SEDIMENT BUDGET ANALYSIS

Method Indicator		
Bottom-Up	Hybrid	Top-Down
		YES

Summary of key issues

Issue	Description
Description	Concept of overall sediment mass continuity within estuary system.
Temporal Applicability	Any.
Spatial Applicability	Any.
Links with Other Tools	Always useful as an aid to conceptual understanding.
Data Sources	• Bathymetric datasets (see HTA); • Suspended sediment concentration measurements; • Sea bed density; • Fluvial discharge; • Discharge measurements at the mouth of the estuary; • Estimates of littoral drift made on the basis of standard equations or numerical models and wave data; • Estimates of sediment transport made by numerical models.
Necessary Software Tools / Skills	• Understanding of sediment transport in estuaries; • Geomorphological interpretation of output.
Typical Analyses	• As a conceptual aid to understanding how an estuarine system functions; • As a method of quantifying a bulk flux or mass of sediment which cannot be identified by modelling or field measurement, e.g. residual net transport over long periods.
Limitations	It can be necessary to consider the mathematics of the method in detail to understand whether a particular analytical method can reliably be applied to a given estuary system.
Example Applications	• Humber Estuary; • Mersey Estuary; • Stour/Orwell System.

Introduction

A sediment budget is a balance of the sediment volume entering and exiting a particular section of the coast or an estuary. Sediment budget analysis consists of the evaluation of sediment fluxes, sources and sinks from different processes that give rise to additions and subtractions within a control volume (e.g. a section of coast or an estuary) in order to gain a better understanding of the estuary system. Control volumes on open coasts pertain to sections of a coast which form sediment cells and are controlled by cell boundaries which either inhibit or limit the amount of transport across the cell boundary. A source increases the quantity of material within the control volume and a sink reduces it and 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, where point sources and sinks exist in the form of rivers, other terrestrial outfalls and the open sea. Line sources and sinks may be defined in terms of erosion from cliffs and transfers to or from saltmarshes, wetlands or other intertidal areas. The subtidal beds also needs consideration as an important source/sink as does material stored in suspension within the volume of water that moves back and forth under tidal action within the estuary.

Identification and quantification of all the mechanisms giving rise to sediment transfers can be difficult, and for the most part are approximate estimates of sediment exchange between sources and sinks. These movements are based on measures such as transport potential and sediment demand. Pethick (1992) suggested the sediment audit as an approximate balance that could be carried out on a number of scales, e.g. local, sediment cell, or regional. The relative importance of changes in supply and demand could then be assessed at the different scales being considered.

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

- Definition of changes in surface volume within the control volume to give a balance. This is applicable to non-cohesive shores, where suspended sediment concentrations are low with similar material types; and

- Definition of exchanges in mass to and from the water column to give a mass balance. This is easier to do with cohesive or mixed sediments, large suspended sediment concentrations, and higher degrees 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 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. If the sediment density is known (usually assumed to be the value for quartz of 2650 kg/m^3 unless specific measurements are available) and water density (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 confidence, however, 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.

In contrast, suspended sediment concentrations 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 assumptions of the type of bed change, unless the process can be defined, and a density assigned. Furthermore, in an estuary where the tidal circulation causes a large sediment redistribution within the system, it is possible for net volumes to stay the same but a large transfer of sediment to occur between the bed and the water column, as the erosion and deposition processes alter the bulk density of the material.

It is often necessary to look at sediment mass movements, without considering detailed transfer mechanisms, as it is not always possible to distinguish between bed and suspended load transfers, particularly from measured data, unless this was the objective of the data collection. In estuaries, sources and sinks are best expressed as rates of exchange per tide. Clearly many of the exchanges will not be at steady rates, e.g. cliff erosion, river and marine exchanges are all likely to be heavily influenced by episodic storm events.

Net sediment flux across estuary mouths is difficult to predict, particularly when the sediment flux on the ebb and flood tides are high. Thus, it is usually necessary to treat the marine exchange as the mass or volume that provides a sediment balance. Net sediment flux data 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 budget.

Sediment budgets are a means of synthesising the outputs from numerous available analysis and modelling techniques. A budget can also be calculated from historical data and an analysis of change, enabling comparisons between a similar budget derived using the output from computational models. Model output can be used to predict the likely budget as a result of some change or development in the system, and is usually presented as a tabulation of sources and sinks (for an example see Table 1), or a schematic to illustrate the exchanges occurring (e.g. as tonnes/tide for the Humber, or volume/annum for Southampton Water, Figure 1 Schematic of the net sediment budget model for the Humber Estuary, UK (Whitehead and Townend, 1994)).

Table 1. Summary of sources and sinks for Southampton Water (SW) ($\times 10^3$ m^3/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

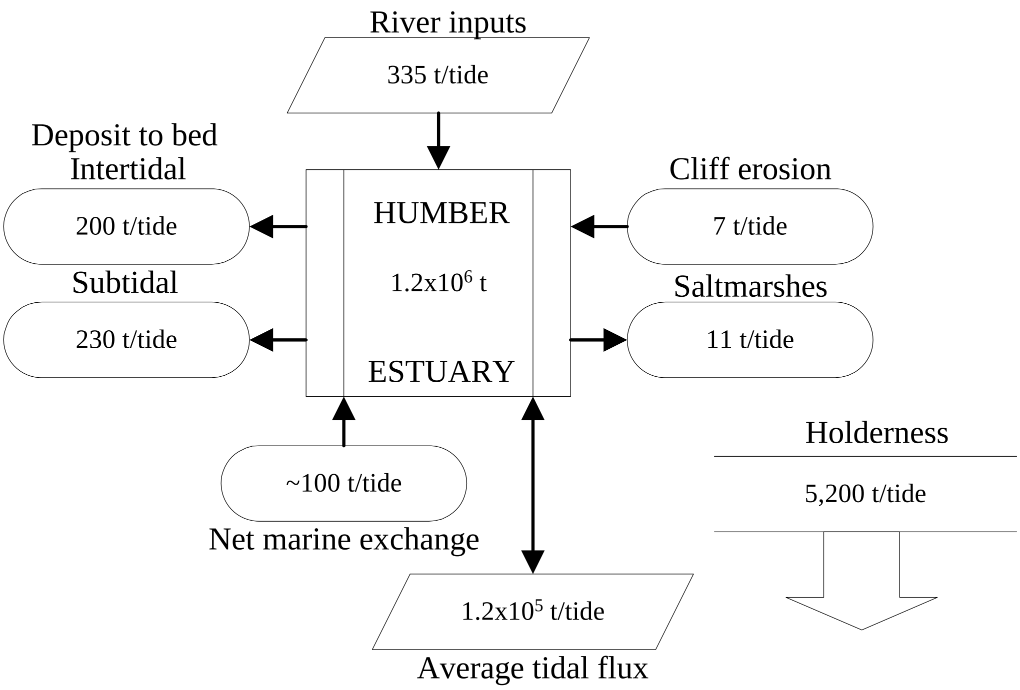

Figure 1. **Schematic of the net sediment budget model for the Humber Estuary, UK (Whitehead and Townend, 1994)**

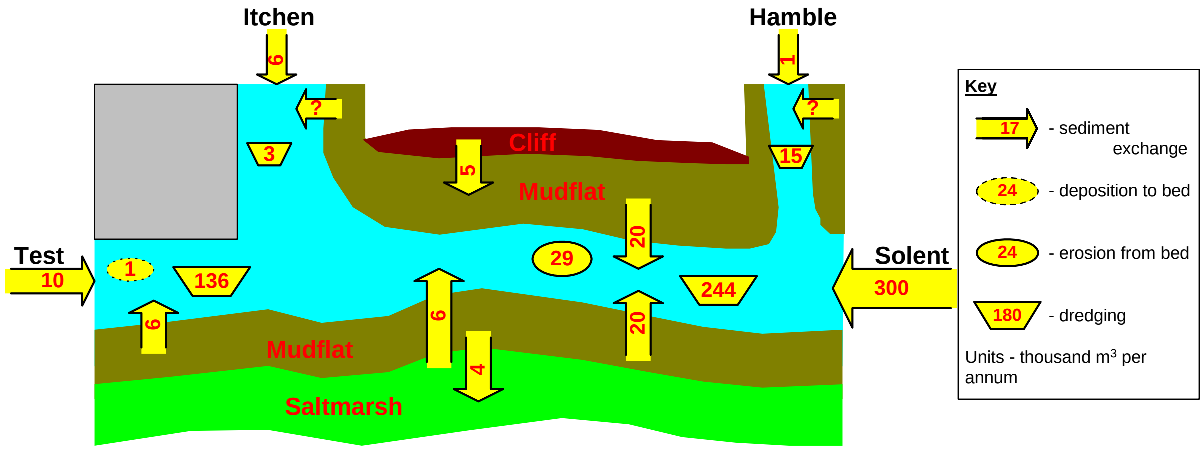

Figure 2. **Schematic of the net sediment budget model for Southampton Water, UK (ABP, 2000)**

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), and intrinsic to the method is the idea of a balancing budget, as shown in the following equation:

[total sediment inputs] – [total sediment outputs] = [increase in total sediment within the system]

A net flux of sediment into the system must be accompanied by accretion or by an increase in suspended sediment concentrations, while a net efflux must be accompanied by a reduction in suspended sediment concentrations and/or erosion. This technique enables the principal sediment transport processes to be identified.

Table 2 presents a list of the main sediment budget contributions that might be considered for a typical estuary under the headings of “inputs” and “outputs” of sediment to the system and “within-system” transfers of sediment, such as between subtidal and intertidal areas or between intertidal areas and saltmarsh.

Table 2. Main sediment budget contributions

Inputs	**Within-System Transfers**	**Outputs**
Main contributions		
Marine influx (sand/mud)	Saltmarsh erosion/accretion (sand/mud)	Efflux to sea (sand/mud)
Fluvial influx (sand/mud)	Intertidal erosion/accretion (sand/mud)	
Littoral drift	Subtidal erosion/accretion (sand/mud)	
	Total mass of suspended sediment in system	
Other man-made contributions		
	Dispersion/disturbance from dredging	Offshore placement
	Vessel-induced erosion of intertidal/subtidal	
Other contributions		
	Cliff erosion	

Sediment contributions

The main sediment contributions can be greatly influenced by both the strength of wave activity and fluvial flow. Therefore, an overall picture of the sediment budget may require data from calm and stormy periods and from the periods of low and high river flow. The drawback to the sediment budget approach is that by definition it requires a considerable amount of data, from observations and/or input from numerical flow and sediment transport models.

Data commonly used in sediment budget analysis

Although sediment budgets are developed from all sources of information available regarding an estuary system the more common sources of data providing input to the method include:

- Bathymetric data sets;
- Suspended sediment concentration measurements;
- Sea bed density;
- Fluvial discharge;
- Discharge measurements at the mouth of the estuary;
- Estimates of littoral drift from standard equations or numerical models and wave data; and
- Estimates of sediment transport made by numerical models.

Comparison of bathymetric data should follow the guidance presented in the HTA Section. Suspended sediment concentration measurements together with the corresponding discharges of water, to represent calm and stormy conditions under conditions of high and low fluvial flow, may enable an assessment of the net sediment fluxes to/from fluvial and marine sources. However, the variable nature of these fluxes over a variety of scales is not well described by the data, so estimates of net sediment fluxes must be inferred from bathymetric data, for example.

Littoral drift is normally estimated on the basis of standard equations, e.g. the CERC method (Soulsby, 1997) or from numerical models for nearshore profile hydrodynamics and sediment transport, e.g. COSMOS (Nairn and Southgate, 1993). Estimating littoral drift is often imprecise, and so well-calibrated sediment transport models can greatly aid the development of a sediment budget as especially as the integrated and net nature of the data required by the sediment budget method is easily obtainable from such models.

It is good practice to recognise that data may be erroneous for various reasons, e.g. due to field measurement error or outmoded measurement techniques, incorrect analysis, the failure of the data to cover all the relevant estuary conditions, the data being taken during an unrepresentative event. Therefore, all data used should be corroborated as far as possible, such as by comparison with other similar estuaries, anecdotal evidence, previous studies and data collection campaigns. Furthermore, it is good practice to quantify the uncertainty in any data used. This is particularly relevant as sediment budgets often feature a small net input or output resulting from much larger gross input/outputs. A small error can cause large changes in the predicted net change in an estuary or even reverse its direction.

Three recent examples of sediment budget analysis from estuaries in the UK are presented here. The first example, from the Humber Estuary, illustrates how the method can be used to identify the key components of an estuary as an aid to understanding the system. The examples from the Mersey Estuary demonstrates how the method can be used to identify the cause of impact. A third example, from the Stour/Orwell system shows how a simple sediment budget model can be used to aid predictive assessment.

Case study: Humber Estuary

A consortium consisting of Binnie Black & Veatch, ABP Research, the University of Newcastle, HR Wallingford and the British Geological Society undertook a programme of Strategic Geomorphological Studies for the Humber Estuary (Environment Agency, 2000). As part of these studies a sediment budget for the Humber Estuary was proposed.

The Humber Estuary is located on the east coast of England and interposes between the Ouse, Don, Aire and Trent rivers and the North Sea. The estuary is 147km long to the tidal limit on the River Trent and 62km long between Trent Falls (the confluence of the rivers) and the sea. Intertidal area takes up around a third of the plan area of the estuary. The estuary is macrotidal with a mean spring tidal range at the estuary mouth of 5.8m.

The Humber Estuary sediment budget was defined on the basis of exchanges in suspended sediment mass contained within the confines of the Estuary. The sediment budget concentrated on the net movement of sediment into the estuary from river and marine sources (and from cliff erosion) and the net deposition from suspension to subtidal, intertidal and saltmarsh (Figure 3; Townend and Whitehead, 2003). The individual components of the sediment budget were calculated from the following bases:

- The fluvial sediment input was derived from the average fluvial discharge and assumptions of typical fluvial suspended sediment concentration;

- The gross tidal flux at the mouth in and out of the estuary was derived from measurements from the LOIS study;

- Net contribution from/to Marine Sources:
  - Net transport was found to be a combination of storm wave activity, gravitational circulation and tidal asymmetry;
  - Geological evidence which showed (historical) sediment import of fine sediments (Rees *et al*., 2000);
  - Mineralogical tracer studies (Cox, 2002) indicated net import of sediment into the Estuary from offshore sources;
  - The net contribution shown in Figure 3 of import 100 tonnes/tide was derived from balancing sediment budget assuming no overall loss of suspended sediment from Humber. However, the uncertainty in this figure (Townend and Whitehead, 2003) is of the order of 50-1500 tonnes/tide.

- Deposition on intertidal (non-saltmarsh) and subtidal areas was calculated from bathymetric analysis and assuming representative bulk densities of 1350 kg/m3 (roughly 500 kg/m3 dry density) for intertidal sediment and of 1550 kg/m3 (roughly 850 kg/m3 dry density) for subtidal sediment-based density probe measurements and densities encountered during dredging operations;

- Deposition/erosion of sediment on saltmarsh areas was calculated on the basis of:

- Changes in saltmarsh area (derived from photogrammetric analysis) multiplied by an assumed saltmarsh cliff height of 0.3m;

- An assumption that the saltmarsh was keeping its position in the tidal frame with respect to sea level rise (1.1mm/yr on the best available evidence, Woodrolfe et al., 1999).

- Cliff erosion was calculated on the basis of the length and height of cliff identified as a source (2.6 km and 5 m, respectively), the estimate of recession rate (0.3 m/yr) and an in situ density of cliff material of 1800 kg/m3; and

- Dredging does take place inside the estuary but the corresponding disposal also takes place within the estuary so there is no net change in terms of sediment balance.

The net fluxes from and to different parts of the Humber Estuary system are presented in Figure 3. The amount of sediment transported in and out of the estuary on every tide is over two orders of magnitude greater than the net flux into the estuary and that the total volume of suspended sediment is an order of magnitude greater than this tidal flux.

Because the net flux in or out of the estuary is small compared to the gross flux, the estimate of net flux contains a fair amount of uncertainty. The initial estimate of net flux (BBV, 2000) suggested net export from estuary owing to the ebb-dominated tidal asymmetry. However, further geological, mineralogical and numerical modelling studies led to the conclusion of net import from marine sources and a revised sediment budget (See Figure 3, Townend and Whitehead, 2003). This example illustrates the iterative nature of sediment budget analysis because of increasing data availability.

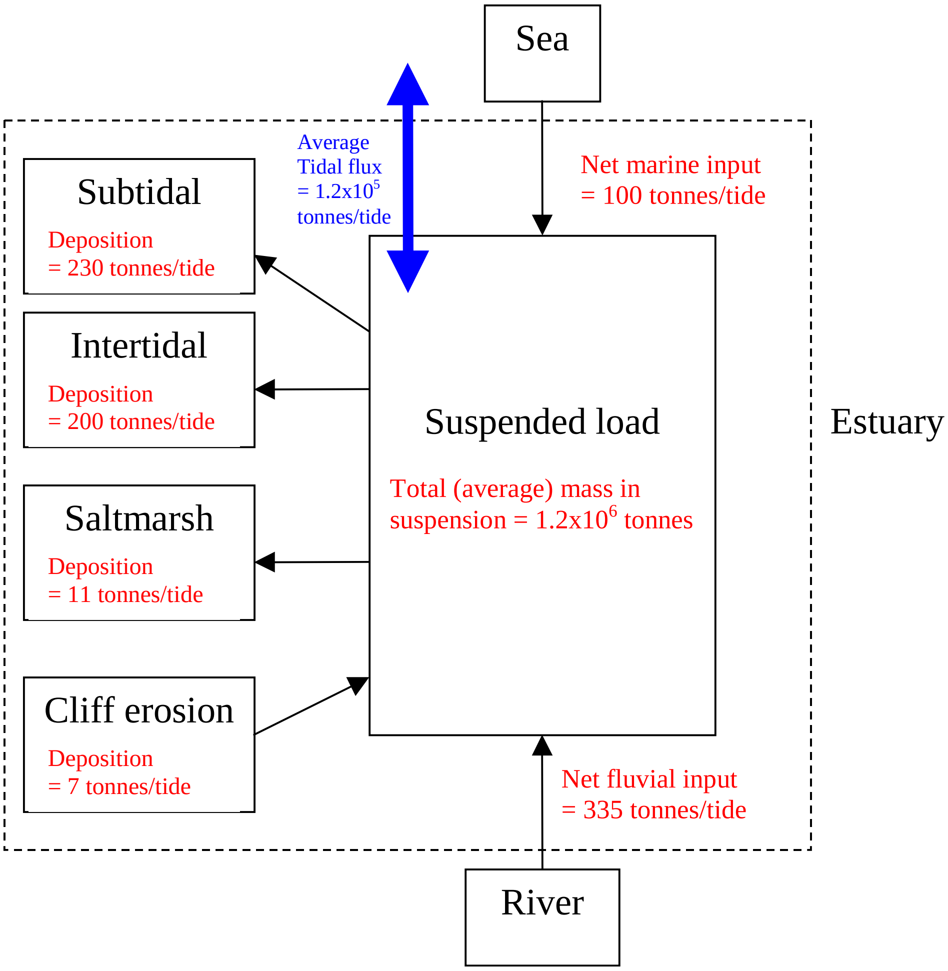

Figure 3. Sediment budget for the Humber Estuary (Townend and Whitehead, 2003)

Sediment budget analysis to aid identification of the causes of impact in the Mersey

Thomas (2000), contributing to the Estuary Research Project Phase 1B funded by Defra and the Environment Agency, investigated the causes of the decline in estuary volume in the Mersey Estuary over the 20th century. Thomas (2000) reviewed bathymetry data, measured over 5 yearly intervals on the same cross-sections from about 1850 onwards.

Previous to 1911 the Mersey Estuary (as measured by estuary volume to a temporally constant datum which varies along the estuary) was in a state of quasi-equilibrium albeit with significant yearly variation. From around 1911, the Mersey experienced significant accretion of sand (Water Pollution Research, 1938; Cashin, 1949; O'Connor, 1987) which reduced the overall volume of the estuary, over a period of around 50 years, from 745 Mm^3 to 680 Mm^3. Analysis of bathymetric change indicates the estuary attained a new equilibrium during the period 1961-1977 (HR Wallingford, 1999).

Previous research into the morphological change in the Mersey has identified the causes of change to be due to the construction of training walls to maintain the navigation channel in Liverpool Bay between 1909 and 1933 (further extended over the period 1945-1960); dredging activity in the sea channels (Cashin, 1949; Price and Kendrick, 1963); sewage disposal (WPRB, 1938); other engineering activity (HR Wallingford, 1999; Thomas, 2000); and littoral drift along the Sefton and Wirral coastlines (Pye and Neal, 1994).

Thomas investigated the relative contributions of all of these effects to the observed morphological change, including using historical literature to obtain information regarding the extent of dredging, sediment and sewage disposal and reclamation; and previous studies (notably the Price and Kendrick, 1963) which had evaluated the significance of the various contributing factors to morphological change, as well as digital ground modelling of charts of Liverpool Bay and the Mersey Estuary. The data were used to develop a diagnostic historical sediment budget for the Mersey Estuary. The sediment budget is based on the schematisation shown in Figure 4.

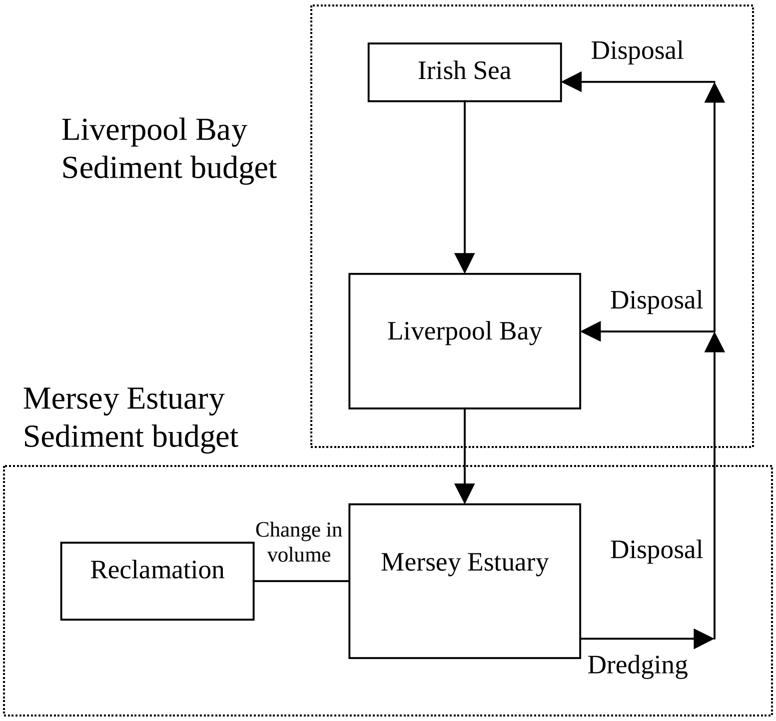

Figure 4. Schematised systems for Mersey Estuary and Liverpool Bay sediment budgets (Thomas, 2000)

The budget revealed that there is a significant change in net supply to the Mersey from before 1906 to the period 1906-1977 and again after 1977; reclamation and disposal within the Mersey contribute little to the overall sediment budget; whilst the dominant contributing affect for the accretion in the Estuary results from influx of marine-based sediment, dredging within the Estuary is a significant factor. Indeed during 1953/4, dredging within the Mersey (with placement outside the Estuary) was able to reverse the overall accretion trends. This was sufficient evidence to corroborate the conclusion of Price and Kendrick (1963) that the accretion within the Mersey was a result of a change in the sediment supply from offshore. Thomas went onto develop a similar budget for Liverpool Bay.

The sediment budget for Liverpool Bay was far more imprecise owing to less bathymetric data and uncertainty regarding how much dredged material from the Mersey was placed back within the Liverpool Bay system, and whether any of it was placed outside of the system. Thomas (2000) found that the main difference between the 1906-33 and 1933-1977 periods is the supply of sediment to Liverpool Bay from offshore. A more detailed examination of changes in Liverpool Bay showed significant erosion of Great Burbo Bank (to the west of the navigation channel) suggesting that this was the specific source of much of the sediment entering the Mersey.

Thomas (2000) used 2D and 3D modelling to hind-cast the annual sediment flux into the Mersey as a result of the spectra of wave and tidal conditions for different historical times; before, during and after the morphological evolution, and found in broad terms that the modelling reflected the changes in sediment transport obtained from the sediment budget. The changes to ebb and flood tide hydrodynamics In Liverpool Bay, caused by the training walls, increased sediment supply to the estuary mouth, which was then transported landward by the near bed residual current in the Mersey. Additionally Thomas' results showed that as the estuary attained approached its new equilibrium the changes in estuary morphology resulted in reduced landward transport.

Use of a sediment budget model to aid impact assessment in the Stour/Orwell

As part of the investigative studies for the Environmental Impact Assessment associated with the proposed 1998-2000 deepening of the approaches to Felixstowe Port HR Wallingford (1998) developed a sediment budget for the Stour/Orwell Estuary system (Figure 5). This sediment budget was slightly revised and updated for a subsequent study for the Environmental Impact Assessment associated with the proposed container terminal development at Bathside Bay, Harwich (HR Wallingford, 2001).

Both the Stour and Orwell Estuaries are relatively short in length at around 20 km including the Harbour, with a 3.6 m mean spring tidal range and very little freshwater flow (both of the order of 1 m^3/s with a negligible sediment input). The principle sediment source is from offshore, in particular the nearshore coast to the east of the Harbour mouth. The intertidal areas within the Stour Estuary and the lower Orwell Estuary are experiencing net erosion which has been continuing throughout most of the 20th century.

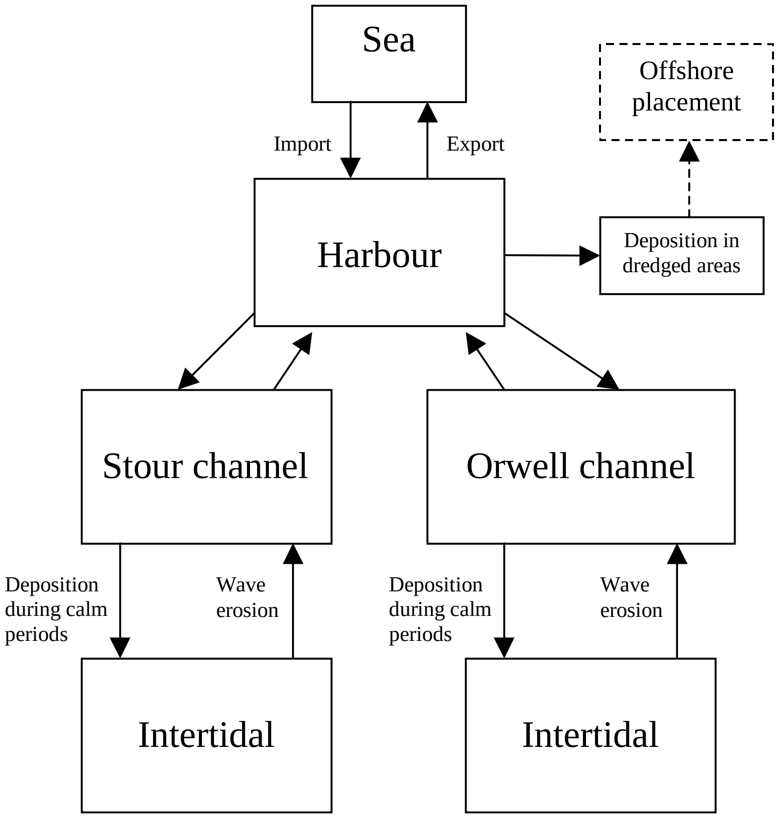

Figure 5. Schematisation of the Stour/Orwell Estuary System (HR Wallingford, 1998)

The sediment budget was developed using an approach based on the concept of two types of behaviour: deposition during calm periods and erosion during wavy periods. During calm periods marine derived sediment enters the estuary and settles on intertidal areas. During erosion periods, waves and currents cause erosion of intertidal areas resulting in the seaward advection of eroded sediment. Most of this sediment is lost from the estuary system on the ebb tide but a proportion of this sediment returns to the estuary and resettles on intertidal areas. This behaviour can be expressed by Equation 1:

$$E = (1 - C)W - D \qquad (1)$$

Where *E* is the net erosion of intertidal areas,
D is the (gross) deposition on intertidal areas from marine import of material;
W is the mass of material eroded from intertidal areas in the estuary system;
C is the proportion of inter-tidal sediment resuspended by waves and redepositing on intertidal areas;

E, the net erosion, was derived from analysis of detailed bathymetric data sets, and C, the proportion of wave-eroded material resettling onto intertidal areas, was derived from calibrated numerical sediment transport modelling. *D*, the gross deposition, is dependent on the overall supply of sediment to the system, M_{sys}, and on the amount of sediment that is removed from the system by dredging, M_{dredge}. *D* was calculated from calibrated sediment transport modelling but adjusted to account for options in the management of dredging and disposal by assuming *D* is proportional to M_{sys}-M_{dredge}. In particular this allowed the effect of disposal of water column recharge in the estuary, instead of offshore placement, to be examined. *W*, the amount of wave erosion from intertidal areas, was derived using the observed estimate for *E,* and values for *C* and *D* gained from numerical modelling. Once derived this value was assumed to be constant except where intertidal was reclaimed, whereupon *W* was adjusted proportionally with the intertidal area.

Best practice in sediment budget analysis

The creation of a sediment budget is an approximate balance that can be carried out on a local scale, e.g. within an obvious control volume such as a length of coast or estuary, or on a wider regional basis. The relative importance of the dominant sediment transport mechanisms can be assessed at any or all of these scales depending on the study area characteristics.

Clearly, the methodology is a data-rich approach but this should not prevent it being used to aid the conceptual understanding of an estuary through the identification of the main sediment transport mechanisms; as well as the identification of the relative contributions of a mechanism or source or sink that there is no information for, through the concept of the balanced budget.

As better and more plentiful information becomes available the quality and reliability of the sediment budget will increase, and in this sense the creation of a sediment budget is an iterative process. The sediment budget studies presented above highlight the requirement for exhaustive review of historical literature, detailing the extent of any morphological change, engineering works, reclamation, dredging and disposal. Without this exhaustive review any sediment budget developed for an estuary is likely to be flawed.

The examples shown above of the Humber, Mersey and Stour/Orwell indicate that sediment budget analysis falls into two different types:

1. The first type is associated with estuaries undergoing significant morphological change (e.g. the Stour/Orwell and Mersey throughout the 20th century). Sediment budget analysis is less about the trend in an estuary and more about establishing the mechanisms by which change is occurring. In such estuaries the influence of sea level rise may be less significant than natural/or man-made influences over the short to medium term and the use of geological methods to evaluate future trends may not be relevant;

2. The second type is associated with estuaries where the morphological change trends are not obvious (e.g. the Humber) and those trends imposed by sea level rise are thus significant. In such estuaries the techniques of accommodation space and geological assessment of sediment are assessment tools used to build up the overall picture of the sediment budget. By definition, because the trends are less obvious the uncertainty in the assessment of trends will usually be greater than in the type of estuary described above.

As noted by Townend and Whitehead (2003) there are two ways in which a sediment budget can be constructed, either;

- By defining the changes in volume bounded by surfaces within a control volume to give a volume balance. This works well for non-cohesive shores where the amount held in the water column is low and the material types throughout the control volume are similar; or,
- By defining the exchanges in mass to and from the water column to give a mass balance. This approach makes more sense where large amounts of sediment are resident within the water column.

Building a sediment budget

The steps required to produce a sediment budget can be summarised as follows:

1. Is there enough reliable information to build a sediment budget? (e.g. observations and well-calibrated numerical model results).

2. Schematise the estuary system into a simple flow chart. Try to devise a schematisation which states the focus of the analysis simply and succinctly.

3. Choose the units of the sediment budget: tonnes/year is usually a good option.

4. Choose whether the budget is to be in terms of cohesive and/or non-cohesive. In practice the cohesive sediment and the non-cohesive sediment budgets may be developed independently, though it may not be necessary to complete both for the sediment budget, depending on the identified requirements of the analysis.

5. Evaluate the most straightforward inputs to the sediment budget first. These are often,

    - Sediment volume within the system (which can be derived from suspended sediment concentration measurements and the volume of the estuary from charts);
    - the fluvial input to the system (which can be derived from fluvial discharge and concentration).
    - The morphological trend (derived from comparison of bathymetric data).

6. Some sediment budget inputs can be difficult to derive from observations, e.g. net flux from or to the sea in wide estuaries and the extent of erosion of intertidal area resulting from wave action, and so it may be best to derive these values by balancing the budget and providing data for all the other budget contributions. If this is not possible then the derivation of these contributions may require in-depth analysis, numerical modelling of sediment transport and/or further data collection to determine the sediment contributions.

7. With the possible exception of the contributions discussed in Step 6, try to quantify all of the sediment budget contributions presented in Table 2. Do not neglect the effects of dredging and disposal and treat all information regarding dredging and disposal as being estimates with considerable inherent uncertainty.

8. Build iteratively; start on the basis of the available data and gradually improve the sediment budget as knowledge of the system and better data becomes available. Try to independently examine the veracity (or at least plausibility) of each of the sediment budget components using back of the envelope calculations, comparison with other similar estuaries, anecdotal information, etc.

9. Undertake a thorough search for historical and anecdotal data (including geological data if relevant). Use this historical data to improve the data in the sediment budget and to aid the understanding of the sediment budget result.

10. Once numbers are available to complete the sediment budget, assess the uncertainty in the all the contributions to the sediment budget. Is the uncertainty in the sediment budget too great to make it a meaningful budget?

Conclusions

The creation of a sediment budget is an approximate balance that can be carried out on local or regional scales. The relative importance of the dominant sediment transport mechanisms can be assessed at any or all of these scales depending on the characteristics of the study area. The method is highly dependent on modelling and/or field data and a thorough understanding of the historical changes in estuary morphology and anthropogenic intervention. It is very important to understand the uncertainty inherent in the development of a sediment budget, as the conclusions may sometimes depend on relatively minor changes in sediment inputs to the system relative to the sediment outputs

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