could be launched from is required. It would be possible to sail a vessel up from a launching / jetty location in or around Bridgwater.
- It is assumed the MAE would launch close to the dredge site without the requirement for crane assistance.
- The length of the flood tide is estimated at around 2 to 2.5 hours in duration at this location, with significant bias in the tidal currents. Therefore, to maximise dredging efficiency it is suggested that dredging takes place following slack water at high tide, as the ebb tide current begins to accelerate.
- Dredging at this point in the tide offers several benefits:
  - Water levels are at a relative maximum – meaning that more of the sediment that requires dredging is under water and accessible to conventional WID equipment and the MAE.
  - Once sediment is mobilised by the WID or MAE the flow direction is downstream.
  - The WID can be used to 'chase' or push the agitated sediment, now in suspension downstream augmenting the effects of the natural (ebb) current – this is considered an advantage over the MAE.

- If the WID technique is deemed to be successful following evaluation of the dredging trial, it is suggested that the dredging equipment could be modified to including jets for washing the bank above the water line. The MAE could be used to induce controlled slope collapse for material above the water line.
- Siltation rates are expected to be variable over the length of this section, with higher siltation rates expected at the downstream end. Therefore, proportionally greater dredging effort will be required in this area.
- The specific conditions under which the dredging technique will be most successful is dependent upon the combination of tidal and freshwater flow:
  - Times when the dredging technique should not be used – during any flood tide conditions;
  - Time when the dredging technique will be less successful – during neap ebb tides, and ebb tides with little or no freshwater flow;
  - Times when the dredging technique will be most successful – during spring ebb tides with moderate to high freshwater flow.

5.6.5. Maintenance 2

This section of the maintenance dredge (3.5km) is located at the most downstream end of the Parrett system where dredging is recommended. The use of agitation / hydrodynamic dredging is recommended in this area once pioneer dredging has been completed and the viability of agitation / hydrodynamic dredging has been established.

This area is expected to have the highest siltation rates, and therefore will require the largest proportion of maintenance dredging effort. Specifically, around 4 times the amount of dredging is estimated to be required in this area compared to Maintenance 1.

5.6.6. Maintenance 3

This section of the maintenance dredge (4.0km) is located on the previously dredged River Tone. Trials of an agitation / hydrodynamic method is recommended in this section as some areas are likely to be now due for maintenance dredging. This section also represents a different hydrodynamic environment to the Maintenance 1 area, for the following reasons:

- Tidal characteristics are different – the flood tide is less than 2 hours in duration, allowing for a longer, and on average, slower flowing ebb tide. The tide range is also smaller.
- Water depth changes associated with neap tides are less pronounced – affecting the duration of time that sediment that requires dredging is below the water line.
- Freshwater flow will have a greater relative effect on the flow characteristics within the channel – therefore the combination of conditions when agitation / hydrodynamic dredging is not effective / most effective will be different to that further downstream (for example at the Maintenance 1 area).

5.6.7. Maintenance 4

This section of the maintenance dredge (4.0km) is located on the upstream River Parrett. Observations made for Maintenance 3 relating to an agitation / hydrodynamic dredging method are also applicable for this location.

The use of agitation / hydrodynamic dredging is recommended in this area once Pioneer dredging has been completed and the viability of agitation / hydrodynamic dredging has been established.

5.7. Estimated Dredging Costs

An assessment of dredging costs has been made, based on the information made available (including high-level costs for the 8km pioneer dredging, detailed costs for the 2.2km maintenance dredging and supplementary tender information). HR Wallingford has also considered other sources of information including the CIRIA cost standards and our own project experience.

The dredging costs do not include supporting activities such as environmental surveys and mitigation measures.

5.7.1. Approach for pioneer dredging

The proposed pioneer dredging methods are outlined in Section 5.6. The estimated costs consider the following:

1. Method 1 - Use of Excavator Dredging and disposal to back of bank using a D1 exemption;
2. Method 2 - Use of Excavator Dredging and disposal for agricultural benefit (using a SR2010 No.9/10 standard rules permit) including transport to disposal location.

Cost sensitivity to using alternative methods has been calculated:

3. Method 3 - Use of an amphibious excavator instead of pontoon mounted plant (in order to reduce the costs associated with mobilisation and deployment of the pontoon);
4. Method 4 - Use of a low-water content pump to transport material from the point of dredging a distance of 1km, using an amphibious excavator. The excavator would load a hopper and pump system designed to transport high solids content material (this is an attempt to avoid intermediate handling).

5.7.2. Approach – Maintenance

The proposed maintenance dredging methods are outlined in Section 5.6. The estimated costs consider the following:

1. Use of a WID to mobilise sediment and ‘chase’ the material downstream from the point of dredging.
2. Use of a MAE to disaggregate sediment and pump it back into the channel.

5.7.3. Estimated Costs – Pioneer

Estimated costs of pioneer dredging are shown on Table 5.3.

Table 5.3: Estimated costs of pioneer dredging

Method	Estimated Value / Cost (£/m^3)	Estimated Value / Cost (£/m^3)	Estimated Mobilisation, Demobilisation and other contractor overheads (£)	Estimated Mobilisation, Demobilisation and other contractor overheads (£)	Estimated design, permitting and compensation (non-contractor overheads)(£/m^3)
	Low	High	Low	High	At 25% of the average base dredge rate[1]
Method 1 – Excavator to 'back of bank'	5.2[2]	8.5[3]	£150,000[4]	£250,000[5]	1.7
Method 2 – Excavator and disposal for agricultural benefit	23.1[6]	37.5[7]	Same as Method 1	Same as Method 1	Same as Method 1
Cost change using Method 3 instead of Method 2	-3.8	-4.5	Within estimate range – although likely to be at lower end (no pontoon)	Within estimate range - although likely to be at lower end (no pontoon)	Same as Method 1
Cost change using Method 4 instead of Method 2	-7.2	-11.6	Within estimate range	Within estimate range	Same as Method 1

[1] Information provided by EA (20 April 2016) suggests that 25% of project costs for the 8km pioneer dredged were associated with 'over-heads' (e.g. design and supervision, compensation and land access etc.) and not dredge contract costs. Therefore we assume as some of these costs will be fixed, a value of £1.7/m^3 for similar, non-contractor related overheads for the next phase of pioneer dredging work.

[2] Low unit rate derived from tender return information for most recent maintenance dredging works – this is for 'back of bank working'. Data provided by the SRA (14 April 2016)

[3] High unit rate derived from tender return information for most recent maintenance dredging works – this is for 'back of bank working'. Data provided by the SRA (14 April 2016)

[4] Low mobilisation cost based on low range obtained from tender return information for most recent maintenance dredging works. Mobilisation methodology would be same for future pioneer dredge using similar dredge methodology. Data provided by the SRA (14 April 2016)

[5] High mobilisation cost based on high range obtained from tender return information for most recent maintenance dredging works. Mobilisation methodology would be same for future pioneer dredge using similar dredge methodology. Data provided by the SRA (14 April 2016)

[6] Low unit rate derived from tender return information for most recent maintenance dredging works – this is for pontoon mounted and then disposal for agricultural benefit. Data provided by the SRA (14 April 2016)

[7] High unit rate derived from tender return information for most recent maintenance dredging works – this is for pontoon mounted and then disposal for agricultural benefit. Data provided by the SRA (14 April 2016)

Table 5.4 to Table 5.7 provide a summary of the breakdown of dredging costs for the two main methods, and the cost differences for the alternative methods for method 2. It assumed, that 50% of the pioneer dredge volume will be disposed of to back of bank using a D1 exemption, and 50% will be disposed of for agricultural benefit using a SR2010 No.9/10 permit.

Table 5.4: Pioneer 1 cost estimate breakdown – Total dredge volume 50,000m^3

Dredge Volume	Cost Estimate (low range)	Cost Estimate (high range)
Non-contractor over-head (rate x volume)	£85,000	
Mobilisation	£150,000	£250,000
Cost of dredge (rate x volume) – Assume 50% is 'back of bank' under D1	£131,000	£212,000
Cost of dredge (rate x volume) – Assume 50% is disposal to agricultural benefit under SR2010 No.9/10	£577,000	£937,000
Total	**£943,000**	**£1,485,000**

Table 5.5: Pioneer 2 cost estimate breakdown – Total dredge volume 40,000m^3

Dredge Volume	Cost Estimate (low range)	Cost Estimate (high range)
Non-contractor over-head (rate x volume)	£68,000	
Mobilisation	£150,000	£250,000
Cost of dredge (rate x volume) – Assume 50% is 'back of bank' under D1	£105,000	£170,000
Cost of dredge (rate x volume) – Assume 50% is disposal to agricultural benefit under SR2010 No.9/10 with pontoon mounted excavator	£462,000	£750,000
Total	**£784,000**	**£1,238,000**

Table 5.6: Pioneer 1 cost estimate breakdown using Method 3 instead of Method 2

Total dredge volume 50,000m^3

Dredge Volume	Cost Estimate (low range)	Cost Estimate (high range)
Non-contractor over-head (rate x volume)	£85,000	
Mobilisation	£150,000	£250,000
Cost of dredge (rate x volume) – Assume 50% is 'back of bank' under D1	£131,000	£212,000
Cost of dredge (rate x volume) – Assume 50% is disposal to agricultural benefit under SR2010 No.9/10 with amphibious excavator	£483,000	£784,000
Total	**£848,000**	**£1,331,000**

Table 5.7: Pioneer 1 cost estimate breakdown using Method 4 instead of Method 2

Total dredge volume 50,000m^3,

Dredge Volume	Cost Estimate (low range)	Cost Estimate (high range)
Non-contractor over-head (rate x volume)	£85,000	
Mobilisation	£150,000	£250,000
Cost of dredge (rate x volume) – Assume 50% is 'back of bank' under D1	£131,000	£212,000
Cost of dredge (rate x volume) – Assume 50% is disposal to agricultural benefit under SR2010 No.9/10 using a low-water content pump to transport material 1km	£398,000	£646,000
Total	**£764,000**	**£1,194,000**

The overall effect of using Method 3 in place of Method 2 is to reduce the estimated cost by around 10%. The main cost saving is associated with the use of the amphibious excavator dredger. This eliminates the need for mobilisation and use of a pontoon.

The overall effect of using Method 4 in place of Method 2 is to reduce the estimated cost by around 20%. The main cost saving is associated with the use of the amphibious excavator dredger and low water content pump instead of barges to transport material up to 1km from the dredge site. This eliminates the need for mobilisation and use of a pontoon for the excavator, and also eliminates the need for barges to transport material from the dredge site to the bank.

It should be noted that the actual costs will vary, and will be driven by a Contractors equipment availability and choice, as well as commercial considerations.

5.7.4. Estimated Costs – Maintenance

A summary of the estimated costs of maintenance dredging are shown in Table 5.8.

Table 5.8: Maintenance 1 to 4 cost estimate breakdown

Total dredge volume 98,000m^3/yr, comprising of 35,000m^3/yr from Maintenance 1; 50,000m^3/yr from Maintenance 2 and 13,000m^3/yr from Maintenance 3 and 4.

Dredge Volume	Cost Estimate (low range)	Cost Estimate (high range)
Non-contractor over-head (rate x volume)[8]	£9,800	
Mobilisation[9] (fixed fee)	£5,000	£150,000
Dredge Rate[10] (based on production, duration and costs)	£3.3/m^3	£5.5/m^3
Total	**£340,000**	**£700,000**

5.8. Monitoring approach

5.8.1. Proposed method

The topographic and bathymetric survey technique presently used makes use of a real-time kinematic (RTK) GPS measurement method. Point measurements of elevation at spacing of around 1-1.5m on transects 50m apart are made. Whilst this is an established method, it does have drawbacks:

- The data collected does not provide high resolution or full coverage of the river channel;
- Because of the method used to collect the bathymetry data, additional uncertainty is introduced to the data beyond that inherent to the survey equipment.

Our recommendation is to use sonar (Multi-Beam Echo Sounder) for bathymetric data collection and an aerial based photogrammetry survey technique for topographic data. Both techniques would be supported by kinematic GNSS (Global Navigation Satellite System) positioning. This has the potential to provide increased accuracy in elevation and position (to order 50mm), improved horizontal resolution (sub-1m) and greater coverage compared to the current methods. The product of the surveys could be used to develop a high-resolution 3D digital elevation model (DEM) of the surveyed area. This can then be used to provide:

- Variations in channel and river bank elevation levels at higher resolution than presently available;

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[8] A rate of £0.1/m^3 has been assumed for non-contractor overheads, bearing in mind the reduced access requirement and disposal constraints. It is assumed that very limited design work would be required, as the design would reference the pioneer dredge design work.

[9] For the WID the quoted mobilisation to site fee is £5,000. For the MAE a low-estimate (£150,000) based on tender return information for mobilising excavator and supporting equipment to site for the recent maintenance dredging work.

[10] Dredge rate based on: WID daily cost of £2000, working for 6 hours and a dredge rate of 100m^3/hr. For the MAE this cost includes for additional cost of cutter adapter.

- A much more accurate assessment of potential dredging quantities;
- An understanding of the changes and development of channel morphology to inform dredging campaigns.

For bathymetric survey works the platform used would be a remotely operated vessel (ROV) whilst for topographic survey unmanned aerial vehicle (UAV) are typically used. The bathymetry survey would be completed at times of high water level, and the topographic survey at times of low water level.

The survey instrumentation and high resolution positioning information would be mounted on the surface vehicle and is operated by remote control by a surveyor on the ground, who guides the vessel along a pre-planned survey track. The vehicle's position is displayed in real time on a visual display such as tablet or laptop PC. This remote operation is made possible by the telemetry link, typically based on UHF radio, which allows two way communication between the vehicle and the operator such that the vehicle's position can be displayed in real time along with the bathymetric data being acquired and commands sent back to the vehicle to manoeuvre it over the planned track.

Other variants include fully autonomous vehicles where the vehicle is pre-programmed with a mission plan (survey track) which is executed automatically by the vehicle, again taking input from the vehicle's on-board positioning system, and returning to the operator once the mission is completed.

Figure 5.5: ROV used to collect (sonar) bathymetry data

Figure 5.6: UAV used to collect (photogrammetry) topographic data

5.8.2. Scheduling

Initially, it is proposed that 4 elevation surveys per year would be carried out (one per season). As knowledge of accretion rates and dredging performance is improved, it is likely that the number of surveys will be reduced. Bearing in mind that most of the dredging will be carried out in the autumn, two surveys per year may be sufficient in the long term (before and after the dredging campaigns). The same equipment would be used for the River Brue but the frequency of surveys would be much less, probably less than once per year after the maintenance dredging has been completed and surveyed.

5.8.3. Estimated Costs

The cost of survey work using the techniques described above will depend on the availability of equipment. If, for example, the equipment had to be purchased and then amortised over the duration of a survey contract involving several surveys, the cost per survey might be as high as £60,000 for a survey covering 20km of river. If it is possible to hire the equipment, the cost per survey could be significantly less, but no quotations were obtained from the survey contractors contacted during the study.

The former cost estimate would comprise of an estimated cost of around £20,000 for the topographic survey and £40,000 for the bathymetry survey. In this case it is conservatively assumed that a survey contractor does not currently own the equipment to undertake the surveys and would need to purchase both the ROV and UAV. The cost of purchasing the equipment would be amortised over an assumed 2-year period, it is likely that subsequent surveys would then be completed at a discounted rate.

This method does however have major benefits compared with the currently used survey technique. The method provides the ability to survey long lengths of river relatively quickly and covers the river in detail, thus allowing more detailed and accurate dredging and siltation volumes to be calculated. The regular surveys should cover all the critical reaches so that the full effects of dredging can be identified, not just the reach that has been dredged. For the 16 km of river covered by the pioneer and maintenance dredges on the Parrett and Tone, the cost of a conventional survey would be about £32,000 (assuming 50 m cross-sections at £100/section). A survey of 16km of river might cost in the range of £35,000 to £55,000 using the recommended techniques depending on whether the equipment is bought or rented.

6. Timing of dredging and mitigation measures

Table 6.1 shows the main environmental constraints by month and the potential importance of each constraint at each dredging location. It also shows the impact of each type of operation on the environmental constraints. By combining these three matrices, it is possible to estimate the environmental impact in terms of a score for each constraint for each month at each location.

This is done by assigning scores of 3 (high), 2 (medium) and 1 (low) to each of the three matrices and then multiplying the numbers together.

For example, the impact of Pioneer 1 dredging on water voles in December would be:

2 (Medium environmental constraint) x 2 (Medium location constraint) x 1 (low dredging impact) = 4

The scores are shown in Table 6.2 to Table 6.8 for Pioneer dredging 1 and 2 and Maintenance dredging 1 to 5 respectively. The tables show when dredging is proposed and also highlight scores that exceed 5 and scores that exceed 10. This provides a high level overview of the main environmental constraints of each dredging activity.

It is immediately apparent that the constraints have the least impact during September, October and November. However there are impacts throughout the year and mitigation measures will be needed at each location.

It should be appreciated that the scores are based on a high level analysis to provide an indication of the potential constraints at each site. A more detailed environmental assessment will be needed for planning and implementing each dredging activity.

Table 6.1: Environmental constraints for each dredging location

Constraints	
High	
Medium	
Low	

	Environmental Constraints Calendar (irrespective of site)												Parrett tidal					Tone tidal	Brue	Dredging methods	
													Lower	Upper	Lower	Mid	Upper				
Environmental constraint	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Pioneer 1	Pioneer 2	Maintain 2	Maintain 1	Maintain 4	Maintain 3	Maintain 5	Excavation	Agitation
Bathing waters & water quality	Low	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Medium	Medium	Medium	Medium	Low	Low	Low	Low	Medium
Water voles	Medium	Low	Low	Low	Medium	Medium	Medium	Medium	Low	Low	Low	Medium	Medium	High	Low	Low	Medium	Medium	Medium	Low	Medium
Badgers	Medium	High	High	High	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Otters	Low	Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Low	Low	Low	Medium	Medium	Low	Low	Low	Low	Low	Low	Low
Tree & hedge management (incl. breeding birds & roosting bats)	Medium	Medium	Medium	High	High	High	Medium	Medium	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low
Wintering birds	High	High	Medium								Medium	High	Low	Low	Low	Low	High	Medium	High	Low	Low
Breeding birds		Low	Medium	High	High	High	Medium	Low					Medium	Medium	Low	Low	Low	Low	Low	Low	Low
Glass eels	Low	Medium	Medium	Low									High	High	Medium	Medium	Medium	Medium	Low	Low	Medium
Fish	Low	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low	High
Rare invertebrates (in channel)	Medium	Medium	High	High	High	High	High	High	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Low	High	Low	Medium
Rare invertebrates (riparian)	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Low	Medium	Medium	Low	Medium	High	Medium	Low	Low	Medium

Source: P Brewin, Parrett IDB

Table 6.2 shows the environmental constraints for the Pioneer 1 dredging. Particular issues include the presence of water voles and wintering birds. Mitigation measures might include dredging of one bank only to minimise damage to habitats and disturbance to mammals and birds.

A particular constraint that is not shown on the table is salinity of the dredged material. This should be assessed as part of the planning of the dredging, as this may affect disposal options.

Table 6.2: Environmental constraints: Pioneer 1 dredging

	Parrett Tidal (lower), Pioneer 1, Excavation											
	Environmental Constraints Calendar									Dredging period		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bathing waters & water quality	2	2	2	2	4	4	4	4	4	2	2	2
Water voles	4	2	2	2	4	4	4	4	2	2	2	4
Badgers	4	6	6	6	4	2	2	2	2	2	2	2
Otters	2	4	4	4	4	4	2	2	2	2	2	2
Tree & hedge management (incl. breeding birds & roosting bats)	4	4	4	6	6	6	4	4	2	2	2	4
Wintering birds	6	6	4	0	0	0	0	0	0	0	4	6
Breeding birds	0	2	4	6	6	6	4	2	0	0	0	0
Glass eels	2	6	6	2	0	0	0	0	0	0	0	0
Fish	2	2	2	2	4	4	4	4	4	4	2	2
Rare invertebrates (in channel)	4	4	6	6	6	6	6	6	4	4	4	4
Rare invertebrates (riparian)	2	2	4	4	4	4	4	4	2	2	2	2
	32	40	44	40	42	40	34	32	22	20	22	28

Source: Based on P Brewin data

Table 6.3 shows the environmental constraints for the Pioneer 2 dredging. Particular issues include the presence of water voles and habitat for hairy click beetles. Mitigation measures might include dredging of one bank only to minimise damage to habitats. There are also wintering birds, particularly in the Southlake Moor SSSI. These would be present during the dredging period. Mitigation measures include dredging this part of the river before the birds arrive, and adopting techniques that minimise disturbance as far as possible.

Table 6.3: Environmental constraints: Pioneer 2 dredging

	Parrett Tidal (upper), Pioneer 2, Excavation											
	Environmental Constraints Calendar									Dredging period		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bathing waters & water quality	2	2	2	2	4	4	4	4	4	2	2	2
Water voles	6	3	3	3	6	6	6	6	3	3	3	6
Badgers	2	3	3	3	2	1	1	1	1	1	1	1
Otters	2	4	4	4	4	4	2	2	2	2	2	2
Tree & hedge management (incl. breeding birds & roosting bats)	2	2	2	3	3	3	2	2	1	1	1	2
Wintering birds	3	3	2	0	0	0	0	0	0	0	2	3
Breeding birds	0	2	4	6	6	6	4	2	0	0	0	0
Glass eels	3	9	9	3	0	0	0	0	0	0	0	0
Fish	2	2	2	2	4	4	4	4	4	4	2	2
Rare invertebrates (in channel)	4	4	6	6	6	6	6	6	4	4	4	4
Rare invertebrates (riparian)	2	2	4	4	4	4	4	4	2	2	2	2
	26	35	40	35	37	36	31	29	20	18	18	22

Source: Based on P Brewin data

Table 6.4 and Table 6.5 show the environmental constraints Maintenance dredging 1 and Maintenance dredging 2 respectively. As the turbidity levels in the Parrett System are already high, the potential impact on fish as a result of agitating the sediment may be relatively insignificant. Mitigation measures might include monitoring of water quality (particularly Dissolved oxygen and temperature) and modifying dredging operations to minimise adverse impacts.

It is proposed that the dredging starts at the end of the tourist season to minimise adverse impacts on bathing and other water activities. As the dredging would be carried out annually, the environmental assessment should consider the long-term impacts.

Table 6.4: Environmental constraints: Maintenance 1 dredging

	Parrett Tidal (lower), Maintain 1, Agitation											
	Environmental Constraints Calendar									Dredging period		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bathing waters & water quality	4	4	4	4	8	8	8	8	8	4	4	4
Water voles	4	2	2	2	4	4	4	4	2	2	2	4
Badgers	2	3	3	3	2	1	1	1	1	1	1	1
Otters	1	2	2	2	2	2	1	1	1	1	1	1
Tree & hedge management (incl. breeding birds & roosting bats)	2	2	2	3	3	3	2	2	1	1	1	2
Wintering birds	3	3	2	0	0	0	0	0	0	0	2	3
Breeding birds	0	1	2	3	3	3	2	1	0	0	0	0
Glass eels	4	12	12	4	0	0	0	0	0	0	0	0
Fish	6	6	6	6	12	12	12	12	12	12	6	6
Rare invertebrates (in channel)	4	4	6	6	6	6	6	6	4	4	4	4
Rare invertebrates (riparian)	4	4	8	8	8	8	8	8	4	4	4	4
	34	43	49	41	48	47	44	43	33	29	25	29

Source: Based on P Brewin data

Table 6.5: Environmental constraints: Maintenance 2 dredging

	Parrett Tidal (lower), Maintain 2, Agitation											
	Environmental Constraints Calendar									Dredging period		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bathing waters & water quality	4	4	4	4	8	8	8	8	8	4	4	4
Water voles	4	2	2	2	4	4	4	4	2	2	2	4
Badgers	2	3	3	3	2	1	1	1	1	1	1	1
Otters	1	2	2	2	2	2	1	1	1	1	1	1
Tree & hedge management (incl. breeding birds & roosting bats)	2	2	2	3	3	3	2	2	1	1	1	2
Wintering birds	3	3	2	0	0	0	0	0	0	0	2	3
Breeding birds	0	1	2	3	3	3	2	1	0	0	0	0
Glass eels	4	12	12	4	0	0	0	0	0	0	0	0
Fish	6	6	6	6	12	12	12	12	12	12	6	6
Rare invertebrates (in channel)	4	4	6	6	6	6	6	6	4	4	4	4
Rare invertebrates (riparian)	2	2	4	4	4	4	4	4	2	2	2	2
	32	41	45	37	44	43	40	39	31	27	23	27

Source: Based on P Brewin data

Table 6.6 and Table 6.7 show the environmental constraints Maintenance dredging 3 and Maintenance dredging 4 respectively. The impacts on fish are indicated as being high, and similar mitigation measures will be needed to those proposed for Maintenance dredging 1 and Maintenance dredging 2. As the turbidity of the water is less in this part of the river system, the relative impact on fish may be greater. Other concerns include in-channel mammals and invertebrates, and surveys may be needed during planning and implementing the dredging.

As the dredging would be carried out every 2 years, the environmental assessment should consider the long-term impacts.

Table 6.6: Environmental constraints: Maintenance 3 dredging

	Tone tidal, Maintain 3, Agitation											
	Environmental Constraints Calendar									Dredging period		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bathing waters & water quality	2	2	2	2	4	4	4	4	4	2	2	2
Water voles	8	4	4	4	8	8	8	8	4	4	4	8
Badgers	2	3	3	3	2	1	1	1	1	1	1	1
Otters	1	2	2	2	2	2	1	1	1	1	1	1
Tree & hedge management (incl. breeding birds & roosting bats)	2	2	2	3	3	3	2	2	1	1	1	2
Wintering birds	6	6	4	0	0	0	0	0	0	0	4	6
Breeding birds	0	1	2	3	3	3	2	1	0	0	0	0
Glass eels	4	12	12	4	0	0	0	0	0	0	0	0
Fish	6	6	6	6	12	12	12	12	12	12	6	6
Rare invertebrates (in channel)	4	4	6	6	6	6	6	6	4	4	4	4
Rare invertebrates (riparian)	4	4	8	8	8	8	8	8	4	4	4	4
	39	46	51	41	48	47	44	43	31	29	27	34

Source: *Based on P Brewin data*

Table 6.7: Environmental constraints: Maintenance 4 dredging

	Parrett Tidal (upper), Maintain 4, Agitation											
	Environmental Constraints Calendar									Dredging period		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bathing waters & water quality	2	2	2	2	4	4	4	4	4	2	2	2
Water voles	8	4	4	4	8	8	8	8	4	4	4	8
Badgers	2	3	3	3	2	1	1	1	1	1	1	1
Otters	1	2	2	2	2	2	1	1	1	1	1	1
Tree & hedge management (incl. breeding birds & roosting bats)	2	2	2	3	3	3	2	2	1	1	1	2
Wintering birds	9	9	6	0	0	0	0	0	0	0	6	9
Breeding birds	0	1	2	3	3	3	2	1	0	0	0	0
Glass eels	4	12	12	4	0	0	0	0	0	0	0	0
Fish	6	6	6	6	12	12	12	12	12	12	6	6
Rare invertebrates (in channel)	4	4	6	6	6	6	6	6	4	4	4	4
Rare invertebrates (riparian)	4	4	8	8	8	8	8	8	4	4	4	4
	42	49	53	41	48	47	44	43	31	29	29	37

Source: Based on P Brewin data

Table 6.8 indicates that the environmental constraints on the Brue will be less than on the Parrett and the Tone. However the impacts could still be significant, for example on wintering birds in the adjacent SSSI. A summary of constraints and potential mitigation measures for the reach between Westhay Bridge and North Drain is given in the method statement for dredging in this area (Exo-Environmental 2014).

Table 6.8: Environmental constraints: Maintenance 5 dredging

	Brue, Maintain 5, Agitation											
	Environmental Constraints Calendar									Dredging period		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bathing waters & water quality	1	1	1	1	2	2	2	2	2	1	1	1
Water voles	2	1	1	1	2	2	2	2	1	1	1	2
Badgers	2	3	3	3	2	1	1	1	1	1	1	1
Otters	1	2	2	2	2	2	1	1	1	1	1	1
Tree & hedge management (incl. breeding birds & roosting bats)	2	2	2	3	3	3	2	2	1	1	1	2
Wintering birds	3	3	2	0	0	0	0	0	0	0	2	3
Breeding birds	0	1	2	3	3	3	2	1	0	0	0	0
Glass eels	1	3	3	1	0	0	0	0	0	0	0	0
Fish	1	1	1	1	2	2	2	2	2	2	1	1
Rare invertebrates (in channel)	2	2	3	3	3	3	3	3	2	2	2	2
Rare invertebrates (riparian)	1	1	2	2	2	2	2	2	1	1	1	1
	16	20	22	20	21	20	17	16	11	10	11	14

Source: Based on P Brewin data

More detailed work will be required in the dredging contracts to assess the magnitude of the constraints and decide mitigation measures. Mitigation measures for the Parrett and the Tone are provided in Parrett IDB, 2015.

7. Procurement approach

Presently the SRA uses contractors to undertake dredging on Main Rivers (including the Parrett system). The contracts are let by the responsible Flood Management Authorities (the Environment Agency and the IDBs).

The procurement approach has been developed with the following considerations in-mind:

- To deliver the best value for the SRA;
- To deliver best practice in the dredging methods used;
- To provide a solution that is sustainable.

It is proposed in the procurement approach to undertake the works under contract rather than build up an in-house capability. The works will include:

- Design work and hydraulic modelling;
- Survey;
- Pioneer dredging;
- Maintenance dredging.

The design work and hydraulic modelling for the dredging would be carried out by consultants who are already familiar with the relevant hydraulic models and are also familiar with the river system.

The survey work will involve the use of specialised survey equipment which would be utilised for a few days every year. It requires specialist operatives for both the ROV and the UAV. It is recommended that this is carried out under contract to provide the specialist equipment and operatives when required. An alternative would be for the SRA to have in-house capability, but this would not be efficient because of the relatively low utilisation of the equipment and the need to maintain the required level of expertise.

The pioneer dredging work consists of ‘one-off’ activities that are normally carried out under contract.

The maintenance dredging could possibly be carried out by an in-house team using equipment that is owned by the SRA. However it is proposed to contract this work out for the following reasons:

- The work would not be continuous: maintenance dredging should be limited to September to December (i.e. 4 months of the year) to minimise environmental impacts;
- The frequency of dredging in different parts of the river system varies: whilst annual dredging might be needed for the downstream reaches of the Parrett, the frequency of maintenance dredging elsewhere will be less. For rivers such as the Brue, maintenance dredging might be needed once every five or more years;
- The daily timing of work would depend on tidal conditions, and would therefore require tidal working. Marine survey contractors are familiar with this requirement whereas it is not a routine procedure for an in-house workforce;
- In-house working is likely to require the purchase and maintenance of the required dredging plant, particularly for specialist techniques such as agitation or water jetting. It is likely that this would be uneconomic for the limited periods when the equipment is required;
- In-house working would also require trained staff to be available during the dredging season.

It is however proposed that the analysis of survey results and the planning of the dredging programme is carried out by the SRA, either directly or using consultants. The reason for this is that it will allow the SRA to closely monitor the effectiveness of the dredging, plan future dredging activities and manage the available budgets for dredging work.

7.1. Previous dredging works

It is understood that the procurement of previous pioneer dredging works was undertaken by the Environment Agency. The pioneer dredging contracts also included the design and contract specification, developed by Galliford Try and Black and Veatch. The dredging was undertaken by Land and Water Services (as part of a Joint-Venture or subcontracted by Galliford Try and Black and Veatch). It is understood that the design work was procured through the Environment Agency’s Water and Environment Management (WEM) Framework.

The SRA commissioned the Parrett Internal Drainage Board to procure the recent maintenance dredging contract. As the majority of the ‘design’ work (i.e. development of cross-section dimensions etc.) had been completed for the pioneer work, the contractor was employed to simply re-instate the design cross-section. The dredging work was procured through competitive tender, administered by the Parrett IDB.

7.2. Maintenance dredging trials

The purpose of the dredging trials is to assess the effectiveness of alternative maintenance dredging methodologies. The trials will be primarily evaluated on their technical capability before evaluating their cost-benefit. Both methods proposed offer a more sustainable approach to disposal of the dredge material and are expected to reduce costs, particularly in the longer-term once site specific knowledge has been acquired.

It is proposed that the dredging trials are conducted separately to any maintenance dredging contract. This will ensure that the trials are conducted in an independent setting, free of influence from the preferred methods of contractors that could already be engaged in dredging works.

The dredging trials could be undertaken as a relatively small scale activity:

- If less than 500m^3 is dredged using an agitation / hydrodynamic method it would be exempt from MMO licencing – although the MMO would need to be informed;
- Day rates for use of a WID are of order £2000, plus mobilisation and other costs. However, costs for use of a MAE with cutter-pump will be higher;
- Channel cross-section designs already exist for the 8km pioneer dredge – this covers Maintenance 1 and 3 where trials are proposed;
- Current bathymetric monitoring methods and cross-section designs could be used to determine the effectiveness of the dredging method at removing the dredged material, prior to commissioning of higher resolution survey methods;
- Based on an initial trial dredge of around 500m^3, and a volume of 10m^3/m of river bank the trial dredge would affect around 50m of river bank – this would be covered by a repeat (pre and post dredge) survey of upstream and downstream cross-sections.

The main uncertainty around the use of a MAE is the use of the cutter-pump adapter. The advantages offered by the amphibious nature of the equipment are relatively obvious and it is not considered necessary to trial it. Therefore, the trial will relate to the effectiveness of the cutter-pump adapter. This could be trialled using a conventional excavator from an easy to access bankside location.

Subject to the availability of funds, trials of both methods of agitation / hydrodynamic dredging is recommended. It is proposed that the trials are procured by competitive tender using a rates-based contract. It will be important not to limit any possible innovation and therefore it will be essential to take account of the technical approach when selecting the contractor(s) for this work. It is also possible that further trials using different contractors might be undertaken at a later date, depending on the success of the initial trials.

7.3. Potential suppliers for dredging trials

Potential suppliers of Water Injection Dredging equipment, suitable for use on the Parrett System include, for example:

- Van Oord (UK) – West Sussex;
- GPS Marine – Kent;
- Land and Water Services – East Sussex.

Potential suppliers of the cutter-pump adapter and excavators suitable for use on the Parrett System include, for example:

- Good Child Marine – Norfolk, suppliers of Italdraghe cutter-pump adapters;
- Dragflow – Italy, suppliers of Dragflow cutter-pump adapters;
- Land and Water Services – East Sussex (amphibious or conventional excavator);
- WM Longreach – Shropshire (amphibious or conventional excavator).

All of these contractors have been contacted in the development of this report. In addition, a local engineering firm, Kingcombe Aquacare, was also contacted to discuss their experience and capability with respect to dredging. Whilst they do not retain WID equipment, they are capable of fabricating and undertaking modification to existing vessels, such as installation of water jets on to an existing WID to increase its capability.

7.4. Future pioneer dredging

If the Environment Agency administers future pioneer dredging contracts (based on the cost-benefit of performing the dredging), future dredging contracts would be procured through the Environment Agency's WEM Framework. If however the IDBs administer the future pioneer dredging contracts, it would be possible to advertise the work and obtain tenders from a wider range of contractors.

There are several contractors considered capable of completing the pioneer dredging work based on the methods outlined in this report and their track record include for example:

- Land and Water Services – East Sussex;
- WM Longreach – Shropshire;
- Kier Group – London.

All of these contractors have been contacted in the development of this report. Other contractors are available locally to the Somerset Levels area with suitable equipment. However, their track record in providing excavating (dredging) services has not been established.

The proposed contracts would be based on rates. Whilst it is expected that conventional dredging techniques will be used, tenderers will be invited to offer alternative methods, for example the use of low-water content pump to transport material. In this case, trials of new methods may be requested if there is uncertainty in their performance.

The reason for not undertaking separate trials is that the methods of pioneer dredging will depend on the methods, plant and equipment that are already available to contractors. There is little point requesting a method in a tender document that would be difficult for contractors to provide.

7.5. Future maintenance dredging

The future methods of maintenance dredging will depend upon the effectiveness of the agitation / hydrodynamic dredging techniques. If the method(s) prove to be successful then it is suggested that the method representing best value is carried forward and deployed in future maintenance dredging campaigns.

Initially, this could form a 5-year contract with a break-clause after 2-years. It is recommended that maintenance work is undertaken under contract for the reasons given in the introduction to Section 7. However, the SRA may consider it advantageous in the longer-term to develop an in-house dredging capability that would allow the SRA to undertake their own dredging at the end of a 5-year contract. In order to do this the following should be considered:

- The acquisition of operational dredging experience and knowledge within the SRA and delivery body will be required. This could be done through close involvement of the dredging contractor's activities and training;
- Review and analysis of bathymetric and topographic data to understand the effectiveness of dredging, and response of the Parrett System to dredging;

- Eventual purchase or lease of dredging equipment, along with employment of dredge equipment operators;
- Any in-house operation will be restricted by the Standard Terms and Conditions of employment for operatives and staff as the work will be governing by the tidal cycle and river conditions;
- Any in-house bid should be tendered alongside external competition.

7.6. Monitoring

It is proposed that the monitoring work is procured by competitive tender for a fixed period, which could be a 5-year contract with a break-clause after 2-years. The reason for this is that tenderers may have to buy equipment, which would then be amortised over the period of the contract. The contract would include processing of data to provide completed surveys in a form that will allow the SRA to use the results for modelling, planning of dredging activities and other purposes.

8. Realisation of benefits of the dredging

The report is concerned with identifying the possibilities for future dredging but does not include a benefits assessment. This benefits considers the potential benefits and the ways in which they might be estimated.

8.1. Potential benefits of dredging

The opportunities for dredging are based on the hydraulic benefits of dredging in terms of the reduction in flood water levels and flood durations in key areas. It recognises the need to maintain the completed dredging and therefore includes both pioneer (new) and maintenance dredging. This section considers how the benefits of dredging might be defined and measured so that the SRA is able to assess the potential benefits and the realisation of those benefits.

The benefits of dredging include the following:

1. To reduce direct flood impacts on properties, businesses, agriculture, transport and utilities;
2. To reduce health and other adverse impacts of flooding on people;
3. To reduce pumping and other operational costs;
4. To reduce indirect impacts including the consequences of flooding on businesses, tourism, schools and health services;
5. To reduce the requirement for emergency response;
6. To reduce wider indirect impacts on the region;
7. To maintain water channels in order to maintain the condition of the Levels and Moors for drainage, landscape, culture and natural environment reasons;
8. To maintain current levels of protection and to take into account that risk will increase over time.

Dredging also has potentially adverse impacts. An important requirement of dredging will be to minimise adverse impacts including suitable mitigation measures where appropriate. This will also assist in the process of complying with EU regulations including Habitats Regulations, the Water Framework Directive and the Bathing Water Directive.

Flood damages are caused on a regular basis during relatively frequent flood events. Summer flooding is particularly damaging because of the impacts on crops, agriculture and the environment. However, little flood damage data was available for inspection during the development of the report, and the best damage information was for the winter 2013/14 floods. These floods were exceptional due to the extent and long duration of flooding. An assessment has been made of the damages caused by the winter 2013/14 flood, as shown in Table 8.1 (Parsons Brinkerhoff, 2015).

Table 8.1: Estimated damages caused by the 2013/14 flood

Category of impact	Low estimate (£m)	Central estimate (£m)	High estimate (£m)
Direct damages:			
Rail impacts	12.8	17.0	21.3
Local government and emergency response impacts	14.3	16.8	19.3
Residential property impacts	12.0	16.0	20.0
Highway and travel impacts	9.0	12.0	15.0
Agricultural impacts	4.1	5.5	6.9
Social impacts	1.6	3.2	4.8
Impacts to business premises	2.5	3.3	4.1
Utility impacts	0.7	0.8	0.9
Total direct damages:	**57.0**	**74.6**	**92.3**
Indirect damages (on business):	4.4	8.8	13.2
Impacts assessed qualitatively (mainly wider impacts on the region):	21.0	35.0	42.0
Overall total	**82.4**	**118.4**	**147.5**

Source: Parsons Brinckerhoff 2015

These figures clearly show that the damages were very significant. The Environment Agency has estimated how much some of these damages would have been reduced by as a result of the 8 km of dredging that took place in 2014 on the River Parrett downriver of the River Tone confluence and the River Tone downriver of Hook Bridge (Environment Agency 2015). These included the following:

- Reduction in flood risk to between 50 and 80 residential properties out of a total of about 165 residential properties that flooded. This represents about 40% of the residential properties;
- The duration of closure of the A361 road would be reduced from the 9-10 weeks that occurred in 2013/14;
- The flooding of the Taunton to Bristol railway line may not have occurred;
- Reduction in the duration of flooding on North Moor and Salt Moor;
- Other benefits include reduction in the impacts of flooding on people, businesses, agricultural land, transport and access.

The Environment Agency assessment also indicated the reduction in damages that would have occurred as a result of flood mitigation measures including additional pumping.

The overall reduction in flood damages from the dredging might have been of the order of £30 million to £40 million in the winter 2013/2014 although some of the benefits of dredging are extremely difficult to estimate. For example, the impacts on people including health effects and trauma can be very significant but very difficult to assess.

The difficulties of using the above information to assess the potential benefits of dredging include the following:

1. The return period of the 2013/14 event is not known, and a wider range of events is needed to fully assess the benefits;
2. Works carried out to reduce flood risk since the 2013/14 event including improvements to roads and the railway line, ring banks for local communities, improved pumping facilities and improvements to flood banks and other structures. These works will reduce the benefits that can be achieved by dredging. As a result, the benefits of specific dredging activities will be reduced.

8.2. Estimation of the benefits

Flood management activities including dredging are normally justified using standard appraisal techniques that take account of costs, economic benefits, impacts on people and impacts on the environment. However the situation in Somerset is not typical of other locations in England. This is because the area is vulnerable to frequent floods which have very different impacts depending on season, and also long duration flooding.

For example, the spring/summer flood of 2012 was particularly damaging for not only agriculture but also to a lesser extent wildlife because it occurred during the growing and cropping season. There was extensive damage to grass swards and vegetation which will have had impacts on the wildlife and ecology associated with wet grassland grazing. Due to the higher temperature of the water on the moors this flooding also resulted in reduced oxygen levels within the water and instances of fish kill. The winter 2013/14 flood had a particularly long duration: residential properties, farms, roads, railways and other facilities were flooded for several months with very severe consequences for individuals, communities and businesses.

Environmental damage is also a very important factor in the Somerset Levels because of the environmental sensitivity of the area and the close relationship with water levels and flooding. Whilst flooding can have some environmental benefits, avoidance of environmental damage is an important benefit of flood mitigation.

In order to estimate the benefits of dredging, it is necessary to identify the full range of potential impacts caused by flooding and the potential benefits (and disbenefits) that could be provided by dredging. These are summarised below for the following four areas: the tidal reaches of the River Parrett and the River Tone; the River Sowy and Kings Sedgemoor Drain; the River Parrett upriver of Oath sluice; and the River Brue.

Dredging of the tidal sections of the River Parrett and the River Tone can reduce the amount (and frequency) of flooding in Curry Moor, Hay Moor, North Moor and Salt Moor caused by high fluvial flows over Hook Bridge spillway, and can allow earlier pumping from the moors by reducing river levels. This reduces the duration of flooding. The benefits include reduction in the flooding of property, roads, the railway, farms and agricultural land. In addition, the amount of pumping required to remove floodwater from the moors would be reduced and pumping of water from West Sedgemoor would be facilitated by lower river levels.

Dredging of the tidal sections of the River Parrett can reduce the amount of water that flows into the Sowy River via Allermoor and Beazleys spillways and then into Kings Sedgemoor Drain, thus reducing flooding in

Kings Sedgemoor and the adjacent areas. The benefits include reduction in the flooding of property, roads, farms and agricultural land.

Dredging of the tidal sections of the River Parrett can also reduce water levels very slightly in the River Parrett further upstream. This, combined with the shorter duration of flow over Hookbridge, Beazleys and Allermoor spillways, allows the pumping stations in the river system upstream of Langport to start pumping earlier and to operate for longer periods. This in turn provides a wide range of benefits including reduction in flooding of property (including the Westover Trading Estate), roads and agriculture.

Dredging of the River Brue will reduce the frequency of flooding on agricultural land and may also provide water level benefits for land drainage. It may also reduce frequency and severity of flooding of property and infrastructure although the benefits have not been considered in detail in this report. Benefits of dredging to the environment include those that arise from the ability to administer Water Level Management Plans.

In some areas there are disbenefits of dredging, particularly in relation to the environmental impacts on wetlands and other conservation areas. In addition, dredging operations can have adverse impacts including those on river channel flora and fauna. Adverse impacts of dredging must also be taken into account in the assessment of benefits.

It is apparent that there is a wide range of potential benefits from dredging of the rivers. In order to estimate the benefits, the following work is required:

1. Identify the full range of flood impacts and potential benefits (and dis-benefits).
2. Decide a method for evaluating each of the impacts. It is likely that a method involving Multi-Criteria Analysis (MCA) will be needed to cover the full range of impacts.
3. Select a base case for the benefits assessment. This should be the river system immediately before the proposed works are carried out.
4. Use hydraulic modelling to estimate flood impacts without the proposed works in place.
5. Use hydraulic modelling to estimate flood impacts with the proposed works in place.
6. The difference between these results will be the benefits of the dredging.

In order to follow this procedure, it is necessary to define the flood events that should be used for the analysis and their probability of occurrence, so that the annual average damage can be estimated. The flood events should cover the full range of events that are known to be damaging to the Somerset Levels, particularly severe and long duration flooding (2013/14) and summer flooding (2012). Two possible options are considered:

1. Use the recent record of historic floods to estimate the damages for each flood, say from the year 2000 onwards. The return period of each flood should be estimated based on longer term flood flow and flood volume data.
2. Use longer term flood flow and flood volume data to estimate return period floods at the upstream gauging stations, and undertake hydraulic modelling to determine river flows and flooding in the moors for these events.

Option 1 has the benefit that it uses information from floods that have been known to occur. This avoids the need to consider the large number of factors that contribute to flood events including combinations of flows from the River Parrett and the River Tone, the timing of the floods, the duration of the floods and (to a lesser extent) tidal conditions.

The floods would have to be hydraulically modelled with and without proposed dredging, and therefore there would be a need to collate relevant information on the floods including flows, levels and flooded extents.

Option 2 is a technically more correct approach, but the analysis requires assessment of a wide range of factors and combinations, and could prove to be onerous and provide results that do not reflect what has actually happened.

Option 1 is therefore considered to be the most suitable method for benefit assessment taking account of the current availability of information.

This method for assessing the potential benefits of dredging is to use historic flood information including river flows and water levels. It would be necessary to adapt the historic floods to present day conditions. This would be achieved by running the fluvial and tidal boundary conditions from the historic floods on an up-to-date version of the model in order to estimate the impacts under present day conditions. This would provide the baseline for assessing dredging options.

Flood damages would be calculated using a MCA approach. Economic damages would be estimated using standard procedures but other damages and benefits of flooding would be estimated using scoring and weighting. This requires an assessment of the extent and importance of each type of flood damage. The results are combined with economic damages to obtain an overall estimate of the damages for each flood event.

The flood events would then be run on the model with proposed dredging in place in order to calculate the hydraulic benefits. The results would then be used to estimate the damages with the proposed dredging in place, and the benefits of the dredging.

A benefits assessment should be undertaken for all of the proposed dredging activities. Those for maintenance dredging would compare the benefits of dredging with the benefits that are lost if the rivers are not maintained.

9. Long-term dredging opportunities

9.1. Overview

The purpose of this report is to identify the possibilities of dredging for flood risk reduction with the intention of considering detailed requirements such as licensing and environmental assessment proportionately if the possibility of further worthwhile dredging is identified. This section covers the specific dredging requirements, including design, modelling and monitoring. It does not include the environmental surveys and monitoring that will be needed.

The first step for future dredging will be to establish regular monitoring of the river channel bathymetry and a monitoring contract is suggested for implementation in summer 2016. It is proposed that a contract lasting at least two years is let to allow the survey contractor to build up experience in surveying of the Parrett and Tone River channel and banks. The timing and content of the first survey will take account of the already completed dredging.

Importance of monitoring

The monitoring is a vital component of the approach to dredging. The results will be used to decide the timing, locations and amounts of future dredging in order to optimise the dredging programme and minimise the risk of unnecessary or not very effective dredging activities. This means that the programme and costs associated with the dredging will vary depending on the results of the monitoring.

The proposed dredging activities are shown on Figure 9.1 and consist of the following:

- Two sections of ‘pioneer’ (or new) dredging, on the Parrett downriver of the current dredging (referred to as ‘Pioneer 1’) and on the Parrett upriver of the Tone confluence (referred to as ‘Pioneer 2’);
- Four areas of maintenance dredging of the Parrett and Tone, for the current and completed dredging on the Parrett (referred to as ‘Maintenance 1’), for Pioneer 1 (referred to as ‘Maintenance 2’), for the completed dredging on the Tone (referred to as ‘Maintenance 3’) and for Pioneer 2 (referred to as ‘Maintenance 4’);
- One area of maintenance dredging on the Brue (referred to as ‘Maintenance 5’).

Figure 9.1 is a repeat of Figure 4.6, but is reproduced here so that Section 9 provides a standalone overview of dredging opportunities.

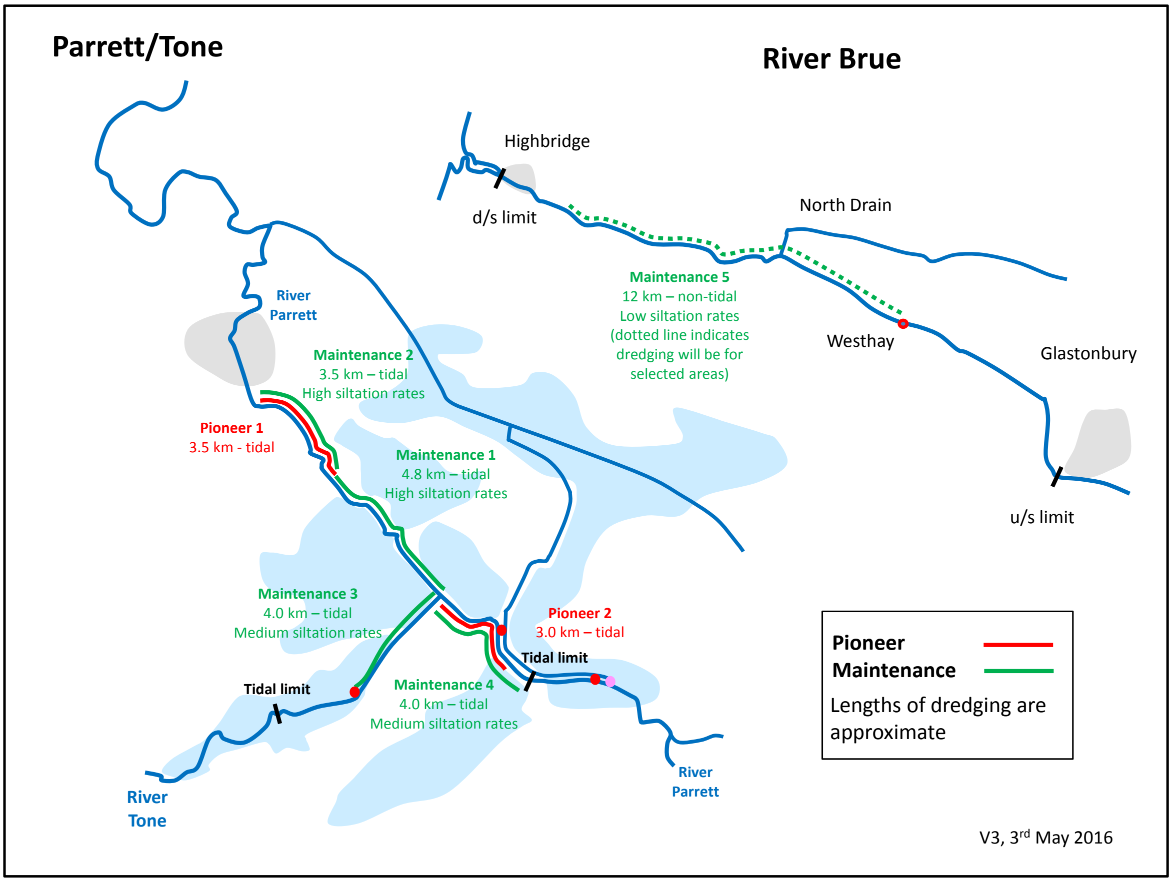

Figure 9.1: Proposed dredging activities

It is recommended that hydraulic designs are developed for all of the proposed new dredging including the maintenance dredging on the River Brue. The effectiveness of the designs will be tested by hydraulic modelling. A geomorphological assessment will also be needed. The cross-section shapes for the new dredging should be designed in such a way so that the amount of sedimentation that occurs after dredging is minimised as far as possible. This is intended to optimise the hydraulic benefit that can be achieved per unit volume of dredged material, and minimise the amount of future maintenance dredging that will be needed.

A 10-year provisional dredging programme is shown in Figure 9.1. The programme is intended to provide a reasonably even distribution of annual costs for the first three years, after which the activities will consist of regular monitoring and maintenance. However the actual dates for the dredging programme will be decided by the SRA based on a number of factors including:

- available budgets and other SRA priorities;
- the time needed for pre-dredge activities including environmental surveys;
- the results of monitoring of the bathymetry of the river channels.

The proposed method of maintenance dredging is either by water injection or agitation, where the sediment is mobilised and dispersed downriver by the current. This avoids the need for disposal of the sediment by other means, but will require trials to identify the best method. Both methods will be included in the trials, and tenderers will be given the opportunity to propose other innovative techniques.

Trials are proposed at two locations: one in the dredged section of the Parrett downriver of the Tone confluence and the other in the dredged section of the Tone. This is because the sedimentation regime is different at the two locations, with more sediment movement at the downriver location.

In addition, some interim maintenance dredging is suggested after the trials are completed if the river channel monitoring indicates that this is necessary and if the trials identify one or more satisfactory methods for maintenance dredging, bearing in mind that different methods may be more appropriate for different locations. This could be carried out under an extension of the same contract used for the dredging trials. This is referred to as 'Interim Maintenance 1 & 3', as it covers the areas covered by Maintenance dredging 1 and 3.

The pioneer dredges on the Parrett downriver of the current dredging and upriver of the Tone confluence would be carried out using conventional methods similar to those already adopted, but the tender documents will include an option for tenderers to offer an alternative method based on different technologies. The dredging on the River Brue would also be carried out using excavators, either from the bank or from floating plant depending on where the dredging is to be carried out.

It is initially suggested that maintenance dredging for the Parrett downriver of the confluence (Maintenance 1 and 2) will be undertaken annually. It is also suggested that maintenance dredging of the already dredged area on the Tone and the Parrett upriver of the confluence (Maintenance 3 and 4) is carried out every 2 years under the same contract as Maintenance 1 and 2.

It is proposed that the contract for Maintenance 1, 2, 3 and 4 covers a number of years in order to develop a reliable maintenance system and the associated expertise. However, the specific frequency of the maintenance dredging activity will be dependent upon the production achieved and results of the periodic elevation surveys.

A cycle of maintenance dredging will then be carried out which will be determined based on the results of monitoring and prior dredging. This assumes the following provisional frequencies of dredging, although this is likely to change as the results of the monitoring surveys of the rivers are reviewed:

- River Parrett downriver of the Tone confluence (Maintenance 1 and 2): annual maintenance;
- River Parrett upriver of the Tone confluence and the dredged section of the Tone (Maintenance 3 and 4): maintenance every two years;
- River Brue between Glastonbury and Highbridge (Maintenance 5): maintenance every five years.

It is proposed that all pioneer and maintenance dredging is carried out between September and December to minimise environmental impacts.

9.2. Components of the dredging programme

The components of the dredging programme are listed in Table 9.1 and shown on the provisional programme on Figure 9.2. Figure 9.2 also indicates the periods when procurement would be undertaken, and the cost profile. The programme will require adjustment depending on decisions by the SRA on the timing of dredging activities.

Table 9.1: Components of the dredging programme

Activity	Date	River	Length (km) (approx.)	Comments
Monitoring	From Year 1	Parrett, Tone, Brue	16 (Parrett / Tone) plus 12 (Brue)	Costs based on 16km survey of the Parrett and Tone System.
Design and modelling	Year 1	Parrett, Tone, Brue	-	Modelling to identify dredging location/volume; hydraulic design to identify section shape
Pioneer 1	Sep – Dec, Year 1	Parrett	3.5	Length depends on design. May include dredging downriver of the M5
Pioneer 2	Sep – Dec, Year 2	Parrett	3.0	Length depends on design.
Maintenance 1, 2, 3 & 4 - trial	Sep/Oct, Year 1	Parrett	0.2	Trial on completed Parrett and Tone dredging
Interim Maintenance 1 & 3	Nov/Dec, Year 1	Parrett, Tone	8.8	Maintenance of Parrett and Tone dredging completed in 2014/2016
Maintenance 1 & 2	Annual from Oct Year 2	Parrett	8.3	Maintenance of completed Parrett dredging and Pioneer 1
Maintenance 3 & 4	Oct – Dec, Year 3 and 2-yearly thereafter	Parrett, Tone	8.0	Maintenance of completed Tone dredging and Pioneer 2
Maintenance 5	Sep – Dec, Year 3 and 5-yearly thereafter	Brue	5.0	Length depends on hydraulic modelling.

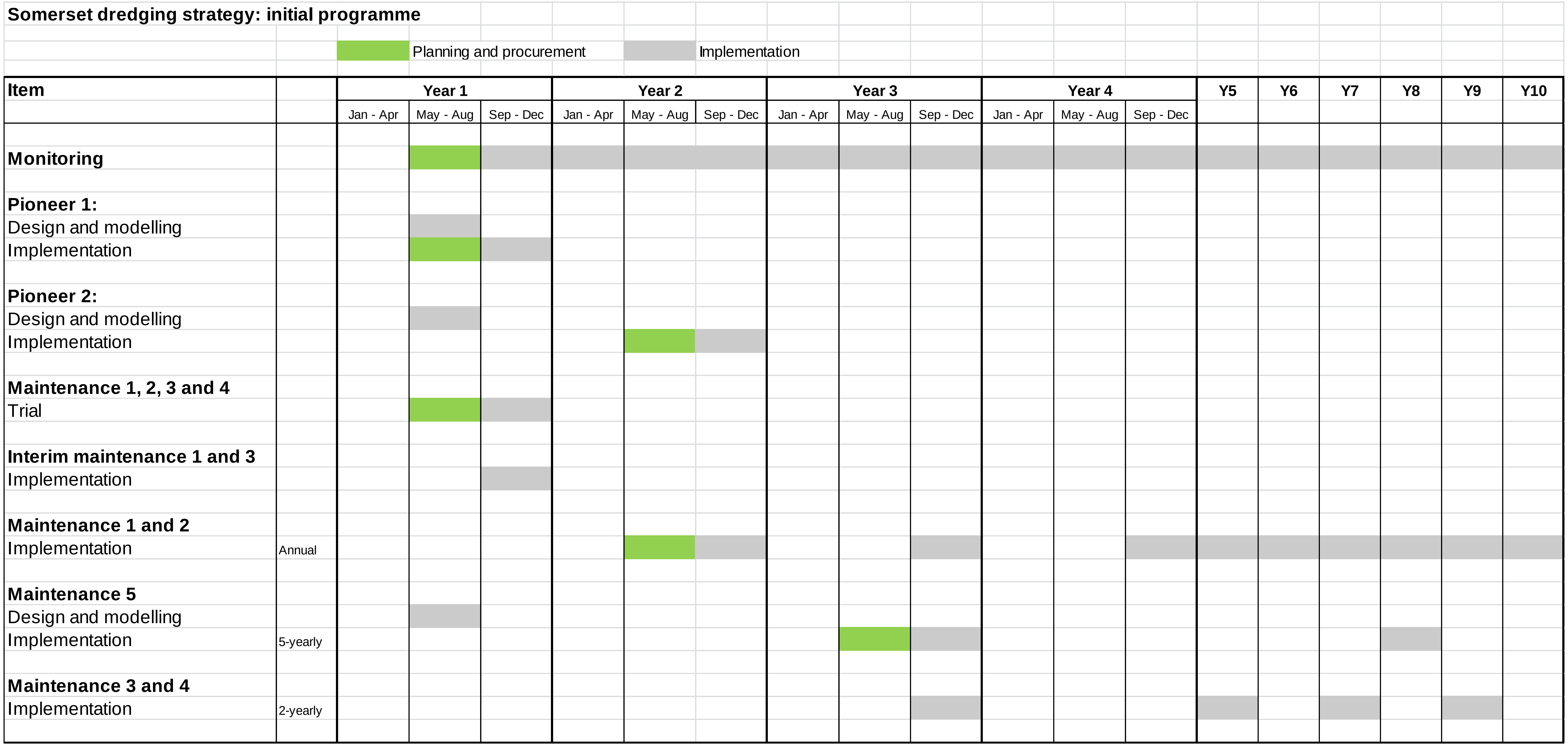

Figure 9.2: Dredging programme

Table 9.2 to Table 9.10 summarise each of the proposed dredging activities.

Table 9.2: Monitoring - summary

Activity:	Monitoring
Method:	Survey of river channel using a ROV and UAV with high accuracy positioning equipment.
Equipment:	ROV (for example Arc-boat), to be use for in-channel survey at high water; drone to be used for bank survey at low water; surveys to be combined using computer software to create high-resolution 3D model.
Location	All dredged areas: about 16 km on Parrett and Tone and up to 12 km on the Brue. Additional areas to be surveyed as required.
Timing:	Initially four times per year on the tidal Parrett and Tone. Frequency will be adjusted based on results. It is assumed that the frequency will reduce to two times per year over the longer-term Once a year on the Brue.
Estimated dredging quantities	N/A
Estimated cost:	£35,000 – 55,000 per survey (Parrett System and Brue are independent surveys). An initial cost of £55,000 is used, reducing to £35,000 after 2018.
Type of contract:	Fixed price per survey.
Procurement:	Competitive tender for a 2-year contract which may be extended
Access issues:	None if using ROV. If surveyed using conventional vessel a launch location upstream of Burrowbridge needs to be identified.
Material disposal:	N/A
Permits:	None
Environmental constraints:	None
Potential problems and alternative methods:	Loss or damage to equipment during a survey is a risk that can be mitigated by use of good practice and timing of surveys. Turbidity is not expected to be a problem – Contractor required to select appropriate instrumentation
Comments:	Results will be compared with conventional survey to demonstrate effectiveness. Benefits include increased coverage and high resolution surveys.

Table 9.3: Hydraulic design and modelling - summary

Activity:	Hydraulic design and modelling
Method:	Hydraulic modelling to identify the extent and volume of dredging for Pioneer 1 and 2, and Maintenance 5. Hydraulic analysis for cross-section design.
Equipment:	Existing hydraulic models for hydraulic modelling.
Location	Entire Parrett and Tone system model, to assess effects elsewhere. River Brue model from Glastonbury to Highbridge.
Timing:	Year 1
Estimated dredging quantities	N/A
Estimated cost:	£40,000
Type of contract:	Fixed price for a specified amount of work
Procurement:	Competitive tender or direct award to consultant(s) with experience of the models and the river system.
Access issues:	N/A
Material disposal:	N/A
Permits:	N/A
Environmental constraints:	None.
Potential problems and alternative methods:	A trade-off will be needed between potentially conflicting objectives including a large enough cross-section to achieve desired benefits, a hydraulically efficient cross-section to minimise future sedimentation and the requirement to minimise environmental disruption. It is likely that iteration and consultation will be needed to achieve the best design.
Comments:	The current design cross-sections have a 1 in 2 side slope. This is not very stable, and slumping has occurred. A shallower slope would be preferred but space is limited.

Table 9.4: Pioneer 1 dredging - summary

Activity:	Pioneer 1 dredging
Method:	Excavation from bank and pontoon mounted machines.
Equipment:	Backhoe excavators; pontoon for river work (including supporting barges); tractors and trailers for disposal of spoil.
Location	About 3,500 m of the River Parrett downriver of completed dredging. The exact length will depend on the dredging design.
Timing:	September to December, Year 1
Estimated dredging quantities	50,000 m^3
Estimated cost:	£800,000 to £1,500,000
Type of contract:	Fixed price (overheads) plus rate (dredge volume)
Procurement:	Competitive tender. Tenderers may be asked to offer an alternative method of using of amphibious excavator and pumping spoil from floating plant.
Access issues:	Access for plant will not be possible in areas where there are narrow banks with roads behind, narrow banks and buildings. Power lines appear to be in the current 750 m pioneer dredge section. Dredging may be needed under the M5. Require pontoon/plant entry location.
Material disposal:	Back of bank where possible Otherwise removal and spread to agricultural land It will be necessary to check the salinity of dredged material. If it is unsuitable for agricultural land, an alternative method of disposal would be needed.
Permits:	Disposal exemption – D1 and SR2010 No.9/10
Environmental constraints:	Bathing waters (medium risk: Sep); Water voles (medium risk: Dec); Fish (medium risk: Sep - Oct) Rare invertebrates (in-channel) (medium risk: Sep - Dec) No placing of spoil in Screech Owl Nature Reserve
Potential problems and alternative methods:	Access downstream of the M5 is limited, hence recommend evaluation of pumping dredge material method using low water content slurry.
Comments:	The dredging methods suggested are tried and tested. Significant changes to these methods (e.g. use of trailer-suction hopper dredgers or cutter-suction dredgers) are not considered practical.

Table 9.5: Pioneer 2 dredging - summary

Activity:	Pioneer 2 dredging
Method:	Backhoe excavation from the right (east) bank.
Equipment:	Backhoe excavator and tractor/trailers for removal of spoil.
Location	About 3,000 m of the River Parrett upriver of the Tone confluence. The exact length will depend on the dredging design.
Timing:	September to December, Year 2
Estimated dredging quantities	40,000 m^3
Estimated cost:	£800,000 to £1,250,000
Type of contract:	Fixed price (overheads) plus rate (dredge volume)
Procurement:	Competitive tender. Tenderers may be asked to offer an alternative method of using of amphibious excavator where access is considered an issue.
Access issues:	Access not possible on the left (west) bank.
Material disposal:	Back of bank for the section south of Beazleys spillway to Oath lock. Removal by lorry for Beazleys spillway and areas within the SSSI boundary, and then disposed of for agricultural benefit unless it is possible to dispose to back of bank in the SSSI.
Permits:	Disposal exemption – D1 and SR2010 No.9/10
Environmental constraints:	Bathing waters (medium risk: Sep); Water voles (high risk: Dec); Fish (medium risk: Sep - Oct) Rare invertebrates (in-channel) (medium risk: Sep - Dec) No placing of spoil in Southlake Moor SPA on the right bank.
Potential problems and alternative methods:	Excavator access to the left bank because of long reach requirement and stability of banks. Investigation into the stability of banks recommended. Access could be improved with the use of an amphibious excavator.
Comments:	The dredging methods suggested are tried and tested. Significant changes to these methods (e.g. use of trailer-suction hopper dredgers or cutter-suction dredgers) are not considered practical.

Table 9.6: Maintenance 1, 2, 3 & 4 dredging trial - summary

Activity:	**Maintenance 1, 2, 3 & 4 dredging - trial**
Method:	Two methods have been identified that are considered worth trialling: 1) Use of water injection dredger – injection of high pressure water into river bed / bank to mobilise sediment for dispersion. 2) Use of modified amphibious excavator with cutter-pump adapter to disaggregate material and pump back to water column for dispersion Elevation surveys will be required pre and post dredge.
Equipment:	1) Water injection / hydrodynamic dredger 2) Use of modified amphibious excavator with cutter-pump adapter
Location	Two lengths of 50-100 m: one on completed dredging downriver of Burrowbridge and one on completed dredging on the River Tone.
Timing:	September and October, Year 1
Estimated dredging quantities	N/A – although MMO exemption possible if quantity under 500m^3
Estimated cost:	£50,000-100,000 (total including pre and post survey)
Type of contract:	Fixed price contract with specified method. Contract could be extended under a fixed price (overheads) and rates (dredge volume) arrangement for Interim Maintenance dredging 1 & 3.
Procurement:	Competitive tender – notify potential suppliers
Access issues:	Boat entry location
Material disposal:	N/A
Permits:	Discussion with MMO recommended - exemption possible if quantity under 500m^{3}.
Environmental constraints:	Bathing waters (medium risk: Sep); Fish (medium risk: Sep - Oct)
Potential problems and alternative methods:	If the method is not initially effective it will be possible to improve the method (equipment and timing) once the problems have been investigated. Detailed evaluation of long-term use of current method using excavation and disposal would be required if method not considered effective.
Comments:	New method

Table 9.7: Interim Maintenance 1 and 3 dredging - summary

Activity:	Interim Maintenance 1 & 3 dredging
Method:	Dependent upon results of dredging trials.
Equipment:	Dependent upon results of dredging trials.
Location	This will cover the dredging completed in 2014 and 2016 on the Parrett (4.8 km) and the Tone (4 km). The exact locations will depend To be decided based on the results of monitoring.
Timing:	November and December, Year 1
Estimated dredging quantities	40,000 m^3
Estimated cost:	£150,000 to 400,000 assuming full mobilisation is required
Type of contract:	Fixed price (overheads) and rates (dredge volume) contract with specified method based on trials. Contract could be combined with the dredging trial.
Procurement:	Competitive tender (trial) – extension for Interim Maintenance
Access issues:	Boat entry location
Material disposal:	N/A
Permits:	Discussion with MMO required. Impact assessment of agitation technique likely to be required.
Environmental constraints:	Bathing waters (medium risk: Sep); Water voles (high risk: Dec); Fish (medium risk: Sep - Oct).
Potential problems and alternative methods:	It is expected that the method will be based on the maintenance dredging trial method. Volume of maintenance dredging unknown. MMO licencing requirement needs to be established.
Comments:	New method

Table 9.8: Maintenance 1 and 2 dredging – summary

Activity:	**Maintenance 1 & 2 dredging**
Method:	Method determined during the trial
Equipment:	Equipment decided during the trial
Location	About 8.3 km of the River Parrett downriver of Burrowbridge.
Timing:	October to December, Year 2 and annually thereafter
Estimated dredging quantities	70,000 to 90,000 m^3 per year
Estimated cost:	£250,000 to £650,000k
Type of contract:	Assured depth (maintenance of cross-section) or fixed price (overheads) and rates (dredge volume)
Procurement:	Competitive tender for 4-year period (combined with Maintenance 3 & 4)
Access issues:	Boat entry location if WID successful
Material disposal:	Discussion with MMO required. Impact assessment of agitation technique likely to be required.
Permits:	MMO
Environmental constraints:	Water voles (medium risk: Dec); Fish (medium risk: Oct)
Potential problems and alternative methods:	MMO licencing requirement needs to be established. Volume of maintenance dredging unknown. Risk of high siltation in Maintenance 2.
Comments:	Volume of maintenance dredging unknown – therefore consideration of dredger productivity required if siltation volume found to be high.

Table 9.9: Maintenance 3 and 4 dredging – summary

Activity:	Maintenance 3 and 4 dredging
Method:	Method determined during the trial
Equipment:	Equipment decided during the trial
Location	About 4 km of the River Tone (confluence to Hook Bridge spillway) and about 4 km of the River Parrett (confluence to Oath sluice).
Timing:	October to December, Year 3 and every two years thereafter
Estimated dredging quantities	26,000 m^3 every two years
Estimated cost:	£100,000 to £300,000
Type of contract:	Assured depth (maintenance of cross-section) or fixed price (overheads) and rates (dredge volume)
Procurement:	Competitive tender for 4-year period (combined with Maintenance 1 & 2)
Access issues:	Boat entry location if WID successful
Material disposal:	Discussion with MMO required. Impact assessment of agitation technique likely to be required.
Permits:	MMO
Environmental constraints:	Water voles (medium risk: Dec); Wintering birds (high risk: Nov – Dec) Fish (medium risk: Oct)
Potential problems and alternative methods:	MMO licencing requirement needs to be established. Volume of maintenance dredging unknown.
Comments:	Volume of maintenance dredging unknown – although expected to be significantly lower than Maintenance 1 & 2.

Table 9.10: Maintenance 5 dredging - summary

Activity:	Maintenance 5 dredging
Method:	Excavation by bank mounted machines. Disposal to back of bank.
Equipment:	Excavators
Location	12 km of the River Brue between Westhay and Hackness sluice. Exact locations to be determined during the design.
Timing:	September to December, Year 3 and 5-yearly (but this will depend on the results of survey).
Estimated dredging quantities	40,000 m^3 every 5 years
Estimated cost:	£400,000 to £700,000
Type of contract:	Fixed price (overheads) and rates (dredge volume)
Procurement:	Competitive tender
Access issues:	Access satisfactory to the right bank. Narrow embankment may affect access on the left bank. Power lines downstream of Westhay Bridge. Trees along the channel edge downstream of the South Drain connection.
Material disposal:	To bank
Permits:	D1
Environmental constraints:	SSSI between Westhay Bridge and North Drain Water voles (medium risk: Dec); Wintering birds (high risk: Nov – Dec); Fish (medium risk: Sep - Oct); Rare invertebrates (high risk: Dec)
Potential problems and alternative methods:	Trees downstream of South Drain confluence
Comments:	

Table 9.11: Cost profile

Year	Activity	Cost (£ '000)	Annual cost (£ '000)
2016	Monitoring	110	
	Designs for dredging	40	
	Pioneer 1	1,500	
	Maintenance 1 & 3: trial	100	
	Interim Maintenance 1 & 3	400	2,150
2017	Monitoring	220	
	Pioneer 2	1,250	

Year	Activity	Cost (£ '000)	Annual cost (£ '000)
	Maintenance 1 & 2	650	2,120
2018	Monitoring	110	
	Maintenance 1 & 2	650	
	Maintenance 3 & 4	300	
	Maintenance 5	700	1,760
2019	Monitoring	70	
	Maintenance 1 & 2	650	720
2020	Monitoring	70	
	Maintenance 1 & 2	650	
	Maintenance 3 & 4	300	1,020
2021	Monitoring	70	
	Maintenance 1 & 2	650	720
2022	Monitoring	70	
	Maintenance 1 & 2	650	
	Maintenance 3 & 4	300	1,020
2023	Monitoring	70	
	Maintenance 1 & 2	650	
	Maintenance 5	700	1,420
2024	Monitoring	70	
	Maintenance 1 & 2	650	
	Maintenance 3 & 4	300	1,020
2025	Monitoring	70	
	Maintenance 1 & 2	650	720
	Cost for 10-year programme (2016 prices)		12,670

The costs are taken from Tables 9.2 to 9.10 using the upper limit where a range of costs is indicated. If the lower limit is taken, the costs would be £6.06 million with a median value of £9.37 million.

The costs do not include environmental surveys and mitigation measures. There is some flexibility in the costs estimates because of the uncertainty in costs, and it may be possible to accommodate the environmental surveys and mitigation measures within the upper limit estimate. However data on these costs is needed to provide a more complete cost estimate.

10. References

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Environment Agency (2011)	*Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities*, Report by the Environment Agency, 2011
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Jacobs (2010)	*River Brue Model Study, Appendix D, Hydraulic Modelling Report, Final*, Jacobs on behalf of the Environment Agency, October 2010
Lonsdale (2013)	*The Potential Alternative Uses Of Dredged Material in the Humber Estuary*, Jemma-Anne Lonsdale, University of Hull and the Environment Agency, The Interreg IVB North Sea Region Programme,
Parrett IDB (2015)	*Parrett and Tone Maintenance Dredging: Environmental Impact Scoping and Assessment*, Parrett IDB (on behalf of the SRA), Version 4, 11 November 2015
Partrac (2008)	*Sediment sampling/analysis report,* Report P1022.05.D010v02, Partrac Ltd, February 2009 *Sediment sampling/analysis report, summer survey,* Report P1022.05.D023v01, Partrac Ltd, September 2009
Partrac (2009)	*Sediment budget report (River Parrett/Tone) Summer,* Report P1022.05.D026v02, Partrac Ltd, December 2009 *Sediment budget report (River Parrett/Tone) Winter,* Report P1022.05.D021v01, Partrac Ltd, March 2009
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Appendices

A. Hydrology and hydraulics of the river systems

A.1. Flood hydrology

Flood hydrology for the river systems on the Somerset Levels is complex, for the following reasons:

- There are extensive lowland areas that provide flood storage during flood events. This means that peak flood flow within the channels will be lower than peak flood flows for the same events at the upstream limits of the moors.
- In order to assign flows of different return periods to different parts of the river systems, it would be necessary to model the process of flood storage in the levels and moors.
- Design flood events should take account of both peak flood flow and flood volume, as flood volume is the main factor that affects flooding on the moors.

The recent flood modelling for the Parrett and Tone has been undertaken using the full 2013/14 event, which was a long period of high flows where water levels on the moors were continually 'topped-up'.

At present, a set of design events that would be suitable for investigating flood management options for the tidal reaches of the Parrett and Tone does not appear to exist.

A conventional hydrological analysis has been carried out for the River Brue, which has been used to predict flood flows for a range of return periods throughout the river system. The results illustrate the impacts of attenuation on peak flood flows, as follows for the estimated 1% (1 in 100-year) flood flow:

Upriver model limit:	94 m^3/s (0.1% event – 157 m^3/s)
Downriver of Glastonbury:	27 m^3/s (0.1% event – 36 m^3/s)
Downriver of Westhay Bridge:	32 m^3/s (0.1% event – 33 m^3/s)
Tidal outfall at Highbridge:	62 m^3/s (0.1% event – 62 m^3/s)

The flow at Highbridge will be influenced by the tidal outfall structure.

A.2. Hydraulics: River Parrett and River Tone

An assessment of the hydraulics of the river system has been made using the model of the rivers that was available to HR Wallingford in early 2014. Whilst the model has been improved since that time, the fundamental hydraulic principles have not changed. The purpose of this section is to illustrate principles that affect dredging.

A.2.1. Water levels in the river channels

A longitudinal section of the River Parrett between Langport and Combwich is shown on Figure A.1. The section shows the water surface profiles for a fluvial flow on the Parrett of about 40 m^3/s under both high and low spring tide conditions.

A similar longitudinal section is shown in Figure A.2, with a range of fluvial flow combinations on the Parrett and Tone up to a maximum combined flow of about 60 m^3/s in combination with high spring tide.

The events shown on the longitudinal sections are as follows:

- Event 1: 10 m^3/s on the Parrett and 20 m^3/s on the Tone
- Event 4: 10 m^3/s on the Parrett and 50 m^3/s on the Tone
- Event 5: 20 m^3/s on the Parrett and 10 m^3/s on the Tone
- Event 6: 30 m^3/s on the Parrett and 10 m^3/s on the Tone
- Event 7: 40 m^3/s on the Parrett and 10 m^3/s on the Tone

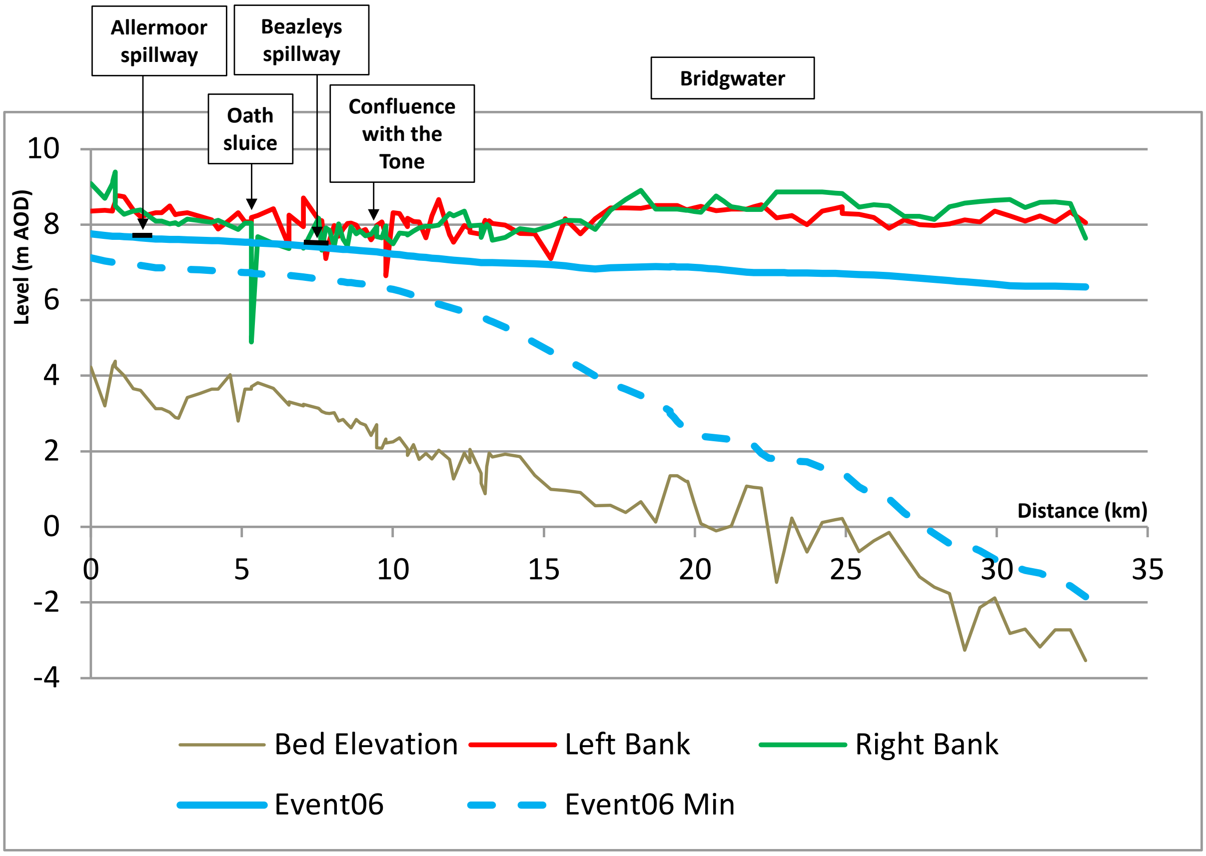


Figure A.1: River Parrett: longitudinal section showing high and low tide

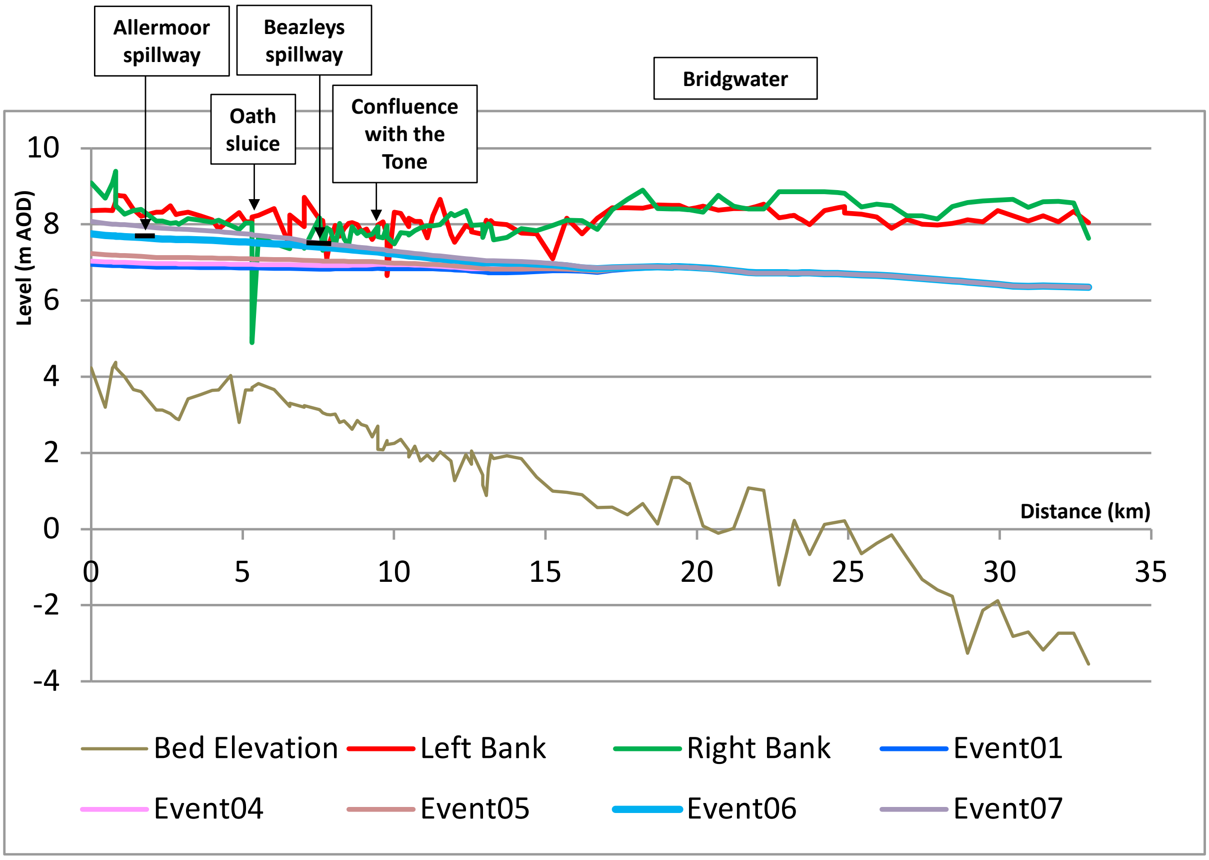


Figure A.2: River Parrett: longitudinal section showing high tide water levels

These longitudinal sections show the following:

- Maximum water levels are dominated by the tide from Bridgwater downriver. This boundary will change depending on the tide. The bank levels are generally higher downriver of the upriver limit of Bridgwater.
- Water levels are affected by the tide for the full length of the modelled section of the Parrett, including water levels upriver of Oath sluice. The tide range is relatively small at Burrowbridge and further upriver for this fluvial flow, but gradually increases further downriver.
- For the larger events on the Parrett, the water levels are controlled to a large extent by the spillways.

A longitudinal section of the River Tone between Newbridge sluice and the confluence with the Parrett is shown on Figure A.3 under high tide conditions. The events shown on the longitudinal sections are as follows:

- Event 4: 10 m^3/s on the Parrett and 50 m^3/s on the Tone
- Event 7: 40 m^3/s on the Parrett and 10 m^3/s on the Tone

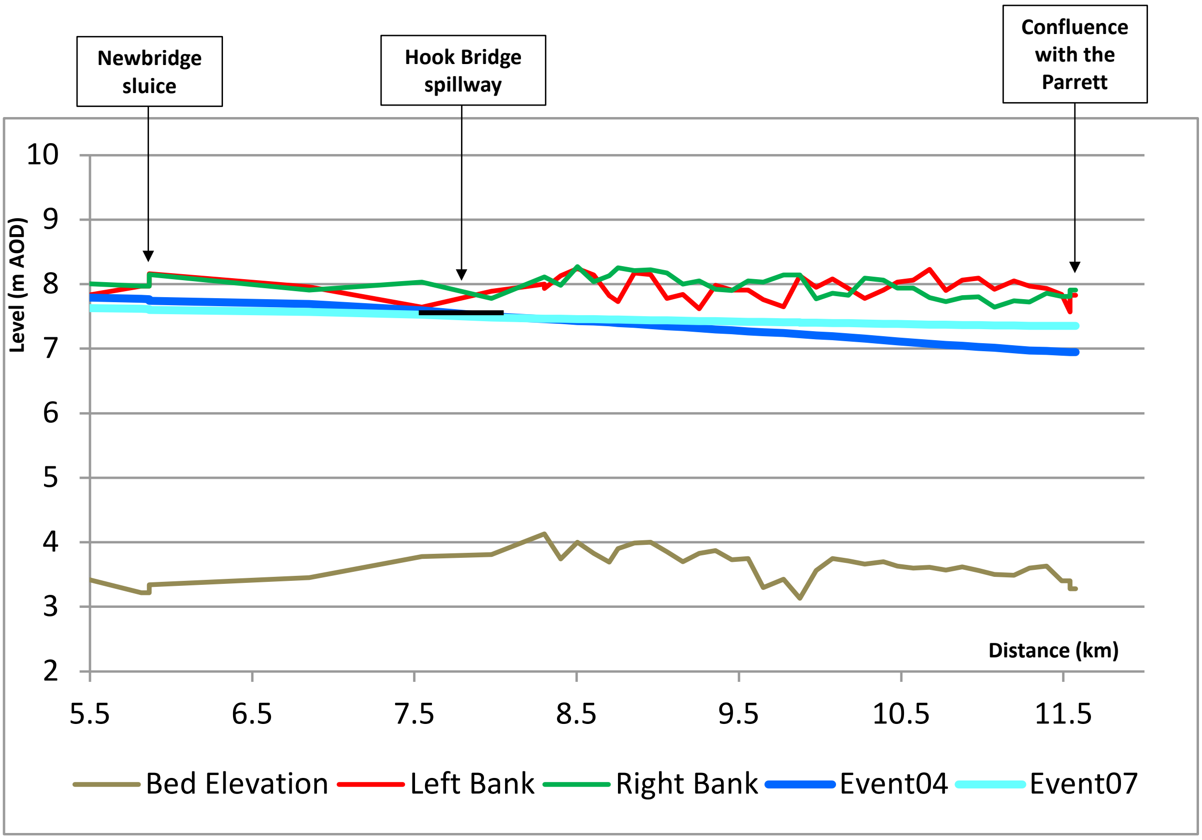


Figure A.3: River Tone: longitudinal section showing high tide water levels

The longitudinal section shows water levels for a high fluvial flow on the Tone with a normal flow on the Parrett, and a high fluvial flow on the Parrett with a normal flow on the Tone. This longitudinal section shows the following:

- The water level for a large fluvial event on the Tone is controlled by the Hook Bridge spillway. This also controls the amount of flow on the reach between the spillway and the Parrett.
- A high flow on the Parrett causes backing up of the Tone, which in turn leads to overtopping of the Hook Bridge spillway. This explains why dredging on the Parrett upriver of the confluence has a large impact on flooding in North Moor.

A.2.2. Impact of the spillways

It is apparent that the spillways have a vital impact on the river systems and, in particular, the amount of water that leaves the river system and potentially causes flooding. With regard to the objectives in Section 3.3, the spillways that affect flooding in each area are as follows:

- Flooding in Kings Sedge Moor is caused to a large extent by water from the River Parrett that overflows via the Allermoor and Beazleys spillways.
- Flooding in North Moor is caused to a large extent by water that passes over Hook Bridge spillway. The relationship is not direct because of the storage of water that occurs in Curry Moor. Flooding in North

Moor occurs when water from Curry Moor overflows via the Athelney and Lyng cutting spillways. However the primary source of flood water is from the Tone via Hook Bridge spillway.

This section considers how much of the river flow is contained within the river channels, how much passes over the spillways, and the way in which dredging can affect these flows. The analysis is based on information that has been made available for the study but does not include modelling of new options.

The locations and sizes of the spillways are as follows:

- Allermoor: 2.8 km upriver of Oath sluice; length 525 m; level 7.8 to 7.9 m AOD
- Beazleys: 2 km downriver of Oath sluice; length 305 m; level 7.43 to 7.52 m AOD
- Hook Bridge: 3.5 km upriver of the Parrett confluence; length 525 m; level 7.39 m AOD

It is understood that Beazleys spillway is primarily intended to control high tidal water levels and it is therefore of less importance for fluvial flood management.

Figure A.4 and Figure A.5 show the relationship between water level and flow in the River Parrett at Allermoor and Beazleys spillways respectively. The flows in the River Tone are generally 10 m^3/s. The dredging indicated on the diagrams refers to the 8 km dredge between Hook Bridge spillway and Northmoor pumping station.

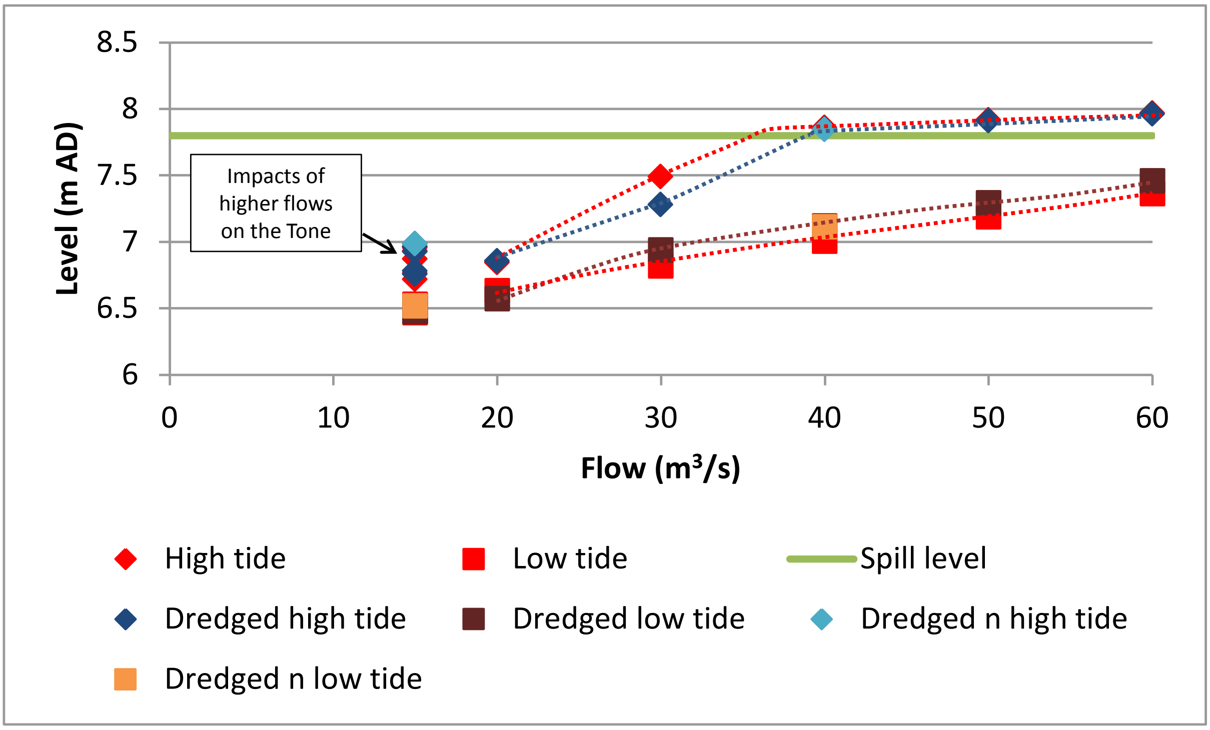


Figure A.4: Predicted water levels at Allermoor spillway

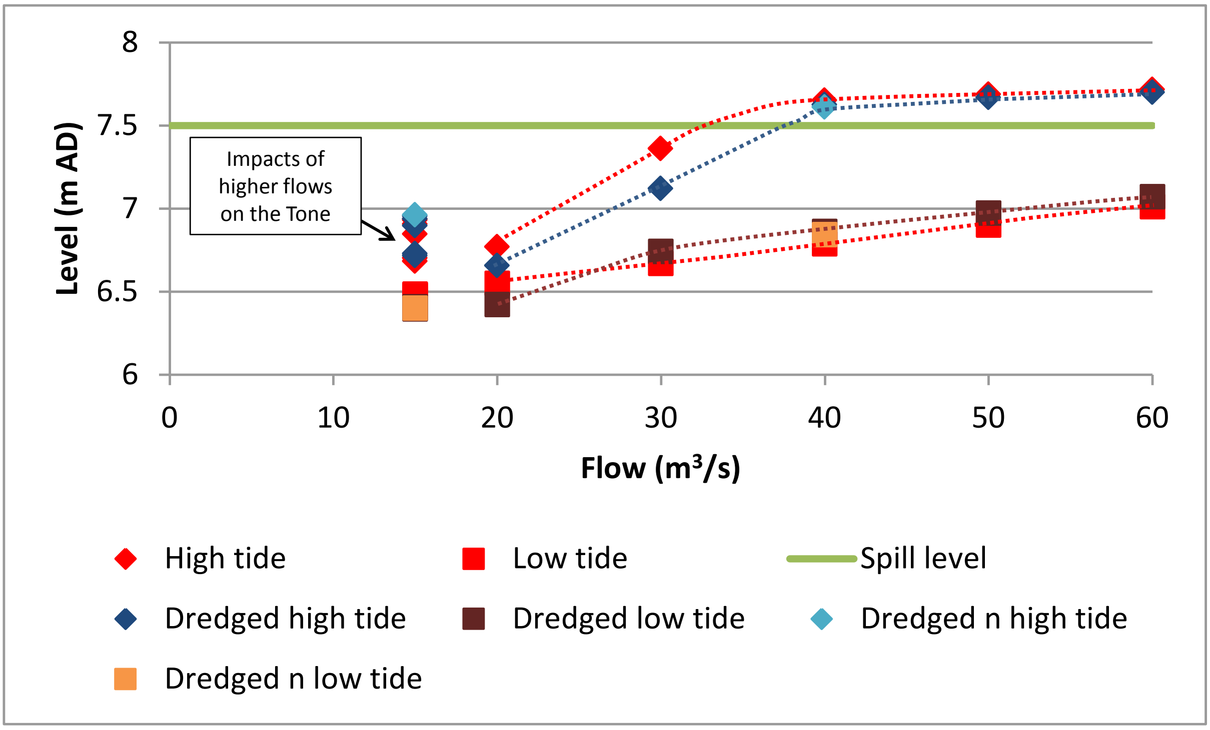


Figure A.5: Predicted water levels at Beazleys spillway

The modelling includes a number of different flows on the River Tone ranging from 20 to 50 m^3/s, combined with a flow of 15 m^3/s on the Parrett. The results indicate that the effect on Parrett water levels of changes in flows on the Tone is relatively small at the spillways.

The plots in Figure A.4 and Figure A.5 indicate the following:

- The maximum capacity of the River Parrett at Allermoor spillway is about 40 m^3/s during high water on a spring tide. This capacity increases to more than 60 m^3/s at low tide.
- The maximum capacity of the River Parrett at Beazleys spillway is about 30 m^3/s during high water on a spring tide. This capacity also increases at low tide.
- The similar capacity of the river at the two spillways supports the view expressed by consultees that Beazleys spillway is primarily intended to manage tidal water levels. Most of the flow that exceeds the river capacity is discharged via Allermoor spillway.
- The impact of the 8 km dredge on water levels at the spillways on the Parrett is small.

It is apparent from the figures that the capacity of the river is very affected by tidal conditions, and it is not possible to state a single design flow for the river channels.

Figure A.6 shows the relationship between water level and flow in the River Tone at Hook Bridge spillway. The dredging refers to the 8 km dredge between Hook Bridge spillway and Northmoor pumping station.

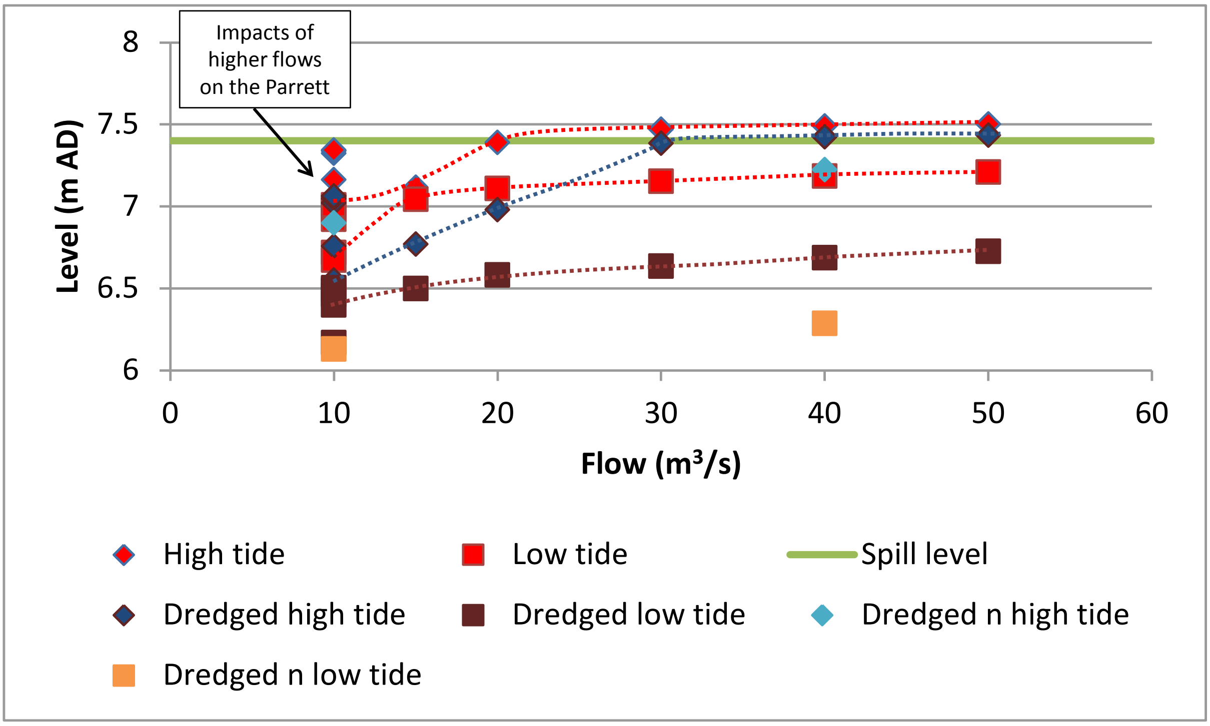


Figure A.6: Predicted water levels at Hook Bridge spillway

The flows of 15 m^3/s and upwards have a flow of 15 m^3/s on the Parrett. There are several model runs with flows of 10 m^3/s on the Tone, each combined with a different flow on the Parrett. All model runs are combined with a spring tide. Figure A.10 indicates the following:

- The capacity of the River Tone at high tide is about 20 m^3/s at Hook Bridge spillway without the dredging (and with a flow of 15 m^3/s in the Parrett).
- The capacity of the River Tone at high tide is about 30 m^3/s at Hook Bridge spillway with the dredging (and with a flow of 15 m^3/s in the Parrett).
- The capacity of the River Tone at low tide is in excess of 50 m^3/s. The dredging has a large impact of channel capacity at low tide.
- High flows in the River Parrett can cause overtopping of Hook Bridge spillway with a flow of 10 m^3/s on the Tone during periods of high tide. This is reduced by the dredging.
- The plot also shows the effect of reducing Manning's 'n' in the model to represent a smooth dredged surface. High tide levels are reduced by about 0.2 m and low tide levels by about 0.4 m.

It is apparent that the capacity of the River Tone is very affected by tidal conditions, and it is not possible to state a single design flow for the river channel.

The above discussion is based on a limited number of model runs, but it indicates a number of features of the system. Some general conclusions regarding the spillways are as follows:

- Dredging on the River Tone (and the associated dredging on the Parrett downriver of the confluence) reduces flows over Hook Bridge spillway, and therefore flooding on North Moor.
- Dredging of the River Parrett upriver of the confluence would reduce flow over Allermoor (and Beazleys) spillways, and will reduce flooding on Kings Sedge Moor.

- Dredging of the River Parrett upriver of the confluence will increase flows on the Parrett at the confluence and increase water levels on the Tone. This will increase flow over Hook Bridge spillway, and therefore flooding on North Moor.

The changes in capacity of the River Tone (and therefore flow over Hook Bridge spillway) are shown diagrammatically on Figure A.7. The figure shows the general effect on the river capacity at high tide of failure to maintain the existing dredging, dredging of the Parrett upriver of the Tone confluence and dredging of the Parrett downriver of North Moor.

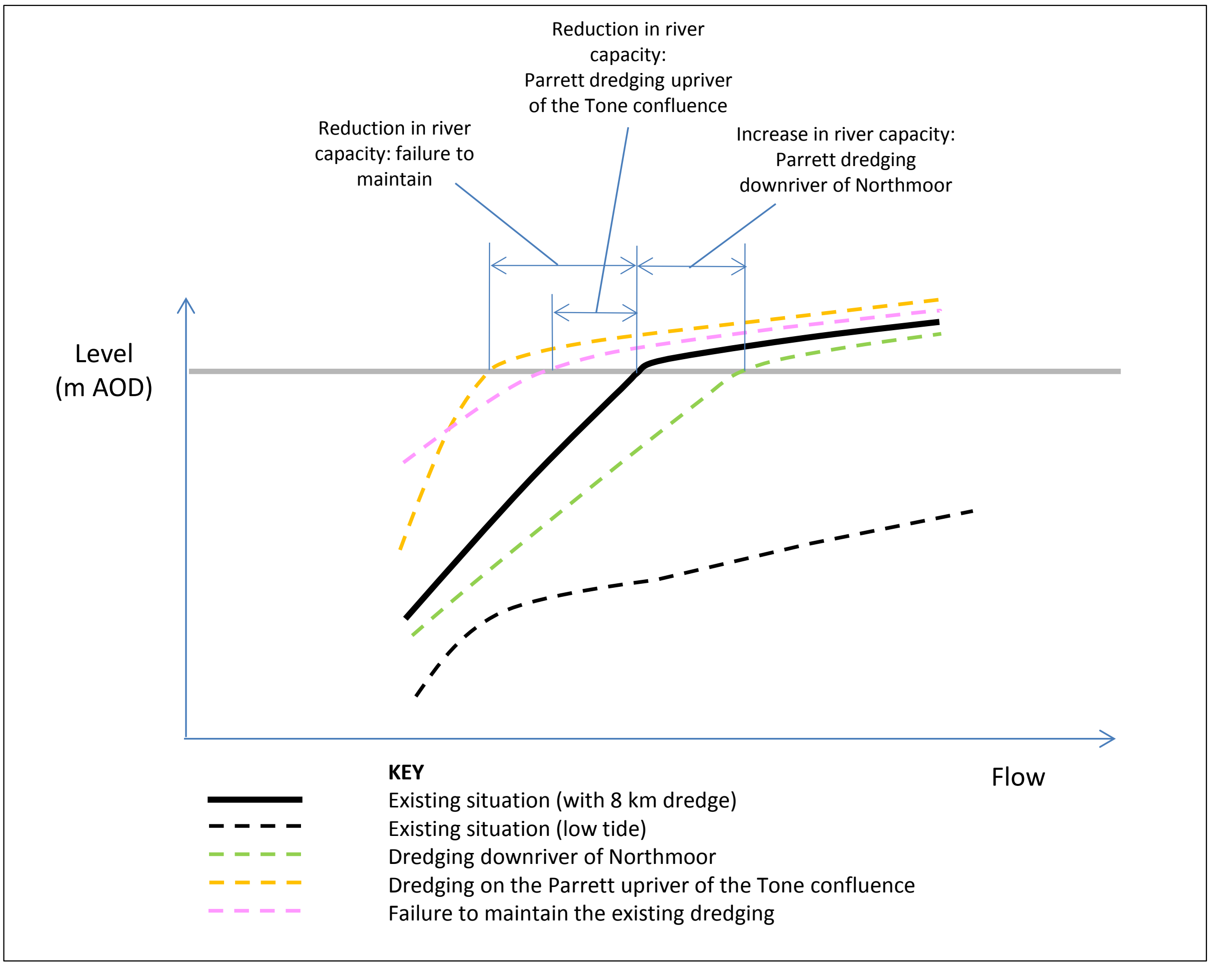


Figure A.7: Impacts of dredging on flow over Hook Bridge spillway at high tide

A similar diagram is shown on Figure A.8 for Allermoor spillway, indicating the changes in capacity of the River Parrett (and therefore flow over Allermoor spillway) at high tide for different dredging options.

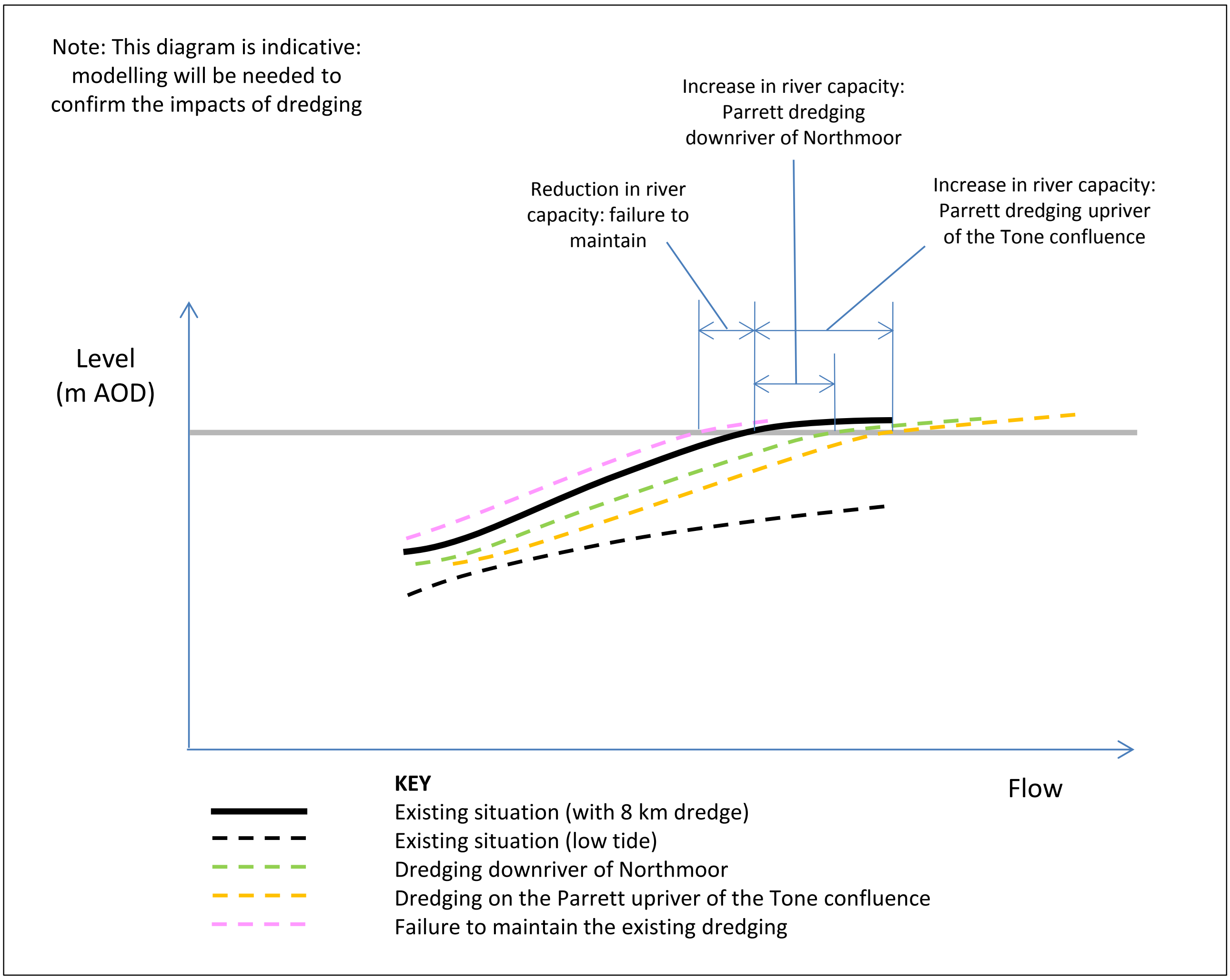


Figure A.8: Impacts of dredging on flow over Allermoor spillway at high tide

In view of the variable flows in the river channels, the design criteria to be used for dredging are related to flood volume, specifically the flood volume that causes flooding on North Moor, Kings Sedge Moor and upriver of Allermoor spillway. For convenience, these are represented by flood levels for particular flood events.

A.3. Hydraulics: River Brue

The River Brue between Glastonbury and Highbridge forms part of a lowland drainage system. It has a number of tributaries which flow into the Brue either by gravity or pumping. The hydraulics of the system are typical of a lowland fluvial drainage system with the exception that there is a tidal outfall structure, where water backs up at high tide and discharges at low tide.

There is a control structure just upstream of the M5 motorway crossing consisting of sluice gates. This is used to raise water levels during low flow periods but the gates are open during flood events.

Peak flood flows in the river are restricted by upstream attenuation and typically range from 27 to 32 m^3/s for a range of flood events (see Section A.1).

A.4. Locations of dredging: River Parrett and River Tone

It has been identified in earlier studies that dredging of the River Parrett downriver of the existing 8 km dredge and the current 750 m dredge will provide flood reduction benefits in North Moor. It has also been identified that dredging of the River Parrett upriver of the Tone confluence will reduce flood flows to Kings Sedge Moor and reduce flood levels on the Parrett further upriver.

Figure A.9 shows the cross-sectional area of the River Parrett channel from Langport to Bridgwater. The data are taken from the 2015 model of the Parrett, that includes the 8 km dredge together with recent survey data. The figure also shows an indicative design cross-section where the bed is parallel to the existing bed, the bed width is constant and the side slopes are 1 in 2. The figure also shows an indicative design cross-section upriver of the confluence, with a narrower bed width and higher bed level.

The design is approximate because the size of the channel is limited by physical constraints (roads, buildings, etc.) and, as noted above, it is not possible to define a design flow. The primary objective here is to identify a consistent cross-sectional area without constrictions.

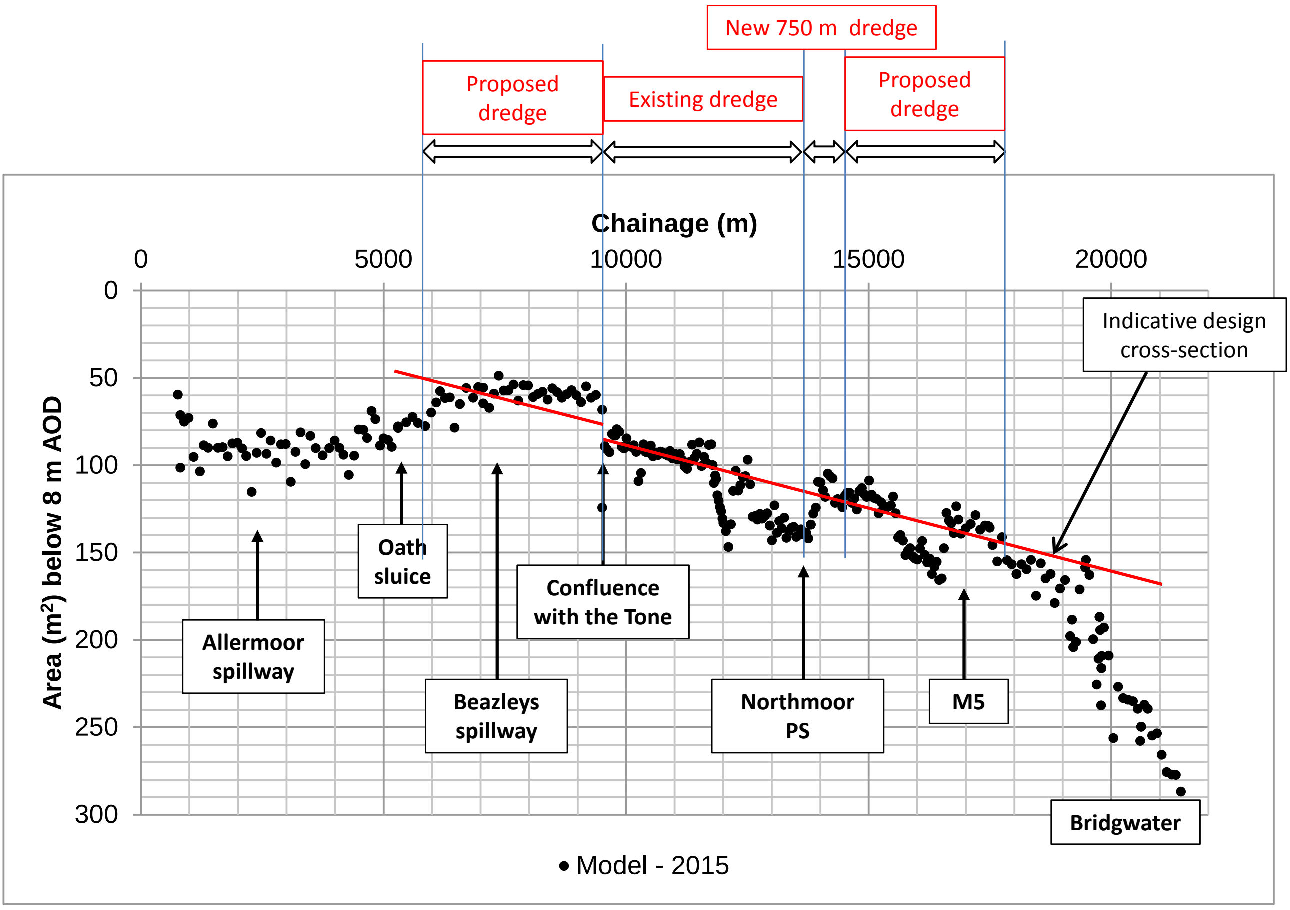


Figure A.9: River Parrett cross-sectional area showing proposed dredging locations

Figure A.9 indicates two areas where dredging would be needed to achieve these design cross-sections: two locations totalling about 3,000 m downriver of the present 750 m dredge and one location totalling about 3,000 m upriver of the Tone confluence.

The analysis in CH2M Hill 2015 includes a scenario to dredge upriver of Oath sluice. However Figure A.9 suggests that this would not be necessary. Figure A.10 and Figure A.11 show a typical cross-section in this reach, which indicates a large cross-sectional area of about 80 m^2. Dredging is therefore not proposed in this reach.

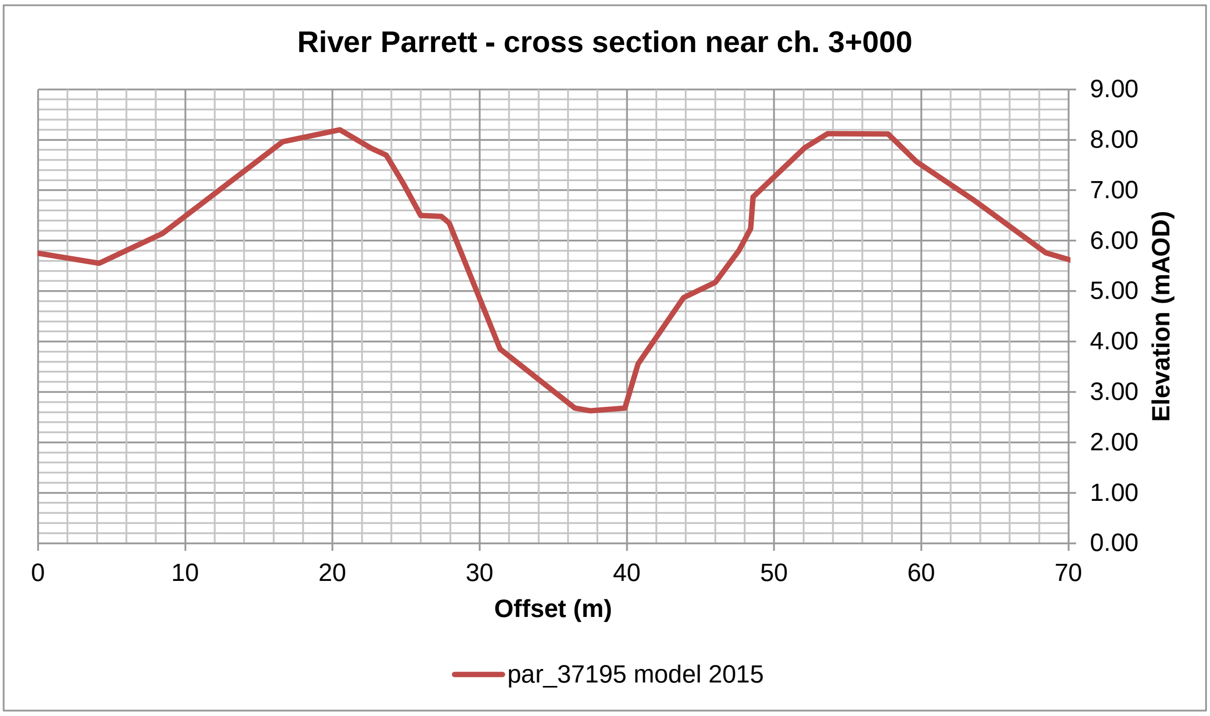


Figure A.10: River Parrett cross-section upriver of Oath sluice

Figure A.11: River Parrett upriver of Oath sluice

Figure A.12 and Figure A.13 shows a section of the River Parrett between Oath sluice and the Tone confluence. This section is clearly constricted and there is significant siltation. Dredging is proposed in this reach and a potential design section is indicated.

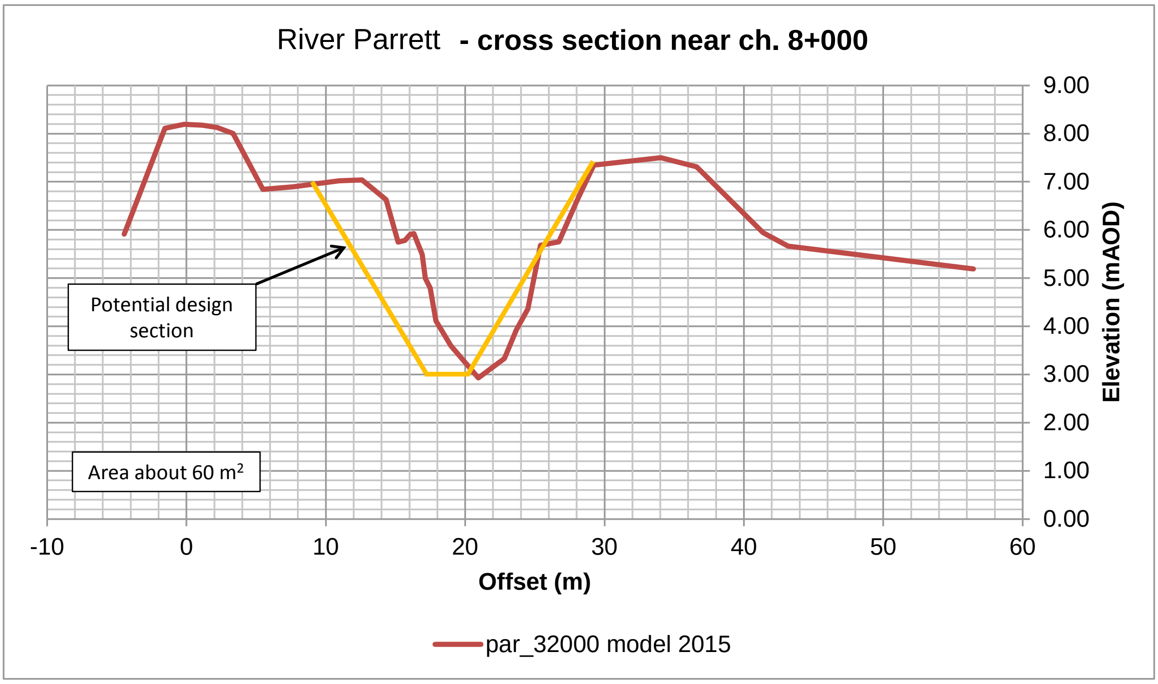


Figure A.12: River Parrett cross-section between Oath sluice and the Tone confluence

Figure A.13: River Parrett between Oath sluice and the Tone confluence (looking upriver)

Figure A.14 and Figure A.15 show the Parrett downriver of the confluence, where dredging took place in 2014. The section is clearly regular. Maintenance dredging of the lower half of this reach took place in 2016 and regular maintenance will continue to be required.

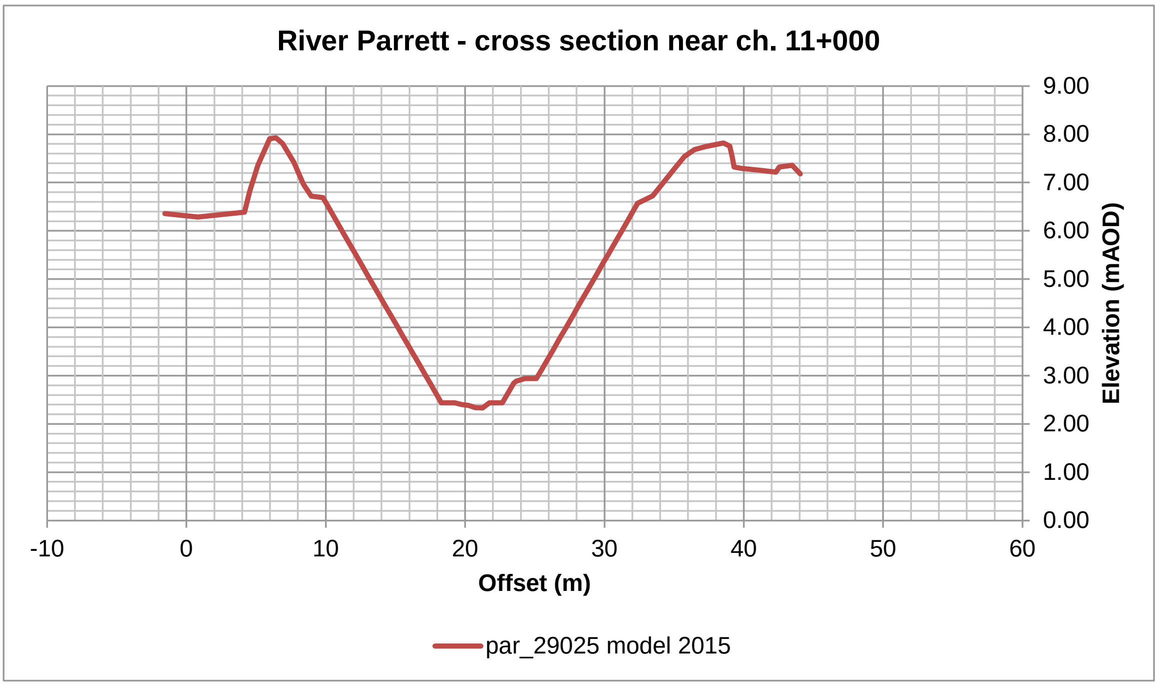


Figure A.14: River Parrett cross-section between the Tone confluence and Northmoor PS

Figure A.15: River Parrett cross-section between the Tone confluence and Northmoor PS

Figure A.16 shows another cross-section of the Parrett within the section that was dredged in 2014. It can be seen from Figure A.9 that the cross-section is larger than the approximate design section. The reason is apparent from comparison with Figure A.14: the river is wider at this point and the bed width is wider.

This section was included in the 2016 maintenance dredging, and Figure A.16 also shows siltation that occurred after the 2014 dredge and the maintenance dredging that was carried out in 2015/2016. The tendency of the siltation is to narrow the bed width. This indicates that widening of the river bed in this area will lead to further siltation.

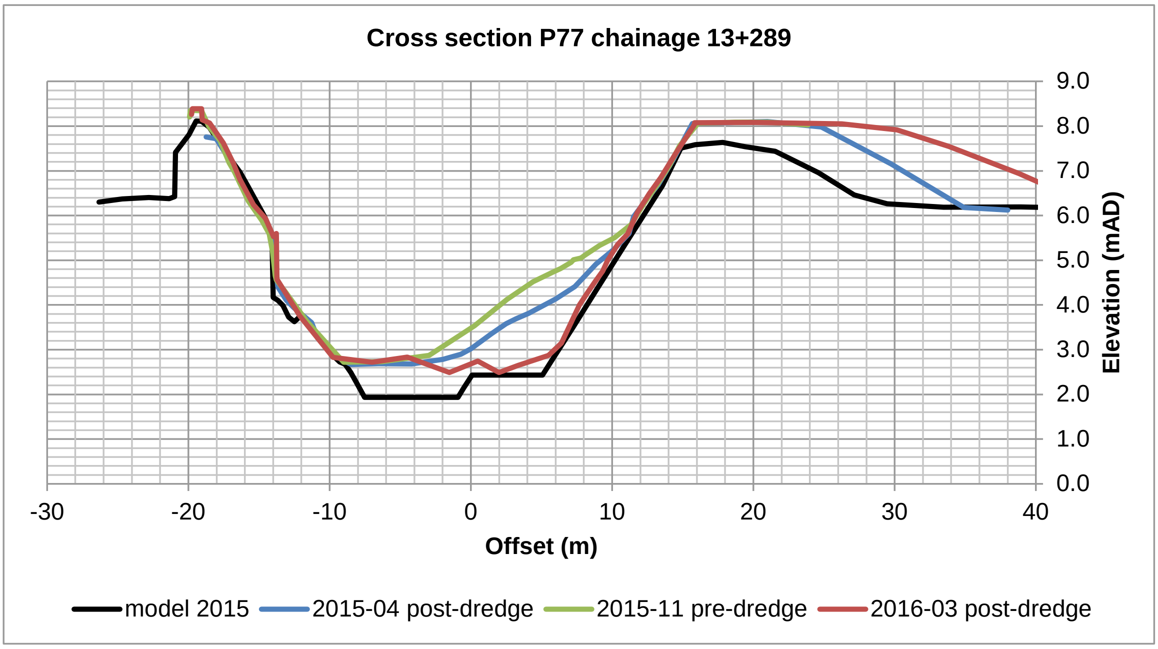


Figure A.16: River Parrett cross-section showing siltation and maintenance dredging

Figure A.17: River Parrett cross-section after maintenance dredging in 2016

Figure A.18, Figure A.19 and Figure A.20 show cross-sections of the River Parrett in areas where future dredging is proposed, together with an indication of the amount of dredging required to provide the approximate design section indicated on Figure A.9. These sections indicate the variability in channel size: dredging would be needed at Ch. 15000 and 17000 but not at Ch. 16000.

Figure A.21 shows a section of river downriver of Northmoor PS where dredging will be carried out as part of the 750 m dredge, illustrating the way in which the banks have accreted and vegetation has grown.

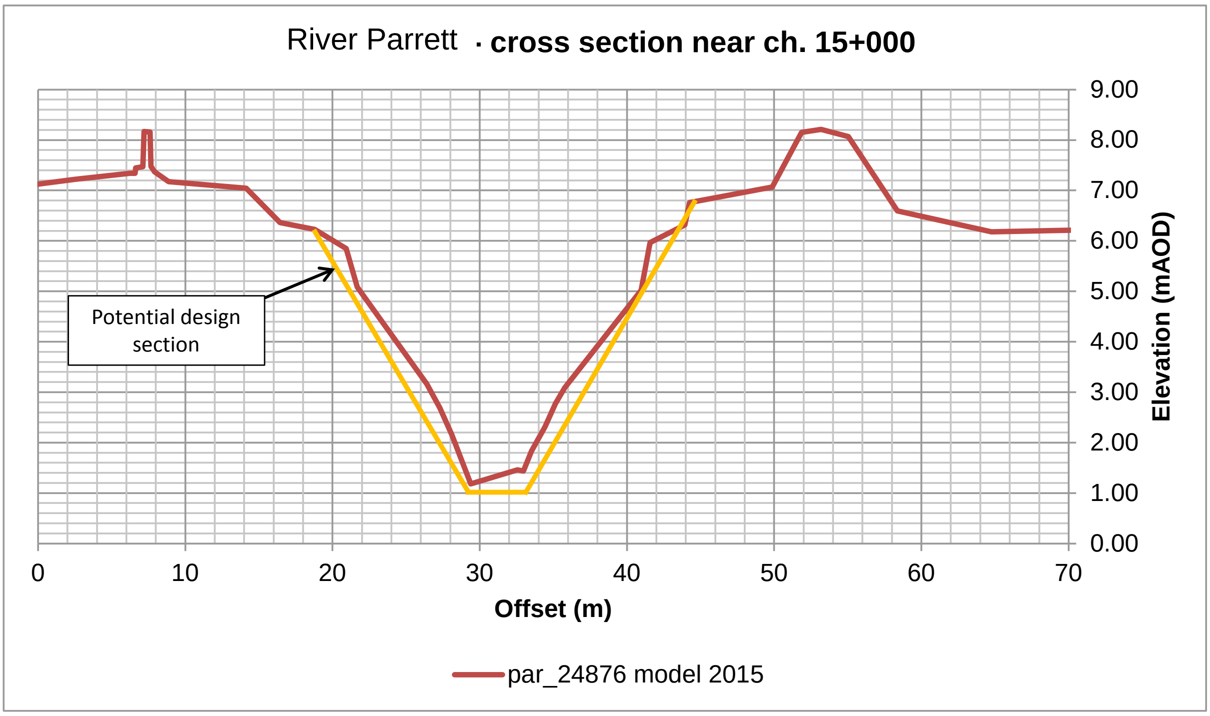


Figure A.18: River Parrett cross-section downriver of the current 750 m dredge: Ch 15000

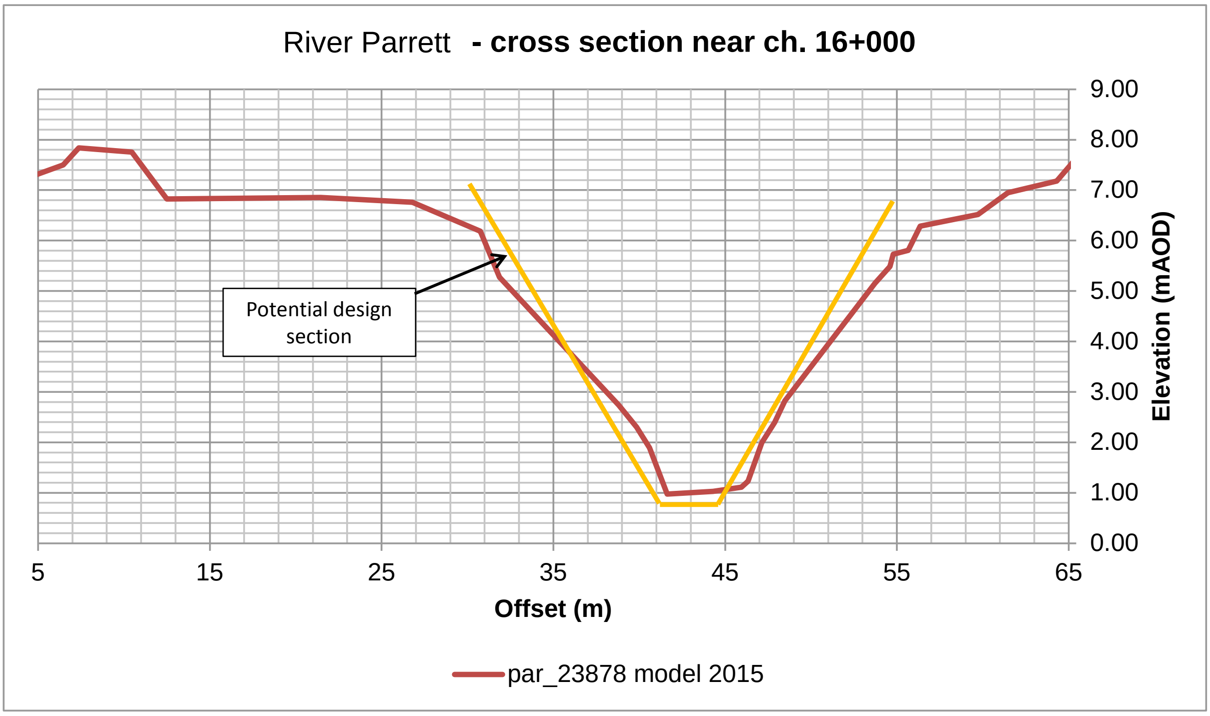


Figure A.19: River Parrett cross-section downriver of the current 750 m dredge: Ch. 16000

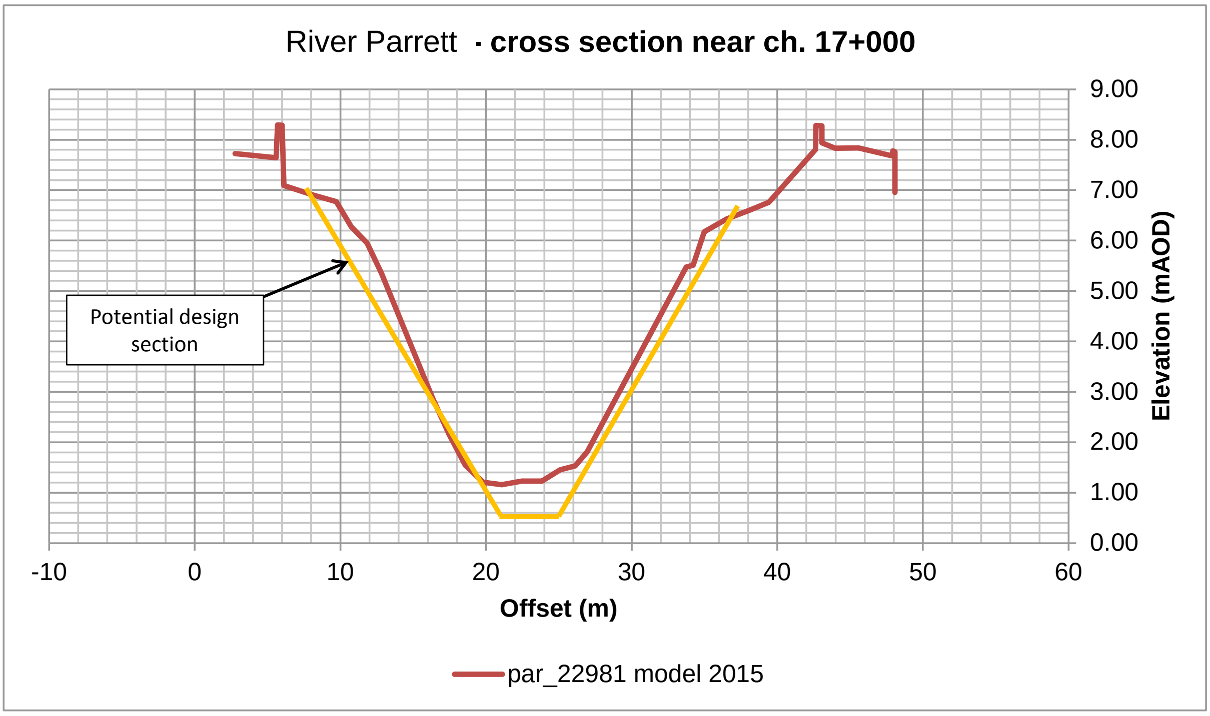


Figure A.20: River Parrett cross-section near the M5 motorway crossing

Figure A.21: River Parrett cross-section downriver of Northmoor PS

Figure A.22 shows a cross-section of the River Parrett near Bridgwater. The area of this section is significantly larger than the section in Figure A.20, where dredging is proposed.

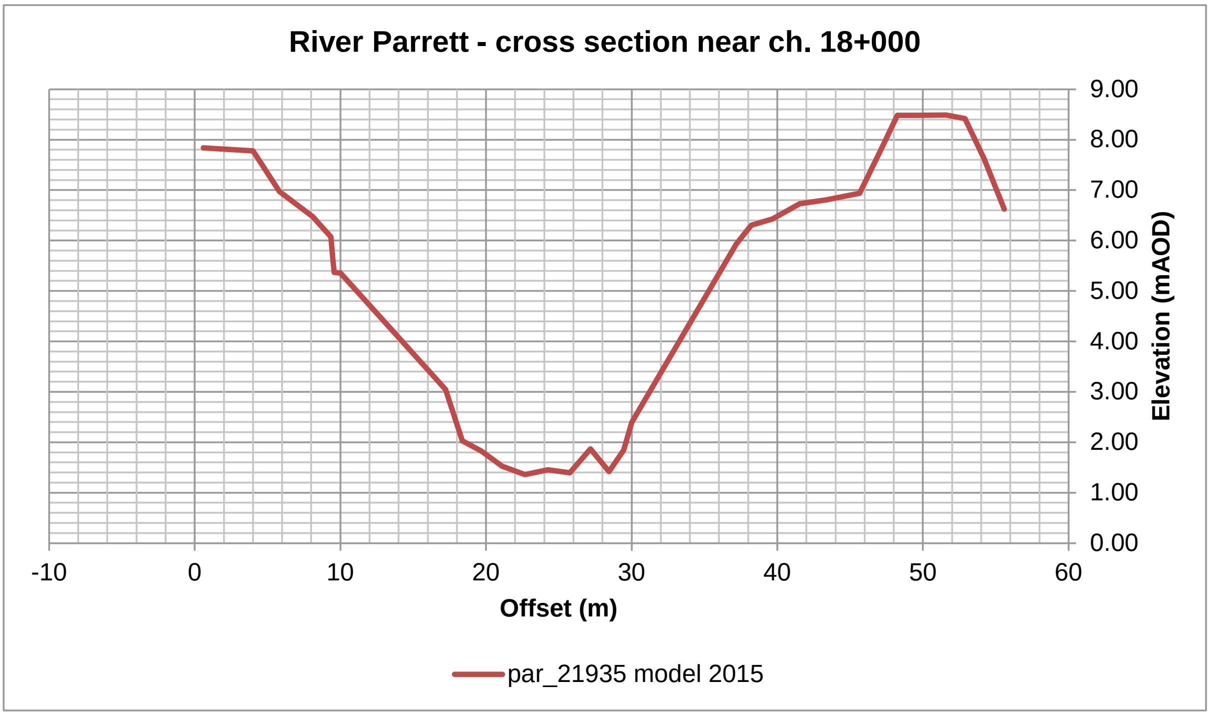


Figure A.22: River Parrett cross-section near Bridgwater

Cross-sectional areas of the River Tone from Hook Bridge spillway to the confluence with the Parrett are shown on Figure A.23. The River Tone was dredged from Hook Bridge spillway to the confluence with the Parrett in 2014. The figure shows the pre-dredging cross-sectional areas and two plots representing the post-dredging area: data from the April 2015 survey and data from the 2015 model. It is apparent that these two data sets are similar, but the model contains more detail.

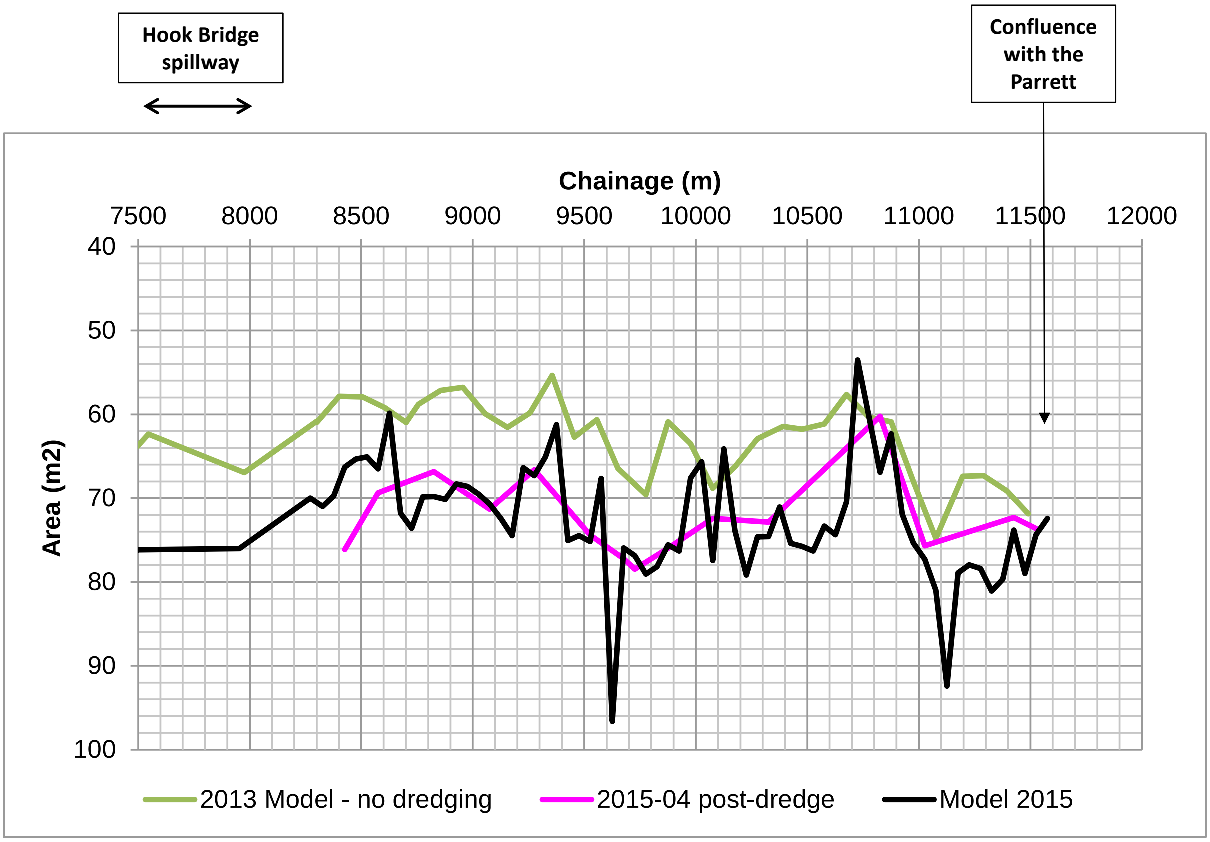


Figure A.23: River Tone channel cross-sectional area (below 8 m AOD)

Figure A.23 shows that there is considerable variation in the cross-sectional areas, which range between 60 and 80 m^2. Figure A.24 and Figure A.25 illustrate that the variation in area is caused by variations in width of the channel (but not variations in depth). Figure A.3 show that the bed level is relatively constant. The river is constrained by buildings, roads and other features, particularly on the south bank (Figure A.26).

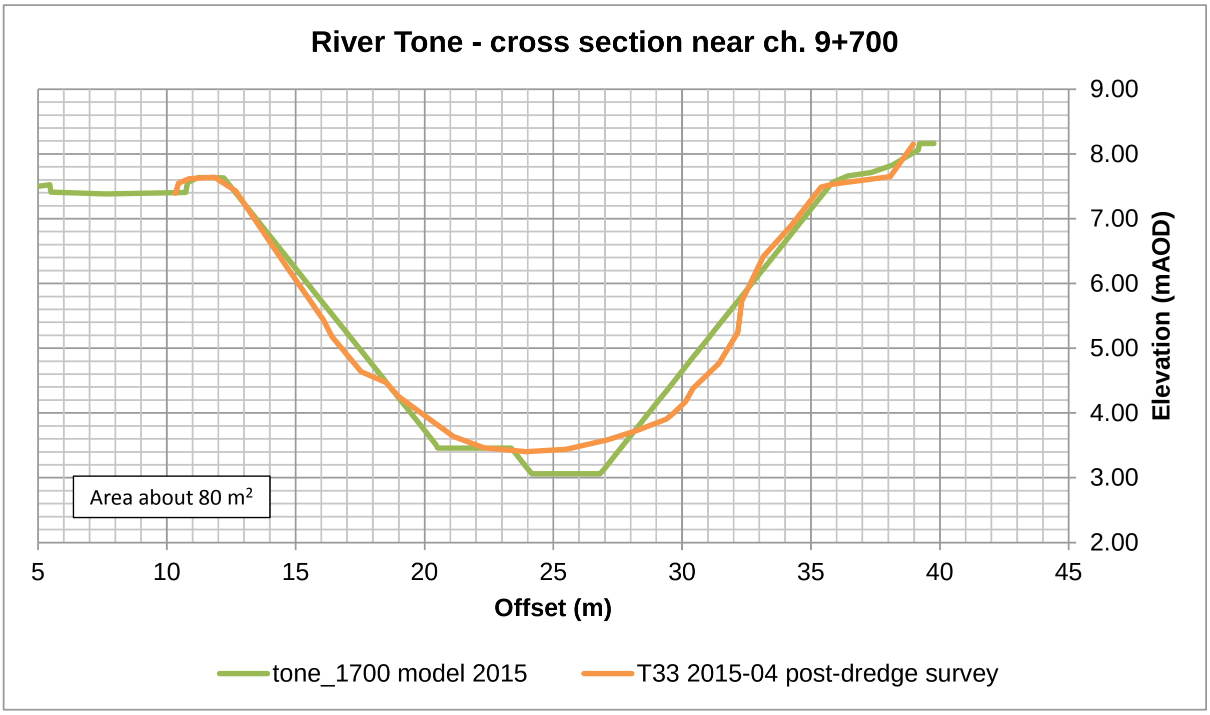


Figure A.24: River Tone channel cross-section: wide section

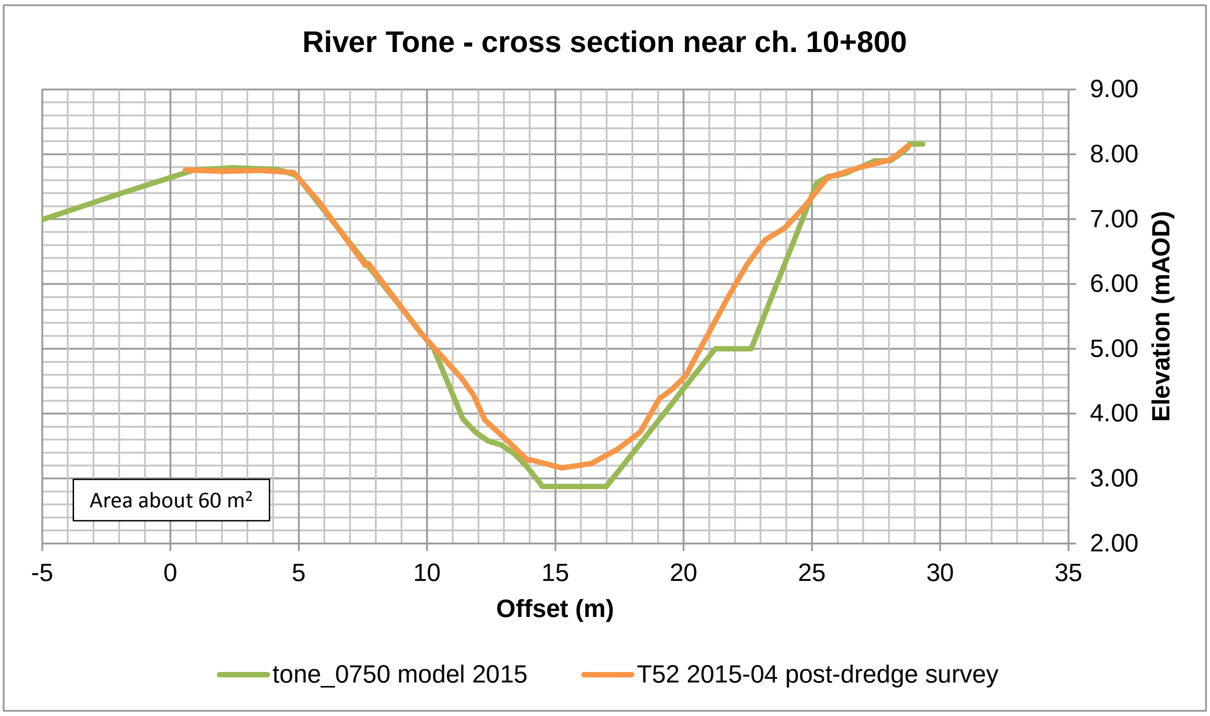


Figure A.25: River Tone channel cross-section: narrow section

Figure A.26: River Tone looking downriver

A.5. Locations of dredging: River Brue

Figure A.27 shows a longitudinal section of the River Brue that has been assembled using a range of data including:

- Data used to construct the 2010 model, including a channel bathymetric survey (from which, cross-sections were derived) and field surveys at river structures;
- Surveys carried out in 2013 downstream of Westhay Bridge, with and without siltation.

The longitudinal section indicates a relatively uniform bed level downriver of Westhay Bridge to Highbridge. There is an increase in bed level of about 2 m upriver of Westhay Bridge at the confluence of the Division Rhyne system.

Dredging has been considered for the 4.5 km reach downriver of Westhay Bridge, and the 2013 survey provided information of the amount of soft silt in this area. Figure A.28 shows channel cross-sectional area, based on the 2010 and 2013 surveys. The figure includes areas from the 2013 surveys and the earlier 2010 surveys. The areas are below a fixed datum of 3.8 m AOD.

An indicative design cross-section has been included on Figure A.28, which has a capacity of about 30 m^3/s in the reach downriver of Westhay Bridge and provides a constant trapezoidal channel cross section where the bed is parallel to the existing bed. It is apparent that, whilst some dredging may be required between

Westhay Bridge and North Drain, the channel is constricted downriver of North Drain between Chainages 11500 and 6000 approximately.

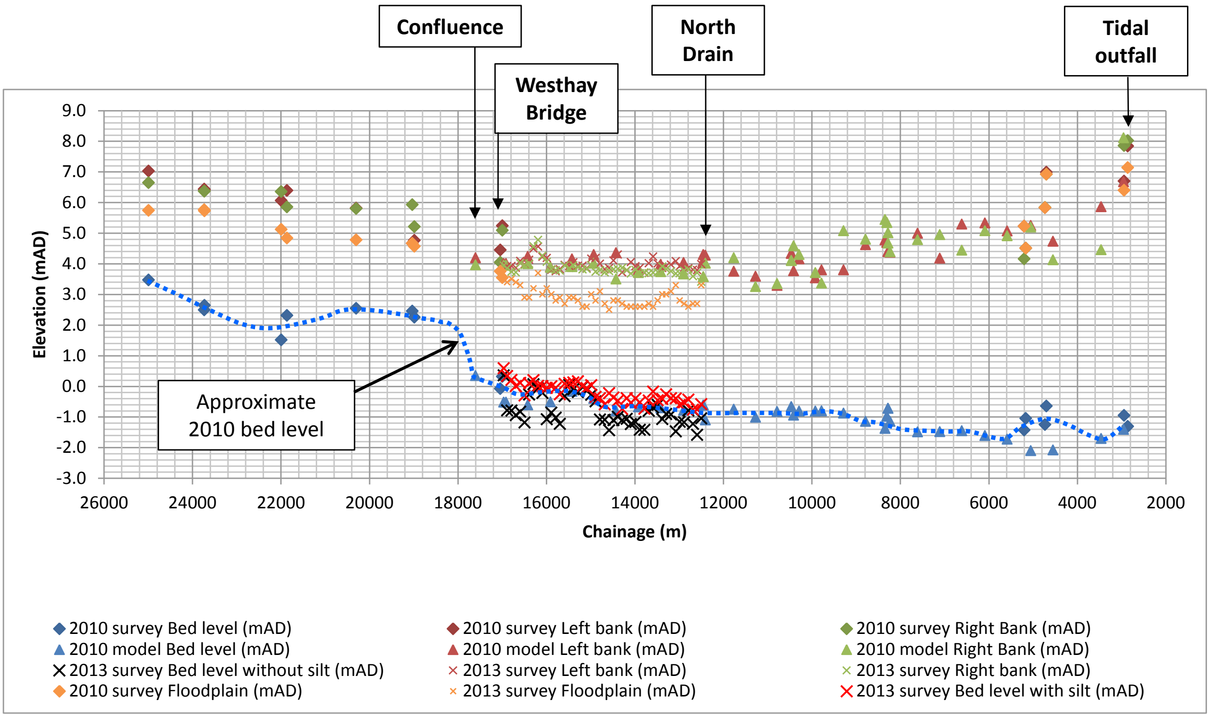


Figure A.27: River Brue longitudinal section

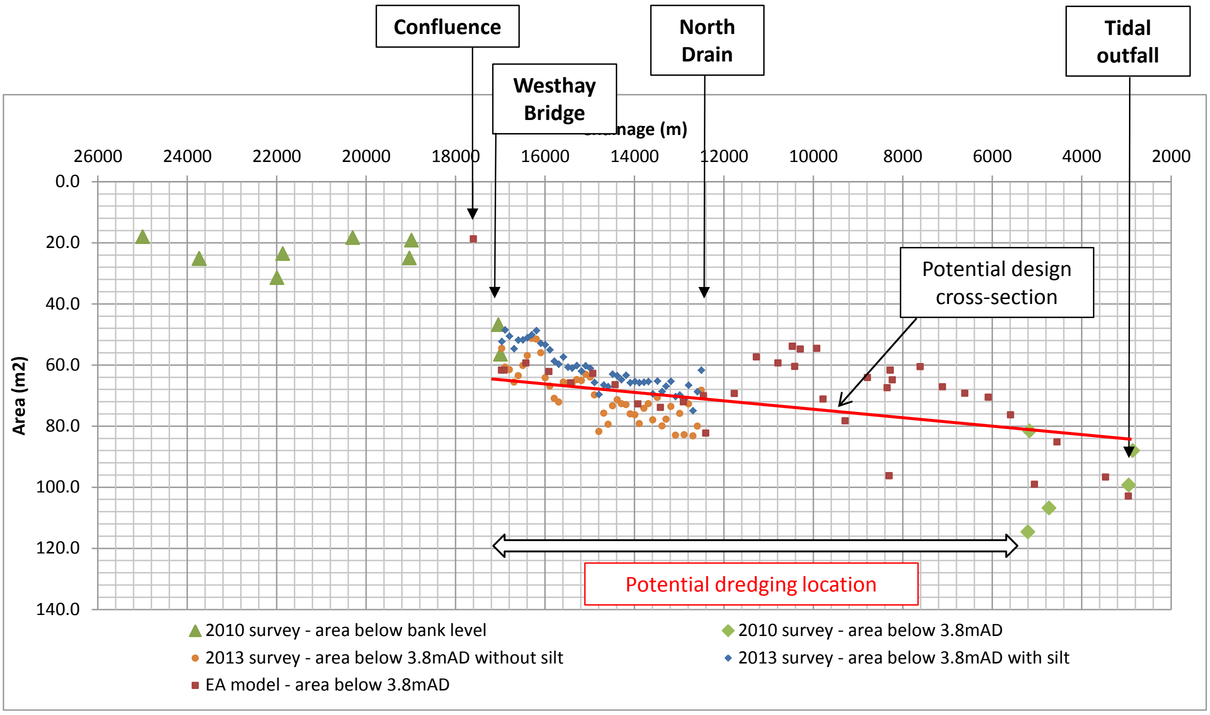


Figure A.28: River Brue channel cross-sectional area showing potential dredging locations

Figure A.29 shows a number of river cross-sections. The smaller cross-sectional area and higher bed level upriver of the confluence just upstream of Westhay Bridge is apparent. The cross-section at Ch 10787 shows that the area is reduced downstream of North Drain because the bed level is higher and the channel is narrower than the upstream section (Ch 14093). The cause of the smaller section further downstream is that the channel is narrower than the reach upstream of North Drain (compare Ch 8234 and 14093).

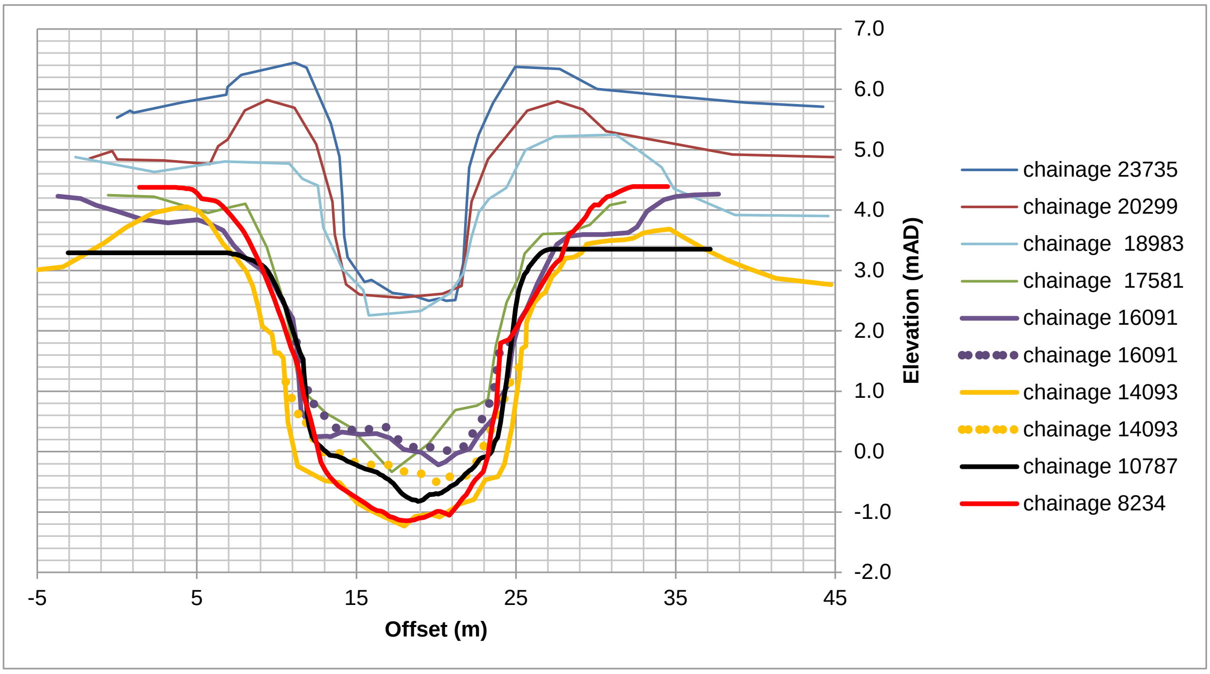


Figure A.29: River Brue channel cross-sections

Whilst Figure A.28 indicates the approximate location of dredging, it is recommended that a further survey is carried out from Westhay Bridge to about Ch 5000. It is also recommended that a hydraulic design for the river is formalised in order to guide decisions regarding future dredging.

B. Sediment Transport

B.1. Data sources

Key sources of data that have been identified relating to measurements of flow and sediment within the tidal sections of the Rivers Parrett and Tone include; the October 1977 field survey complete by Hydraulics Research Station (HRS) for data downstream of Bridgwater, a further field survey completed by Hydraulics Research Wallingford (HRW) in October 1985 upstream of Bridgwater to the tidal limit, and most recently by Partrac (Autumn / Winter 2008 and Summer 2009) again upstream of Bridgwater to the tidal limit.

Further general information has been obtained from a review of other relevant documents identified in Appendix D.

B.2. Data limitations

The data produced by each study that is referenced above is not without limitations that should be acknowledged and considered when using the information to develop a conceptual model, these include:

- The HRS and HRW studies are now 30 or more years old and, the channel condition with respect to dredged or un-dredged state, at the time of the measurements, is also not known. Therefore it is not possible to comment on how representative the measurements are of the current (post-pioneer and maintenance dredge) channel form.
- The Partrac studies are affected by several factors that reduce the value of the data, including:
  - The observed turbidity values during particular spring flood tides were beyond the level which the instrument was able to measure. During the Autumn / Winter measurement campaign the equipment at 3 of the 6 sites failed to record data.
  - The measurement campaign was undertaken prior the 8km pioneer and 2.2km maintenance dredge. The specific channel condition with respect to siltation is not known.
  - Further equipment failure (at other monitoring sites) during both the Autumn / Winter and Summer campaigns produced an incomplete measurement record. To complete the record Partrac relied upon extrapolation and correlation analysis.
  - The sediment flux calculations are derived from “Single point estimates of TSS (total suspended solids)”. The report comments that “Single point estimates of TSS are adequate for flux calculations, as the profiling data indicate a well-mixed water column in all cases”. A review of this data suggests that there was a factor of 3 difference between the lowest and highest TSS values recorded at each site during the Summer campaign. No further information on the location within the channel and water column (horizontal position or depth) where these measurements were made is provided in the reports.
  - Whilst a flow velocity profile has been applied to the point measurements of current speed in order to determine a depth averaged flow speed, no such analysis has been applied to the TSS data, to determine a concentration profile.

In summary it is considered that the HR Wallingford measurements provide some information on the hydrodynamic and sediment transport characteristics of the Parrett system. The Partrac measurements provide additional insight into some aspects but the data limitations mean that only limited conclusions can be made.

B.3. Development of a conceptual model of sediment transport

Siltation is, in general terms, a process that constantly affects the tidal sections of the Rivers Tone and Parrett, however, it is variable spatially and temporally and is driven by several factors. Consideration has been made of these factors and their in-combination effects to develop a conceptual model of sediment transport within the Parrett system. The purpose of the conceptual model is to help inform understanding of where and when siltation is likely to occur, its relative magnitude and the key factors affecting it. This will assist in determining the potential future management of siltation within the Parrett System.

B.4. The Parrett and Tone System

The Rivers Parrett and Tone drain around 1665km^2 of Somerset and Dorset in to the Bristol Channel (Partrac 2008). Both of the rivers experience relatively significant water level changes associated with tides and freshwater run-off. The interaction of these waters, and there effect on sediment transport is complex. As a result of high tidal currents the Parrett is highly turbid, and large amounts of suspended sediment is transported within the system.

B.5. Estuarine Processes

Several key processes occur within estuaries that affect the way in which the sediment load is delivered by the marine (salt) water and freshwater, a summary of them and there applicability to the tidal sections of the Parrett System is given below. From measurements made (relating to variability in water level, current speeds and salinity) it is appropriate to consider the sections of the Parrett and Tone Rivers where dredging has taken place, and is likely to be required in the future as ‘estuarine’.

B.5.1. Type of estuary

From a tidal range perspective, the Parrett System is considered *Hypertidal*, (Davies 1964) with the mouth at Stert Point experiencing a mean spring tide range of around 11m. From a morphology perspective the lower estuary (downstream of about Bridgwater, which has not been subject to extensive realignment) is considered to be an example of a *drowned river valley* (Fairbridge 1980).

Estuarine systems generally fall into one of three categories with respect to the balance of fresh and salt water inputs (Cameron and Pritchard 1963):

1. *Stratified* – where the turbulent, mixing forces are unable to overcome the buoyance generated by density differences between the fresh and salt water.
2. *Partially mixed* - where the turbulent, mixing forces are able, to some degree, overcome the buoyance generated by density differences between the fresh and salt water.
3. *Well mixed* - where the turbulent, mixing forces are able, to a large degree, overcome the buoyance generated by density differences between the fresh and salt water.

Several attempts (e.g. Hansen and Rattray 1963, Prandle 1985) have been made to define, numerically, boundaries associated with the three estuary types. Simmons (1955) suggests that a classification can be developed from understanding the flow ratio (the ratio of river flow over a tidal cycle to tidal prism): a ratio of 1.0 or greater implies fully stratified, when the ratio is around 0.25 the estuary is partially mixed and with a ratio of 0.1 or less the estuary is well mixed.

Table B.1 presents the results using Simmons (1955) method for the Parrett System, which considers a typical discharge of 10m^3/s and an extreme discharge of 80m^3/s for the System and a tidal prism of 3Mm^3 upstream of the M5 (Black and Veatch 2011).

Table B.1: Estuary classification based on Simmons (1955) method

Condition	Total freshwater flow per tidal cycle (12.5 Hrs) m^3	Nominal Tidal Prism m^3 (B&V 2011)	Simmons (1955) ratio	Classification
Average system flow (10m^3/s)	450,000	3,000,000	0.15	(nearly) well mixed
Extreme system flow (80m^3/s)	3,600,000	3,000,000	1.2	highly stratified

Whilst the results indicate that the System has the potential to display a range of classifications, the specific condition within the estuary varies in time and space. It is reasonable to expect that under neap tide conditions and large freshwater input it is likely that *stratified* conditions would exist downstream of the mean location of saline intrusion. Conversely, under spring tide conditions and low freshwater input is likely that *well mixed* conditions will persist over the length of the saline intrusion.

The high suspended sediment loads can also contribute to conditions where density stratification occurs, due to the relative density of the highly turbid marine waters compared to the low turbidity freshwater.

B.5.2. Key processes

Determining the type of estuary that the System is, is important for determining the types of phenomenon that affect sediment transport and their relevance. Phenomena which are thought to be key to the system are:

- Tidal pumping;
- Sediment dynamics;
- Turbidity maximum;
- Deliberate modification to channel cross-sections.

The turbidity maximum is a key phenomenon with respect to siltation. Associated with the general location of the turbidity maximum is a zone of shoaling zone comprising of muddier sediments. These muddier reaches are observed in most macro and hypertidal estuaries, a key example is seen in the River Thames.

B.5.3. Turbidity maximum

During periods that the System is in a well or partially mixed condition a *turbidity maximum* is likely to be present. This is a zone of high suspended sediment concentration, higher than those located in the river or lower down the estuary and which is often located at, or near to, the head of the salt intrusion (Dyer 1997). The *turbidity maximum* is a point where the effects of tidal asymmetry and/or salinity gradients (which produce net landward transport) are broadly balanced by the effect of freshwater discharge (which produces net seaward transport).

Dyer (1997) also notes that in hypertidal estuaries, suspended sediment concentrations in the turbidity maximum can reach 1000's to 10,000's mg/L and contain a mass that is several times the mass of sediment delivered by the river system annually.

The turbidity maximum also moves up and down the estuary during the tide and due to the influence of freshwater flow, and concentrations alter as it does because of entrainment and settling of sediment. At about high water the turbidity maximum is located well up the estuary and concentrations reduced because of settling. At low water the turbidity maximum is located down estuary, and reduced concentrations occur once again due to settling at slack water. Material is then re-eroded during the flood and ebb tides, and the cycling of sediment between the channel bed and banks and the water column continues. The effect of tidal currents on sediment dynamics is discussed in subsequent sections.

On a tidally averaged basis the location of the turbidity maximum at spring tides is further up the estuary than at neap tides. This is due to the increased mean water level at the head of the estuary caused by the increased range. Spring tides enhance the deposition of sediment on the intertidal areas at the head of the estuary due to the long slack water period over high water, together with the higher concentration. Under large freshwater discharges the turbidity maximum moves downstream, and within the River Parrett freshwater flows can enhance the ebb tide sufficiently to induce net erosion of tidal sediments.

The mass of sediment in suspension varies between spring and neap tides, this is particularly apparent on the Parrett System. Analysis by HRS (1985) illustrates a strongly non-linear relationship between tidal range and suspended sediment concentration at various locations along the Parrett System (Figure B.1). The increased tidal range of spring tides affects the suspended sediment concentration, but also the propagation of the high concentrations upstream in the Parrett System.

Unfortunately similar measurements, relating concentration to tidal range upstream of Bridgwater were not made, and therefore it is not possible to determine with the same level of certainty under what conditions the high suspended sediment concentrations propagate further up the Parrett System.

However, data collected by HRS (HRS 1977) and reported in Burt (1980) demonstrates that the average limit of the saline intrusion on the Parrett is around 24km upstream of Stert Point (Figure B.2). This coincides with the reach between Westonzoyland Pumping Station (around 21km upstream of Stert Point) and Burrowbridge (around 29km upstream of Stert Point). On the basis that the location of the turbidity maximum is broadly represented by the limit of saline intrusion, it suggests that, on average, a turbidity maximum of the Parrett system is located in this reach.

This view is further supported by the analysis of the relationship between tidal range for both spring and neap tides and distance upstream of Stert Point, presented in Figure B.3 and Figure B.4. The tidal limits of the Parrett and Tone system are located 33 km and 34 km respectively upstream of Stert Point (Oath sluice and Newbridge sluice). This analysis demonstrates that under mean neap and mean spring tidal conditions, the tidal limits of the Parrett and Tone system are further upstream than the limit of saline intrusion.

Extrapolation of the relationship suggests that without the presence of Oath or New Bridge sluices, the tide (under mean spring or higher tides) could propagate further inland.

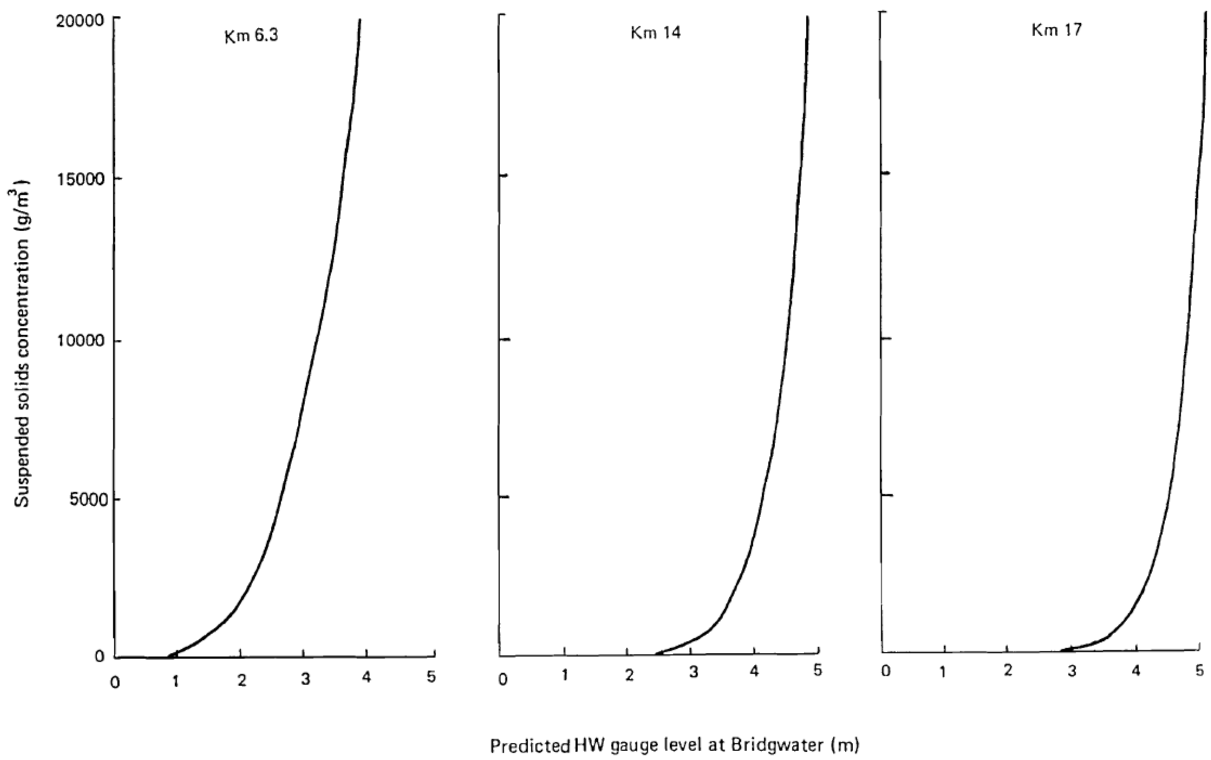


Figure B.1: Relationship between suspended sediment concentration and tidal level (tidal range) at Bridgwater

Source: HR Wallingford report EX1428, 1985

Notwithstanding the limitation identified with the Partrac data, a review of the flux values calculated by Partrac (Partrac 2009) suggests the mass of sediment moved within the system decreases with increasing distance upstream of the M5 crossing during summer (under low flow conditions). The largest fluxes occur between the first monitoring site (upstream of the M5) and second monitoring site (upstream of Westonzoyland Pumping Station). Furthermore analysis of sediment samples collected by Partrac (Partrac 2008) indicates that sediment size (from sample analysis) is broadly similar at the sites monitored along the Parrett System with the exception of the most downstream site, which had a slightly smaller average particle size. This information further supports the idea that this is zone, between the M5 crossing and Burrowbridge, is where the turbidity maximum is likely to be located.

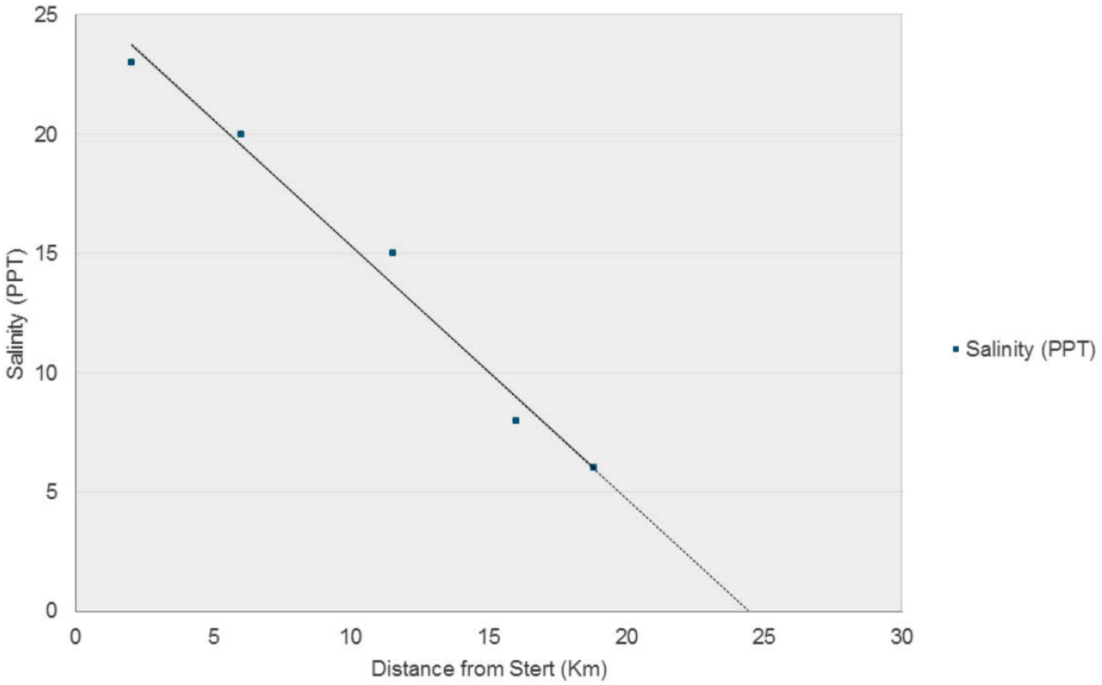


Figure B.2: Average salinity along the tidal section of the River Parrett

Source: Burt (1980). Pilot Study of the River Parrett: Interim Discussion Paper.

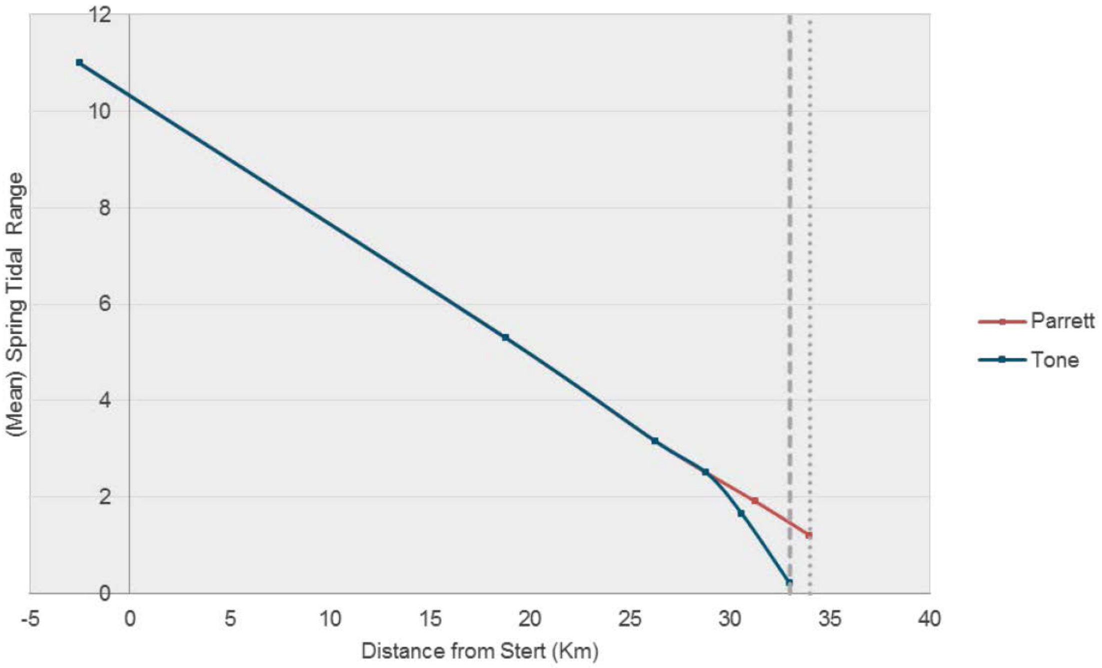


Figure B.3: Relationship between spring tidal range (m) and distance from Stert Point on the Parrett and Tone Rivers (N.B the tidal limits are denoted as dashed grey lines).

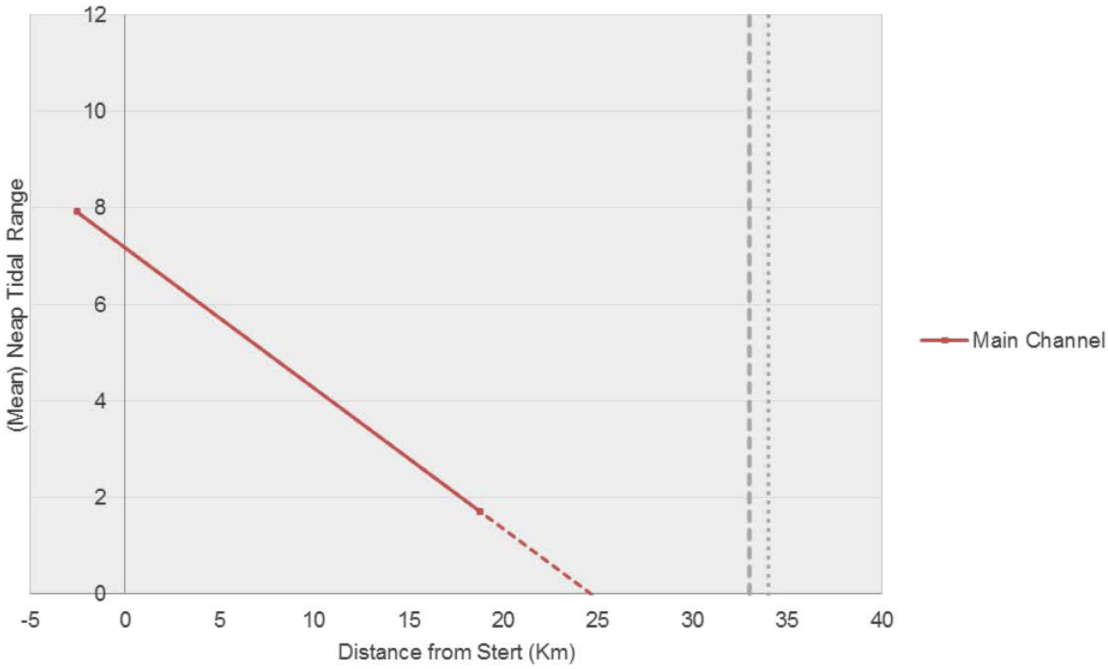


Figure B.4: Relationship between neap tidal range (m) and distance from Stert Point on the Parrett and Tone Rivers (N.B the tidal limits are denoted as dashed grey lines)

B.5.4. Tidal pumping

Along with vertical gravitational circulation and sediment dynamics, tidal pumping is key factor contributing to the generation and maintenance of the turbidity maximum.

Both the Rivers Parrett and Tone experience changes in water levels associated with tides and freshwater flow, with the balance of influence changing from tidally dominated to freshwater dominated with increasing distance upstream.

The tidal limit of the Parrett is given as Oath Sluice around 33 km from Stert Point, and the tidal limit of the Tone is given as New Bridge Sluice around 34km from Stert Point along the main channel. Tidal range diminishes with distance up the river channel from the Bristol Channel (Table B.2).

Table B.2: Mean tidal levels

Location	Mean Low-water Spring Tide	Mean Low-water Neap Tide	Mean High-water Neap Tide	Mean High-water Spring Tide	Range (Mean Spring)
Burnham on Sea (Stert Point -2.5Km)	-0.1m	2.4m	7.9m	10.9m	11.0m
Bridgwater (Stert Point +18.8Km)	-	-	1.7m	4.6m	4.6m

Source: UK Hydrographic Office (UKHO) Tidal Data (2016) to Port of Bristol Datum

The timing (phasing) to tidal water levels is also modified with increasing distance up the river channel. Typically the duration of the flood tide and ebb tide is around 6 to 6.5 Hrs in length, at Burnham-on-Sea. At Bridgwater this has changed to a flood tide of around 2.5 to 3 Hrs in length, with an ebb tide of around 9 to 10 Hrs in length.

Water level information upstream of Bridgwater was collected as part of the 1985 Hydraulics Research Wallingford (HRW 1985) studies, and a summary of the changes in water level at different locations along the River Parrett and Tone is given in Table B.3. Note that the predicted high-water level for this survey was 5.3m AOD at Bridgwater. Freshwater flow was low during the period of the survey and therefore provides a good representation of level changes associated with tidal influence.

Table B.3: Water levels from HRW's 1985 survey

Location	Date of measurement	Tide type	Lowest recorded water depth	Highest recorded water depth	Range
Pipe Bridge (Stert Point + 26.3Km)	15 October 1985	Mean Spring	0.6m	3.75m	3.15m
Stathe (Stert Point +31.3Km)	15 October 1985	Mean Spring	0.7m	2.6m	1.9m
Athelney (Stert Point +30.6Km)	15 October 1985	Mean Spring	0.7m	2.35m	1.65m

Source: HR Wallingford October 1985 field data – Hydraulics Research Wallingford Report EX1428

The data collected by HRW also includes timing of the minimum and maximum water depths along the Parrett and Tone channels, this is summarised in Table B.4.

Table B.4: Timing of water-levels along the Tone and Parrett from HRW’s 1985 Survey

Location	Date of measurement	Tide type	Lowest recorded water depth - time	Highest recorded water depth - time	Flood tide duration
Pipe Bridge (Stert Point + 26.3Km)	15 October 1985	Spring	07:15	09:11	1Hr 56Mins
Stathe (Stert Point +31.3Km)	15 October 1985	Spring	08:15	09:50	1Hr 35Mins
Athelney (Stert Point +30.6Km)	15 October 1985	Spring	08:01	09:10	1Hr 09Mins

Source: HR Wallingford October 1985 field data – Hydraulics Research Wallingford Report EX1428

The relationship between (mean) spring tidal range and duration of the flood tide is given in Figure B.5. The figures illustrate that along with a progressive reduction in tidal range along the river channels, the flood tide duration decreases. Both of these phenomena are caused by friction, since the crest of the tidal wave ends up moving faster than the trough.

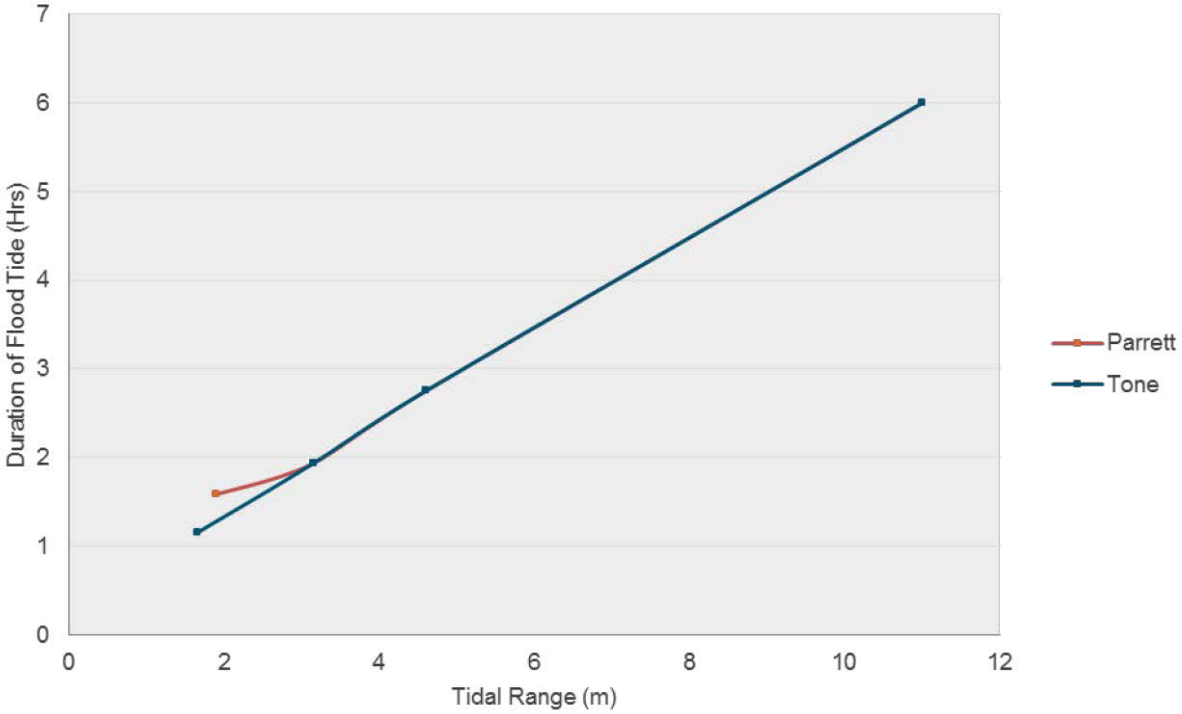


Figure B.5: Relationship between duration of flood tide and spring tide range on the Parrett and Tone Rivers

During times of low river flow, the asymmetry in the tide (significantly shorter flood tide duration compared to ebb tide duration) causes the suspended sediment flux to be greater during flood tides due to relatively increased flow velocities. As illustrated in the figures above the tidal asymmetry increases inland, and will do so until the influence of river flow becomes important in amplifying the ebb tide velocities. This occurs somewhere landward of the saline intrusion associated with a particular tide. The concept of tidal pumping is illustrated in Figure B.6 and Figure B.7.

Measurements of current velocities made by both HRW (1985) and Partrac (2009) during low flow conditions indicate that flood tide velocities are significantly larger than ebb tide velocities. Measurements of suspended sediment concentrations made by HRW (1985) also indicate significantly larger suspended sediment concentrations during the flood tide (order 1000s mg/l) and the ebb tide (order 10s to 100s mg/l). The measurements made by HR Wallingford were made during a low river flow period and relatively large tidal range at Bridgwater.

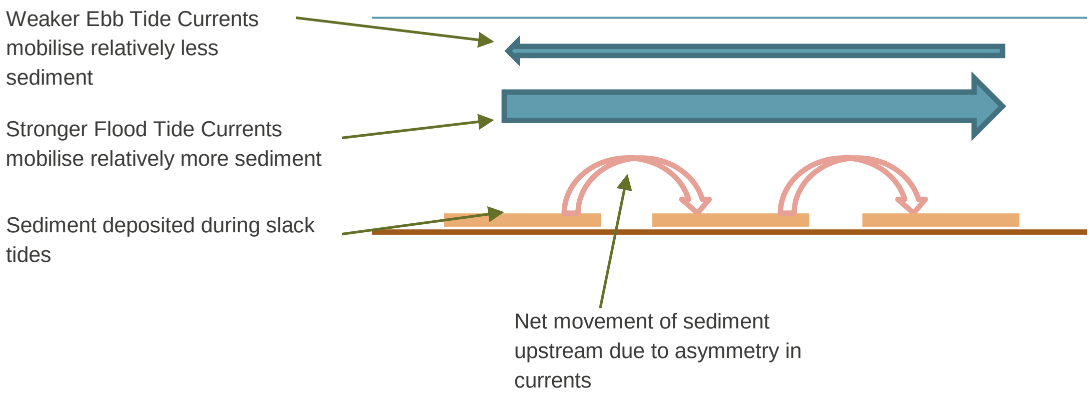


Figure B.6: Tidal Pumping - mechanism

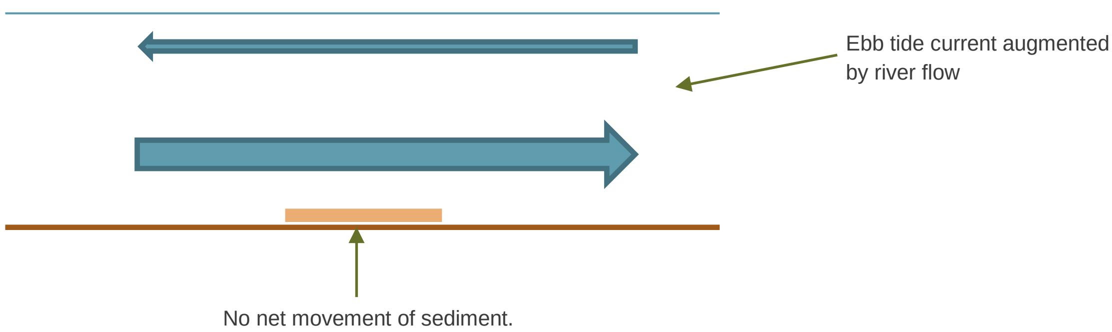


Figure B.7: Tidal Pumping – limitation due to river flow

B.5.5. Sediment dynamics

The settling and erosion of sediment causes the sediment to become separated from the transporting flow at specific times during the tidal cycle. Various 'lags' can occur due to different processes, some of the key lags which have the most profound effect on sediment transport include:

- *Threshold lag* – this is produced by the need for current velocities to exceed a critical value before sediment will start moving or settling. In a tidal cycle with a short, relatively fast flood current and a long slow ebb current (as per the Parrett System) the duration for transport of sediment on the ebb tide will reduce much more rapidly than on the flood tide as the threshold increases.
- *Settling lag* – is the delay caused by the particles settling out of suspension. Before the sediment that is in suspension reaches the bed (as it may have several meters of water to settle through) it can be advected to a different location.
- *Erosion lag* – this is associated with the variation in threshold conditions with increase depth through the sediment created by consolidation. This implies that as different layers of sediment are eroded due to the currents, different layers may be easier or more difficult to eroded, contributing to different rates of release of sediment.

In the Parrett System, it is considered that because of the strong asymmetry in the tide that *Threshold lag* is a key process.

B.6. Effect of freshwater input on sediment transport

A synthetic time-series of water level and current information is presented in Figure B.8. The time-series and associated calculations use nominal values, the purpose is to represent a location in the lower tidal section of the Parrett that experiences a flood tide of around 2.5 Hrs in duration, a range of 3m and peak current speeds of order 1.5m/s. The ebb tide is around 10 Hrs is duration with peak current speeds of order 0.3m/s. Given that on the whole, the water volume that is exchanged is constant and the flood duration is around 1/5th of the ebb duration, peak flood currents speeds are assumed to be 5 times the ebb velocity. The black line on the figure denotes the separation between flood and ebb tide.

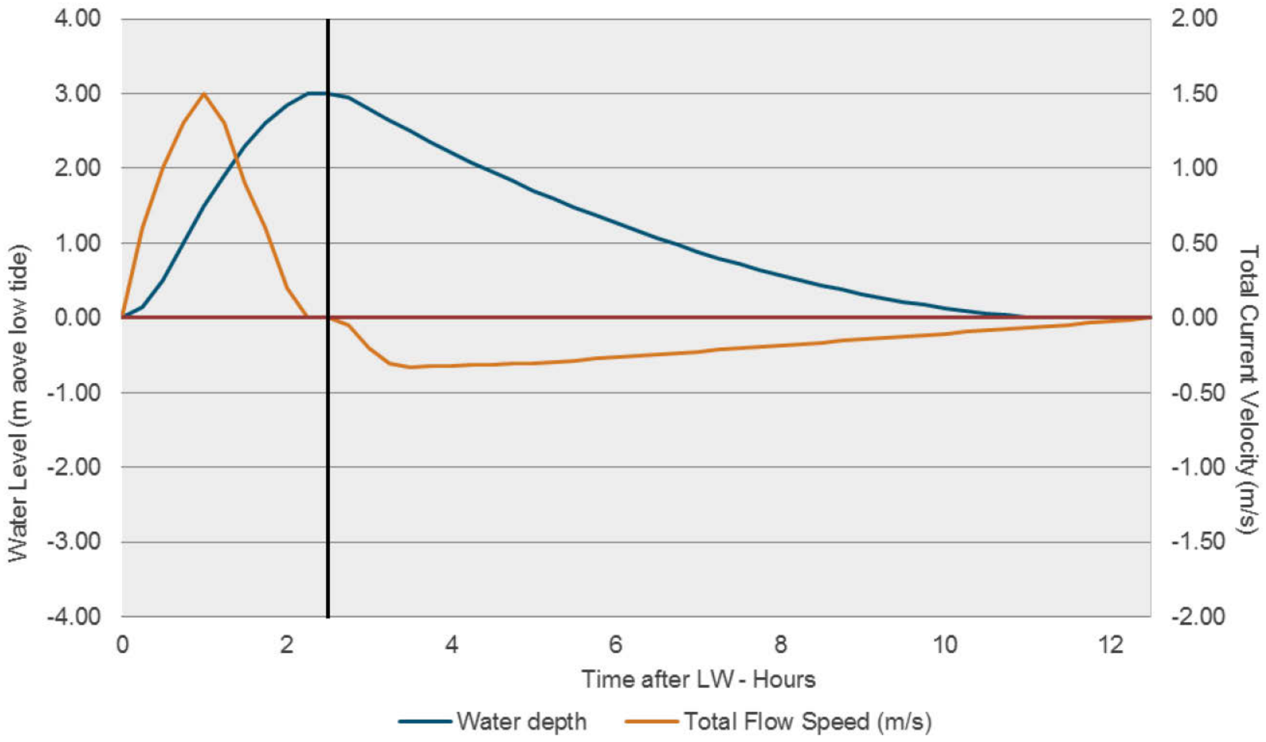


Figure B.8: Synthetic time-series of water level and current speed for a location in the lower tidal section of the Parrett

Using standard formula (see Whitehouse et al. 2000) it is then possible to calculate when during the tidal cycle erosion, suspension or deposition occurs (Figure B.9).

Figure B.9 demonstrates that during the flood tide shear-stresses are significantly greater than that required to erode sediment and therefore bring it in to suspension. This means that any sediment that is eroded will be transported upstream with the tidal current. During the ebb tide, shear stresses are significantly reduced and do not exceed the value required to re-erode sediment that will have settled out over the slack high-water period. Sediment remaining in suspension after high water will continue to settle, and will not be transported back downstream as the currents on the ebb tide do not exceed the threshold velocity for erosion. Overall during this tidal cycle, in this example, there is a net deposition of material (the amount that settles is greater than the amount eroded).

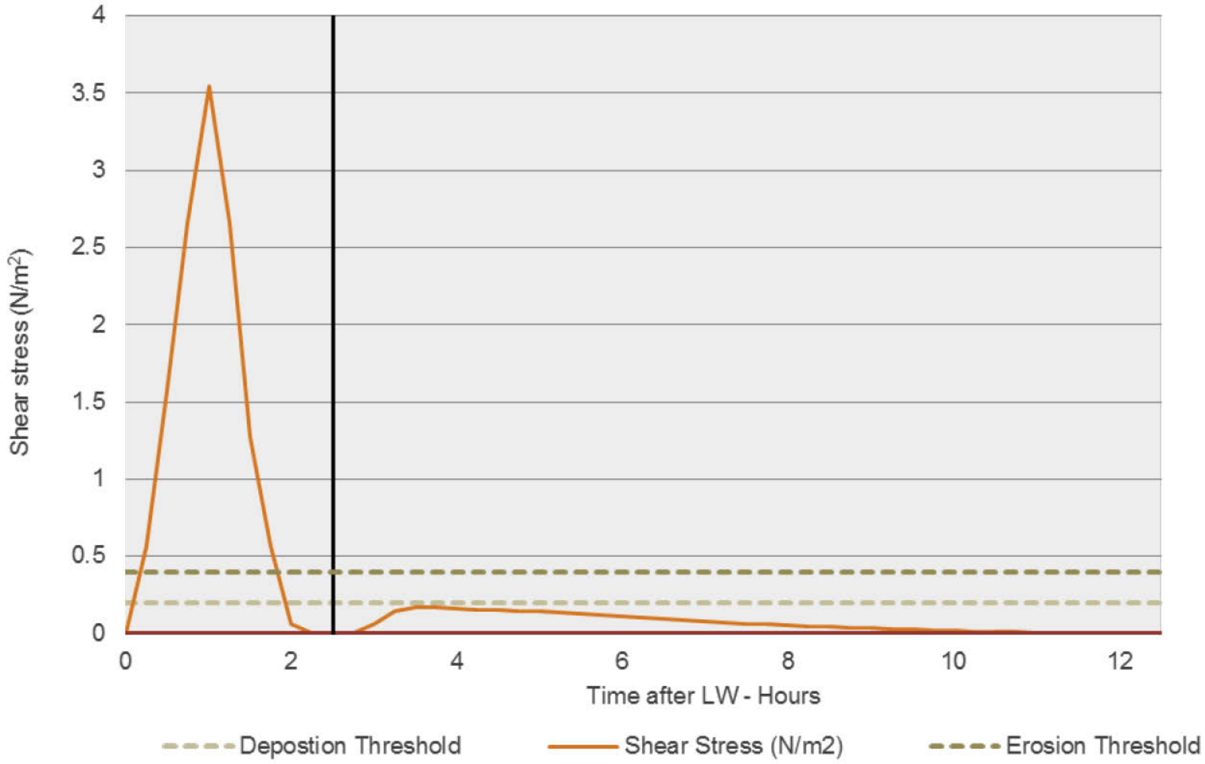


Figure B.9: Synthetic time-series of shear-stress for a location in the lower tidal section of the Parrett

If we now consider a case where a freshwater discharge is superimposed on to the tidal currents a different pattern is simulated. Figure B.10 and Figure B.11 include the effect of a 0.7m/s freshwater (seaward) flow at all stages of the tide, based on a channel cross-section of around 50m^2, this is equivalent to a freshwater flow of 35m^3/s. It is clear to see that the mean flood velocity is reduced, along with the associated shear-stress. The ebb tide velocity is now significantly increased and more persistent in nature. The magnitude of the shear stress on the ebb-tide has increased and as a consequence, during this tidal cycle at this location there is a net erosion of material (the amount that settles is less than the amount eroded).

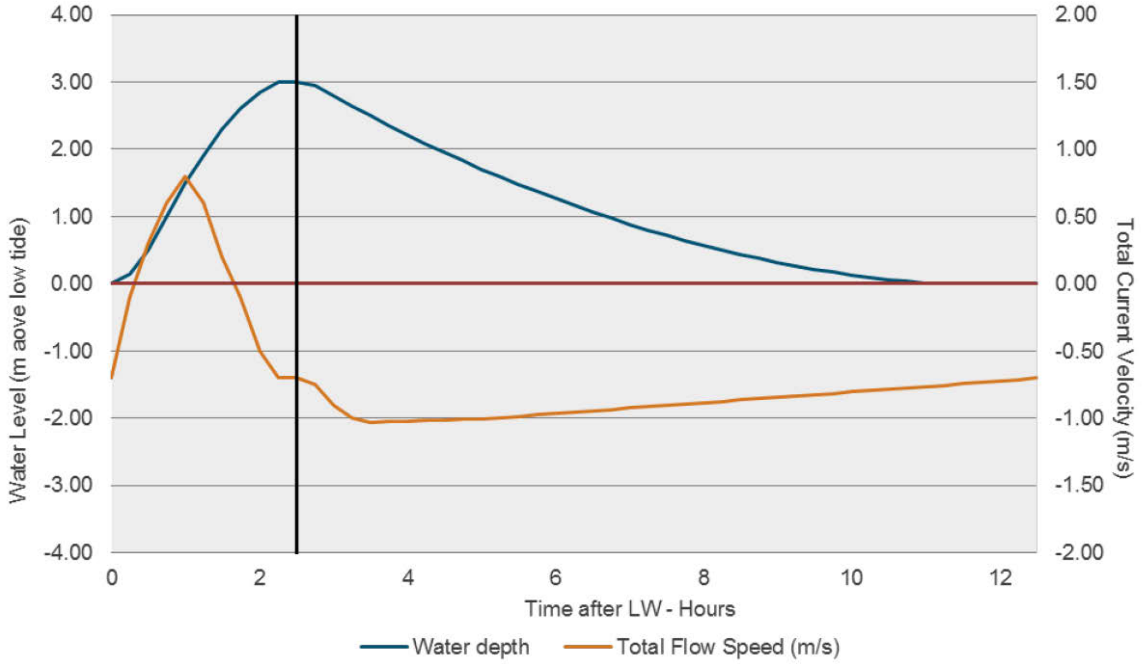


Figure B.10: Synthetic time-series of water level and current speed for a location in the lower tidal section of the Parrett including a freshwater flow of 0.7m/s

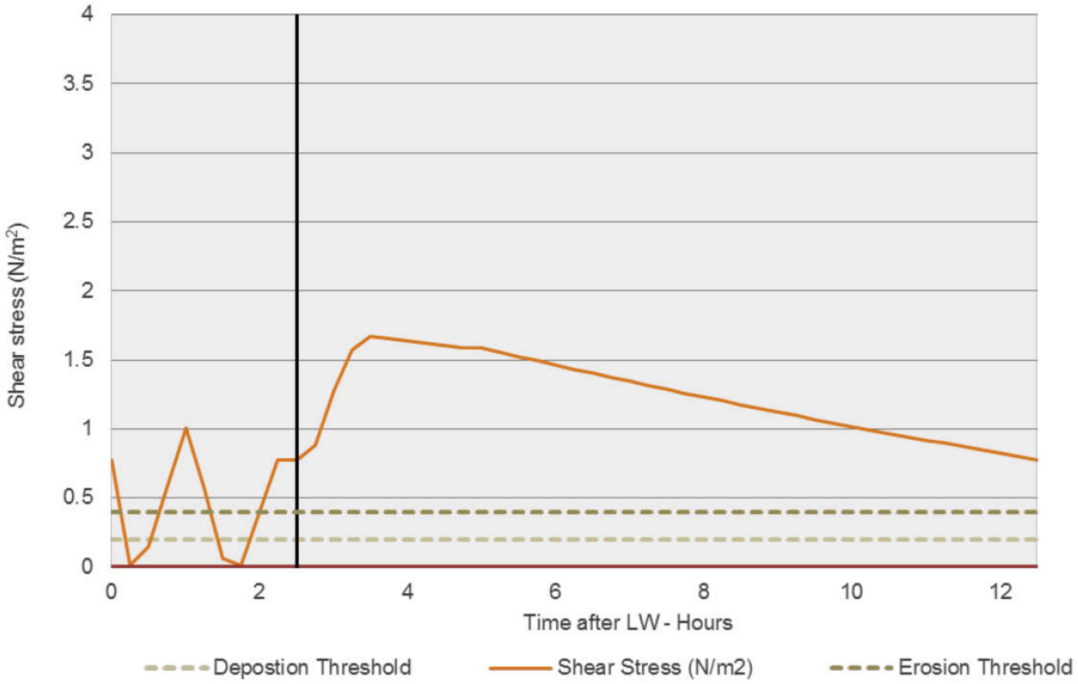


Figure B.11: Synthetic time-series of shear-stress for a location in the lower tidal section of the Parrett including a freshwater flow of 0.7m/s

B.7. Deliberate modification of the channel cross-section

The effect of modifying the local channel cross-section through dredging could have two consequences:

1. For a given discharge the local mean flow velocity will decrease – (as the same discharge is now required to go through a larger cross-sectional area);
2. For locations downstream of the location where the cross-section has been increased, the local mean flow velocity will increase – the upstream volume has increased and therefore the discharge into it is required to increase.

Both of these consequences will impact upon the sediment transport compared to a non-modified channel cross-section:

1. The increased cross-sectional area will promote sedimentation within these dredged sections.
2. There is the potential for additional volumes of sediment laden water to be drawn upstream to locations where dredging has occurred.

B.8. Location of sedimentation in the channel

After reviewing elevation cross-section information and inspecting potential dredge locations during site visits, the following concept is suggested as the mechanism by which material accumulates in the channels.

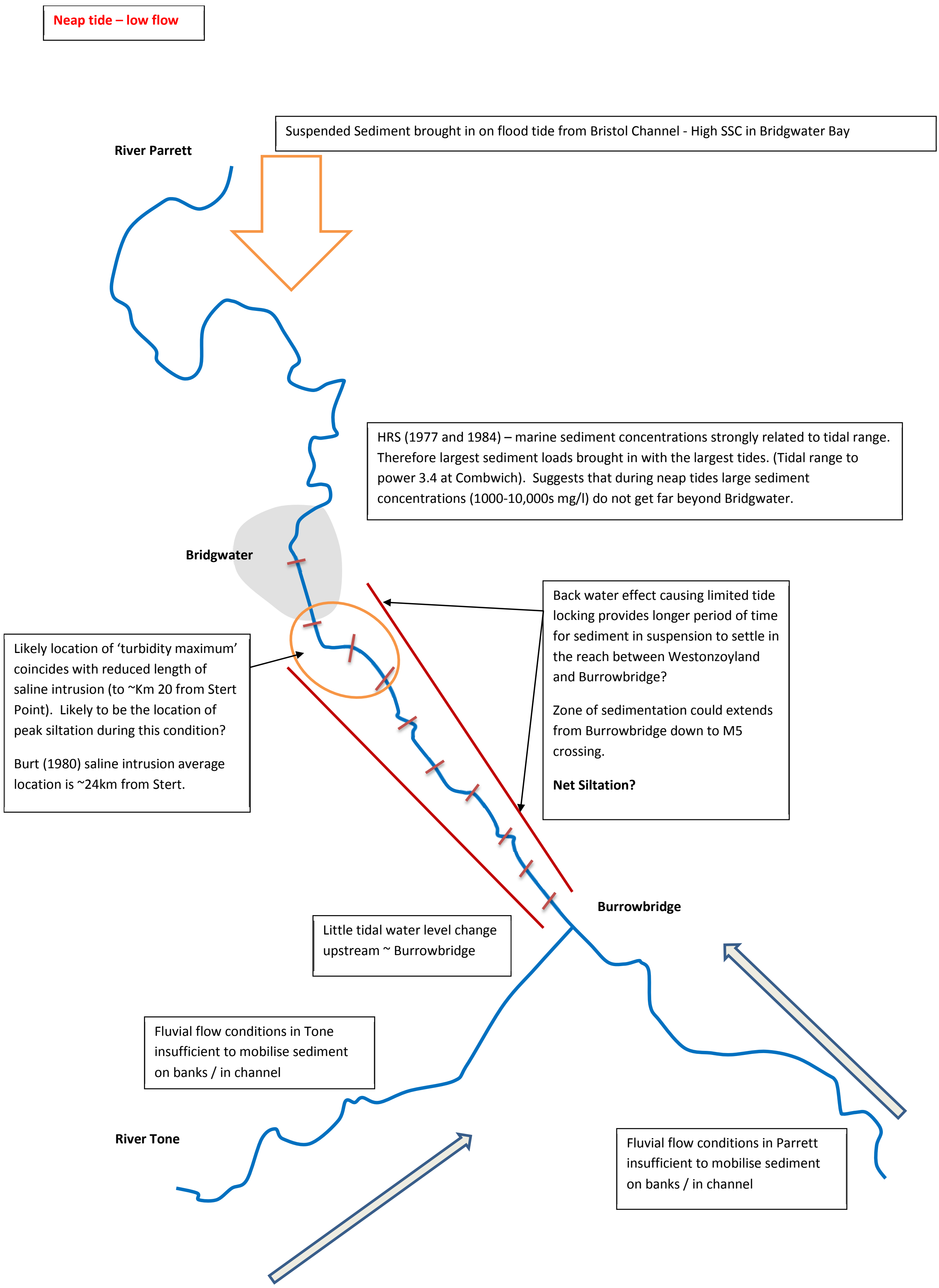
- Following dredging, sedimentation initially occurs across the full width of the channel, below the mean water level mark. The specific location where sediment accumulates will be controlled by the local hydrodynamics, such that sediment will tend not to accumulate on the outsides of bends but accumulate on the insides of bends.
- Once the cross-section has been sufficiently reduced by sedimentation, the constriction will locally increase the flow speed and will therefore maintain the channel cross-section such that the absolute channel depth is not reduced significantly from the post-dredge condition.
- Further sedimentation tends to occur higher up the bank profile, creating a ‘terrace’ or ‘berm’ over time.
- The precise cause of the pattern of sedimentation is not known, but the following hypothesis is suggested for straight sections of the channel (and can be modified accordingly for channel bends):
  - The dredged cross-section is initially smooth and too large for the mean flow and therefore sedimentation occurs, and is distributed relatively evenly.
  - Lower flow speeds are experienced at the edges of the channel due to the effects of friction. This friction can be enhanced by the presence of vegetation.
  - Lower flow speeds at the edge of the channel also offers a longer period of time for material to settle out of suspension, increasing rates of deposition.
  - As sedimentation occurs, the flow is more focussed in the centre of the channel due to the reduction in cross-sectional area. This in turn reduces or stops sedimentation in the centre area of the channel.

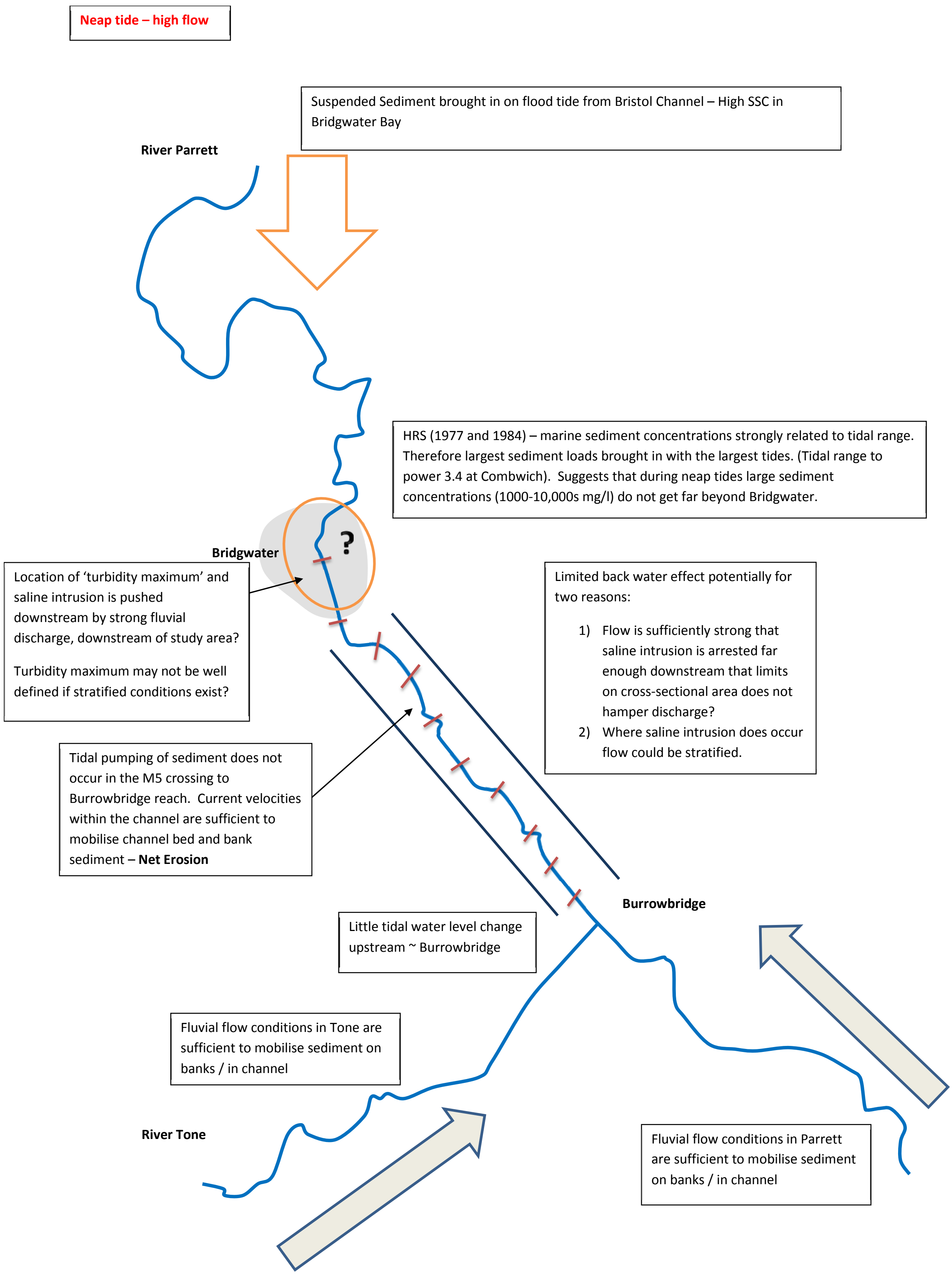
B.9. Conceptual model of sediment transport

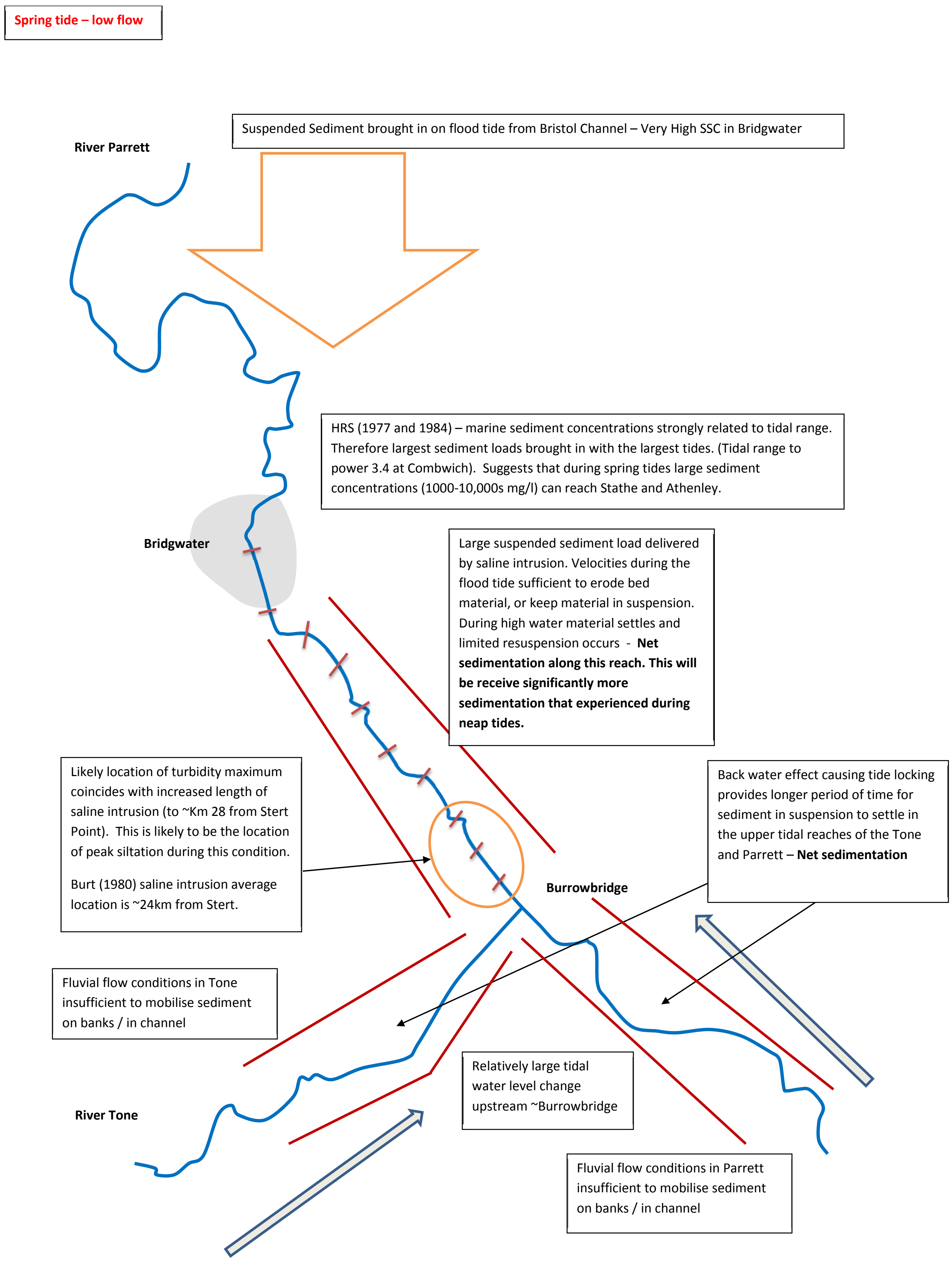
The behaviour of sediment and water within the Parrett system under different conditions is as follows:

- Neap tide, low freshwater flow – Sedimentation is most likely to occur along the section between Bridgwater and Burrowbridge. Sedimentation rates are relatively low due to relatively low suspended sediment concentrations.
- Neap tide, high freshwater flow – Sedimentation is unlikely to occur anywhere in the system. Fluvial flow prevents deposition and augments the ebb tide flow. Relatively low suspended sediment concentrations during neap tides. The Partrac data on sediment flux under high flow conditions (29 to 31 July 2009) shows that the sediment flux increases in a downstream direction, indicating that deposition of fluvial sediments may not be significant. There is however uncertainty in these data.
- Spring tide, low freshwater flow – Sedimentation is possible across the whole Parrett system, through a combination of the influence of marine waters and tide locking. Sedimentation rates are expected to be very high along the Bridgwater to Burrowbridge section, and moderate to high (dependent upon the level of tidal influence) along the Tone and Parrett rivers upstream of the confluence due to relatively high suspended sediment concentrations.
- Spring tide, high freshwater flow – The sedimentation pattern is not clear under these conditions, as it will depend upon the specific conditions that occur. However, upstream of the Parrett and Tone confluence, sedimentation is possible due to tide locking. Closer to the tidal limits erosion could occur due to the dominance of the freshwater flow. Downstream of the confluence, flood tide sedimentation could be balanced by ebb tide erosion.

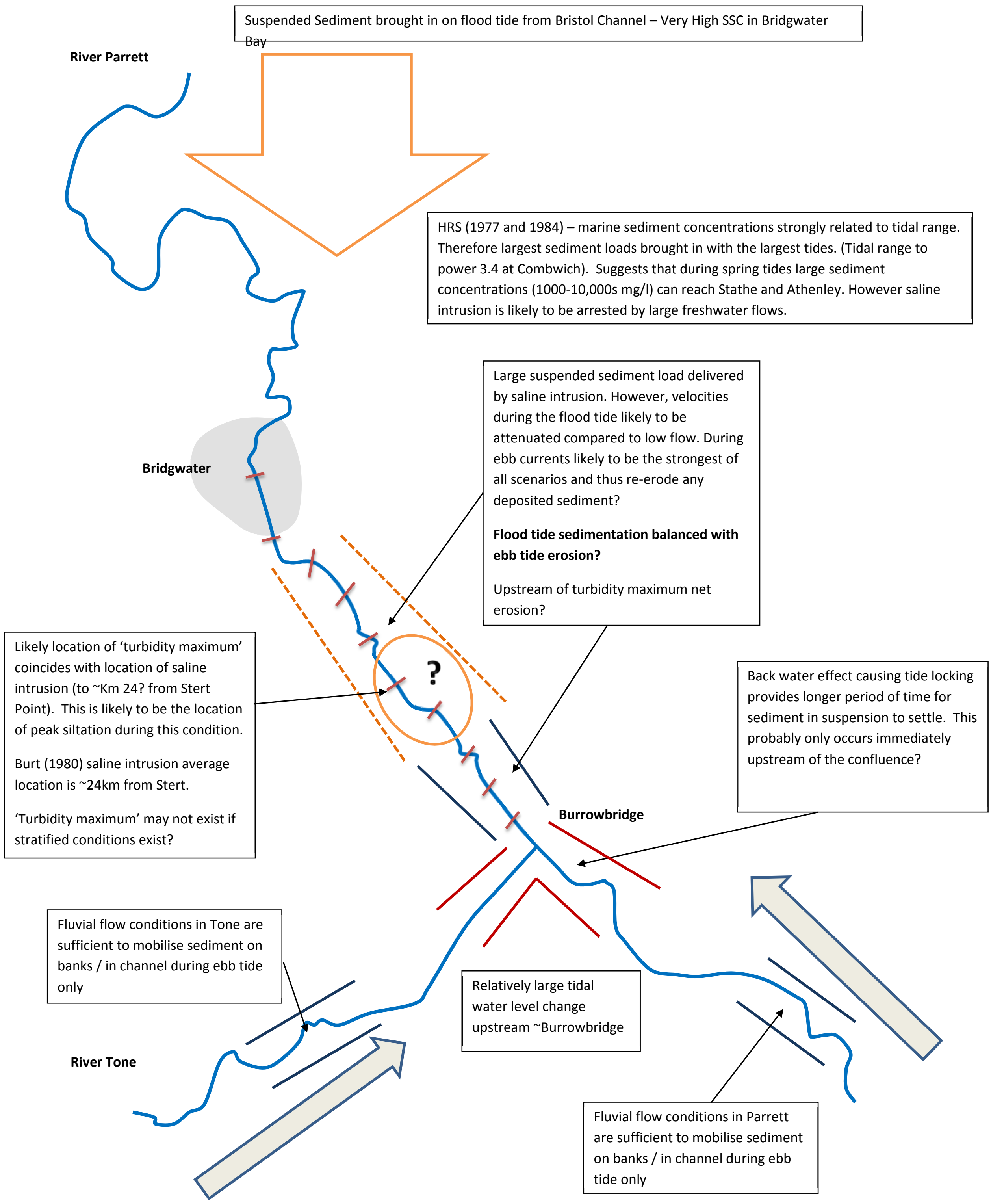
These four conditions are illustrated on the four maps shown below.


Neap tide – low flow
Suspended Sediment brought in on flood tide from Bristol Channel - High SSC in Bridgwater Bay
River Parrett
HRS (1977 and 1984) – marine sediment concentrations strongly related to tidal range. Therefore largest sediment loads brought in with the largest tides. (Tidal range to power 3.4 at Combwich). Suggests that during neap tides large sediment concentrations (1000-10,000s mg/l) do not get far beyond Bridgwater.
Bridgwater
Back water effect causing limited tide locking provides longer period of time for sediment in suspension to settle in the reach between Westonzoyland and Burrowbridge?
Zone of sedimentation could extends from Burrowbridge down to M5 crossing.
Net Siltation?
Likely location of 'turbidity maximum' coincides with reduced length of saline intrusion (to ~Km 20 from Stert Point). Likely to be the location of peak siltation during this condition?
Burt (1980) saline intrusion average location is ~24km from Stert.
Burrowbridge
Little tidal water level change upstream ~ Burrowbridge
Fluvial flow conditions in Tone insufficient to mobilise sediment on banks / in channel
River Tone
Fluvial flow conditions in Parrett insufficient to mobilise sediment on banks / in channel


Neap tide – high flow
Suspended Sediment brought in on flood tide from Bristol Channel – High SSC in Bridgwater Bay
River Parrett
HRS (1977 and 1984) – marine sediment concentrations strongly related to tidal range. Therefore largest sediment loads brought in with the largest tides. (Tidal range to power 3.4 at Combwich). Suggests that during neap tides large sediment concentrations (1000-10,000s mg/l) do not get far beyond Bridgwater.
?
Bridgwater
Location of 'turbidity maximum' and saline intrusion is pushed downstream by strong fluvial discharge, downstream of study area?
Turbidity maximum may not be well defined if stratified conditions exist?
Limited back water effect potentially for two reasons:
1) Flow is sufficiently strong that saline intrusion is arrested far enough downstream that limits on cross-sectional area does not hamper discharge?
2) Where saline intrusion does occur flow could be stratified.
Tidal pumping of sediment does not occur in the M5 crossing to Burrowbridge reach. Current velocities within the channel are sufficient to mobilise channel bed and bank sediment – **Net Erosion**
Burrowbridge
Little tidal water level change upstream ~ Burrowbridge
Fluvial flow conditions in Tone are sufficient to mobilise sediment on banks / in channel
River Tone
Fluvial flow conditions in Parrett are sufficient to mobilise sediment on banks / in channel


Spring tide – low flow
River Parrett
Suspended Sediment brought in on flood tide from Bristol Channel – Very High SSC in Bridgwater
HRS (1977 and 1984) – marine sediment concentrations strongly related to tidal range. Therefore largest sediment loads brought in with the largest tides. (Tidal range to power 3.4 at Combwich). Suggests that during spring tides large sediment concentrations (1000-10,000s mg/l) can reach Stathe and Athenley.
Bridgwater
Large suspended sediment load delivered by saline intrusion. Velocities during the flood tide sufficient to erode bed material, or keep material in suspension. During high water material settles and limited resuspension occurs - **Net sedimentation along this reach. This will be receive significantly more sedimentation that experienced during neap tides.**
Likely location of turbidity maximum coincides with increased length of saline intrusion (to ~Km 28 from Stert Point). This is likely to be the location of peak siltation during this condition.
Burt (1980) saline intrusion average location is ~24km from Stert.
Back water effect causing tide locking provides longer period of time for sediment in suspension to settle in the upper tidal reaches of the Tone and Parrett – **Net sedimentation**
Burrowbridge
Fluvial flow conditions in Tone insufficient to mobilise sediment on banks / in channel
Relatively large tidal water level change upstream ~Burrowbridge
River Tone
Fluvial flow conditions in Parrett insufficient to mobilise sediment on banks / in channel

Spring tide – high flow



B.10. Implications for dredging

If agitation or hydrodynamic dredging techniques are to be employed as a means of maintaining the channel cross-section, it is clear that the specific conditions under which this type of dredging technique will be successful is dependent upon the combination of tidal and freshwater flow.

There is insufficient data available to formulate a detailed plan of which combination of tidal level and freshwater flow conditions would permit dredging using agitation or hydrodynamic dredging techniques. However, some guidelines are given below:

- Times when the dredging technique should not be used – during any flood tide conditions as material will be dispersed upstream and, under low freshwater flow conditions, will settle out and not be re-eroded until the necessary flow conditions are met. If material remains in-situ for extended periods of time, consolidation will occur and the material will become more difficult to re-erode;
- Time when the dredging technique will be less successful – during neap ebb tides, and ebb tides with little or no freshwater flow. Ebb tides have slower flow velocities and neap ebb tides have the slowest velocities of all tides. This has two implications:
  - The flow may not be sufficient to keep dredged material in suspension, therefore the distance travelled from the dredge location will be small;
  - If flows are strong enough to maintain the material in suspension, the distance travelled (a function of mean flow speed) will be less on neap ebb tides and could resettle within the reach.
- Times when the dredging technique will be most successful – during spring ebb tides with moderate to high freshwater flow. As commented above, spring ebb tide velocities will be largest offering the best chance for the dredged material to remain in suspension and to be transported (downstream) the greatest distance. Freshwater flows will augment the ebb tide current, prevent re-settlement and enhancing the distance travelled.

B.11. References

Burt, T N (1980)	*Pilot Study of the River Parrett*: Interim Discussion Paper.
Cameron and Pritchard (1963)	*Estuaries*. In: The Sea (Ed. MN Hill), Vol 2 Wiley New York, 306-324
Davies (1964)	*A morphogentic approach to world shorelines*. Z. Geomorhol. **8**, 127-142
Dyer, K (1997)	*Estuaries: A physical introduction*, Wiley, New York
Fairbridge (1980)	*The estuary: its definition and geodynamic cycle*. In Chemistry and Bio-geochemisty of Estuaries (Eds. E Olausson and I Cato). Wiley, New York 1-35
Hansen and Rattray (1966)	*New dimensions in estuary classification*. Limnol. Oceanog. **11**, 219-326
HRS (1985)	*River Parrett Dredging Study*, Report EX1428
Partrac (2008)	*River Parrett Literature Review*. Report P1022 05 D001V01, Partrac Ltd, February 2009
Partrac (2009)	*Hydrodynamic Report Summer 2009*. Report P1022 05 D024V02, Partrac Ltd, September 2009
Prandle, D (1985)	*On salinity regimes and the vertical structure of residual flows in narrow tidal estuaries*. Est. Coast. Shelf Sci. **20**, 615-635
Simmons (1955)	*Some effects of upland discharge on estuarine hydraulics*. Proc. Am. Soc. Civ. Eng. **81**, No. 792
Whitehouse et al. (2000)	*Dynamics of Estuarine Muds*, Thomas Telford

C. Dredge material type

This appendix shows the location of the geotechnical investigation for the 2014 8km dredge on the Parrett and the Tone (Figures C.1 and C.2), and the results of the DPSH soil tests in terms of N, the number of blows needed to drive a standard rod 100mm (Figures C.3 and C.4).

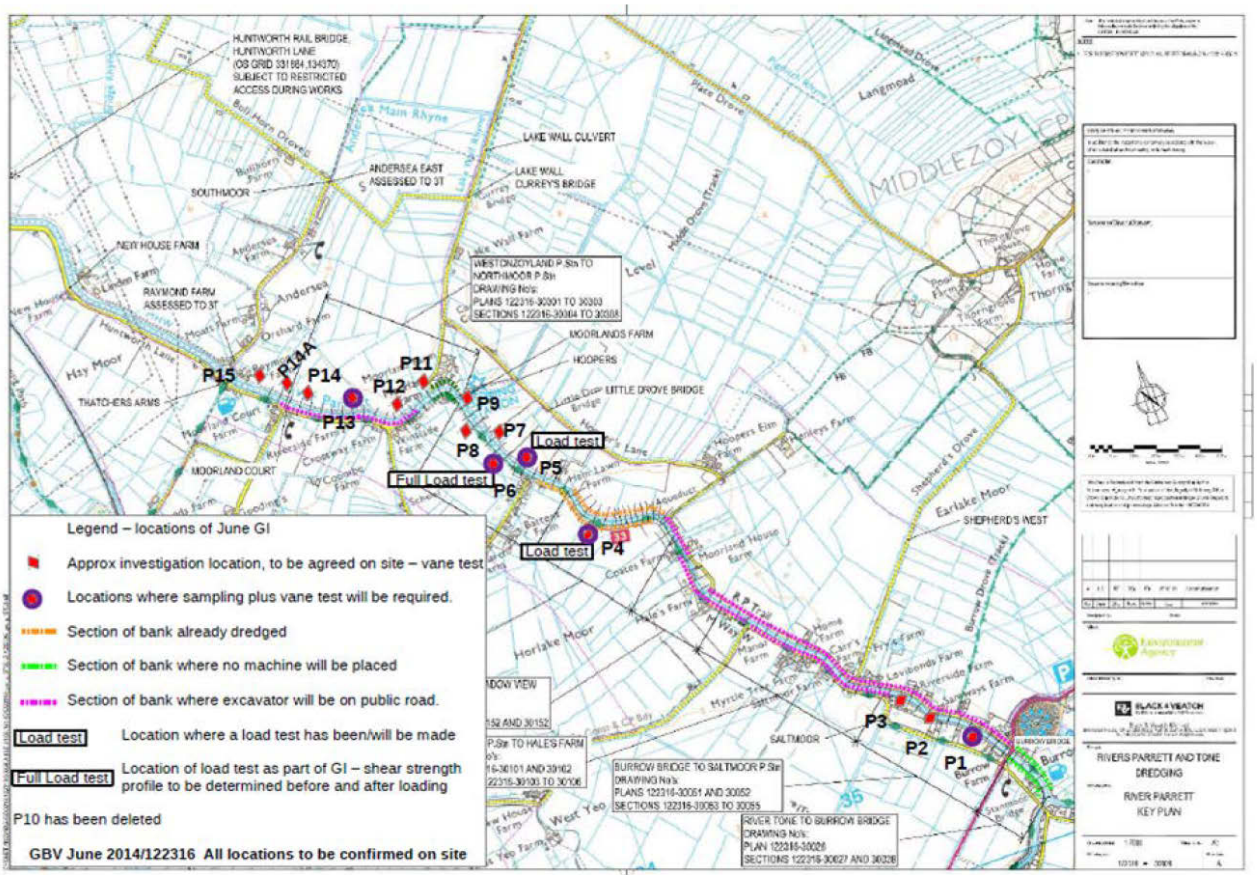


Figure C.1: Location of geotechnical investigation on the River Parrett of the 2014, 8km pioneer dredge

Source: Parrett and Tone Dredging Ground Investigation, South West Geotechnical, January 2015

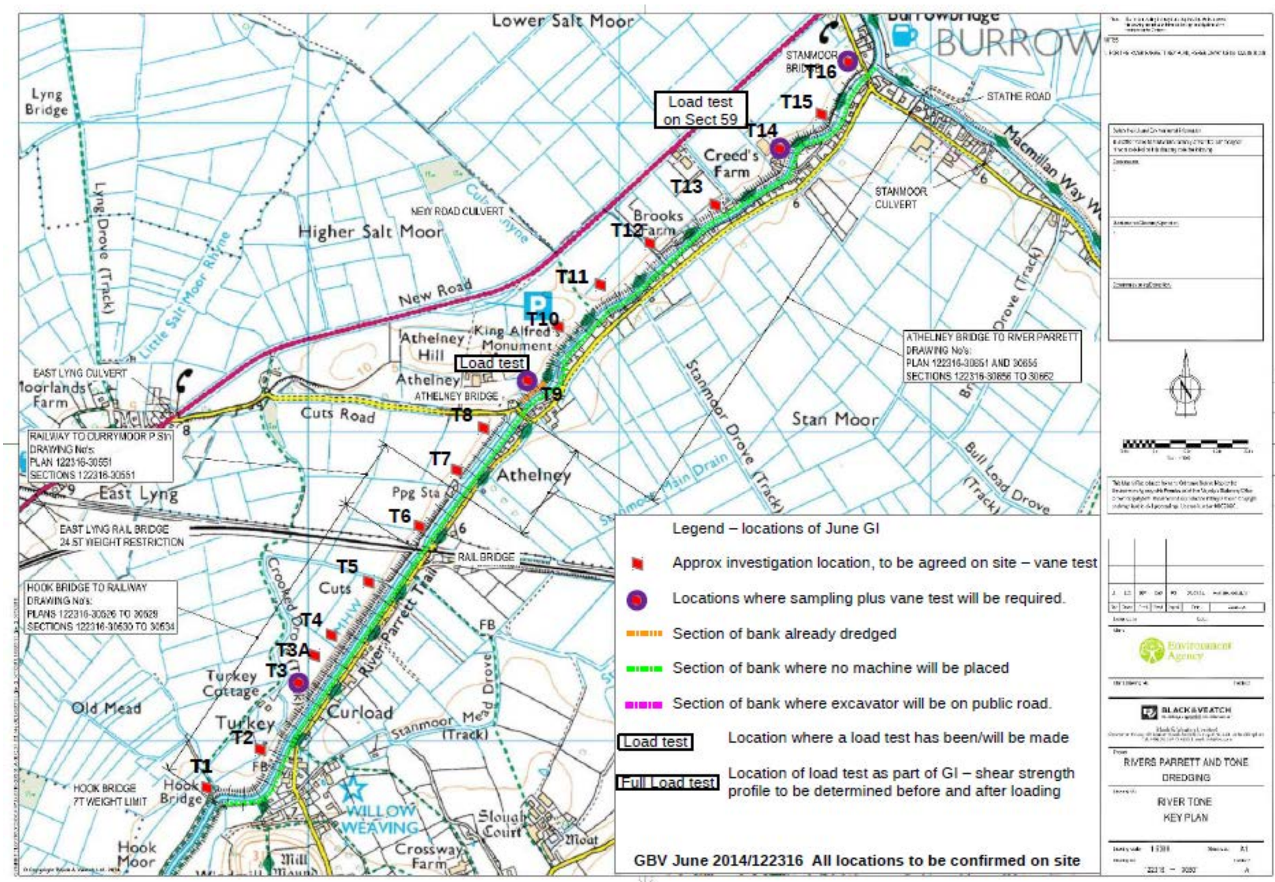


Figure C.2: Location of geotechnical investigation on the River Tone of the 2014, 8km pioneer dredge

Source: Parrett and Tone Dredging Ground Investigation, South West Geotechnical, January 2015

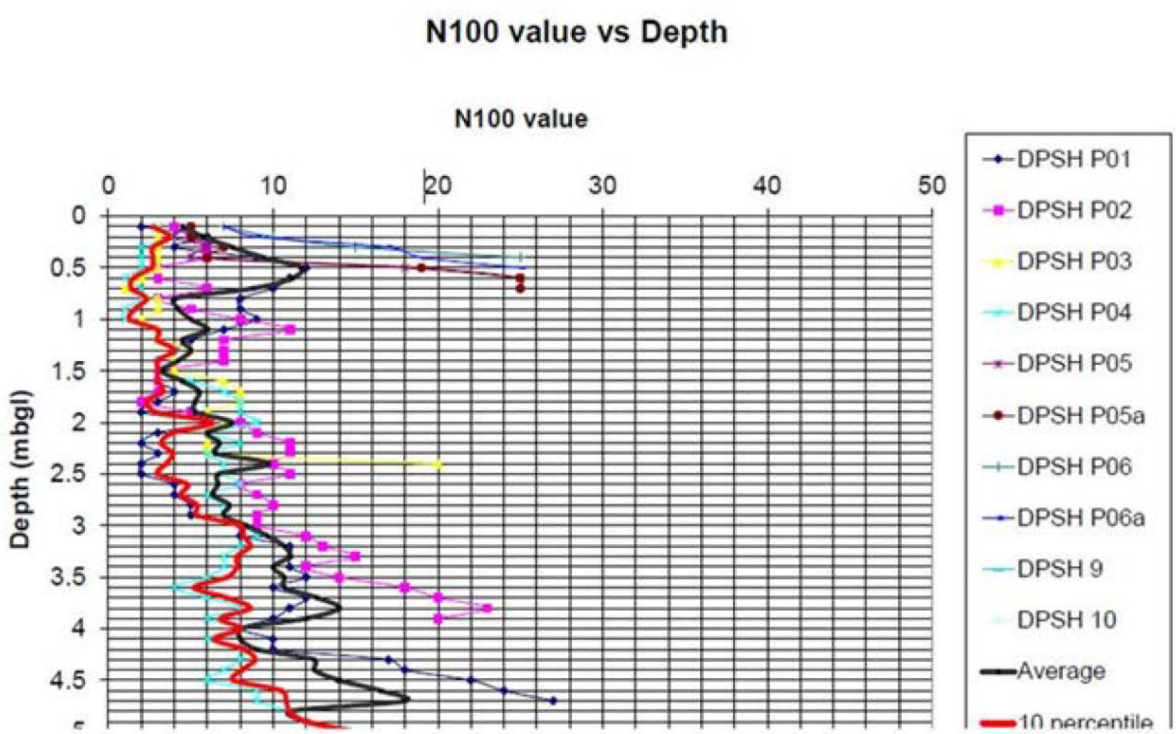


Figure C.3: N100 values vs. Depth below ground level for the River Parrett for the 2014, 8km pioneer dredge

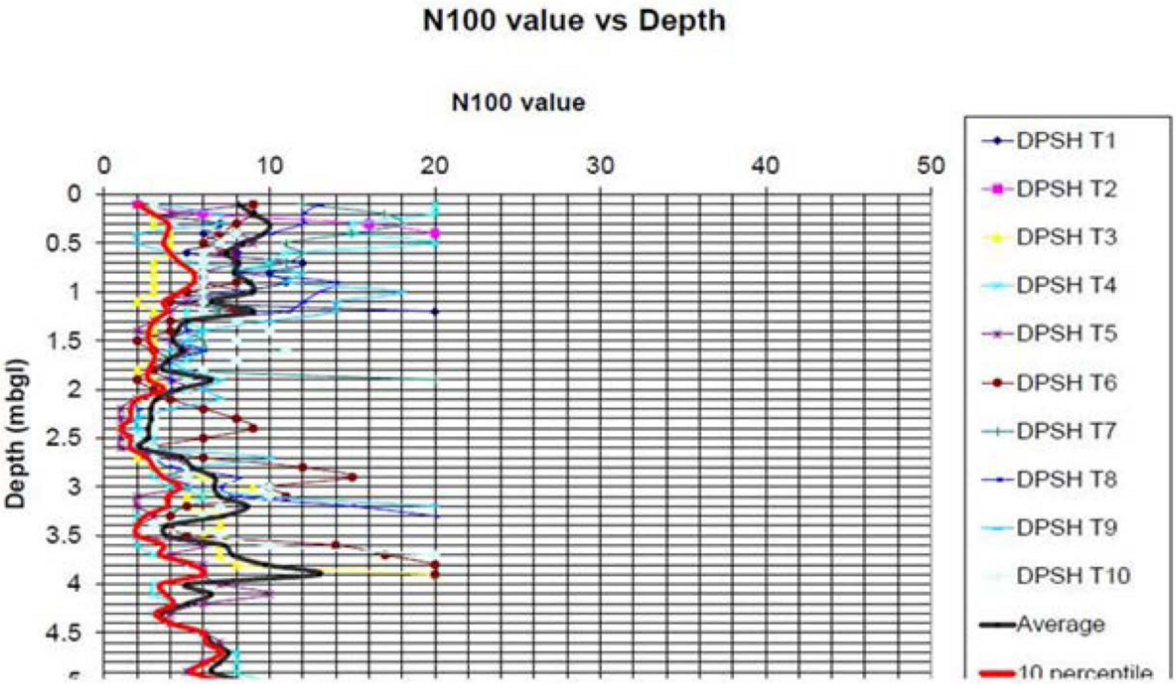


Figure C.4: N100 values vs. Depth below ground level for the River Tone for the 2014, 8km pioneer dredge

D. Document list

A list of documents and data that has been provided and reviewed as part of the study is given in the table below.

Table D.1: Summary of reports and documents used for the study

Background documents		
Tone Valley Scheme	Report, Oct 1963	Somerset River Board
Scheme description including design flows (these have low return period flows, which suggest that upstream rural flooding is accepted). Detailed description of works, which concentrates on the upstream urban areas. Design standard 1 in 50 years (1 in 100 years taking account of freeboard) in Taunton. Lower standards downstream. Frequency and magnitude of spills into Currymoor will be reduced. Water will not enter Northmoor in a repeat of the 1960 flood. Overspill into Currymoor should not occur for the MAF. The scheme clearly did not consider the type of long duration event that occurred in 2013/14 (which is not surprising). Appendices: Hydrology calculations; regime, including a recognition that the scheme would increase tidal siltation; hydraulic calculations.		
Parrett barrage investigations.	Papers, 1979	Tinkler and Thorne
Proposed barrier site at Dunball. Design fluvial flows (about 150 m^3/s on each of the Parrett and Tone, combined with pumped flow to give 264 m^3/s). In practice this flow would not reach the barrier site because of overtopping into the moors. Tidal silts brought in on the flood tide. Weaker ebb flows do not remove all the sediment, which builds up. 12T/m of channel removed in the year following dredging on the Tone. Part of barrier purpose is to remove silt. Tidal water does not reach the barrier during design flood conditions, and therefore there is no need to create flood storage by closing the barrier. Siltation would occur downriver of the barrier which may require dredging for navigation and maintaining flood capacity.		
The Somerset Levels and Moors Flood Action Plan	Note and PowerPoint summary	SRA
Summary of the Action Plan including a list of actions and costs. There are six actions related to dredging (about 10% of all actions).		

Innovative dredging methods for the Rivers Parrett and Tone	Report, Aug 2013	Exo environmental for the SBDC

4 methods described:

- excavator and side-casting;
- excavator and pipeline (pontoon mounted excavator plus hopper and pump to pipe for disposal; range 1.5 km; solid dredged material; cost: £10/m^3);
- submersible pump and hydraulic transport (pump on excavator; material pumped by pipeline; range 1.5km; dredged material needs de-watering);
- cutter suction and hydraulic transport (cutter suction floating plant; material moved by floating pipeline; range 3km; dredged material needs de-watering).

Reference to algal growth affecting drainage in summer 2012. Refers to Tone Valley Scheme Report (1960). Comparative cross-section at Stanmore Bridge for five surveys (1999 – 2012) plus 1960s profile.

Dredging of 10 pinch points (15,000 m^3): estimated cost provided of about £15/m^3. Trial costs £80k to £90k for one week. Costs in report to not seem to consider many factors (environment, disposal or re-use costs, etc.)

Managing the flows and mud population of the Parrett estuary	Technical note, Apr 2015	R Kirby

Discussion of marine mud characteristics. Suggestion of using silt traps, potential uses of dredged materials and use of the Parrett barrier to manage silts. This requires an understanding of how the sediment silts behave during a tide cycle.

The effects of sediment loading on morphology and flood risk in a lowland river system	PhD thesis	Steve F Dangerfield

Concerned with catchment sediment loading on a lowland river (the Tone). Fluvial sediments (not tidal).

Trigger points	Technical note, Mar 2015	EA

Three documents: synopsis, key levels and technical note.

These documents set out the operational approach for Currymoor, Northmoor and Salt Moor including the pumping stations. Key levels are provided.

The benefits of dredging “provide opportunities to make maximum use of pumping capacity especially on high tides at an earlier stage of the flood”.

There are high water level pumping restrictions on some pumping stations. At Currymoor pumping station, if the river level rises above 7.45 m AOD, pumping into the river would raise levels and cause water to pass over Hook Bridge spillway and back into the moors.

Guidance documents		
Sustainable management of dredged material from inland waterways: good practice guide	Report, May 2013	AINA. Provided by SRA
Good general summary of dredging methods, waste issues and legislation, but focussing on non-tidal inland waters including canals. This will be directly relevant for the River Brue.		

Dredging for the Parrett and Tone: summary and background documents		
Feasibility Report on Potential Dredging of the Rivers Parrett and Tone	Report, Mar 2013	Land & Water
This appears to refer to the 8 km dredge. Constraints include: Fish spawning: July to September Elver fishing season: 15/2 to 25/5 Nesting: March to May Hairy click beetle areas Land spreading: after harvest (say Sept/Oct) Discussion of licensing, access and equipment. Quantities and budgets including extra items to consider (e.g. survey and compensation) Indicative cost of water injection or agitation techniques for maintenance. Typical cross-sections for the Tone and the Parrett.		
River Parrett and Tone Dredging Project	Note, Feb 2014	EA
Two-page briefing.		
Parrett and Tone pinch points	Map, undated	EA
Map showing pinch points: 3 on Parrett in 2km reach d/s Burrowbridge; 7 on Tone in 2km reach u/s confluence (to rail crossing). These pinch points were identified after the 2012 flooding. Some dredging was carried out for pinch points on the Tone (but not much).		
Dredging Briefing – Winter 2015/16, The Stream	Briefing, undated	SRA
Summary of pioneer dredging and maintenance dredging; benefits of 8 km dredge. This includes		

dredging plan and timing. The 2.2 km was carried out in Winter 2015/16 (completed in March), to be immediately followed by a 750 m new dredge downriver of Northmoor pumping station.		
The Stream: Progress updates for Autumn 2015 and Easter 2016	Newsletters	SRA
Summary of progress including dredging plans and plans for the River Sowy.		
Reducing flood risk in Somerset	Briefing, undated	EA
Summary of the benefits of new dredging plus pumping in quantitative and qualitative terms. 6 properties on Allermoor, Hay Moor and West Sedgemoor, and 142 properties on Northmoor flooded in 2013/14; reference to model results.		
Parrett Right Bank: Monks Leaze Clyse to Beazleys Spillway, Long Term Options Feasibility Study	Report, Nov 2009	B&V for the EA
Covers banks from just u/s of Allermoor spillway to Stathe (including Oath). Brief summary of previous studies. Objective to reduce scour on the right bank of the river caused by overtopping. Lowering of Allermoor spillway recommended, which will divert more water into the Sowy River.		
Parrett and Tone dredging schedule	Map, undated	
Map showing the dates when section of the 8 km dredge was carried out. Dredging took place between March and October 2014.		

River Brue dredging		
River Brue Maintenance Pilot Method Statement	Report, Jul 2014	Exo environmental for the SBDC
Method for removing 38,000 m^3 of material downstream of Westhay. Volumes for 46 sections over 4.48 km. Design section; material type; environmental consideration; contamination not expected to be a problem; sediment to be on the back of the riverbank; method of dredging using excavators; work upstream; other considerations; ecological survey and mitigation measures including timing; proposed monitoring; site restoration. A clear and concise document.		

Document	Type/date	Author/source
HR Wallingford reports		
River Parrett dredging study, Report EX1428	Report, Apr 1986	HR Wallingford
Good insight into dredging issues including rate of re-accretion, timing of dredging and theoretical movement of water (although agitated sediment may not settle, and come back upriver). Discussion of dredging impacts on tidal volume and velocities, and consequent impacts on sedimentation. Dredging reduces velocity and the ability of the flow to scour material deposited at slack water. Time for deposition is short but amount can be significant. Estimates of net siltation per tide: includes siltation at Stathe and Athelney on spring tides. Sensitivity of erosion and deposition to different tide heights. Estimate of time taken to re-establish channel regime after dredging estimated to be 6 to 12 months. Information about excursion distances for water elements on different tides. It is unclear what this means about the effectiveness of dredging because material may not settle before it is picked up on the next incoming tide. Estimated agitation dredging rates provided with examples: need for surveys. Clear statements about high sediment load on large tides. Suggested method for agitation dredging: important to work downstream.		
River Parrett dredging strategy, Report EX3480	Report, Aug 1996	HR Wallingford
Provides a specification for a dredging strategy but does not provide any insight into sediment processes or the effectiveness of different dredging techniques.		
River Parrett flooding. Appraisal of possible solutions: agitation dredging, Report EX4433	Report, Aug 2001	HR Wallingford
Some history to 2001; lack of systematic data before 2001; good general summary of sediment issues but difficult to draw detailed conclusions because of lack of data; complex processes affected by: uncertain rates of accretion and erosion; changes with season; changes with different tides (springs, neaps, etc.); fluvial flows; bank slumping. Recommendation of the most efficient times for agitation dredging: early ebb stages of the spring tides. Dredging during neaps also works but is less effective. High fluvial flows obviously help to move sediment. It is advisable to dredge in the autumn to remove summer sediment and prepare for the flood season. Sections 5 and 6 provide a good general review that could form the basis of background text in this dredging report. This is because readers of the report may not be aware of some of the issues that are raised.		

<table>
<tr><td colspan="3">It is apparent that the channels are 'unnaturally large' after dredging and out of regime. This contributes to low velocities and siltation.

A dredge on the Parrett where tidal sediments occur will fill from downriver (which appears to be the experience they are having).</td></tr>
<tr><td>River Parrett flooding study, Phase II, Report EX4563</td><td>Report, May 2002</td><td>HR Wallingford</td></tr>
<tr><td colspan="3">This report describes options for a tidal sluice to restrict the amount of silt entering the Parrett. It is not concerned with protecting Bridgwater from surge tides.

Three sites: Stert, Dunball and Moorland (upstream of Bridgwater).

Good summaries of how the system works and environmental issues.

The method of operation is to exclude the flood tide and allow the upstream channel to be enlarged without rapid re-siltation.</td></tr>
<tr><td>HR Wallingford archive material</td><td></td><td></td></tr>
<tr><td colspan="3">HR Wallingford has a large archive of historic material including survey data. Much of this is paper-based.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

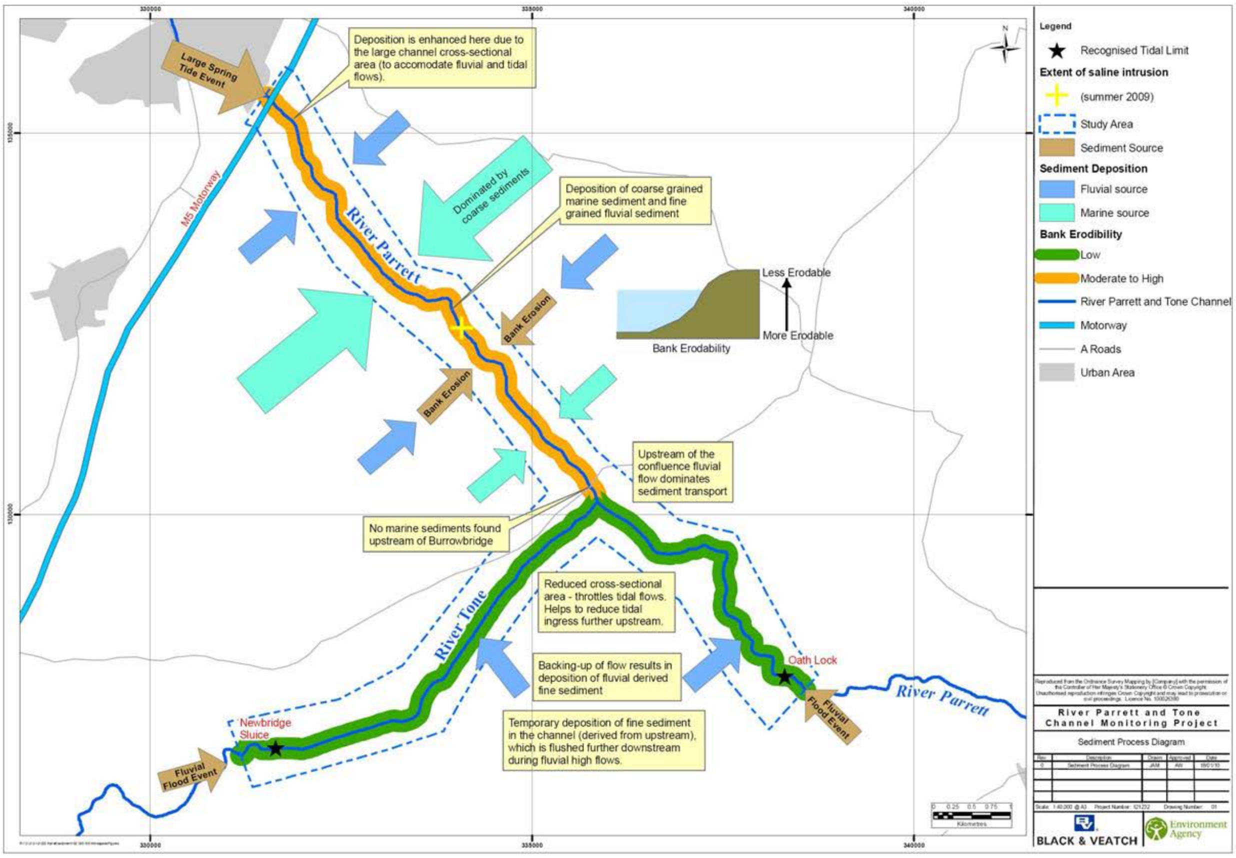
<table>
<tr><td colspan="3">River Parrett and Tone. Channel monitoring Project</td></tr>
<tr><td>River Parrett and Tone. Channel monitoring Project. FINAL. Executive Summary Report and Summary Report</td><td>Two reports, Feb 2011</td><td>B&V</td></tr>
<tr><td colspan="3">An important report from a detailed study that attempted to improve the understanding of the sediment system. The study included winter and summer sediment monitoring programmes.

Some of the information in the reports does not seem to be consistent with other knowledge, and there may be shortcomings in the surveys.

Some key conclusions:
Marine sediment enters the system on spring tides but not during smaller tides;
Very little marine sediment passes upstream of Burrowbridge;
Sediment in the rivers upstream of Burrowbridge is fluvial (although this does not appear to be correct, based on other information obtained for the study);
Frequent dredging may be needed for marine sediments but occasional (regular) dredging on the Tone (fluvial sediments);
Parrett out of regime near the M5, which could lead to siltation;
Sediment is contaminated (although this is an erroneous conclusion).
There is an issue of backing up upstream of the confluence during spring tides, causing siltation.</td></tr>
</table>

- It is suggested that dredging should be avoided on high spring tides.

Figure 6 of the summary report shows the sediment sources (reproduced below).



Refers to 7 sets of survey data from Nov 2003 that can be used to observe changes in cross-sections. *We have not seen these.*

Regular surveys are recommended to plan future dredging (i.e. an adaptive approach supported by good survey).

The report contains six dredging scenarios and two non-dredging scenarios. The results imply that the Parrett and Tone dredging would have the best effect. The results also provide some insight into system behaviour.

The report provides a high level dredging strategy.

The report provides a high level regime analysis (Appendix B) (*although this is not considered by HR Wallingford to be appropriate*).

There are concerns regarding the data and interpretation in this report and the associated Partrac reports.

Comments on agitation dredging:

- Evidence on the performance of agitation dredging seems sketchy.
- The report suggests that any agitated material deposits a short distance downriver, and any agitation dredging should occur from upriver to downriver.
- Suggestion that removal of sediment from the system could cause erosion elsewhere in the

system (the HR Wallingford reports suggest that the sediment source should be considered as unlimited). • Comparisons between sections at different times are discussed and provide the basis for the suggested poor performance of agitation dredging. The comparisons also indicate that any benefits of dredging are lost quite quickly.		
***Parrett & Tone Sediment Study: Literature Review**, P1022.05.D001v0*	Report, Feb 2008	Partrac
Summary of previous work from 1977 to 2007 with a list of references covering 1997 to 2006.		
***Parrett & Tone Sediment Study: Project Plan and Timeline**, P1022.05.D005v01*	Report, Feb 2008	Partrac
This summarises the monitoring work to be carried out in the project.		
***Field testing of acoustics in the River Parrett**, P1022.05.D008v01*	Report, Mar 2008	Partrac
Trial of an ADCP meter. High turbidity is a problem. Some practical problems identified such as access for boats to the river and access under bridges.		
***Sediment Sampling/Analysis Report**, P1022.05.D010v02*	Report, Feb 2009	Partrac
Sediments samples collected on the Tone and Parrett in November 2008 (10 sites). In addition, cohesive strength measurements were taken at a larger number of locations. Material described as coarse silt except the most downstream point (medium silt). Particle size data and cohesive strength data. Settling velocity data and changes in turbidity with time. It is suggested that only the coarser fractions will settle (fine sand) (*although it is evident that silt occurs on the river banks*). Sediment could erode for much of the time although vegetation can limit erosion. Compaction affects erodibility.		

***Hydrodynamic Monitoring on the River Parrett/Tone (Winter)**, P1022.05.D012v02*	Report, Feb 2009	Partrac
Monitoring from 21/11/2008 to 11/12/2008: spring tides with normal flows (R Parrett: 10 m^3/s; Tone 5 m^3/s) followed by fluvial flood (R Parrett: 40 m^3/s; Tone 20 m^3/s). Flows, velocities, suspended sediment and salinity. Measurements of particle size and bank erodibility. Presentation of information could be better, for example providing levels and data as m AOD.		
***Sediment Budget Report (Winter)**, P1022.05.D021v01*	Report, Mar 2009	Partrac
Monitoring from 21/11/2008 to 11/12/2008: spring tides with normal flows (R Parrett: 10 m^3/s; Tone 5 m^3/s) followed by fluvial flood (R Parrett: 40 m^3/s; Tone 20 m^3/s). Most analysis on 3 sites: 2 (Parrett at Northmoor), 4 (Parrett tidal limit) and 6 (Tone tidal limit). Some erosion predicted at Site 2 during the flood. Continuous downstream flow at upper Parrett gauge. The Tone backs up during high tides under normal conditions and during the Parrett flood. Downstream sediment flux during flood at site 2: no data for normal tides. Sediment during flood only at sites 4 and 6. Sediment budget: no data at site 2 for tides. Analysis appears weak. No allowance is made for time of travel of sediment (4 to 5 hours?). The figures do however indicate deposition between sites 4/6 and site 2 during the flood. This seems odd. It is concluded that no marine sediments enter the system during high tides because there are no changes in salinity.		
***Contaminant Analysis Report**, P1022.05.D022v01*	Report, Apr 2009	Partrac
Pollution is identified in material samples, but this is understood (from SRA) to be organic hydrocarbons from vegetation, which is not considered to be a problem.		
Sediment Sampling/Analysis Report *(Summer)*, *P1022.05.D023v01*	Report, Sep 2009	Partrac
Samples collected in July 2009 as for the winter survey. Almost all very fine sandy very coarse silt. Particle size data, cohesive strength data and settling velocity data It is suggested that only the coarser fractions will settle and erosion potential increases downriver. Stability of materials on the bank increases with bank height. Conclusions appear similar to the winter survey.		

***Hydrodynamic Monitoring on the River Parrett/Tone (Summer)**, P1022.05.D024v01*	Report, Sep 2009	Partrac
Sites: 1 (Parrett downriver), 2 (Parrett, Northmoor PS), 7 (Parrett d/r Burrowbridge), 3 (Parrett u/r Burrowbridge), 5 (Tone u/r Burrowbridge), 6 (Tone, tidal limit). Period covered: July/August 2009. 2 high fluvial flow periods: the first on the Tone and the second on the Parrett. Presentation of information could be better, for example providing levels and data as m AOD. Some plots are not clear and are too condensed to see results clearly. Problems with loggers at sites 5 and 6 (Tone). Water level hydrographs showing impacts of tides and high river flows. TSS measurements: very high site 1 (downstream), unclear at site 2, some very high at site 7, much lower at site 3; generally lower at sites 5 and 6 but some spikes. According to the discussion, tidally derived sediment reaches sites 7 and 3, and site 5 on the Tone. Current velocity data does not show direction. Velocity data indicates that Parrett causes Tone to back up, but the reverse is less obvious. Saline intrusion only observed up to site 2 (at Northmoor PS). This is linked to marine sediment penetration. Flow reversal occurs downriver of Burrowbridge with very high sediment concentrations. Deposition and erosion occurs on each tide. Highest TSS concentrations on the Parrett at sites 1 (downriver) and 2 (Northmoor). Cross-section data indicates a constriction downriver of Burrowbridge (site 7).		
***Sediment Budget Report (Summer)**, P1022.05.D026v01 and v02*	Report, Sep 2009	Partrac
Same summer monitoring period as above: July and August 2009. Bank stability higher u/r Burrowbridge Breaks in the data record for sites 7, 5 and 6. Sediment movement on large tides at all sites. Fluvial flow sediment smaller but extends for longer period than tides. Downriver sediment flux during a tide is lower but lasts longer. Plots of incoming and outgoing sediment and sediment mass per day. Incoming and outgoing sediment volumes are similar for spring tides, with net erosion near Burrowbridge. Most of the erosion and deposition occurs between sites 1 and 2, with net accretion between these stations. Net upriver movement on some days at sites 1, 2 and 7. Sediment moves upriver for some of the time at all sites. The fluvial sediment is about 3% of the total outflow for the spring tide sequence and about 15% during a high flow period. Sediment is eroded during the fluvial event.		

A summary of results is mapped separately. The accuracy of the method (with one sample point) should be reviewed. Confidence in the results is affected by apparent errors in the analysis. However the results give a good indication of where sediment activity occurs.		
***Comparison Report: Summer/Winter Surveys**, P1022.05.D027v01*	Report, Dec 2009	Partrac
Scope for comparison is limited. Direct comparison made for summer and winter high flow periods, which gave similar results. Discussion of differences in sediment transport for spring and neap tides. Summer floods on Parrett and Tone separately, and winter flood on both rivers. Summer flood flows eroded tidal sediment. Winter flood results are unclear, but suggest some deposition of fluvial sediment. This may not be correct. Results indicate that bank material would be eroded in most circumstances but this does not appear to take account of vegetation.		

Effectiveness of additional dredging		
Effectiveness of additional dredging	Leaflet, Jan 2015	EA
Summary of the ten dredging sites; identification of the Parrett from Northmoor to the M5 as the top priority. No dredging on the Brue (because the Brue dredging was originally to be covered under separate funding). Glastonbury millstream is priority 4.		
Review of the effectiveness of further dredging – Axe, Brue, Parrett & Tone	Report, Jan 2015	CH2M Hill for EA
These are the 10 sites: Sites on the Brue are Panborough Drain and Glastonbury Mill Stream. Reference to the Brue design model and Brue model study (October 2010 Jacobs). Model includes Glastonbury Mill Stream. Calibrated for 2 events. Model reviewed in 2014 and improvements planned. Impact of dredging on 100-year flood assessed. Approximate dredging costs. High level environmental requirements. Parrett/Tone system: impact of dredging on 2013/14 event. Modelling details: assumes Manning's 'n' unchanged by dredging. Reference to bank raising under asset recovery programme works.		

Langport to Tone confluence: LiDAR cross-sections; assumes dredging from bank and some water working, with disposal onto land (or stockpiled for earthwork); very ‘process-led’ WFD assessment; SSSI constraints on R/B Stathe to Burrowbridge; dredging causes reduction in spilling at Allermoor, leading to increase in flow into Currymoor and Northmoor; summary of environmental designations and constraints.

Northmoor to Bridgwater: This is d/s of the 4km Parrett dredge; high level assessment using conventional dredging methods (long reach excavators on banks and pontoon to deepen bed); summary of constraints; hydraulic benefits (lowering WLs on Currymoor and Northmoor); environmental constraints.

Ham to Hook Bridge: This is u/s of the 4km Tone dredge; reduces flow into Currymoor and Northmoor, but the benefit is small; environmental constraints.

Panborough Drain: Small drain in catchment that flows into the Brue by pump or gravity, depending on levels. Conventional dredging methods with excavators on one bank. Draw down from 2014 event: dredging shortens inundation time from 7 days to 6 days; up to 0.45 m reduction in water levels. Brue tidal effect 0.3 to 0.4 m. Costs and high level environmental assessment. Dredging improves the conveyance of flood water to the pumping station but the benefits of dredging appear small.

Glastonbury Millstream (offtake from the Brue at Glastonbury which discharges into the Brue further downstream): Need to regularly remove silt in u/s and d/s sections (but not central engineered channel). Conventional dredging methods with excavators on one bank. Flood benefits appear marginal although there appear to be some water supply and drainage benefits.

The report is supported by technical notes on modelling for the dredging options. Relevant notes are covered below (TN16, 20, 21 and 23).

***River Tone dredging upstream of Hook Bridge** – impacts on flood risk*	Technical Note (16), Sep 2014	B&V

Channel enlarged between Ham weir and Hook Bridge.

Baseline includes 8 km dredge plus bank raising on Parrett as part of asset recovery programme.

2013/14 event modelled: results presented for flood of 5 to 10 February 2014.

Results measured in terms of changes in water levels, flood volumes on the moors and pumping times.

Water levels in moors are reduced but the mechanism is not stated: I think it is over the banks for West Currymoor and West Moor, but could be over the banks plus Hook Bridge spillway into Currymoor.

Overall effects on levels are small.

River Parrett dredging (downstream of Northmoor) – *additional dredging study*	Technical Note (20), Jan 2015	B&V
Increases in channel width of 2m and 4m by reducing berm widths. New ISIS 1D model 'recently built' by B&V. Baseline includes 8 km dredge plus bank raising on Parrett as part of asset recovery programme. 2013/14 flood event: Results for Jan – May 2014 plus 3 Jan 2014 peak high tides (about 7.8 m AOD at Bridgwater, Northmoor and Tone confluence). Section areas below 6 m AOD: 50 m^2 at Northmoor and 70 m^2 at M5. Same roughness used, pre and post dredging; normal pump operation with no temporary pumps. Overall increase in section is small and space is limited. Up to 240 mm drop in levels at Northmoor (and 15 days reduction in duration, 10%). Little impact elsewhere. Benefits for smaller floods but flooding of properties only occurs in extreme events. Some impacts on tidal water levels (increase to Northmoor, reduction u/s Northmoor). Max change 90 mm on the extreme Jan 2013 tide. Larger decrease for low tides.		
River Parrett dredging (Langport to Tone confluence) – *impacts on flood risk*	Technical Note (21),Dec 2014	B&V
Increases in channel width by reducing berm widths: scenario 1, 2m widening from Langport to Allermoor spillway; scenario 2, 4m widening from Allermoor spillway to the Tone confluence. New ISIS 1D model 'recently built' by B&V. Baseline includes 8 km dredge plus bank raising on Parrett as part of asset recovery programme. 2013/14 flood event: Results for Dec 2013 – May 2014. Section areas below 6 m AOD: 24 m^2 u/s Tone and 45 m^2 u/s Allermoor spillway. Scenario 1 has little impact (but a surprising reduction of 90mm at Tone confluence). Scenario 2 has large increase on Northmoor (300 mm) plus smaller decreases elsewhere (up to 30 mm except 80 mm on Kings Sedge Moor). The increase is primarily due to less water passing into the Sowy, and more water in the Tone/Parrett system.		

River Parrett dredging (Allermoor spillway to Tone confluence combined with downstream of Northmoor) *– impacts on flood risk*	Technical Note (23),Jan 2015	B&V
Assumptions as previous notes (other works, pump operation, roughness, etc.). Scenario: 4 m widening from Allermoor spillway to the Tone confluence (scenario 2 in TN 21) plus 2m width from Northmoor to M5 (scenario 1 in TN 20). 2013/14 flood event: Results for Dec 2013 – May 2014 plus 3 Jan 2014 peak high tides (about 8 m AOD at Bridgwater, Northmoor and Tone confluence with adjustment). Increase of levels of 170 mm on Northmoor and reduction of 110 mm on Kings Sedge Moor. Smaller reductions elsewhere further u/s on Parrett.		

Hydraulic modelling		
River Brue Model Study. Appendix D Hydraulic Modelling Report, Final	Report, Oct 2010	Jacobs
Description of the hydraulic model that extends from Highbridge to Lovington, upstream of Glastonbury. The reach downriver of Westhay was covered by swath bathymetry, hence there are no formal cross-sections. Model results show the same flow for all design flood events in our reach of interest (31 cumecs). This means that the river will be full to capacity, and surplus water will go elsewhere.		
Somerset Levels modelling – 2014 Modelling report	Report, Oct 2014	B&V
Modelling report for the 2013/14 event. It is assumed that attenuation was taken into account between gauging stations and model boundaries by modelling overflow into the floodplains and moors. The spillway coefficients are low (p 28). Some flow gaugings were available but they do not appear to have been used for calibration. There are 14 gaugings listed in the report (pp 20 and 21).		
Somerset levels and moors flood risk advice: assessment of reduced impact of 2013/14 flood if dredging had been undertaken	Technical note, Feb 2014	B&V
Use of ISIS model. Flow data used for 16/12/13 to 31/01/14. Promise to update later using Feb 2014		

data. Area tested 4km on Tone and 4km on Parrett. Downstream boundary at Northmoor PS; five dredging scenarios; impacts on Currymoor (limited, because of overflow into Northmoor) and Northmoor (WL reduction up to 1 m). Results also shown on the presentation *Independent Review: Somerset Levels and Moors model* (EA). This shows that dredging on the Parrett and Tone can reduce flood levels in North Moor. This document provides hydraulic benefits only and does not consider flood risk.		
Independent review: Somerset levels and moors model	PowerPoint presentation	EA/B&V
Seems to be a summary of the Feb 2014 technical note.		
Somerset Levels Hydraulic Model	Technical note, undated	HR Wallingford
Prepared for Government meeting; shows impact of extending the model; slight differences in model results but generally the impacts of dredging are similar to B&V model. Generally the model calibration is not very good.		
Somerset levels and moors – Parrett catchment modelling for 20y FAP	PowerPoint presentation undated	EA/B&V
Model re-built by B&V and then used for the 20-year flood action plan by CH2M Hill. 1D ISIS model. Justification of assumptions. Peak level calibrations and some hydrographs. Estimated rainfall return periods; estimated flood volume return periods for moors. Estimated benefits of dredging and pumps in terms of numbers of properties affected. Proposed changes to EA flood map. Tested the following: • Improvement to Sowy: enlarge channel, open Monks Leaze Clyce more; • 10 dredging locations; • Ring banks for communities; • Increase pumping capacities; • Barrier: impact of barrier on flooding on the moors would be minimal; • Reduce inflows by 2% by improved agricultural practices; • Setting banks back in 5 locations (one on Parrett u/s Tone confluence); • Temporary pumps on canal: not effective; • Spreading floodwater using new structures: not considered cost-beneficial (!); • Flood storage in mid-catchments: small benefit on 2013/14 event; • Raising banks u/s Langport: impacts small.		

Somerset levels and moors asset management strategy. Technical Note 1 – Capacity of the River Tone	Technical Note, Sep 2012	EA

Good summary. It appears that velocities (and therefore capacity) are lower than design because of backing up from the Parrett.

Refers to movement of the bed in a flood (but no evidence presented).

Design flows; channel areas; impact of backing up from the Parrett

10 cross-sections covering 2003 to 2012 plus the design section.

Channel considered to be in regime: enlargement would require more regular dredging.

Benefit in reducing Parrett levels.

Reference to Technical Note 2 on erosion and deposition

Somerset levels and moors asset management strategy. Lower Tone and Parrett – Historic flood levels and hydraulic modelling study	Technical Note, Jan 2013	EA

Modelling of dredging on the Tone, dredging on the Tone and Parrett, plus raising of the Tone left bank and raising of Hook Bridge spillway.

Significant benefits on Northmoor for dredging options in Nov 2012 flood (max level drops from 4.8 m to 3.8 m. Plots should be compared with 2013/14, where option D reduced levels to 4.2 m.

Raising of bank and spillway would have adverse impacts elsewhere.

Results presented for 10-year and 100-year floods. Reduction on Northmoor is 0.54 m in a 100-year event (cf. 0.8 m for Option D in 2013/14 event).

More detail given in an earlier version of the note including baseline statistics and more return periods.

Somerset levels and moors asset management strategy. Lower Tone and Parrett – Currymoor and Northmoor *Scheme Options (costs and benefits)*	Technical Note, Jan 2013	EA

Two versions: the meeting version concentrates on costs, benefits and funding. Good appraisal of options.

The early version includes a discussion of water injection dredging and estimates of dredging costs.

Reference to monitoring "to ensure that the silts remain mobilised".

Some comments on the environmental damage caused by flooding at different times of year.

<table>
<tr><td>Allermoor and Beazleys/River Tone spillway rating curves</td><td>Two technical memoranda, Feb and Apr 2015</td><td>CH2M Hill</td></tr>
<tr><td colspan="3">Very clear reports describing the development of spillway rating curves.
Levels, dimensions and photos of the spillways provided
New Cd values that are much higher than the B&V values (1.16, 0.81 and 1.2 for the river spillways, cf B&V value of 0.035).
Cd values by hydraulic calculation. There does not appear to be any calibration data for the river spillways, but there are spot gaugings for Athelney spillway and Lyng cutting.</td></tr>
<tr><td>Interim Hydrology Report v2</td><td>Report , Apr 2016, incomplete</td><td>CH2M Hill</td></tr>
<tr><td colspan="3">Hydrology report for the Somerset levels and moors. It includes the Tone/Parrett and Brue and covers peak flows and flood volumes. The report is intended to provide design events, but is incomplete.
A study of the tidal Parrett /Tone and the Brue downstream of Glastonbury would require flows at the reach boundaries taking account of attenuation upriver of the boundaries.</td></tr>
</table>

<table>
<tr><td colspan="3">Environmental and appraisal</td></tr>
<tr><td>Parrett and Tone Maintenance Dredging: Environmental Impact Scoping and Assessment</td><td>Technical Note v4, Nov 2015</td><td>Parrett IDB</td></tr>
<tr><td colspan="3">Refers to area of 70 m^2 for the 8 km dredge.
Environmental constraints are least in the autumn.
Spring or summer constraints: spawning and migrating fish; breeding birds and water voles; bathing waters.
Wintering birds in winter.
Recommendation for re-profiling on one bank only.
Causes of environmental effects are dredging, vegetation clearance, vehicle movement, disposal including spreading, compound and effect of dredging (changing flood risk).
List of impacts and those scoped in or out (23 scoped in).
Mitigation measures and some guidance on preferred timing.
List of mitigation effects and residual significance. The mitigation measures have major impacts on the timing and methods of dredging, and the need for surveys and monitoring.</td></tr>
</table>

Parrett and Tone Maintenance Dredging: Habitat Regulations Assessment	Technical Note v2, Nov 2015	Parrett IDB
Dredging restricted to 1 October to 14 February. It is concluded that the dredging will cause a reduction in surface water conditions on Currymoor for wintering birds. This is in direct conflict with the requirement to reduce flooding. Summary of designated sites (although no maps of the sites are given). Summary of impacts Significance of impacts: most could be significant because of uncertainty. Monitoring will be implemented to identify impacts.		
Parrett and Tone Maintenance Dredging: Water Framework Directive Assessment	Technical Note v4 and spreadsheets, Nov 2015	Parrett IDB
Required mitigation measures include: • Morphological diversity should be retained or reinstated where possible. • Rough rather than smooth banks should be sought where possible. • Within any section, only one bank should undergo works in any one year. • Monitor water quality against predetermined thresholds. Contingencies required should dredging result in poor water quality (e.g. stop dredging, use of aerators, apply hydrogen peroxide). Work should be carried out in the autumn. Re-planting or re-seeding of banks is advised, together with consideration of off-site mitigation. Comment: Bearing in mind that the rivers are ‘flood channels’, and their capacity should be maximised, offsite mitigation may be better than in-channel mitigation where possible.		
Somerset economic impact assessment of the winter 2013/14 flooding	Report, Feb 2015	Parsons Brinckerhoff
Total damages estimated as £118 million (range £82 million to £147 million). Includes direct (£75 million), Indirect (£9 million) and qualitatively assessed (£35 million). Estimates broken down: rail £17m; emergency costs £17m; residential property £16m; roads/travel £12m; agriculture and environment £6m; social £3m; business £3m; utilities £1m; indirect (business) £9m); other £35m. Comment: Flood risk was reduced by the 8 km dredge to between 50 and 80 residential properties. If it is assumed that 40% of residential property and 10 to 20% of other damages would be avoided by the dredging, the benefit of the dredging during the event would be about £20 million.		

Key datasets	
Dataset and source	**Comment**
River Parrett and Tone hydraulic model (HR Wallingford)	2013 version; ISIS 1D model Includes full datasets Used for the hydraulic review
River Parrett and Tone hydraulic model (EA)	2015 version; 1D Flood Modeller Pro model Includes full datasets Used for 2013/14 event
River Brue hydraulic model (EA)	Based on 2010 1D/2D version but converted to a 1D ISIS model Includes full datasets Includes flows for different return periods
River Brue survey, 2010 (EA)	Includes cross-sections at structures
River Brue survey, 2013 (SDBC)	46 sections for 4.5 km reach downstream of Westhay Bridge, with and without silt
River Parrett and Tone survey (SDBC)	Pre-dredge (April 2014 and 2009 data) and design cross-sections for the 8 km dredge. CAD format
River Parrett and Tone survey, April 2015 (SDBC)	Covers 2014 8 km dredge on the Tone and Parrett
River Parrett survey, November 2015 (SDBC)	2.2 km maintenance dredge
River Parrett survey, March 2016 (SDBC)	2.2 km maintenance dredge
Data for the Partrac study (EA)	
Hydrometric data for 1/10/14 to 01/04/16 (EA)	Chiselborough flow; Bishops Hull flow; Northmoor level; West Quay level

The following site visits were undertaken as part of the study.

Table D.2: Summary of site visits

Date	Area	Purpose
02 March 2016	River Parrett – Burrowbridge to M5 on both east and west banks.	Initial site visit
24 March 2016	Rivers Parrett and Tone – New Bridge Spillway to M5 – east and west bank on Tone, west bank only on Parrett	Inspect confluence of Tone and Parrett. See if there is evidence for change in marine to fluvial along the tidal sections (i.e. observation of change in vegetation, channel form and sediment type)
21st April 2016	River Parrett – Burrowbridge to Beazleys spillway; Oath sluice and upstream of Oath. River Brue – downstream of Westhay Bridge. River Tone under low water level conditions.	Inspection of potential dredging locations

E. Consultations

The consultations that have been carried out are listed in Table E.1, including the relevance of the consultees to dredging on the tidal sections of the Parrett and Tone and the River Brue.

Table E.1: List of consultees

Name	Date of meeting	Relevance
Nick Stevens, Iain Sturdy, Phil Brewin, Rachel Burden and Alys Lambert	2 March 2016	Project start-up meeting with EA and IDB staff in which technical issues were discussed
Nick Stevens, Iain Sturdy and, Phil Brewin	15 March 2016	SDBC senior staff – Discussion on dredging locations
Andy Wallis (BV), Nick Stevens, Iain Sturdy and Phil Brewin	15 March 2016	Modelling Consultant and SDBC senior staff – Discussion of hydraulic modelling of the Parrett, Tone and Brue.
Andy Wallis (BV)	15 March 2016	Modelling Consultant – hydrological modelling of the Parrett and Tone.
Members of the SRA Dredging Strategy Board	18 March 2016 and 21 April 2016	SRA Dredging Strategy Board
Rachel Burden (EA)	21 March 2016	EA member of Dredging Strategy Board
Graham Quarrier and James Yarham (EA)	21 March 2016	EA officers responsible for pioneer dredges (8km and 0.75km)
Ali Wintle (EA)	21 March 2016	Waste Officer for the Environment Agency
Mark Doyle (EA)	21 March 2016	Previous experience of dredging trials on the Parrett
Nick Stevens, Iain Sturdy, Rob Kidson:	24 March 2016	Chief Executive, Chief Engineer and Project Engineer for the SDBC – Discussion centred on general experience of dredging
Chris Smith (EA)	31 March 2016	Managed Partrac monitoring study and provided data.
Simon Foyle (EA)	-	Previous experience of dredging trials on the Parrett. Unable to make contact
Paul Rayner and Damien Debski (CH2M Hill)	31 March 2016 and 06 April 2016	Responsible for the effectiveness of dredging study. Undertook modelling of the Parrett, Tone and Brue. Involved with Parrett barrier study.
Peter Rossiter (ex-IDB)	04 April and 12 April 2016	Historical dredging experience of the Parrett and Tone

Name	Date of meeting	Relevance
Bob Kirby (Independent Consultant)	-	Meeting delayed
David Ayres (ex-MAFF regional engineer)	05 April 2016	Knowledge of the Tone scheme and subsequent dredging activities
Damian McGettrick (WM Longreach)	06 April 2016	Contractor for maintenance dredge
John Buttivant (EA)	7 April 2016	Project manager for the Parrett barrier project
Bill Gush and Fiona Moore (Land and Water)	13 April 2016	Contractor for pioneer dredge
Andy Pitcher (AP Surveys)	14 April 2016	Survey contractor for channel surveys
Gerrad van Raalte (Ex-Royal Boskalis Dredging)	22 April 2016	Ex- Royal Boskalis Dredging
Rob Forse (Somerset County Council)	28 April 2016	Procurement

Summaries of some of the meetings are given in the subsequent tables.

Project start-up meeting

02 March 2016

Key technical points for project development are covered below. Contractual and other non-technical issues are not included here.

Present:

Nick Stevens (NS, SDBC), Iain Sturdy (IS, SDBC) and Phil Brewin (PB, SDBC), Rachel Burden (RB, EA), Alys Lambert (AL, EA), David Ramsbottom (DR, HR Wallingford), David Middlemiss (DM, HR Wallingford)

IS – Dredging season is usually autumn to maximise benefit of dredging.

NS - Initial modelling work started in 1996 when the model was developed by Posfords. It had been enhanced and upgraded on a number of occasions.

RB – Black and Veatch (BV) has undertaken a significant amount of modelling of the Parrett and Tone, with Andy Wallis using ISIS model. RB noted that a summary presentation has been produced by the EA and can be viewed / shared with HR Wallingford.

NS – Summarised that after the flooding in the summer of 2012, before the severe flooding of winter 2013/14, the Agency had commissioned modelling work on the Parrett and tone to consider the matter of dredging. The work identified dredging an 8 km length to the 1960's improved profile would have significant beneficial effects on water levels in Currymoor and Northmoor/Saltmoor. Funding was sought from FRM organisations in Somerset however insufficient contributions were forthcoming 10 dredging 'hotspots' were also identified and works undertaken a selected sites where land based access was possible.

RB - Following severe winter floods of 2013/14 and with the knowledge of the significant impact dredging would have on flood levels central government made emergency funds available and thus this pioneer dredging could be carried out.

IS – The dredging of the 8 km in 2015 has been followed up with a 2.2 km maintenance dredging where fresh silt had accumulated at the downstream end of the pioneer dredging section.

DM – asked if data was available prior to recent dredging works. IS noted very good data is available for the recent maintenance and pioneer dredging sites but that earlier data was not as thorough.

RB – some dredging on Parrett and Tone done through the 1990's,following the flooding in the mid 1990's Further dredging work was undertaken in the early 2000's.Following this dredging and the absence of a good understanding of the sediment/silt dynamics an investigation into siltation rates and hydrodynamics was conducted by Partrac in 2007-2009. Agitation dredging techniques trialled in 2003.

NS –Following the earlier investigation work by HR there was a view that only agitation techniques were economic in the longer-term. Furthermore , following the dredging trial projects in the mid to late 1990's some views existed that that agitation varied in its success (i.e. can you prove the material is removed and doesn't come back?). NS commented that there was quiet period in dredging from ~2004-2012. Agitation had been used in the 1980s to 1990s but it was phased out – suggests that there is an element of rediscovery required. DM commented that it would be good to understand the historical techniques used and who we need to talk to about the dredging that has been done.

RB – advised that for the 10 locations identified where dredging could be undertaken there is an EA summary document and supporting technical summaries for each site. Sites decided by feeding in

2013/14 flood hydrograph.

RB – noted that there are lots of criteria (hydraulic, ecological, population, cost, benefit, downstream impacts) to assess the dredging against. The Somerset levels are 'designed' to flood and Curry Moor is classed as a reservoir from a safety point of view. There are also numerous SSSIs, RAMSAR and SPA sites - changes to hydrology will be important impact to consider in any assessment.

IS – explained that it would be good to understand the impact of additional pioneer dredging upstream of Burrowbridge on the balance of water around the Parrett and Tone confluence. This was summarised in a diagram.

DR – asked what dredging is currently done on the River Brue. IS not sure what dredging is currently done across the Brue catchment but is aware none is carried out in the lower reaches of the River Brue. There is popular opinion that some work is required. Maintenance dredging of the River Brue has not been done for some considerable time.

DR – asked what data was available for the Brue. RB responded that a modelling study has just been completed. IS noted that there is probably some data, but not as detailed / complete as the Parrett and Tone.

IS – clarified that complete survey, 50m river cross-sections were available for 8km pioneer dredging on the River Parrett including; assessment, pre-contract and re-measure survey. This data is held by EA. This data is also available for 2.2km maintenance dredge.

DM – asked about volumes and costs of 2.2km maintenance dredge. IS stated £443k M for 23,000m^3, or around £19.26/m^3. The forthcoming 750m pioneer dredge will be £2.14M for 23,000m or around £93/m. DR - asked if BoQs / Tender information could be supplied.

DM – raised question over disposal of material. IS noted that the maintenance material is put on the back of the bank wherever possible, but this cannot be repeated often as there has been a lot of material removed. NS noted that working from pontoons is not as common as thought. Material can be disposed on land if can prove 'agricultural betterment'. Farmers accept for free, but payment for access, loss of arable land etc. required.

RB – to obtain permission is very complicated, and mitigation measures (in all forms) can make things very expensive viz. the 750m pioneer dredging.

Consultation meeting with Andy Wallis and SDBC

Highbridge, 15th March 2016 (10am to 4:15pm)

Present:

Andy Wallis (AW, B&V), Nick Stevens (NS, SRA), Iain Sturdy (IS, SRA), Phil Brewin (PB, SRA), David Ramsbottom (DR, HR Wallingford).

Purpose of study is the management of silt and vegetation, to allow the SRA to decide dredging and deliver in a sustainable way while providing value for money.
This meeting covered mostly dredging locations and modelling, and a separate (similar) meeting will be needed for dredging.
Parrett/Tone Agitation dredging helps to control vegetation; vegetation makes silt more solid; reed and grass vegetation; slumping of river banks is common. Potential impacts of agitated sediment on marine shellfish in the bay. AW is doubtful about effectiveness of agitation dredging but we didn't have a good discussion on this. He mentioned that flow velocities are generally low (the Partrac reports have information on this).
Cross-sections required for the following surveys: • Pre-pioneer dredge, Mar/Apr 2014: all sections • Post-pioneer dredge: all sections • Monitoring survey Apr 2015 (every other section) • Pre-contract survey of 2.2 km maintenance dredge • Post dredge survey for 2.2 km New survey for whole 8 km section to be commissioned soon.
Design sections reported to be achieved in post-pioneer dredge survey but the Apr 2015 survey showed that much material had returned, particularly at the bend at Westzoyland and further downstream. AW felt that the post-pioneer dredge survey may not have been entirely correct. He implied that this could be related to measurement of the amount dredged. AW concerned that speed of the pioneer dredge led to problems: too many teams and deposition of disturbed material in completed sections.
Material in 2.2 km maintenance dredge is marine. Some accretion further u/s, but less.
There are some areas of rock, placed to stabilise banks.
DR interested in Partrac data (probably held by the EA or Partrac). Monitoring affected by dredging during the survey period.
Need to review sediment monitoring techniques. Is there a modern technique that could be used to improve understanding of sediment movement? Difficult to find a suitable location on the Parrett for

monitoring.
750 m dredging limit based on money available. Preferred dredge would be to the M5.
1960s sections from Tone scheme: prescriptive for Tone but target section areas and wetted perimeters for Parrett to North Moor: Scheme stops at North Moor. David Ayres is the person to talk to.
AW feels the April/May 2012 event was important as it caused flooding in the growing season.
No evidence that changes in the catchment have a significant impact on the Moors.
Lots of survey carried out after the 2013/14 flood. This is catalogued by BV.
Water enters Curry Moor from the Tone in the fluvial reach and this was one of the 10 dredging sites.
Issue of how long different areas will flood with different flow distributions: an acceptable balance between flooding west of the Parrett and flooding on the Sowy/KSD system is needed.
General dredging approach: • Maintain what has been dredged (8 km and new 0.75 km) • Consider dredging on Parrett u/s of Burrowbridge and d/s of the existing Parrett dredge (4 km + 0.75 km). • Implement maintenance dredging on the Brue
The Partrac contamination report was misleading. The hydrocarbons in the samples are understood to be from degraded plants (i.e. natural).
There is a problem of depressed areas in fields caused by drying out of the peat and poor farming practices. The question of using dredgings to raise these land levels was discussed.
Members want to challenge the regulations regarding disposal of dredged material (although I don't know exactly what).
The environmental designations on the Parrett are complex and restrict disposal.
AW is concerned about combinations of measures. Whilst we are concerned with dredging, dredging and pumping was used in 2013/2014 and it could be argued that pumping is more effective than dredging. There is mis-information, which suggests that dredging is more effective than it actually is.
The WFD requires that we should demonstrate we are doing the best we can. Options include dredging, pumping and dredging + pumping. Dredging + pumping appears to be the most effective.
AW said that the model of the Parrett/Tone was considered to be a tool as there are too many variables to obtain definitive answers.
Model history:

Modelling recommendations were made after the 2000 flood but nothing happened. 2000 flood affected the Tone and Parrett. A flood occurred in April/May 2012 on the Tone. It was about a 1 in 10-year event but was the largest that has occurred in the growing season. Seasonality of flooding is important. There was also a winter flood in 2012 (about a 1 in 15-year event). Options for reducing flood risk in Curry Moor were investigated in 2012/13. There was no budget for major dredging and 10 pinch points were identified. Some dredging was done on some of these, but not very effective. Little confidence in the pre-2014 model because of lack of good calibration data. The model was run during the 2013/14 flood event and options for dredging and pumping were tested during the event. Calibration results were poor, particularly for tidal propagation. This was ‘fixed’ temporarily using high ‘n’ values. The 8 km dredge was identified as being beneficial, and work started on the dredging. The model was completely revised to include the upstream moors (u/s of Langport) and the Penzoy river. The Tone and Sowy were updated. The revised model calibrated well although there were still some tidal issues (for example, observations show 2 tidal peaks at Bridgwater). Benefits of the 8 km dredge were estimated. Ten sites were identified for potential further dredging. These were modelled by CH2M Hill. Best benefit was Parrett d/s of 8 km dredge. The sites were modelled using the 2013/14 event. Combinations of sites were also modelled (HR Wallingford has not seen this). No other events have been modelled.
Comments on the system: The Tone cross-section downstream of Hook Bridge is understood to be smaller than upstream because of physical constrictions. Curry Moor was a flood storage area in the 1960s River Tone scheme. There is a strategy for the Sowy which is to be implemented. The capacity will be increased from 17 to 24 m^3/s.
The river downstream of Northmoor is difficult to maintain. DR suggested a sediment sink has been created upstream of Northmoor pumping station by the dredging, which would result in sedimentation here first. The worst siltation of the 8 km dredge has occurred at the bend at Westzoyland and between Westzoyland and North Moor. DR also suggested that the dredging should be designed so that the cross-section does not decrease in the downstream direction.

IS unhappy with some of the dredging tests. Dredging was modelled on the Parrett upstream of Burrowbridge but improvements were not made downstream. This resulted in backing up of the Tone and more flooding on Curry Moor/North Moor.
SRA want further modelling and will consider a variation to the contract. Modelling could be carried out by AW (who knows the model well). Some modelling also needed on the Brue.
Reference to EA trigger point work, which defines when pumps should be switched on, gates opened, etc. AW said that this is very important.
AW would like to model downstream of M5 and through Bridgwater, as there is a fluvial constriction caused by sediment and bridges.
The modelling and dredging approach must consider the balance of flow between the Parrett and the Sowy.
More events may be needed for the modelling (e.g. smaller events that cause flooding of agricultural land and affect wetlands). DR suggested the development of small/medium floods based on inspection of historic data. These events would be used to show the relative benefit of different dredging options.
Modelling to be discussed at Friday meeting: • Hydraulic impact of dredging on Parrett u/s Burrowbridge together with downstream improvements on the Parrett. For example, a widening of 2m u/s Burrowbridge combined with a widening of 2m d/s Northmoor was discussed. • Review of transitions from dredged to undredged downstream of Northmoor, for hydraulic efficiency and to minimise risk of silt traps. • Dredging on the River Brue. • Quantification of impacts. • Relative benefits of each approach. • Consideration of other events. A widening of 4m u/s Burrowbridge combined with a widening of 2m d/s Northmoor has been modelled, and caused a 170mm increase in levels at North Moor without pumping, according to an EA note dated 8/12/14. IS wants to look at other options. DR concern is that we have no 'design criteria' to aim at, so it will not be clear when we have reached the best answer.
Dredging trials will need to consider all aspects of dredging including permissions, permits, exemptions, etc.
There was little discussion of the systems, but AW commented that velocities are low and therefore agitation may not be very effective.
The Brue is included to ensure the study covers the north and south parts of the levels.
The normal water level in the Brue is below land level but it has banks, and flood levels exceed ground levels. A flood occurred in Apr/May 2012 and a 1 in 10-year event occurred in 2013/14.

Deposits in bed; summer weed issue.
The section between Westhay and North Drain contains silt, and maintenance dredging is proposed. IS has a report showing details.
The river has a tide flap (mitre gates) at Highbridge and there is a sluice for summer penning at Hackness.
IS to provide a summary of how the system works.
Model history: 2008 model: 2D, did not work 1D model after 2013/14 event from Lovington to Highbridge: not tested System contains lots of pumps and syphons Channel has soft and hard bed: silt in bed, not banks Good access on right bank There is about 40,000 m^3 of silt in a 4.5 km reach, which has been promoted as maintenance dredging. No big floods on the Brue since 1970s (summer) and 1960.
Need to prove dredging is needed: hydraulic impact for different events, flooding and benefits.
Full flood study requires significant work. Proposed to assess impact of dredging on bankfull flow, with and without silt. Changes in flood conditions could be inferred from these data.
The flood banks on the Brue u/s of Westhay are low and in poor condition. There is an opportunity to set the banks back and restore the river.
IS feels that the Brue dredge is relatively easy maintenance dredging. It would require the normal habitat and geomorphological assessments and this has been discussed with the EA.

Strategy Board meeting

Taunton, 18th March 2016 (9am to 11am)

Present:

Sarah Diacano (chair), Tony Bradford, Jamie Walker (Somerset CC), Nick Stevens (SRA), Iain Sturdy (SRA), Phil Brewin (SRA), Rachel Burden (EA), David Ramsbottom (DR, HR Wallingford).

Agreed that our objective is to achieve the greatest hydraulic impact. We are: • Deciding where to dredge • Deciding the best methods • Deciding which trials to carry out
Dredging approach should cover all steps needed to deliver work (including permits, environmental requirements, etc.)
SRA will development an overall communications plan for the project (Jonathan H of SRA)
Tony Bradford: Different maintenance methods will be needed in different places on the Parrett. Vegetation is a factor.
Best time to dredge the Parrett is the autumn (low environmental constraints and high river flows).
A risk calendar was suggested, where constraints for each month of the year are identified.

Consultation meetings: EA

Bridgwater, 21st March 2016

Present:

Rachel Burden, Graham Quarrier, James Yarham, Mark Doyle, Ali Kintle (all EA), David Ramsbottom and David Middlemiss (HR Wallingford).

RB provided a summary of post 2013/14 works
Issue of balance between keeping water in the Parrett and diverting it down the Sowy. IDB want to keep water in the Parrett to reduce risk to farmers near the Sowy/KSD.
Tim Anderson is responsible for survey in the EA.
GQ and JY discussed recent dredging campaigns including issues of low flows, vegetation management to protect habitats, their understanding of how the river behaves, etc.
Some discussion of other methods. Lagoons need land (£10,000/acre for arable). Agitation may be suitable in the autumn when there are high flows.
WFD requires interference with rivers to be minimised. Maintenance of the Tone every 4 years may be OK. Can we identify a more sustainable method for the Parrett and optimise channel width d/s Burrowbridge?
GQ to supply a Dutch report on dredging.
Discuss environmental issues with Phil Brewin. John Phillips of the EA undertook a WFD assessment for the maintenance dredge.
Need to dispose on arable land because of potential harm to animals if material used for pasture.
Barrier will be used to protect Bridgwater from tidal flooding and create storage volume for fluvial floods (similar to Thames barrier).
Potential value of Partrac data and HR Wallingford data to help understand the system.
Mark Doyle provided a summary of dredging trials: • Dragging bank material into the channel was not very effective because of low velocities. • Agitation dredging not effective because of low depths for vessels, material too cohesive and velocities low. These should be viewed as 'lessons learnt': we should consider how we can overcome these problems. Note that 1 in 3 is considered to be the natural slope for the material. The current designs are 1 in 2, and there is no space to widen the channel in many locations.
We could undertake simple tests to demonstrate how cohesive material might be broken up.

Ali Wintle provided information on waste management including the exemptions and permits that are used. Whilst no permit may be needed for agitation dredging, there could be environmental impacts (to be considered by the EA land & water team and the EA fisheries & biodiversity team. Land availability for spreading could be an issue.
What is the difference in requirements for pioneer and maintenance dredging?
We should consider the impacts of salinity as the dredging proceeds downstream. The EA has guidance on salinity levels and permitting is done by the national team. HR to contact the national team for guidance (Matthew Caple). We could arrange for simple tests to determine the salinity of sediment along the river.
Idea of conceptual flood and sediment models, to be included in the report. These will explain in ‘high level terms’ what is going on. It will also provide the basis for deciding what to do.

Consultation meeting with representatives of SRA on dredging matters

SRA HQ at Highbridge, 24 March 2016

DSM – David Middlemiss, HR Wallingford

NS – Nick Stevens, SRA

IS – Iain Sturdy, SRA

PB – Phil Brewin, SRA

RK – Rob Kidson, SRA

DSM provided before the meeting a set of questions to stimulate discussion on dredging matters, these included:

1) What assessments were required before dredging could be undertaken?
2) What mitigation measures were required?
3) What are the type and specification of the Contracts for the Pioneer and Maintenance dredging – do they differ in approach? Copies of the contracts / specification of the works would be very helpful.
4) Different contractors are being used for the recent Pioneer and Maintenance dredging – what is the reason?
5) Where and what dredging techniques were / are being used?
6) What was the recorded and perceived successes / limitations of the different techniques? (were trials conducted?) How were the different techniques assessed?
7) What were / are the proposed / actual dredge volumes (as measured)?
8) How are the dredge volumes being measured?
9) How is the dredged material disposed of? What options were / are available and how were they assessed?
10) Are there records / data for pre, during and post dredging?

    Records / data could include:

    Tender and design documents, BoQs, bathymetry measurements, flow and level measurements, dredge records (volumes, duration, costs etc.), sediment property analysis, suspended sediment concentration data.
11) How has the dredging contractor performed – what are the performance metrics being used?
12) What, in your opinion are the challenges of undertaking dredging on the Parrett, Tone and Brue?
13) How is access arranged to undertake the dredging? (some access to private property is required)
14) What conditions of the dredging and disposal licence have been most challenging to adhere to?

15) Would the IDB consider developing in-house dredging capability?
IS commented that assessments of the material type were performed prior to the dredging, but these assessments focussed on the nature of the contaminants in the material and determination of suitability for spreading on agricultural land.
DM raised the point about other impacts, such as traffic management – IS stated that there were no issues with traffic management, only temporary restrictions whilst unloading dredging plant etc.
IS noted that the disposal operation operated with a D1 licence requirement, and under flood defence consent with compensation for the landowners where necessary. NS noted that he believed that this type of operation was not the intention of Section 14 and 15 of the Land Drainage act, but is the way in which the EA has interpreted that regulation.
DM enquired about costs – IS noted that cost information quoted by DM from the EA came from the SRA. Values of about £15 / m^3 were mentioned for the maintenance activity, with costs of about £70 / m^3 mentioned for the capital work. The **significant increase in the cost for capital works is associated with the fact that there is a lot more preparatory work as this is a design and build operation**, hence includes Consultant's fees, Contractor's Risk and Licencing. RK stated that split in volume was 70% back of bank and 30% on field for maintenance, with range of £10 to 20 $m/^3$.
NS made observation that a potential issue remained with the use of the EA's framework for procurement – how do you remain competitive and use a framework agreement for procurement? Timing and economics at the time that the framework was set-up could influence matters. EA use framework, SRA use competitive tender.
NS / IS noted that **elevated costs for the next 750m pioneer dredge is associated with the poor access** – large proportion has to be done using floating equipment.
DM commented on the EIA aspects – what was required?
PB commented that 'Water Voles' and 'Clicky Beetles' were sensitive species living in the area. The EIA had been done for the Pioneer works already, so the process could be 'recycled'**. Mitigation included 1 bank working** and surveys prior to operations / tender process. Note that ecology is seasonal.
DM discussed a potential approach of using mechanical means for the Pioneer works and agitation / jetting as a means to complete the maintenance.
NS commented on the trials that had previously taken place (DM noted that had been raised by Mark Doyle during consultation with the EA). **Found that agitation technique was not very successful for pioneer material – material remained in situ in the channel. DM commented that this material seems to be well consolidated and perhaps that agitation more suited to more loose 'maintenance' material**.

NS commented that a figure of '12t/m/yr' was a value that had been quoted historically as the siltation rate – **therefore production rate for the agitation / jetting technique was important.**
DM enquired about SRA's views of developing in-house dredging capability? NS commented that at face value the SRA would prefer not to. Although the IDB has got some plant, currently 60-70% is subcontracted out. Own equipment has a high downtime and is not well utilised.
NS noted that in the context of agitation techniques and the potential timing (being related to times of tides etc.) would be concerned about staffing the activity and how to measure the effectiveness of the work.
DM enquired about the volumes that had been dredged? RK commented that they were waiting on final confirmation of the recent maintenance dredging campaign – but the specification value was 22,700m^3 and looks like 21,230m^3 has been dredged. RK commented that post pioneer dredge the material returned quickly.
DM enquired about the performance of the dredging contractor – had they had any issues or challenges?
RK noted that the performance of the contractor had been very good, and really any issues centred on the Contractor understanding how the Parrett 'worked'; at times the water flow was too strong for the equipment to operate. The use of a '3D dig system' allowed more accurate locating of the bucket on the return cut hence more consistent profile.
RK noted the profiles were the same target as the Pioneer dredge – the 1960's Tone Valley scheme with a design flow for 100+ cumecs.
DM and RK then met in RK's office and RK provided DM with the following documentation: 1) Maintenance dredge Tender document 2) Maintenance dredge Tender document return from unsuccessful contractor. 3) CD containing pre Pioneer, post Pioneer and pre Maintenance dredge survey information (in CAD format).

Consultation phone calls with Paul Rayner, Damian Debski and Chris Weeks (CH2M Hill)

31st March and 6th April 2016

31st March: Paul Rayner (Exeter)
CH2M has undertaken modelling on dredging scenarios but in PR's view they were not joined up. There is therefore scope for more scenario modelling.
CH2M took over the Parrett/Tone model from B&V and made some changes. These included floodplain changes and changes connected with trigger points. It also included changes to spillway coefficients. In CH2M's view, the B&V spillway coefficients were low. The changes affected the calibration of the model.
Damian Debski has the best knowledge of dredging scenarios.
Chris Weeks undertook design scenarios. The strategic thinking had already been done in the FAP.
PR felt that flooding will only be prevented by major works but this is not affordable.
The improvement to the Sowy/KSD was considered by PR to be an effective spend. He is aware that the IDBs prefer the dredging solution.
The Sowy was originally designed for 30 cumecs but was installed at 17 cumecs apart from the structures, which can take 30 cumecs. The current improvement will increase the capacity to 24 cumecs.
The works have been constrained by funding issues.
6th April: Paul Rayner, Damian Debski and Tom Toogood
Parrett and Tone model: A B&V model report is available (dated 2014), requested from the EA. This was used for simulating the 2013/14 event CH2M took over the model. They thought the model was generally OK. They made the following changes: • Added new features (for example, asset recovery) • Added the Stert managed realignment • Re-rated the five spillways (3 on the rivers plus Athelney and West Lyng) including revising the coefficients. 2 notes were produced on this work. • Added the Beerwall flood relief culverts, which are on the floodplain under the A372 road • Extended the model further upriver (upriver of our section)
CH2M have developed design flows for the model and produced a hydrology report, requested from the EA.

The Parrett and Tone model produced by CH2M has the following:

- Design dredged cross-sections were used throughout. This means that the dredge survey data have not been used.
- Manning's n values that are the same as the pre-dredge condition. This is arguably conservative (but the change of roughness over time is unknown).
- There were some sensitivity tests undertaken on Manning's n which can be seen in the scenario results. The changes were of the order of 20%.

With regard to the modelling of the ten sites:

- The model was being updated when this work was carried out.
- B&V did 6 sites. The feasibility of the work was checked by CH2M
- CH2M did four sites: two on the Brue and two on the Axe
- CH2M has also tested most things in the FAP (as reported)

Brue model:

- Originally the Jacobs 1D/2D model but updated into a 1D model by CH2M.
- The model has been extended upstream of our area of interest, and new survey was carried out for this. Our area still has the original 2009/10 cross-sections.
- CH2M has improved the calibration. Their work is nearly complete, and the objective is to deliver a model that can be used for design purposes.
- The main issue is confidence in the right design event because of the different types of events that can occur.
- There is a Jacobs modelling report, which the EA will provide.

Damien is doing modelling for the proposed barrier.

Consultation phone calls with David Ayres

04 and 05 April 2016

David Ayres is the ex-MAFF regional engineer for the area. He worked for the river board from 1963 and became assistant Regional Engineer in 1980. He became Regional Engineer for the South West and Midlands in 1990 and retired in 2006.

He provided a summary of his knowledge of the Tone Valley Scheme. Some key points are as follows:

- The design allows for the combined Parrett and Tone flows downstream of the confluence
- The in-channel flow has a low return period (about MAF). This means that overtopping of Hook Bridge spillway could occur regularly.
- Design values of Manning's n are low.
- Cross-section area of Tone reduced by 35% in about 15 years)
- Lowering of Allermoor spillway by 200 mm is a concern.

The original Tone and Parrett Relief schemes were separate. The Tone scheme provided 1 in 30-year protection (1 in 100-year if 2ft freeboard was used up).

Freeboard was provided for settlement.

The spillways at Hook Bridge and Athelney existed before the scheme, and provide flood storage.

The Allermoor spillway existed before the Parrett Relief scheme. The Parrett Relief (Sowy) scheme was designed for 1000 cusecs but was constructed to half this size (500 cusecs – 14 cumecs) but bridges were full size. The scheme included Monks Leaze Clyse.

Allermoor spillway has been recently lowered by 200 mm which means that overflow occurs much quicker than it used to. This was done because of low spots on the banks. DA would have raised the banks.

Curry Moor PS can pump when there is no flow over Hook Bridge. Thereafter pumping is stopped to prevent recirculation of water.

Before the Tone Valley Scheme (TVS) flooding occurred annually over Hook Bridge and less frequently over Athelney. Water entered Northmoor but did not flood Moorland. Northmoor PS had large pumps but a small channel. This was improved in 1990.

After the TVS the Hook Bridge spillway did not run for several years (although it was a 'low flood' period).

This information was obtained from the annual reports, which state the times when Hook Bridge was overtopping.

Most of the dredging for the TVS occurred on the Tone as the channel was doubled in size. Not much dredging on the Parrett. Silting began quickly and berms formed at MTL. The Tone dominated flows at the confluence.

The EA stopped maintenance in 1995 (although DA does not consider agitation as dredging).
Two jetting pumps were used from the bank to remove material and prevent slipping of the banks. There was also a jetting boat called 'Persevere' with a jet pump on the front.
Simon Foyle is a key contact for dredging.
Silt comes in on the tidal bore, a 2ft high wave. Silt is stirred up on each tide and carried further upriver. The channel was full of silt in 1976. In DA's view the silting problem from u/s is insignificant.
There were no concerns regarding capacity downriver of Northmoor.
In 2013/14 there were no critical floods on other rivers. The problem was a lack of capacity.
DA has not come across the idea of silt traps for the Parrett. There is a lack of space along the banks for widening the channel.
DA generally agrees with the strategy of the Sowy River but there is a severe constriction at Dunball caused by 2 bridges.
DA does not recall any capital dredging on the Brue.
If a long section is plotted, it would show a low central area at North Drain. The ground levels are higher at Highbridge. The central area is drained via North Drain and the PS. There was also a scheme for the South Drain.

Consultation phone call with Peter Rossiter

04 April 2016

Peter Rossiter worked for the Somerset Rivers Authority as the assistant area engineer for O&M from 1970 to 1980. He became area engineer for the southern part of the Levels when Phil Robinson retired in 1980.
Two dredging issues: • Tidal silts in the Parrett and Tone • Channels that feed the pumping stations, which are non-tidal. These are cleaned when required, possibly once every 6 to 10 years.
The present problem has arisen because of the lack of maintenance of the tidal reaches.
The tide brings silt in. When the flow stops, the water level is high and sediment drops out on the top of the banks in the areas of lowest velocity. The silt then provides a good location for vegetation formation, which traps further silt. The tidal silts extent as far upriver at the tidal limits. The sluices are penned for irrigation in the summer and there is little fluvial flow. In 1976/77 the river was heavily silted at Oath with a very small fluvial flow. In the winter the gates are raised to allow fluvial flow, which pushes the tide downriver. The tide may get as far as the confluence during normal river flows.
Water that is pumped into the river from the land has a low silt content because the silt has already settled in the flat drainage channels.
The Tone and the Parrett upstream of the tidal limits are flat and slow, and it is likely that sediment settles out. In fluvial floods the fluvial sediment does not seem to settle anywhere (and observations such as Ben's video indicate that the water is clear). Fluvial flows are likely to erode tidal silts.
The objective of the dredging was to keep the channels clear downriver of the three spillways (Hook Bridge, Allermoor and Beazleys).
The main area to dredge was from the tidal limits to Northmoor. Downriver of Northmoor, dredging was more difficult because of development etc., and it was less effective.
There is a question of whether to dredge to the spillways or to the tidal limits. In my view it should be the tidal limits.
The channel and flood banks u/s of the tidal limits are stable and little work was needed.

Agitation system used to maintain channels: • Dragline excavator with a 50-60ft jib which could reach across the channel, for areas where access was available. • Water jetting at locations where access was a problem. Agitation used because of the practical problems and costs of removing material. Peter described the recent dredging as an excellent public relations exercise, but very expensive.
The dragline was effective. This was shown by inspection of the dredged section at low water. It must be done when water is flowing downstream. It is difficult to see what you are doing when the water level is high.
The water jetting consists of engines and powerful hoses on wheels. Jetting was undertaken from the banks.
Agitation dredging was carried out in a downstream direction. It was normally carried out on the ebb tide in the summer when the water levels were not high and operatives could see what they are doing.

Consultation meeting with Damian McGettrick – WM Longreach

Bridgnorth, 06 April 2016

DM met with Damian McGettrick to discuss the recent maintenance dredging activity on the Parrett, from a Contractor's perspective.
DM enquired about any issues or challenges that the Contractor had faced during the works. DMc responded that access to land was sometimes an issue – and made planning of dredging works during operation more difficult. DMc suggested that better co-ordination / planning with land owners would be useful.
DMc suggested that key issue is where can the dredge material be disposed of? Material was put on the back of banks mainly with some being distributed across arable land. Wondered if this was sustainable in the longer-term.
DMc suggested that the survey profile interval at 50m was also a little large – as some patches between the profiles experienced sedimentation, which won't have been captured in the survey.
DMc noted that working from the river reduces production rate and increases costs significantly.
DMc was of the view that the material was not suitable for pumping – concern over tailwater and management of this water? Material seems to dry out quickly when dredged.
DMc no issues with water depth – although heard that issues with water depth during Pioneer work (had to build temporary weir to raise water levels). Current speeds did present problem – lost 3 weeks work. Quoted typical productively of 80 -100m^3/Hr.
DMc suggested that larger plant would have longer reach and therefore could work from 1 bank – this would improve productivity and access. However, ground pressure of bigger plant would require investigations –proving that bank failure was not a risk.
DM commented on use of 3D system to improve accuracy – DMc confirmed this, noting practical accuracy of 50mm

Consultation phone call with John Buttivant (EA)

07 April 2016

The proposed Parrett barrier will: • Keep high tides out of the estuary (John mentioned '7.5 or 8 m') • Be closed at low tide during fluvial events to provide a storage volume for fluvial floods • In addition the consultant will look at whether the barrier can be used to keep marine silt out of the system.
A full exclusion barrage has been rejected for several reasons including drainage, environment, cost, etc.
The barrier as planned at present will not close on normal spring tides.
DR said that we will inspect the Partrac data to understand better the mechanism for tidal silts entering the estuary (e.g. which tides, how much comes in, how much goes out, etc.).
There may also be HR Wallingford data on this, but it is all hard copy.
The EA consultant is CH2M Hill. Charles Schelpe is the technical review lead and Nigel Pontee has undertaken a geomorphological study. DR to contact CH2M Hill to discuss including checking that we are using the same reports and, if possible, obtain a copy of the geomorphological study report.
Andy Hohl is the EA project manager and was also the PM for the post 2013/14 works. (andy.hohl@environment-agency.co.uk)

Consultation meeting with Bill Gush (Regional Director) and Fiona Moore (Business Development Manager), Land and Water Services

Albury, 13 April 2016

DM began by explaining the scope of the study and that as part of the Consultation he would like to understand LAWS views with respect to dredging on the Parrett and Tone Rivers.
DM enquired with respect to LAWS thoughts on disposal options, noting that material was placed: • Back of bank (U1 / D1) • Spreading to confer benefit (U10) FM noted that material could be used to raise embankments – but planning permission would be required.
BG noted that the 8km dredge had created a large 'sump' in the middle of the river reach - contributing to trapping of sediment.
FM note that the development of a 'sump' or silt trap not a bad idea? – observed that there is plenty of land located near the M5 for widening the river. FM also noted that the siltation returned very quickly following 8km pioneer dredge and therefore, perhaps, near constant dredging would be required in this section?
FM noted that sensitive species (Hairy Click Beetle and Water Voles) were located around the confluence (Beetles) and only on the Tone (Voles). Recent survey for the 0.75km Pioneer dredge identified no voles.
DM raised the potential use of agitation technique. BG noted that it can't be dismissed, but the formation of the sediment is higher up the bank so equipment would need to be modified.
BG agreed with the observation that a 'little and often' would be a better approach to dredging than leaving it for extended period of time.
FM noted that LAWS had conducted a review of the EXO Environmental Report.
BG noted that ECI had taken place with SCC for dredging under Blake Bridge in Bridgewater – this was going to be WID technique and required licencing by the MMO.
BG confirmed the volume of the 8Km dredge was 132,000m^3
FM confirmed the volume of the next 0.75km Pioneer dredge was 13,000m^3
FM commented that there was delay in getting access to land.
Cost difference between the 8km and 0.75km related to use of floating plant and access issue – only 200m can be done from the bank side.
BG made the comment that should the 'whole catchment' be looked at in terms of managing the

water levels.
FM noted that lots of environmental monitoring was done during the 8km dredge

Consultation phone call with Andy Pitcher, AP Surveys.
14 April 2016

DM began by explaining the scope of the study and that as part of the Consultation he would like to understand AP survey's views on surveying (techniques) on the Parrett and Tone
DM asked about the technique used. AP stated it was an RTK attached to a pole (3.5m long) with a silt shoe attached with elevation measurements taken every 1-1.5m (horizontally).
AP noted that use of sonar might be better method, but not preferred by the IDB as concerns over the accuracy (+/- 100mm).
Originally quoted for 25m sections – but cost too much so reduced to 50m sections.
DM questioned how the bed is detected – AP agreed this is subjective, and dependent upon the pressure used on the Pole. To ensure consistency in approach AP has carried out all water based survey work where soft sediment is likely to be encountered.
DM questioned AP view on accuracy - on dry areas, 20-50mm might be reasonable, in water 50-100mm?? Difficulty with holding pole vertical during strong current flows.
DM asked for AP's views on use of MBES and Drone – AP agreed that 3D model would be much better. Potentially accuracy improved and would fill in gaps between sections. However, limitations with those survey techniques should be considered (i.e. vegetation affecting data / interpretation)
AP noted that analysis of the maintenance dredge using 3 methods identified volume differences of order 10% (2000m^3).
AP confirmed that material does build up on flanks of channel and there appears to be a difference between the pioneer and maintenance material. Although vegetation does return (grasses?) fairly quickly.
AP noted that bank stability is a concern – design profiles usually 1:2, sometimes 1:1.75 and wonders to what extent slumping contributes to the maintenance material?

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