

SEDIMENT BUDGET ANALYSIS

A sediment budget is a balance of the quantity of sediment entering and leaving a selected segment of coast or estuary. It is based on the quantification of sediment transport, erosion and deposition within a given control volume, where, typically, the quantities are defined in terms of sources, sinks and the processes which give rise to additions and subtractions (US Army Corps, 1992). A source increases the quantity of material within the control volume and a sink reduces it. For open coasts it is usual to think of a length of coast as the control volume, where, ideally, the length forms a sediment cell, with control points at either end that either inhibit or limit the amount of transport across the cell boundary. Within the cell there may be point sources and sinks, such as tidal inlets, and line sources and sinks, such as movements on and off the beach.

An estuary provides a readily defined control volume. Again point sources/sinks exist in the form of rivers, other terrestrial outfalls and the open sea. Line sources/sinks may also be defined in terms of transfers on and off the intertidal, erosion from cliffs and transfers to or from saltmarshes/wetlands. It is however necessary to also consider the subtidal bed of the estuary as an important source/sink and the material stored in suspension within the volume of water that moves back and forth under tidal action within the estuary.

In many cases it can be difficult to identify, let alone quantify, all the mechanisms that give rise to sediment transfers. It may however be possible to derive approximate estimates of the amounts moving to and from sources and sinks based on measures such as transport potential and sediment demand. In effect one establishes an account and as with any account, the prime requirement is that it balances. For this reason, Pethick suggested the sediment audit as an approximate balance that could be carried out on a number of scales (eg local, sediment cell, or regional). The relative importance of changes in supply and demand could then be assessed at the different scales being considered (Pethick, 1992).

There are two ways in which the budget can be constructed:

- (i) define the changes in volume of the surfaces within the control volume to give a volume balance. This works well for non-cohesive shores, where the amount of sediment held in the water column is low and the material types throughout the control volume are similar; and
- (ii) define the exchanges in mass to and from the water column to give a mass balance. This approach is more readily defined where sediments are cohesive or mixed, large amounts of sediment are resident within the water column and there is a high degree of variability in the sediment dynamics within the control volume.

The latter approach is also directly compatible with modelling of suspended and bed load transport, which usually gives erosion and deposition as a mass rather than a volume, and field surveys, such as of sediment flux and concentrations, which similarly tend to use mass as the unit of measurement.

Typically, however, the data will be available as a mix of volume changes and concentrations or mass changes. Hence, some assumptions will have to be made to convert all the data to either one of the above conventions. This usually entails defining:

- a bulk density;
- sediment particle density; and
- water density;

to convert from dry solids (mass) to volume or vice versa. For volumetric changes it is possible to estimate the bulk density from knowledge of the sediment geotechnical properties and an understanding of the processes. Knowing the sediment density (usually assumed to be the value for quartz of 2650 kg/m^3 unless specific measurements are available) and the density of water (often taken as 1025 kg/m^3 for saltwater and 1000 kg/m^3 for freshwater) the mass of dry solids can be calculated with some confidence¹. In contrast, values given as concentrations (eg suspended loads) have no *a priori* density associated with them as this will depend on the type of material, deposition conditions, time to consolidate, etc. To convert such quantities to a volume therefore requires the type of bed change to be assumed (unless the process can be defined) and a density assigned. Furthermore, in an estuary where the tidal circulation causes a large redistribution of sediment within the system, it is possible for no net change in volume to occur but a large transfer of sediment to take place between the bed and the water column, as the erosion and deposition processes alter the bulk density of the material. It is for these reasons that it is often preferable to work in terms of mass rather than volume.

When developing an approximate budget it is often necessary to look at mass movements of sediment, without considering the mechanisms of transfer in detail. Whereas a modelling exercise might seek to distinguish between bed and suspended load transfers, this level of abstraction is generally not possible from measured data, unless the data were collected with this purpose in mind. In order to retain a clear appreciation of relative magnitudes, it helps to consider the exchanges in the context of the resident volume of sediment in suspension within the estuary. Since this is usually expressed as the average mass of sediment present over a tidal cycle, it follows that sources and sinks are best expressed as rates of exchange per tide. Clearly many of the exchanges will not be at steady rates (eg cliff erosion, river and marine exchanges are all likely to be heavily influenced by episodic storm events) nonetheless the resultant net change can be expressed as an average rate per tide.

In the case of estuaries it is often extremely difficult to predict with any confidence the net flux across the mouth. This is particularly so when the sediment flux in and out on the ebb and flood are high such that the net exchange is difference between two very large numbers. In such circumstances it is usually necessary to treat the marine exchange as the mass or volume that provides a sediment balance (assuming of course that all other sources and sinks have been identified and adequately quantified). Any information on gross or net sediment flux through the mouth can be used to assess whether such an estimate is reasonable and may provide information on the level of uncertainty associated with the estimate and hence the budget.

The sediment budget is one means of synthesising the outputs from a number of the other analysis and modelling techniques that are available. Quite often it is possible to construct a budget from historical data and an analysis of change. This can then be compared with a similar budget derived using the output from computational models. If this is in reasonable agreement, model output can be used to predict the likely budget as a result of some change or development in the system. There are various ways this can be presented, such as a tabulation of sources and sinks, [Table 1](#), or a schematic to illustrate the exchanges taking place (eg as tonnes/tide for the Humber, [Figure 1](#), or volume/annum for Southampton Water, [Figure 2](#)). A case study for the Humber outlines the basis of a net sediment budget and highlights the difficulties and uncertainties encountered (Townend & Whitehead, 2003).

¹ spatial variability will often be the main source of uncertainty. Within an estuary there is often significant variation in the density of material on the bed, depending on the amount of settlement, consolidation and re-erosion that has taken place.

Table 1 - Summary of sources and sinks ($\times 10^3 \text{ m}^3/\text{year}$)

Sources of Sediment			Sinks and Removal of Sediment		
Intertidal erosion	SW	40	Intertidal siltation	SW	-
	Test	9		Test	3
	Itchen	nd		Itchen	nd
	Hamble	nd		Hamble	nd
Subtidal erosion	SW	29	Subtidal siltation	SW	-
	Test	-		Test	1
	Itchen	nd		Itchen	nd
	Hamble	nd		Hamble	nd
Cliff erosion	SW	5	Dredging	SW	244
River load	Test	10		Test	136
	Itchen	6		Itchen	3
	Hamble	1		Hamble	15
Saltmarsh		6	Saltmarsh		4
Marine import		300			
Total		406	Total		406

nd = no data

Figure 1 - Schematic of the net sediment budget model for the Humber Estuary, UK

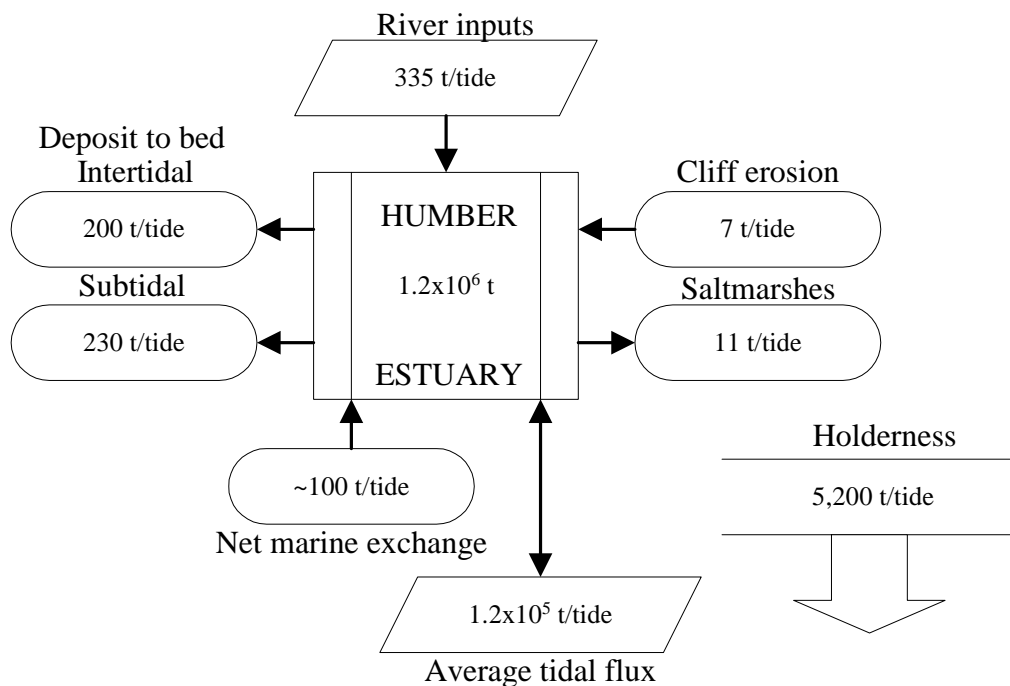
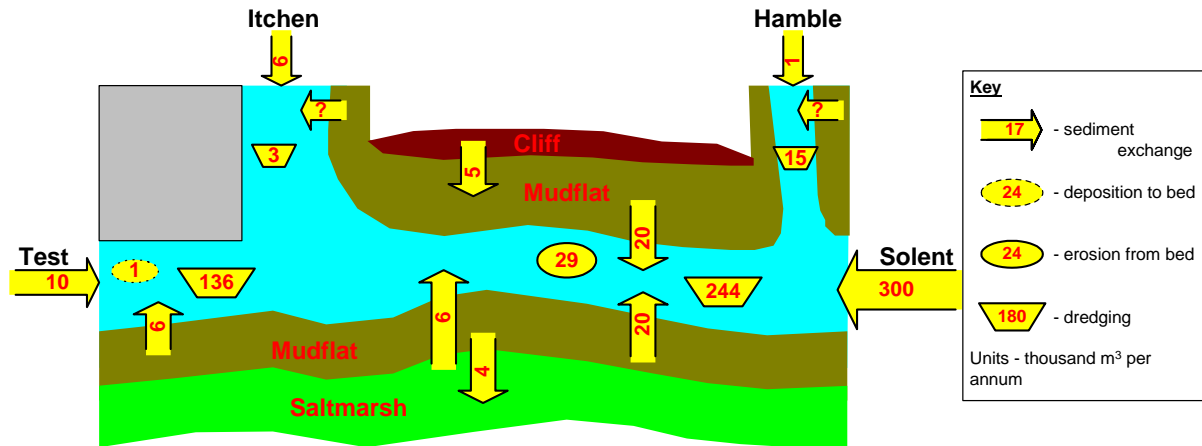


Figure 2 - Schematic of the net sediment budget model for Southampton Water, UK



Following essentially the same principles as those outlined above, the US Army Corps have developed SBAS (for details of SBAS see the [US Army Corps web site](#)).

References

Pethick JS, 1992, Strategic planning and coastal defence, In: 27th River and Coastal Engineers Conference, MAFF, London, pp. 3.1.1-3.1.7.

Townend IH, Whitehead PA, 2003, A preliminary net sediment budget for the Humber Estuary, The Science of the Total Environment, 314-316, 755-767.

US Army Corps, 1992, Shore Protection Manual, US Army Corps, Vicksburg.