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Royal Borough of Windsor & Maidenhead

FLOOD LIAISON GROUP

TUESDAY, 4TH JULY, 2017

At 6.00 pm

in the

ASCOT AND BRAY - TOWN HALL,

SUPPLEMENTARY AGENDA

PART I

ITEM	SUBJECT	PAGE NO
7.	ACTIONS FROM PREVIOUS MEETING To receive an update on actions carried out from previous meetings *Thames Bathymetric Survey report.*	3 - 78

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DRAFT REPORT REV 3

River Thames Bathymetric Data Analysis

Prepared for

Environment Agency

January 2016

Burderop Park
Swindon SN4 0QD
United Kingdom

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Acronyms and Abbreviations

GNSS	Global Navigation Satellite System
MBES	Multi Beam Echo Sounder
NGR	National Grid Reference
ODN	Ordnance Datum Newlyn
RMS	Root Mean Square
SBES	Single Beam Echo Sounder
SD	Standard Deviation
SHWL	Standard Head Water Level

1 Summary

Bathymetric surveys of all 44 reaches of the navigable non-tidal River Thames from the River Coln confluence upstream of Lechlade to Teddington Lock some 200Km downstream have been reviewed and compared with the aim of determining if there have been significant changes in channel bathymetry since wide scale dredging of the river ceased in 1998. A total of 94 individual surveys have been analysed in the study and the results are combined with a previous study in 2009 (44 surveys) to provide an assessment of all surveys since 1998.

Results

Over the complete period of the available surveys, the data do not show a clear trend of increasing average bed level (sedimentation) with time since reach dredging ceased in 1998.

For the full period of data available for each reach (9 to 20 years depending on the reach), most reaches (30 out of 40) show a net reduction in average bed level (increase in flow depth and conveyance) between the earliest and latest surveys.

For most reaches the average reach bed level has fallen in the first half of the period and then risen in the second half. However, there is considerable variation in the change in levels and the magnitude of many of the changes are within the range of uncertainty in the original survey data.

The surveys show that there has been a net increase in bed levels for all eight reaches from Rushey to Osney, for Bray reach and for Molesey reach (for Molesey reach the net increase in bed level is less than the range of uncertainty in the survey data).

The reaches from Rushey to Osney have only two surveys per reach and have the shortest history of survey data (9 years). From the data it is not possible to determine whether the net rise in level in the last 9 years is part of a longer term trend in increasing level. For half of these reaches the change in level is within the range of uncertainty in the original survey data.

Bray reach is immediately downstream of the diversion to the Jubilee River flood channel. The flow regime in this reach, together with Boveney and Romney reaches, has changed following the commissioning of the Jubilee River in 2002. A more detailed examination of the data available for these reaches does not indicate any trend of increasing or decreasing bed levels in these reaches since 2003.

Although the longer term net changes in reach bed levels and volumes are generally small relative to the range of uncertainty in the data, larger shorter term intermediate variations in average bed level have been recorded.

Within each reach the magnitudes of erosion and deposition vary both along and across the channel through the formation of pools and shoals or bars, even where there is no net change in reach bed volume. These features have the potential to obstruct navigation and may affect flow capacity.

Flood conveyance

A sample assessment of the change in channel cross-section conveyance resulting from changes in channel bed levels indicates a relative change of between around 3% and 7% in conveyance at flood level for a change in average bed level of 100mm, depending on the reach and flood level.

Due to the relatively low standard of protection along the river, the flow in the river channel during even low return period floods is only a part of the total flow along the river corridor. The variation in the overall conveyance of the river corridor at flood level as a result of changes to channel bathymetry is therefore less than the variation in conveyance of the channel cross-section itself.

Flood water levels depend on the conveyance of the channel and floodplain, the effects of structures such as bridges and the weirs and gates at the downstream end of each reach and variations in the river channel such as bends and flow splits around islands. The effect of these features on flood levels can be comparable to the channel conveyance and in order to determine the overall effect of any changes in channel cross-section conveyance on flood water levels, the effect of such features must also be considered.

Analysis of gauge records of water level and flow in one sample reach (Bray) for the period 2003 to 2015 indicates a similar magnitude of variation in channel conveyance to that estimated from the bathymetric surveys. This suggests that such gauges may be a useful means of monitoring changes in reach conveyance. Analysis of flow records for this reach suggests a degree of correlation between periods of low average flow, lower conveyance and higher bed levels and between periods of high average flow, increased conveyance and lower bed levels.

Navigation

The latest bathymetric surveys for the 40 reaches from Rushey to Teddington have been reviewed in relation to the published minimum depth of the navigation fairway at Standard Head Water Level. Locations in the navigation fairway where the water depth is less than the minimum have been identified. A total of 20 shoals where the water depth is below the minimum over part of the fairway have been identified and a further 41 shoals where the depth is within 300mm of the minimum and which may pose an obstruction in the near future have been identified (Table 7 and Appendix 6 to this report).

The shoals occur in 33 of the reaches. No shoals were identified in Godstow, Iffley, Caverhsam, Hambleden, Hurley, Boveney and Romney reaches. Most of the shoal locations are in lock cuts, the tails of locks or approaches to locks. These locations are vulnerable to persistent longer term deposition because they are areas of low energy and the river does not have the power to pick up and move the sediment. Other locations include bridges, meander bends and around islands. In these locations variations in river flow can result in the movement or removal of shoals as well as the formation of new shoals.

In 12 of the locations shoals were identified and targeted by the Environment Agency for removal following the surveys. In some of these locations it was found that in the time between the survey and commencement of the shoal dredging operation (six months), the shoals had eroded to the point that dredging was no longer required.

Dredging

A review of historic dredging records indicates that for the reaches from Hambleden to Teddington the historic average volume dredged per annual operation is similar to or less than the estimated maximum annual erosion and deposition volume recorded in the surveys. For Hurley, Temple, Cookham and Chertsey reaches the average dredge operation volumes are greater than the annual volumes of change but only three or four dredging operations are recorded.

For the reaches upstream of Hambleden the historic average volume dredged per operation is far greater than the maximum annual volume of change recorded in the surveys. For all of these reaches, except Marsh, only two surveys are available over periods of between 9 and 11 years and so the estimated annual volume changes from the surveys may underestimate actual annual rates to a greater degree than for the reaches with more frequent surveys.

The average volume of material removed from a reach in each historic annual dredge operation is equivalent to a depth of typically around 100mm to 150mm across the whole reach, comparable to many of the changes recorded by the bathymetric surveys and at the limit of certainty of the survey data. Exceptions are Rushey, King's, Godstow and Clifton reaches where an average depth of up to 400mm has been removed in a single operation.

The latest survey bed levels within the historic dredge zones of the fifteen reaches below Hurley Lock (Temple to Teddington) have been compared with the design dredge levels. For 35 of the 49 individual dredge zones, the average survey bed level within the zone is at or below the design level. Of the 14 zones where the average bed level is higher than the design level (located in Temple, Cookham, Bray, Boveney, Penton Hook, Chertsey, Sunbury and Molesey reaches), the difference in average bed level is within the range of uncertainty in the survey data in half the zones. The indicative dredge quantity for restoring the average bed levels to the historic dredge bed level in all 14 zones is around 80,000m^3 at an order of magnitude cost of around £6.5million. The resulting increase in channel conveyance at the winter 2014 flood level could be between 4% and 8% locally. However the overall increase in conveyance of each reach would be lower. This is within the range of natural variation in conveyance over the survey period in some reaches.

Strategy

- Flood conveyance

  The available bathymetric surveys do not show a clear trend of continually increasing bed volume and level with time over the period of the records.

  Many of the net changes recorded over the complete period of the data are less than or close to the confidence level in the data. However, where more frequent surveys are available these indicate that larger interim changes in bed level and volume can occur over shorter term periods (one year or less for example).

  The magnitude of the variations in reach bed volume recorded by the surveys and of the corresponding variations in channel flood conveyance are comparable to those resulting from historic dredging operations.

  The current cost of dredging in the lower reaches of the Thames is estimated to be of the order of £0.2million per Km for a 100mm average reduction in bed level and an average increase in channel cross-section conveyance of around 4% at 2014 flood levels, assuming the channel is dredged along the whole of a reach – an indicative cost of around £1million for Penton Hook reach for example.

  In order to remove periodic short term increases in bed level and maintain the river at a more constant bed level the data suggests that regular local dredging will be necessary in order to respond to natural variations in bed level.

  The costs and environmental impacts of making and maintaining substantially larger changes in bed level will be greater. Although the available surveys indicate that current bed levels are relatively stable, subject to short term variations, it is not possible to infer that a significantly reduced bed level would behave in the same way. Historically, the maximum reduction made in bed levels through the Thames and Mole Improvements Schemes in the 1960s and 1970s is understood to be approximately 300mm – equivalent to 6% of the channel flow depth in Staines at the 2014 flood level. The records suggest that outside of these schemes most dredging has been at the level of managing natural variations in bed levels rather than further increases in depth. There is therefore no historic evidence of the behaviour of the river following larger changes in bed level.

  Given the level of investment and environmental impacts involved in a strategy of closely maintaining a particular design level, an assessment of the benefits of such a strategy are needed in terms of the increase in standard of protection and flood damages avoided given the estimates of cost and conveyance benefit made in this study.

- Navigation

  The current strategy for shoal removal is successful in maintaining the navigation requirements of the river. For the latest surveys of the 40 river reaches between Teddington and Rushey only 20 shoals where the fairway depth is less than published depth have been identified in this study. Most of these shoals have already been investigated and removed where necessary. A further 41 locations where the depth is approaching the minimum navigation depth or the fairway width is narrow have been identified for future monitoring. It is evident however that clear marking of shoals and obstructions is important in some areas where the fairway width is limited and where shoals can migrate.

Limitations of the analysis

Interrogating the bathymetric data to identify any long term trends in changes to the river's morphology is limited by the nature and timing of the surveys. In particular:

i) For most reaches, a 'baseline' survey is not available to capture the bathymetry at the time that wide-scale reach dredging stopped in 1998. In some cases, a survey only took place up to 9 years after this date and in most reaches, the latest reliable record of reach dredging is earlier than 1998.

ii) In the case of seven of the fifteen lower reaches between Hurley and Teddington locks, the last reach dredge was earlier than 1987 (for some reaches, this is more than 10 years before the first available survey).

iii) The frequency of the surveys is relatively low - half the reaches have only two surveys per reach, spanning a varied time interval of up to 11 years.

iv) The surveys in different reaches are often in different years and at different times of the year and have not generally been made in response to particular flow events in the river. Only limited comparisons between different reaches can therefore be made.

v) The surveys do not cover the entire channel area. For a fair comparison between surveys, the area of analysis in each reach is limited to the common area of coverage for all surveys of the reach.

vi) The differences in channel bed levels between successive surveys are often less than or similar to the estimated level of uncertainty within the survey data. The accuracy and level of detail in the older surveys is less than the current surveys.

2 Scope

2.1 Need for study

The Environment Agency has powers to maintain public rights of navigation and manage flood risk, as well as a duty under the Water Framework Directive (WFD) to help protect and where necessary maintain river conditions with the aim of achieving good ecological status or good ecological potential. This includes protecting and restoring characteristic geomorphological processes, thereby protecting spawning fish and habitats under S2 (4) of the SAFFA (1975).

Historically, wide scale dredging of the River Thames was undertaken between 1932 and 1998 with the intention of maintaining navigation and maintaining or increasing flow conveyance. There is the possibility that the river bed levels have increased since 1998 through the deposition of sediment which may obstruct navigation and may increase flood risk. Since wide scale dredging stopped, the Environment Agency has carried out limited local dredging to removal shoals to achieve a balance between its statutory duties. In order to inform an appropriate maintenance strategy for the River Thames and to ensure that the Environment Agency complies with its statutory duties, evidence and an understanding of any changes in river bed levels due to ongoing geomorphological processes is needed.

The Lower Thames Dredging Study (Halcrow Group Ltd, 2009) analysed bathymetric survey data of the River Thames reaches from Temple to Teddington dating from 1995 to 2008. The present study will identify the changes in bed levels since the 2009 study and so extend the previous study results to provide evidence of the longer term changes in channel bed levels. The present study will also provide an assessment of the changes in bed level for all the navigable reaches of the river upstream of Temple, not included in the previous study. Figure 1 shows the study area and the location of the individual river reaches. Detailed maps are provided in Appendix 1.

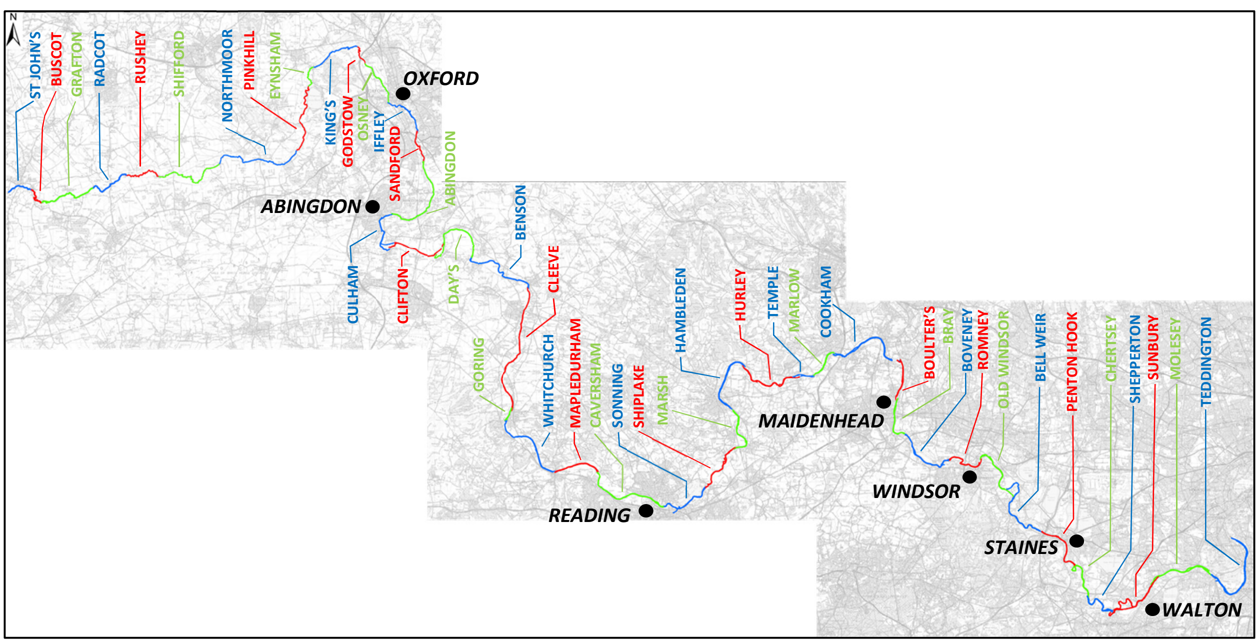


Figure 1. Study area

2.2 Objectives

The objectives of the study are:

1. Analyse current and historic bathymetric data, river flow data and dredging reports to determine how the River Thames reacts geomorphologically to varying flows.
2. Provide a detailed fluvial geomorphological analysis and interpretation of the data to provide an explanation of what is being presented, as far as the data allow.
3. Compare trends in erosion and deposition along the study reaches by comparing bathymetric surveys undertaken by the Environment Agency over the last 20 years to determine whether the river is self-scouring during flood events. This analysis of data will include reference to the results of the Lower Thames Dredging Study (2009). Determine whether there are areas of consistent build-up of deposition, where no evidence of self-scouring is present.
4. Suggest a programme of dredging, along with locations (should dredging be determined to be necessary) which will consider the requirements of flood risk management, water supply and navigation with the need to conserve biological diversity.
5. Provide an explanation of what can be seen from recent bathymetric data and the effectiveness of any recommended remedial measures.
6. Determine how much material has been transported through the reaches naturally and compare to historical dredged volumes and provide approximate costs of dredging this amount of material.
7. Provide a summary of river bed changes including net changes in bed level for cross sections on each reach from all available bathymetric surveys. Compare net and average changes in bed levels.
8. Use results from bathymetric surveys to evaluate degree of temporal patterns and downstream sedimentation. Compare temporal sedimentation patterns with river flow records for the study area.

3 Data

3.1 Data sources

The principal sources of data for the study are:

1. Bathymetric surveys
2. River flow gauge records
3. Previous studies and dredging records

3.2 Bathymetric surveys

3.2.1 Available data

Bathymetric surveys provide measurements of the river bed level referenced to the UK national level datum – Ordnance Datum Newlyn (ODN). Between April 2014 and June 2015 the Environment Agency undertook bathymetric surveys covering all 44 reaches of the River Thames from Inglesham (St John's Reach), the usual upper navigable limit of the river, to Teddington Lock, the limit of the Environment Agency's navigation authority. Maps showing the location of the reaches are provided in Appendix 1.

These surveys have been compared to previous surveys of each reach to determine the changes in river bed levels since wide scale maintenance dredging ceased. The dates and number of previous surveys available varies in each reach. For the reaches from Temple to Teddington, earlier surveys (dated up to 2008) were previously analysed in the Lower Thames Dredging Study (Halcrow Group Ltd, 2009). The results from that study are included in the present study but the data have not been re-analysed.

Three survey methods have been used to collect the data analysed in this study:

1. Pole and single beam echo-sounder
2. Single beam echo-sounder (SBES)
3. Multi beam echo-sounder (MBES or 'swath survey')

The method used depends on the reach and date of survey. Since 2003, all reaches below Radcot have been surveyed using the MBES or 'swath' method. Earlier surveys in these reaches have been surveyed using the SBES method. The upper four reaches (St John's to Radcot) are shallower and susceptible to weed growth which limits the survey method that can be used. To date all surveys for these reaches have been undertaken using a pole and single beam echo-sounder.

Table 1 shows the surveys considered in this study and the method for each survey. Further details of the individual surveys are provided in Appendix 2.

Table 1. Bathymetric Surveys

Available Data

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
St John's	Pole															Pole						Pole
Buscot			Pole													Pole						Pole
Grafton			Pole													Pole						Pole
Radcot						Pole										Pole						Pole
Rushey													MBES									MBES
Shifford													MBES									MBES
Northmoor													MBES									MBES
Pinkhill													MBES									MBES
Eynsham													MBES									MBES
King's													MBES									MBES
Godstow													MBES									MBES
Osney													MBES									MBES
Iffley											MBES											MBES
Sandford											MBES											MBES
Abingdon											MBES											MBES
Culham											MBES											MBES
Clifton											MBES											MBES
Day's											MBES											MBES
Benson											MBES											MBES
Cleeve											MBES											MBES
Goring											MBES											MBES
Whitchurch											MBES											MBES
Mapledurham											MBES											MBES
Caversham										MBES											MBES	
Sonning										MBES											MBES	
Shiplake										MBES											MBES	
Marsh										MBES							MBES				MBES	
Hambleden										MBES							MBES				MBES	
Hurley										MBES							MBES				MBES	
Temple		Analysed								Analysed					Analysed						MBES	
Marlow										Analysed					Analysed						MBES	
Cookham						Analysed				Analysed					MBES							MBES
Boulters									Analysed	Analysed					Analysed							MBES
Bray		Analysed								Analysed					Analysed							MBES
Boveney										Analysed					Analysed							MBES
Romney					Analysed						Analysed				Analysed							MBES
Old Windsor									Analysed	Analysed	Analysed			Analysed	Analysed		MBES	MBES	MBES	MBES	MBES	
Bell					Analysed				Analysed					Analysed	Analysed		MBES	MBES	MBES	MBES	MBES	
Penton Hook										Analysed				Analysed	Analysed		MBES	MBES		MBES	MBES	
Chertsey		Analysed							Analysed						Analysed						MBES	
Shepperton					Analysed				Analysed						Analysed						MBES	
Sunbury									Analysed						Analysed		MBES	MBES	MBES	MBES	MBES	
Molesey										Analysed				Analysed							MBES	
Teddington				Analysed						Analysed				Analysed							MBES	

Pole and echo-sounder SBES MBES Analysed in 2009 Study

3.2.2 Survey methods

3.2.2.1 Pole and Single Beam Echo Sounder

In this method a survey pole is used to physically detect the bed of the river from a boat. The relative position and level of the pole is surveyed from a ground based total survey station on the bank of the river. The position of the ground station is established using a GNSS (Global Navigation Satellite System) receiver. At locations where the water depth is too deep to use a pole, a Single beam Echo Sounder is used (see Section 3.2.2.2).

This survey method produces data comprising a set of discrete point elevations, usually along a line across the river channel (a cross-section of the channel). The interval between points usually varies but is typically around 1m. An example cross-section is shown in Figure 2.

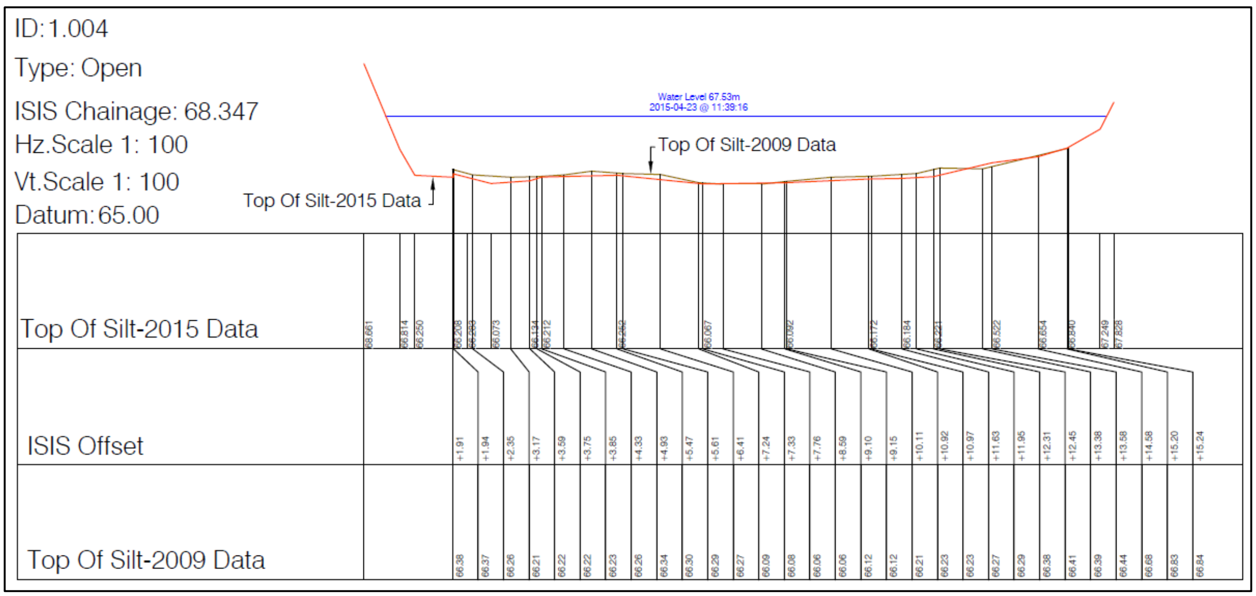


Figure 2. Example Processed Survey Data (Pole and SBES)

3.2.2.2 Single Beam Echo Sounder

This device emits a beam of sound vertically downwards to the bed of the river and measures the time taken for the echo from the river bed to return to the device, from which the depth of water is calculated. The position and level of the echo sounder is either surveyed from a ground based total survey station or obtained directly from an integrated GNSS receiver.

This survey method produces data comprising a set of discrete point elevations, usually along a line across the river channel (a cross-section of the channel) and at other locations if required, e.g. along the river centreline. The interval between points usually varies but is typically around 1m. A typical data set is shown in Figure 3.

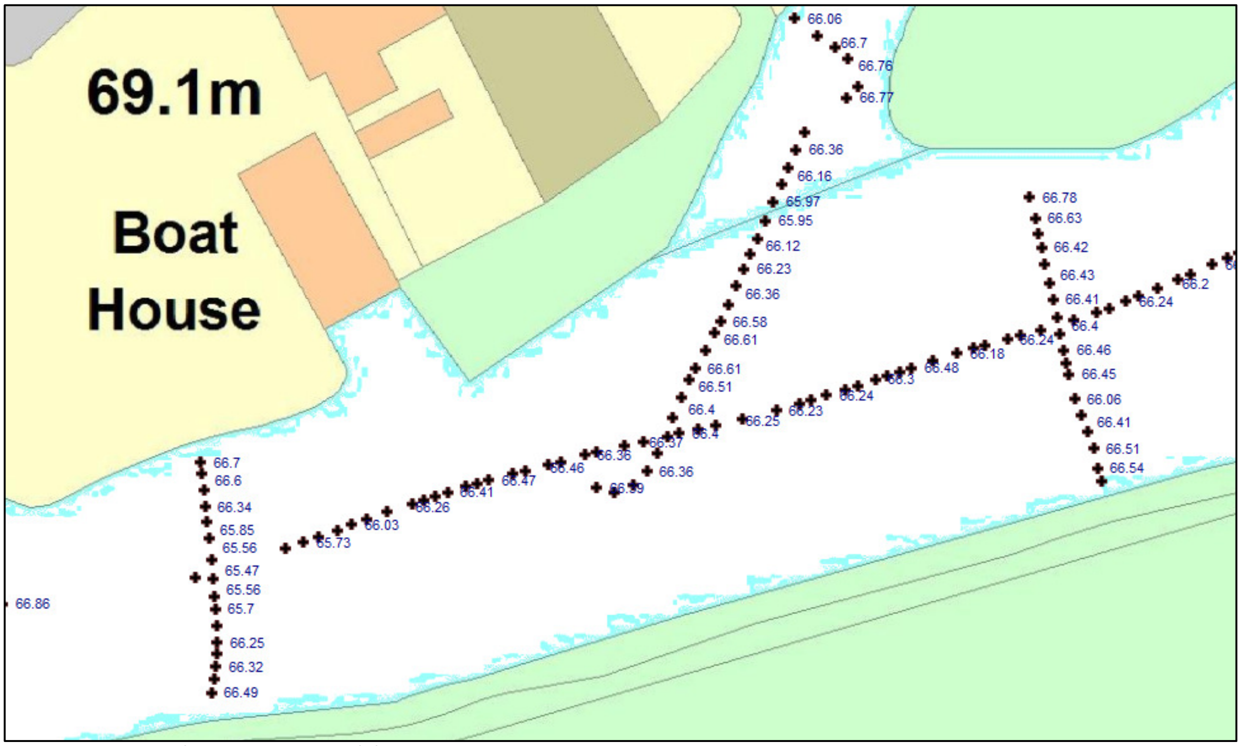


Figure 3. Example Processed Survey Data (SBES)

3.2.2.3 Multi Beam Echo Sounder

This system uses a large number of very narrow adjacent sound beams arranged in a fan-like swath of typically 90 to 170 degrees across. The array of beams provides very high angular resolution and accuracy. The system collects echo soundings over a wide area of the river bed. Attitude sensors allow for the correction of the boat's roll and pitch and a gyrocompass provides accurate heading information to correct for vessel yaw. A boat-mounted GNSS receiver is used to obtain the position of the receiver. Sound speed profiles (speed of sound in water as a function of depth) of the water column are used to correct for refraction or "ray-bending" of the sound waves owing to non-uniform water column characteristics such as temperature, conductivity, and pressure. Computer software processes the raw echo data, correcting for all of the above factors as well as for the angle of each individual beam. The data is used to produce a 'cloud' of raw point data of river bed elevation which can be further processed as required.

For the MBES surveys of the River Thames undertaken in 2014 and 2015, the typical density of points in the raw cloud data is typically between 150 and 250 points/m². The point data is used to produce a regular grid of elevation data at 0.5m horizontal intervals (point density of 4 points/m²) based on a triangulated surface model of the raw data. The processing system will interpolate across gaps in the cloud data of up to 2.5m. Gaps of a greater size are not filled and appear as a gap in the grid data. Typically such gap interpolation accounts for very little of the overall survey area for any given reach (less than 1%).

A typical data set is shown in Figure 4.

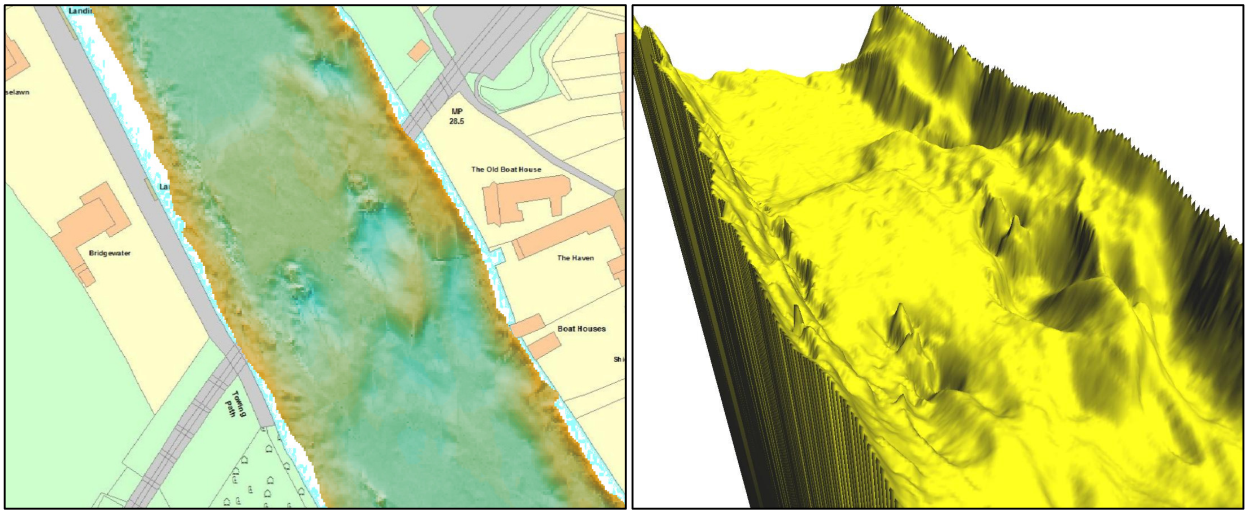


Figure 4. Example Processed Survey Data (MBES)

3.2.3 Survey data resolution

Each method of survey provides river bed levels at specified points in the river. The resolution, or density, of the bed level data varies between the different methods.

For the upper four reaches (St John's to Radcot), all the surveys are Pole and SBES surveys with cross-sections surveyed typically every 200m along the river and with data points typically every 1m across the river at each cross-section.

For the reaches downstream of Radcot, all the surveys analysed in this study are MBES surveys with elevation data provided in either a 0.5m or 1.0m horizontal resolution grid.

3.2.4 Survey data uncertainty

Potential sources of uncertainty in the data are as follows:

1. Pole and SBES
   - errors in GNSS position of control stations
   - errors in relative position measurement between control station and pole/SBES
   - uncertainty in locating bed level with foot of sounding pole
   - variations in speed of echo sounding in water column and spurious reflections (SBES)
   - survey vessel movements
2. MBES
   - errors in GNSS position of MBES/survey vessel
   - variations in speed of echo sounding in water column and spurious reflections
   - survey vessel movements
   - interpolation of output grid data from raw point cloud data

For the surveys undertaken in 2014 and 2015 an assessment of the potential uncertainty in the processed elevation data through 'ground truthing' is included as part of the survey deliverables. Due to improvements in survey equipment and GNSS technology the uncertainty in the older surveys is likely to be greater than in the most recent surveys.

3.2.4.1 St Johns to Radcot (Pole and SBES surveys)

For these reaches an indicative assessment of the uncertainty in the data has been made through a comparison of surveyed levels on 'hard structures' (bridge soffits for example) with previous survey levels and a comparison of surveyed water levels at each section along a reach.

The assessment indicates that the range of uncertainty in surveyed levels may be up to +/-0.20m.

3.2.4.2 Rushey to Teddington (MBES surveys)

For these reaches an independent SBES survey of sample bed levels has been made relative to ground based GNSS control stations. The sample bed levels have been compared to the processed MBES elevation grid data and a statistical analysis has been made of the level differences.

For the reaches from Rushey to Osney the mean difference in MBES and ground based survey levels and standard deviation (SD) of the differences have been provided. For the reaches from Iffley to Teddington the systematic difference in levels and Root Mean Square (RMS) of the differences are provided, as illustrated in Figure 5.

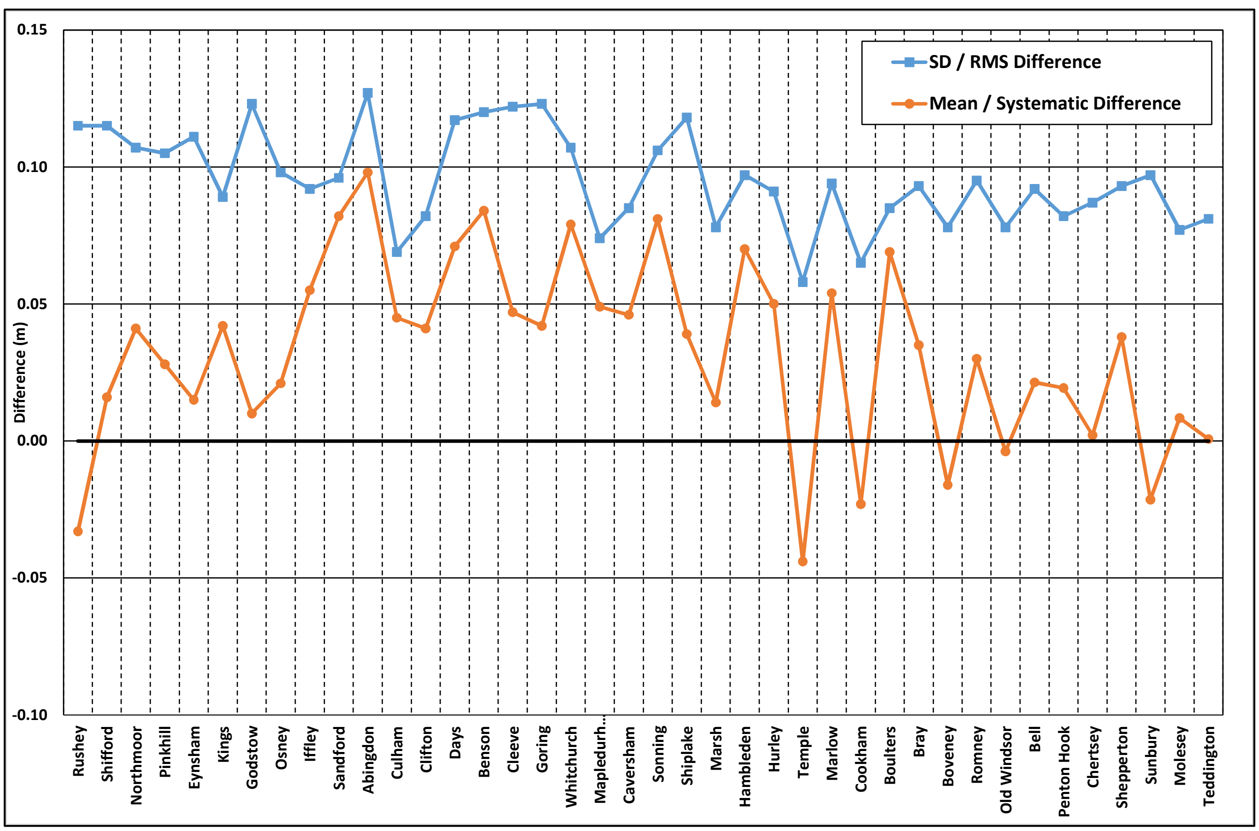


Figure 5. MBES Survey Ground Truthing Results

The SD or RMS of the differences is typically around 0.10m. Statistically, this means that 66.7% of the data can be expected to be within +/-0.10m of the true values and 99.7% of the data can be expected to be within +/-0.30m. The mean or systematic difference in levels is in the range -0.05m to +0.10m.

3.2.5 Confidence levels

The uncertainties in the individual bathymetric surveys should be considered when comparing surveys for the same reach taken at different times.

Ground truthing of the MBES surveys undertaken in 2014 and 2015 indicates a typical RMS error of 0.10m on absolute bed levels and average systematic errors of 0.05m for this type of survey on the River Thames.

In terms of the calculated difference in bed level between two surveys at any particular location, the RMS error of the differences in two surveys with individual RMS errors on absolute levels of 0.10m is approximately 0.14m. This means that 66.7% of the calculated differences in survey levels can be expected to be within +/-0.14m of the actual difference. Combined with the average systematic error of 0.05m, the confidence level in calculated differences in bed level between two surveys at any particular location is considered to be +/-0.2m for the MBES surveys.

In terms of the calculated difference between the average bed level for a whole reach, random errors in measurement are reduced to the mean or systematic error for the reach. Given the range of mean error identified in the 2014 and 2015 surveys (-0.05m to +0.10m), the confidence level in calculated differences in average reach bed level is considered to be not less than +/-0.1m for the MBES surveys.

Uncertainties in the Pole and SBES surveys of the upper four reaches have not been quantified statistically. However, spot checks on structural levels and surveyed water levels indicate that the uncertainty in river bed levels may be greater than for the MBES surveys of the other reaches. The cross-sections in the 2015 survey have been surveyed at the same locations as the 2009 survey (to within a specified tolerance of +/-3m, but generally closer). The cross-section locations in the earlier surveys do not always coincide with the later ones and there is reduced confidence in comparing some of these cross-sections.

3.3 Flow data

Table 2 lists the River Thames flow gauge data that have been considered in the study. The gauge locations are shown on the drawings in Appendix 1.

Table 2. River Thames flow gauge data

Gauge Name	Station ID	NGR	Date from	Date to
Cricklade	0190TH	SU0940194229	Jan 2004	May 2015
Eynsham	1200TH	SP4449908703	Jan 2004	May 2015
Farmoor	1100TH	SP43830673	Jan 2004	May 2015
Sutton Courtenay	1800TH	SU5170294623	Jan 2004	May 2015
Reading	2200TH	SU7180274065	Jan 1994	May 2015
Maidenhead	2604TH	SU90148138	Jan 2003	May 2015
Taplow*	2603TH	SU9045281950	Feb 2003	May 2015
Windsor	2700TH	SU98047724	Jan 1990	Dec 2014
Staines	2900TH	TQ03507133	Oct 1994	Dec 2014
Kingston	3400TH	TQ17786985	Oct 1994	May 2015

* Jubilee River

The mean daily flow at the gauges over the period of the bathymetric surveys has been used to assess the geomorphological response of the river to the variations in river flow.

3.4 Previous studies and dredging records

The following additional sources of information have been considered in this study:

1. Lower Thames Dredging Study, Final Report, Halcrow Group Ltd, July 2009

   - Assessment of river bed level changes for surveys prior to 2008 for the reaches from Temple to Teddington;

   - Summary of dredging records for reaches from Temple to Teddington (data obtained from 1998 study)

   - Dredging cost estimates

2. River Thames Dredging Study, Scoping Study, Final Report, July 1998

   - Details of design channel bed levels and geometry

   - Additional information regarding dredging of the Thames

3. Miscellaneous historic records of dredging for all reaches of the Thames between 1948 and 1974 (provided by the Environment Agency)

4. Records of shoal dredging in the Thames in 2014 (provided by the Environment Agency)

4 Methodology

To meet the objectives of the study the following methodology has been adopted:

1. Process all bathymetric survey raw data to a standard grid format and calculate differences in river bed level between successive surveys for each reach
2. Prepare results from difference calculations:

   - river bed volume differences

   - maximum, minimum and average river bed level differences for each reach and for sample cross-sections in each reach

   - produce 'river activity' plans for each reach showing areas and depths of erosion and deposition between surveys
3. Combine survey results with those from previous studies and review to identify any trends in bed level changes
4. Review survey results in conjunction with river flow hydrographs to assess response of the river to flow events
5. Prepare indicative assessment of impact of bed level changes on navigation and flood conveyance
6. Review and summarise environmental constraints to dredging
7. Review and summarise costs of dredging
8. Prepare preliminary assessment of any need for and scope of dredging and monitoring strategy

The latest surveys, undertaken in 2014 and 2015, have been delivered in three phases as follows:

Phase 1 : Old Windsor to Teddington

Phase 2 : Caversham to Romney

Phase 3 : St John's to Mapledurham

The surveys for each phase were processed on delivery. Individual technical reports of the analyses were prepared which have been compiled in Appendix 2 of this report.

4.1 Bathymetric survey processing

4.1.1 Pole & SBES cross-section data (St John's to Radcot)

The cross-section data have been processed using Microsoft Excel spreadsheets.

Due to the relatively large interval between the surveyed cross-sections for the upper four reaches (typically 200m), grid elevation data was not produced from the cross-section points due to the high degree of interpolation required between cross-sections. Similarly, the errors in estimating volumes from cross-sections at this spacing are considered to be too great to allow meaningful comparisons to be made between the surveys.

Inspection of the data shows that whilst the 2009 and 2015 cross-sections are generally located at the same positions, cross-sections from the earlier surveys do not always coincide and the difference in location can be 10m or greater. This does not allow meaningful comparisons to be made with the earlier surveys due to the variability of the river bed profile over this magnitude of distance.

For these reaches, comparisons have been limited to the 2009 and 2015 surveys and only at locations where the cross-sections coincide as follows.

1. Identify coinciding cross-sections for the 2015 and 2009 surveys for the reach
2. Calculate cross-section area and width at Standard Head Water level for each cross-section in each survey
3. Calculate average bed level at each cross-section from cross-sectional area and width at Standard Head Water Level and calculate differences in average bed level between surveys at each cross-section
4. Process raw numerical data to provide long section plots of the results
5. Produce river 'activity' plans showing location of cross-sections and change in average bed level at each cross-section from calculation results

4.1.2 MBES data (Rushey to Teddington)

Processing of the MBES survey data have been undertaken using ESRI ArcGIS (version 10.2) with the ESRI Spatial Analyst extension and ArcGIS Python and VBA scripts for additional calculations.

All survey data was supplied as unformatted 'XYZ' text data at varying horizontal resolution (0.5m to 2.0m) and grid offsets. In order to derive the require outputs, the data for each reach was processed as follows:

1. Raw unformatted text data converted to point shape file data
2. Point shape file data converted to raster format file at same horizontal resolution
3. Common area of survey polygon defined for all surveys in each reach and individual survey raster files clipped to the reach common area polygon
4. Grids of difference in bed level calculated for each pair of successive surveys together with summary statistical results based on a 0.5m regular grid (corresponding to highest resolution of source survey data)
5. Sample cross-section lines defined at 200m intervals along each reach river centreline
6. Statistical results calculated from each grid of bed level differences for each cross-section line for long section information
7. Raw numerical data processed to provide summary tables, charts and long section plots of the results
8. Contoured river 'activity' plans produced from grids of bed level difference for each grid.

5 Results

5.1 Overview

The changes in channel bathymetry between surveys for each reach are presented as follows:

i) net change in reach bed volume – the absolute net volume of material eroded or deposited in the reach as a whole between the survey dates (MBES surveys only - Rushey to Teddington)

ii) change in average reach bed level – the net change in volume expressed as the change in average bed level over the reach to allow the change to be more readily understood in terms of its significance in relation to channel flow depth and to allow results for reaches of varying length and area to be compared directly (MBES surveys only - Rushey to Teddington);

iii) change in average bed levels calculated along cross-section lines at 200m intervals along the reach – to provide an indication of the variation in change along the length of the reach (all reaches);

iv) change in bed levels at all points in the survey data – presented as plans showing the spatial distribution of bed level changes over the whole area of the reach (MBES surveys only - Rushey to Teddington, for other reaches average change at cross-sections are shown).

The net change in average bed level over the complete period of the surveys and the maximum and minimum changes in average bed level for all surveys for a reach are listed in Table 3. Positive changes indicate deposition (increase in bed level) and negative changes indicate erosion (reduction in bed level). Figure 6 illustrates the results in terms of the variation in average depth of water at SHWL.

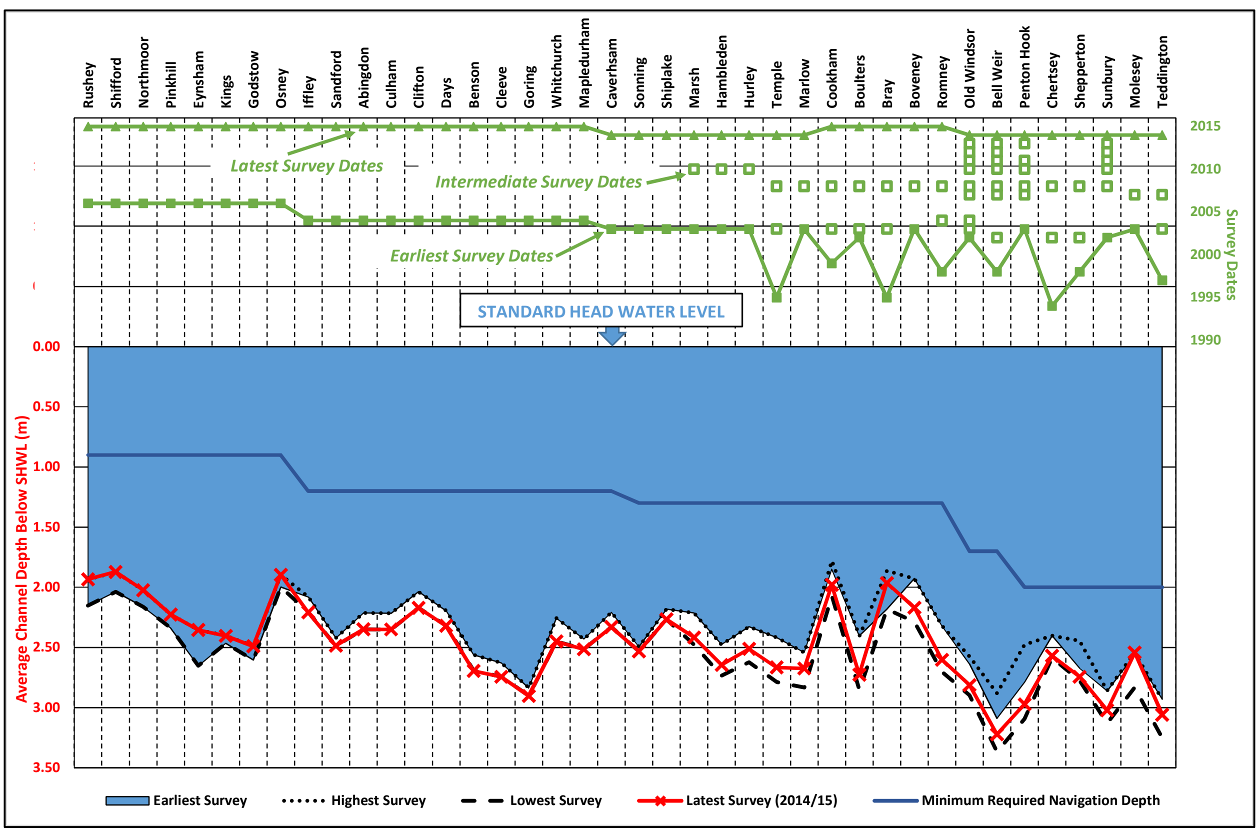


Figure 6. Summary of average reach bed level changes

Table 3. Summary Results of Bathymetric Surveys

Reach	Surveys Earliest	Surveys Latest	Total Period of Record (years)	Net change in average bed level over period of record (m)	Total number of surveys for reach	Range of changes in average bed level over period of record (m) Maximum	Range of changes in average bed level over period of record (m) Minimum
Rushey	2006	2015	9	**+0.22**	2	**+0.22**	*
Shifford	2006	2015	9	**+0.17**	2	**+0.17**	*
Northmoor	2006	2015	9	**+0.14**	2	**+0.14**	*
Pinkhill	2006	2015	9	**+0.11**	2	**+0.11**	*
Eynsham	2006	2015	9	**+0.30**	2	**+0.30**	*
King's	2006	2015	9	+0.06	2	+0.06	*
Godstow	2006	2015	9	**+0.11**	2	**+0.11**	*
Osney	2006	2015	9	+0.10	2	+0.10	*
Iffley	2004	2015	11	**-0.13**	2	*	**-0.13**
Sandford	2004	2015	11	-0.06	2	*	-0.06
Abingdon	2004	2015	11	**-0.14**	2	*	**-0.14**
Culham	2004	2015	11	**-0.13**	2	*	**-0.13**
Clifton	2004	2015	11	**-0.13**	2	*	**-0.13**
Day's	2004	2015	11	**-0.13**	2	*	**-0.13**
Benson	2004	2015	11	**-0.13**	2	*	**-0.13**
Cleeve	2004	2015	11	**-0.12**	2	*	**-0.12**
Goring	2004	2015	11	-0.07	2	*	-0.07
Whitchurch	2004	2015	11	**-0.19**	2	*	**-0.19**
Mapledurham	2004	2015	11	-0.09	2	*	-0.09
Caverhsam	2003	2014	11	**-0.12**	2	*	**-0.12**
Sonning	2003	2014	11	-0.04	2	*	-0.04
Shiplake	2003	2014	11	-0.08	2	*	-0.08
Marsh	2003	2014	11	**-0.20**	3	**-0.20**	**-0.26**
Hambleden	2003	2014	11	**-0.17**	3	**-0.17**	**-0.26**
Hurley	2003	2014	11	**-0.18**	3	**-0.18**	**-0.29**
Temple	1995	2014	19	**-0.25**	4	-0.08	**-0.37**
Marlow	2003	2014	11	**-0.13**	3	**-0.13**	**-0.29**
Cookham	1999	2015	16	**-0.13**	4	+0.07	**-0.22**
Boulters	2002	2015	13	**-0.32**	4	**-0.22**	**-0.45**
Bray	1995	2015	20	**+0.22**	4	**+0.32**	0.00
Boveney	2003	2015	12	**-0.24**	3	**-0.24**	**-0.36**
Romney	1998	2015	17	**-0.28**	4	-0.10	**-0.38**
Old Windsor	2002	2014	12	**-0.18**	10	+0.06	**-0.26**
Bell Weir	1998	2014	16	**-0.13**	9	**+0.21**	**-0.28**
Penton Hook	2003	2014	11	**-0.18**	7	**+0.31**	**-0.31**
Chertsey	1994	2014	20	**-0.17**	4	-0.07	**-0.18**
Shepperton	1998	2014	16	-0.07	4	**+0.23**	-0.10
Sunbury	2002	2014	12	**-0.16**	7	**-0.12**	**-0.27**
Molesey	2003	2014	11	+0.02	3	+0.02	**-0.27**
Teddington	1997	2014	17	**-0.13**	4	**-0.13**	**-0.32**

(shaded)	Indicates increase in average bed level
*	Indicates only two surveys available – single calculation of change
BOLD	Indicate results greater than data uncertainty range

Figure 7 shows the bed levels for each survey in terms of the average reach bed level relative to the latest surveyed level. There is no common date for the first survey for each reach but the latest surveys have all been collected within a period of eleven months, providing a closer common reference point in time for all the reaches.

Over the complete period of the surveys, the data do not show a clear trend of increasing average bed level (sedimentation) with time since reach dredging ceased in 1998.

For the full period of data available for each reach (9 to 20 years depending on the reach), most reaches (30 out of 40) show a net reduction in average bed level (increase in flow depth) between the earliest and latest surveys.

For most reaches the average reach bed level has fallen in the first half of the period and risen again in the second half. However, there is considerable variation in the change in levels and the magnitude of many of the changes are within the range of uncertainty in the original survey data.

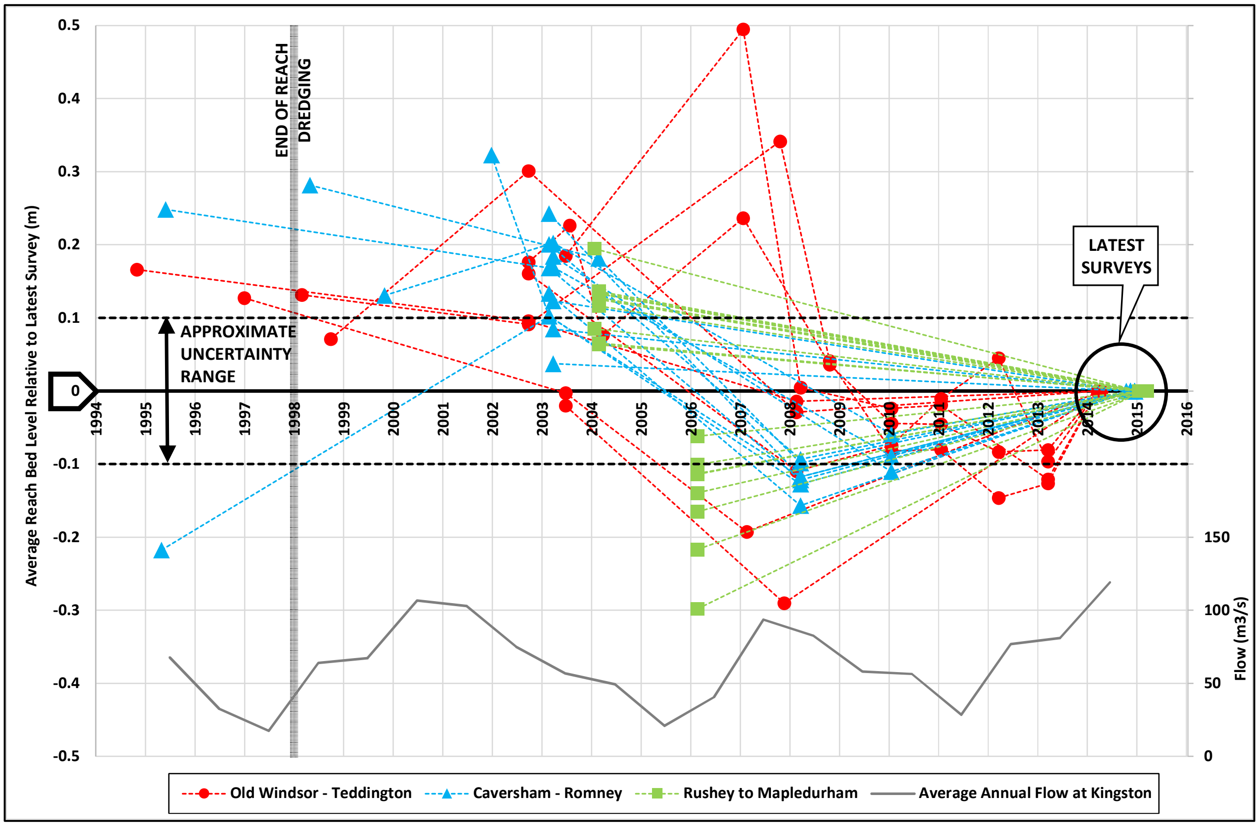


Figure 7. Average reach bed levels for all reaches since end of reach dredging relative to current level

Net increases in bed level are recorded for all eight reaches from Rushey to Osney, for Bray reach and for Molesey reach.

The reaches from Rushey to Osney have only two surveys per reach and have the shortest period of record (9 years). From the data it is not possible to determine whether the rise in level in the last 9 years is part of a longer term trend in increasing level. For half of these reaches the change in level is within the range of uncertainty in the original survey data.

Bray reach is immediately downstream of the diversion to the Jubilee River flood channel. The flow regime in this reach, together with Boveney and Romney reaches, has changed following the commissioning of the Jubilee River in 2002. The change in flow regime may result in changes to the sediment processes in these reaches. The data for these reaches are examined further in Section 5.2.

For Molesey reach the net change in bed level is 0.02m which is less than the range of uncertainty in the survey data.

Although the net changes in reach bed levels and volumes are small relative to the range of uncertainty in the data, larger shorter term variations in average bed level have been recorded.

Within each reach the magnitudes of erosion and deposition vary both along and across the channel through the formation of pools and shoals or bars. These features may have the potential to obstruct navigation or affect flow capacity even where there is no net change in reach bed volume.

A complete tabulation of results, long section plots and a commentary for each reach are provided in Appendix 2, grouped according to the 2014 and 2015 survey campaigns as follows:

- Phase 1 : Old Windsor to Teddington
- Phase 2 : Caversham to Romeny
- Phase 3 : St John's to Mapledurham

Reach activity plans showing the spatial distribution of changes in each reach between each pair of successive surveys are provided in Appendix 3.

5.2 Geomorphology

5.2.1 Overview

River channel form is determined by the balance of sediment supply and water supply to the channel. Under conditions of stable sediment and water inputs, the river channel works towards creating a morphology that efficiently carries water and sediment downstream. However, in reality inputs of water and sediment are never stable, and this leads to changes in channel morphology to adjust to supply. As a result, bed features form and reform in response to short term variations in sediment supply and flow (a flood, for example) but remain stable within limiting thresholds of change. If a progressive or sudden change occurs in either the sediment supply or flow regime, the channel will try to adjust to this by altering its planform and/or bed morphology in response to the new regime, but this response will not necessarily be immediate (Thorne et al, Knighton).

It is expected that the largest changes in bed form and level (both erosion and deposition) will occur under the highest flows when the river has more energy to be able to pick up sediment from the bed and banks and transport this sediment downstream, as well as a greater volume of sediment entering the river from tributaries and runoff. It would also be expected that the upper catchment would be a source of sediment, with transport through the middle and deposition downstream.

For over 200 years the water level in the River Thames has been formally regulated above the natural depth for the average gradient of the river for the purposes of navigation and milling. Water levels are controlled by a combination of fixed crest weirs and moveable sluice gates. As well as maintaining water levels these structures act to regulate the movement of sediment in the Thames, and therefore the ability of the river to erode and transport material. At higher flows these structures have less effect on water levels but can still present an obstruction to flow and downstream sediment transfer. In addition to these structures, numerous bridge crossings and side channels also alter flow patterns and sediment supply. Engineered walls and embankments along the channel act to fix its position, restricting lateral channel adjustment and sediment supply to the channel. These also act to increase the discharge of the channel during high flow events by preventing the storage of water (and sediment) on the floodplain.

The principal direct interventions in the river regime in recent times have been the commencement (in around the 1930s) and subsequent cessation (in 1998) of large scale dredging campaigns of river reaches and the commissioning of the Jubilee River flood diversion channel in 2002.

Historically, dredging of the River Thames has been a combination of wide scale reach dredging to increase or maintain flow conveyance and shoal removal to maintain navigation depths. Since 1998 only local shoal removal for navigation has been undertaken. The total volume of dredged material for the whole of the river in 2014 was approximately 7,000m^3 compared to around 60,000m^3 per annum between 1946 and 1975 and around 28,000m^3 per annum in the 1990s. However, dredging records are incomplete and vary in detail between reaches and time periods and therefore the exact quantities, locations and timing of all the historic dredging in each reach are not clear. Complete and reliable records are only available for the period since 1987.

Since 2002, flow has been diverted to the Jubilee River flood relief channel once the flow in the Thames upstream of Maidenhead exceeds around 180m^3/s (subject to a maximum diversion of 180m^3/s). The diverted flow is returned to the Thames downstream of Romney weir, thereby reducing the frequency and duration of higher flows in the Bray, Boveney and Romney reaches. The Jubilee River has been operated for 26 separate periods of high flow in the last 13 years.

5.2.2 Limitations

Interpretation of the bathymetric data and confidence in identifying any long term trends in changes to the river's morphology from the data, for example as a result of the cessation of dredging or changes in flow regime, are limited by the nature of the data.

i) For most of the reaches, surveys are not available at the date of cessation of wide scale reach dredging (1998 at the latest). The first surveys for some reaches are up to 9 years after this date, representing 30% of the time period from 1998 to the most recent survey. This means the baseline state of the reach at the end of the dredging period is not generally available. For most reaches, the most recent reliable record of wide scale reach dredging is earlier than 1998 – for seven of the 15 lower reaches between Hurley and Teddington locks, the last reach dredge was earlier than 1987, the earliest date from which reliable occurs are available and more than 10 years before the first available survey for some reaches.

ii) The differences in bed volumes between surveys will include any volume removed from the river by dredging. This has not been corrected for in the results due to a lack of records in the period since wide scale dredging ceased. However based on the total shoal dredge volume for 2014 of 7,000m^3, this difference is well within the range of uncertainty in the survey data.

iii) The frequency of the surveys is relatively low - half the reaches have only two surveys per reach, spanning a time interval of up to 11 years.

iv) The surveys in each reach are often at different dates and have not generally been made in response to particular flow conditions in the river.

v) The surveys do not cover the entire channel – areas of shallow water where navigation is not possible and the channel beneath obstructions such as pontoons and moored vessels are excluded. The area of coverage varies between individual surveys of a reach. For a fair comparison between surveys of a reach at different dates, the area of analysis in each reach is limited to the common area of coverage for all surveys of the reach.

vi) The differences in channel bed levels between successive surveys are often less than or similar to the level of uncertainty in the source survey data.

vii) Surveys prior to 2002 were not undertaken by the MBES method. For these surveys the data comprises SBES cross-sections, typically at 50m intervals. The volume and average bed level differences were calculated from these surveys in a previous study (Lower Thames Dredging Study, July 2009) and are included in this report. The uncertainty in the differences between the older surveys is likely to be greater than between the latest MBES surveys.

5.2.3 River scale changes

The changes in average reach bed level, which are representative of the net volumes of erosion and deposition in each reach, have been compared to the river flow over the period of the surveys for all the reaches in the study.

There is no common date for the first survey for each reach and the first survey dates vary between 1995 and 2006. However, the latest surveys have all been collected within a period of eleven months, providing a closer common reference point in time for all the reaches. Reach results have therefore been considered in terms of the average reach bed level relative to the latest surveyed level.

The average absolute systematic error estimated from ground truthing of the latest surveys is 40mm. The uncertainty range in differences in average bed levels between surveys is therefore considered to be around +/-100mm.

5.2.3.1 Old Windsor to Teddington

Figure 8 shows the results for the reaches in Phase 1 of the latest survey campaign (Old Windsor to Teddington, at the downstream end of the study area) together with the daily flow, annual mean flow and long term mean flow at the Kingston gauge in the Teddington reach. The frequency of surveys is greatest for these reaches with up to 10 surveys available for individual reaches. There is however a gap of four years in the surveys between October 1998 and October 2002, a period of higher than average flows and a gap of almost three years between April 2004 and February 2007, a period of lower than average flows. Connecting lines are shown between successive surveys for a reach to help indicate the direction of change for each reach but this does not imply a uniform change in bed level between surveys.

Historic average bed levels are mainly within +/-100mm of the latest surveys. Prior to the January 2003 flood, bed levels were generally higher than current levels. Over the lower than average flow period between 2003/2004 and 2007, net increases in bed levels of up to 300mm are recorded for Old Windsor, Bell Weir and Penton Hook reaches while net reductions in bed levels of up to 300mm are recorded for Molesey and Teddington reaches. The difference in timings of the surveys in 2007 in relation to the high flows at the start of the year may partly explain this difference in behaviour. The surveys for Old Windsor and Penton Hook were collected in February, prior to the high flow in early March whereas the Teddington and Molesey surveys were collected in March and December. However, the Bell Weir survey of November 2007 shows a higher level than the previous survey in 2003. Although the data is limited, it appears that the combination of the period of lower than average flows from 2003 to 2006 followed by higher than average flows in 2007 and 2008 have resulted in more activity in these reaches than in other time periods.

Between 2008 and 2014 the average bed level in most reaches has changed very little. Molesey and Teddington reaches, at the downstream end of the study area and at the limit of the fluvial section of the Thames, both show increases in level between 2007 and 2014 of 300mm and 200mm respectively. However since no intermediate surveys exist, the timing of changes over the period are not known. For reaches where surveys are available in early 2013 (Old Windsor, Bell Weir, Penton Hook and Sunbury), an increase in average bed level of around 100mm is recorded, within the range of data uncertainty.

Analysis of additional cross-section surveys at the Staines flow gauge in Penton Hook reach (see Section 5.3.1 and Appendix 4) indicate that changes in average level can occur more rapidly than the reach bathymetric surveys suggest. Figure 9 shows the average reach bed levels for Penton Hook from the bathymetric surveys and the average bed level at the Staines flow gauge for 2007 and 2008. The additional survey at the gauge site in November 2007 shows a reduction in average bed level at that location of 400mm between November 2007 and April 2008 although this may not necessarily be reflected in a similar change for the whole reach over this period.

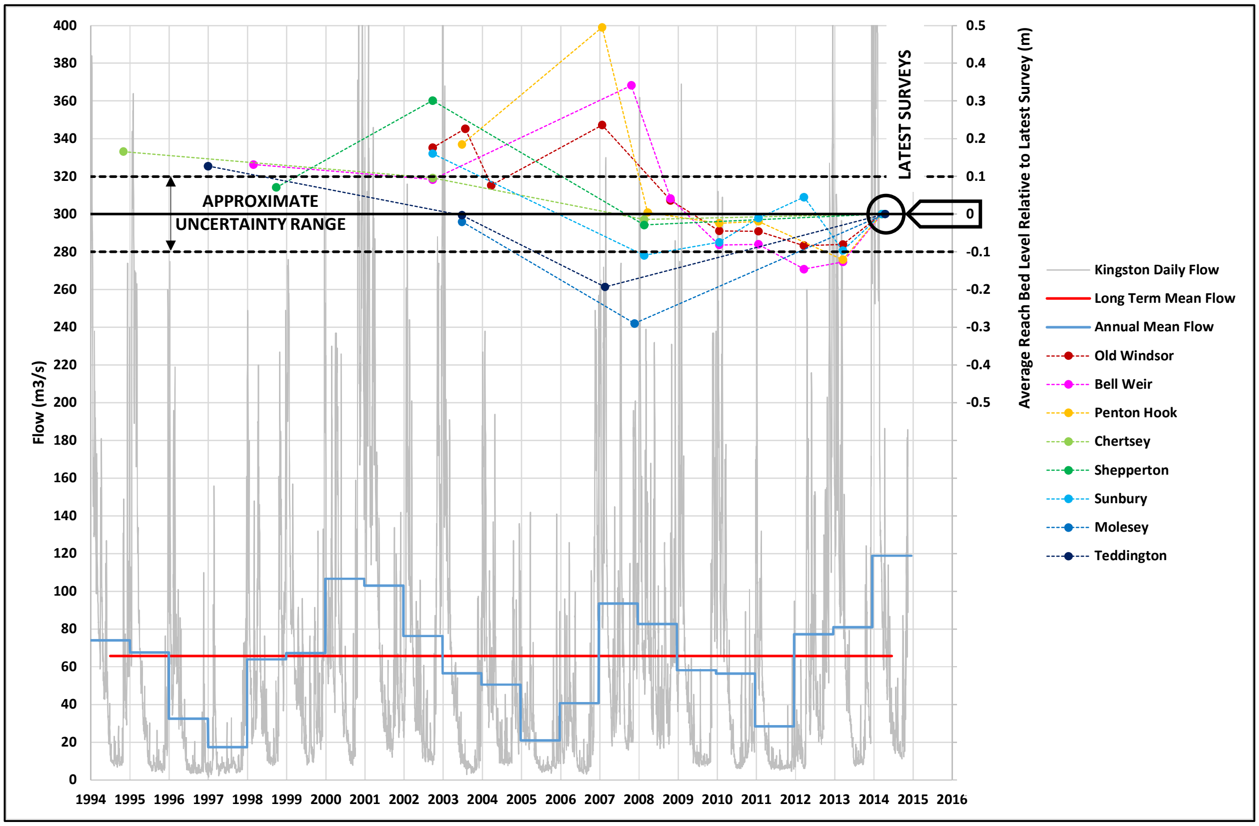


Figure 8. Changes in reach bed level and river flow (Old Windsor to Teddington)

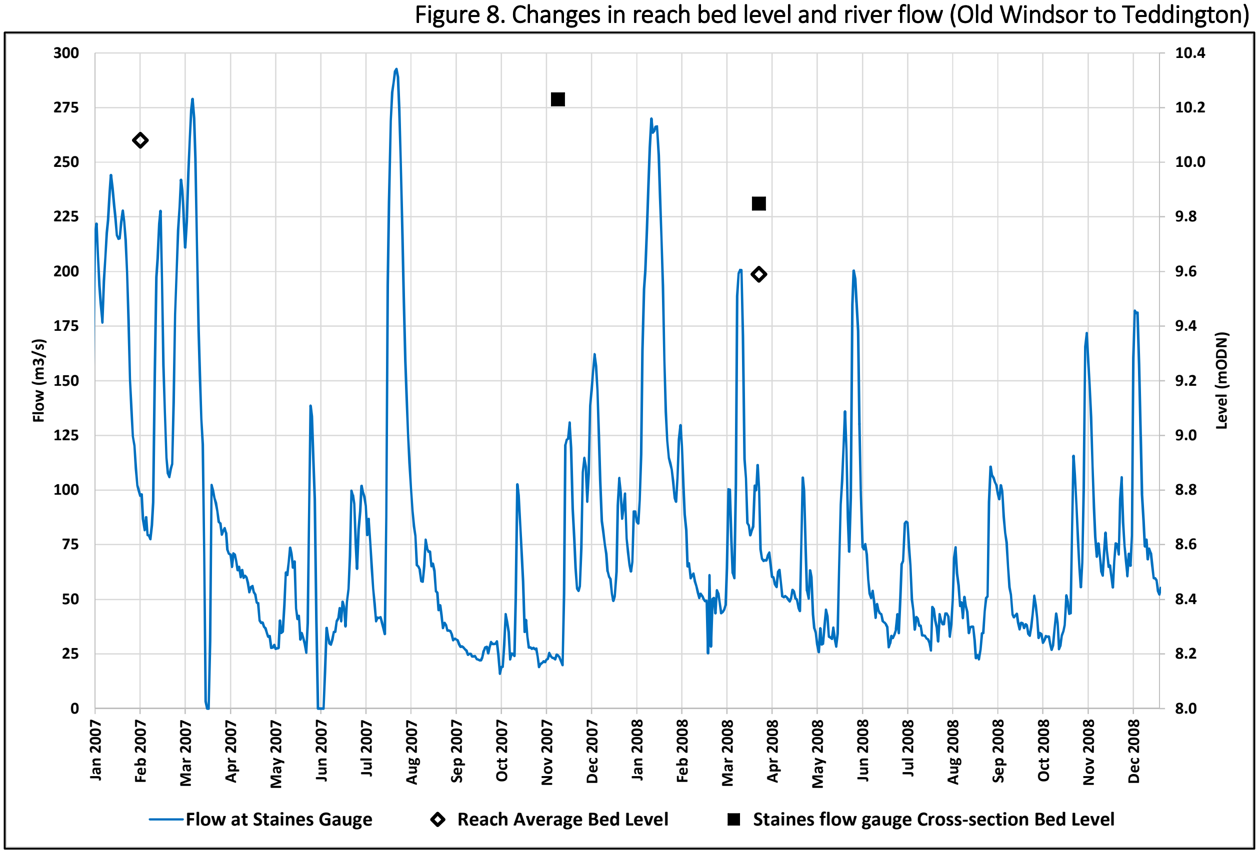


Figure 9. Changes in bed level and river flow (Penton Hook reach and Staines flow gauge)

5.2.3.2 Caversham to Romney

Figure 10 shows the results for the reaches in Phase 2 of the latest survey campaign (Caversham to Romney) together with the daily flow, annual mean flow and long term mean flow at the Reading gauge in the Caversham reach. The results for the Phase 1 reaches are included for comparison. The frequency of surveys is not as great as for the Phase 1 reaches. Up to 4 surveys are available for individual reaches but only two surveys are available for Caversham, Sonning and Shiplake reaches.

Although there are larger gaps in the data and the differences in bed level are not much greater than the range of uncertainty, the results are generally consistent with those for the Phase 1 reaches: bed levels prior to 2004 are generally higher than current levels and bed levels in 2008 and 2010 are generally lower than current bed levels. The exception is Bray reach which shows a net increase in level between the earliest survey (1995) and the latest survey (2015) of 200mm. In common with other surveys before 2002, the 1995 survey for Bray is an SBES cross-section survey and there is greater uncertainty in comparing the average bed level from this survey to the subsequent 2003 MBES survey. The potential impact of the Jubilee River on this reach is discussed further in Section 5.2.5.

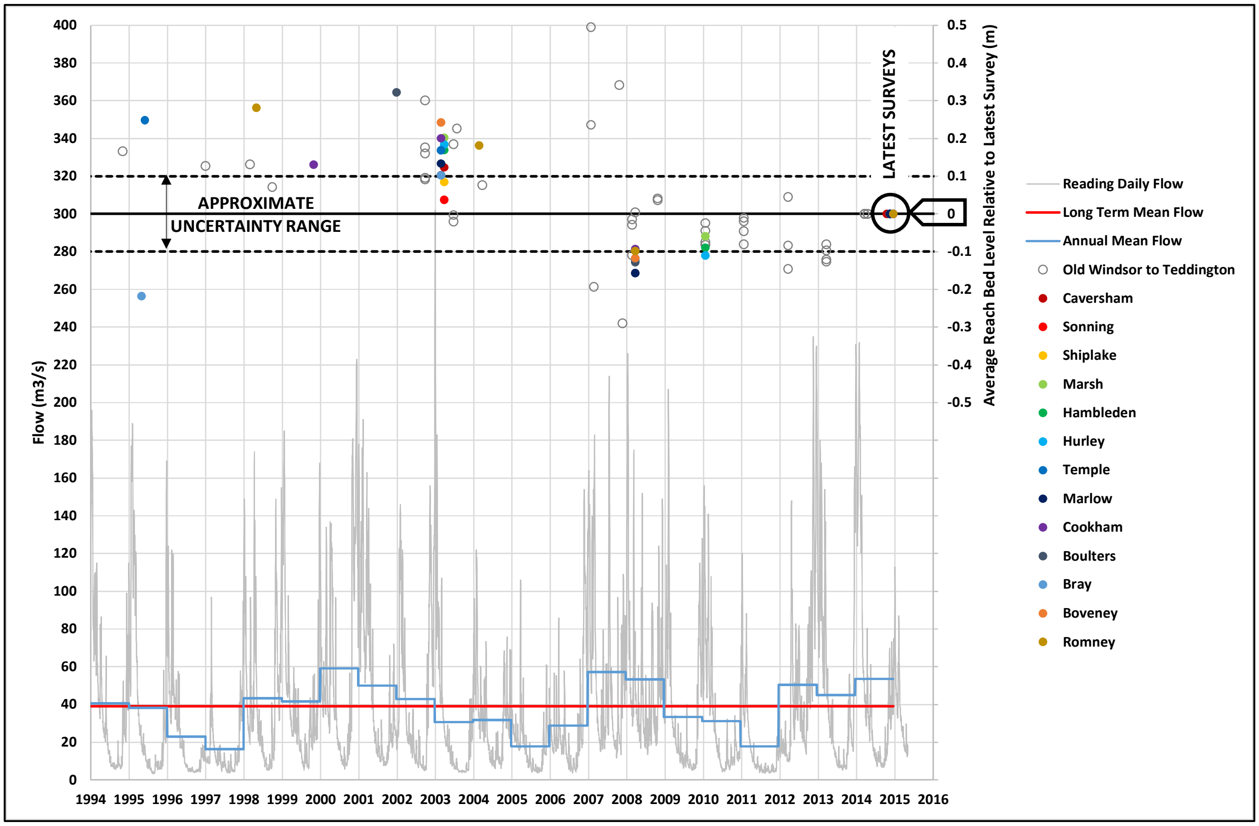


Figure 10. Changes in reach bed level and river flow (Caversham to Romney)

5.2.3.3 Iffley to Mapledurham

Figure 11 shows the results for the reaches downstream of Oxford (Iffley to Mapledurham) in Phase 3 of the latest survey campaign together with the daily flow, annual mean flow and long term mean flow at the Sutton Courtenay gauge in the Clifton reach. The results for the Phase 1 and Phase 2 reaches are included for comparison. Only two surveys are available for each reach, collected in 2004 and 2015.

Although there are no intermediate surveys between the 2004 and 2015 surveys, the results are generally consistent with those for the Phase 1 and Phase 2 reaches in that the 2004 bed levels are all higher than the current levels, although the difference in level for some reaches (Sandford, Goring and Mapledurham) is within the range of uncertainty.

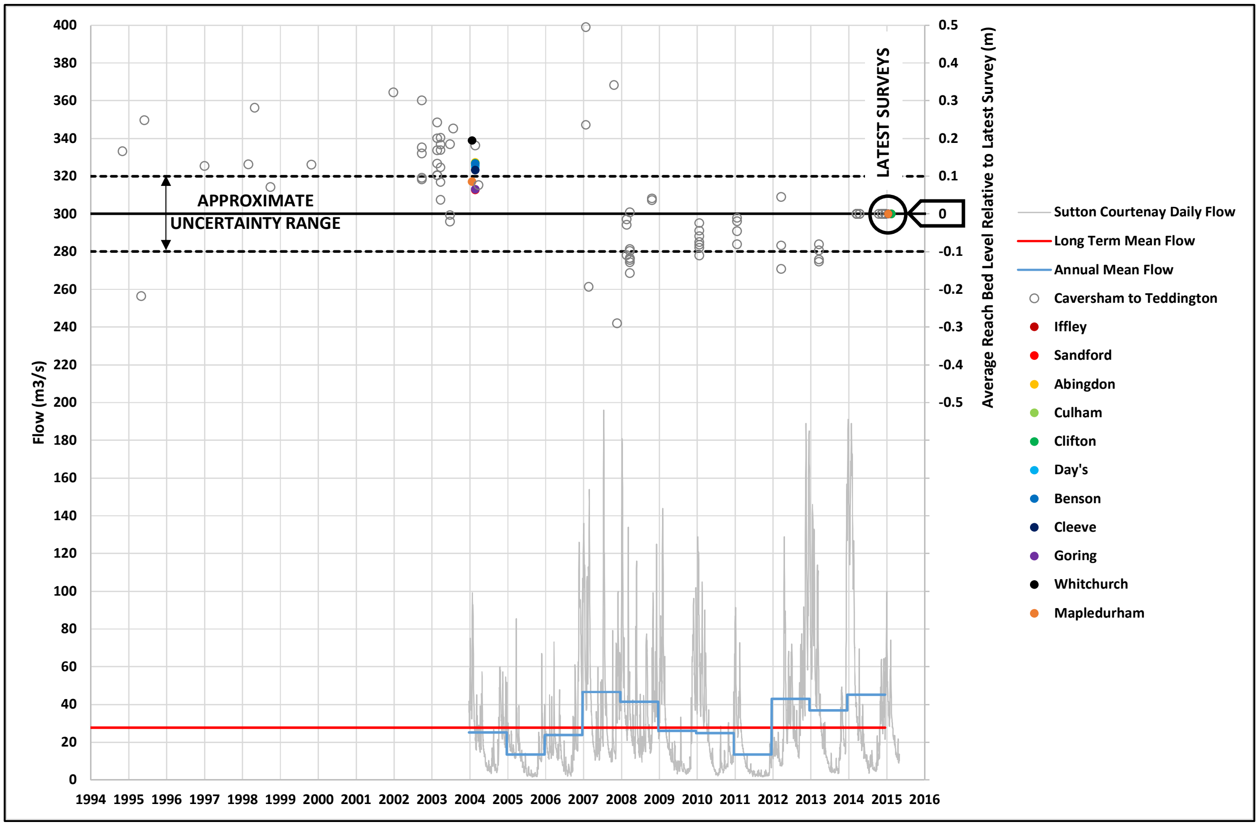


Figure 11. Changes in reach bed level and river flow (Iffley to Mapledurham)

5.2.3.4 Rushey to Osney

Figure 12 shows the results for the reaches upstream of Oxford (Rushey to Osney) in Phase 3 of the latest survey campaign together with the daily flow, annual mean flow and long term mean flow at the Farmoor gauge in the Pinkhill reach. The results for the Phase 1, Phase 2 and Phase 3 reaches downstream of Oxford are included for comparison. Only two surveys are available for each reach, collected in 2006 and 2015.

No surveys are available in any of the other reaches between 2004 and 2007 and therefore the results for these reaches cannot be compared directly with others. The results show some consistency with a general trend of increases in bed level since 2008 in the other reaches (up to 300mm for of Molesey). For four of the eight reaches, the difference in bed level between 2006 and 2015 is less than or similar to the level of uncertainty in the data. The reaches above Oxford are generally the least constrained sections of the river and show evidence of active meandering. The greater degree of planform activity may result in greater transient variations in average bed level (or reach volume). The data for Eynsham reach, which shows the largest change in average bed level is illustrated further in Section 5.2.4.

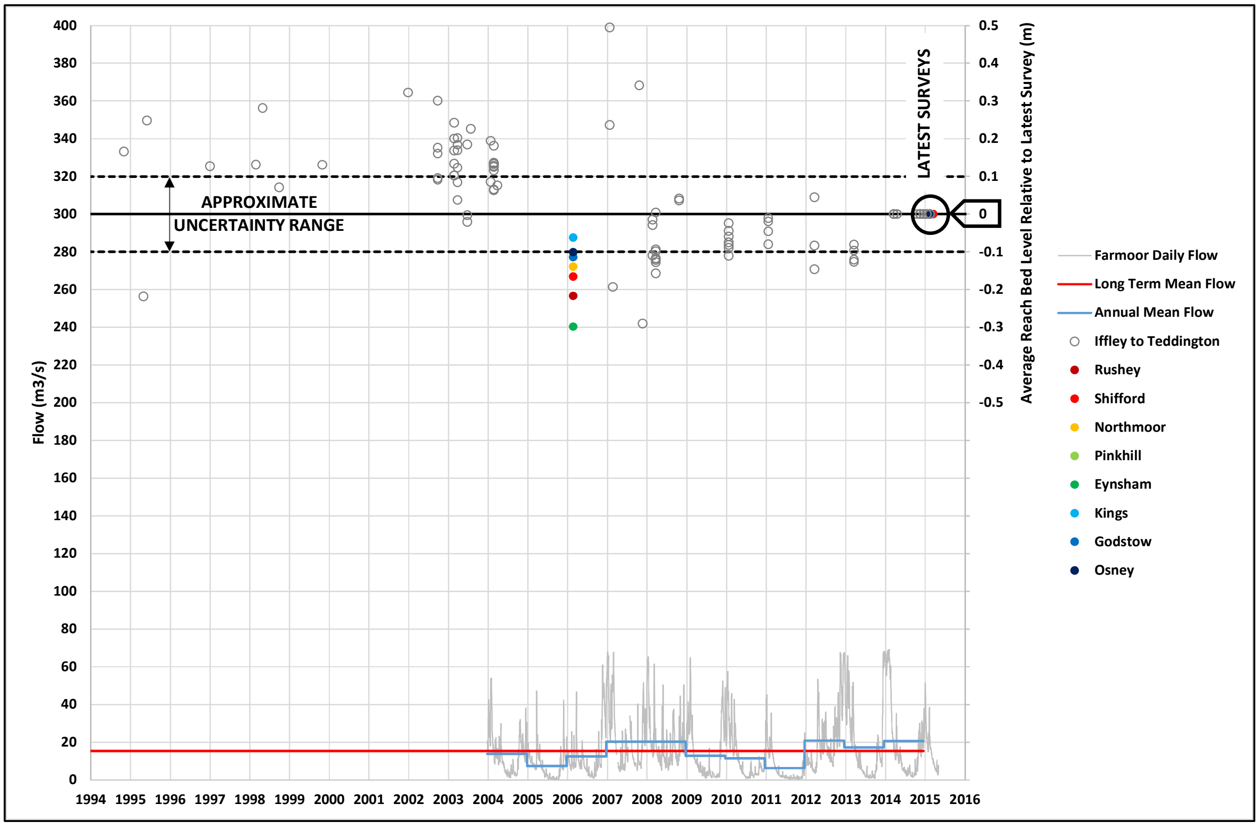


Figure 12. Changes in reach bed level and river flow (Rushy to Osney)

5.2.4 Local scale changes

Analysis of the change in channel morphology between the surveys shows a variety of local scale variations in erosion and deposition of the bed within a reach and within a cross section, demonstrating the complex nature of the river and its processes.

For example, meander bends often experience erosion on the outside of the bend and deposition on the inside due to the variation in flow speed across the channel.

This behaviour is evident in the surveys at many locations, even where the channel planform is relatively constrained. Figure 13 shows the change in bed levels at the meander around Ham Island at the upstream end of Bell Weir reach. Here the 2008 and 2014 surveys show how the movement of bed forms are responsible for some of the zones of erosion and deposition in the difference between surveys. The individual 2008 and 2014 surveys show where the bed forms have moved to create some of this change.

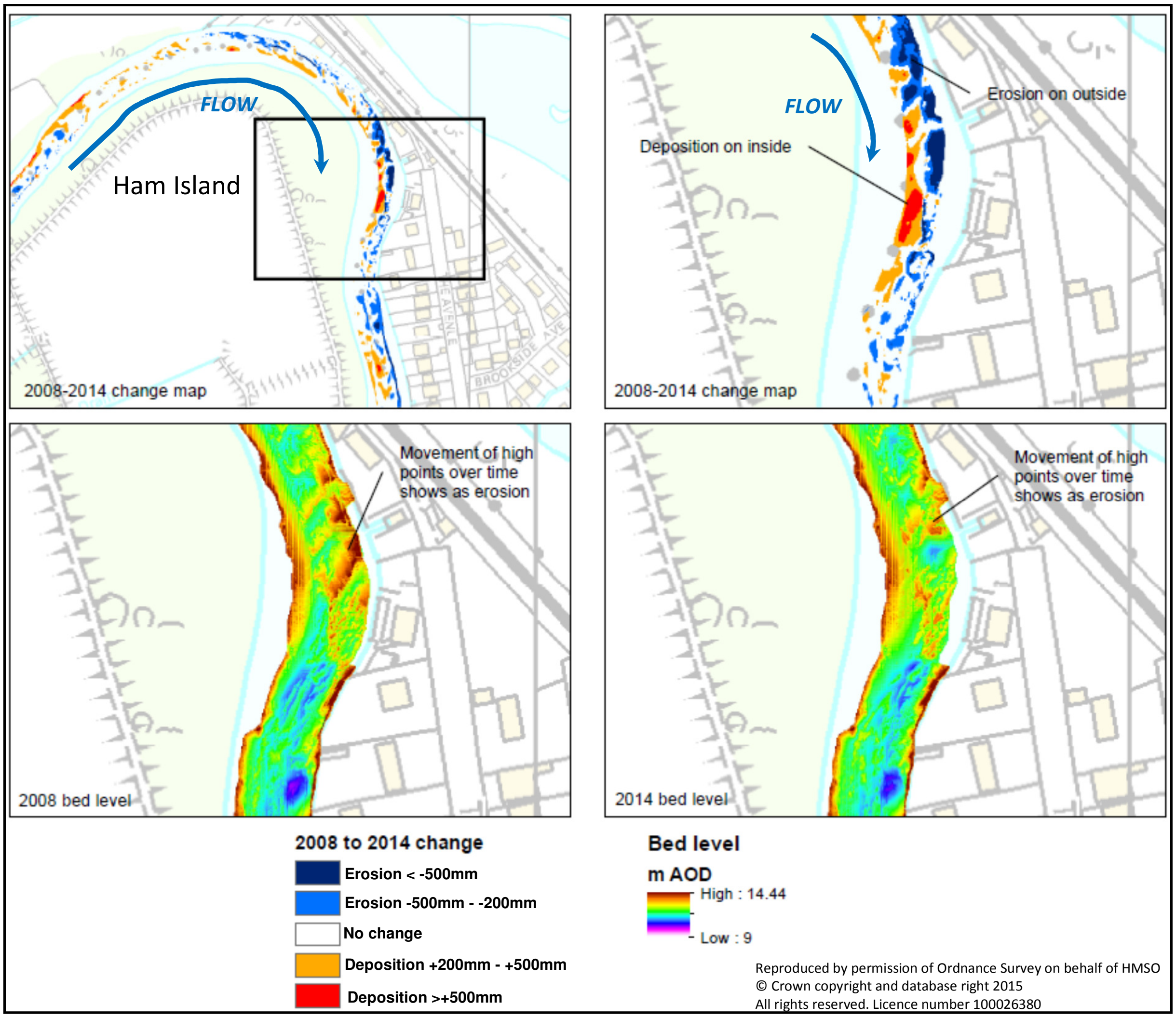


Figure 13. Example of meander behaviour : Bell Weir reach

The reaches upstream of Oxford are generally the least constrained sections of the river and show evidence of active meandering. Only two surveys are available for these reaches (2006 and 2015) and all show a net increase in average bed level over this period, despite having large areas of erosion. The largest change in average level (300mm) is recorded for Eynsham reach. Figure 14 shows the channel behaviour around one bend upstream of Swinford Bridge. The cross-section shows the channel migrating through deposition on the inside of the bed (where velocities are lower, and the channel does not have the energy to transport sediment) and erosion on the outside of the bend, forming a pool.

The flow in Eynsham reach is influenced by the abstraction to Farmoor reservoir at the downstream end of Pinkhill reach. The average abstraction represents approximately 10% of the mean flow in the river and the reduced discharge in this location is likely to result in increased deposition. Figure 15 shows the changes in channel planform in the same area since 1945, as recorded by aerial photographs. Approximate channel outlines traced from the photographs suggest a trend of increasing channel width and reduction in sinuosity between 1945 and 2014. The cross-section in Figure 14 shows an imbalance in the area of erosion and deposition, reflected in the overall net deposition volume for the reach. These changes in river cross-section and planform may indicate an increase in sediment inputs to these reaches over the record period. The greater degree of planform change in these reaches may result in greater transient variations in bed level ad volume. However, in the absence of intermediate surveys it is not possible to identify any definite trend in behaviour or confirm the magnitude of transient changes.

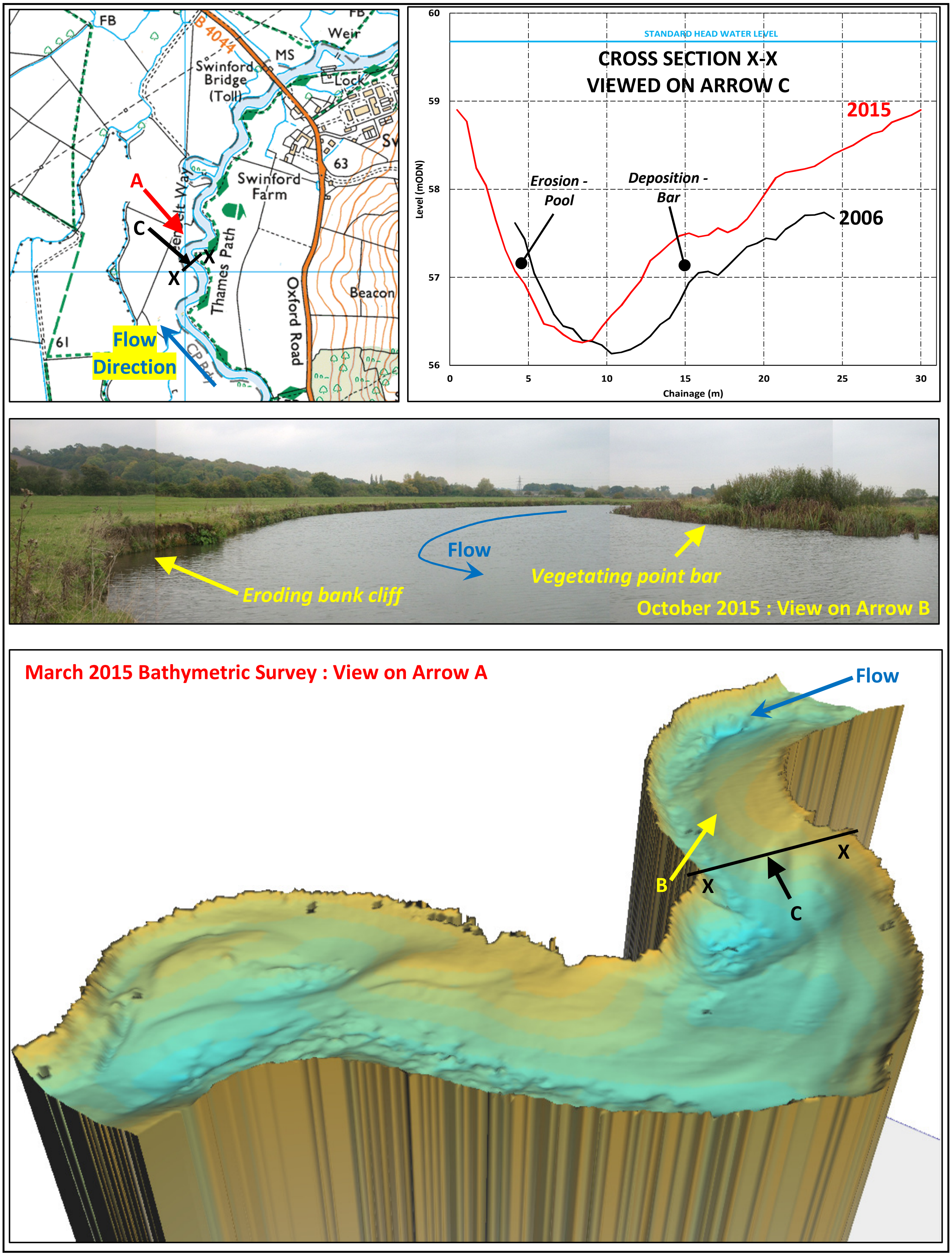
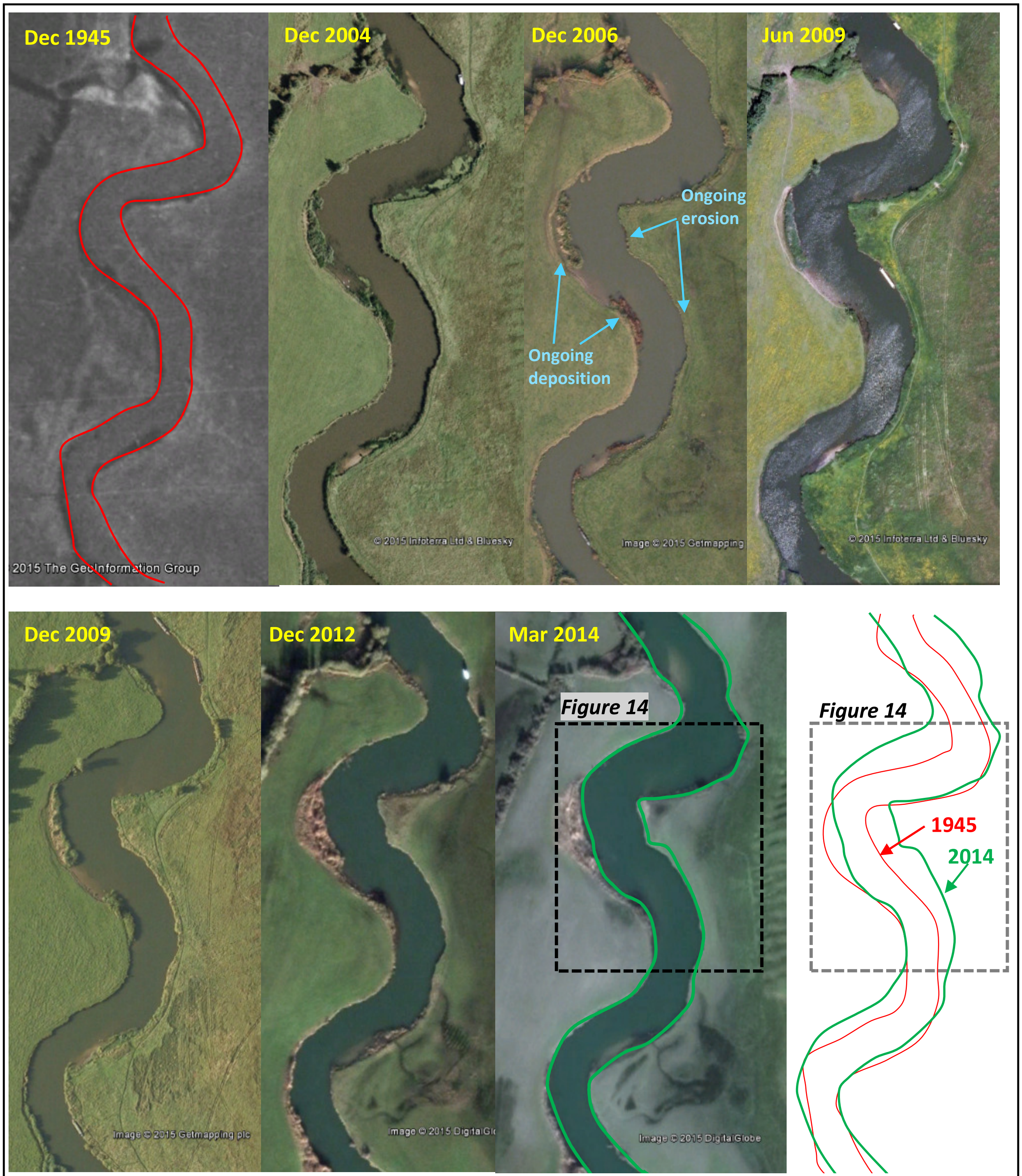


Figure 14. Example of Active Meander : Eynsham Reach



Aerial images © 2015 Google Earth. © 2015 DigitalGlobe, Getmapping plc, Infoterra Ltd & Bluesky, The Geoinformatics Group. Annotation © 2016 CH2M HILL.

Figure 15. Example of Planform Change in an Active Meander : Eynsham Reach

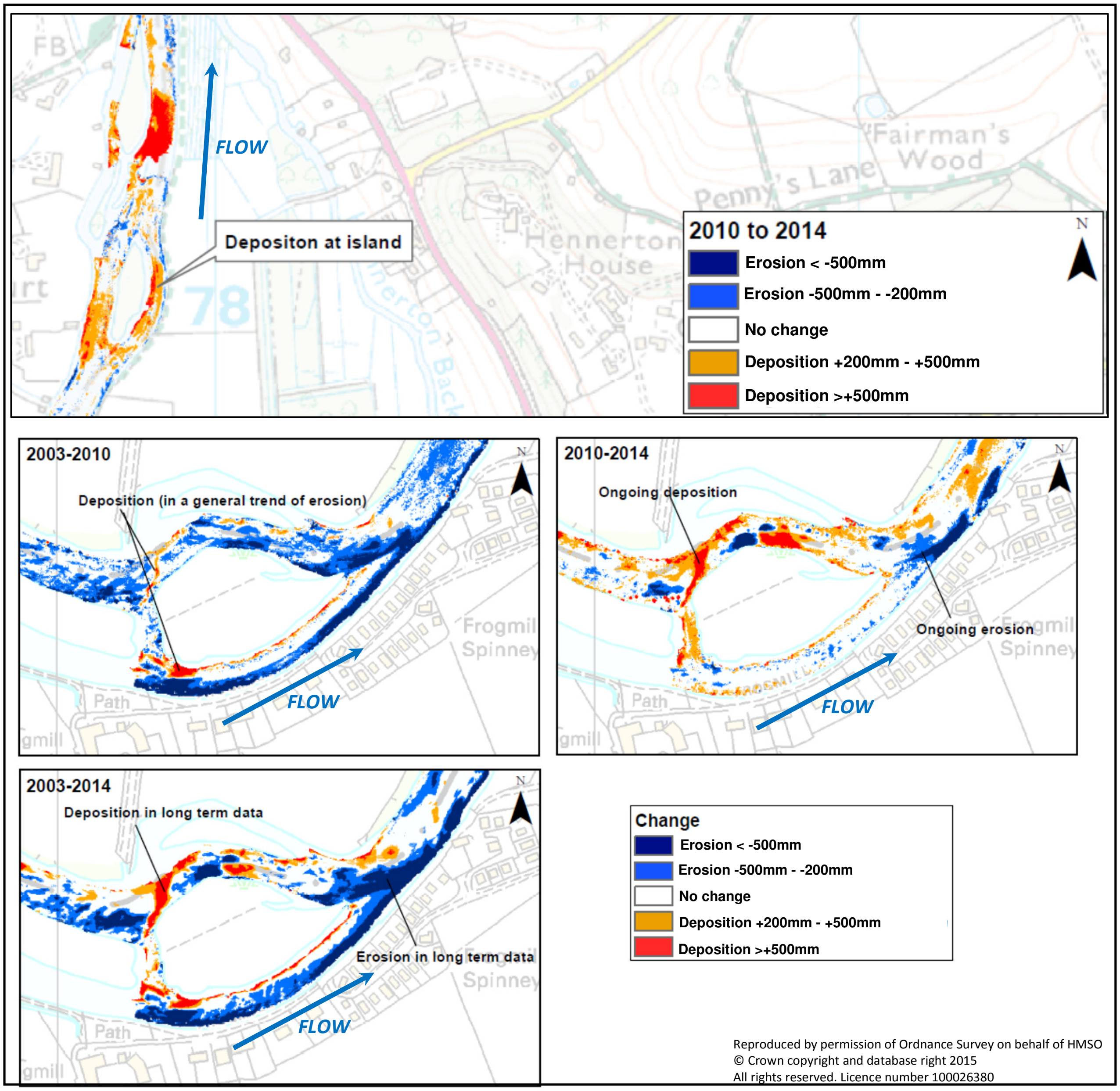


Figure 16. Example of behaviour at islands

The analysis also shows that structures such as bridges and weirs tend to be associated with areas of deposition and erosion. Deposition will occur behind these structures as they impound flow, and velocity is reduced, and erosion occurs downstream as the channel has increased energy from the reduction in sediment load.

Flow splits around islands are also dynamic, associated with local short term change in bed levels as shown by the examples in Figure 16. In the top example (downstream of Shiplake) the island is encouraging deposition, as the flow is split, reducing channel energy as friction increases. The lower example (upstream of Hurley and located on a meander bend), is more complex, with deposition at the entrance of the north channel. This appears to encourage flow to the southerly channel, which is eroding in response to the increase in discharge.

5.2.5 Jubilee River

The Jubilee River is operated to limit the flow through Maidenhead to a target maximum of around 180m^3/s when the flow in the Thames upstream exceeds this value. Flow is diverted from the Thames to the Jubilee River upstream of Boulter's Weir and returns to the Thames at the upstream end of Old Windsor reach. This reduces peak flows in the Bray, Boveney and Romney reaches compared to the reaches upstream and downstream and may reduce the amount of natural erosion in these reaches although the volume of sediment entering the reaches may also be reduced

The reach results for Bray reach indicate a net increase in average bed level (or reach volume) since the earliest survey (1995). The increase (220mm) is not large relative to the uncertainty in the differences between surveys (+/-100mm). Bray reach is immediately downstream of the diversion to the Jubilee River. The flow regime in this reach, together with Boveney and Romney reaches, has changed following the commissioning of the Jubilee River in 2002. The change in flow regime may result in changes to the sediment processes in these reaches. Appendix 2 provides further details of the assessment for this reach.

Figure 17 shows the recorded flow at Windsor and Maidenhead flow gauges and shows the impact of the operation of the Jubilee River since it was commissioned in 2002.

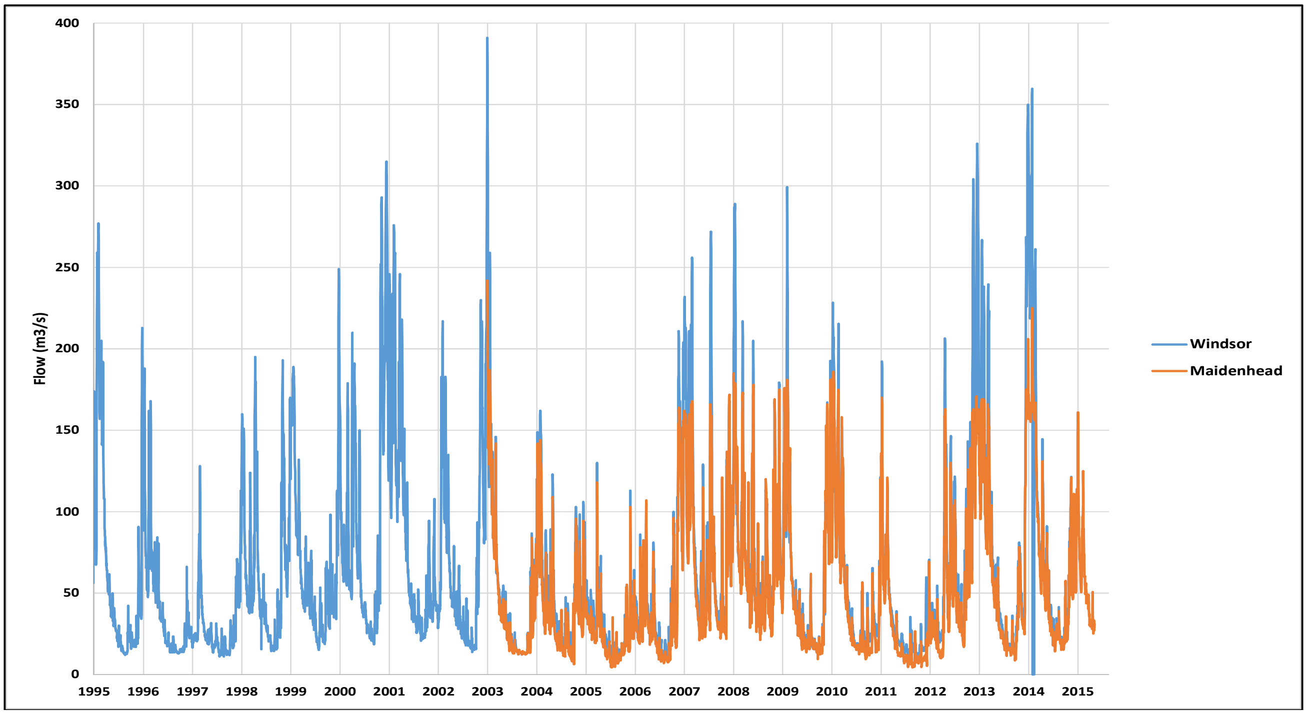


Figure 17. Effect of Jubilee River operation on flow in the River Thames

There is insufficient survey data prior to the commissioning of the Jubilee River (2002) to enable a complete comparison with bed level changes following commissioning. The net changes in bed levels have been compared further for two periods following commissioning – 2003 to 2008 and 2008 to 2015 – for which surveys for all reaches between Marsh and Teddington are available at similar dates. Where survey dates do not exactly coincide with the selected dates the nearest dated survey has been selected.

Figure 18 shows the frequency of flow in the Bray, Boveney and Romney reaches of the Thames (Maidenhead gauge) compared to the flow in the Thames upstream and downstream of these reaches (Windsor gauge) for the two periods selected for bed level change comparisons. For both periods the operation of the Jubilee River results in the loss of periods of flow above around 180m^3/s in the Bray, Boveney and Romney reaches (75 days of such flows for the period 2003-2008 and 158 days for the period 2008-2014). The average reduction in flow during these days is 59m^3/s and 82m^3/s respectively.

The net changes in average bed level for each of the reaches between Caversham and Teddington for the two selected periods are summarised in Figure 19. For the first period (2003-2008) all reaches show net erosion (except for Bell Weir which shows no significant change) and the average depths of erosion in Bray, Boveney and Romney reaches are similar to or greater than those in the reaches upstream and downstream of these reaches. In this period there are fewer high flow events and the frequency and magnitude of flow diversion to the Jubilee River is less than in the second period.

In the second period (2008-2014) where the diversion of flow is more significant, the five reaches downstream of the Jubilee River diversion (Old Windsor to Shepperton) show either net erosion or only minor deposition, whereas Bray, Boveney and Romney reaches all show net deposition. The reduction in peak flows in these reaches in this period may have reduced the amount of erosion and hence increased net deposition. However, the reaches upstream of the Jubilee River (Boulters to Temple) also show net deposition. The Thames flow in the reaches below Bell Weir is increased by tributary flows (such as the Colne) which may limit long term deposition in these reaches.

Overall, for the combined period 2003-2014, all reaches show net erosion or little change.

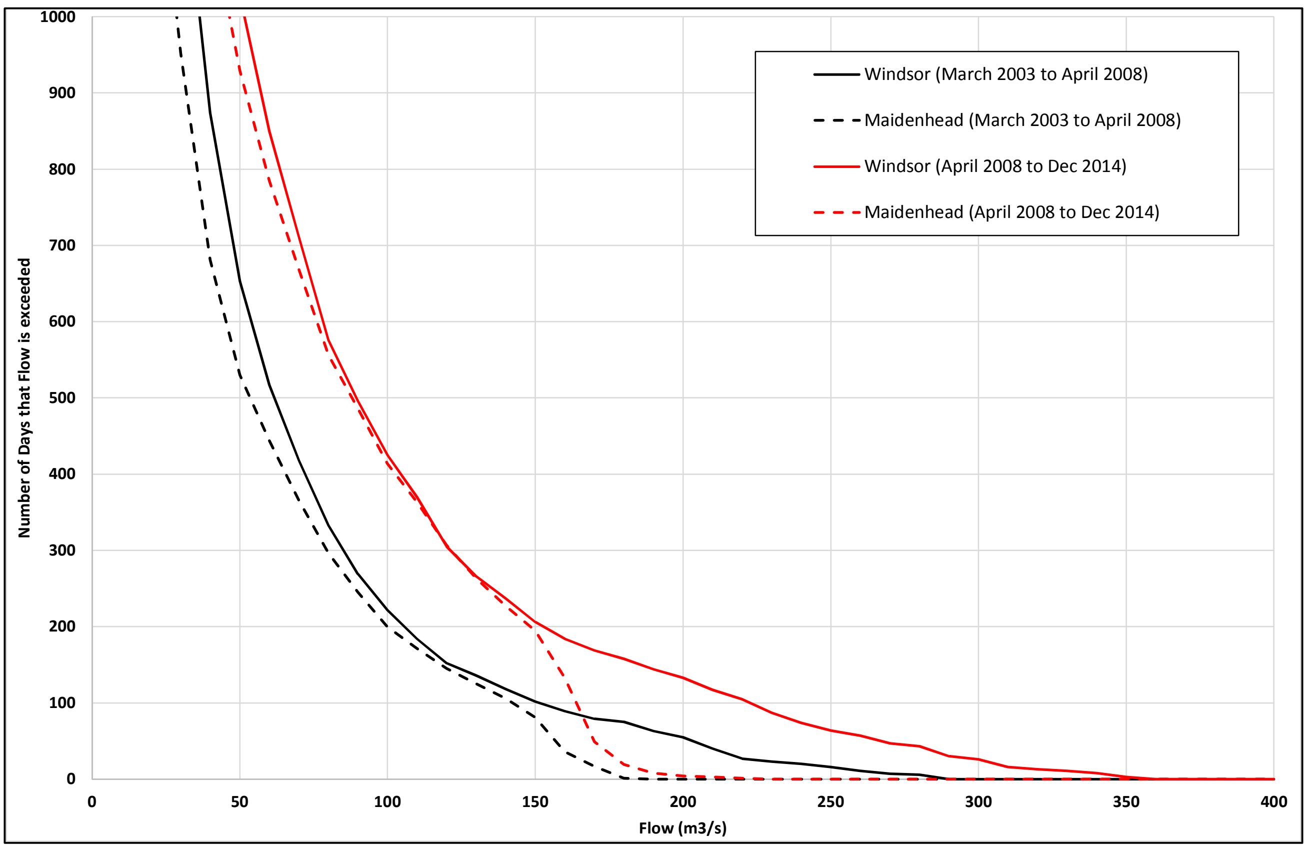


Figure 18. Change in flow frequency due to Jubilee River operation

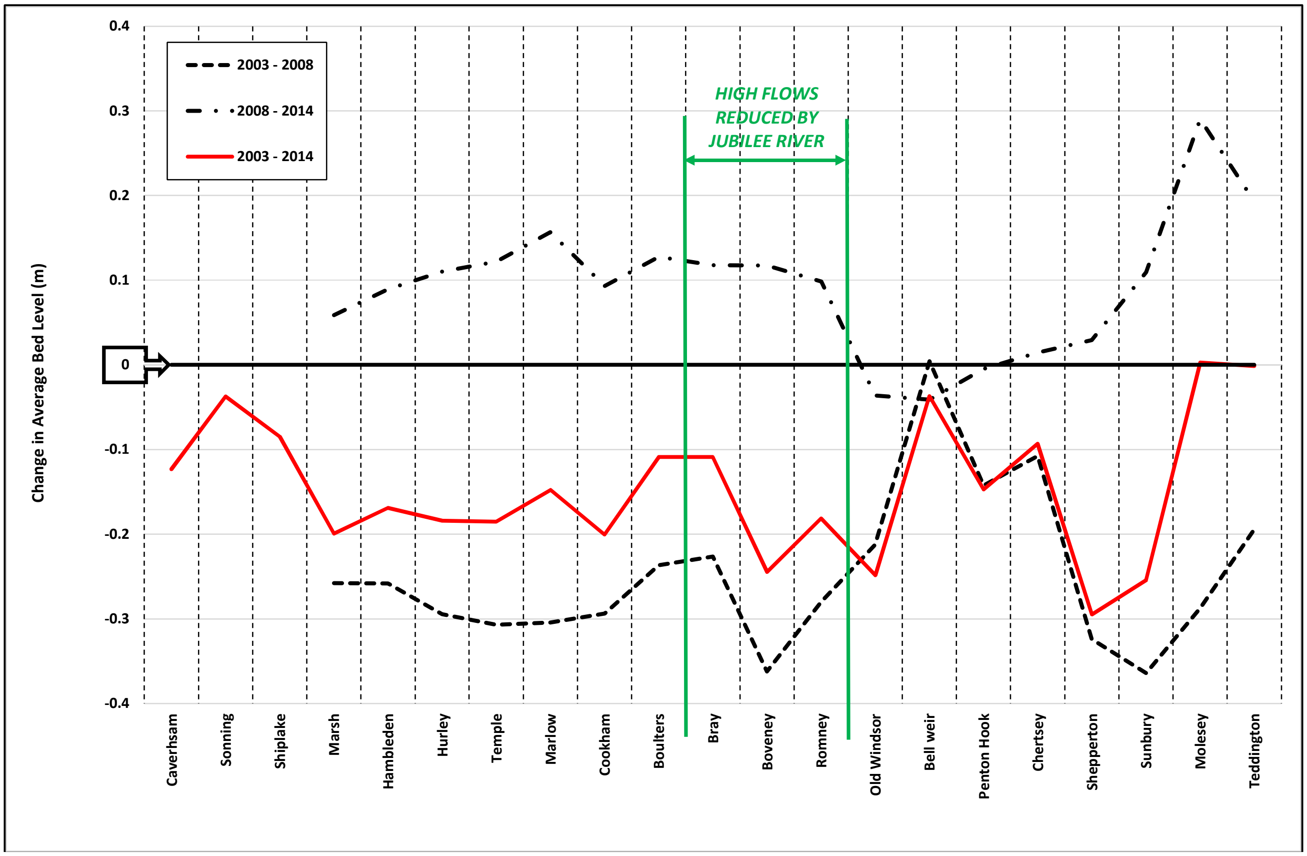


Figure 19. Changes in average bed level : Caversham to Teddington (2003-2008 and 2008-2014)

5.2.6 Summary

The available surveys provide evidence that both erosion and deposition are occurring in different parts of the river system. The generally low frequency of the surveys, differences in timing between surveys in different reaches, the timing of surveys in relation to flow events and the relatively short total period of record in relation to the timescale of geomorphological processes results in no clear relationship between the data for reach bed volume or level changes and river flow.

The data tend to indicate a reduction in reach bed volumes for the period up to 2004 and an increase in bed volumes from 2008 to the latest surveys in 2014 and 2015. The magnitude of net volume change in each reach between successive surveys is within the uncertainty range of the survey data for at least 40% of the survey comparisons. The net volume change between the earliest and latest surveys for each reach shows a net reduction for 75% of the reaches, although transient changes in bed volume can exceed the net change in volume over the record period. Significant net increases in bed volume are recorded for Rushey, Shifford, Northmoor, Pinkhill, Eynsham and Godstow reaches, all upstream of Oxford, and Bray reach, downstream of the diversion to the Jubilee River.

The period of data for reaches upstream of Oxford (9 years) is the shortest in the study and therefore there is no evidence of longer term trends. These reaches are morphologically active and relatively unconstrained and there is evidence of planform change. Examination of the available data for Bray reach and the reaches upstream and downstream indicates no clear relationship between bed volume change and flow diversion to the Jubilee River.

Where net reach bed volumes do not change significantly between surveys, there is evidence in the data for all reaches of morphological activity and local areas of erosion and deposition, particularly around structures and other features in the river.

5.3 Flood conveyance

The flow in a channel cross-section at a particular water level or depth can be calculated using Manning's equation for open channel flow (Chow, Chapter 6-1):

$$\text{Flow } (m^3/s) = K \,.\, S^{1/2}$$ **Equation 1**

Where *K* is the conveyance of the channel cross-section and *S* is the slope of the water surface at the cross-section. The conveyance is a measure of the channel capacity at a given water level or depth. The actual flow depends also on how steep the water surface along the channel is.

The channel conveyance at a particular water level depends on the cross-sectional area (*A*) and wetted perimeter (*P*) of the channel cross-section, as defined in Figure 20 below, together with the Manning's roughness coefficient (*n*) of the channel. The roughness coefficient is a measure of the frictional resistance to flow due to the surface roughness of the channel, vegetation and other obstacles to flow.

$$K = A^{5/3} \,.\, P^{-2/3} \,.\, n^{-1}$$ **Equation 2**

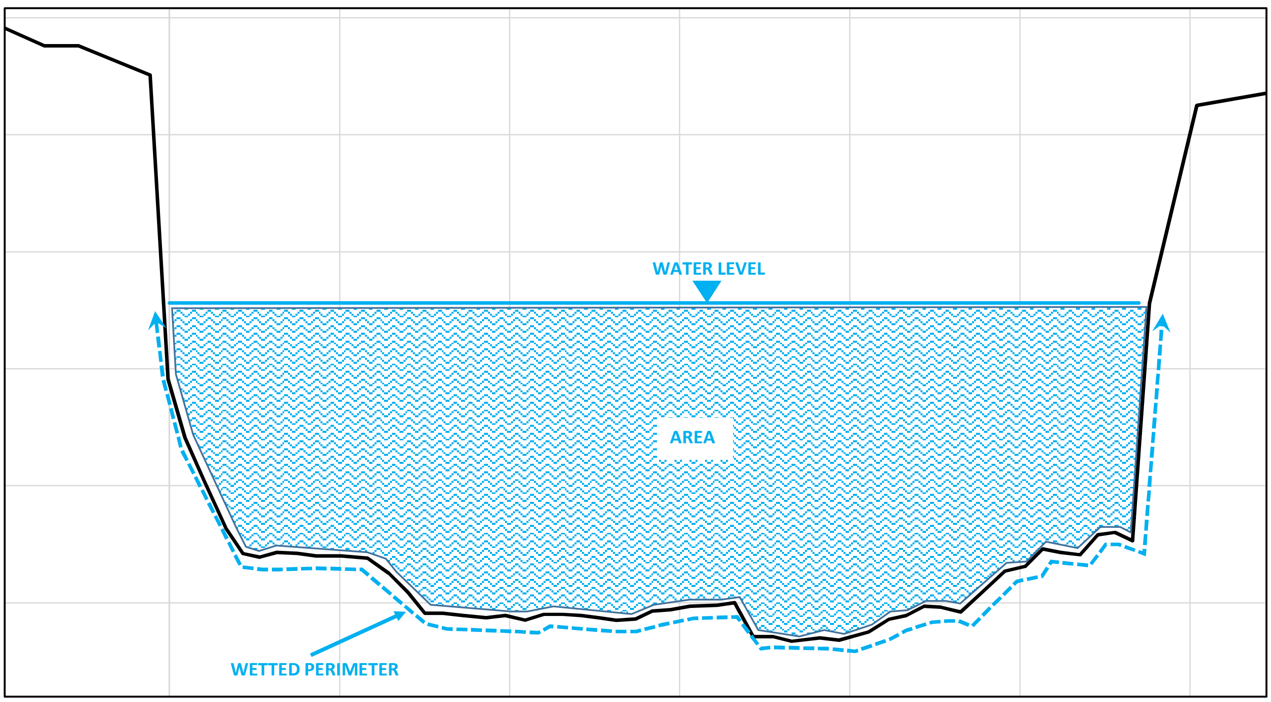


Figure 20. Definition of cross section properties

The variations in the channel bed levels recorded in the surveys result in variations in the channel cross-section properties and the channel conveyance, or the flow that can be carried by the channel at a particular water level or depth, at each point along the river.

In order to understand the significance of the bed level changes recorded by the surveys in relation to the flood conveyance of the channel, an assessment has been made of the change in channel conveyance recorded by the surveys through:

- a detailed analysis of local conveyance variations based on survey cross-sections at five sample locations
- an indicative assessment of the potential magnitude of change in cross-section conveyance in each reach relative to bed level change

The actual capacity of the channel also depends on the effect of structures such as weirs and bridges which are not included in this assessment. The effect of such structures on flood water levels in a reach can be similar to or greater than the channel conveyance.

5.3.1 Sample locations assessment

The variation in channel conveyance at a specific channel cross-section has been assessed at the following five locations:

- Oxford – approximately 500m upstream of Botley Road Bridge (Osney Reach)

  Available surveys (2006 and 2015) indicate a general increase in bed levels between the Castle Mill Stream bifurcation and Botley Road Bridge.

- Reading – approximately 20m upstream of Reading Bridge (Caversham Reach)

  Available surveys (2003 and 2014) indicate an increase in bed levels around Reading Bridge.

- Maidenhead – approximately 150m downstream of Boulters Lock (Bray Reach)

  This area lies immediately downstream of the diversion to the Jubilee River. Available surveys (1995, 2003, 2008 and 2015) indicate a possible trend of deposition in Bray reach. Two cross-section locations, separated by approximately 55m, have been assessed to examine the variation in changes in channel conveyance along a river reach.

- Staines – at Staines Flow Gauge, approximately 330m downstream of Staines Bridge (Penton Hook Reach)

  In addition to the bathymetric surveys of the reach, local channel cross-section surveys are undertaken regularly at this location for updating of the flow gauge characteristics and have been used to extend the available data set (1999, 2003, 2007, 2008, 2010, 2011, 2013, 2014).

- Walton – approximately 40m downstream of Walton Bridge (Sunbury Reach)

  Bathymetric surveys indicate significant deposition in the central section of the channel downstream of Walton Bridge between 2013 and 2014.

At each location the channel cross-section properties and conveyance have been calculated for each available survey at the 2014 flood water level using a typical Manning's roughness coefficient of 0.033. The conveyance has been calculated only for the portion of the cross-section covered by all surveys. The change in local channel conveyance over time has been calculated as a percentage of the conveyance for the earliest available survey and is independent of the assumed value of roughness coefficient.

Figure 21 shows the changes in average bed level and conveyance relative to the earliest survey at each cross-section.

Detailed results and cross-section drawings for each location are presented in Appendix 4. The cross-section drawings also show the maximum bed level meeting the Environment Agency's current Navigation Level of Service at each location. For the Maidenhead, Staines and Walton cross-sections, the historic design dredge level for flood defence is indicated on each cross-section together with the bank side zones where dredging is not carried out under current Environment Agency practice. The conveyance for the most recent survey (2014 or 2015) has been calculated for both the actual survey data and with the design dredge level applied across the permissible portion of the cross-section.

It should be noted that the absolute values of conveyance tabulated in Appendix 4 are indicative only, based on the value of roughness coefficient assumed above and that the assessment of relative change in conveyance assumes the roughness coefficient is the same in each survey. In practice, the roughness may vary between the survey dates as a result of changes to the bed composition and profile.

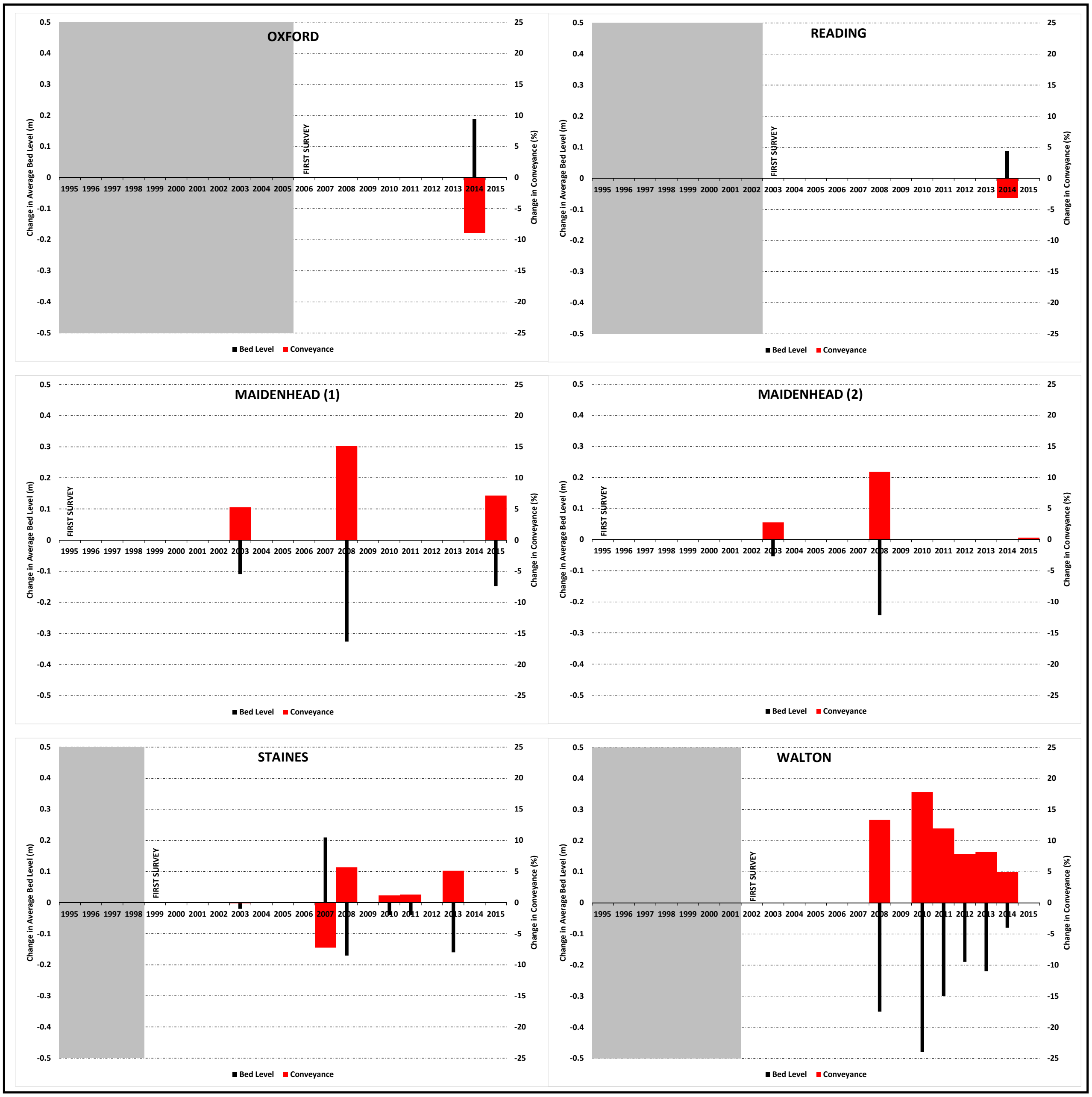


Figure 21. Changes in average bed level and corresponding change in conveyance at sample cross-sections

For the sample cross-sections in Oxford and Reading, for which only two surveys are available, a reduction in local channel conveyance at the 2014 flood level is recorded of approximately 9% and 3% respectively in the period between the two surveys (9 years and 11 years respectively).

In the case of the Oxford cross-section, the River Thames channel in this location carries around 33% of the total River Thames flow at the 2014 flood level due to diversion upstream to the Seacourt Stream and Castle Mill Stream and floodplain flow. The reduction in overall flood conveyance of the river corridor at the 2014 flood level will therefore be less than the reduction in conveyance of the River Thames channel at this location.

At the other sample locations the majority of the 2014 flood flow is carried in the river channel.

For the two cross-sections in Maidenhead, the conveyance for all surveys has increased, by up to 15% in 2008, compared to the earliest survey (1995). For the Staines cross-section the conveyance varies between -7% and +6% of the earliest survey (1999) and the difference between the latest (2015) and earliest (1999) conveyance is less than 0.1%.

For the Walton cross-section the conveyance for all surveys has increased, by up to 18% in 2010, compared to the earliest survey (2002). The surveyed channel bathymetry at this location is influenced by the flow field through Walton Bridge – the piers of the old bridge structure are likely to have concentrated flow resulting in scour holes downstream of the structure. The old bridge structure and piers were removed in 2013 and replaced with a clear span bridge. The increase in average bed level between the 2013 and the 2014 survey may partly be due to the change in flow field at this location. However, the 2014 conveyance is still approximately 5% greater than the earliest survey (2002).

For the Maidenhead, Staines and Walton cross-sections, the conveyance for the most recent survey (2014 or 2015, depending on location) has also been calculated with the design dredge level applied across the permissible portion of the cross-section.

For the two Maidenhead cross-sections the conveyance with the design dredge level is approximately 4.1% and 0.5% greater than the latest survey (2015). However the dredged conveyance is less than the actual conveyance in 2008 for the first cross-section and less than the actual conveyance in 2003 and 2008 for the second cross-section.

For the Staines cross-section the conveyance with the design dredge level is 7.7% greater than the latest survey (2014) and around 2% greater than the largest actual surveyed conveyance (2008).

For the Walton cross-section the conveyance with the design dredge level is around 25% less than actual conveyance in 2014. This is due to the deep scour zone downstream of the bridge.

5.3.2 Relative changes in cross-section conveyance

The detailed assessment of conveyance at sample locations provides an indication of the local changes in channel conveyance recorded by the surveys. Figure 22 shows the change in average bed level and change in conveyance at the 2014 flood level for all the surveys for the six sample cross-sections. For these cross-sections, the change in cross-section conveyance at flood depth is approximately proportional to the change in average bed level at a rate of 4% per 100mm change in average bed level for the range of bed level changes recorded.

For a given absolute change in bed level, the relative change in cross-section conveyance depends on the depth of flow, and reduces with increasing water depth. From Equation 2 it can be shown that for a given cross-section the conveyance is approximately proportional to $d^{5/3}$ where d is the average depth of flow. On this basis the approximate potential rate of change in cross-section conveyance has been calculated for each reach for a 100mm increase and decrease in the earliest survey reach average bed level, as shown in Figure 6. The changes are calculated for the average depth at SHWL and for the average depth at water levels of 1m above SHWL and 2m above SHWL, the typical range for the 2014 flood.

Figure 23 shows that at SHWL the potential change in conveyance for a 100mm change in bed level varies between 5% and 11% depending on reach with an average change of 7%. At a flood level 2m above SHWL, the change in conveyance for a 100mm change in bed level varies between 3% and 5% with an average change of 4%, similar to the results for the sample cross-section calculations.

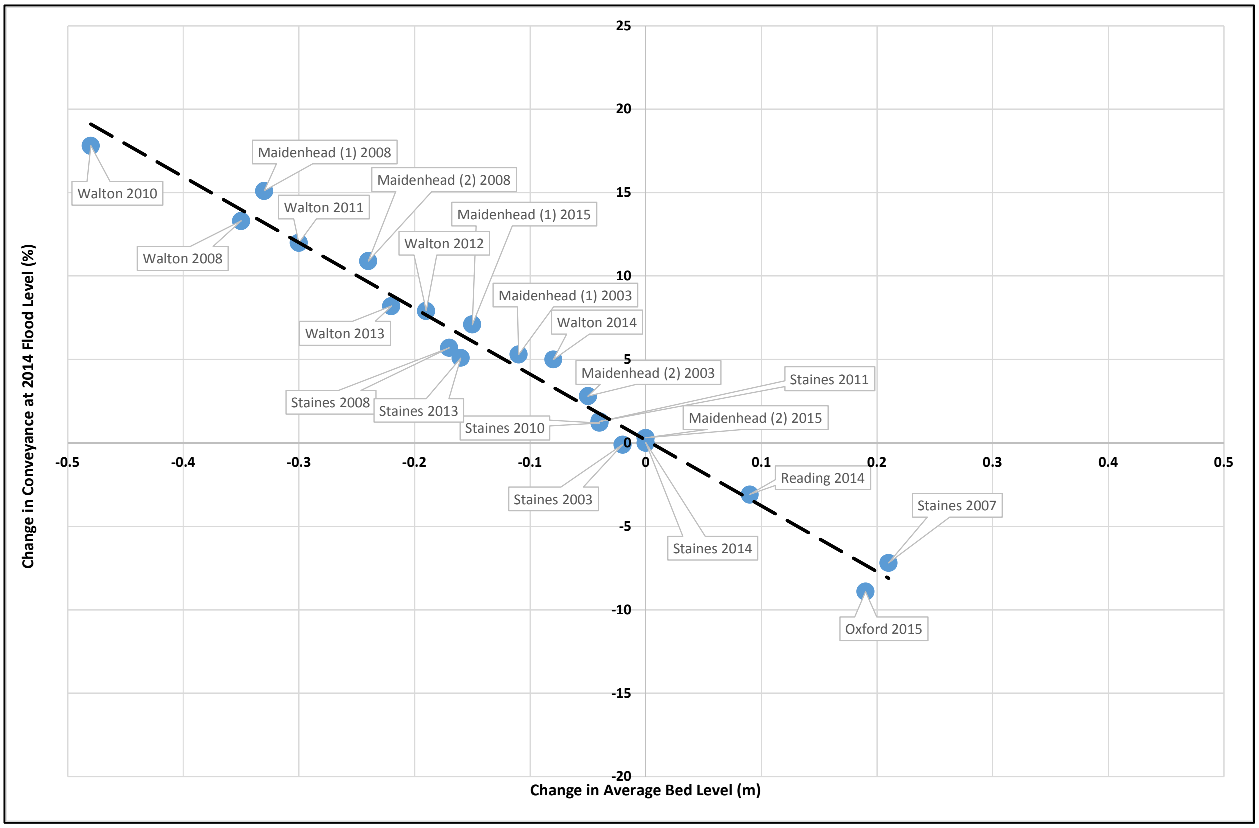


Figure 22. Relationship between change in cross-section conveyance and average bed level at sample cross-sections

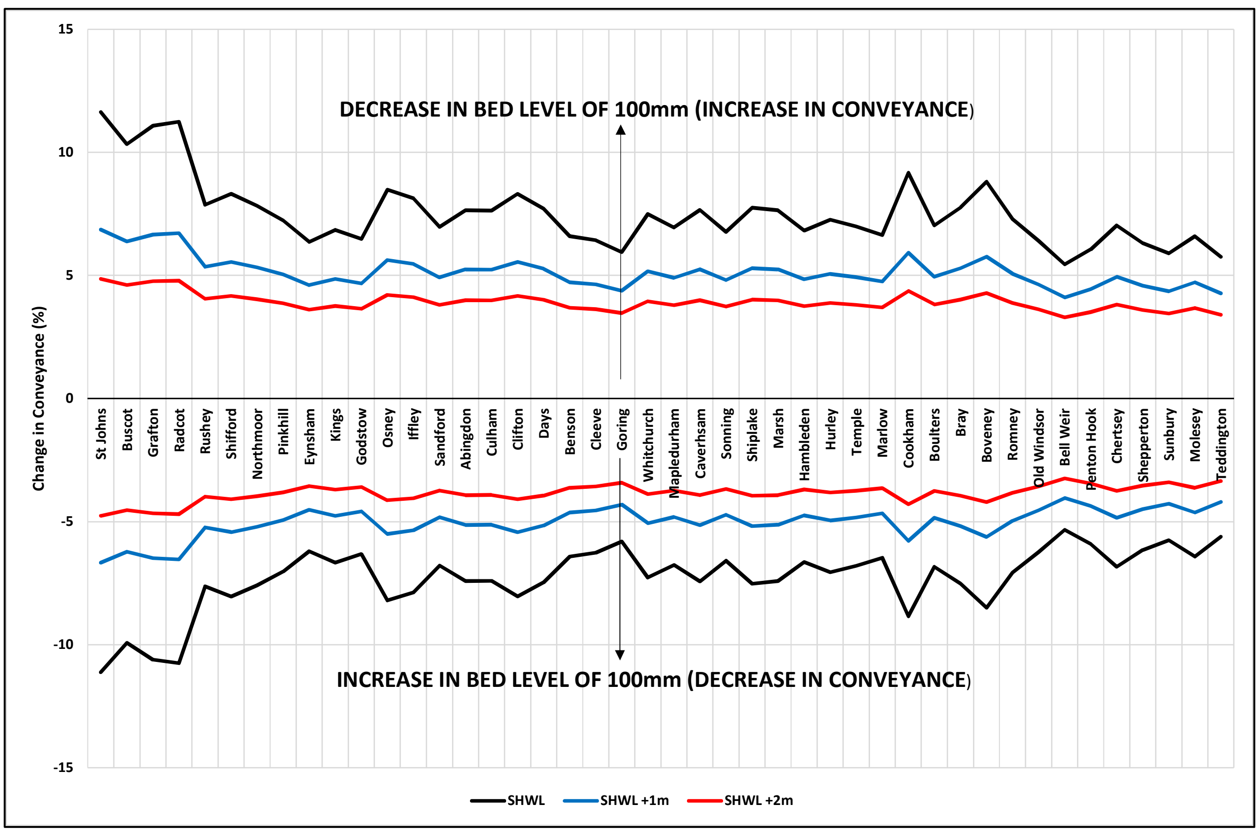


Figure 23. Potential relative changes in channel cross-section conveyance in each reach

5.3.3 Gauge records

Sample records of the flow and water level in the River Thames have been reviewed in order to compare the changes in reach conveyance estimated in the study with any evidence of changes in channel conveyance in the gauge records. The tail water level record at Boulter's Lock, representative of the water level in the Thames at the head of Bray reach and the flow record at Maidenhead Bridge, approximately 1Km downstream, have been assessed for the entire period of the flow record (2003 to 2015).

Figure 24 shows the mean daily flow at Maidenhead together with that at the Windsor flow gauge, approximately 13Km downstream, and the dates of the bathymetric surveys for Bray reach. Twelve periods (P1 to P12) of higher flow (greater than 150m^3/s at Maidenhead) where the regulating structures are likely to be fully open and water levels are not influenced by their operation have been identified for analysis. The Windsor flow gauge includes the flow diverted to the Jubilee River upstream of Boulter's weir, which returns to the Thames approximately 1Km upstream of the Windsor gauge. The gauge locations are shown in Drawing 3 in Appendix 1.

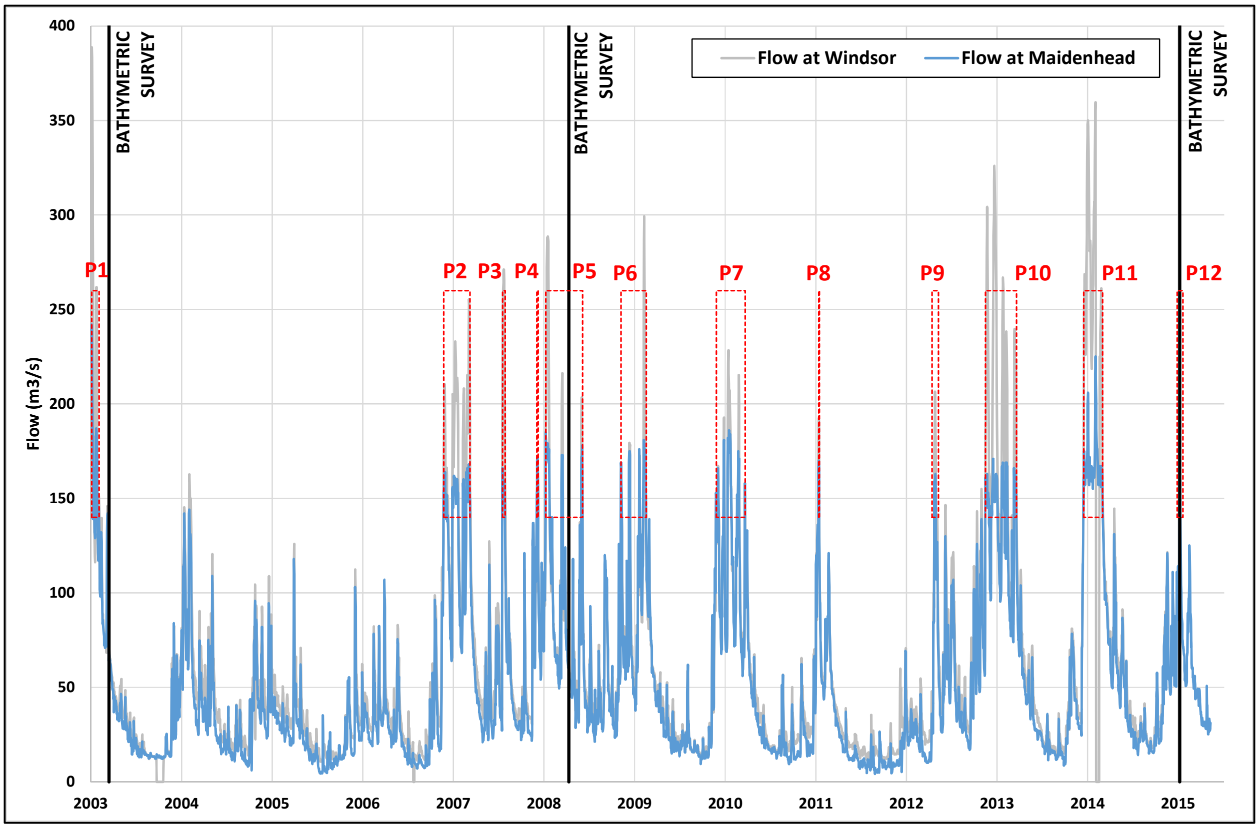


Figure 24. Flow record for Bray reach

Figure 25 shows the relationship between the water level and flow at Boulter's Lock tail at the head of Bray reach for each of the periods for which the flow exceeds 150m^3/s (periods P1 to P12 on Figure 24). Boulter's Lock is approximately 13Km upstream of the confluence of the Jubilee River and the River Thames and therefore the water level depends only on the flow in the reach and is independent of the flow in the Jubilee River.

Although there is scatter in the data, the rating relationship between flow and water level for each individual high flow period is relatively well defined. The data show differences in the rating for each flow period. For example, for a flow of 170m^3/s, the average water level at the head of Bray reach varies between 22.15mODN in period P6 (November 2008 to February 2009) and 22.45mODN in period P3 (July 2007).

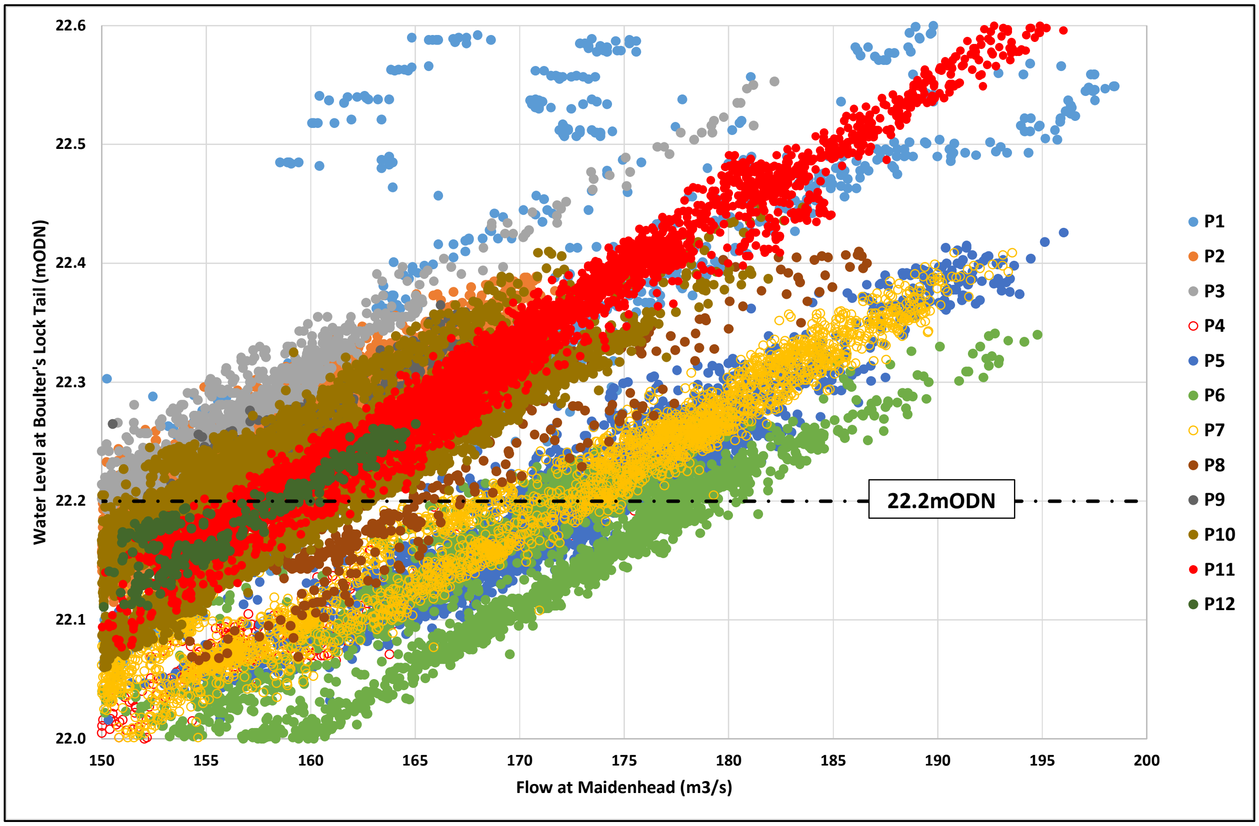


Figure 25. Gauged Flow and Water Level in Bray Reach

Allowing for inaccuracies in flow gauging, the data in Figure 25 suggest variations in the conveyance of the river channel between the flow periods examined. The difference in conveyance between periods is illustrated in Figure 26 in terms of the difference in the average flow for each period at a water level of 22.2mODN (approximately 1m above SHWL) and the average flow at the same water level for the first flow period (P1, January 2003), expressed as a percentage of the 2003 flow. The changes in conveyance at 2014 flood level calculated at the sample cross-sections in Maidenhead, approximately 150m downstream of Boulter's lock (see Section 5.3.1), are also plotted together with the average bed levels for the whole of Bray reach calculated from the bathymetric surveys.

The changes in conveyance calculated at the sample cross-sections (at 2014 flood level, 22.97mODN, approximately 2m above SHWL) and the changes in average reach bed level are consistent with the changes in conveyance indicated by the gauge data. This suggests that such gauge data could be a useful means of monitoring changes in conveyance at the reach scale.

Sediment erosion, transport and deposition and the resulting channel morphology depend on magnitude and duration of flow in the river. Figure 26 shows the 50% exceedance flow (34m^3/s) for the complete gauge record at Maidenhead and the 50% exceedance flow in each calendar year as an indicator of the flow activity in the river. There is a degree of correlation between periods when the annual 50% exceedance flow is lower than the long term average, lower conveyance and higher average bed level and between periods where the annual flow is higher than average, higher conveyance and lower average bed level.

Figure 27 shows the changes in conveyance calculated at the Staines Flow Gauge sample cross-section in Penton Hook reach together with the 50% exceedance flows and shows a similar degree of correlation between river flow, bed level and conveyance.

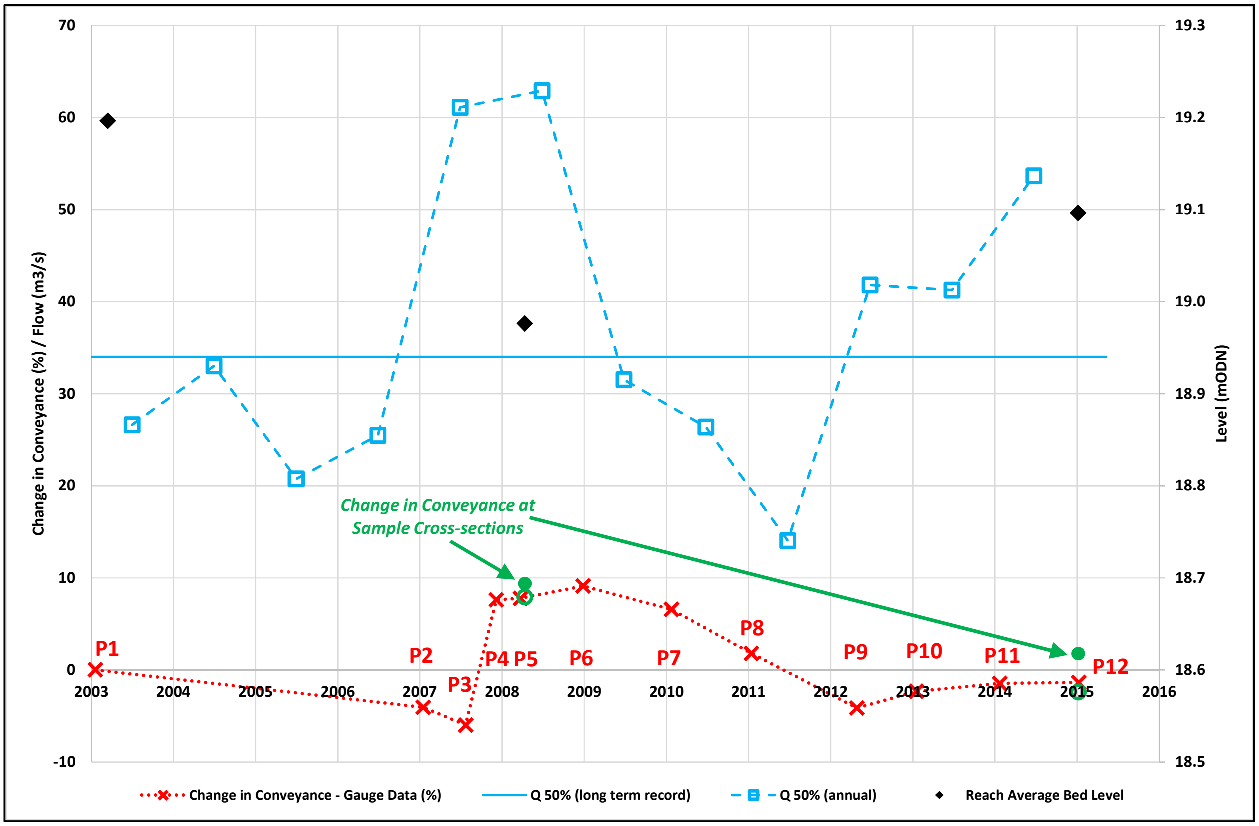


Figure 26. Changes in conveyance in Bray Reach

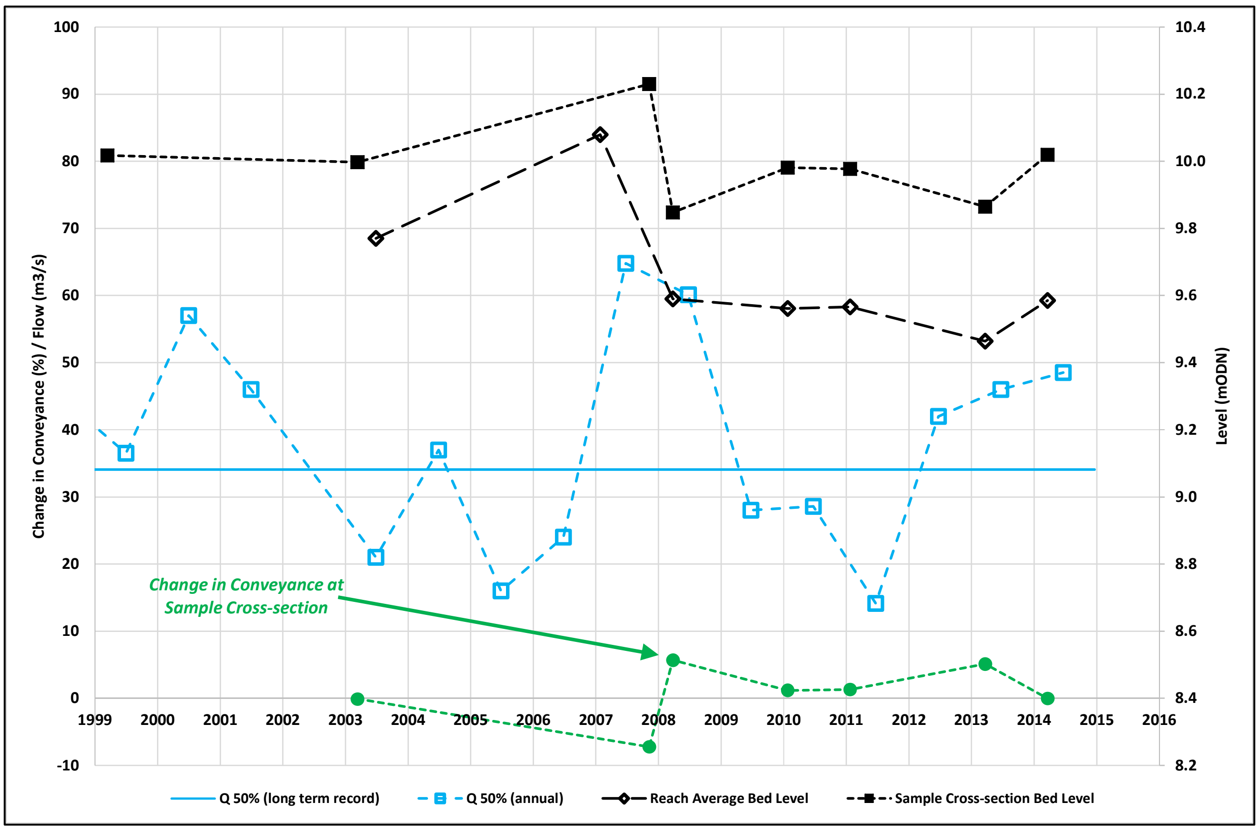


Figure 27. Changes in conveyance in Penton Hook Reach

5.3.4 Conclusions

The assessment of the change in channel cross-section conveyance resulting from changes in channel bed levels indicates a change of between around 3% and 7% in conveyance of a cross-section at flood level for a change in average cross-section bed level of 100mm, depending on the reach and flood level.

For comparison, a change in cross-section conveyance of 3% to 7% corresponds to the change in conveyance due to a change in the value of channel roughness coefficient of between 0.001 and 0.002 (relative to a typical Manning's roughness coefficient of 0.033). This magnitude of change in roughness coefficient is within the range of variation in roughness coefficient due to seasonal changes in vegetation or the formation and deformation of channel bed forms such as dunes and ripples without any change in average bed level (Reducing Uncertainty in River Flood Conveyance - Roughness Review, DEFRA/Environment Agency, 2003).

Analysis of gauge records of water level and flow in one sample reach (Bray) indicates a similar magnitude of variation in channel conveyance to that estimated from the bathymetric surveys and that such records may be useful in monitoring changes in reach conveyance. Analysis of flow records for this reach suggests a degree of correlation between periods of low average flow, lower conveyance and higher bed level and between periods of high average flow, higher conveyance and lower bed level.

Flood water levels depend on both the conveyance of the channel cross-section and the effect of structures such as the weirs and gates at the downstream end of each reach and bridges together with river channel variations such as bends and flow splits around islands and the conveyance of the floodplain. The effect of these features on flood levels can be comparable to the channel conveyance and in order to determine the overall effect of any changes in channel cross-section conveyance on flood water levels, the effect of such features must also be considered.

Figure 28 shows the 2014 flood levels from Cookham to Romney and the corresponding approximate water surface slope for uniform flow conditions, where the flow is controlled by gravity and channel conveyance alone such that the water surface is parallel to the average bed gradient. It can be seen, for example, that in the 2014 flood the average water surface gradient of the channel in Bray reach was 1m in 3.9Km whereas the uniform flow gradient would be around 1m in 2.6Km. The increase in water level at Boulters weir, at the upstream end of the reach was 0.95m, slightly greater than the total rise in water level along the whole of the channel in Bray reach. The variation in channel cross-section conveyance can have less effect on water levels in locations where the influence of other features in the river are important.

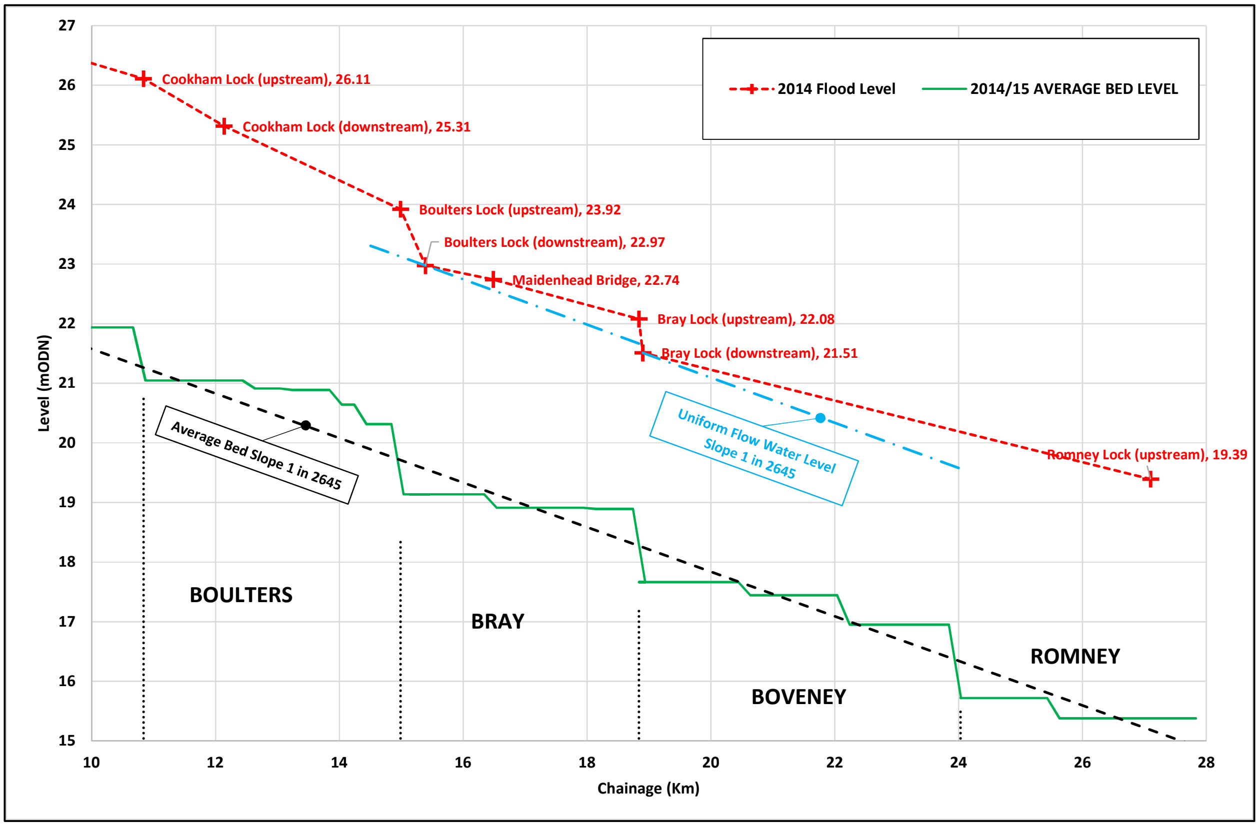


Figure 28. Effect of structures on flood levels

5.4 Dredging

Dredging has been recorded in the River Thames upstream of Teddington since the late 1940s with the intention of maintaining a navigable channel and managing flood risk by maintaining the channel flow capacity. In 1998 full channel dredging ceased and since that date only isolated shoals are dredged for navigation purposes.

Under the historic dredging regime for the lower reaches (from Hurley to Teddington locks), periodic hydrographic or bathymetric surveys were undertaken to identify areas where dredging was required to achieve a defined bed level for flood conveyance. The date and method by which the design criteria were established are not clear but may have arisen following the 1947 flood (River Thames Dredging Study, July 1998).

5.4.1 Design dredge depths

The most recent design dredge depths for the lower reaches of the river are recorded on the 1971 Thames Improvement Scheme contract drawings and are included in subsequent reach surveys. The extent of dredging across the channel cross-section is thought to originally have been based on a trapezoidal cross-section with bank slopes of 1:3, corresponding to an approximately 10m wide bank margin on each side of the channel. In later years, in order to protect fish habitat, dredging was only carried out over that part of the channel cross-section where the bed level is at least 1.5m below SHWL and no closer than 10m to the river bank, including an allowance for bank stability, as shown in Figure 29 (Appendix 2, River Thames Dredging Study, July 1998). The corresponding extents of the 'dredge zones' for each reach are delineated on more recent survey drawings.

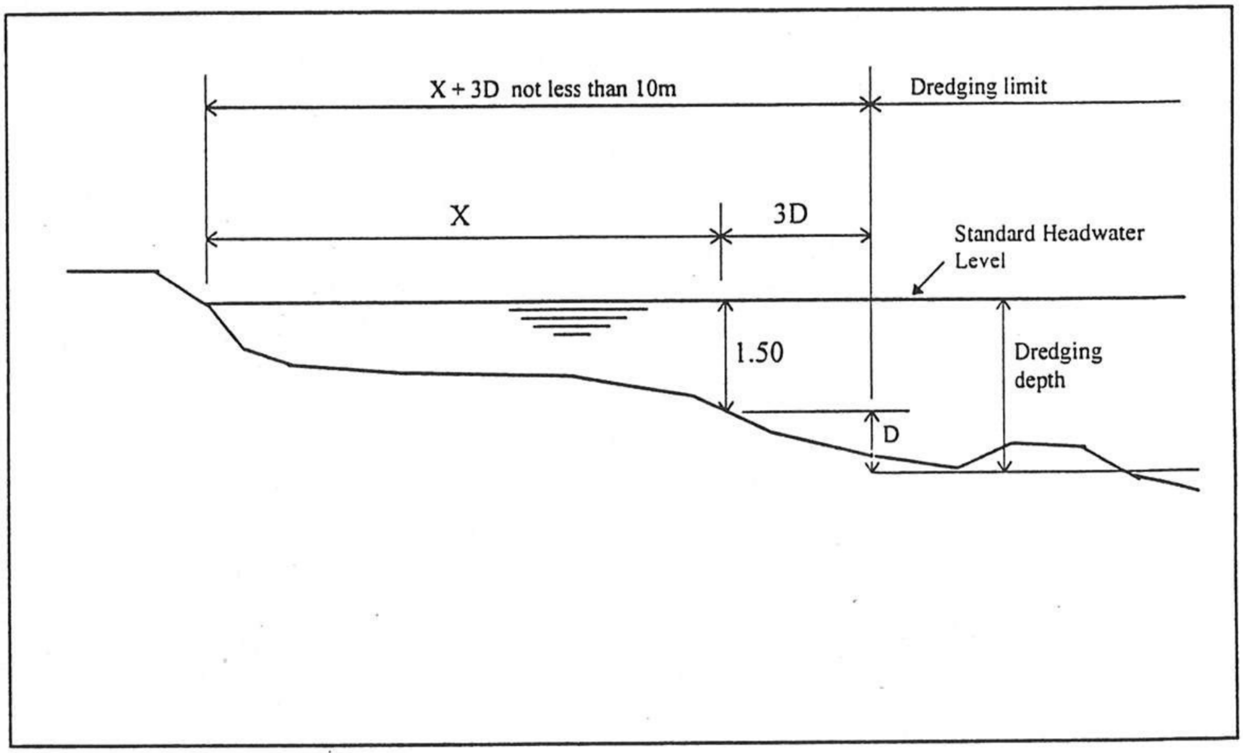


Figure 29. Channel dredging limit (Appendix 2, River Thames Dredging Study, July 1998)

Figures 30 and 31 show the historic design dredge levels for each dredge zone in the lower reaches of the Thames (from Hurley to Teddington locks) together with the latest bathymetric survey bed levels (2014 or 2015 depending on the reach). The plots show the average surveyed bed level within the historic dredge zones for sample cross-sections at 200m intervals along the river together with the average surveyed bed level over each entire dredge zone.

The surveys indicate that although the cross-sectional average bed levels vary by up to around 1m above design level, the average surveyed bed level in each dredge zone is less than or equal to the historic design dredge level in 35 of the 49 individual zones. The difference in average level in 7 of the remaining 14 zones is within the range of uncertainty in the survey data.

Temple : The average bed level in the first dredge zone is 0.15m above the dredge depth of 2.7m.

Cookham : The average bed level in the second dredge zone is 0.01m above the dredge depth of 2.2m.

Bray : The average bed level in the first dredge zone is 0.50m above the dredge depth of 2.4m and the average bed level in the second dredge zone is 0.04m above the dredge depth of 2.2m.

Boveney : The average bed level in the first dredge zone is 0.17m above the dredge depth of 2.2m and the average bed level in the second dredge zone is 0.23m above the dredge depth of 2.4m.

Penton Hook : The average bed level in the first dredge zone is 0.02m above the dredge depth of 2.7m and the average bed level in the second dredge zone is 0.13m above the dredge depth of 2.9m.

Chertsey : The average bed level in the first dredge zone is 0.04m above the dredge depth of 2.7m and the average bed level in the second dredge zone is 0.02m above the dredge depth of 2.8m.

Sunbury : The average bed level in the second dredge zone is 0.11m above the dredge depth of 3.0m and the average bed level in the second dredge zone is 0.04m above the dredge depth of 3.7m.

Molesey : The average bed level in the third dredge zone is 0.01m above the dredge depth of 2.7m and the average bed level in the fourth dredge zone is 0.22m above the dredge depth of 3.0m.

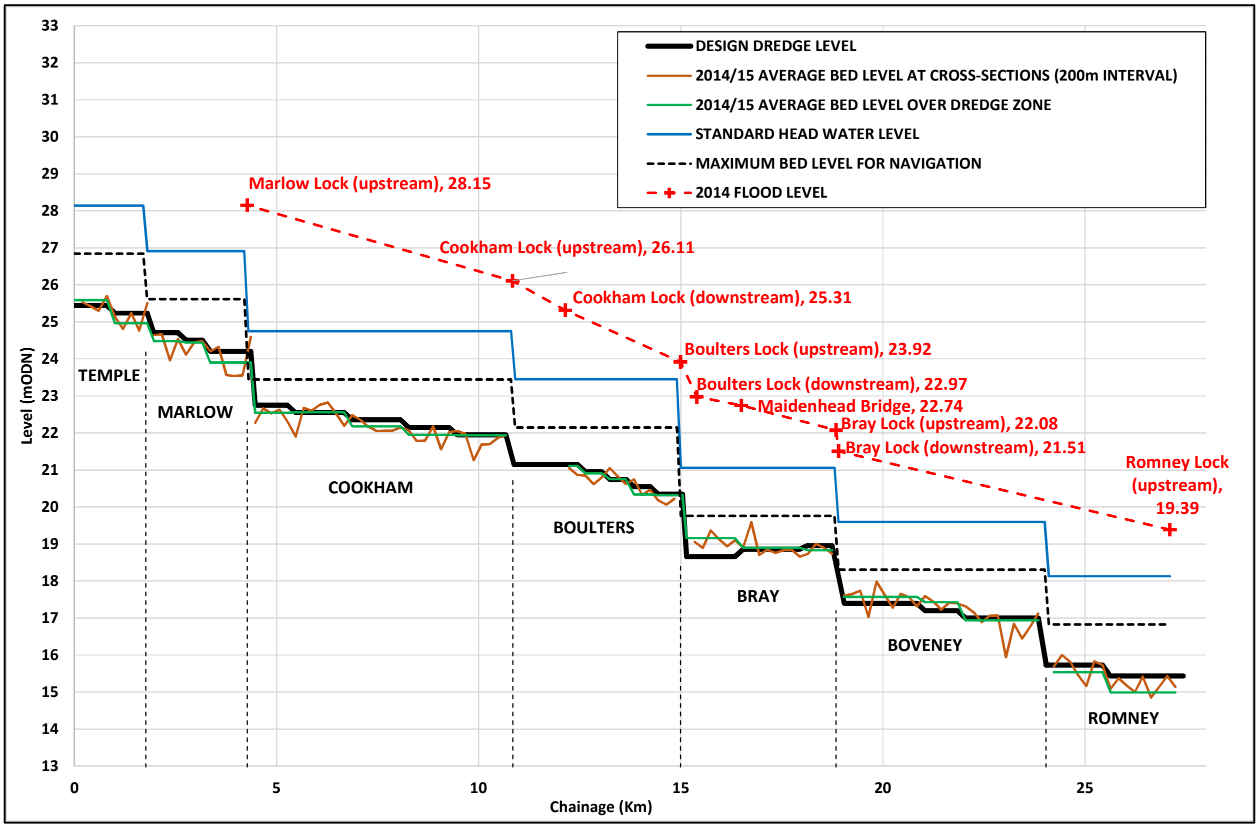


Figure 30. Current bed levels and design dredge levels (Temple to Romney)

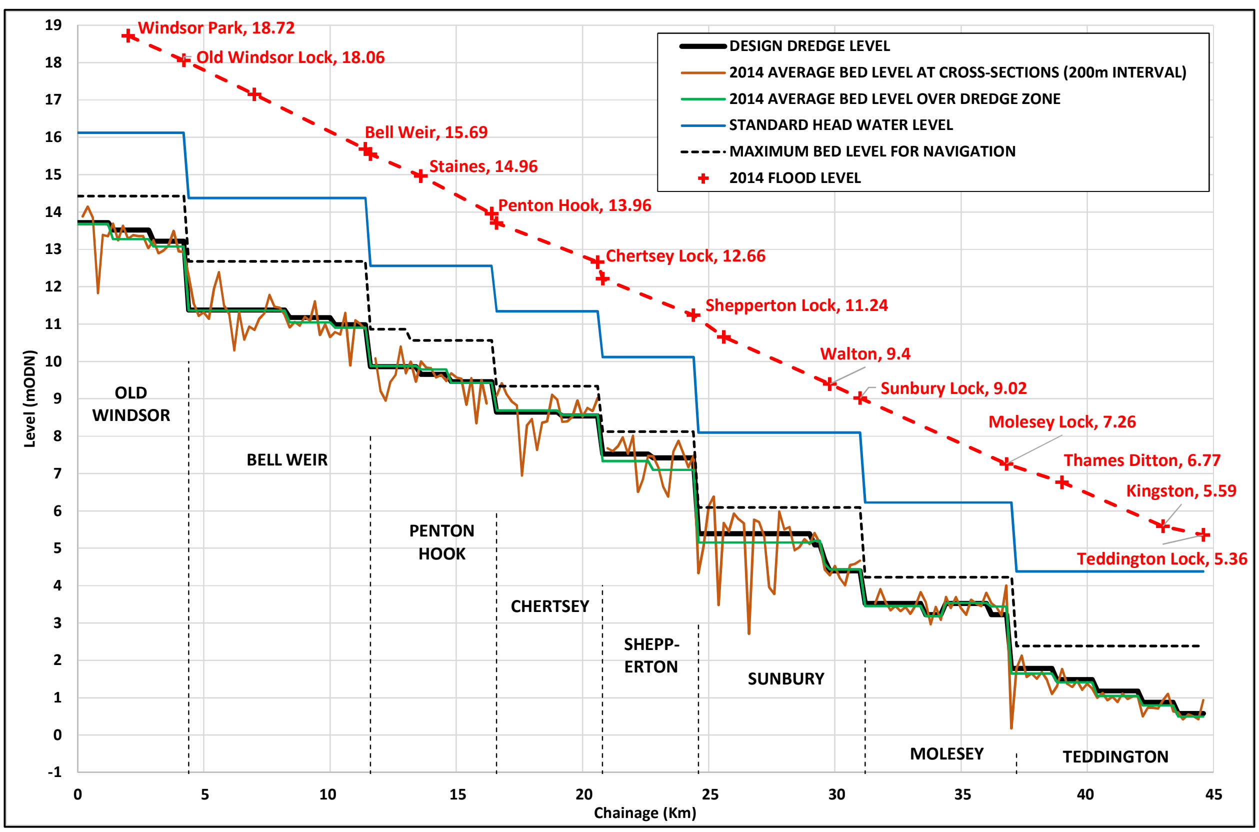


Figure 31. Current bed levels and design dredge levels (Old Windsor to Teddington)

A sample detailed comparison of the surveyed bed levels and design dredge levels across the entire historic dredge zone for a reach (Penton Hook) is included in Appendix 5 to illustrate the variation in channel depth and shape within the dredge zone of a reach.

Figure 32 shows the average 2014 survey bed levels in the dredge zones for Penton Hook reach for cross-sections at 200m and 10m intervals along the reach together with the design bed level and width of the dredge zone at each cross-section.

The data in Figure 32 shows a correlation between the width of the dredge zone, which is representative of the total width of the channel, and the average surveyed bed level at each cross-section. Bed levels tend to be lower where the channel is narrow and higher where the channel is wider, reflecting the effect of the channel width on the flow velocity and the tendency to erode in the narrower sections and deposit in the wider sections. Figure 32 also shows the average survey bed level in each of the three dredge zones. Although the average bed levels at each sample cross-section vary by up to around 1m from the design level, in the first and last zone the average survey level is within +/-30mm of the design level. In the central dredge zone the average survey bed level is 130mm higher than the design level.

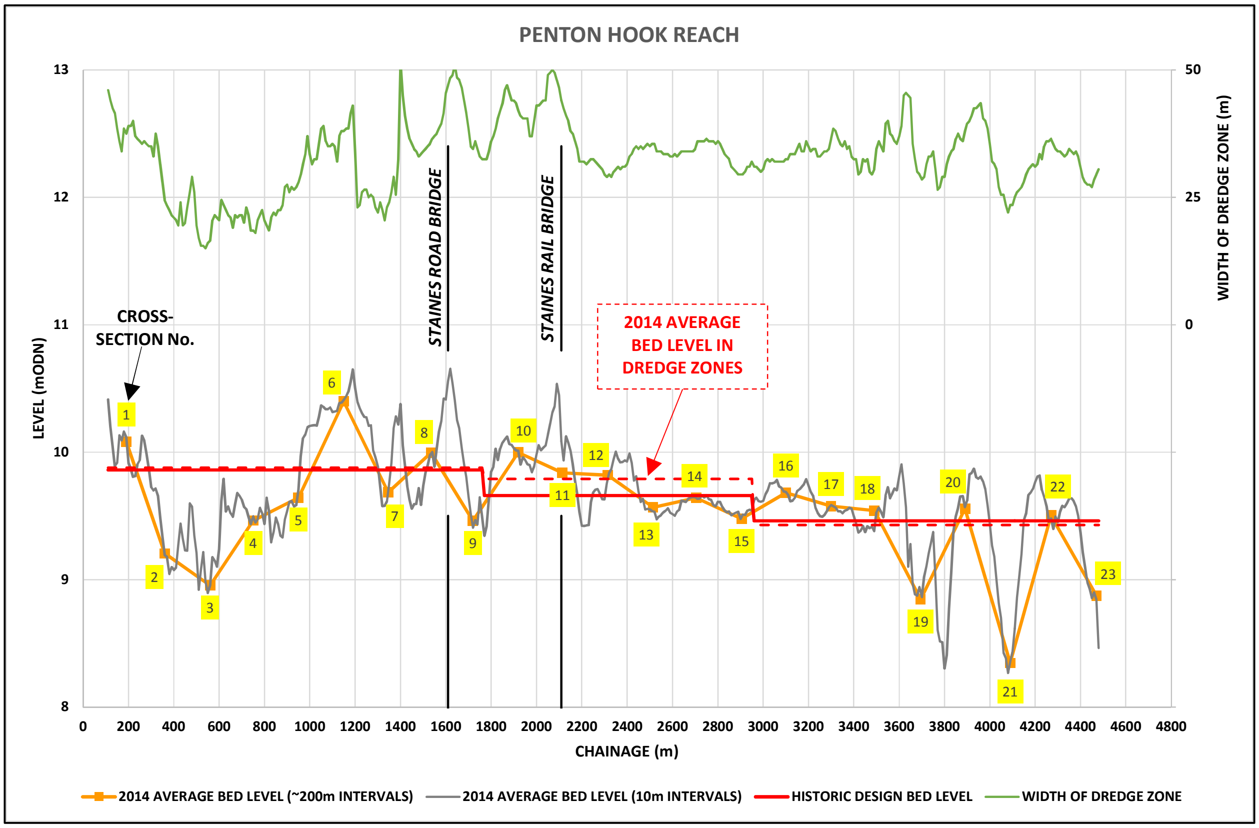
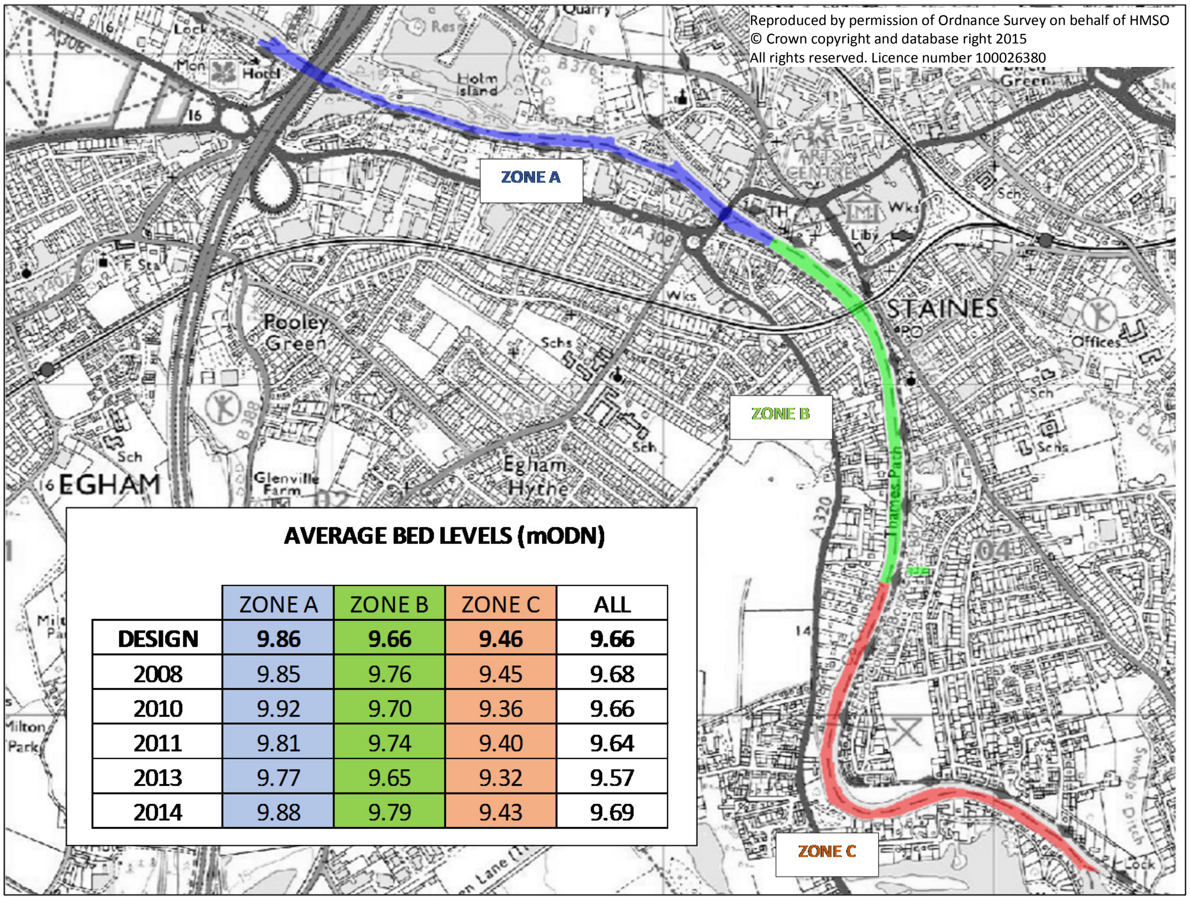


Figure 32. 2014 Survey bed levels and dredge levels (Penton Hook Reach)

Figures 33, 34 and 35 compare the historic design bed levels and the average survey bed level in each of the three dredge zones and for all three zones for all surveys of Penton Hook reach since 2008. In all three zones the average bed level is within +/-150mm of the design level over the period of the surveys and the average level over all three zones is within +/-100mm over the period of the surveys.

The results suggest that the total bed volume within the dredge zones is relatively stable over the period of the surveys and similar to the design bed volume. However, the shape of the river channel along the reach is modified from the design profile by the flow in the river in response to variations in the width and planform of the river and other features in the channel – bridges, for example.



	ZONE A	ZONE B	ZONE C	ALL
DESIGN	**9.86**	**9.66**	**9.46**	**9.66**
2008	9.85	9.76	9.45	9.68
2010	9.92	9.70	9.36	9.66
2011	9.81	9.74	9.40	9.64
2013	9.77	9.65	9.32	9.57
2014	9.88	9.79	9.43	9.69

Figure 33. Location of dredge zones and average survey bed levels in dredge zones (Penton Hook Reach)

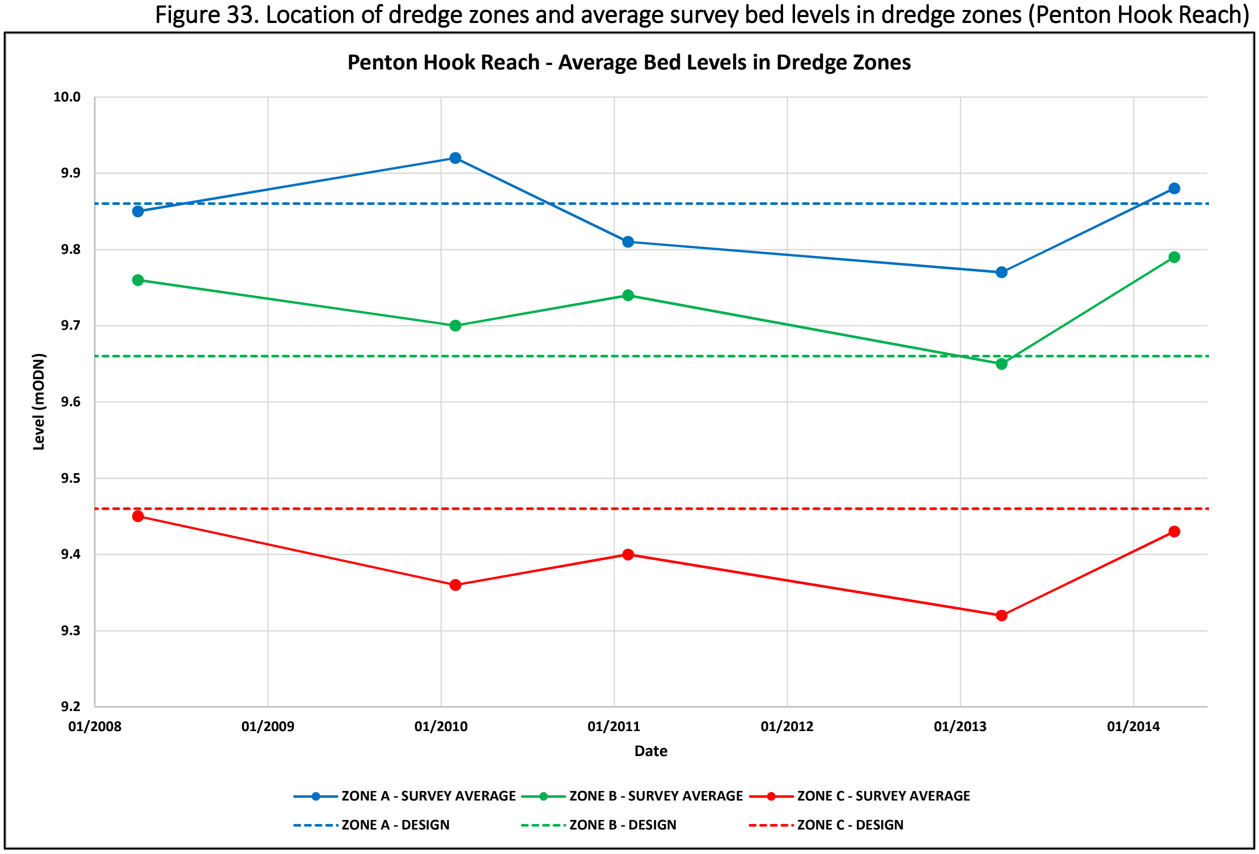


Figure 34. Average survey bed levels and design levels in each dredge zone since 2008 (Penton Hook Reach)

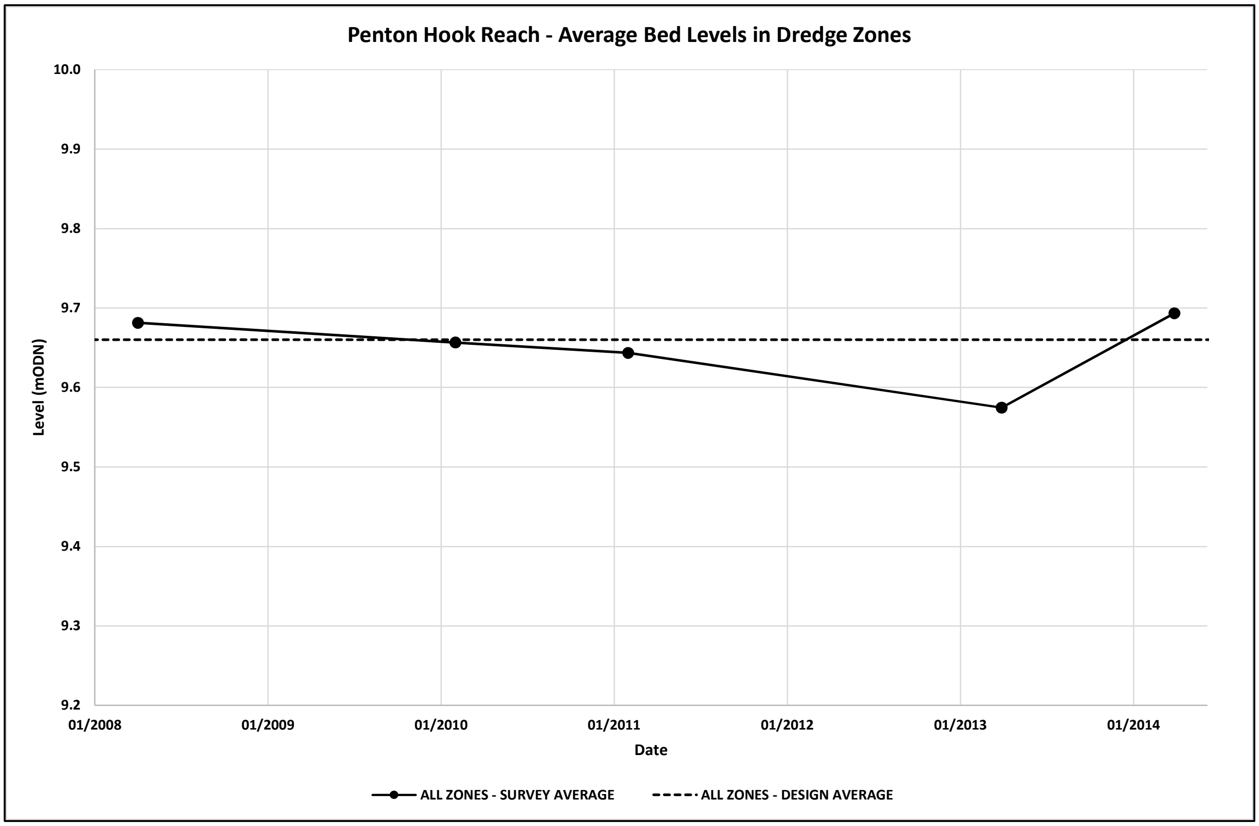


Figure 35. Average survey bed levels and average design level over all dredge zones since 2008 (Penton Hook Reach)

5.4.2 Dredged conveyance

Table 4 summarises the results of the conveyance calculations for the sample cross-sections in the lower reaches of the river (see Section 5.3.1 and Appendix 4). The average bed levels of the cross-sections from the latest surveys are compared to those if the surveyed channel were dredged according to the historic dredge level and the extents shown in Figure 28.

The difference between the current survey average bed level and the average bed level with dredging is generally less than the difference between the current survey average bed level and the design dredge level. This is because the dredge level is not applied across the whole of the surveyed cross-section. For example, for the two cross-sections in Bray reach, the historic dredge level is around 0.4m lower than the average surveyed bed levels in 2015 for both cross-sections. However, allowing for the ‘no dredge’ zones along the river banks, the average bed levels with dredging are 0.12m and 0.01m lower than the 2015 average bed level. The consequent increases in local channel conveyance at the 2014 flood level through dredging are 4.1% and 0.5%. Applying the dredge bed level at the Walton cross-section results in less conveyance than the survey cross-section because the dredge level is above the actual bed level.

As discussed in Section 5.3.1, the local channel conveyance at the two Bray cross-sections in earlier surveys (2003 and 2008) is greater than that with the dredged bed level and the dredged channel conveyance at the Staines cross-section is 2% greater than the largest surveyed conveyance (2008).

Table 4. Change in bed level and conveyance with dredging

Cross-section	Reach	Average Bed Level from Latest Survey (mODN)	Historic Dredge Bed Level (mODN)	Difference (m)	Average Bed Level with Dredging to Historic Level (mODN)	Difference (m)	Increase in Channel Conveyance with Dredge Bed Level[1]
Maidenhead (1)	Bray	19.09	18.66	-0.43	18.97	-0.12	+4.1%
Maidenhead (2)	Bray	19.08	18.66	-0.44	19.07	-0.01	+0.5%
Staines	Penton Hook	10.02	9.66	-0.36	9.77	-0.25	+7.7%
Walton	Sunbury	4.28	5.10	+0.82	5.12	+0.84	-25.0%

[1] conveyance calculated at local 2014 flood level

5.4.3 Dredging quantities and costs

Records of historic dredging of the lower Thames (Hurley to Teddington locks) between 1946 and 1998 are summarised in the River Thames Dredging Study (Mott MacDonald July 1998). Original records of dredging for the reaches upstream of Hurley Lock have been reviewed under this study. Collated records for each reach are available for the period 1948 to 1967. For the period 1968 to 1973, estimates of the total volume dredged for the whole river are available together with an indication of the areas dredged but no detailed breakdown of volume by reach was available for this study and this data has not been considered further. In general, the record data should be considered as indicative of the overall scale of historic dredging operations due to missing data and estimated quantities.

The average volume dredged from each reach per annual dredging operation is shown Figure 36 together with the number of recorded dredging operations and the indicative maximum annual volume of erosion and deposition recorded from the bathymetric surveys over the period of the surveys. Since the intervals between surveys are often several years the actual maximum annual rates of erosion and deposition are likely to be higher due to intermediate changes in volume between the surveys. Figure 37 shows the data expressed as an average depth over the reach.

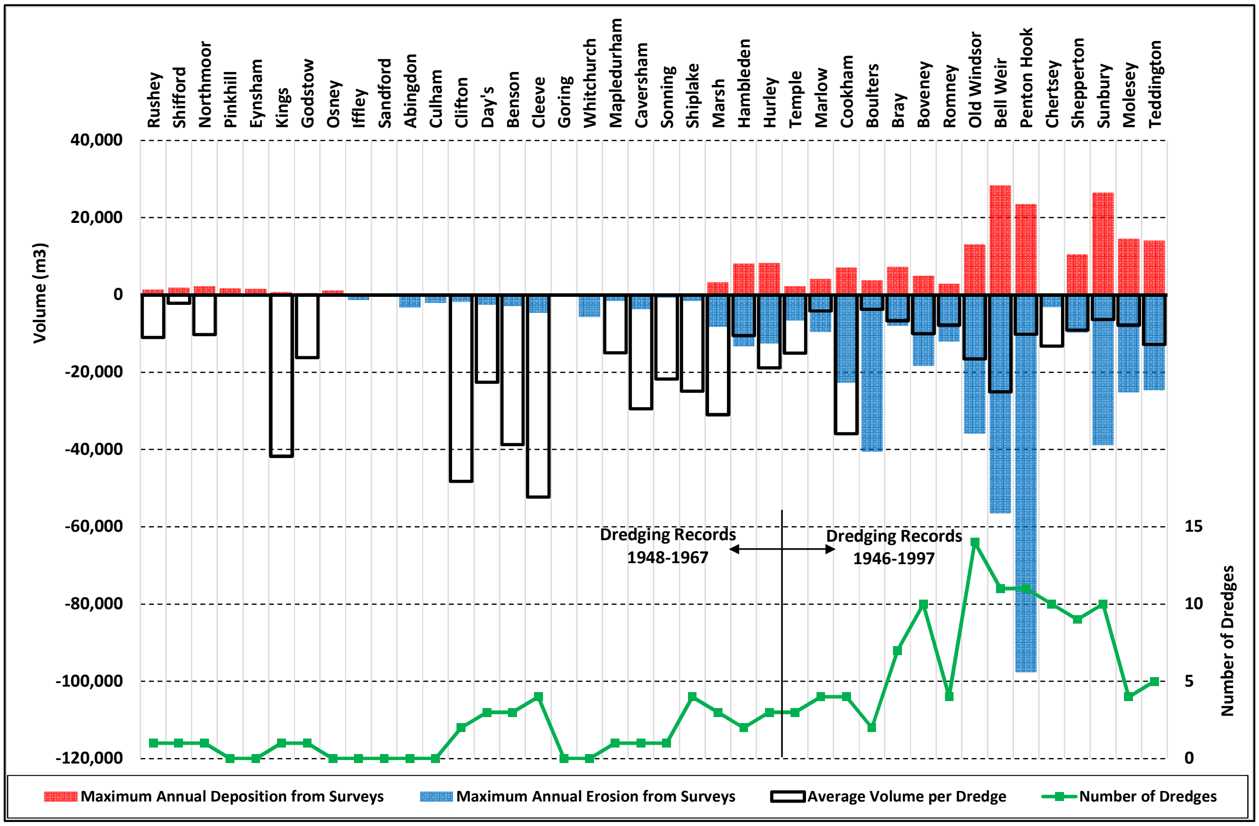


Figure 36. Historic Dredge Volumes and Surveyed Bed Volume Changes

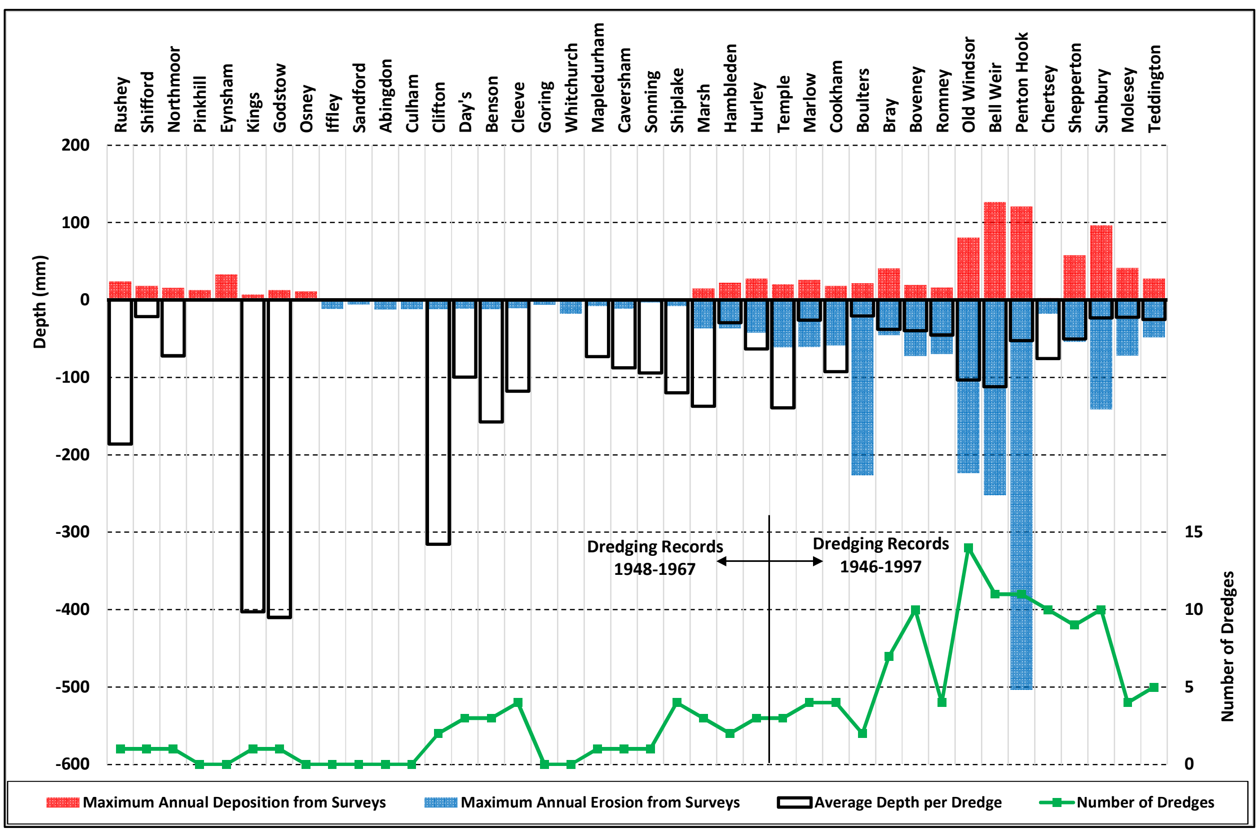


Figure 37. Historic Dredge Depths and Surveyed Bed Level Changes

For more than half of the reaches (Rushey to Shiplake) only two surveys are available and therefore only one annual volume of deposition or erosion for the survey period is estimated.

Records from the most recent programme of shoal removal in 2014 indicate that the total volume of shoal material removed over all reaches of the river was approximately 7,000m^3.

The survey data indicate that, where more than two surveys are available, the maximum annual volumes of erosion and deposition recorded in each reach are generally similar or the erosion volume is greater than the deposition (net erosion over the period of the surveys).

For the reaches from Hambleden to Teddington, the historic average volume dredged per operation is similar to or less than the maximum annual volume of change recorded in the surveys. For Hurley, Temple, Cookham and Chertsey reaches the average dredge operation volumes are greater than the annual volumes of change but only three or four dredging operations are recorded.

For the reaches upstream of Hambleden the historic average volume dredged per operation is far greater than the maximum annual volume of change recorded in the surveys. For all of these reaches, except Marsh, only two surveys are available over periods of between 9 and 11 years and so the estimated annual volume changes from the surveys are likely to underestimate actual annual rates to a greater degree than for the reaches with more frequent surveys. The number of dredging operations recorded for these reaches, for the period 1948 to 1967, is also smaller - less than five per reach. No operations are recorded in this period for nine of the reaches and for most of the other reaches only one operation is recorded. Although further operations have occurred between 1968 and 1998, the information available for the period 1968 to 1973 suggests the total number of operations to 1998 is likely to be low.

The average depth of material removed from a reach in each dredge operation is typically around 100mm to 150mm over the full reach area. Exceptions are Rushey, King's, Godstow and Clifton reaches where an average depth of up to 400mm has been removed in a single operation.

The average cost of shoal removal in 2014 was approximately £50/m^3 and the dredged material was disposed of within the river. Based on the 2009 upper bound cost estimate for dredging and disposal outside the river (Halcrow Group Ltd, July 2009), and allowing for inflation, the present cost of dredging and disposal based on the previous estimate would be approximately £80/m^3 without any consideration of other factors affecting costs.

Table 5 provides a simple indication of the quantities and costs of dredging to achieve average bed levels equal to the historic design dredge levels in all dredge zones of the lower reaches of the Thames (Hurley to Teddington lock) based on the latest bathymetric surveys of these reaches (as illustrated in Figures 30 and 31). It is assumed that the majority of the dredged material would need to be disposed of outside of the river channel. It should be noted that these quantities relate to reducing the average bed level to the design level and that some parts of the channel would remain above design level. The corresponding quantities for reduction of all bed levels to the design level would be greater.

The analysis of the effect of dredging on channel conveyance at sample cross-sections (Section 5.3.1 and Appendix 4) suggests the local increases in channel cross-section conveyance at the 2014 flood level could be of the order of 4% to 8%. In dredging locations upstream of structures which have a significant backwater effect, for example upstream of Chertsey, Bray and Boulter's weirs, the increase in conveyance may have less effect on flood water levels. The increase in conveyance of the reaches overall will be less than local increases since only part of the reaches are dredged.

Table 5. Indicative Dredging Volumes and Costs

Reach	Design Depth (m)	Average Dredge Depth (m)	Dredge Zone Area (m^2)	Indicative Dredge Volume (m^3)	Indicative cost (£)
Temple	2.7	0.15	33,930	5,090	407,000
Cookham	2.2	0.01	75,000	750	60,000
Bray	2.4	0.50	41,150	20,580	1,646,000
	2.2	0.04	72,140	2,890	231,000
Boveney	2.2	0.17	75,550	12,840	1,027,000
	2.4	0.23	54,450	12,520	1,002,000
Penton Hook	2.7	0.02	52,360	1,050	84,000
	2.9	0.13	43,310	5,630	450,000
Chertsey	2.7	0.04	75,460	3,020	242,000
	2.8	0.02	67,270	1,350	108,000
Sunbury	3.0	0.11	19,600	2,160	173,000
	3.7	0.04	55,750	2,230	178,000
Molesey	2.7	0.01	112,660	1,130	90,000
	3.0	0.22	45,490	10,010	801,000
TOTAL				**81,250**	**6,499,000**

5.5 Navigation

The Environment Agency is the navigation authority for the River Thames upstream of Teddington Lock and maintains a published level of service for the fairway between the locks. The current minimum navigation depths are presented in Table 6.

Table 6. Navigation Standard of Service

River Section		Minimum depth (m)
From	**To**	
Lechlade Bridge (St John's Reach)	Folly Bridge, Oxford (Iffley Reach)	0.9
Folly Bridge, Oxford (Iffley Reach)	Reading Bridge (Caversham Reach)	1.2
Reading Bridge (Caversham Reach)	Windsor Bridge (Romney Reach)	1.3
Windsor Bridge (Romney Reach)	Staines Bridge (Penton Hook Reach)	1.7
Staines Bridge (Penton Hook Reach)	Teddington Lock (Teddington Reach)	2.0

The latest bathymetric surveys (2014-2015) for all 40 reaches from Rushey to Teddington have been reviewed in relation to the required minimum depth at SHWL. Shoals in the navigation fairway where the water depth is less than the minimum depth or is within 300mm of the minimum depth are listed in Table 7. Plans showing the water depths at each location are provided Appendix 6. Only shoals in the main navigation fairway between locks have been identified. Shallow branches or backwaters have been ignored. It should be noted that dredging to allow bankside mooring may be necessary in some locations.

Table 7. Shoals recorded in 2014 and 2015 Surveys

Reach	Depth within 300mm of minimum requirement	Depth less than minimum requirement
Rushey	Meander downstream of Old Man's Bridge	
Shifford	Downstream of Tadpole Bridge	
Northmoor	Shifford Lock tail	
Pinkhill	Bends upstream and downstream of Farmoor Reservoir intake	
Eynsham	Pinkhill Lock tail, Downstream of Pinkhill Cruiser Station, meanders upstream of Swinford bridge, downstream of Swinford Bridge	
Kings		Downstream of Eynsham Lock and weir
Godstow		
Osney	Downstream of Godstow Lock, Tumbling Bay Bathing Place	
Iffley		
Sandford	Downstream of Iffley Lock, Downstream of Fiddlers Elbow	
Abingdon	Downstream of Sandford Lock (2 locations), 1Km upstream of Lower Radley	
Culham	Abbey Meadow (Abingdon), Culham Cut (footbridge)	
Clifton	Clifton Cut	Culham Lock tail (Tollgate Road Bridge)
Days	Clifton Lock tail, Clifton Hampden Bridge and Boathouses dowwnstream	
Benson		Day's Lock tail, Benson Lock entrance
Cleeve	Benson Lock tail	
Goring	Cleeve Lock tail	
Whitchurch	Goring Lock tail	Whitchurch Lock approach
Mapledurham	Whitchurch Lock tail	
Caverhsam		
Sonning		Thames & Kennet Marina entrance
Shiplake	Hallsmead Ait Head	
Marsh	Downstream of Railway Bridge downstream of Shiplake lock	Willow Marina channel
Hambleden		
Hurley		
Temple	Hurley Lock tail	
Marlow	Temple Lock tail	
Cookham	Marlow Lock tail	Cookham Lock Cut
Boulters	Boulter's Lock Cut	
Bray		Boulter's Lock tail
Boveney		
Romney		
Old Windsor		New Cut*, Blackpotts Bridge*, Romney Lock tail*
Bell Weir	Bell Weir Lock approach	Old Windsor Lock tail*
Penton Hook	Staines road bridge, Staines rail bridge, Penton Hook Lock approach	
Chertsey	Chertsey Lock approach*	
Shepperton	Chertsey bridge and bends downstream*, Pharaohs Island head, Shepperton Lock approach	Chertsey weir pool*
Sunbury	Sunbury Lock Cut	Shepperton Lock tail*, D'Oyly Carte Island*, entrance to Walton Marina*
Molesey	Head of Platt's Eyot	Sunbury Lock tail*, Head of Tagg's Island*
Teddington		Thames Ditton Island*

* indicates shoal removed in 2014 after surveys completed (dredged or naturally eroded)

A total of 61 shoals which may potentially affect navigation have been identified from the 2014-15 surveys. Figure 38 illustrates one of the shoals (a point bar) identified from the 2015 survey, upstream of Swinford Bridge in Eynsham reach. The shoal is marked by a buoy but remains a hazard for inexperienced users of the river.

Most of the shoal locations identified from the surveys are in lock cuts, the tails of locks or approaches to locks. These locations are vulnerable to persistent longer term deposition because they alter flow patterns and rarely have high velocity flows. Other locations include bridges where piers can impound flows resulting in deposition upstream and pier scour can result in local deposition downstream, meander bends where bars can develop due to the flow field around the bend and around islands where the flow energy is reduced. In these locations variations in river flow can result in the movement or removal of shoals as well as the formation of shoals.

The shoals occur in 33 of the 40 reaches. No such shoals were identified in Godstow, Iffley, Caverhsam, Hambleden, Hurley, Boveney and Romney reaches. Water depths at SHWL are less the minimum navigation requirement at the time of surveys in 20 locations but not necessarily across the full fairway width. At the remaining locations water depths are within 300mm of the minimum requirement at SHWL at the time of survey.

In 12 of the locations identified the shoals were targeted by the Environment Agency for removal following the surveys. In some of these locations (inside bend Chertsey Meads, tail of Weybridge Moorings/D'Oyly Carte Island, tail of Sunbury Old Lock, head of Taggs Island, tail of Steven's Eyot, tail lay-by Teddington Barge Lock) it was found that in the time between the survey and commencement of the shoal dredging operation (six months), the shoals had mobilised such that no dredging was required, demonstrating that the river is dynamic and regularly changing and reworking its bed.

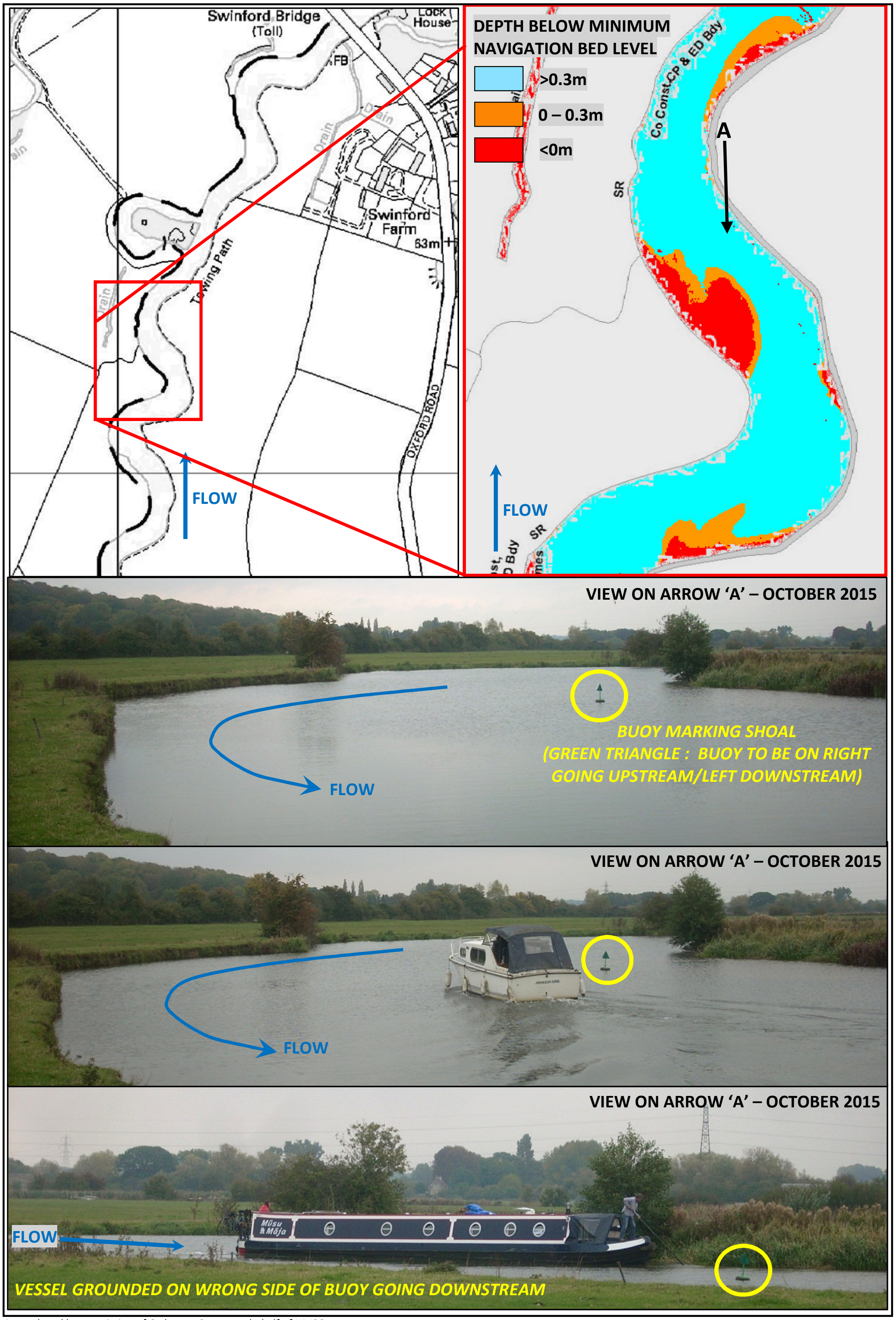


Figure 38. Navigation requirements : Eynsham reach

5.6 Environment

Dredging is potentially damaging to the ecology of the river and must consider environmental legislation on protected species and sites, and the Water Framework Directive 2001 (WFD). In terms of the WFD, there is a need to protect, enhance and improve the ecological status of water bodies, and the Environment Agency have a statutory responsibility to achieve this. River flow determines sediment and both contribute to the determination of the nature of the habitat. Sediment management is disruptive to the benthic, instream and riparian ecosystems by having an impact on macrophytes, sediments, invertebrates and fish.

5.6.1 Legislative Background

The WFD requires all natural water bodies to achieve both good chemical status and good ecological status. For each River Basin District, a River Basin Management Plan (RBMP) outlines the actions required to enable natural water bodies to achieve this. Water bodies that are designated in the RBMP as Heavily Modified Water Bodies (HMWB), such as the lower reaches of the Thames, may be prevented from reaching good ecological status by the physical modifications for which they are designated, for example navigation and flood defence. Instead they are required to achieve good ecological potential, through implementation of a series of mitigation measures defined in the applicable RBMP (and in some cases updated since the publication of the RBMP).

New activities that affect the water environment, such as dredging, can adversely impact biological conditions either directly or indirectly by changing the supporting hydro morphological, physiochemical or chemical quality elements, which might lead to deterioration in water body status or potential. In some cases a water body cannot meet its WFD objective of good ecological status or potential. The overall ecological status of a water body is primarily based on consideration of its biological quality elements (fish, invertebrates and plants). In order to achieve the overall WFD aim of good ecological status or potential, physiochemical and hydro morphological quality must also be considered of sufficiently high quality.

5.6.2 Water Framework Directive Status

At the time the Thames River Basin Management Plan (RBMP) was published (2009), 23% of surface waters were at good or better ecological status; and 28% of assessed surface water bodies at good or better biological status. In the Thames River Basin District (RBD) 26% of 259 artificial and HMWB were at good or better ecological potential compared to 21% of 312 natural water bodies. Figure 39 shows the ecological status or potential across the Thames River Basin District. Large stretches of the Thames are either good, moderate or poor status; in general the status is higher in the western upstream section of the river compared to downstream section where it becomes subject to Heavily Modified Water Body Status.

5.6.3 Conservation designations in the Thames

There is a legal requirement to maximise the opportunities for habitat creation and preservation, and management. The Thames contains a diverse range of internationally and nationally important (and designated) habitats including meadows, wetlands and reed beds that contain rare and protected species, as well as areas given a regional or local status. Many of these sites are intricately associated with the river through flow or water level dependence; some also rely on inundation so are sensitive to higher flows. There is also a requirement to conserve and enhance valued habitats for species with particular reference to Biodiversity Action Plan (BAP) species.

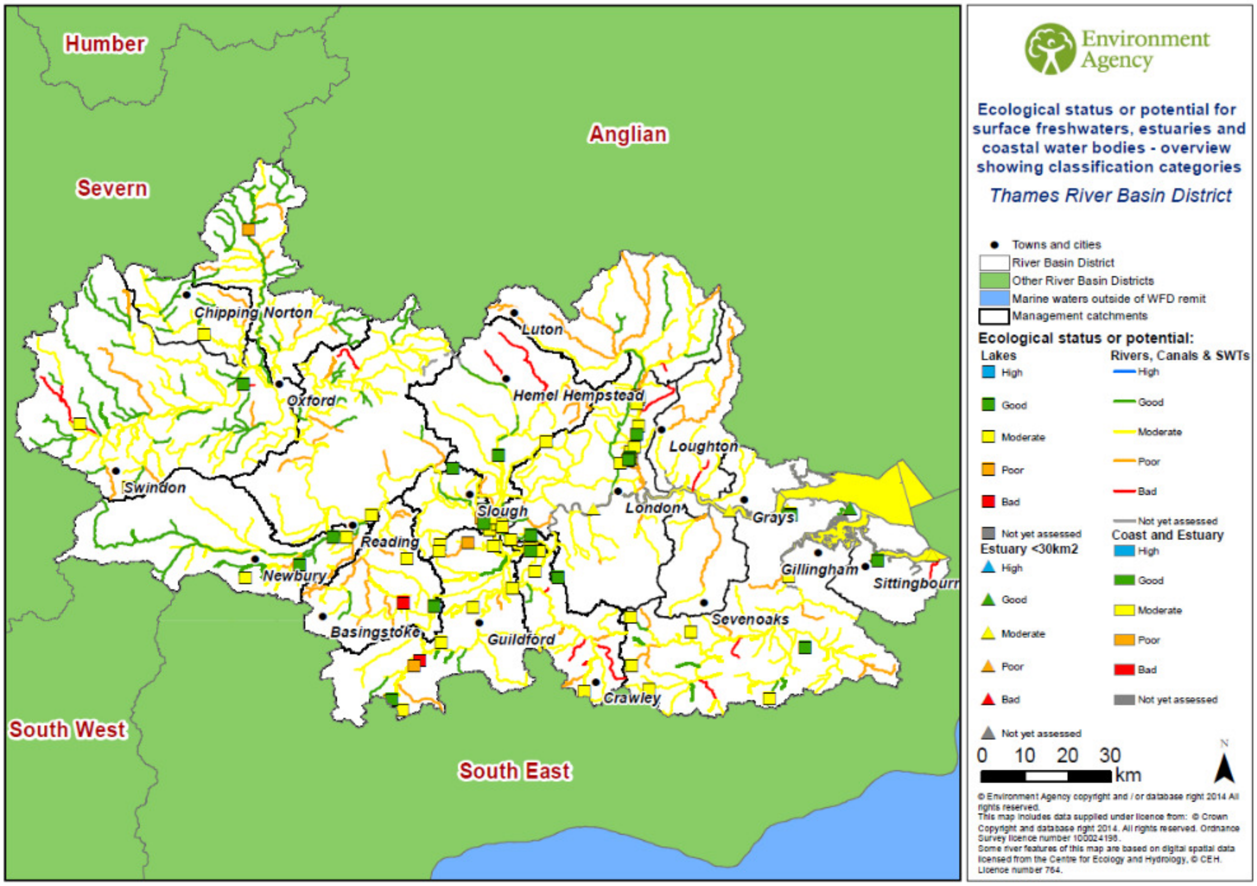


Figure 39. Thames River Basin District : Ecological Status

Figure 40 illustrates the extent of protected areas within the Thames. There are two National Nature Reserves (NNR), North Meadow and Chimney Meadows, and 35 water-related Sites of Special Scientific Interest (SSSI) along the Thames Corridor. This equates to about 6% of the Thames valley. Most of the SSSIs are at moderate ecological status or potential with a small number of stretches classed as either good or poor. There are 18 designated BAP habitats within the Thames Corridor, predominantly reedbeds and fens, plus some UK BAP species: Otter, Water Vole, Snakeshead Fritillary, Loddon Lilly, Creeping Marshwort, Fine Lined Pea Mussel, Depressed River Mussel, Greater Water Parsnip, Club-tailed Dragonfly, Tassel Stonewort and Desmoulins Whorl Snail.

The River Thames corridor supports other BAP species which use the riparian habitat, including Snipe and Lapwing, and Natterer's and Daubenton's bat. Approximately 6% of NCA (National Catchment Area) of the Thames' BAP habitat includes 2,000 hectares of wetland habitat. More than 800 ha of water bodies are classed as internationally important – SPA and RAMSAR for wildfowl. The Thames forms part of the West London water bodies SPA and RAMSAR site – wetland restoration and flood management. There are 4 SACS – 3,000 ha which are noted for invertebrate interest. The habits include: 294 ha of lowland meadows; 20 ha of fens; 1,133 ha of lowland dry acid grassland; 68 ha of lowland heathland and 17 ha of lowland calcareous grassland. Some river valley meadows and pastures are regionally important for wading birds, including small breeding numbers of lapwing, snipe, curlew and redshank, and large wintering numbers of lapwing and golden plover. The area also contains several candidate Special Areas of Conservation (cSAC) including: North Meadow and Clattinger Farm (Wiltshire); the Oxford Meadows (Oxfordshire); and Little Wittenham (Oxfordshire).

Within the boundary of Greater London, the Thames is classed as a Site of Metropolitan Importance (SMI). This is not a statutory designation but nationally or internationally designated sites are included in the boundaries of SMIs. The sites are identified as being of strategic importance for nature conservation and biodiversity across London.

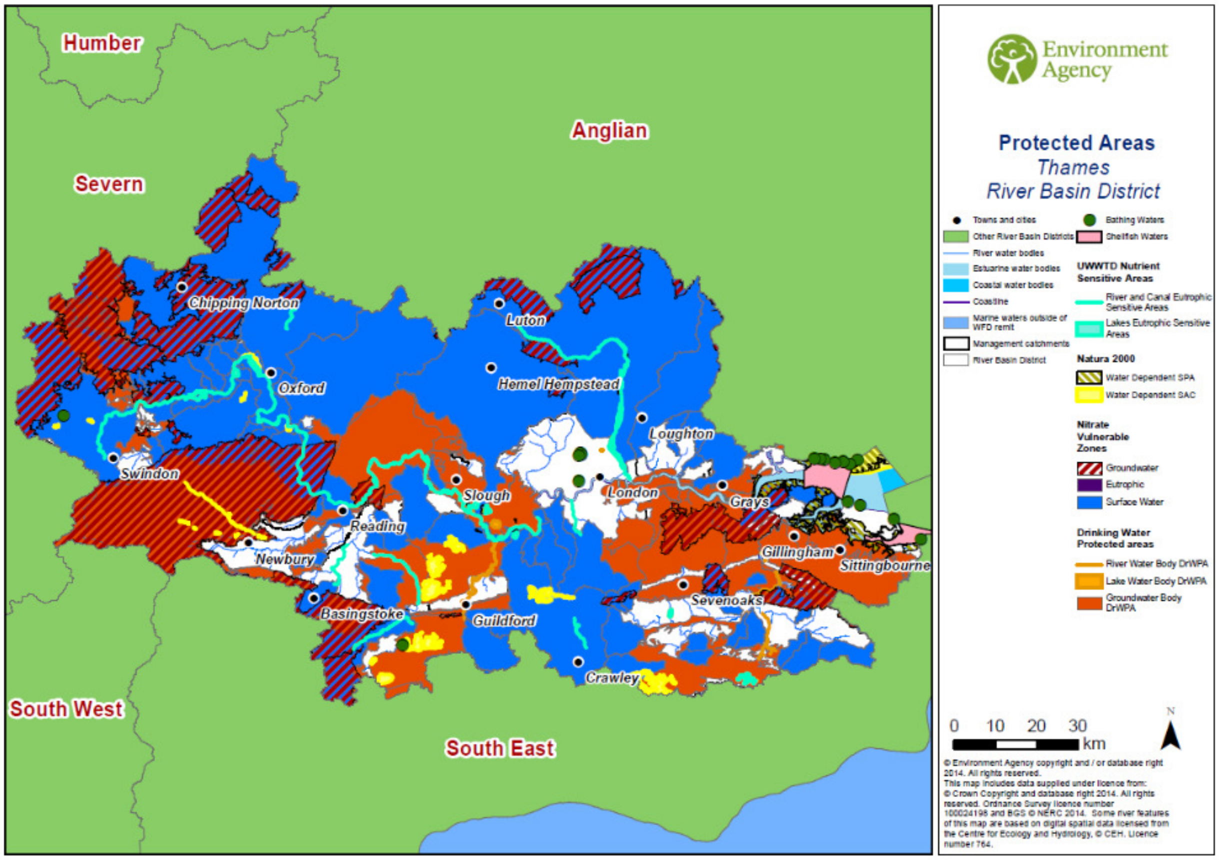


Figure 40. Protected areas in the Thames River Basin District

5.6.4 Dredging

The practices of either selective shoal removal or large scale sediment removal across whole sections of river channel can have consequences and impacts on the river environment.

The positive consequences of shoal removal are that some riverine systems can have too much sediment, limiting flow, causing poor water quality, and homogenous habitat. This is particularly important in designated sites that are in decline or unfavourable because of over-siltation, for example. In this case, sediment management can be considered as good practice. In particular, it is a useful tool for restoring natural in-channel and riparian morphology, and processes, particularly where the bed has been smothered by silt. It can be used to support the development and sustainability of riverine habitats. On the whole, in these particular cases, dredging could improve the condition of the site, and prevent further deterioration. Furthermore, improvement could also see an improvement in WFD water body status.

Conversely, dredging can have significant direct and indirect negative consequences for ecosystems, and therefore the status of the designated sites, and also WFD compliance. It can reduce species numbers and habitat quality which can prevent the achievement of WFD objectives, potentially leading to water body status deterioration. Dredging can significantly reduce the ecological value of sedimentary features, for example, which can have significant impacts not only for WFD but for other designations, particularly if sites are within Special Sites of scientific Interest or Special Areas of Conservation (SSSIs or SACs). Habitats become more homogeneous, with both quality and quantity of habitat being reduced.

Riverine dredging not only removes habitat and substrate, thus reducing the physical environment and species numbers, but can also disrupt geomorphological processes, and can reduce floodplain connectivity. The reduction in water levels associated with dredging can also dramatically alter the hydrology of the floodplain, reducing the frequency of shallow floods and lowering groundwater levels. The species diversity, and habitat quantity and quality of floodplain meadows can be compromised, leading to a decrease in insects, flora and fauna, and birds – particularly breeding wading birds. This is particularly important where there are fens, lowland meadows and acidic grassland SSSIs, for example Chimney Meadows SSSI in Shifford reach. It could also lead to degradation of RAMSAR/SPA sites, which are particularly important on wildfowl. Dredging upstream in a river can lead to other parts of the river becoming sediment starved, resulting in increased erosion and potential loss of habitat.

Dredging can reduce the diversity and density of invertebrate species, which is likely to have knock-on impacts on fish, and subsequently on top predators such as otters and fish-eating birds like kingfishers. Dredging gravels can damage vital spawning grounds for national species of conservation concern, such as Atlantic salmon, brown trout, European bullhead and lampreys – many of these exist in areas of SAC or SSSI within the Thames study area. These species rely on clean gravel, shallow water and oxygenated flowing water to spawn successfully. Even if spawning grounds are protected, the displaced sediment and/or increased sediment load resulting from dredging activities (through increasing suspended sediment concentrations within the water column) can smother fish eggs and juveniles. Dredging can also lead to habitat loss for juvenile flow-loving species such as salmon, trout and grayling, alter fish community and/or population structure and reduce total fish density and biomass compared to non-dredged areas. These fish may not even be present for considerable amounts of time (years).

Dredging can decrease soil stability along banks, leading to greater sediment input and bank erosion. Sometimes sediment features, such as bars, do not recover as the dredging process leads to 'fossilisation' of the planform because of bank processes and bank feature development being inhibited. This is less likely to be a problem in the lower reaches of the Thames due to the degree of bank stabilisation and protection but in the upper reaches, particularly above Oxford, where more active activity in the banks is observed, the effect may be greater.

If dredging is undertaken sensitively, marginal habitats can be retained, so that invertebrate and fish populations are either little affected or recover quickly. Sedimentation can also be managed outside the river through measures such as reducing soil runoff from farmland, particularly in the upper reaches of the Thames and preventing increased bank erosion through poaching by grazing livestock.

6 Dredging strategy

6.1 Overview

In general, over the majority of reaches, the bathymetric surveys do not show a definite trend of increasing or decreasing bed volume or average bed level with time. A possible exception are the reaches above Oxford, but it should be noted that only two surveys are available for these reaches so it is unclear whether or not the increase recorded is part of a longer term trend.

The surveys do show that average reach bed levels vary with time according to river flow conditions and that periods of both net erosion and net deposition are recorded. Insufficient data is available to determine the exact relationship between river flow and the changes in reach volume or the interaction between different reaches of the river.

The impact of these short term changes in bed levels on flood risk and associated damages has not been quantified.

Locally, the changes in bed level can obstruct the navigation fairway and it is clear that some limited shoal removal is needed periodically to maintain navigation rights and that clear marking of obstacles is needed. Given that shoals migrate, the position of these obstructions should be checked annually and after any significant flood event.

Three alternative dredging strategies are identified:

Strategy 1 : Monitor and Minimum Intervention

This is the lowest cost strategy and has the lowest environmental impact. It allows reach volumes or bed levels to vary naturally with time on the basis that there is no long term trend of increasing level and reduction in conveyance. The strategy has two main components.

Monitoring and analysis programme

- Regular surveys (reach wide bathymetry and local cross-sections) and review and analysis of data to improve understanding of the behavior of the river and identify any changes in the behavior which warrant a reappraisal of strategy.

- Potential ‘remote’ monitoring of reach conveyance using level and flow gauges in parallel with surveys, possibly including installation of new gauges, subject to proving of the value of this method.

Further details are provided in Section 6.3 below.

Removal of persistent shoals obstructing navigation

- From the monitoring programme, identification of shoals which obstruct the navigation fairway (a minimum width of approximately 8m to 14m depending on reach is generally required) and removal of material as required together with local monitoring of shoals which have the potential to obstruct navigation in the future.

Strategy 2 : Hold the Level

This strategy seeks to maintain reach bed volumes (or average bed levels) and channel conveyance more closely at a defined position (the present state or a recent historic state) through regular, selective dredging in order to prevent periodic short term increases in bed level and reductions in conveyance. The strategy could be applied to all reaches or targeted at reaches where the benefit is greatest.

The strategy will include the monitoring element of Strategy 1. Dredging will be triggered and specified in response to changes in bed levels identified from the monitoring programme. Some additional shoal removal for navigation at locations outside the main flow channel (lock cuts for example) will also be undertaken as required.

The strategy is more expensive than Strategy 1 since it will involve a greater volume of dredging, and will require more detailed environmental impact assessment, including more clearly defined 'no dredge' zones. The cost of this level of regular investment will require a detailed benefit-cost assessment to quantify the benefits of reducing the range of river bed level variations on flood damages.

Based on the available surveys the volume of dredging may be equivalent to a depth of around 100mm-200mm over a whole reach (around 30,000m^3 for Penton Hook reach for example) approximately every 5 years.

Strategy 3 : Maximise and Maintain Capacity

This strategy seeks to make a sustained increase to the present channel conveyance through reach wide dredging to reduce the current channel bed levels. The strategy could be applied to all reaches or targeted at reaches where the benefit is greatest.

The objective of the strategy is to reduce flood frequency and damages. The initial increase required in channel depth could be several times that in Strategy 2. The benefits of deepening the river channel are ultimately limited by the regulating structures at the downstream end of each reach and the natural gradient of the river. Regular maintenance dredging of the deepened reaches will be necessary and the dredge volumes may be greater than Strategy 2. In some reaches (where regulating structures are seen to be the limiting factor), additional works to modify those structures may also need to be considered.

The strategy will include the monitoring element of Strategy 1. Some additional shoal removal for navigation at locations outside the main flow channel (lock cuts for example) will also be undertaken as required.

The strategy is more expensive than Strategy 2 and will require a detailed environmental impact assessment. It is possible that environmental legislation will limit the extent of the dredging and the resulting benefits. The cost of the initial and regular levels of investment will require a detailed benefit-cost assessment to quantify the benefits of the increased channel capacity on flood damages.

6.2 Discussion

In the absence of a clear trend of increasing bed levels and a detailed benefit-cost assessment of strategies to maintain alternative river bed levels, Strategy 1 is considered appropriate for the majority of the reaches at the present time. In the event that the results of monitoring under this strategy indicate a change in the behaviour of the river or indicate longer term trends, the choice of dredging strategy should be reappraised.

In parallel with Strategy 1, an assessment of the benefits of the different levels of dredging under Strategy 2 and 3 could be considered. Initially this could be applied to a sample reach or reaches (Old Windsor, Bell Weir and Penton Hook are suggested). This could include hydraulic modelling of the reaches with alternative bed profiles to determine flood levels for a range of return periods under each profile and an assessment of the resulting damages and costs.

Consideration might also be given to applying the Strategy 2 approach to sample reaches together with more frequent monitoring of subsequent changes in bed levels. Depending upon observed changes in these reaches, future consideration might be given to adopting Strategy 2 more widely in the reaches most likely to benefit from a more closely maintained conveyance.

6.3 Monitoring

All three of the identified dredging strategies include a monitoring programme which should include the following elements.

6.3.1 Bathymetric surveys

The reaches above Oxford (Rushey to Osney) should be surveyed again within two years or following any high flow or low flow period (to be defined) in order to inform on any trend of deposition in these reaches. Surveys of selected reaches in the lower Thames (Old Windsor to Teddington) and at selected intermediate reaches should be made at the same time to help understand the movement of sediment along the river.

Surveys of the lower reaches (Old Windsor to Teddington) should continue at an interval of six months to one year and, where possible, before and after any high and low flow periods.

There is merit in surveying the whole river within a single campaign in order to improve understanding of river scale trends that cannot be investigated at present due to inconsistencies in the timing of surveys.

6.3.2 Navigation and Dredging

Shoals identified in this study as potential obstructions to navigation should be monitored on a regular basis – annually for example, or following high or low flow periods. Results of the monitoring and any subsequent shoal removal should be systematically recorded together with the exact location of removal, volume removed, sample particle size analysis and disposal location.

6.3.3 Key locations

Key locations could be identified where more regular monitoring of bed levels will help to improve the understanding of the channel behaviour – for example where regular shoal dredging is needed to maintain navigation or where sedimentation is perceived to increase flood risk. Monitoring at these locations could be by cross-section surveys rather than MBES surveys.

6.3.4 Remote monitoring

Analysis of water level and flow records for Bray reach indicate that such data may be useful as a means of remotely monitoring the changes in the conveyance of a reach.

Historic data (where available) for water level and flow at the locations with existing gauges identified in Table 8 could be reviewed to confirm whether it provides a reliable means of monitoring changes in reach conveyance. If so, a method for ongoing monitoring of gauge data to identify changes in conveyance or to trigger surveys or a review of dredging strategy could be established. If beneficial, the installation of additional water level gauges at the locations identified to provide further monitoring points could be considered.

Table 8. Potential gauges for remote monitoring of conveyance

No.	Reach	Water Level Gauge	Existing/ New	Flow Gauge (all existing)	Comments	
1	Teddington	Downstream of Mole	New	Kingston		
2	Molesey	Sunbury Lock Tail	Exist	Kingston (Thames) & Esher (Mole)	Possible influence of Mole flow on water levels	
3	Shepperton	Chertsey Lock Tail	Exist	Staines	Possible influence of Wey flow on water levels	
4	Chertsey	Penton Hook Lock Tail	Exist	Staines		
5	Penton Hook (below Colne)	Downstream of Colne	New	Staines		
6	Bell Weir	Downstream of Old Windsor Weir	New	Windsor		
7	Old Windsor (above Jubilee River)	Romney Lock Tail	Exist	Windsor (Thames)	Some influence of Jubilee River operation	
8	Old Windsor (below Jubilee River)	Downstream of Jubilee River	New	Windsor		
9	Romney	Boveney Lock Tail	Exist	Maidenhead	Possible influence of Jubilee River flow on water levels	
10	Boveney	Bray Lock Tail	Exist	Maidenhead		
11	Bray	Boulter's Lock Tail	Exist	Maidenhead		
12	Boulter's	Cookham Lock Tail	Exist	Maidenhead (Thames) & Taplow (Jubilee River)		
13	Caversham	Mapledurham Lock Tail	Exist	Reading	Possible influence of Kennet flow on water levels	
14	Days	Clifton Lock Tail	Exist	Sutton Courtenay	Possible influence of Thame flow and Didcot abstractions on water levels	Accuracy of gauges at higher flows less reliable due to greater degree of out of bank flow in upper Thames at lower return periods
15	Clifton	Culham Lock Tail	Exist	Sutton Courtenay	Possible influence of Didcot abstractions on water levels	
16	Culham	Abingdon Lock Tail	Exist	Sutton Courtenay		
17	Eynsham	Pinkhill Lock Tail	Exist?	Farmoor	Possible influence of Evenlode flow on water levels	
18	Pinkhill	Northmoor Lock Tail	Exist?	Farmoor	Possible influence of Farmoor abstraction on water levels	
19	Northmoor (downstream of Windrush)	Downstream of Windrush	New	Farmoor	Possible influence of Farmoor abstraction on water levels	

6.4 Data analysis

Various types of additional analysis of the recorded bed levels can be made to obtain valuable insights into the morphological processes and to inform potential options for addressing unacceptable flood risk along each reach.

In particular:-

- Evaluate difference for a) first and last survey and b) previous and last (to give a better idea of long and short term trends).

- Undertake flood modelling to represent conditions at the times of different surveys. This would indicate the impact of bed level change on flood levels and the number of properties impacted.

In addition, preparing a sediment budget of the catchment to understand the sources of sediment would help identify if there are potential catchment management methods that could reduce sediment inputs and impacts on navigation and flood risk as well as giving a better understanding of the river morphological processes.

7 References

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