SUSPENDED SEDIMENT TRANSPORT IN THE TAMAR ESTUARY

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Abstract

The aim of this study was to develop and apply a sediment transport model to the lower Tamar estuary, to explain the suspended particulate matter variability observed within the tidal cycle, its transition in character from neap to spring tides, and to describe the distribution of bed sediment in the lower estuary.

Suspended sediment concentrations, obtained from the lower Tamar estuary using optical back scatter sensors, showed a depth-averaged concentration of 0.02 kgm^{-3} throughout most of the spring-neap cycle. On spring tides the concentration increased to 0.15-0.20 kgm^{-3} either side of low water; however, the concentration maxima did not correspond to the time of maximum tidal flow which suggests the importance of sediment advection.

The observations were simulated using two-dimensional depth-averaged models of tidal currents and suspended sediment concentrations. Harmonic constants generated by the tidal model were used to estimate the advective terms and the bed shear stress in the sediment transport model. The sediment model included three size fractions which represented the low settling velocity wash load (2 µm), the cohesive (25 µm) and the non-cohesive (75 µm) suspended loads. During spring tides the bed sediment (25 µm and 75 µm fractions) was resuspended in the upper model region and advected down estuary on the ebb tide in agreement with the observed concentration maxima. The finer silty material (25 µm) was deposited in the shallower upper model region whereas the sand sized particles (75 µm) accumulated in the deeper parts of the estuary in agreement with published data. At neap tides no sediment resuspension was simulated in the lower estuary, again in agreement with observations.

1. Observations

The Tamar estuary (Figure 1) is a drowned river valley in SW England, which has a mean tidal range of 3.5 m and an annual mean freshwater discharge of about 27 m^3s^{-1}. The upper reaches of the estuary are narrow (50-100 m) and a turbidity maximum is present in summer (e.g. Uncles and Stephens, 1993), which migrates down estuary in winter due to increased river discharge. At spring tides the turbidity maximum is clearly defined and the concentration reaches a peak value of 2-3 kgm^{-3}, but at neap tides it is more diffuse with maximum values of about 0.2 kgm^{-3}. The middle reaches are wider with extensive areas of tidal flats and a central channel. In the lower reaches, the Hamoaze, the depth increases (15-20 m) and there are fewer intertidal areas.

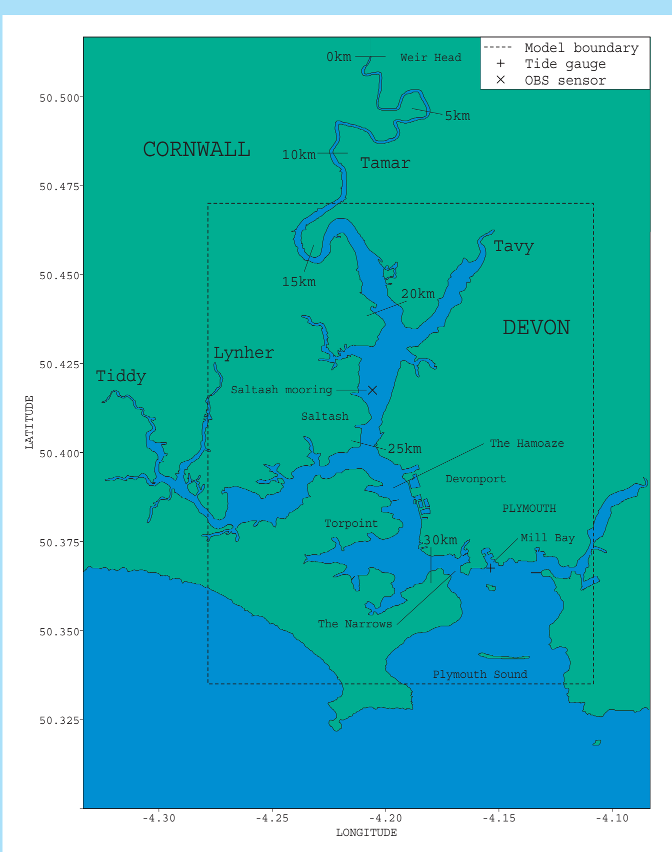

Figure 1: The Tamar estuary showing the instrument locations (tide gauge and optical back scatter (OBS) sensor) and the model boundary.

Two recording current meters were suspended from the stern of a boat moored 1 km north of Saltash for a period of six months in 1997 (Figure 1). The mean depth at the mooring was approximately 8 m and the current meters were suspended at depths of 2 m and 5 m below the surface. The lower instrument was fitted with an optical back scatter (OBS) sensor and spot readings of suspended sediment concentration were recorded every 10 minutes at the start of each velocity averaging period. The OBS sensors were calibrated by the Tidal Waters Research Group at the University of Birmingham using pumped suspended sediment samples and recently deposited bed sediment.

2. Model Validation

A 2-D tidal model of the Tamar estuary was developed using the standard shallow water non-linear equations with a numerical scheme that was centred in both time and space, and included an algorithm to enable drying of shallow areas. Tidal analysis of a six month tide gauge record from Mill Bay (Figure 1) provided harmonic constants which were used to force the elevation across the open boundary at Plymouth Sound. Tidal velocities obtained from the harmonic constants generated by the model showed good agreement with drogue tracks recorded in the estuary (Figure 2). Figure 2a shows a simulated drifter compared with a drogue released during a flood spring tide on 31 July 1996. Good agreement was also achieved with a drogue track from an ebb tide on 9 September 1997 (Figure 2b). The harmonic constants were used to estimate the advective terms and the bed shear stress in a 2-D sediment model of the Tamar.

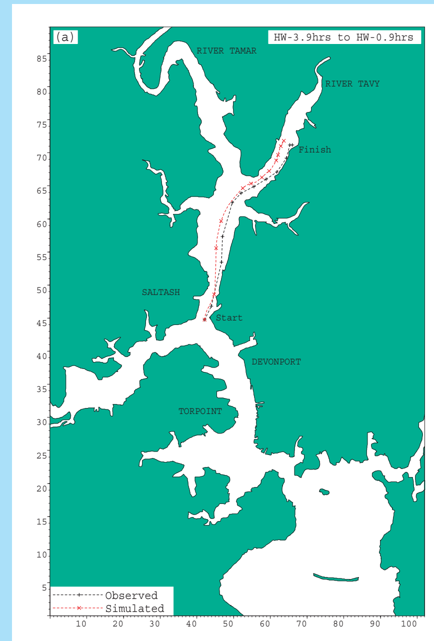

Figure 2a: Observed and simulated drogue trajectories on 31 July 1996.

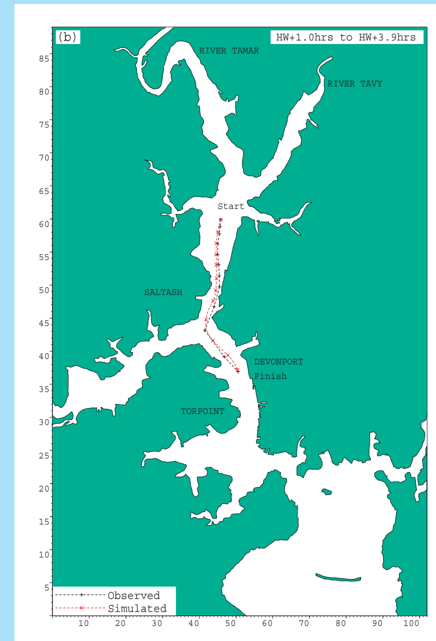

Figure 2b: Observed and simulated drogue trajectories on 9 September 1997.

The sediment balance was described by the depth-averaged, advection-diffusion equation:

$$\frac{\partial(h\overline{C})}{\partial t}+\frac{\partial(h\overline{u}\overline{C})}{\partial x}+\frac{\partial(h\overline{v}\overline{C})}{\partial y}=\frac{\partial}{\partial x}\left(hK_X\frac{\partial\overline{C}}{\partial x}\right)+\frac{\partial}{\partial y}\left(hK_Y\frac{\partial\overline{C}}{\partial y}\right)+M\left[\left(\frac{u_*}{u_{*e}}\right)^2-1\right]-w_sC_b\left[1-\left(\frac{u_*}{u_{*d}}\right)^2\right]$$

where h is the instantaneous depth (mean depth plus surface elevation), $\bar{u}$ and $\bar{v}$ are the depth-averaged velocities and K_X and K_Y are the diffusion coefficients in the x and y directions. $\bar{C}$ is the suspended particulate matter (SPM) concentration, M, the erodability, w_s, the settling velocity and u_* is the friction velocity. C_b, is a near-bed SPM concentration, and u_{*e} and u_{*d} are the critical erosion and deposition friction velocity, respectively.

The mean sediment grain size in the Tamar estuary is in the range 20-30 µm (Uncles *et al.*, 1992) so a 25 µm grain size was used to classify the cohesive sediment fraction in the model. A 2 µm grain size was chosen to represent the low settling velocity wash load and the non-cohesive fine sand was given a nominal 75 µm grain size. A number of parameters required by sediment transport models are poorly defined, site specific and not easily determined from field data. Appropriate values were selected from the literature for the Tamar model: a critical deposition friction velocity of 0.008 ms^{-1}, an erodability of M = 3.5 x 10^{-5} $kgm^{-2}s^{-1}$ and an erosion threshold that increased linearly from 0.025 ms^{-1} at Weir Head to 0.040 ms^{-1} at the Narrows.

3. Sediment Simulations

Figure 3 shows the simulated depth-averaged SPM concentration compared with a 15 day section of the Saltash time series from July 1997. At spring tides the model reproduced the background concentration and the ebb tide concentration peaks to within a factor of 2. The observed low water concentration minima were simulated by the model in a manner that was consistent with the data but the flood tide peak was not reproduced because the critical erosion friction velocity in the model increased down estuary. Further simulations (Tattersall *et al.*, 2002), which allowed recently deposited sediment to be resuspended more easily, enabled the flood peak to be reproduced to within a factor of 5. The model results confirm that no bed sediment was resuspended or advected past the mooring at Saltash during neap tides. The instrument was sensitive to about 1 kgm^{-3} above which it became saturated. At low water spring tides the instrument was often close to the bed and exceeded the sensor range; periods when this occurred are shaded grey in Figure 3.

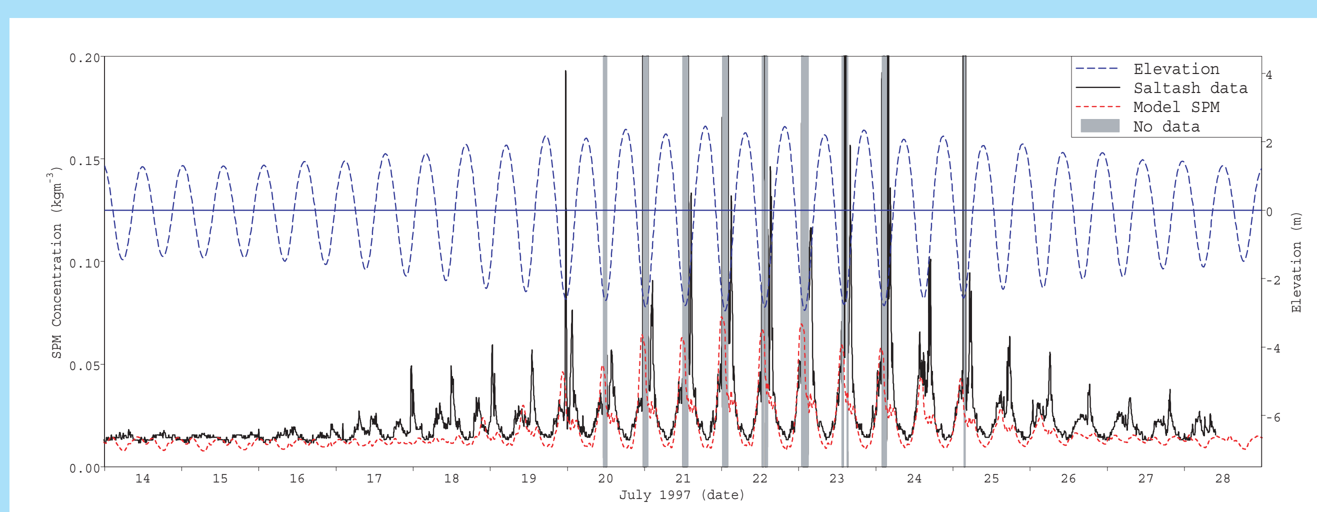

Figure 3: Observed and modelled suspended particulate matter (SPM) concentration from the Saltash mooring data set during July 1997. The elevation for the mooring location was simulated using the model.

4. Sediment Redistribution

The sediment model was used to simulate 8 springs-neaps cycles (approximately 4 months) and Figure 4 shows the change in bed elevation and composition at high water neaps after this time. In Figure 4a the main depositional areas are shown in green and blue and are generally the shallower regions at the sides of the estuary, towards the head of the rivers Tamar, Tavy and Lynher, and in the Hamoaze. Areas of erosion are shown in red and orange and occurred in the central channel north of Saltash, in the Narrows and in Plymouth Sound. Admiralty charts show that the Hamoaze is continually dredged to maintain the minimum depth for shipping, while the simulated erosion sites in the Narrows and in Plymouth Sound are rocky outcrops where the bed is clear of sediment.

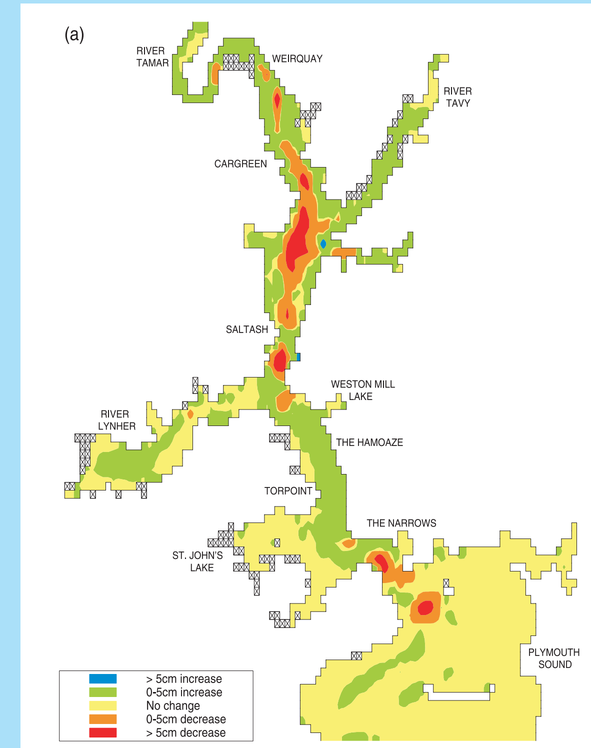

Figure 4a: Simulated change in bed elevation after 4 months. Areas of erosion are shown in red/orange colours and depositional areas are in green/blue. The hatched grid cells represent dried intertidal areas.

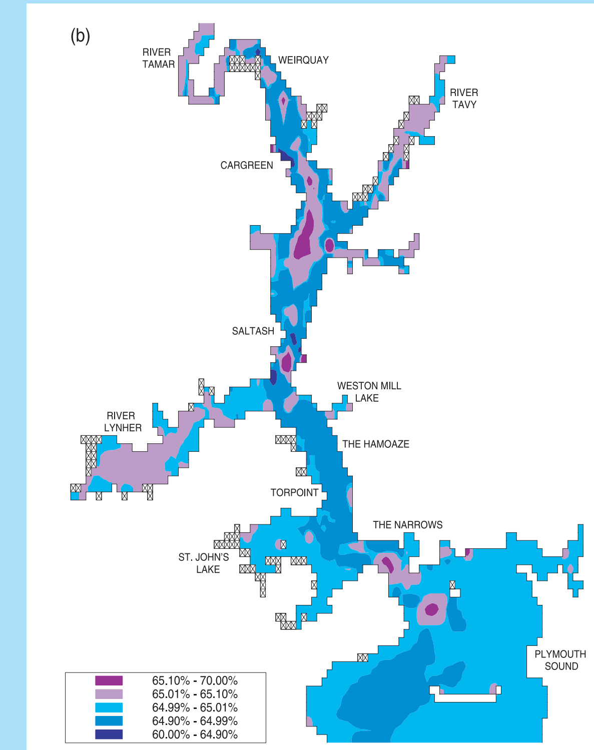

Figure 4b: Bed composition after a 4 month simulation showing the percentage volume of cohesive sediment. Purple areas show a net increase of cohesive sediment and the dark blue colours show where the proportion of non-cohesive sediment increased.

The model was initiated with the bed composed of 65% cohesive sediment (25 µm) and 35% non-cohesive sediment (75 µm). Figure 4b shows the percentage of cohesive bed sediment at high water neap tides after 8 springs-neaps cycles. An increase in the proportion of cohesive sediment (purple areas) indicates either net accretion of cohesive sediment or removal of non-cohesive sediment. Conversely, an increase in the proportion of the non-cohesive fraction (blue areas) demonstrates the removal of fine sediment or a build up of sand. Comparison of Figures 4a and 4b suggest that the accretion in the upper reaches of the rivers Tamar, Tavy and Lynher was due to an increase in the proportion of fine sediment, while the accretion in the Hamoaze was due to an increase in sand. In the model simulations, more sand than silt was removed from the main erosion area in the central channel north of Saltash. In general there was an accretion of silt in the shallower upper reaches of the estuary and an increase in the proportion of sandy bed sediment in the deeper Hamoaze, which is in broad agreement with Stephens *et al.* (1992) who showed that silt content increased with distance from the Narrows.

Summary

Observations of suspended sediment at Saltash showed a background concentration of 0.02 kgm^{-3} throughout the springs-neaps cycle. Superimposed was a two-peaked increase in concentration, the first peak corresponding to the late ebb and the second to the early flood tide. Simulations of the sediment regime in the Tamar using a 2-D sediment transport model confirmed that there was little or no sediment resuspension in the lower estuary at neap tides. At spring tides, the modelled sediment was advected down estuary on the ebb tide in agreement with the recorded increases in SPM concentration. The 0.15-0.20 kgm^{-3} observed peaks were reproduced to within a factor of 2-5 by the model. After 4 months (8 springs-neaps cycles) the simulation showed an accumulation of fine silty particles in the upper reaches of the estuary and an increase of sandy sediment in the deeper Hamoaze, in agreement with published data. The main area of erosion was to the north of the Saltash mooring, close to the confluence of the rivers Tavy and Tamar.

Acknowledgements

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References

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