SEDIMENT IMPACT ANAYSIS FOR THE LOWER THAMES FLOOD STRATEGY STUDY

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INTRODUCTION

Sediment impact assessment was performed during the Lower Thames Flood Strategy Study to assess the geomorphological sustainability of river-bed re-profiling to reduce flood risk in the reach between Datchet and Teddington. The specific objectives of the sediment study were to:

i. estimate how much sediment is likely to be deposited in, or eroded from, the study reach by flows up to and including long return interval flood events for 'do minimum' and 'bed reprofiling' options that would lower the bed by 0.5 to 1 m;

ii. estimate an average annual rate of sedimentation for the 'do minimum' and 'bed reprofiling' options.

MORPHOLOGY OF THE RIVER THAMES

The study reach of the River Thames has the characteristics of a mature, lowland river with well developed meanders and reaches divided by stable, mid-channel islands. The movement of water and sediment along the river has been controlled by locks and weirs for over a century. These structures present obstructions to the natural movement of sediment and dredging was, historically, required to maintain a navigable channel. The banks along much of the navigable river have been stabilised by revetment and, therefore, the river is unable to adjust its planform.

SEDIMENTATION AND SEDIMENT TRANSPORT

Analysis of dredging records: Dredging records for the Lower Thames, investigated as part of the Lower Thames Dredging Study (Mott MacDonald, 1998), show that dredging has declined from the high activity of the late 1940s to the late 1990s, following the 1947 flood, and that since 1997, there has been very little dredging in the study reach. The reduction in dredging over recent years may be related to a reduction in sediment supply due to river engineering throughout the Thames basin. The recent cessation of dredging reflects not only a reduced need, but also stringent new environmental controls on the disposal of dredged material, coupled with increased costs of disposal.

It is believed that the quantities of sediment dredged annually in the study reach were broadly in balance with annual rates of sedimentation for the 10-20 year period prior to 1997, when dredging ceased, suggesting a sedimentation rate of about 37 000 tonnes/year. Since then, bed elevations are thought to have increased somewhat, in response to the lack of dredging (Smith, pers. comm., 2005).

Suspended sediment concentration from the Thames: No long term record of suspended sediment concentration has been published for the Lower Thames. However, HR Wallingford (1988) report measurements over a 3-month period in 1987 (Figure 1).

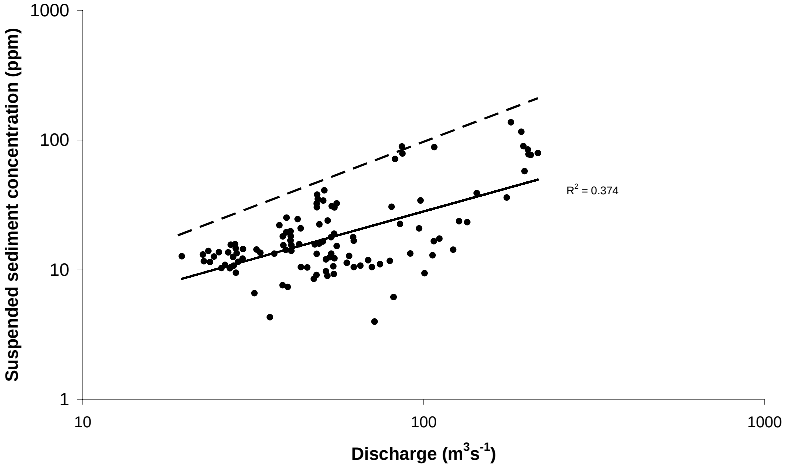

Figure 1 Sediment rating curve at Boulters Weir from HR Wallingford (1988).

The best-fit regression line for the data in Figure 1 has the form: $C = aQ^b$, where, $a = 0.97$ and $b = 0.78$. This equation gives a sediment concentration at near bankfull flow of only 91.5 ppm. On most river systems, the value for the exponent b, typically falls in the range 1 to 2 (Walling and Webb, 1992). Hence, the above relation probably under-estimates suspended sediment concentrations, particularly at high flows. Des Walling (pers. comm. 2005) suggests that suspended sediment concentrations in the Lower Thames may reach 250-300ppm at bankfull flow. If a value of unity were used for exponent b in the above equation, a suspended sediment concentration of 250 ppm would be obtained for a bankfull flow of 256 m^3s^{-1}, which may be more reliable than the value based on the limited measured data. Hence, in the modelling section of this study, the Q-C relation obtained using this higher exponent was used as well as the Q-C relation for the measured data, to specify *upper* and *lower-bound* estimates of sediment inflow concentration.

Sediment load estimates: Q-C relations can be used to estimate the total suspended sediment load transported during a specific time period by combining the sediment concentration with the discharge record. The upper and lower bound sediment concentrations from Figure 1 were converted to sediment loads in tonnes/day and the sediment transport for each discharge class was multiplied by the frequency of occurrence at the Windsor gauge between 1979 and 2004 to estimate the suspended sediment load transported during that period. Dividing these totals by the number of years of record gives a lower-bound annual sediment load estimate of 45 000 tonnes and an upper bound estimate of 158 000 tonnes. This equates to an upstream sediment yield in the range 6-22 t km^{-1} which is considered appropriate given the land use characteristics and sediment control upstream (Halcrow, 2001). These sediment loads are, however, considerably higher than the estimated average annual rate of sedimentation (37 000 tonnes/year). This indicates not only that some of the bed material load passes through the study reach, but also that at least 70% of the total granular load is actually ‘wash load’, which is held permanently in suspension and hence, does not accumulate on the river bed. If 25% of this material is assumed to deposit in the study reach (75% being through-put load and washload), 11- 40 000 tonnes will be deposited in the channel (not including sediment contributions from the tributaries). When considered alongside the estimate of 37 000 tonnes from dredging/hydrographic survey analysis, it suggests that the measured Q-C relation may indeed underestimate sediment concentration.

Suspended sediment concentrations from the Jubilee River and tributaries: In addition to specifying the upstream Q-C relation for the River Thames, Q-C relations must be specified for tributary and other inflowing channels for the purposes of sediment impact assessment. The tributaries and inflowing channels in the study reach are listed below in downstream order. As no measured sediment concentrations are available for these watercourses Q-C relations were formulated from available, qualitative information.

- Jubilee River (flood diversion channel)
- River Colne (tributary)
- River Wraysbury (tributary)
- Colne Brook (tributary)
- River Wey (tributary)
- River Mole (tributary)

The Jubilee River diversion channel carries a high proportion of the total flow in the Thames during a 5-year event and, therefore, represents a potentially important sediment inflow. Analysis of aerial photographs during the 2003 flood on the Lower Thames indicate that the sediment concentration in the Jubilee River diversion channel was higher than that in the main river. However, the concentration may have been elevated because it was the first time the channel was operational. In the modelling, the suspended sediment concentration inflow from the Jubilee was, therefore, assumed to be the same as the inflow from the main Thames. The Rivers Wey and Mole are the most important tributaries in terms of discharge. In the River Wey Environmental Management Strategy (Mott MacDonald, 1997), the sediment concentration is estimated to be 200 ppm at 10 m^3s^{-1} and 400 ppm for a mean annual flood flow of 28.4 m^3s^{-1}. To obtain a Q-C relation for the tributary inflow boundary, higher and lower flow concentrations were extrapolated based on these estimates. Since the River Mole has some similar catchment characteristics to the River Wey, this Q-C relation was also used as the inflow boundary for the Mole tributary. There is no published information regarding sediment concentrations for the remaining tributaries and so Q-C inflow relations were assumed to be the same as in the main river. Errors resulting from this assumption are not significant because their collective discharge contribution is minor (12 m^3s^{-1} for the 5 year design event) and, therefore, their collective contribution of sediment will also be small.

Suspended sediment composition: The only reported information on suspended sediment composition in the Lower Thames is provided from a 25 litre water sample collected from the silt monitoring station just upstream of Boulters Weir as part of the Maidenhead Morphological Study (HR Wallingford, 1988). The D_{50} and D_{75} of the silt-sized fraction were found to be 0.005mm and 0.017mm, respectively. Since material of sand-sized or coarser (>0.063 mm) was not analysed, these values represent only the finer fraction of the sediment load. It is likely that the D_{50} and D_{75} would have been somewhat coarser if the whole particle size distribution had been analysed, better representing suspended sediment characteristics in the River Thames. Since there is little reported information on the suspended sediment composition of the tributaries, they are assumed to be the same as those in the main river.

Surface bed material: A series of bed material gradation curves arising from the available data are plotted in Figure 2. Bed material is generally dominated by fine-medium gravel (70-

95%) and medium-coarse sand (5-25%), although individual samples range from fine-medium sand dominated (with some silt/clay material) to coarse gravels-dominated. The degree of variability is shown by the 'min' and 'max' curves representing the finest and coarsest of 40 samples analysed (HR Wallingford, 1988).

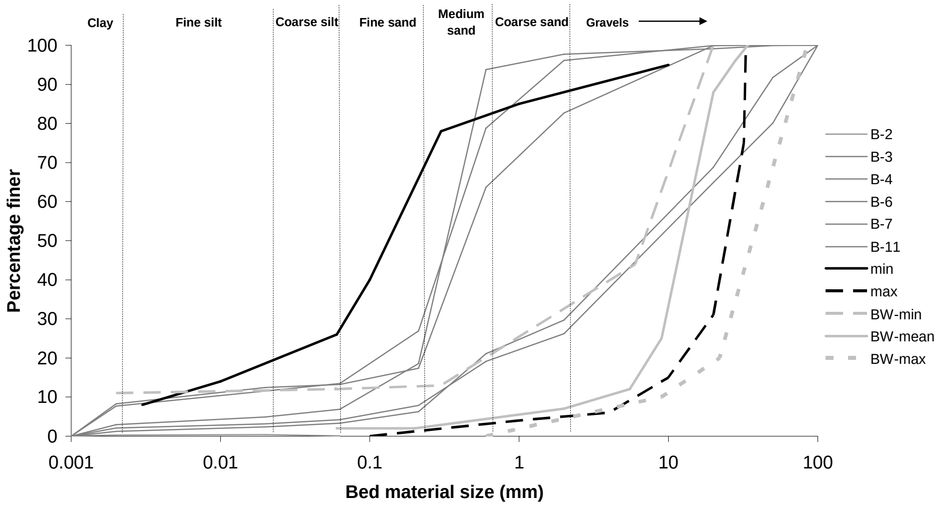

Figure 2 Bed material gradation curves for samples taken from the Lower Thames.

Subsurface bed material: The sediment stratigraphy from borehole logs was used to infer the composition and variability of subsurface material. The upper layer is floodplain alluvium, which is typically composed of fine silt, sand and clay and has an average thickness of approximately 3 m. This is underlain by a much coarser, gravel-dominated complex. The Lower Thames flows across these gravels for most (if not all) of the study reach. The thickness of the gravel unit averages 4.2 metres, although this ranges from about 1 metre to over 6 metres. Hence, deepening the river by re-profiling the bed is likely to expose gravel similar to the existing bed material in most locations. However, there is a risk of underlying London Clay being exposed in some downstream locations, where the gravel unit only about 1 m thick.

iSIS-SEDIMENT MODELLING

The 1-D iSIS sediment transport model was used to estimate the sediment impacts in the study reach of 'do minimum' and 'bed re-profiling' options. Modelling involved three stages:

1. assessing the sensitivity of model output to sediment boundary conditions; inflow suspended sediment concentrations; inflow suspended sediment composition; and bed material composition.
2. simulating the geomorphological impact of design flow events with return periods of 2, 5 and 20-years and a constant lower flow (25% exceedance at Teddington) for 'do minimum' and 're-profiling' options.
3. predicting the long-term average annual rate of erosion/deposition from the event-based analyses described above.

iSIS-sediment uses equations for sediment transport and sediment continuity to calculate sediment transport rates, erosion/deposition and bed elevation changes within a modelled reach. Cross-sections are updated according to predicted quantities of erosion/deposition and the hydraulic model is updated accordingly at the end of each timestep. Sediments can be divided into as many as 10 particle size classes. Transport rates for each size fraction are predicted using one of four sediment transport equations. Fractions can be specified as either cohesive or non-cohesive. In this study, the Westrich-Jurashek sediment transport equation was used for cohesive sediments (< 0.032 mm) and the revised Ackers-White sediment transport equations were used for all coarser fractions.

A base iSIS-sediment transport model was completed and tested, with gate movement rules added to the model to ensure water levels stay above the Standard Head Water Levels at each of the lock reaches (i.e. the levels retained for navigation). This is necessary as much of the sediment deposition is likely to occur as the flows recede after an event, as well as possibly during lower flow periods.

iSIS-sediment was run for the 2, 5 and 20-year return period flows, and a constant in-bank flow to account for lower flows. Sediment boundary conditions were specified for the channel bed and for all upstream inflow boundaries. Suspended sediment inflows into the Lower Thames (upstream, Jubilee and tributaries) were specified as Q-C boundaries. It was assumed that the density of all sediments was 2650 kg m^{-3} and a constant bed porosity of 0.6 was used.

To predict event-based and longer-term average rates of erosion/deposition, the upper and lower bound estimates of sediment concentration were applied for sediment inflow boundaries. Sensitivity analyses were undertaken to identify model response to variations in bed material and suspended material composition.
Based on the results of sensitivity analyses, it was decided to appraise options for the range of flow boundaries using three sets of sediment boundary conditions:

1. measured (lower bound) inflow sediment concentration and coarse bed material.
2. high (upper bound) inflow sediment concentration and coarse bed material.
3. measured inflow sediment concentration and intermediate bed material.

Sediment Impact of events for ‘do minimum’ option: In Figure 3, net deposition amounts are plotted for the three return period events and the constant, in-bank flow. There is greater uncertainty in the reach response for higher return period events. Both model runs with coarse bed material result in aggradation, but when the bed material has the intermediate composition, net aggradation is recorded at the constant flow and 2-year event, but the study reach degrades for longer return period events. Given that the bed material is composed of approximately 70-95% gravel, it is unlikely that net degradation would actually occur in the study reach. However, the intermediate bed results do suggest that areas of the bed in which there are high proportions of sand sized material (>20%) may scour during events with return periods of 5-years or longer.

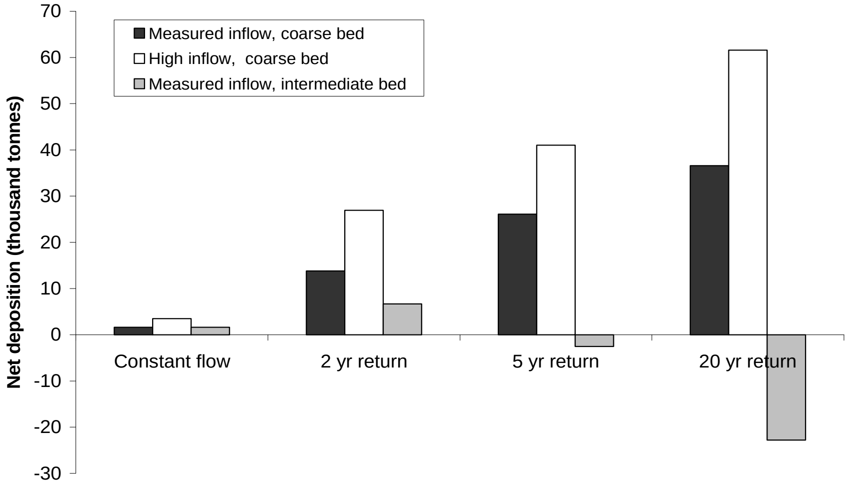

Figure 3 Net deposition at Teddington for the ‘do minimum’ option.

Based on these results, average rates of sedimentation would be in the range 23 to 44 000 tonnes/yr for a lower and upper bound inflow sediment concentrations with a coarse bed, but only about 7 000 tonnes/yr for a lower bound inflow concentrations with an intermediate bed material. Since the analysis of hydrographic surveys and historic dredging records yielded an average annual rate of sedimentation of 37 000 tonnes, the coarse bed estimates seem to provide more reasonable upper and lower bound estimates of sedimentation rates. Assuming an active bed width of 30 m and uniform deposition throughout the study reach, these estimates represent siltation rates of approximately 12 to 25 mm/yr. These are however only estimates because actual rates of deposition will vary between sub-reaches and more locally around shoals and hydraulic structures.

Sediment impact of bed re-profiling: The bed re-profiling option was modelled by taking the iSIS model representing existing conditions and lowering the bed of the river to 4.0m below the Standard Head Water Level (SHWL: the navigation water level maintained by the downstream weir and sluice structures at each lock). The depth below SHWL is constant between the lock, weir and sluice structures, resulting in a stepped profile (Figure 4). The re-profiled sections of river bed are roughly trapezoidal, with an increased depth of 0.5 -1 metre. Although the degree of bed lowering varies across the cross-section, deepening has only been applied between bank toes to prevent over-steepening of the banks and so maintain bank stability. Hence, deepening has been applied to roughly the central third of the river.

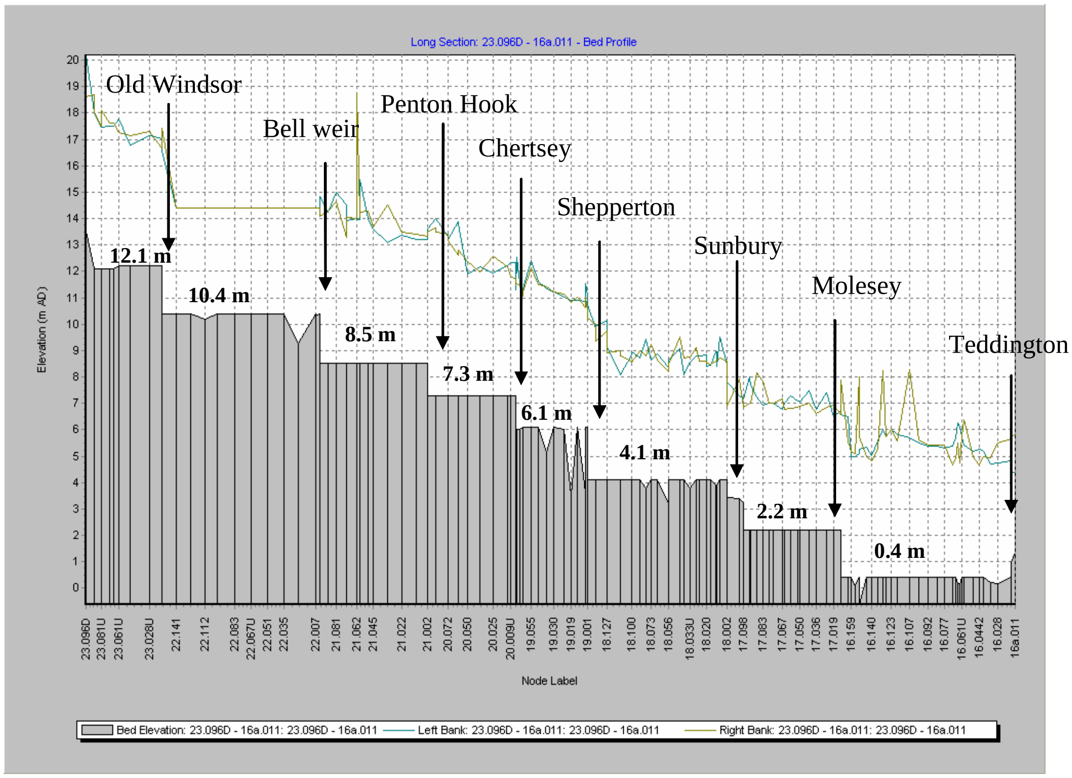

Figure 4 Long section of the study reach after bed re-profiling in the model.

In Figure 5, net rates of deposition are compared for the three return period events and the constant in-bank flow for the 'do minimum' and 're-profiling reach 3' options. The inflow sediment concentration is the measured (lower bound) Q-C relation, with the coarse bed composition, since this better represents bed composition through most of the study reach. Net deposition rates for the are similar for the 'do minimum' and 're-profiling' options. This suggests that sediment impacts associated with bed re-profiling are not serious and that the longterm average annual rate of sedimentation is unlikely to increase dramatically.

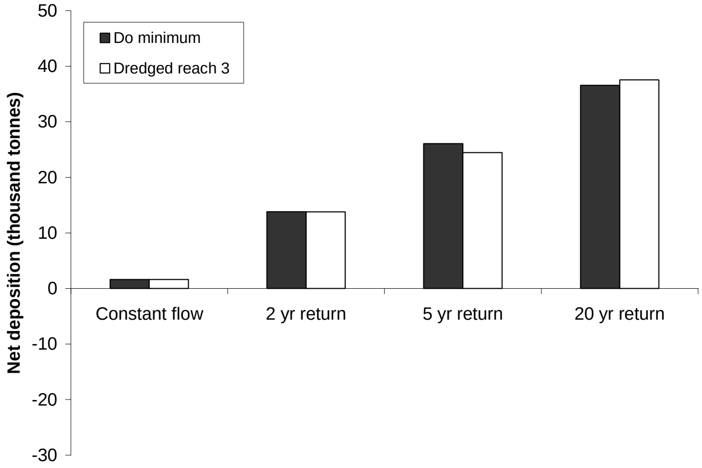

Figure 5 Net deposition for the 'do minimum' and 'bed re-profiling options'.

CONCLUSIONS

Dredging records, measured sediment transport data, and iSIS-sediment transport modelling used in the Lower Thames Flood Strategy Study indicate a long-term annual rate of sedimentation in the range 23-44 000 tonnes or 12-25 mm/yr. iSIS-sediment modelling results suggest that river bed re-profiling will not lead to a significant increase in the rate of sedimentation providing that bed lowering is restricted to between bank toes. The sediment impact assessment used here was developed in conjunction with the UK Flood Risk Management Research Consortium www.floodrisk.org.uk funded by the EPSRC under grant GR/S76304/01, jointly with NERC, the Joint Defra/EA R&D programme, the Scottish Executive, the Rivers Agency (Northern Ireland) and UK Water Industry Research.

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