DATA REQUIREMENTS

Introduction

Historical changes within estuaries can be identified by variations in bathymetry, mouth width, intertidal area etc. In identifying change, historical data plays a vital role both for analysis and use in calibrating and validating models. Collating all available data at the beginning of a study invariably influences further data requirements, and the types of further analysis and modelling to be undertaken. Data quality is also an important issue. For existing data, it is essential to establish a description of the data source; how it was obtained; and what quality control has been undertaken. Similar information is required for new data, however this forms part of the survey specification, along with the levels of resolution and accuracy required.

The discussion presented in this document takes the issues listed above, building on the practical advice presented in the 'Guide to prediction of morphological change within estuarine systems' (EMPHASYS, 2000) and in the Estuary Research Programme FD2110 Uptake Project workshops. Thus, it incorporates a basic approach to data that can be extended to most, if not, all predictive studies (one of example of such studies is Dearnaley *et al*. (2004).

Data Requirements for Conceptual Model Development

Initially, it is useful to identify the data requirements for the development of a system's conceptual model (Figure 1); highlighted in red text are those steps directly dependent on data collection and/or analysis. Most of a conceptual model's development is data dependent. This reliance of conceptual model development, and hence Expert Geomorphological Analysis (EGA), on data is often over-looked. Although EGA often utilises top-down methods associated with broad brushstroke data, the understanding of the system (before any impact assessment) is developed from the raw field data. A thorough understanding of what constitutes good, bad or unrepresentative data is essential. Moreover, even the broad-brushstroke data used by top-down models is dependant upon raw field data, and hence to maintain confidence in a geomorphological assessment it is essential to understand and demonstrate the reliability of the underlying data.

The informed use of good quality data will lead to a robust conceptual model and thus confidence in the assessment results (Box 1). Conversely, bad quality data will lead to uncertainty in the assessment results.

Bottom-up modelling requires data to:

- Define the model coastline and bathymetry;
- Define the model boundary conditions;
- Establish key sediment transport parameters; and,
- Establish calibration data.

Box 1. Summary of Approach to Data

Quality (and quantity) of data

↓

A **robust** conceptual model

↓

Confidence in the results (certainty)

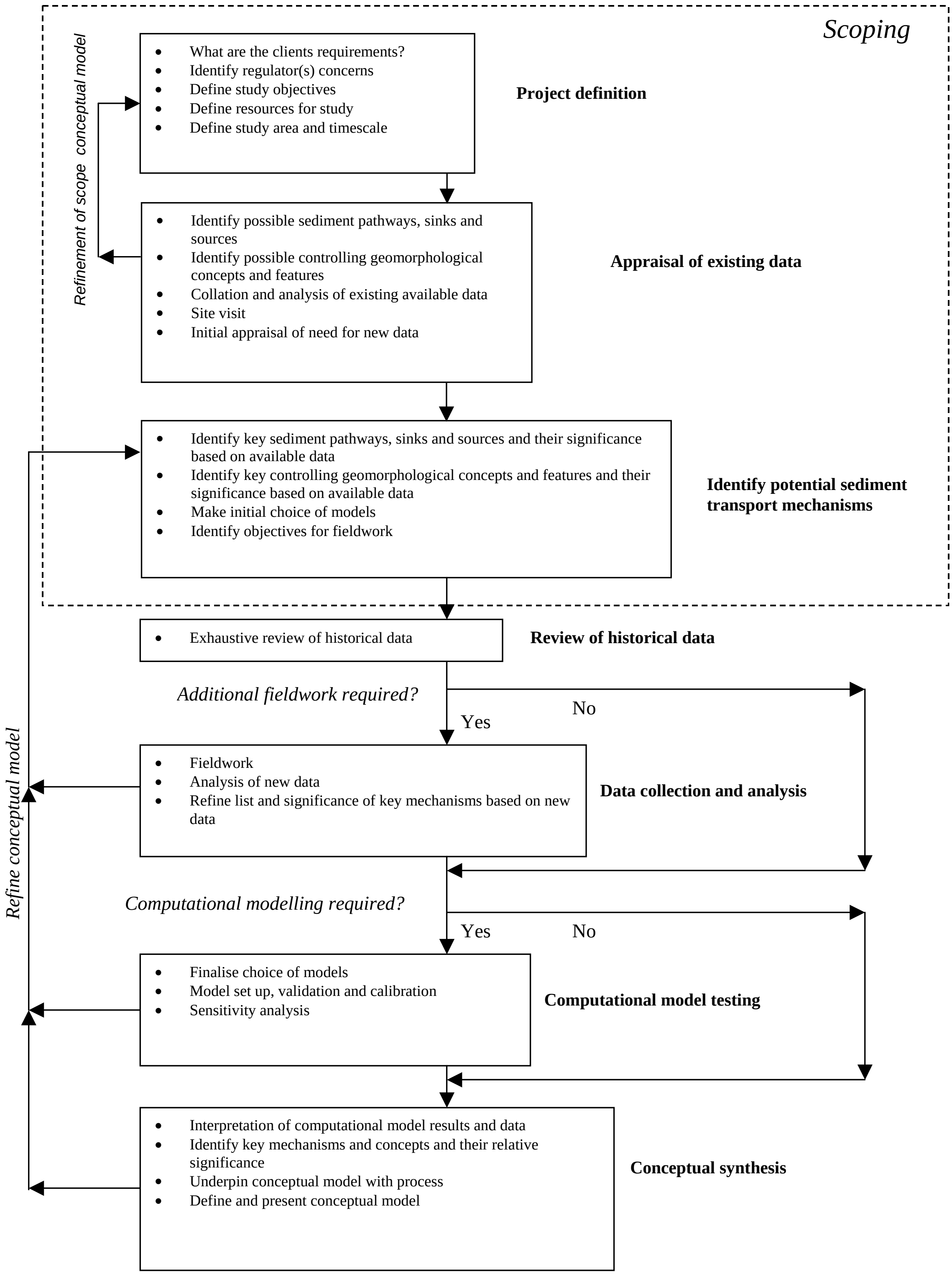

Figure 1. Summary of stages of development of conceptual model (red text indicates a dependency on data)

Appraisal of existing data

At the start of a project, it is important to make best use of the data already available. A thorough investigation of existing data should lead to a better understanding of the key processes involved and forms the basis for a sound conceptual model. The data types that can be utilised are summarised in Box 2.

Box 2. What Data Might Be Available?

- Bathymetry/coastline/topography;
- Dredging/disposal records;
- Tidal levels, waves, currents, salinity, water quality;
- Seabed sediments, suspended sediments, bedforms;
- Sediment and sedimentary characteristics;
- Biota, vegetation;
- Geological.

With existing data, the issue of quality is even more important than for new field data because there is no control and often no appropriate description of data collation methods, particularly with historical data. It is therefore important to check the data quality, datums and projections.

Data is often available from previous studies, however, presence of data in a report does not ensure its reliability. For instance, suspended sediment measurements made using a sensor rather than water samples are often prone to unreliability unless a thorough calibration is demonstrated. Moreover, some data can be considered to just be unreliable by its very nature, e.g.:

- Measurements of current speed/direction of below 0.1m/s;
- Settling velocity measurements using gravimetric analysis;
- Sediment parameters (erosion stress etc) on the basis of laboratory measurements.

The recommended approach to existing data can be summarised as 'Trust Nothing Without Checking'. Where possible, the consistency of different data should be established using simple calculations, which will aid the identification of problem data sets.

Collection of further field data

After collating and analysing existing data to develop an initial understanding of key sediment transport mechanisms within the study area, the next step is to assess further data collection requirements. This requirement should come from the identification of gaps in the understanding of the key sediment transport processes within the conceptual model; the required accuracy of the assessment; and the budget/time constraints of the study. In particular, there are three common situations where further data may be required:

- Lack of existing data;
- To understand key mechanisms; and
- For model calibration and validation.

The definition of further field data collection campaigns will depend on the level of knowledge regarding the key processes identified within the initial conceptual model; or the model requirements; the time and spatial scale of the key processes; and the study budget/time scale. Any new field data collection should consider the purpose to which any collected data will be used and should complement existing data. It is advisable to balance the costs of data collection against the achievable quality, or detail, of the outputs. Typically this will require consideration of the various parameters used to drive a particular model or assessment and whether the typical values in the literature or existing data are adequate, or if there is a requirement for site-specific values. It is important to relate the likely significance of the results to the quality of output required and then work back to define the information needed to deliver the necessary quality with an appropriate degree of confidence.

The complexity of data collection and its likely quality should also be considered, including an awareness of any errors inherent in the method used. For large, or commercially or politically sensitive, studies the additional data collation may be both comprehensive and should be expected. For such studies the field data collection needs to be planned in advance, particularly as the field experiments may need to occur at set times of the year, or over the course of a year, to obtain the relevant data.

Collecting data in the marine environment is invariably expensive and a failed field campaign will be costly. Many problems encountered can be mitigated by appropriate design and planning, and in particular the following considerations are important:

- Ensure adequate data quality;
- Build in flexibility to respond to some data failure;
- Be aware of errors inherent in the method used;
- Ensure that any new data collected complements the existing data;
- Consult with the surveyor before data collection to ensure the end use is understood; and
- Check whether the collection requires permission (e.g. disposal of dredged sediment requires a FEPA license).

In spite of the best preparation, significant errors can occur in the collected data. However, it is common that errors do not become apparent until the data is extensively used. This may require further time and resources to provide analysis, and perhaps, re-analysis of the data. After the provision of data, there should be a discussion period between the survey contractor and the end-user.

Data resolution and accuracy

Resolution and accuracy issues need to be considered for both the measured data and the model set-up. Instruments and the limitations of working in the field will often constrain the data resolution and accuracy with which it can be measured. This is often overlooked and yet it can have a significant effect on the proper use of the data and interpretation of model outputs. It is not uncommon for inexperienced practitioners to assert that the model is poor because it does not compare favourably with the measured data, when, in fact, it is the measured data that is poor. Table 1 provides some indicative values of measurement accuracy, taking account of instrument accuracy and other influences such as movements of the measurement platform, sampling limitations, background noise and operator error. If models are calibrated against measured data with given accuracy levels, there is little point in reporting model results to a significantly higher degree of accuracy as this gives the impression of a precision that is non-existent.

The resolution of a predictive model is also critical to the outcome. This is particularly the case for process-based "bottom-up" methods where the way in which space and time is divided up (discretised) can influence the results. For instance, if the spatial resolution is inadequate, the model may not reproduce the correct flow structure. The spatial scale must also be consistent with the features being modelled. To examine the effects of a dredged channel or land reclamation, it is necessary to have a cell size that adequately resolves the flow (typically at least 5 cells within the feature's width). Similarly, if the temporal resolution is inadequate, the model may be unstable, or will not resolve fluxes in sufficient detail to accurately determine change between different cases. In both cases, the test is to establish the model resolution for which the outputs have converged, such that further reduction in resolution does not significantly alter the results.

Table 1. Indicative values of measurement accuracy for various parameters

Parameter	Indicative Measuring Accuracy
Water levels	0.01m
Bed levels:	
- vertical	0.1m
- horizontal	3.0m
Current speeds (impeller device)	0.1 m/s
Turbidity	15 mg/l

For regime and equilibrium "top-down" methods, the issue is often more about recognising what can and cannot be resolved. Questions of accuracy are also more likely to relate to an appreciation of how the particular technique was derived and the degree of statistical certainty associated with it.

Model calibration and validation

Model calibrations should be objective and transparent, i.e. understandable to non-modellers. The key aim is to enhance confidence in the assessment or model results. It is worthwhile defining the calibration target (i.e. defining what properties are most important to predict with error below a certain threshold) before calibration commences. This exercise will clarify the calibration process to other interested parties and gives an objective context for the process because it is not possible to reproduce the observations exactly.

Calibration is traditionally the first stage in the application of a particular model, once the set-up stage has been completed. Typically, the model is initially run with parameters taken from the literature, available data and the benefit of the user's previous experience. The model outputs are then tested against some measured data and selected parameters adjusted until a satisfactory fit is obtained.

Calibration is often subjective and dependent on qualitative judgements of the modeller regarding whether the model has successfully achieved its performance target. For this reason, it is advisable to use an objective assessment of model performance. Examples of this are:

- A simple calculation of mean error between model prediction and observation (e.g. water level, current speed, bathymetric change, etc);
- Tabulation of the percentage of model results within various levels of tolerance; or
- The use of statistical measures of model fit such as the Brier Skill Score (Sutherland *et al*., 2004; Haigh *et al*., 2005).

For the calibration of an EGA, which makes use of the results of previous modelling studies, it is prudent to check the model calibration used in previous studies. Although stated as "good" or "reasonable" in the report, an independent assessment may reveal a less acceptable result.

Only those parameters that will not change for all of the cases to be studied should be adjusted during the calibration stage of a numerical model and to do otherwise invalidates the whole calibration process. Historically this stage has been heavily influenced by the modeller's experience. However, as modellers share knowledge, and with model development within an expert system framework to guide the user in the choice of parameters, this is becoming less of an issue (Chau & Chen, 2001). Indeed, for truly deterministic models, the calibration stage is not necessary; effort should be focussed on the validation stage and understanding the reasons for differences between observed and computed results (Cunge, 2003).

After calibration, the input parameters are fixed and the model is run for one or more different cases and validated against independent measured data. For example, a flow model may be calibrated against water level data for a spring tide and then validated against water level and flow measurements for a neap tide. Alternatively, the model may be run for selected tidal constituents to calibrate the model and then validated for other constituents using a combination of water level and flow data. What is important is that any tuning of the model parameters is only done during the calibration stage and the validation is then based on information that, as far as possible, is independent of the data used for calibration. This improves the severity of the test and hence adds to the credibility of the model set-up.

It is quite common for the results of calibration and validation to be presented as plots of model versus measured data. This provides a useful illustration of how well the model is performing, but gives little information about the quality of the fit or the severity of the test. Thus, it is far better to consider some quantitative measure of the error between measured and model data (e.g. RMS values) and the potential error sources (Errors and Uncertainty).

In a formal sense a hypothesis test can be formulated. This helps to explore whether the model represents real effects or is doing no better than would be expected by chance. For instance, the null hypothesis H_o may be that the model is doing no better than chance. Statistical error testing can then examine whether the hypothesis should be accepted or rejected and consider the probability of accepting the hypothesis when it should be rejected (a Type 1 error), or rejecting the hypothesis when it should be accepted (a Type 2 error). These concepts are central to a more formal scientific method for establishing experimental knowledge (Mayo, 1996).

Data uncertainty

Data is prone to uncertainty, both from the inherent spatial and temporal variation of a given property but also from the measurement device used to characterise the property. It is important to allow adequate time to review data, prior to analysis and use, to ensure serious errors are identified and the overall level of error is minimised.

It is good practice to make a best estimate of the likely error in the data and an assessment of the uncertainty that this error will have on the model results. Some examples of how this can be done at the level of a geomorphological assessment are presented in Boxes 3 to 5, and more information can be found in the Error and Uncertainty section.

Box 3. Example of Effect of Maintenance Dredging and Disposal on Upstream Intertidal Areas

Most maintenance dredging usually entails offshore disposal of sediment. In muddy estuaries especially the artificially deepened channel and/or berth will trap sediment that would otherwise remain in suspension if the channel/berth was not there. The trap effectively reduces suspended sediment concentrations in general in the estuary and hence the flux of sediment onto intertidal areas.

The calculation of the resulting impact (if any) on the intertidal areas arising from this process can be undertaken at varying levels of complexity. For this example, though, we will assume (as in the case with the Stour/Orwell) that the natural deposition on the intertidal areas is proportional to the average concentration occurring over the intertidal, which itself is roughly proportional to the annual flux of sediment, S, into the estuary from offshore.

If the annual offshore disposal of maintenance dredged material from the channel/berth is D then the concentrations in the estuary, and hence the deposition on the intertidal area is proportional to (S-D)/S. In this example the proportional reduction in the rate of deposition (*dep*) and hence the morphological impact on the intertidal is given by *dep*.D/S. Now if the data relating to the maintenance dredging and disposal is not accurate there could be an error of for example 50% in the value D, and hence the error in the assessment of impact is ± *dep*.D/2S.

Box 4. Example of Effect of Error in Current Data on Estimate of Future Morphological Change

In this example a morphological prediction has been undertaken (unspecified in this example) using standard sand transport formulae and data derived from a calibrated flow model. The flow model is well calibrated with peak current speeds in the region of 1m/s and errors in the prediction of peak flood and ebb speed are of the order of 10%.

For the purpose of this example we will assume that the sediment transport formulae is of the form, $S=a.V^n$ where S is the sand flux, V is the current speed and a and n are constants and n has a value of between 3 and 4. The proportional error in the sand transport flux (which is proportional to any resulting morphological change) then is roughly 30-40%. Further error will come from the uncertainty in the sediment transport formula itself.

Box 5. Effect of Survey Error on Estimate of Future Morphological Change

In this example a morphological prediction has been undertaken (unspecified in this example) but the initial rate of morphological change (and the final extent of the change) is a function of the observed volume change between two bathymetric surveys taken five years apart. It is important to know the likely error in the volume comparison between surveys in order to know the error in the estimate of the rate and magnitude of resulting morphological change.

Suppose the two original bathymetric surveys were roughly composed of 100 data points, on average 50m apart. Suppose also that the surveys were undertaken by the same surveying team of good reputation, and undertaken at the same time of year, using the same methodology. Standards for hydrography indicate that the standard error in each measurement of depth would be around 0.15m and that the random measurement error in a volume based on 2x100 data points is then $\frac{0.15V}{\sqrt{200}} \approx 0.01V$ where V is the calculated volume change between the two surveys. The error caused by random measurement error is therefore around 1% and insignificant. However there are other sources of error and in this example we consider the error from coarse data resolution. To evaluate the magnitude of this error the volume calculation is repeated but this time taking every second measurement from both surveys. Suppose then that the difference in the original and reduced data calculations of volume was 20%. This is then representative of the error from coarse data resolution in the surveys and has a significant effect on the uncertainty in the prediction of morphological change.

Data Types, Uses, Sources and Errors

Bathymetric data

Bathymetric data is used for:

- Establishing the history and rate of morphological change;
- Running baseline model simulations; and
- Providing calibration data (bed level/volume change) for sediment transport models.

Sources of bathymetric data include:

- Surveys, usually covering navigation channels but sometimes intertidal;
- Admiralty Charts, usually based on navigation surveys, so intertidal data is sparse;
- LiDAR, which when ground-truthed can provide highly detailed intertidal data;
- Dredging surveys, the quality of which can vary, and which will be confined to a navigation area of high accretion rate;
- Aerial photographs and satellite images, which can be useful but often not available for the period required unless specifically taken for a purpose;
- Ordnance Survey maps, which are limited to giving information on MHW and MLW; and
- Beach profile surveys of which the quality can vary.

Bathymetric data needs to be detailed and consistently measured or its use becomes limited. Bathymetric data can contain errors and the key sources of error are listed below:

- Systematic errors: e.g. resulting from an inherent error in the survey methodology. This error tends to cancel out if two surveys using are compared which used the same methodology;
- Measurement bias e.g. lead line measurements;
- Random measurement errors:
  - For current standards of hydrography see S44 (4^{th} edition) (IHO, 1998);
  - Vertical errors usually more important than horizontal errors;
  - Horizontal errors usually only significant when measuring bathymetry on steep slopes or as a result of the changes in positioning that resulted from the WGS84 protocol;
- Navigation charts generally highlight the shallowest bathymetric measurements and therefore are biased to some extent;
- Rounding Errors: depths are usually rounded down (van der Wal and Pye, 2003, ABPmer, 2002);
- Metrification: This conversion may result in the introduction of errors. (ABPmer, 2002);
- Chart/Survey Dates: Modern charts (e.g. Admiralty Charts) are often composites of a number of surveys over different years; and,
- Datum errors and/or changes:
  - Errors in old datums e.g. pre 1921 Liverpool datum (for more information see Doodson and Warburg, 1941); and,
  - Changes in datums over time as a response to changes in water level (e.g. the Port of London Authority changed their chart datums around 1970).

Flow data

Water level data

The principle source of water level data is from tidal gauges although in many cases the tidal predictions available from Admiralty Tide Tables (themselves based on harmonics derived from analysis of tide gauges) is sufficient. Water level data experiences all the datum problems discussed under bathymetric data. Additionally, water level measurements can be affected by meteorological effects such as storm surges and waves. There is a need for accompanying measurement of meteorological data to identify these additional effects.

Current data

Current data is one of the most important resources for understanding how an estuary system functions and for developing a conceptual model.

Sources of current data:

- ADCP (Acoustic Doppler Current Profiler): the best if available since ADCP gives measurements of current speed and direction throughout the water column;
- Current meter: usually reliable but limited to point measurements;
- Admiralty Tidal Diamonds: Often historical and therefore may be false if large local morphological change has occurred. Date of origin can be pinned down by investigating historical admiralty charts; and,
- Float tracking: a rough method for establishing current magnitudes but useful for establishing residual trends in currents. Susceptible to error from wind effects.

Current data can give misleading readings if:

- The current magnitudes are below 0.1m/s;
- If the internal compass reading is unreliable (not uncommon);
- If historical (due to morphological change);
- If placed at a fixed level on an intertidal area, since the sensor is experiencing a change in water depth as well as changes in depth-averaged current speed; and,
- If vessel mounted in large waves and low current speeds – wave induced orbital velocities will produce considerable scatter on the tidal or wind driven current signal.

Salinity measurements

Salinity gradients cause residual density currents and affect the tidal current flow. Any assessment of current flow in an estuary is therefore incomplete without some assessment of salinity gradients. Even a well-mixed estuary will have horizontal salinity gradients producing a residual landward current near the bed.

Salinity measurements are normally made using a rapid drop profiler deployed from a vessel. Measurement errors are not normally significant except if the sampling frequency of the profiler is low compared to the speed at which the profiler is dropped or raised through the water column. If the frequency is low, each salinity measurement will be an average salinity over a significant depth of water and near-bed readings may be erroneous.

Wave data

Wave data can be measured using a number of methods, for instance:

- Pressure gauge;
- ADCP;
- Accelerometer mounted on a wave buoy;
- High Frequency radar; and,
- Voluntary Ship Observations.

All of these devices have their advantages and disadvantages and will produce different sorts of errors. More complete surveys will include measurements of waves from more than one device.

The most common errors in wave measurements tend to come from the following sources:

- Lack of inclusion of the effect of attenuation of the recorded pressure signal with water depth; and
- Failing to sample at a sufficiently high frequency to capture high frequency waves.

Wave measurements differ from other typical estuary phenomena measurements in that it is less common to calibrate predicted wave action against field data, although this is not necessarily good practice. Wave measurements are generally undertaken in order to calculate design conditions for engineering structures.

Waves are in essence non-deterministic and occur as a result of both local wind activity and as a result of ocean swell. Both components can be important in estuaries and each component is essentially derived from different sources. The swell component has a longer period and results from the inshore transformation (due to refraction, shoaling, friction etc) of a wave generated offshore. The local wave is generated from wind blowing over a certain fetch (again transformed by refraction, shoaling, friction etc). For any assessment of wave action within an estuary it is important to have offshore and inshore wave climate information.

Sediment transport data

The collection of sediment transport data is expensive and often technically difficult. Additionally, since sediment transport is greatest during storms (which are by definition hard to monitor) and the largest spring tides there are considerations of whether data collected is representative. The most common measurements of sediment transport are as follows:

- Concentrations:
  - Water samples;
  - Optical device measurements;
  - Laser diffraction measurements;
  - ADCP back scatter;
- Morphological change; and,
- Dredging records.

The principal problem with measuring suspended sediment concentration is that water sampling is time consuming and costly but is the only independent method of establishing concentration. The other methods, whilst quicker and, in the case of ADCP backscatter, allowing through depth measurements, require calibration against water samples. Hence measurements using one of these non-direct measurement methods are associated with considerable uncertainty unless the calibration of sensor reading against water sample observations is presented.

Additionally, instrument response is a function of particle size and even if well calibrated against total solids content there will be uncertainty in the sensor readings resulting from natural variation in the particle size distribution over time.

Less commonly measurements of the following are undertaken:

- Bed density;
- Settling velocity; and
- Identification of bedforms and of material type using multi-beam sonar and side-scan sonar imaging or acoustic sediment discrimination systems, with ground-truthing provided by seabed grab samples.

Bed density can be important in sediment budget analysis and assessment of morphological change because it relates mass of sediment, as predicted using sediment transport formulae, to volume change. However, bed density varies both spatially and with depth and establishing representative values for use in morphological assessment is not a trivial task.

Although the settling velocity of sand particles is fairly well established (e.g. Soulsby, 1997) and a range of methods exist for mud (e.g. Whitehouse *et al*., 2000) the measurement of settling velocity of mud flocs is a technically complex subject. Best practice at present is to undertake *insitu* measurements using sophisticated measurement devices which do not disturb the sediment floc structure and enable video footage of floc settling to be taken e.g. the INSSEV device (Fennessy *et al*., 1994). Estimates of settling velocity made without this type of approach will have shortcomings, although laser diffraction devices (e.g. the LISST particle size and distribution analyser) claim to be able to measure floc settling velocity while retaining the benefit of a device that can be easily deployed. In particular the traditional method of gravimetric analysis (the use of water sampling from settling columns) should not be used because the sampling process causes re-circulation of settling flocs and underestimates settling velocity by up to an order of magnitude (Dearnaley, 1996).

Dredging data

Dredging data can often be the only way of establishing the tendency for deposition in an estuary system and can be especially important for establishing key sediment parameters in sediment transport model studies. Comprehensive dredging records (where, when and how much) are an extremely valuable resource but they need to be kept over a decent period to be reliable. Types of dredging data include:

- (Repeat) bathymetric surveys following a dredge;
- Pre and post dredge bathymetric surveys;
- Data based on number of hopper loads taken to disposal site;
- Data from local Harbour Authorities on:
  - Harbour operations (lock operations, turning areas, ferry traffic, pilotage);
  - Past and present dredging (capital and maintenance);
  - Locations and history of use of disposal sites;
- Information held in Regulators' databases (e.g. Defra disposal database); and,
- Data from dredging Contractors who have worked at the site.

The best dredging data is derived from pre- and post-dredge bathymetric surveys by measuring exactly what was removed from the dredged area. Data based on hopper loads only measures what was taken from the site, not what was additionally disturbed from/released at the site during operations.

A starting point is the Defra database of disposal although this database is by no means complete and only as good as the data supplied to it. The database only includes information on disposal rather than the amount dredged (i.e. there is no information about sediment "spilled" during dredging or used for beneficial use).

History of management and natural changes

Any geomorphological assessment is incomplete without taking into account anthropogenic effects resulting from:

- Archaeology;
- Embanking/reclamation;
- Training walls;
- Bridge building/removal;
- Dredging/disposal;
- Foreshore/dune management; and,
- Industries such as brick-making.

and additionally the effect of large-scale natural changes such as:

- Saltmarsh loss (e.g. Poole Harbour); and,
- Eel-grass loss (e.g. Stour Estuary, Essex)

This information is derived from the journals of the local Port or engineer, anecdotal sources, old records and history books. When taking into account the long-term evolution (for instance since the start of the Holocene period) it is also necessary to consider the Roman, medieval and pre-industrial land reclamation that may be more responsible for recent morphological trends in the estuary system. Table 2 gives an indication of the importance of this phenomenon.

Table 2. Habitat loss in English estuaries (Healy and Hickey, 2002, adapted from Davidson *et al*., 1991)

Estuary Name	Area Lost (ha)	Reclamation Period
The Wash	47,000	Since Roman Times
Severn Estuary	c. 8,000	Since Roman Times
Dee Estuary	6,000	Since 1730
Humber Estuary	4,600	1600-1850
Greater Thames Estuary	4,340	Mostly pre-1800
Tees Estuary	3,300	Since 1720
Ribble Estuary	2,320	Since 1800
Morecambe Bay	1,320	1200-1900
Ore/Alde/Butley Estuary	3,640	Since 1200
Deben Estuary	2,240	Since 1200
Stour Estuary	1,600	Since 1200
Blyth Estuary	1,280	Since 1200
Orwell Estuary	980	Since 1200
Southampton Water	690	Since 1830
Poole Harbour	530	Since 1807
Portsmouth Harbour	490	Since 1540
Mersey Estuary	490	1800-1900

Estuary geometry data

The estuarine geometric parameters often used in the context of conceptual model development, EGA and other analyses are as follows:

- Tidal prism/tidal volume;
- Cross-section area;
- Depth;
- Length; and,
- Width.

Most of these parameters can vary seasonally (high and low fluvial flow) and over the spring-neap cycle. When evaluating these parameters it is important to make it clear under which conditions these parameters were derived. Which conditions most characterise an estuary is not an easy question to answer conclusively but in general spring tide conditions are considered to be more representative than mean or neap tide conditions. It is therefore suggested that these parameters be evaluated for spring tide conditions except where there is a good reason for evaluating under other or all types of conditions.

Tidal prism/tidal volume

Tidal prism and tidal volume are terms which are used interchangeably; both relate to water volume flowing into the estuary from the sea on the flood tide, however, there is a subtle distinction between these two properties. Tidal volume is the water volume flowing into an estuary from the sea on a flood tide, and out again on the ebb, and can be evaluated using a numerical flow model. Tidal prism is the volume within the estuary bounded by the LW and HW levels (usually referring to the spring tide) and therefore tidal prism can be derived from bathymetric data. Tidal volume and tidal prism should be very similar, differing primarily because HW and LW are not experienced synchronously along an estuary length.

Often tidal prism is estimated using a fixed elevation for HW and LW along an estuary. This can enable a more rapid assessment of tidal prism from bathymetry. However, a more accurate assessment must reflect the fact that HW and LW vary along an estuary. In an upper estuary an approximation using a fixed level may become too inaccurate for the resulting estimate to be useful. It should be stated which option has been used when generating estuary tidal prisms/volumes.

Cross-section area

The calculation of cross-section area consists of the integration of a profile of bathymetric data across an estuary transect. The calculation itself is straightforward and use of the trapezoidal rule will generally suffice, but the selection of a transect can sometimes be problematic. In some estuaries the LW channel can diverge considerably from the general alignment of the MSL and HW level. At such locations the direction of the water flow may be significantly different at different times in the tide (Figure 2) and it may be difficult to evaluate the discharge through the channel if a simple, obvious cross-section does not exist. It is best, therefore, to locate cross-sections in places where this problem does not arise.

For geomorphological assessment there are two cross-section area parameters that are most relevant:

- Cross-section area at MSL: used in regime theory with O'Brien type prism-area relationships; and
- Cross-section area at peak discharge: also used in regime theory peak discharge-area relationships, where the benefits of a numerical flow model can be utilised, but may significantly differ from the width at MSL in the upper estuary.

The calculation of cross-section area may also be important for deducing average estuary depth at HW and LW, and usually the water levels of relevance are around mean spring LW and mean spring HW.

Depth

In some instances an average estuary depth is required. When considering average estuary depth it is important to note that there are several ways to average depths that vary significantly along an estuary and it is possible to result in a large variation of values. For instance, average depth can be calculated as an arithmetic average, $(\Sigma h_i)/N$) or a geometric average, $(\Pi h_i^{1/N})$ and this will give smaller and larger results respectively. Friedrichs and Aubrey (1994) overcame this problem by stating average depths as a range of values to account for the uncertainty, e.g. Thames, 8.5±0.7m, Tamar, 2.9±0.2m, Delaware 5.8±0.3m.

Cross-section averaged current speed

Cross-section averaged current speed features directly or indirectly in many tools for estuary assessment. In particular, cross-section averaged current speed may be used as a means of deriving the tidal prism or peak discharge through a section. The easiest way to derive this variable is to generate the estuary flows using a numerical model. The software associated with the model will then provide the cross-section averaged current speed either as a direct output or provide a means for integrating cross-section area and discharge so that the cross-section averaged current speed can be deduced.

Single point measurements of current speed in an estuary do not represent a good estimate of cross-section averaged current speed. This is because there is significant variation in current speed across a cross-section especially as current speeds will reduce in the shallower waters on either side of the channel. Where the only basis for deriving cross-section averaged current speed is a single point measurement the estimate can be improved to some extent using the following procedure, assuming that the point measurement represents the largest current speeds in the centre of the channel.

Assuming Chezy's law is valid (equivalently Manning's law can be used with a slightly different outcome but the same qualitative result),

$$v = C\sqrt{rs} \tag{1}$$

where: v is the current speed;
r is the hydraulic depth (equal to the cross-section area divided by the wetted perimeter and roughly equal to average depth);
C is the Chezy constant.

Longitudinal water slope is assumed to be the same at all points along a cross-section transect, and the current speed is assumed to vary gradually in the longitudinal direction.

Equation 1 then gives,

$$\frac{v}{v_{max}} = \sqrt{\frac{r}{r_{max}}} \tag{2}$$

where: v_{max} and r_{max} is the maximum current speed and depth in the middle of the channel;
v and r are the current speed and depth anywhere along the transect.

Equation 2 gives a method of estimating the variation in current speed along the transect. Once this variation is known each velocity estimate can be multiplied by the depth at that point to produce an overall discharge and cross-section area and hence the cross-section averaged current speed.

Cross-section width

Cross-section width suffers from the same problems of identification as cross-section area but, subject to uncertainty in identifying alignment of a representative cross-section, is a fairly straightforward a parameter to evaluate. For geomorphological assessment there are four widths that are relevant:

- Width at MSL: used in regime theory with O'Brien type prism-area relationships. Closely related is width at peak discharge which is also used in regime theory peak discharge-area relationships but may significantly differ from the width at MSL in the upper estuary;
- Width at LW and width at HW: a measure of the extent of the LW or HW channels, and both can be used in the context of evaluating tidal asymmetry. Usually the level of relevance is around mean spring LW or HW.

Estuary length

Estuary length is commonly a loosely specified parameter and some care should be taken in the derivation of this parameter, and particularly in the use of values derived by other parties. The estuary length is the length from the seaward limit of the estuary to the normal upstream tidal limit, which for almost all cases can be taken as that stated on OS maps.

Estuary length defined in this way is commonly a function of the presence of weirs at the upstream end of an estuary and therefore may differ from the natural, or at least pre-industrial, length of the estuary. Some authors have suggested a means of calculating estuary length on the basis of other parameters (e.g. Pethick, 1994, Prandle, 2003) and a distinction has to be made between the estuary length used by these authors (which is not a function of man-made influence) and the observed man-influenced values.

Figure 2 shows the problems that can arise when defining the seaward limit of an estuary. Two schematic examples are shown; one that can be said to typify, for example, the Thames and Severn Estuaries where in effect an arbitrary downstream limit is often chosen, and one that can be said to typify estuaries where a definite headland exists, for instance in the Fal, the Stour/Orwell, and the Mersey estuaries. The potential for different decisions to be made by different researchers/consultants regarding the seaward limit means that it is very important to state the seaward limit chosen so that others know what has been done. It is best to maintain consistency with the definition of the seaward limit used in previous studies unless there is a good reason to change.

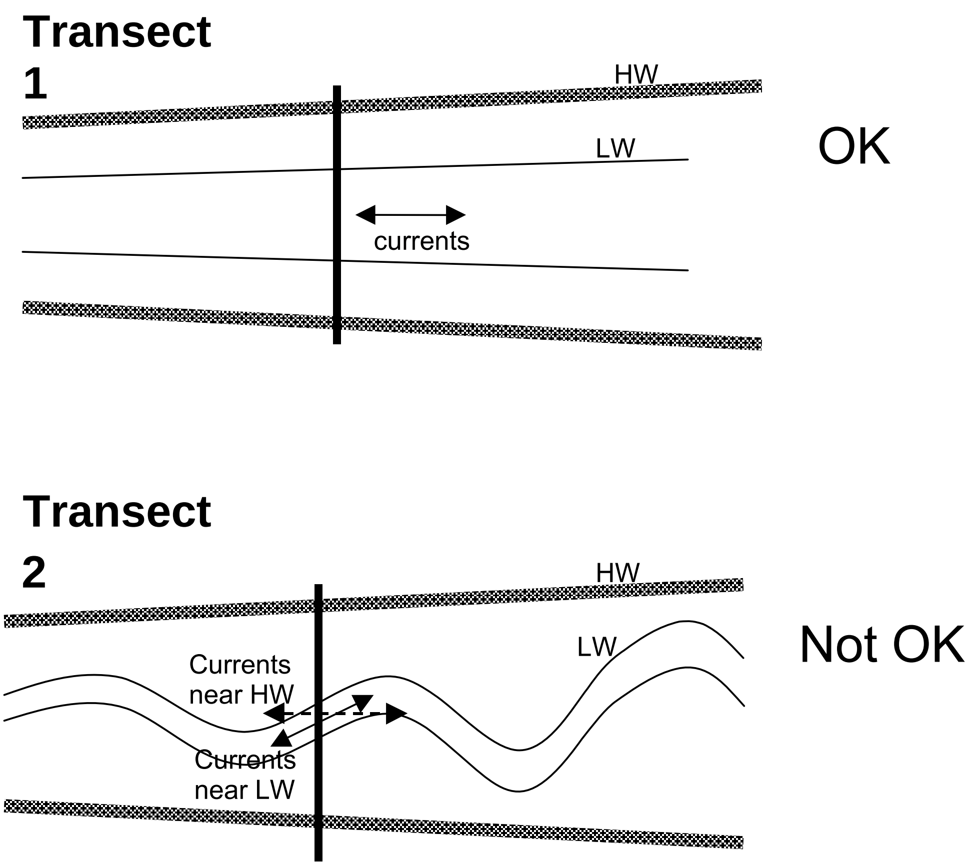

Figure 2. Considerations when choosing a cross-section

Data for long term predictions

For long-term assessments of morphological change there are additional data requirements to the data outlined above, for example:

- Climate change data:
  - sea level change;
  - history of the wind and wave climate;
- Synoptic historical data sets;
- Bedrock and surface geology; and,
- Feedback between biology/vegetation and morphological change.

Over long periods of time the extent of sea level rise becomes significant and needs to be incorporated into any hindcasting or forecasting of change, as do changes in the wind and wave climate. Hindcasting of morphological change is aided considerably by synoptic historical data sets of hydrodynamics and bathymetry, which, though rare, do exist for some estuary systems.

For future predictions of morphological change it is essential to know how the evolution of the estuary may be constrained by geology. Also important is the role of biology and vegetation in controlling morphological change, however, at present there is very little scientific knowledge regarding the morphological feedback from biology and vegetation, which represents an additional uncertainty.

Conclusions

1. Data is paramount to EGA studies and the use of data should be carefully managed in such studies to enhance confidence in the assessment;

2. The assumption that there is enough data in all cases to inform EGA studies needs to be verified at the outset of any study;

3. Data is (generally) site-specific and collection of data is time-consuming and expensive;

4. Collection of data is not the end of the problem - each type of data has sources of error associated with its collection and processing which need to be understood;

5. Understanding of the technical aspects of collection and the use for which the data is being collected will reduce the level of uncertainty in the data;

6. Review and analysis of data are essential and this can be a time-consuming and hence an expensive part of the process;

7. There is a requirement in every study to allow some flexibility in the project scope and budget if at the end of the data review it is clear that the previously anticipated activities need to be modified or new tasks are identified to achieve the goals of the study; and,

8. There is a requirement to understand how uncertainty associated with the data used in a study feeds through to the conclusions of that study.

References

ABPmer, 2002, Humber SMP. Historical Analysis: Review of Potential Lead Line Variations in the Period 1930-1040. Internal Technical Note. ABPmer, Southampton.

Chau, K.W. and Chen, W., 2001, A fifth generation numerical modelling system in coastal zone. Applied Mathematical Modelling 25, 887-900.

Cunge, J.A., 2003, Of data and models. Journal of Hydroinformatics 5(2):75-98.

Davidson, N.C., Laffoley, D. d'A., Doody, J.P., Way, L.S., Gordon, J., Key, R., Drake, C.M., Pienkowski, M.W., Mitchell, R., and Duff, K.L., 1991, Nature Conservation and Estuaries in Great Britain. Peterborough, UK: Nature Conservancy Council, 422p.

Dearnaley, M.P., 1996, Direct measurement of settling velocities in the Owen Tube: A comparison with gravimetric analysis, Netherlands Journal of Sea Research, 36, 41-47.

Dearnaley, M.P., Baugh, J.V. and Spearman, J.R., 2004, Modelling sediment transport and sedimentation. Proceedings of the Maintenance II Conference, Institute of Civil Engineers, 2004.

EMPHASYS, 2000, A guide to prediction of morphological change within estuarine systems, Report TR 114 produced by the EMPHASYS consortium for MAFF project FD1401, Estuaries Research Programme, Phase 1, December 2000.

Fennessy, M.J., Dyer, K.R. and Huntley, D.A., 1994, INSSEV: an instrument to measure the size and settling velocity of flocs in-situ. Marine Geology 117, 107-117.

Friedrichs, C.T. and Aubrey D.G., 1994,

Haigh, I., Norton, P. and Townend, I., 2005, Understanding and predicting morophological change in the inner Humber Estuary. Proceedings of the 29th International Conference on Coastal Engineering, J. McKee-Smith (ed.), pp. 2493 – 2505.

Healy, M.G. and Hickey, K.R., 2002, Historic land reclamation in the intertidal wetlands of the Shannon estuary, western Ireland, Journal of Coastal Research, 36, 365-373.

IHO, 1998, *IHO standards for Hydrographic Surveys*, International Hydrographic Organisation, Special Publication Number 44, 4th edition, 23pp.

Mayo, D.G., 1996, Error and the growth of experimental knowledge. The University of Chicago Press, London, 520pp.

Pethick, J., 1994, Estuarines and wetlands: Function and form. In: R.A. Falconer and P. Goodwin (eds.), Wetland Management, Proceedings of the International Conference, Institution of Civil Engineers, London, pp.75-87.

Prandle, D., 2003, Relationships between tidal dynamics and bathymetry in strongly convergent estuaries. Journal of Physical Oceanography, 33, 2738-2750.

Soulsby, R.L. (1997). Dynamics of Marine Sands. A manual for practical applications. Thomas Telford Publications, 272pp.

Sutherland, J., Peet, A.H. and Soulsby, R.L., 2004, Evaluating the performance of morphological models. Coastal Engineering, 51, 917-939.

Van der Wal, D. and Pye, K., 2003, The use of historical bathymetric charts in a GIS to assess morphological change in estuaries. The Geographical Journal, 169 (1), 21-31.

Whitehouse, R., Soulsby, R., Roberts, W. and Mitchener, H., 2000, Dynamics of Estuarine Muds. Thomas Telford, London, 232pp.